

Paper II

Pietrosemoli, S.; Tang, C. **2020, Animal Welfare and Production Challenges Associated with Pasture Pig Systems: A Review**. *Agriculture*, 10 - 6, 1 - 34. 06/2020. ISSN 2077-0472

Review

Animal Welfare and Production Challenges Associated with Pasture Pig Systems: A Review

Silvana Pietrosemoli ^{1,2,*} and Clara Tang ³

¹ Department of Animal Science, College of Agriculture and Life Sciences, North Carolina State University; Raleigh 27695-7621; NC, USA; Silvana_pietrosemoli@ncsu.edu

² Departamento de Producción Agraria, Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas, Universidad Politécnica de Madrid; Madrid 28040, Spain

³ Department of Plant and Microbial Biology, College of Agriculture and Life Sciences, North Carolina State University; Raleigh 27695-7612; NC, USA; cvtang@ncsu.edu

* Correspondence: Silvana_pietrosemoli@ncsu.edu

Received: 30 April 2020; Accepted: 8 June 2020; Published: 10 June 2020

Abstract: A review of published literature was conducted to identify pasture pig production system features that pose risks to animal welfare, and to develop recommendations aimed at improving the wellbeing of the animals managed in those systems. Pasture pig production systems present specific challenges to animal welfare that are inherent to the nature of these systems where producers have little room to make improvements. However, these systems present other challenges that could be reduced with a carefully designed system, by adopting appropriate management strategies and by avoiding management practices that are likely to negatively affect animal wellbeing. In pasture pig production systems, exposure to extreme temperatures, potential contact with wildlife and pathogens (especially parasites), vulnerability to predators, risk of malnutrition, pre-weaning piglet mortality, complexity of processes for monitoring and treating sick animals, and for cleaning and disinfection of facilities and equipment are among the main threats to animal welfare.

Keywords: pasture pig systems; threats; animal welfare; pasture-based pig systems; pig production; alternative pig production;

1. Introduction

The new millennium brought a worldwide growing interest for animal welfare [1]. The livestock sector reacted by developing recommendations relevant to the wellbeing of farm animals, consequently encouraging producers to adopt and implement them. Additionally, consumer demand for better production practices contributed to the development of responsible production systems in which animal welfare principles are incorporated into daily management practices. These systems are generating animal products that represent an alternative to satisfy niche-markets customers who require ethically sourced, safe, healthy, and environmentally friendly-produced goods. For this reason, one can infer that animal welfare presents ethical and productive implications. However, the multidimensional character of the welfare concept complicates reaching a consensus around a unique definition [2].

The different components of the pork supply chain can have divergent perceptions regarding animal welfare. Consumers emphasize the mental aspect of animal welfare, relating it to the prospect of providing animals with living conditions that resemble natural settings [3]. Veterinarians, scientists, and other animal care professionals' orientation toward animal welfare pay more attention to the physical health, animal performance, and production efficiency [4]. Farmers, being conscious

of the animal welfare impact on productivity, focus on the physical wellness of animals prioritizing performance and health. Farmers' actions to improve animal welfare have been associated in increases in productivity [5]. Millet et al. suggest that the different pork supply chain stakeholders' points of views do not align; moreover, it would seem that they are not founded on similar scientific grounds [6]. Additionally, different welfare problems could be weighted differently by the different interested parties [6,7].

The combination of these different perspectives in welfare have evolved into a more complex and holistic concept, which should be assessed by trained personnel. It is worth noting that animal welfare is a broad and complex [6] concept that involves aspects related to physiology, physical health, emotional state, and animal behavior. The World Organization for Animal Health (OIE) defines animal welfare as the state of the animal that reflects the way it is coping with the conditions in which it lives [8]. To attain satisfactory animal welfare, animals need to be provided with responsible care, proper housing, prevention and treatment of diseases, adequate management and nutrition, humane handling, and when needed, humane euthanasia. Overall, animals should be kept in a distress free environment where they are free to express their innate behavior [9].

Pork is the second most consumed meat in the world [10] and it can be produced within a variety of production systems, ranging from extensive backyard to highly specialized indoor systems. The level of welfare that animals may experience within each of the production systems is also diverse. Public perception tends to relate extensive systems with lower environmental impact and better animal welfare [11,12]. Groups of consumers declared a willingness to pay preferential prices for products derived from these kind of production systems [13,14]. In 2019 the National Restaurant Association showed that since 2014, sustainably raised, and locally produced beef and pork cuts appear in the top ten overall choices of their customers [15]. Furthermore, studies conducted in the United States showed that 78% of consumers rated as "important" the way food animals had been raised [16]. This evidence supports the existence of a favorable purchasing behavior toward pasture-raised meat. Previous studies associated animal welfare mostly with management practices and how well those operated instead of focusing on production system typology [17–19].

Among the extensive systems, it is important to mention pasture-based pig production systems in which pigs of different productive categories are kept on pastures where they can graze, receive feed and water, and are provided with shelter [20]. In addition to their contribution to animal nutrition, the presence of well-established pastures reduces the creation of mudflats, soil compaction, and runoff [21]. The lack of ground cover has been associated with greater piglet mortality rates attributed to mud being brought inside the huts by the sows, boosting humidity and bacterial contamination [22]. The implementation of pasture rotation and adequate animal stocking rate adapted to edafo-climatic conditions, forage species, and grazing animal categories, favor the maintenance of plant cover [21]. Pasture environments approximate the natural habitat of pigs, which is conducive to the expression of foraging, rooting, and exploratory behaviors. Pastures contribute to animal comfort while modifying the temperature near the soil surface leading to enhanced animal welfare [20,23,24]. Greater environmental complexity, the opportunity of selecting both the physical and social environment, and the greater availability of space per animal are advantages attributed to pasture pig systems when compared to indoor confinement systems [17]. However, if not properly managed, these systems may pose risks both to the environment [21] and to animal welfare [25,26], especially for subordinate individuals [17].

Animal welfare assessment comprises measurements of physiological responses, health, behavior, and productivity. Animal welfare has been broadly studied for pig units, leading to the definition of science-based best management practices available to farmers for improving the functioning of their operations. However, despite the enormous amount of information, few studies have focused on animal welfare in pasture-based pig operations. This document aims to review scientific information on pasture pig production systems, identifying system features that pose risks to animal welfare, and suggest recommendations to improve the wellbeing of the animals managed within such systems.

2. Materials and Methods

A search in the literature was conducted to identify potential threats to animal welfare that are likely to impact pasture pig production. The search conducted in the database Web of Science included 20 years of data from 2000 to 2020, and was performed exploring the keywords: pasture pork, pasture pigs, free-range pig systems, pasture-based pigs, outdoor pigs, organic pigs, animal welfare, and pasture pig production. The review was limited to on-farm processes. Transport and slaughter impact on pig welfare were considered beyond the purposes of this paper.

The initial search yielded 250 articles, which were subsequently screened based on reviews of the abstracts. Unrelated articles were excluded. This filtering yielded 187 articles. Complementary searches related to specific topics included in the manuscript outline that appeared lacking in information were performed using Google and Google Scholar. A total of 238 articles fulfilled the inclusion criteria and were incorporated in the review. Scarcity of information specific to pasture pig systems, which was one of the main constraints found, was overcome by including information related to outdoor, free-range, and organic pig production systems.

3. Results

3.1. *The Pasture Environment*

Pastures are complex ecosystems where a great variety of elements and organisms interact. They are similar to the environments in which pigs evolved, and consequently better suited to fulfil their physiological and psychological needs than other systems [24,27]. Pasture and indoor-confinement rearing environments differ considerably and might generate differences in the welfare of pigs managed in those production systems. A note of caution was raised by Pandolfi et al. when reviewing the results of welfare studies in pasture production systems with pigs resettled from other systems. The previous rearing environment, management, pig health, wetness, filthiness conditions of pens and paddocks, and stocking rates can lead to unexpected responses to the pasture systems [28].

Location of the pig unit can represent a challenge to pig welfare. The health and welfare of sows reared on pastures will be reliant on ground conditions, which is related to soil texture, proneness to flooding, stocking rate, and stocking management [29,30]. Greater prevalence of health issues and mortality rates are expected in poached soils because these conditions favor pathogens and parasite survival as well as pigs remaining wet and dirty [23]. Additionally, muddy soil can become slippery and can cause falls and injuries [31]. Similarly, stony soils could cause feet injuries, joint ailments, and ultimately lameness. Soft soil could cause overgrown claws while damp soil conditions could cause toe erosion in older pigs [32]. Holes, hollows, tree stumps, wires, or thorns can be the cause of injuries and lesions [33]. Sites exposed to strong winds, and where long periods of extreme cold, frost, and snow can be expected, are also not appropriate. Careful choice of location, suitable housing, and implementing of adequate management strategies can alleviate the negative impacts of the environment on pig welfare.

3.1.1. Exposure to Climatic Elements

Weather conditions including precipitation, temperature, humidity, solar radiation, wind strength, wind direction, rainfall, and atmospheric pressure can cause stress to pigs kept on pastures [25,34]. The initial manifestations of stress to weather are restlessness, irritation, and aggressiveness [35], followed by other behavior changes. Ultimately, extreme weather leads to injuries, lower growth rate, and reproductive performance (boar libido, semen quality, and reproduction rate), and in the manifestation of stereotypes [36]. The impact of environmental conditions on pigs will vary depending on age, weight, reproductive stage, health condition, feeding status, and production systems [29,35]. Heat or excessive cold could cause thermal stress on grazing pigs [12,25,37]. The upper limit of the temperature comfort zone decreases as pigs age, 32 to 35 °C for pigs under 3 kg, 26 to 35 °C for pigs in pre-nursery, and 10 to 35 °C for grower-finishers and sows and boars greater than 100 kg [38]. Lactating sows could suffer more from heat stress as a consequence of their higher feed

intake and metabolic activity, whereas dry sows can be more prone to cold stress because of their feed restriction level [30]. The preferred temperature for dry and lactating sows oscillates between 12 to 31 °C, and 7 to 26 °C, respectively [39,40].

In a study where average temperature varied between 15.6 and 29.0 °C, and temperature humidity index (THI) fluctuated between 62.4 to 75.1; it was shown that increased temperature at the moment of service favors sow reproductive performance with a greater number of piglets born, whereas when high temperatures take place at farrowing the reproductive performance of sows is negatively impacted [12]. Impaired reproduction derived from heat stress has been related with embryonic losses in sows, and decreased spermatogenesis and lower libido in boars [33]. Sows exposed to high temperature (≥ 22 °C) have shown longer farrowing and longer birth intervals among piglets. Conversely, piglets profit from greater temperature and temperature–humidity indexes after farrowing, with a significant decrease in pre-weaning mortality [12]. Furthermore, season and environmental temperature have shown to influence piglet mortality [41]. For instance, increased numbers of stillborn have been reported during periods of high temperature (≥ 27 °C) [42]. Similarly, sows exposed to temperatures greater than optimum showed reduced feed intake and milk and colostrum production, shorter nursing periods, and increased piglet mortality, as a direct result of crushing and starvation [23,33,43,44].

Even though in grazing systems animals are exposed to weather conditions to which they would not be exposed to in confinement, they have greater opportunities to express thermo-regulation behaviors including wallowing, changing position, and modifying their lying posture (huddling, piling, and spreading out) [45]. Sows kept on pastures showed lower heat stress, with respectively lower skin temperature (32.1 vs. 30.8 °C) and lower respiratory frequency (31.04 vs. 26.07 mov/min) than sows managed indoors [46]. The impossibility of pigs to relieve themselves from high temperatures can lead to displays of stress and become a welfare issue. The European Food Safety Authority (EFSA) has reported an increase in tail-biting episodes frequency among pigs due to high temperature. Heat stress begins to manifest itself with panting but if not controlled it could lead to collapse and death of the animal [47].

In East Balkan traditional breeds seasonal differences in activity and behaviors were identified for piglets. Piglets were more active during spring-time and cooler times of the days as compared to summer and warmer times of the day. During cooler temperatures piglets were more active and fed more intensively, whereas during warmer temperatures resting in the shade and wallowing were more frequent [48]. These authors concluded that environmental temperature and reduction in vegetative ground cover are important factors that impact behavior and productivity of pasture pigs [48]. Parrini et al. reported a similar behavior towards heat stress in Cinta Senese, an Italian heritage breed, and their crosses with Large White [34]. Similarly, seasonal influence has also been reported in piglet mortality, where higher mortality rates were found during the summer and lower in the spring [37,48].

Low temperatures could cause hypothermia in pre-weaning and recently weaned piglets in pasture systems; thus, becoming a potential risk for their welfare [29,49,50]. Pigs managed under low temperatures grow slower and are more susceptible to diseases such as pneumonia caused by *Mycoplasma hyopneumoniae* [51]. Adult pigs tolerate low temperatures better than higher ones. However, when subjected to long periods of low temperatures, older pigs can lose body condition [29]. Indoor-managed animals maintained constant rectal temperatures throughout the seasons, whereas outdoor pigs' rectal temperatures fluctuated throughout the seasons, which could translate into difficulty managing temperature during winter months. Outdoor-housed sows showed a greater variation in back-fat, longer claws, and lower reproductive rates [29]. Wind and snow intensify the effects of low temperatures. Snow accumulation can also restrict access to areas where animals are located or affect electric fencing. The impact of the wind on animal welfare differs among seasons.

In the course of hot weather, wind can be favorable contributing to heat dissipation, but the opposite can happen during cold weather when it would be necessary implement measures to minimize its effect. Wind can influence the location of the pigs in the paddocks. Regardless of environmental temperature, pigs will avoid exposure to areas of high wind speed and their response

to it will depend on seasons, breeds, and body weight [35,51]. Pigs that did not have access to wind protection during winter showed decreased growth rates. Duroc pigs showed greater improvements in growth rates compared to Yorkshire or Danish Landrace pigs. Heavier pigs (weight ≥ 29 kg) performed better in unshielded pens [51].

Contrary to many indoor-confined pigs, pasture pigs are exposed to sunlight. Exposure to natural photoperiod could impact the reproductive behavior and performance of sows [39]. Decreases in milk production have been related with shorter photoperiods [23]. High solar radiation can cause sunburns in animals with light colored skin, which can show redness of the skin and changes of posture caused by pain [26,29,52]. Additionally, photosensitization in response to the ingestion or contact to certain plants such as parsley (*Petroselinum crispum*) [53], turnips, parsnips, rape (*Brassica* spp.) or celery (*Apium graveolens*) leaves [33], (*Medicago sativa*), clover (*Trifolium* spp), oats (*Avena sativa*), carrots (*Daucus carota* subsp. *Sativus*), and buckwheat (*Fagopyrum esculentum*) [54] can also cause severe blistering to sun exposure. Pigs grazing bermudagrass (*Cynodon dactylon*) have presented signs of photosensitization and ataxia (author's personal observation, unpublished), which are consistent with the symptoms (incoordination of the forelimbs, collapse of posterior legs, stiffness, and crab crawling) described by Williamson et al. [55]. These animals recovered quickly when placed in the shade.

Some weather elements can also have a combined effect on pigs' behavior. Pigs used shelters more frequently with high environmental humidity, wind, and low temperature. Sow nesting behavior is also influenced by environmental conditions. The effort of sows, the location of the nest, and the amount of materials used in cold, rainy, and windy conditions seem to prompt the construction of stronger nests that can provide more protection to the piglets than nests built under high environmental temperatures [35]. Cold and drafty conditions could lead to an increase tail biting resulting in higher rates of tail lesions among outdoor-managed pigs as compared to indoor-reared pigs. Furthermore, outdoor pigs could also have higher prevalence of skin lesions during summer and attributed them to insect bites compared to indoor pigs [11]. Additionally, African swine fever also presents a seasonal prevalence in free-range pigs in Sardinia, Italy [56].

3.1.2. Exposure to Wild Animals and Pathogens

3.1.2.1. Exposure to Wild Animals

Pasture pigs could be exposed to biosecurity threats to a greater extent than pigs reared in confinement [12,57]. The health and well-being of grazing pigs may be threatened by exposure to wild animals which can act as predators or be pathogen reservoirs [58–61], transmit diseases [62], damage equipment and facilities, and ingest and contaminate both feed [63] and bedding of grazing pigs [58,63,64]. Some of these threats include: insects, snakes, birds, rodents, raccoons (*Procyon lotor*), badgers (*Meles meles*), foxes (*Vulpes vulpes*), coyotes (*Canis latrans*), feral pigs (*Sus scrofa domesticus*), wild boars (*Sus scrofa* L.), ravens (*Corvus corax*), eagles (*Aquila audax*), and feral and pet dogs (*Canis lupus*), and cats (*Felis catus*) [23,58–60,65,66]. The lack of appropriate fencing and the closeness to wooded areas encourage predator attacks [23]. Predators prefer to prey on piglets but scare adult pigs to the point that they break fences and escape. In lactation paddocks, this could cause piglet mortality due to starvation. Approaches for wild animal control include lethal and non-lethal strategies. Lethal strategies include trapping, snaring, shooting, and poisoning [67]. Common non-lethal strategies are permanent or seasonal wildlife exclusion fences [68], perimeter fences, double fencing [69], herding, stalling at night, avoiding the accumulation of organic waste, maintaining feeders and feed storages in proper conditions, keeping feed in dry and tightly closed containers, not allowing pets in the production unit, cleaning-up feed spills, and appropriate disposal of carcasses. The use of guard animals such as sheep dogs, donkeys (*Equus asinus*), llamas (*Llama glama*), and alpacas (*Vicugna pacos*) can help discourage invaders [60].

The efficacy of predator control methods is related to predator species and mitigation strategy more than with livestock type. Farmers in Wyoming, USA, considered that the diverse mitigation

strategies available were effective in the control of foxes and coyotes, somewhat effective with large carnivores, and least effective controlling avian predators [67]. The use of non-lethal strategies is practical in small-scale farms, while its implementation in large areas could become inefficient. In the USA, the most used non-lethal mitigation measure across different farms sizes are livestock guardian dogs [70]. However, their use should be subject of a cost (acquisition and maintenance) versus benefits (reduction in losses) analysis [70]. The use of donkeys or camelids present lower maintenance costs due that part of their diet is provided by forages grown in the farm. Special care must be given to the control of rats (*Rattus* spp.) and mice (*Mus musculus*), as they can become important reservoirs of pathogens such as *Salmonella*, *Leptospira*, *Yersinia*, *Brucella suis*, *Erysipelothrix rhusiopathiae*, and *Brachyspira hyodysenteriae* [66,71]. Performing frequent movements of the operation is a useful strategy to reduce *Salmonella* infestation [72]. It is important to avoid using cats in rodent control programs due to the risks associated with the transmission of *Toxoplasma gondii* [58,63,65]. Similarly, mammals (including feral and wild pigs) and birds have been identified as reservoirs of African swine fever virus [73], *Salmonella* [72,74,75], and *Streptococcus suis* as the causative agent of meningitis, arthritis, endocarditis, pneumonia, and septicemia in pigs [76,77].

3.1.2.1.1. Wild Boar

The rapid expansion of wild boar presence represents a special risk for pasture pigs due to an increase in the frequency of potential contacts. Undesirable mating among domestic and wild pigs and the potential contamination with shared pathogens are the most common threats [78,79]. Wild boars have not only been reported as playing an important role in the transmission of parasites, bacteria, and viruses to domestic animals but also to humans [80–83]. These animals have been identified as potential sources of African swine fever virus [56,73,84], Aujeszky's disease [78,79], brucellosis [78,79,82], *Campylobacter* [80], classical swine fever [85], giardiasis [80], salmonellosis [81], *Streptococcus suis* [77], toxoplasmosis [81,82], trichinellosis [61,82], tuberculosis [86,87], and yersiniosis [81] in domestic animals, and leptospirosis, tuberculosis, hepatitis E, brucellosis, and trichinellosis in humans [56,78,83]. Conversely, Batista Linhares et al. indicated greater probability of contagion of enzootic pneumonia caused by *Mycoplasma hyopneumoniae* from domestic pigs to wild boars [88]. Pathogens can also be transmitted through consumption of contaminated meat, as in the case of bacteria such as *Escherichia coli*, *Listeria monocytogenes*, and *Campylobacter* [80,81] or viruses such as African swine fever [73] and classic swine fever [85].

Appropriate fences help reduce contact between wildlife and livestock [68]. Based on an assessment on risk factors for contacts between wild boars and domestic pigs, pig fences should be higher than 60 cm to avoid intrusions [78]. According to the same authors, breeds such as the Mantgalitza that are most phenotypically and genetically similar to wild boars; thus, potentially more attractive to them, presented a higher frequency of undesired mating than Landrace or Large White sows. Therefore, on farms raising these pigs a wire-mesh external fence should be used in addition to the electric fence to prevent undesired crossbreeding [78]. Conducting biosecurity programs and disease surveillance protocols both for wild and domestic pigs are key to minimize the risk of introduction and transmission of diseases on pig farms in particular against African swine fever, classic swine fever, Aujeszky's disease, and porcine brucellosis [56,79,89].

3.1.2.2. Exposure to Pathogens (Parasites, Bacteria and Viruses)

Under a grazing environment, pigs are exposed to greater contamination risks with pathogens causative of diseases that can impair their health and welfare, or can be transmitted to humans [25,63,65]. Additionally, the implementation of biosecurity measures and control programs is far more complex in pasture systems [57,90,91]. *Salmonella* and *Campylobacter* were found in soil from paddocks managed with pigs [91]. Compared with pigs in intensive confinement systems, outdoor pig herds have presented a higher prevalence of *Salmonella* [92], *Toxoplasma* [91,93], *Trichinella* [93], *Leptospira Bratislava* [33,57], *Ascaris suum* [94,95], and *Taenia solium* [93].

In Mediterranean areas, the role of extensively raised pigs in the transmission of the *Mycobacterium tuberculosis* complex causing tuberculosis has been established [86,96]. In the Netherlands, Van der Giessen et al. reported higher incidence of *T. gondii* in pigs from free range farms than in confinement (33% vs. 4%). However, no differences among the production systems were observed for *Trichinella spiralis* [97]. Similarly, in Mexico, Ortega-Pacheco et al. found that the risk of infestation by *T. gondii* in farms with less than 400 pigs was 28 times higher than that in bigger farms and reported an association among automatic feeder type and infection risk [98]. According to Wallander et al., access to pasture in Sweden is one important risk factor in pig transmission of *T. gondii* [58]. Pablos-Tanarro et al. found a higher prevalence of *T. gondii* in Iberian sows managed in extensive systems compared to intensive systems [66]. More recently, Castillo-Cuenca et al. reported seropositivity to *T. gondii* in 86% of the Iberico pig farms tested, with higher prevalence in sows than in fattening pigs [65].

Sutherland, Webster, and Sutherland compared information from different countries, and indicated that in the Netherlands pigs managed outdoors showed higher levels of infestation with *Ascaris suum* and *Eimeria* spp. compared to pigs managed in confinement. Nonetheless, the same authors found no differences between production systems in relation to the prevalence of *Oesophagostomum* spp. and *Trichuris suis*. In samples collected in Austria, 75% presented eggs from gastrointestinal parasites (*A. suum*, *Oesophagostomum* spp., *Coccidia*, and *T. suis*) and 30% of the sampled animals had lice and scabies. At the time of slaughter, 50% of the animals had white liver spots, indicators of previous infections with *A. suum*. In Denmark, 28% of weaned piglets and 33% of fattening animals were infected with *A. suum*, 4% of weaned animals and 13% of fattening animals were positive for *T. suis*, and 20% of sows for *Oesophagostomum* spp. No ectoparasites were detected in these animals [95]. More recently, Vázquez reported incidences of mixed infections of *T. suis* and *Lawsonia intracellularis* in Iberico pigs and their crosses reared in the Dehesa [99].

Some of those pathogens, such as *Salmonella*, *Campylobacter*, *Ascaris suum*, and *Trichuris suis*, can survive in soil, water, shelters, and huts of pasture environments [91,100,101], and could represent a significant risk of infection [97]. As a strategy for parasite control in pasture systems, it is important to implement periodic parasitology monitoring of the herd [86,102]. Certain management strategies have proven effective in reducing parasite infestations in pasture pig operations. Among them: avoiding the use of moist areas with a tendency to become waterlogged, implementing pasture rotation [72,101], decreasing the stocking density, using forage mixtures (including forages with high tannin concentrations), mixed animal species grazing [103], and integrated use of anthelmintics [57].

3.1.2.3. Ingestion of Toxic Elements

A threat to the wellbeing faced by pigs managed on pastures is the potential ingestion of toxic plants and mushrooms [33,104]. In the United Kingdom, there have been described pig intoxications and in some cases deaths due to the consumption of ferns (*Pteridium aquilinum*, subspecies *latiusculum* and *atlanticum*) containing toxic and carcinogenic substances [105]. Grazing pigs ingest a considerable amount of soil while foraging [57]. Rivera Ferre et al. reported sow fecal ash concentrations up to 937 g kg⁻¹ DM and 450 g kg⁻¹ fresh weight of stones [106]. Similarly, Jurjanz and Roinsard indicated that grazing lactating sows ingested on average 0.3 kg of soil/sow/d [107]. This situation could potentially expose grazing pigs to the risk of ingestion of contaminants, including toxic metals that could be found in the paddocks [57]. Toxic components could accumulate in animal tissues such as muscle, liver, and kidneys, and affect animal health; this could also represent a risk for humans consuming meat from these pigs.

3.1.2.4. Exercise

Compared with other systems, pasture systems offer pigs a greater opportunity to carry out more physical activity [6], which would result in better animal welfare [35,108]. The impossibility of behaving naturally due to confinement, and the privation of environmental stimulation have been identified among the main causes of boredom and frustration in indoor managed pigs [24,39].

Additional potential consequences to lack of exercise are more health related: impairment of the cardiovascular system, and weakness of bones and muscles which frequently cause lameness [41]. However, free-range pigs have been reported to have more frequent and severe osteochondrosis than indoor pigs; nevertheless, these pigs did not show lameness [109]. The greater opportunity of exercise in outdoor systems could have reinforced the joint supportive tissue and contributed to alleviate the pain [109,110]. Furthermore, increased exercise translated into better physical condition in pasture pigs which allowed them to better resist the stress of mixing and the hardships of transport and lairage [111]. Lack of exercise may also have consequences beyond sow welfare such as decreased piglet survival at farrowing [29]. In spite the benefits of exercise, higher physical activity in pastures could be associated with higher energy expenditure [112] and higher nutritional requirements [33] that need to be considered in feeding programs for the sake of grazing pig welfare.

3.2. Animal Genetics

Attaining an appropriate level of welfare under pasture conditions requires adapted and robust animals that are resistant to parasites and pathogens, and that can take advantage of the nutrients provided by pastures [23,113,114]. Prunier et al. discussed the greater influence of genetics in less controlled environments such as in pasture conditions. Traits of importance such as litter size (at birth and at weaning) and pre-weaning survival show heterosis effects (either maternal–crossbred mothers or direct–crossbred piglets), milk production and number of teats show differences among breeds [23]. In terms of animal genetic improvement, the two options for free-range or pasture-based production systems are the use of pure or crossbred pigs selected for high input systems or the use of local heritage breeds [114]. In most European organic systems, locally adapted traditional breeds are preferred for outdoor systems [110].

Traditional pig breeds are well adapted to local environmental conditions including climate, diseases, parasites, and available feedstuff (forages, acorns, chestnuts, birds, small mammals, and soil fauna); thus, becoming a good option for pasture systems, either as pure breeds or in crossbreeding programs [115,116]. Grazing behavior of pigs resulting from crosses of (Landrace x Yorkshire) sows with boars of the traditional breed, Tamworth, grazed more than the progeny of sows of the same genotype with boars of the improved Duroc breed. Conversely, Duroc crossbreds expressed more frequent resting and no difference in rooting behavior [117]. In addition to their adaptation to pasture conditions, another advantage of the traditional breeds is the quality of their meat, an attribute which has earned them the appreciation of restaurant chefs, artisans, and consumers [118–120]. Compared to modern genotypes, local breeds have shown greater fiber consumption and digestibility [121]. The use of traditional breeds also contributes to the maintenance of genetic diversity in livestock species [115].

The main disadvantage of local breeds is their lower economic performance when compared to modern genotypes, which may lead producers to select breeds showing less adaptability for pasture-based systems. Animal breeding and genetic improvement programs should be oriented toward obtaining a balance among lower inputs and greater output goals [122] without sacrificing important traits for these systems such as adaptation and meat quality. Crossbred pigs selected for outdoor systems displaying desired traits, environmental adaptation, and economic efficiency have been developed by breeding companies [29]. Caution should be taken not to create greater problems through breeding programs [123]. Selection for prolificacy could be a source of stress and reduced welfare for both the high-prolific sows and their litters [124]. Sows with larger litter size have shown increased duration of farrowing and piglet mortality, disparity in the number of teats in relation to a greater number of piglets, lower piglet birth weight, and more competition among piglets [125–127]. In these cases, selection for productivity could be associated with reduced mothering ability which is essential in pasture systems with reduced monitoring and intervening possibilities to support animals. These issues indicate the need to reorient the genetic selection, giving more importance to welfare-related traits such as sow longevity and piglet survival [57].

Despite the unsuitable breeding criteria for conventional pigs to outdoor conditions [31], some European farmers use pigs improved for indoor conditions in pasture systems [110,128]. Rööß et al. advised that these animals could not reach their genetic potential when managed on pastures [128]. Additionally, there is increased potential for more frequent and severe joint lesions among these animals suggesting that the leg conformations of modern genotypes are not adapted to the exercise requirements associated with pasture-raising [109,129]. Disease resistance, adaptation to environmental and diets variations, the ability to exploit alternative local feedstuff [114], leg conformation and strength, sow longevity, lean growth, and reproduction rate have been proposed as important traits to be included in selection programs aimed at improving the welfare of outdoor pigs [130]. However, simulation of breeding models for increased welfare (mothering ability and sow longevity) resulted in reduced growth rates for animals raised for slaughter [130]. Nevertheless, sows selected for outdoor production have more robust piglets that show greater pre-weaning survival rates [131]. For animal welfare purposes, genetic selection for litter size should focus on obtaining no more than 12 robust and viable born-alive piglets [125], enhance neonatal survival, and ensuring reduction of intra-litter birth weight variability to improve piglet survival rates [132]. Additionally, selection for maternal behavior (crushing piglets, posture changing at farrowing, piglet-directed aggressions, responsiveness to piglets, and nursing behavior) has been related to piglet survival [132,133]. Aggressive behaviors of pigs are also important for welfare and can be improved by breeding [133]. Breeding programs can moderate aggressive behaviors causing a reduction in tail biting [114]. Chinese Mi pigs were less active and less aggressive than European Landrace–Large White crossed pigs [134]. De Melo et al. compared the behavior of Piau (a local breed) sows to those of crossbreeds (Duroc × Pietrain × Large White and Landrace × Pietrain × Large White) sows in a semiarid area in Brazil. Crossbred sows exhibited more heat stress behaviors and aggressiveness than local sows, suggesting better adaptation to the climate by the local breed [135].

3.3. Expressing Species Specific Behaviors

Pasture systems are more favorable for animal welfare than confinement systems [12,35,49,136], because pigs have a better chance of expressing their species behavioral habits, such as organizing in groups and interacting with their peers, exploring the habitat, foraging, grazing, rooting, and wallowing in the mud, when compared with indoor-reared pigs [136]. Behaviors such as grooming and play are self-rewarding and can be considered an ethological need which ensures welfare of the animals. Inability to express ethological behaviors as a result of environmental restriction or pain can lead to distress and impact the wellbeing of the animals [137], which results in the appearance of stereotypes and other abnormal behaviors [138] that can be considered indicators of reduced welfare [5].

Differences in piglet behavior (during nursing, at weaning, and post-weaning) have been observed in indoor and outdoor systems. Indoor piglets showed more agonistic behaviors (belly-nosing, other oral–nasal interactions) towards mother and littermates than outdoor piglets. Outdoor piglets, in the other hand, interacted with the sows less often and were more active walking and exploring paddocks. Indoor-managed sows interacted with the piglets all the time, whereas outdoor sows reduced the time they dedicated to the piglets from 86% the first day to less than 30% for days 12 and 19 after farrowing. Even though no differences were found among outdoor and indoor sows during active time, outdoor sows spent more time standing, walking, and exploring their surroundings. The observed behavioral differences could be attributed to the distinctiveness of the environments, including space availability and complexity [139].

The limited space and the existence of artificial social structures characteristic of confinement systems can negatively impact social interactions; thus, generating aggressive behaviors [25]. Higher number of skin scratches were registered in indoor-kept piglets, which displayed more resting, drinking, moving, aggressive, and fighting behaviors, whereas outdoor pigs showed higher frequency of investigative and social–play behavior, lower body wounds, and greater weight gain [140]. Studying the behavior of Iberico pigs reared in intensive or extensive production systems,

Temple et al. observed a higher incidence of both positive (nosing, sniffing, licking, and moving gently, 10.0% vs. 2.3%) and negative–aggressive behavior (biting or any other conflictive behavior, 5.1% vs. 1%,) in intensively-managed pigs. Their analysis showed that pigs managed in extensive systems are more entertained and vivacious, in their words “happier and content”. These authors did not detect differences in other behaviors, such as exploratory behavior, or human and animal relationship as a consequence of the rearing production system [141]. Similarly, Parrini et al. observed a reduction in aggressive behavior in Cinta Senese pigs managed outdoors when compared to pigs of the same breed that were reared indoors [34]. Because pasture ecosystems are so diverse, it is possible to provide grazing pigs with more opportunities to further display their vast inventory of specific behaviors in comparison with indoor-reared pigs; hence, reducing aggressiveness and manifestation of stereotypes [57]. In addition, pigs managed on pastures have more room to escape and to move away to avoid aggressive behavior from other pigs.

3.3.1. Rooting

Rooting, one of specific behaviors expressed by pigs on pasture, has been linked to foraging, thermoregulation, and nest-building [35]. Age, sex, genotype, and novelty are some factors related to the expression of rooting behavior [24]. Outdoor housing of pigs encourages the expression of natural behaviors such as rooting and contributes to controlling stressful reactions, both factors of importance for welfare [142]. Indoor-confined pigs with reduced possibilities to root have shown increased abnormal conduct, like fighting and biting, suggesting substitution of behavior [143]. Nevertheless, the use of environmental enrichment strategies proved effective to increase activities like exploring, foraging, playing, and social interactions; thus, improving animal welfare and performance of indoor-managed pigs [24]. Feed restrictions and irregularities in daily feeding management have been associated with hunger and higher rooting frequency [24]. Moreover, pasture conditions such as soil moisture [34,35] and low environmental temperature, have been related with increased rooting behavior [35]. However, rooting may represent a risk of infections with pathogens because of the increased risk of ingesting *Salmonella*, *Campylobacter*, and *T. gondii* oocysts from contaminated pasture and soil [58,91]. Even though rooting is a positive exploratory and feeding behavior [144], it has also been associated with sward deterioration and negative environmental impacts. The creation of bare soil areas through rooting can lead to runoff and erosion [21]. Wet and muddy conditions are frequent during winter in paddocks managed with high stocking rates where the impact of sows rooting behavior prevent the recovery of the vegetation [30].

3.3.2. Wallowing

Wallowing (covering the body with mud) is an important behavior for swine and possibly an indicator of pig welfare itself; it serves multiple functions such as thermoregulation/cooling, sunburn protection, ectoparasite control, social and mating behaviors [145]. The cooling effect of wallowing happens when the water evaporates from the skin, which increases when the coating is composed of mud instead of water because it takes longer for the water in the mud to dry-out [146]. Reductions up to 2 °C of body temperature have been reported in response to wallowing [35]. The layer of mud acts also as a barrier to the sun ultraviolet rays; thus, preventing sunburn [20] and protects the skin from biting insects and parasites such as flies, ticks, and lice [145]. Indoor confinement systems prevent the manifestation of this behavior [147]. Nevertheless, the expression of this behavior could also represent a risk to the welfare of pigs. The use of wallows has been linked to reproductive [148] and health issues [149,150]. *Salmonella* [72,149,151], *E. Coli* [149], and *T. gondii* [58] have been isolated from wallows. Recommendations for a safe use of wallows to reduce the infestation risk include implementing individual-use wallows, positioning wallows away from drinking water sources, and avoiding standing water [22]. In addition to natural shade from trees in pasture systems alternatives to thermoregulation like nebulizers and sprinkler systems could be considered when appropriate. [152]. Effective reduction in heat stress has been observed from pasture pigs when foggers were installed in shaded areas [20].

3.3.3. Excretory Behavior

Pigs, both in semi-natural conditions and in confinement, differentiate areas within the available space and designate certain sections for resting, eating, and defecating. In general, pigs avoid the use of certain areas (nest, rest/lying area, close to feeders, waterers, and wallows) for their excretory behavior [153]. Therefore, from an animal welfare standpoint, it is important to provide sufficient space so that they can differentiate excretory areas from the rest. Lack of enough space could force the animals to lay in the soiled area, becoming a source of stress and a potential health risk. In pasture systems, the manifestation of the eliminatory behavior could create soil nutrients hot-spots in the preferred dunging site [21]. These manure-concentrated sites present the risk of irregular accumulation of parasites eggs in the paddocks, as have been observed for *A. suum* eggs [154]. Periodic movements of the shelters, huts, feeders and drinkers, the frequent allowance of new grazing areas, and the implementation of rotational stocking systems have demonstrate effectiveness in improving the distribution of excreta in the paddocks; thus, reducing the risk of contamination with pathogens [20,21]. Similarly, the provision of rooting areas has been used as a strategy to reorient the excretory behavior toward specific areas of the paddock [155].

3.3.4. Nest Building Behavior

Maternal behavior is appreciable even before farrowing through modifications of social and feeding behaviors. In pastures as in the wild, two to three days before farrowing, sows initiate a series of behaviors, including the search of a secluded place to nest, set up a nest, and reduce food intake [2]. Instinctively, they use grasses, branches, vines, and leaves as nesting material. Once the nest has been built, the farrowing can start. The expression of this behavior to protect the litter from environmental conditions and potential predators [156], has been related with shorter farrowing, better nursing, enhanced maternal behaviors, more colostrum, higher fertility rate, less stillbirth, and healthier and larger litters [127]. Conversely, sows managed in farrowing crates cannot display this behavior. Prolongation of the duration of farrowing was observed in sows that were abruptly confined before parturition [157]. Activity and locomotion could be important for the full expression of normal behavior of pre-parturient sows [158]. Additionally, environmental conditions influence the expression of specific behaviors in the period from pre-parturition to lactation that could impact sows' welfare and even more piglets' survival [159,160].

These observed behaviors reveal the advantages of outdoor pasture systems over confined ones when it comes to animal wellbeing, for the needs of the sow and piglets are better met in pasture systems [161]. Sows are moved to the farrowing-nursing paddocks (either individual or collective containing farrowing huts for each sow) 7 to 10 days before farrowing, allowing them to become familiar with the environment and expressing nesting behavior [60]. Sows are allowed to leave the hut, but the piglets are kept inside for the first 10 to 14 days. This system permits the display of maternal behavior and to strengthen the mother-piglet bonds, favoring a better early lactation [161]. Sows unable to express this normal behavior due to confinement or to the lack of nesting materials will become stressed, which in turn will affect their welfare and that of their piglets [4,103,156]. Furthermore, these sows show greater indifference to the calls of the piglets and a more marked tendency to display aggressive behavior toward them [2] and other abnormal behaviors, such as bar biting, trough-biting, vacuum chewing, and excessive drinking [1]. Relocating pregnant sows outdoors one week prior to farrowing resulted in a greater live-born piglet mortality, which was attributed to more time spent foraging outside of the huts before and after farrowing. Providing sufficient time for the sows to isolate themselves adequately reduced the negative effects on piglet mortality and growth rates [23].

3.3.5. Social Behavior

Pigs are social animals [24] with a strong hierarchical and stable organization formed since birth. Their hierarchy structure is mostly based on age and body size [2]. In the wild, most pigs' activities are conducted in groups [29,162], whose size relates to available resources [163], and include young

and adult animals [147]. In pasture conditions, congregating stimulates nursing, foraging, and can provide protection against predators. Cinta Senese pigs and their crosses on pasture, preferred to conduct their activities in groups most of the time, particularly during morning hours [34]. In groups, dominance relationships between animals are established with subordinate animals having limited access to resources such as feed, water, preferred space, and receiving most of the aggressions [164].

The social status of pregnant sows affects their behavior, with dominant sows being more active, showing more aggression, and displaying higher use of straw, compost, and cotton ropes available in the pen. Subordinate sows are more frequently ousted from the use of the material available [165]. Most negative social interactions in dry sows are the result of competition for feed and social instability while new hierarchies are formed after mixing with unfamiliar pigs [30]. Reduction in aggressive interaction relates to size of the group of sows; lower aggression has been observed both in small groups (less than 9) or large group (more than 25) [30,31]. Increasing the space allowance offered to pregnant sows (3.0 vs 2.25 m² per sow) can reduce the number of one-way aggressions and the number of injuries following grouping [166].

Discrepancies in the social behavior of pigs reared in indoor and outdoor systems are also influenced by intrinsic attributes of the systems, including environmental temperature [139] or muddy pastures condition [144,167]. Confined indoor pigs cannot express social behaviors, which leads to psychological distress [168] and inadequate social comportment. The competitive behaviors are mainly constituted by pushing, head thrusting, and attack sequences that may culminate in bites [2], or more harmful behaviors like tail biting [140,142] or cannibalism [31]. Triggers to tail biting in confined animals can include: high animal density, poor water and feed supplies, competition for these resources, incorrect or fluctuating temperature levels, inadequate ventilation, noise, air currents, high levels of dust and harmful gases (ammonia), lack of opportunities to escape from dominant animals, genetic factors, lack of environmental enrichment (such as materials for rooting), and also general health problems [144,167,169,170].

In pasture systems, pigs are subject to lower social distress, have greater space allowance, and a more diverse environment. In these systems, the occurrence of tail biting indicates the existence of factors that predispose the manifestation such as genetic factors, respiratory issues, diet insufficiencies, and/or pastures muddy conditions [168,171]. Even though outdoor systems are not exempt from aggressive behaviors, their frequency and intensity are lower and cause lesser lesions [168,172]. Lower prevalence of tail lesions, severe body scars, and tail biting damage was reported in pigs reared outdoors than in pigs managed in the combined indoor–outdoor, or in the indoor system [28,110]. To minimize aggressive behaviors in outdoor systems efforts should be oriented to find better ways to reduce the impact of the environmental temperature on the animals [28]. Some strategies have been tested to prevent tail biting in intensive systems by the provision of manipulable substrate [169], and the implementation of exploratory feeding strategies [172], and those have proven effective in reducing aggression and skin wounds. In pasture systems, ample space and environmental diversity contribute to lower tail biting problems [173].

3.3.6. Grouping and Regrouping—Mixing Animals

In indoor-confinement systems, the practice of mixing unfamiliar pigs such as growing pigs or sows is common. However, this practice can also be conducted in pasture pig systems at weaning, at the beginning of the growing–finishing period, when organizing homogeneous groups, within the groups of gestating sows, and during transport. This procedure leads to aggressive interactions resulting in stress, aggressions, skin wounds, lameness, and impaired welfare [50,174,175]. Moreover, frequent mixing could cause chronic stress [176]. Mixing implies the formation of new social hierarchies with potential changes of roles (dominating–subordinate). Piglets reared outdoors during lactation showed lower level of aggressive behavior and lesser lesions when mixed after weaning in comparison with indoor managed pigs. These differences have been attributed to special skills acquired when interacting with same age piglets from other litters and with older pigs, or to a better capacity to handle new situations as a consequence of exposure to a more complex environment [50].

In European organic sow herds, issues after mixing have been observed, such as social competition for feed and resting space, and aggressive behavior culminating in skin and vulva lesions [30].

Implementing appropriate management strategies could avoid the negative consequences of grouping and regrouping [177] both in pasture and in confined systems, because it is advisable to maintain social relationships as stable as possible [31]. When grouping sows, it is recommended to manage a small number of sows, mixing sows of the same parity, and conducting the mixing in areas with ample space [30]. Other practical suggestions include mixing animals at the end of the day, after feeding, increasing feed offer of standard diets, feeding diets high in fiber [171], and spraying animals with scented, odor-covering solutions [178,179].

The production system can also impact the level of aggressions, frequency, and duration. Fighting episodes lasted longer in indoor-confined pigs, whereas outdoor pigs showed lower levels of aggression. In outdoor pigs, the level and the manifestation of the aggression could have been modulated by social behavior lessons learned through early in life interactions with unfamiliar pigs. Indoor-managed pigs displayed indicators that pre-slaughter mixing was more physically stressful for them than for outdoor pigs. For niche production systems, it could be easier to maintain pigs in their natural social groups, thus minimizing mixing practices and their impact on welfare than in indoor-confinement systems [111].

3.4. Management Practices

Implementing appropriate husbandry practices reduces stress among animals; thus, guaranteeing health and welfare, and ideal productive performance [147]. A management program for grazing pigs must take into account such aspects as climatic conditions, available area, soil characteristics, and producer skills and abilities [64]. Management should integrate elements related to housing, feeding program, grassland management, herd organization, selection and breeding plan, reproductive program, and disease prevention [22,62]. Mistakes in the implementation of some of these management practices may cause a decrease in animal welfare [62]. Moreover, incorrect handling could cause stress [177] or be the trigger for pain [137]. Additionally, inadequate handling, housing, equipment, and mixing animal conditions could stimulate the manifestation of aggressive behaviors, and ear and tail bites that negatively affect wellbeing. It is important that animal caretakers receive appropriate training to avoid unnecessarily stressing the animals [57].

3.4.1. Painful Interventions

The typical management of pigs involves the routine execution of surgical procedures, including ear notching, castration, tail docking, teeth clipping, and tusk trimming, without implementing any kind of pain relief (either the use of anesthetics or analgesics). These procedures cause physiological and behavioral changes in pigs in response to suffering and could lead to other ailments such as lesions, abscesses, and neuromas, leading to chronic pain and acute stress [180]. Some of these interventions also prevent the manifestation of species-specific behaviors, compromising health and welfare. The need to find more animal-friendly management alternatives has led to testing different options [180–182]. For example, the use of tattoos, plastic tags, and electronic tags serve as less painful alternatives to ear notching identification [18,181] and instead of using painful injections to deliver medication, the latter can be administered orally, mixed with feed.

Castration is performed in male pigs to control aggressiveness, undesirable mating, and pork “boar taint” (unpleasant odor in entire male meat). The method most frequently used is the surgical elimination of testicles in pigs of young age, which is painful. In most farms, castration conducted without any anesthesia or analgesia, results in pain and impaired welfare for pigs. Some alternatives to minimize the impact of surgical castration have been under evaluation [31,183]; among them, the use of local anesthesia [18,184], immuno-castration (using pigs immune system to produce antibodies against its own reproductive hormones) [18,185], and the production of intact male pigs (marketing pigs before they have reached sexual maturity at approximately 100 kg) [18,186]. The proposed alternatives present advantages and disadvantages that need to be considered carefully. The cost of

combined anesthesia and analgesia makes the practice inaccessible for most farmers [187]. An objection to the use of intact males would be the increased stress due of aggressive and mounting behavior during the finishing period [187]. Contrastingly, good results can be obtained by employing immuno-castration with pigs managed in different housing systems [188]. However, economical comparisons conducted in Germany showed that barrows performed better than boars and immunocastrates [189]. Castrated pigs reared in enriched environments displayed lesser agonistic behaviors, but were harder to manage during saliva sampling, whereas in these environments intact males showed decreased feeding behaviors [190].

Reduction in skatole level has been attained through certain feeding strategies such as ad libitum feeding of intact males [183], addition of fermentable carbohydrates such as sugar beet (*Beta vulgaris*) pulp, high amylase barley (*Hordeum vulgare*), chicory (*Cichorium intybus*), inulin (>6%) and raw potato (*Solanum tuberosum*) starch (>20%) [191–193], and dietary supplementation with plant extracts containing herbal essential oils with antimicrobial activity and tannin-rich extracts found in plantain (*Plantago lanceolata*) [193], Jerusalem artichoke (*Helianthus tuberosus*) [194], and lupins (*Lupinus angustifolius*) [193]. In addition to feeding strategies some management practices (avoiding stress, maintaining clean pens, low stocking rates, sex grouping, limiting re-grouping, providing sufficient access to water and feed, and fasting for more than 14 hours prior to transport) also contributed to reduction of skatole [183]. Based on the high heritability index of androstenone production and its accumulation in fat tissue [195], Switzerland, Belgium, Germany, and France have recently oriented their efforts toward genetic selection of individuals with lower androstenone and skatole concentrations in pig dorsal fat. As a result, some Pietrain boars are being marketed as low risk for boar taint [196]. Additional factors that influence androstenone and skatole levels are the size of the groups, mixing strategies, and slaughter weight.

Another practice pigs are routinely subjected to in commercial farms is tail docking, which is conducted to prevent future tail bites. Tails of one-week-old piglets are surgically removed without the use of anesthetics [197] causing pain and damaging the physical integrity of the animals, and complications result in spinal abscesses. It is necessary to compare the negative impacts of tail biting to those of tail docking to decide the convenience of performing the practice [172]. Castration and tail docking are elective procedures and are not conducted routinely in all pasture pig systems. For example, in many pasture systems tail docking is not performed, and castration is not conducted in many pig farms in the UK and Australia. Nevertheless, in other countries market-driven forces influence farmers' decisions to keep performing the procedures.

In pasture systems, the maintenance of the vegetative ground cover is a key condition to minimize environmental issues [21]. To reduce the damage that pigs cause to vegetation and soil while rooting, animals are fitted with metal rings placed in their noses which decrease rooting by causing discomfort. The use of nose rings, while causing pain, inhibits a range of functional activities including rooting, and causes chewing in a vacuum and digging in the ground with the front legs which suggests compromised welfare [29,198]. Alternatives to nose rings have been employed with different degrees of success. Some examples are the use of forages species that could withstand and recover from rooting, reduction in stocking rates, implementation of rotational stocking systems, manipulation of edible substrate-silage [199], and provision of root crops [200].

3.4.2. Weaning Age

Weaning is a stressful event for both sows and piglets [18,139]. It has been reported that weaning impacts the structure, morphology, and functioning of the intestines, the immune response of piglets, feed intake, growth rate, morbidity, and mortality indexes [201]. Weaning is a gradual process that would end at approximately 17 weeks of age in the wild [202]. The way weaning is handled varies among production systems [50]. In indoor-confinement systems, weaning is frequently conducted abruptly between 3 and 4 weeks of age [203]. Conversely, the minimum weaning age is 40 days in most organic systems; however, in some countries, older ages are stipulated in national standards. However, weaning at 40 d could be early when compared with semi-natural conditions, and still lead

to physiological repercussions [50]. Weaning at an early age interferes with the normal development of pigs and results in stressed pigs having difficulties adapting to new environments [173,203]. The occurrence of clinical problems related to the post-weaning multi-systemic wasting syndrome could be decreased by implementing a late weaning [50]. Hotzel et al. indicated that weaning age impacted the behavior of piglets reared in outdoor systems, which showed more stressful responses when weaned at three weeks than at four weeks of age [204].

Several factors can influence the welfare of pigs during the weaning stage, mixing, rearing conditions, nutritional disorders, changes in health status, and aggressive behaviors [50,205]. Oostindjer et al. reported the importance of allowing teaching–learning interactions between piglets and sows to reduce post-weaning stress, the fasting period, diarrhea, and the effects that these factors can have on post-weaning productive performance [203]. Weaning older piglets allows the introduction of creep feeding; thus, minimizing the nutritional challenges piglets have to face during this period [206]. Delaying weaning to at least six weeks of age can also decrease negative impact on the wellbeing of piglets by increasing immunity and decreasing the transmission of diseases [11]. The economic benefit of late weaning has been discussed [18,207] but it seems advisable to consider that long lactations could represent an additional effort for the sows, and can affect their body condition, their welfare, and the following reproductive cycle [18]. Therefore, it is important to periodically monitor the sows' body condition [25]. However, Kongsted and Hermansen reported that it is possible to maintain sows body condition even in seven-week long lactations [208].

Differences in the post-weaning behavior of sows and piglets and their social interaction have been associated to the rearing system. After weaning, piglets from confinement presented higher frequency of belly-nosing, aggressive interactions, and reduced feed intake [139]. Conversely, outdoor piglets were more active, walked, ate, and explored more, and developed post-weaning adaptation mechanisms (lower frequency of nursing and greater solid food intake), leading to less post-weaning stress [139]. The differences observed among the piglets were a consequence of the social interactions between the sows and their piglets. Indoor piglets had a more frequent and close interaction with their mothers, whereas outdoor sows had more control of the frequency of nursing resulting in a lower level of interaction with the piglets which stimulated piglet solid feeding and exploratory behaviors. Additionally, the more diverse, spacious pasture environment and greater possibilities to conspecific interaction equipped the outdoor piglets to deal better with the stress of weaning [139]. During weaning and mixing day, outdoor-raised pigs were scored as more passive while those raised in confinement received a more inquisitive grade. Outdoor piglets ate more, whereas the confinement-piglets invested more time investigating their surroundings. These differences could be consequence to confinement leading to neophobia, conflicted affective states, and motivation for exploration. The weaning behavior could reveal piglets' physical and physiological ability to manage the challenges imposed by their new environment and the impact on their social development, which subsequently affect their responses to stressful environments [209].

3.5. Feeding Management

Grazing pigs have higher nutritional requirements to compensate for higher thermoregulation energy costs and for greater exercise in pastures. Therefore, seasonal nutritional adjustments are necessary up to 15% increase of the diet energy in colder climates [39]. However, most nutritional requirement tables have been estimated for pigs housed indoors, which could lead to underestimating requirements for outdoor pigs. Necessary corrections to the amount of feed offered per animal need to be made according to live body weight and extreme environmental conditions.

In pasture pig systems, forages can be included as part of the diet as sources of energy, amino acids, vitamins, minerals, and trace elements [37,39,106]; thus, contributing to a reduction of the feeding costs. Forages contribute also to gut filling; thus, helping to reduce hunger sensation in restricted-fed pigs, and can decrease constipation and gastric ulcers [30,39]. Older animals are better fit to utilize forage fiber [121]. The nutritional contribution of pastures to pig diets relates to the vegetation species present, the amount of forage available, vegetation nutritional composition, and

pig voluntary intake [39]. Grazed vegetation intake has been estimated to 0.1 kg DM/d for growing pigs that had access to supplemental feed ad libitum, and 2.0 kg DM/d for dry sows in restricted feeding programs. This intake could fulfill approximately 50% of the daily maintenance energy requirement for dry sows, but less than 5% of growing pig requirements. The nutritional contribution of soil and soil fauna should also be considered [39]. The quantity and quality of supplemental feed required to meet the nutritional maintenance and production needs of each animal category is related to management [57]. Imbalances in the formulation of rations can cause digestion problems and compromise animal welfare [31]. The use of alternative feeds could lead to unmet nutritional requirements and could contain anti-nutritive factors [30]. Producers and caretakers should be aware of the greater risk of feed contamination with pathogens and mycotoxins [31,39]. In pastures, forage availability in terms of both quantity and quality, follow a seasonal pattern related to precipitation and temperature [37]. This seasonal configuration could produce irregular provision of feedstuff and impact animal welfare and productivity; thus, supplementary feed should be adjusted to overcome this issue [20]. During forage scarcity periods, the possibility of livestock ingesting toxic plants increases [210].

Competition for feed could generate stress and fighting, these situations may go unnoticed and lower-ranking animals may not receive the nutrients they require [17,25]. Animals that receive supplemental feed free-choice could tend to minimize forage consumption. A feeding strategy designed to encourage greater forage consumption consists of restricting the amount of supplemental feed offered to the pigs. However, the growth of pigs could be impacted under feed restrictions greater than 20% of their maintenance level [21]; thus, becoming a potential threat to their wellbeing. When finishing pigs grazed on alfalfa or grass and received restricted diets at either low or high protein levels, Jakobsen, Kongsted, and Hermansen found that pigs on alfalfa grazed more than those on grass. Additionally, greater rooting was observed in pigs on a low protein diet and more frequently under grass grazing. The daily weight gain and feed efficiency of pigs were lower in low protein diets than in high protein diets. However, the weight gain and feed efficiency of pigs in low proteins on alfalfa was greater than those on the same diet and grazing on grass [211]. Restrictions greater than 20% of the maintenance level lead to much greater rooting and foraging behavior, while supplementation of vitamins and minerals had no effect [117]. The damage to vegetation cover could lead to potential welfare issues already mentioned and environmental issues [21]. Feeding restrictions have also been used to manage the fatty acid profile of Iberian pigs before the traditional "Montanera" period, a requirement for traditional Iberico cured meats. However, Lopez-Garcia et al. warn that feeding stress and potentially impaired welfare could result from a restricted diet maintained for a long time (up to a year) during the "pre-Montanera" phase [212].

The nutrition of the sows during the gestational period influences fetal development, birth weight, and colostrum and milk production; thus, contributing to piglet survival [43]. Gestating sows under feeding restriction programs to avoid obesity [144], could alleviate hunger sensations by grazing the forages available in the paddocks, and thus reduce aggression episodes and consequent leg injuries and skin lesions [27,29]. The display of sow abnormal oral behaviors show greater relationship with the restricted feed strategy and the resulting hunger, than with the production system [30,39]. Although sows tend to spontaneously reduce their intake, providing a high level of feed during the last day of gestation was related to heavier piglets and fewer problems for the sows [31]. The feeding management (diet composition, digestibility, feeding strategies, and feeder design) implemented before and after weaning could affect the weaned piglets' welfare-response; this is the reason why it is important to ensure early post weaning feed consumption [50]. The peak of sow milk production happens three to four weeks after farrowing. Following this point, it is beneficial to provide access to creep feeding to ensure the piglets are receiving the amount of nutrients required [23].

In general, feeding animals during the coolest time of the day, increasing the number of feedings, and using liquid feed are convenient strategies to overcome the reduced appetite shown by pigs during hot weather. Throughout hot periods, it is convenient to make adjustments to the diets, increasing the energy density, reducing the fiber concentration, and providing abundant water.

Additionally, increase growth performance of indoor pigs under heat stress was observed when pigs were fed either a low protein with low fat diet or a high protein with high fat diet [213]. A daily water supply of adequate quality (dissolved salt and microbiological) is critical to the whole herd on pastures [39]. Ensuring that piglets after four weeks of age or during occurrences of diarrhea have access to water prevents dehydration and is key for health and welfare [23]. Reduced intake of feed in lactating sows has been related with low flow rates of water from drinkers [39]. The supply of water during the warm season is paramount, but shortage of water during winter as a consequence of frozen pipes and drinkers could also pose a problem and should be avoided.

An indicator of the nutritional and health status of the animals is body condition score, which can be related to insufficient feed on offer, competition for access the feed [214], and to over-feeding. It is advisable to monitor the entire herd, but especially the sows to guarantee adequate body condition at the time of farrowing and weaning. Animals at the bottom end of the body condition scale may have a low level of wellbeing. Additionally, sows in better condition can show lower levels of aggressive behavior [30,39]. Body condition monitoring is important to avoid malnutrition which can happen frequently in sows managed outdoors [25]. For example, 3% of Mallorcan Black pigs (a Spanish heritage breed) managed on pastures and receiving no feed supplementation showed poor body condition (visible hip bones and backbone), whereas among pigs receiving cereal supplementation only 0.4% exhibited a low score [215]. The comparison of four feeding methods (individual, group-feeding indoors, group-feeding outdoors, or electronic sow feeding) in different pig farm systems from the UK and The Netherlands did not show differences among the body condition scores recorded for pregnant and lactating sows [214]. However, the loss of body condition due to extended lactations and insufficient nutrients supply was indicated as a frequent ailment among organic lactating sows in the UK and Denmark [30,39].

3.6. Health Management

Health issues have been identified for both indoor and outdoor systems, with differences in the incidence of the different issues. Though, it is possible to deal with those problems by implementing appropriate management strategies [6] so that implications on production and animal welfare can be minimized. An open and ventilated environment and lower stocking densities could contribute to lower respiratory problems and enteric diseases registered in outdoor pigs [29,57,62]. Lower incidence of mastitis, metritis, and agalactia (24.5%), limb lesions, torsion or distention of abdominal organs [32], tail damage and body scars [28], tail bites, belly nosing, and aggressions [216] have also been reported. However, in Hungary, outdoor systems have been associated with a greater incidence of deaths caused by urogenital diseases, heart failure, and locomotor problems than deaths reported in indoor systems [217]. Additionally, in outdoor systems most sow deaths occurred in the periparturient period leading to lower average parity at death than in indoor systems, where most deaths happened during lactation [217]. Similarly, Austrian organic sow herds also reported incidence of urinary tract infections and gastric ulcers [30]. Lameness due to hoof lesions and abscesses was identified as common health issues in European organic sow herds, with some countries expressing more concern about this issue than others [30].

Skin lesions and scars as a result of sunburn, ectoparasites or scratching [30,216], arthritis [218], severe osteochondrosis [109], lameness [28,30,218], and parasitism [57,218] are more frequent in grazing pigs [30,216]. There is a greater prevalence of arthritis-osteochondrosis, tail lesions, bone fractures, skin lesions, liver spots, septicemia, and abscesses in pigs from outdoor systems (both conventional and organic) when compared to pigs from indoor systems. Nevertheless, there is a lower probability for hernia, leg swellings, and hoof abscesses for outdoor pigs [11]. In a comparison of European organic (indoor, outdoor, and combined indoor-outdoor) pig production systems, Leeb et al. found in general few health and welfare issues, reporting no ectoparasites, shoulder lesions or pigs needing hospitalization, and less than 5% tail lesions and conjunctivitis. However, outdoor-managed pigs showed a lower incidence of weaning diarrhea, respiratory problems, and sows' lameness compared to the other two systems [110]. According to Kongsted and Sørensen,

implementing weaning at a later age and providing greater space are advantages of pasture systems that have a beneficial impact on the animals, increasing their immunity and consequently decreasing disease prevalence in these systems [11].

Ectoparasites such as *Haematopinus suis* (lice), *Sarcoptes* (scab mites), *Tunga penetrans* (chigoe flea), *Cochliomyia* (blowflies), and *Dermatobia hominis* (bot fly) have been identified in Brazilian intensive pasture pig systems, whereas *Eimeria*, *Balantidium*, *Isospora*, *Oesophagostomum*, *Strongyloides*, *Ascaris*, and *Trichuris* were some of the reported endoparasites [102]. Ticks (genus *Ornithodoros*) play an important role in the transmission cycle of African swine fever [56,73]. In the Cerrado savannas (Brazil), mowing the vegetation was an effective strategy to reduce the infestation of ticks (*Amblioma cajennense* complex) in pasture-raised pigs by breaking their life cycle [219]. The main groups of parasites registered in suckling pigs in Poland were *Coccidia* and *Strongyloides*. Conversely, in fatteners *A. suum* and *T. suis*, and in sows *Oesophagostomum* spp., were more common [220]. Similarly, Leeb et al. reported infestations with *A. suum* and *T. suis* in weaned piglets managed on pastures [50]. Evaluating European pig systems, Edwards et al. indicated the presence of gastrointestinal parasites as *Oesophagostomum* spp., *Hyostongylus rubidus*, and *Eimeria* spp., and ectoparasites as *Haematopinus suis* and *Sarcoptes scabiei* in organic sow herds [30].

A marked seasonal survival of *A. suum* eggs on pastures and seasonal variations in pig reinfection rates were observed in Denmark. The eggs deposited during the summer months showed lower survival rates in comparison with those deposited during fall [221]. Pastures managed with low stocking rates and low rotation frequency could maintain the vegetation ground cover, which could facilitate the survival of *Oesophagostomum* spp. infective larvae; thus, benefiting parasite buildup [30]. Pig manure can harbor different pathogens (*Salmonella* sp., *Escherichia coli*, *Clostridium* spp., *Mycobacterium* sp., *Enterococcus* spp., *Streptococcus* sp., and *Staphylococcus* sp.) and cysts, eggs, and/or larvae of parasites (*Ascaris* spp., *Oesophagostomum* spp., *Trichuris* spp., *Strongyloides* spp., *Isospora* spp., *Eimeria* spp., *Giardia* spp., *Balantidium* spp., and others) that could persist in pasture environments (soil, water, and vegetation). Manure provides protection against UV radiation, desiccation and elevated temperatures while supplying nutrients. Pathogens can remain viable under the appropriate conditions for many years [222]. Soil texture, organic matter concentration, temperature, moisture, pH, nutrient availability, and competition with indigenous soil microorganisms are factors affecting pathogen survival. In general, cooler temperatures and high moisture favor longer survival. For example, the survival of *Oesophagostomum dentatum* was limited by winter [154]. Eggs, infectious larvae, oocysts, or sporocysts can survive for a long time, even years, as nematodes such as *Ascaris* spp. (up to 9 years), *Trichuris* spp. (up to 11 years), and coccidial oocysts [30,223]. Due to pig excretory behavior, pastures presented an irregular distribution of *A. suum* eggs with the presence of hot spots. The implementation of rotational systems resulted in control helminthic infestations in pasture pig herds [221]. Additionally, it was found that stocking rate influenced the *Ascaris suum* infestation level of pastures [221,222].

Piglet mortality from farrowing to the weaning period is an important issue in pasture pig production [29,127]. Nursing piglet mortality was lower in combined outdoor–indoor and outdoor systems when compared to indoor systems [110]. In outdoor systems, piglet mortality has been associated with factors related to the environment [41,44,224]. Most deaths are the consequence of sows crushing piglets (causing injuries and even death), hypothermia, and starvation, and often happen during the first week of life [43,49,127]. Another important threat to health during this stage is diarrhea (*Clostridium*, coccidiosis (*Isospora suis* and *Cryptosporidium* spp), *E. coli*, and occasionally rotavirus). Post-weaning diarrhea is considered a consequence of management (multifactorial origin) due to the weakening of the immune system resulting from post-weaning stress [62,71]. Diet plays a central role in the prevalence of this health problem [31], which has also been related to viral and bacterial causes (Rotavirus, Salmonellosis, *E. coli*, *Campylobacter*, *Brachyspira hyodysenteriae*, and *Eimeria* spp.) [62,203].

No differences in mortality rate of live-born piglets have been found among indoor and outdoor; however, lower frequency of stillbirths was reported for outdoor pig systems [131]. The main cause of piglet (0–4 day old) death in organic herds in Denmark was sow crushing and starvation specially

in multiparity sows [44]. Higher mortality was observed in larger litters, and was related to long farrowing, weight heterogeneity, presence of stillborn [23,41], decreased colostrum and milk intake, and behavior of piglets (by staying close to their mothers) [23]. The likelihood of piglet survival has been linked to piglet weight and body shape, and their ability to suckle colostrum [12,43]. To reduce the mortality rate, it is important to provide an appropriate microclimate at farrowing time.

Appropriate health status in outdoor herds can be achieved by the implementation of practices like grazing management, genetic selection for disease resistance, adequate feeding program, and the preventive use of plants and fungi [62]. An appropriate grazing management oriented toward ground cover maintenance, implementing pasture rotation, periodical movement of equipment (hut, shelters, feeders, and drinkers) and adopting appropriate stocking rates (in the range of 15 sows and 20 pigs/ha) [21] can help in disease control in pasture pig systems. Additionally, implementation of alternative strategies to prevent infection in organic systems could include the design and maintenance of huts, shelters, pens, paddocks that adapt to the natural behavior of pigs, supplying nutrients according to the requirement of pigs, and the use of herbal treatments [225]. The role of performing huts and shelters movements along the paddocks, and pasture rotations to reduce the contamination with endoparasites and coccidias—*Isospora*, has been emphasized by Prunier et al., [23]. In Denmark, encouraging results have been reported for the control of *Oesophagostomum* spp. through the implementation of better sanitary practices and rigorous pasture rotation [30].

Periodically monitoring, identifying, and isolating pigs needing to be treated in outdoor systems can be complicated, and could affect animal health and welfare [11,33,57]. In outdoor systems, it is possible to underestimate clinical issues and leg disorders because of the complexities in the diagnosis highlighting the importance of the management strategies in the different health and welfare outcomes observed among farms [71]. It is advisable to have health plans including vaccinations and practices to monitor and control ecto and endoparasites adjusted to local conditions and to the diseases of greater incidence, and biosecurity protocols [23,30,31]. Appropriate cleaning and disinfection of shelters and huts between batches of pigs is essential for the control of *Oesophagostomum* spp. and *Hyostrogylus* spp. [30]. Pigs should be handled firmly and calmly to avoid unnecessary pain or stress [31]. It is essential to maintain high standards of hygiene, to use the correct equipment for each intervention, and to properly sterilize syringes, needles, and scalpels [23]. Under certain circumstances, it would be necessary to implement painless and instantaneous euthanasia practices.

3.6.1. Supplementation with Herbal Compounds and Extracts

Some herbals have antioxidative, antimicrobial, analgesic, calming, and sedative properties that could be used to enhance gut health, increase nutrient absorption, improve feed intake and digestibility, minimize heat stress, and reduce pain and stress in pigs; thereby, improving their welfare. It has been suggested that *Aloysia citriodora* and *Stevia rebaudiana* can be used to decrease post-weaning stress and diarrhea in piglets [226,227]. The sedative and relaxing properties of *Valeriana officinalis* and *Passiflora incarnata* were tested as a stress-reducing strategy in finishing pigs. Lower negative social interactions, lesser body lesions, and an increase in body weight were observed in pigs supplemented with the herbal compounds [228]. An herbal mixture containing *Scutellaria baicalensis* and *Lonicera japonica* was added to diets of heat-stressed lactating sows; the sows supplemented with the herbal mixture showed higher feed intake, better dry matter digestibility, reduced backfat loss, and decreased cortisol levels. At weaning, their piglets presented greater weight and a lower diarrhea prevalence [229]. Similarly, giving sows 6 g/day caffeine mixed with the feed three days before farrowing increased gestation length (116.6 ± 0.3 vs. 115.6 ± 0.3 days), reduced the number of sows that delivered stillborn piglets (43.3% vs. 20.6%), and the piglets showed higher rectal temperature measured three hours after birth (38.0 ± 0.2 °C vs. 37.6 ± 0.2 °C) [230].

3.7. Housing and Handling Facilities

To protect pigs from extreme environmental conditions, adequate housing, shade, and alternatives for thermoregulation should be provided. Designing appropriate housing and handling facilities can prevent causing injuries and pain to the animals [137], protect against aggressive interactions with other animals, facilitate access to resources by subordinate animals, and provide safety to caretakers [19,25,31,33,174]. The preference of laying down inside the shelter at night is related to the feeling of protection and not to the feeling of cold. Even the youngest preferred to stay outside with temperatures up to 5 °C. [35]. In pasture pig production systems, individual or collective shelters and huts are portable, favoring the use of new ground for each batch of pigs. Corrugated iron arcs or wooden sheds, insulated or not, are the most frequent type of accommodation [231]. Housing for pasture pig systems should be adapted to animal growth stage, climate, availability of local materials, and labor costs. Shelters should have sufficient space per animals, proper orientation, appropriate construction materials, and good insulation to prevent injuries and illness and threats to animal welfare. Appropriate access to shelters for animals during different weather conditions, and for caretakers for operations of restrain and capture and cleaning, are necessary to ensure welfare of animals in grazing systems [127]. Moreover, shelters should be heavy enough or be anchored to the ground to prevent pigs or strong winds from overturning them.

The physiological needs of the sows in terms of space and substrate and the piglets' needs for protection against crushing and thermoregulation, and the economic performance of the systems should be considered during the design of a sustainable farrowing and lactation environments [159,160]. In pasture-based systems, the assistance to the sows during prolonged farrowing is difficult and the design of farrowing huts should consider features that allow birth supervision and assistance as well as piglets processing [232]. Farrowing-lactation huts should include a creep area and protection features for the piglets (sloped walls, rails, and raised bars), provision of dry absorbent bedding (10–15 cm) to ensure ventilation and avoid drafts, and may include curtains made with plastic strips at the entrances, which can help reduce pre-weaning mortality [31,233]. However, Vieuille et al. suggest caution when using bottom anti-crushing bars since contradictory results on piglet mortality among farms using them has been observed [23,234]. Additionally, farrowing huts can be furnished with barriers (fenders) that prevent piglets from leaving; thus, decreasing possibilities to become prey, but allowing sows to leave and enter at will [161,235]. It is desirable that farrowing huts maintain pleasant temperatures so that sows are motivated to return to them and nurse the piglets. Placing the huts in tree-sheltered areas or mounting a shade structure over huts and shelters can serve this purpose.

Appropriate shelters should consider proper ventilation, insulation, color of ceilings, reflectivity, inclination, and orientation, to ensure proper heat gain or loss of shelters in grazing systems. Shelters should be constructed using insulating material, and with the exterior painted white to reduce the impact of radiant energy [20,22,31,236]. Additionally, insulating the shelter roofs and the use of bedding during summer and winter are necessary to improve pig comfort [31,45]. Temperatures between insulated and uninsulated of farrowing huts were not different during winter months [235]; however, during summer uninsulated huts had higher temperatures and mortality rates in the first 24 h after farrowing than insulated huts. Furthermore, temperatures in uninsulated huts surpassed 25 °C during 5 h per day, which could prevent the sows entering the hut and nurse the piglets. [237]. In Denmark, individual insulated "A frame" farrowing huts furnished with bedding (straw) provided a microclimate able to prevent piglet hypothermia during winter. Nevertheless, during summer the number of stillborn was considered an indicator of heat stress in sows, which increased when hut temperature exceeds 27 °C [238].

During the winter months, air drafts should be avoided in the shelters [31]. It is beneficial to protect entrances, orienting them perpendicularly to the prevailing winds, and to provide bedding [31,33]. This is central to animal welfare, especially in farrowing huts where bedding can fulfill different functions such as nesting material, as a mattress that moderate sow changes of position; thus, reducing the risk of piglets being crushed, and establishing a microclimate that helps newborn piglets [12]. The use of plastic (PVC) strips-curtains on the doors can help minimize the possibility of

the bed material getting wet through rain or snow seepage [31]. If soil around huts and shelters become very wet and muddy, they should be relocated.

Pasture area should guarantee the necessary water supply for the whole herd for one day [231]. During the hottest time of the year, periodic monitoring of the condition of distribution pipes that could be broken by the pigs is necessary to ensure appropriate water supply. It is also desirable to provide water to the piglets within the fender, outside the farrowing hut to avoid dehydration [44]. Heat stress from pasture pigs was alleviated when foggers were used. [20]. Extreme temperatures, both high and low, can affect the water supply systems. In summer, high temperatures heat pipes and drinking fountains; thus, limit water consumption, whereas in winter, pipes and drinking fountains are at risk of freezing. Burying pipes in the subsoil and placing the drinking fountains in the shade help to minimize these negative impacts.

Shade, preferably from natural vegetation, helps reduce the influence of solar radiation and high temperatures on animals and can alleviate thermal stress [20,30,49]. All animals in the group should have simultaneous access to shaded areas. Evaluations of the effect of including trees in pasture systems for pigs have been carried out in Europe. Sows that had access to trees (*Populus* spp.) spent more time outside the shelter compared to those managed in pastures without access to trees [236]. The sows at rest under the trees had a lower respiratory rate (30 vs. 45 breaths per min, respectively) [152]. The trees also act as windbreaks, reducing the sensation of cold [31].

4. Conclusions

Challenges to animal welfare can be found in most pig production systems. Pasture pig production systems pose specific challenges to animal welfare that are inherent to the nature of these systems, in which producers have little room to make improvements. However, these systems present other challenges that could be reduced with a carefully designed system, by adopting appropriate management strategies and by avoiding management practices that are likely to negatively affect animal wellbeing.

The use of animals that are adapted to pasture conditions contributes to improving animal welfare. Among the desirable characteristics that pigs raised under these systems should exhibit are adaptation to extreme temperatures, resistance to diseases, docility, maternal ability, and foraging and grazing aptitude. The design of the production system affects animal wellbeing, the working environment, and the potential environmental impact.

The welfare of pigs managed in pasture production systems may be challenged by the following factors:

- Exposure to extreme temperatures.
- Potential contact with wildlife and pathogens, especially parasites.
- Vulnerability to predators.
- Risk of malnutrition.
- Pre-weaning piglets' mortality.
- Complexity of the processes for monitoring, capturing, and treating sick animals, and for cleaning and disinfection of facilities and equipment.

Key factors to achieve adequate animal welfare include management skills and animal caretaker attitudes; hence, efforts should be made to provide workers and staff with appropriate training and motivation. Conversely, producers and operators can gradually minimize fear and anguish among animals by carefully supervising and finding solutions to issues that often arise, for instance, during feeding, grouping, mixing, and handling of animals.

Author Contributions: Conceptualization, methodology, investigation, resources, data curation, writing—original draft preparation, S.P.; writing—review and editing, S.P. and C.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors gratefully acknowledge Dr. Leonor Salazar, Dr. Jean-Marie Luginbuhl, and the reviewers for their valuable comments and suggestions to improve the quality of this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hötzel, M.J.; Pinheiro Machado, L.C.F.; Dalla Costa, O.A. Behaviour of pre-parturient sows housed in intensive outdoor or indoor systems. *Pesqui. Agropecu. Bras.* **2005**, *40*, 169–174.
2. Scipioni, R.; Martelli, G.; Volpelli, L.A. Importanza del benessere e sua valutazione nel suino. (Pig welfare importance and evaluation). In *Il Benessere Degli Animali da Reddito: Quale e Come Valutarlo*; Bertoni, G. Ed.; Fondazione Iniziative Zooprofilattiche e Zootecniche—Brescia: Piacenza, Italy, **2006**. Available online: <http://hdl.handle.net/11585/49103> (accessed on 11 May 2020).
3. Sørensen, J.T.; Schrader, L. Labelling as a Tool for Improving Animal Welfare—The Pig Case. *Agriculture* **2019**, *9*, 123, doi:10.3390/agriculture9060123.
4. Appleby, M.C. Welfare challenges in sow housing. *J. Am. Vet. Med. Assoc.* **2005**, *226*, 1334–1336.
5. Jääskeläinen, T.; Kauppinen, T.; Vesala, K.; Valros, A. Relationships between pig welfare, productivity and farmer disposition. *Anim. Welf.* **2014**, *23*, doi:10.7120/09627286.23.4.435.
6. Millet, S.; Moons, C.P.; Van Oeckel, M.J.; Janssens, G.P. Welfare, performance and meat quality of fattening pigs in alternative housing and management systems: A review. *J. Sci. Food Agric.* **2005**, *85*, 709–719, doi:10.1002/jsfa.2033.
7. Liljenstolpe, C. Evaluating animal welfare with choice experiments: An application to Swedish pig production. *Agribusiness* **2008**, *24*, 67–84.
8. OIE. *Terrestrial Animal Health Code*, 28th ed., Section 7. Animal welfare; World Organization for Animal Health: Paris, France, **2019**. Available online: https://www.oie.int/fileadmin/Home/eng/Health_standards/tahc/current/chapitre_aw_introduction.pdf (accessed on 10 December 2019).
9. Manteca, X.; Mainau, E.; Temple, D. *What is Animal Welfare*; Farm Animal Welfare Education Centre (FAWEC): Barcelona, Spain, **2012**; p. 1. Available online: www.fawec.org (accessed on 10 December 2019).
10. OECD. *Meat Consumption (Indicator)*; Organisation for Economic Co-operation and Development: Paris, France, **2020**. Available online: doi:10.1787/fa290fd0-en. (accessed on 6 December 2019)
11. Kongsted, H.; Sørensen, J.T. Lesions found at routine meat inspection on finishing pigs are associated with production system. *Vet. J.* **2017**, *223*, 21–26, doi:10.1016/j.tvjl.2017.04.016.
12. Wegner, K.; Lambert, C.; Das, G.; Reiner, G.; Gauly, M. Climatic effects on sow fertility and piglet survival under influence of a moderate climate. *Animal* **2014**, *8*, 1526–1533, doi:10.1017/S1751731114001219.
13. Norwood, F.B.; Lusk, J.L. A calibrated auction-conjoint valuation method: Valuing pork and eggs produced under differing animal welfare conditions. *J. Environ. Econ. Manag.* **2011**, *62*, 80–94.
14. Miranda-de la Lama, G.C.; Estévez-Moreno, L.X.; Sepúlveda, W.S.; Estrada-Chavero, M.C.; Rayas-Amor, A.A.; Villarreal, M.; María, G.A. Mexican consumers' perceptions and attitudes towards farm animal welfare and willingness to pay for welfare friendly meat products. *Meat Sci.* **2017**, *125*, 106–113, doi:10.1016/j.meatsci.2016.12.001.
15. Hearn, H.J.; O'Dell, M. *What's Hot Culinary Forecast 2020*; National Restaurant Association: Washington, DC, USA, **2020**; p.11. Available online: <https://www.restaurant.org/research/reports/foodtrends> (accessed on 27 April 2020).
16. Spain, C.V.; Freund, D.; Mohan-Gibbons, H.; Meadow, R.G.; Beacham, L. Are They Buying It? United States Consumers' Changing Attitudes toward More Humanely Raised Meat, Eggs, and Dairy. *Animals* **2018**, *8*, 128, doi:10.3390/ani8080128.
17. Edwards, S. Welfare of gilts and pregnant sows. In *Achieving Sustainable Production of Pig Meat*; Wiseman, J., Ed; Animal health and welfare; Burleigh Dodds Science Publishing: Cambridge, UK, **2018**; Volume 3, pp. 203–223, doi:10.19103/AS.2017.0013.21.
18. Garcia, A.; McGlone, J.J. Welfare of weaned piglets. In *Achieving Sustainable Production of Pig Meat*; Wiseman, J., Ed; Animal health and welfare; Burleigh Dodds Science Publishing: Cambridge, UK, **2018**; Volume 3, pp. 229–247, doi:10.19103/AS.2017.0013.21.

19. Hemsworth, P.H. Key determinants of pig welfare: Implications of animal management and housing design on livestock welfare. *Anim. Prod. Sci.* **2018**, *58*, 1375–1386, doi:10.1071/AN17897.
20. Miao, Z.H.; Glatz, P.C.; Ru, Y.J. Review of Production, Husbandry and Sustainability of Free-range Pig Production Systems, *Asian-Australas. J. Anim. Sci.* **2004**, *17*, 1615–1634, doi:10.5713/ajas.2004.1615.
21. Pietrosemoli, S.; Green, J.T. Pasture systems for pigs. In *Achieving Sustainable Production of Pig Meat*; Wiseman, J., Ed; Animal health and welfare; Burleigh Dodds Science Publishing: Cambridge, UK, **2018**; Volume 3, pp. 151–202, doi:10.19103/AS.2017.0013.21.
22. Prunier, A.; Lubac, S.; Mejer, H.; Roepstorff, A.; Edwards, S. Health, welfare and production problems in organic suckling piglets. *Org. Agric.* **2014**, *4*, 107–121, doi:10.1007/s13165-013-0052-0.
23. Massey University. *New Zealand Best Practice Guidelines for Free Range Pork Production*; College of sciences. Sustainable farming fund. Crown Copyright—Ministry for Primary Industries: Palmerston North, New Zealand, **2012**; p. 62.
24. Mkwanazi, M.V.; Ncobela, C.N.; Kanengoni, A.T.; Chimonyo, M. Effects of environmental enrichment on behaviour, physiology and performance of pigs—A review. *Asian-Austral. J. Anim.* **2019**, *32*, 1–13, doi:10.5713/ajas.17.0138.
25. Lukovic, Z.; Skorput, D.; Karolyi, D. Pig welfare at different production systems. In Proceedings of the 11th International Symposium Modern Trends in Livestock Production, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, **2017**; pp. 319–326, ISBN 978-86-82431-73-2. Available online: <http://istocar.bg.ac.rs/en/simpozijum/11th-international-symposium-modern-trend-in-livestock-production-11th-13-th-october-2017-belgrade-serbia> (accessed on 17 May 2019).
26. Amory, J.; Wainwright, N. Welfare of pigs during finishing. In *Achieving Sustainable Production of Pig Meat*; Wiseman, J., Ed; Animal health and welfare; Burleigh Dodds Science Publishing: Cambridge, UK, **2018**; Volume 3, pp. 255–278.
27. Lindgren, K.; Bochicchio, D.; Hegelund, L.; Leeb, C.; Mejer, H.; Roepstorff, A.; Sundrum, A. Animal health and welfare in production systems for organic fattening pigs. *Org. Agric.* **2014**, *4*, 135–147.
28. Pandolfi, F.; Kyriazakis, I.; Stoddart, K.; Wainwright, N.; Edwards, S.A. The “Real Welfare” scheme: Identification of risk and protective factors for welfare outcomes in commercial pig farms in the UK. *Prev. Vet. Med.* **2017**, *146*, 34–43, doi:10.1016/j.prevetmed.2017.07.008.
29. Barnett, J.L.; Hemsworth, P.H.; Cronin, G.M.; Jongman, E.C.; Hutson, G.D. A review of the welfare issues for sows and piglets in relation to housing. *Aust. J. Agric. Res.* **2001**, *52*, 1–28. Available online: <https://doi-org.prox.lib.ncsu.edu/10.1071/AR00057> (accessed on 12 May 2019).
30. Edwards, S.; Mejer, H.; Roepstorff, A.; Prunier, A. Animal health, welfare and production problems in organic pregnant and lactating sows. *Org. Agric.* **2014**, *4*, 93–105, doi:10.1007/s13165-014-0061-7.
31. Moerman, M. *L'élevage des Porcs en Agriculture Biologique-Le Bien-Être*; Centre Wallon de Recherches Agronomiques: Belgique, Gembloux, 2019; pp. 1–43. Available online: <http://www.cra.wallonie.be/fr/lelevage-des-porcs-en-agriculture-biologique-le-bien-etre978-> (accessed on 11 January 2020).
32. Killbride, A.L.; Gillman, C.E.; Green, L.E. A cross-sectional study of the prevalence of lameness in finishing pigs, gilts and pregnant sows and associations with limb lesions and floor types on commercial farms in England. *Anim. Welf.* **2009**, *18*, 215–224.
33. Jackson, P.G.G.; Cockcroft, P.D. *Handbook of Pig Medicine*; Elsevier Ltd: Philadelphia, PA, USA, 2007; pp. 296, ISBN 9780702028281, doi:10.1016/B978-0-7020-2828-1.50001-3.
34. Parrini, S.; Acciaioli, A.; Franci, O.; Pugliese, C.; Bozzi, R. Grazing behaviour of Cinta senese and its crossbreed pigs. *Ital. J. Anim. Sci.* **2019**, *18*, 287–291, doi:10.1080/1828051X.2018.1508376.
35. Olczak, K.; Nowicki, J.; Klocek, C. Pig behaviour in relation to weather conditions—A review. *Ann. Anim. Sci.* **2015**, *15*, 601–610, doi:10.1515/aoas-2015-0024.
36. Oliveira Júnior, G.M.; De Ferreira, A.S.; Oliveira, R.F.M.; Silva, B.A.N.; Figueiredo, E.M.; Santos, M. Behaviour and performance of lactating sows housed in different types of farrowing rooms during summer. *Livest. Sci.* **2011**, *141*, 194–201.
37. Edwards, S.A. Intake of nutrients from pasture by pigs. *Proc. Nutr. Soc.* **2003**, *62*, 257–265.
38. Parois, S.P.; Cabezon, F.A.; Schinckel, A.P.; Johnson, J.S.; Stwalley, R.M.; Marchant-Forde, J.N. Effect of Floor Cooling on Behaviour and Heart Rate of Late Lactation Sows Under Acute Heat Stress. *Front. Vet. Sci.* **2018**, *5*, 223, doi:10.3389/fvets.2018.00223.

39. Edwards, S.; Mejer, H.; Prunier, A.; Roepstorff, A. Animal health, welfare and production problems in organic pregnant and lactating sows, in *Animal Health and welfare in organic pig production*, Edwards, S. editor, CORE organic project:1904, International Center for research in Organic Food Systems: Tjele, Denmark **2011**, 22-39 (PDF) available online: <http://orgprints.org/18419> (accessed on 24 April 2020)
40. Bloemhof, S.; Mathur, P.K.; Knol, E.F.; Van der Waaij, E.H. Effect of daily environmental temperature on farrowing rate and total born in dam line sows. *J. Anim. Sci.* **2013**, *91*, 2667–2679.
41. Rangstrup-Christensen, L.; Krogh, M.A.; Pedersen, L.J.; Sørensen, J.T. Sow level risk factors for early piglet mortality and crushing in organic outdoor production. *Animal* **2018**, *12*, 810–818, doi:10.1017/S1751731117002178.
42. Schild, S.L.A.; Foldager, L.; Bonde, M.K.; Andersen, H.M.L.; Pedersen, L.J. Does hut climate matter for piglet survival in organic production? *Animal* **2018**, doi:10.1017/S175173111800201X.
43. EFSA. Scientific Opinion of the Panel on Animal Health and Welfare on a request from Commission on the risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems. *EFSA J.* **2007**, *611*, 1–13.
44. Palova, N.; Krusheva, D.; Nedeva, R.; Marchev, Y. Influence of Pasture Composition and Weather Conditions on the Productivity and Behavioural Reactions of Pigs of East Balkan Breed. *J. Tekirdag. Agric. Fac. The Special Issue of 2nd International Balkan Agriculture Congress Tekirdağ, Turkey, May 16-18, 2017* **2017**. Available online: <http://hdl.handle.net/20.500.11776/2434> (accessed on 6 December 2019).
45. Muns, R.; Nuntapaitoon, M.; Tummaruk, P. Non-infectious causes of pre-weaning mortality in piglets. *Livest. Sci.* **2016**, *184*, 46–57, doi:10.1016/j.livsci.2015.11.025.
46. Rangstrup-Christensen, L.; Schild, S.L.A.; Pedersen, L.J.; Sørensen, J.T. Causes of preweaning mortality in organic outdoor sow herds. *Res. Vet. Sci.* **2018**, *118*, 171–180, doi:10.1016/j.rvsc.2018.02.010.
47. Pedersen, P.; Sousa, P.; Andersen, L.; Jensen, K. Thermoregulatory Behaviour of Growing/Finishing Pigs in Pens with Access to Outdoor Areas. *Agric. Eng. Int.* **2003**, *V*, 1–14.
48. Nazareno, A.C.; Da Silva, I.J.O.; Nunes, M.L.A.; De Castro, A.C.; Miranda, K.O.S.; and Trabachini, A. Caracterização bioclimática de sistemas ao ar livre e confinado para a criação de matrizes suínas gestantes. *Rev. Bras. Eng. Agríc. Ambient.* **2012**, *16*, 314–319, doi:10.1590/S1415-43662012000300013.
49. KillBride, A.L.; Mendl, M.; Statham, P.; Held, S.; Harris, M.; Marchant-Forde, J.N.; Booth, H.; Green, L.E. Risks associated with pre weaning mortality in 855 litters on 39 commercial outdoor pig farms in England. *Prev. Vet. Med.* **2014**, *117*, 189–199, doi:10.1016/j.prevetmed.2014.08.004.
50. Leeb, C.; Hegelund, L.; Edwards, S.; Mejer, H.; Roepstorff, A.; Rousing, T.; Sundrum, A.; Bonde, M. Animal health, welfare and production problems in organic weaner pigs. *Org. Agric.* **2014**, *4*, 123–133, doi:1007/s13165-013-0054-y.
51. Jensen, D.B.; Toft, N.; Cornou, C. The effect of wind shielding and pen position on the average daily weight gain and feed conversion rate of grower/finisher pigs. *Livest. Sci.* **2014**, *167*, 353–361, doi:10.1016/j.livsci.2014.06.028.
52. Hines, E. Keeping Pigs Cool in the Summer Heat. Penn State Extension. 2018. Available online: <https://extension.psu.edu/keeping-pigs-cool-in-the-summer-heat> (accessed on 15 December 2019).
53. Griffiths, I.B.; Douglas, R.G.A. Phytophotodermatitis in pigs exposed to parsley (*Petroselinum crispum*). *Vet. Record* **2000**, *146*, 73–74, doi:10.1136/vr.146.3.73.
54. Iowa State University. Sunburn and Photosensitization. In *Swine Manual Index*; Iowa State University of Science and Technology: Ames, Iowa, **2020**. Available online: <https://vetmed.iastate.edu/vdpam/FSVD/swine/index-diseases/photosensitization> (accessed on 15 January 2020).
55. Williamson, S.; Woodger, N.; Higgins, R.H.; Hands, I. Ataxia associated with sunburn in outdoor gilts: A case report. *Pig J.* **2009**, *62*, 84–87.
56. Cappaia, S.; Rolesua, S.; Coccollonea, A.; Laddomadab, A.; Loia, F. Evaluation of biological and socio-economic factors related to persistence of African swine fever in Sardinia. *Prev. Vet. Med.* **2018**, *152*, 1–11, doi:10.1016/j.prevetmed.2018.01.004.
57. Maes, D.; Dewulf, J.; Piñeiro, C.; Edwards, S.; Kyriazakis, I. A critical reflection on intensive pork production with an emphasis on animal health and welfare. *J. Anim. Sci.* **2019**, *362*, doi:10.1093/jas/skz362.
58. Wallander, C.; Frössling, J.; Dórea, F.C.; Ugglä, A.; Vågsholm, I.; Lundén, A. Pasture is a risk factor for *Toxoplasma gondii* infection in fattening pigs. *Vet. Parasitol.* **2016**, *224*, 27–32, doi:10.1016/j.vetpar.2016.05.005.

59. Paștiu, A.I.; Györke, A.; Blaga, R.; Mircean, V.; Rosenthal, B.M.; Cozma, V. In Romania, exposure to *Toxoplasma gondii* occurs twice as often in swine raised for familial consumption as in hunted wild boar, but occurs rarely, if ever, among fattening pigs raised in confinement. *Parasitol. Res.* **2013**, *112*, 2403–2407, doi:10.1007/s00436-013-3353-z.
60. Fleming, P.A.; Dundas, S.J.; Lau, Y.Y.; Pluske, J.R. Predation by Red Foxes (*Vulpes vulpes*) at an Outdoor Piggery. *Animals-Basel* **2016**, *6*, 60.
61. Murrell, K.D. The dynamics of *Trichinella spiralis* epidemiology: Out to pasture? *Vet. Parasitol.* **2016**, *231*, 92–96, doi:10.1016/j.vetpar.2016.03.020.
62. Salakpal, K.; Karolyi, D.; Lukovic, Z. Sanitary aspects of outdoor farming systems. *Acta Agric. Slov.* **2013**, *4*, 109–117.
63. Stelzer, S.; Basso, W.; Benavides Silván, J.; Ortega-Mora, L.M.; Maksimov, P.; Gethmann, J.; Conraths, F.J.; Schares, G. *Toxoplasma gondii* infection and toxoplasmosis in farm animals: Risk factors and economic impact. *Food Waterborne Parasitol.* **2019**, *15*, doi:10.1016/j.fawpar.2019.e00037.
64. Kijlstra, A.; Eissen, O.A.; Cornelissen, J.; Munniksma, K.; Eijck, I.; Kortbeek, T. *Toxoplasma gondii* Infection in Animal-Friendly Pig Production Systems. *Investig. Ophthalmol. Vis. Sci.* **2004**, *45*, 3165–3169, doi:10.1167/iovs.04-0326.
65. Castillo-Cuenca, J.C.; Díaz-Cao, J.M.; Martínez-Moreno, A.; Cano-Terriza, D.; Jiménez-Ruiz, S.; Almería, S.; García-Bocanegra, I. 2020. Seroepidemiology of *Toxoplasma gondii* in extensively raised Iberian pigs in Spain. *Prev. Vet. Med.* **2020**, *175*, 104854, doi:10.1016/j.prevetmed.2019.104854.
66. Pablos-Tanarro, A.; Ortega-Mora, L.M.; Palomo, A.; Casasola, F.; Ferre, I. Seroprevalence of *Toxoplasma gondii* in Iberian pig sows. *Parasitol. Res.* **2018**, *117*, 1419–1424, doi:10.1007/s00436-018-5837-3.
67. Scasta, J.D.; Stam, B.; Windh, J.L. Rancher-reported efficacy of lethal and non-lethal livestock predation mitigation strategies for a suite of carnivores. *Sci. Rep.* **2017**, *7*, 14105, doi:10.1038/s41598-017-14462-1.
68. Barasona, J.A.; VerCauteren, K.C.; Saklou, N.; Gortazar, C.; Vicente, J. Effectiveness of cattle operated bump gates and exclusion fences in preventing ungulate multi-host sanitary interaction. *Prev. Vet. Med.* **2013**, *111*, 42–50.
69. EFSA. Evaluation of possible mitigation measures to prevent introduction and spread of African swine fever virus through wild boar. *EFSA J.* **2014**, *12*, 3616, doi:10.2903/j.efsa.2014.3616.
70. Saitone, T.L.; Bruno, E.M. Cost Effectiveness of Livestock Guardian Dogs for Predator Control. *Wildl. Soc. Bull.* **2020**, *44*, 101–109, doi:10.1002/wsb.1063.
71. Bonde, M.; Sørensen, J.T. Herd health management in organic pig production using a quality assurance system based on Hazard Analysis and Critical Control Points. *NJAS Wagen. J. Life Sci.* **2004**, *52*, 133–143, doi:10.1016/S1573-5214(04)80009-5.
72. Smith, R.P.; Andres, V.; Dormer, L.; Gosling, R.; Oastler, C.; Davies, R.H. Study of the impact on *Salmonella* of moving outdoor pigs to fresh land. *Epidemiol. Infect.* **2017**, *145*, 1983–1992, doi:10.1017/S0950268817000930.
73. Bisimwa, N.P.; Machuka, E.M.; Githae, D.; Banswe, G.; Amimo, J.O.; Ongus, J.R.; Masembe, C.; Bishop, R.P.; Steinaa, L.; Djikeng, A.; Pelle, R. Evidence for the presence of African swine fever virus in apparently healthy pigs in South-Kivu Province of the Democratic Republic of Congo. *Vet. Microb.* **2020**, *240*, 108521, doi:10.1016/j.vetmic.2019.108521.
74. De Lucia, A.; Rabie, A.; Smith, R.P.; Davies, R.; Ostanello, F.; Ajayi, D.; Petrovska, L.; Martelli, F. Role of wild birds and environmental contamination in the epidemiology of *Salmonella* infection in an outdoor pig farm. *Vet. Microbiol.* **2018**, *227*, 148–154, doi:10.1016/j.vetmic.2018.11.003.
75. Vico, J.P.; Mainar-Jaime, R.C. Salmonellosis in wild birds and its relationship with the infection in finishing pigs. In Proceedings of the 9th International Conference on the Epidemiology and Control of Biological, Chemical and Physical Hazards in Pigs and Pork: SAFEPOK 2011, Maastricht, The Netherlands, 19–22 June 2011; pp. 264–267. Available online: <http://hdl.handle.net/10532/1666> (accessed on 17 May 2020).
76. Johansson, L.M. Meningitis and septicemia in a 7-week-old piglet caused by dual streptococcal infection. *Can. Vet. J.* **2006**, *47*, 796–798.
77. Stanojković, A.; Gogić, M.; Ostojić- Andrić, D.; Petričević, M.; Nišavić, J.; Nešić, K. Wild pigs—The source of zoonotic *Streptococcus suis* strains. In Proceedings of the 11th International Symposium Modern Trends in Livestock Production, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, **2017**; pp. 253–259. Available online:

- <http://istocar.bg.ac.rs/en/simpozijum/11th-international-symposium-modern-trend-in-livestock-production-11th-13-th-october-2017-belgrade-serbia/> (accessed on 17 May 2019).
78. Wu, N.; Abril, C.; Thomann, A.; Grosclaude, E.; Doherr, M.G.; Boujon, P.; Ryser-Degiorgis, M.P. Risk factors for contacts between wild boar and outdoor pigs in Switzerland and investigations on potential *Brucella suis* spill-over. *BMC Vet. Res.* **2012**, *8*, 116, doi:10.1186/1746-6148-8-116.
 79. Meier, R.; Ryser-Degiorgis, M. Wild boar and infectious diseases: Evaluation of the current risk to human and domestic animal health in Switzerland: A review. *Schweiz. Arch. Tierheilkd.* **2008**, *160*, 443–460, doi:10.17236/sat00168.
 80. Finzel, J.A.; Baldwin, R.A. Wild Pigs. UC Cooperative Extension Integrated Pest Management. Publication 74170. 2015. Available online: <http://ipm.ucanr.edu/PMG/PESTNOTES/pn74170.html> (accessed on 30 January 2020).
 81. Fredriksson-Ahomaa, M. Wild Boar: A Reservoir of Foodborne Zoonoses. *Foodborne Pathog. Dis.* **2019**, *16* (3), 163–165. Available online: doi: 10.1089/fpd.2018.2512 (accessed on 17 May 2019).
 82. Hill, D.E.; Dubey, J.P.; Baroch, J.A.; Swafford, S.R.; Fournet, V.F.; Hawkins-Cooper, D.; Pyburn, D.G.; Schmit, B.S.; Gamble, H.R.; Pedersen, K.; et al. Surveillance of feral swine for *Trichinella* spp. and *Toxoplasma gondii* in the USA and host-related factors associated with infection. *Vet. Parasitol.* **2014**, *205*, 653–665, doi:10.1016/j.vetpar.2014.07.026.
 83. Meng, X.J.; Lindsay, D.S.; Sriranganathan, N. Wild boars as sources for infectious diseases in livestock and humans. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **2009**, *364*, 2697–2707, doi:10.1098/rstb.2009.0086.
 84. Guberti, V.; Khomenko, S.; Masiulis, M.; Kerba, S. African swine fever in wild boar ecology and biosecurity. In *FAO Animal production and Health—Manual n° 22*. Rome, Italy, *FAO, OIE and EC*, **2019**; p. 97.
 85. Volker, M. The control of classical swine fever in wild boar. *Front. Microbiol.* **2015**, *6*, doi:10.3389/fmicb.2015.01211.
 86. Cano-Terriza, D.; Rialde, M.A.; Rodríguez-Hernández, P.; Napp, S.; Fernández-Morente, M.; Moreno, I.; Bezos, J.; Fernández-Molera, V.; Saéz, J.L.; García-Bocanegra, I. Epidemiological surveillance of *Mycobacterium tuberculosis* complex in extensively raised pigs in the south of Spain. *Prev. Vet. Med.* **2018**, *159*, 87–91.
 87. Muñoz-Mendoza, M.; Marreros, N.; Boadella, M.; Gortázar, C.; Menéndez, S.; de Juan, L.; Bezos, J.; Romero, B.; Copano, M.F.; Amado, J.; et al. Wild boar tuberculosis in Iberian Atlantic Spain: A different picture from Mediterranean habitats. *BMC Vet. Res.* **2013**, *9*, 176.
 88. Batista Linhares, M.; Belloy, L.; Origgi, F.C.; Lechner, I.; Segner, H.; Ryser-Degiorgis, M.P. Investigating the role of free-ranging wild boar (*Sus scrofa*) in the re-emergence of enzootic pneumonia in domestic pig herds: A pathological, prevalence and risk-factor study. *PLoS ONE* **2015**, *10*, e0119060, doi:10.1371/journal.pone.0119060.
 89. Köppel, C.; Knopf, L.; Ryser, M.P.; Miserez, R.; Thür, B.; Stärk, K.D.C. Serosurveillance for selected infectious disease agents in wild boars (*Sus scrofa*) and outdoor pigs in Switzerland. *Eur. J. Wildl. Res.* **2007**, *53*, 212, doi:10.1007/s10344-006-0080-0.
 90. Davies, P.R. Intensive Swine Production and Pork Safety. *Foodborne Pathog. Dis.* **2011**, *8*, doi:10.1089/fpd.2010.0717.
 91. Jensen, A.N.; Baggesen, D.L. *Salmonella* and *Campylobacter* infections in outdoor organic pigs. In *Proceedings of the 1st IFOAM International Conference on Animals in Organic Production*, Saint Paul, Minnesota, 23–25 August 2006; Gopalakrishnan, O., Melotti, L., Ostertag, J., Sorensen, N. Eds.; IFOAM: Minnesota, USA, **2006**; pp. 96–97. Available online: <http://orgprints.org/9159> (accessed on 26 February 2020).
 92. Hernández, M.; Gómez-Laguna, J.; Tarradas, C.; Luque, I.; García-Valverde, R.; Reguillo, L.; Astorga, R.J. A serological survey of *Brucella* spp., *Salmonella* spp., *Toxoplasma gondii* and *Trichinella* spp. in Iberian fattening pigs reared in free-range systems. *Transbound Emerg. Dis.* **2014**, *61*, 477–481, doi:10.1111/tbed.12049.
 93. Thomas, L.F.; de Glanville, W.A.; Cook, E.A.; Fèvre, E.M. The spatial ecology of free-ranging domestic pigs (*Sus scrofa*) in western Kenya. *BMC Vet. Res.* **2013**, *9*, 46, doi:10.1186/1746-6148-9-46.
 94. Roepstorff, A.; Mejer, H.; Nejsun, P.; Thamsborg, S.M. Helminth parasites in pigs: New challenges in pig production and current research highlights. *Vet. Parasitol.* **2011**, *180*, 72–81.
 95. Sutherland, M.A.; Webster, J.; Sutherland, I. Animal Health and Welfare Issues Facing Organic Production Systems. *Animals* **2013**, *3*, 1021–1035, doi:10.3390/ani3041021.

96. Di Marco, V.; Mazzone, P.; Capucchio, M.T.; Boniotti, M.B.; Aronica, V.; Russo, M.; Fiasconaro, M.; Cifani, N.; Corneli, S.; Biasibetti, E.; et al. Epidemiological significance of the domestic black pig (*Sus scrofa*) in maintenance of bovine tuberculosis in Sicily. *J. Clin. Microbiol.* **2012**, *50*, 1209–1218.
97. Van der Giessen, J.; Fonville, M.; Bouwknegt, M.; Langelaar, M.; Vollema, A. Seroprevalence of *Trichinella spiralis* and *Toxoplasma gondii* in pigs from different housing systems in The Netherlands. *Vet. Parasitol.* **2007**, *148*, 371–374.
98. Ortega-Pacheco, A.; Acosta, V.K.Y.; Guzmán-Marín, E.; Segura-Correa, J.C.; Alvarez-Fleites, M.; Jiménez-Coello, M. Prevalence and risk factors of *Toxoplasma gondii* in fattening pigs farm from Yucatan, Mexico. *Biomed. Res. Int.* **2013**, 231497, doi:10.1155/2013/231497.
99. Vázquez, R. La asociación patológica entre *Trichuris suis* y *Lawsonia intracellularis* en el cerdo ibérico y sus cruces. *Badajoz Vet.* **2016**, *4*, 12–15.
100. Jensen, A.N.; Dalsgaard, A.; Stockmarr, A.; Nielsen, E.M.; Baggesen, D.L. Survival and transmission of *Salmonella enterica* Serovar *Typhimurium* in an outdoor organic pig farming environment. *Appl. Environ. Microbiol.* **2006**, 1833–1842, doi:10.1128/AEM.72.3.1833-1842.2006.
101. Lindgren, K.; Gunnarsson, S.; Höglund, J. Cecilia Lindahl Allan Roepstorff. Nematode parasite eggs in pasture soils and pigs on organic farms in Sweden. *Org. Agric.* **2019**, doi:10.1007/s13165-019-00273-3.
102. Dalla Costa, O.A.; Nelson Morés, N.; Pedroso-de-Paiva, D.; Silva, R.A.M.; Sobestiansky, J.; Monticelli, C.J.; Leite, D.M.G. Acompanhamento parasitário de rebanhos suínos no sistema intensivo de suínos criados ao ar livre—SISCAL. CT/253. In *Embrapa Suínos e Aves*; EMBRAPA Brasil, **2000**; pp. 1–3. ISSN 0100 – 8862.
103. Sehested, J.; Søgaard, K.; Danielsen, V.; Roepstorff, A.; Monrad, J. Grazing with heifers and sows alone or mixed: Herbage quality, sward structure and animal weight gain. *Livest. Prod. Sci.* **2004**, *88*, 223–238.
104. Scipioni, R.; Martelli, G.; Volpelli, L.A. Assessment of welfare in pigs. *Ital. J. Anim. Sci.* **2009**, *8*, 117–137.
105. Henney, J. An evaluation of the use of pigs as a method of bracken control. In *Grazing Animals Project Heritage Grazing Traineeship; Rare Breeds Survival Trust*, UK, **2012**; p. 40. Available online: http://www.grazinganimalsproject.org.uk/habitat_land_management.html?publication=1;154 (accessed on 9 December 2019).
106. Rivera Ferre, M.G.; Edwards, S.A.; Mayes, R.W.; Riddoch, I.; Hovell, F.D. The effect of season and level of concentrate on the voluntary intake and digestibility of herbage by outdoor sows. *Anim. Sci.* **2001**, *72*, 501–510, doi:10.1017/S1357729800052024.
107. Jurjanz, S.; Roinsard, A. Ingestion d’herbe et de sol par des truies au pâturage. *Alter. Agric.* **2014**, *125*, 27–28.
108. Blumetto Velazco, O.R.; Calvet Sanz, S.; Estellés Barber, F.; Villagrà García, A. Comparison of extensive and intensive pig production systems in Uruguay in terms of ethologic, physiologic and meat quality parameters. *Rev. Bras. Zootecn.* **2013**, *42*, 521–529.
109. Etterlin, P.E.; Morrison, D.A.; Österberg, J.; Ytrehus, B.; Heldmer, E.; Ekman, S. Osteochondrosis, but not lameness, is more frequent among free-range pigs than confined herd-mates. *Acta Vet. Scand.* **2015**, *57*, 63, doi:10.1186/s13028-015-0154-7.
110. Leeb, C.; Rudolph, G.; Bochicchio, D.; Edwards, S.; Früh, B.; Holinger, M.; Holmes, D.; Illmann, G.; Knop, D.; Prunier, A.; et al. Effects of three husbandry systems on health, welfare and productivity of organic pigs. *Animal* **2019**, *13*, 2025–2033, doi:10.1017/S1751731119000041.
111. Barton Gade, P.A. Effect of rearing system and mixing at loading on transport and lairage behaviour and meat quality: Comparison of outdoor and conventionally raised pigs. *Animal* **2008**, *2*, 902–911, doi:10.1017/S1751731108002000.
112. Rodríguez-Estévez, V.; Sánchez-Rodríguez, M.; Garcia, A.; Gómez-Castro, A. Average daily weight gain of Iberian fattening pigs when grazing natural resources. *Livest. Sci.* **2011**, *137*, 292–295, doi:10.1016/j.livsci.2010.11.015.
113. Phocas, F.; Belloc, C.; Bidanel, J.; Delaby, L.; Dourmad, J.Y.; Dumont, B.; Ezanno, P.; Fortun-Lamothe, L.; Foucras, G.; Frappat, B.; González-García, E.; et al. Review: Towards the agroecological management of ruminants, pigs and poultry through the development of sustainable breeding programmes. II. Breeding strategies. *Animal* **2016**, *10*, 1760–1769, doi:10.1017/S1751731116001051.
114. Jensen, K.K.; Michalopoulos, T.; Meijboom, F.L.B.; Gjerris, M. Perceptions of Ethical Challenges within the LowInputBreeds Project. *Food Ethics* **2017**, *1*, 109–125, doi:10.1007/s41055-017-0010-8.

115. Edwards, S.; Leeb, C. Organic pig production systems, welfare and sustainability. In *Achieving Sustainable Production of Pig Meat*; Mathew, A., Ed.; Safety, quality and sustainability; Burleigh Dodds Science Publishing: Cambridge, UK, 2018; Volume 1, pp. 249–270, doi:10.19103/AS.2017.0030.13.
116. Kongsted, A.G.; Nørgaard, J.V.; Jensen, S.K.; Lauridsen, C.; Juul-Madsen, H.R.; Norup, L.R.; Engberg, R.M.; Horsted, K.; Hermansen, J.E. Influence of genotype and feeding strategy on pig performance, plasma concentrations of micro nutrients, immune responses and faecal microbiota composition of growing-finishing pigs in a forage-based system. *Livest. Sci.* **2015**, *178*, 263–271.
117. Kongsted, A.G.; Jakobsen, M. Effect of genotype and level of supplementary concentrate on foraging activity and vegetation cover in an organic free-range pig system. *Acta Agric. Scand. Sect. A Anim. Sci.* **2015**, *65*, 139–147, doi:10.1080/09064702.2016.1156152.
118. Barone, C.M.A.; Di Matteo, R.; Rillo, L.; Rossetti, C.E.; Pagano, F.; Matassino, D. Pork quality of autochthonous genotype Casertana, crossbred Casertana x Duroc and hybrid Pen ar Lan in relation to farming systems. *Agron. Res.* **2015**, *13*, 900–906.
119. Lebet, B.; Ecolan, P.; Bonhomme, N.; Méteau, K.; Prunier, A. Influence of production system in local and conventional pig breeds on stress indicators at slaughter, muscle and meat traits and pork eating quality. *Animal* **2015**, *9*, 1404–1413, doi:10.1017/S1751731115000609.
120. Pugliese, C.; Sirtori, F. Quality of meat and meat products produced from southern European pig breeds. *Meat Sci.* **2012**, *90*, 511–518.
121. Ogle, B. Forage for pigs: Nutritional, physiological and practical implications. In *Forages for Pigs and Rabbits*; Phnom Penh MEKARN-CelAgrid: Phnom Penh, Cambodia, **2006**. Available online: <http://www.mekarn.org/proprf/ogle.htm> (accessed on 13 December 2019).
122. Biscarini, F.; Nicolazzi, E.L.; Stella, A.; Paul, J.; Boettcher, P.J.; Gandini, G. Challenges and opportunities in genetic improvement of local livestock breeds. *Front. Genet.* **2015**, *6*, 33, doi:10.3389/fgene.2015.00033.
123. Petrovic, M.P.; Muslic, D.R.; Petrovic, V.C.; Maksimovic, N.; Cekic, B.; Yuldashbaev, Y.A.; Selionova, M.I. Trends and challenges in the genetic improvement of farm animals. In Proceedings of the 11th International Symposium Modern Trends in Livestock Production, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, **2017**; pp. 1–14. Available online: <http://istocar.bg.ac.rs/en/simpozijum/11th-international-symposium-modern-trend-in-livestock-production-11th-13-th-october-2017-belgrade-serbia/> (accessed on 17 May 2019).
124. Baxter, E.M.; Rutherford, K.M.D.; D'Eath, R.B.; Arnott, G.; Turner, S.P.; Sandoe, P.; Moustsen, V.A.; Thorup, F.; Edwards, S.A.; Lawrence, A.B. The welfare implications of large litter size in the domestic pig II: Management factors. *Anim. Welf.* **2013**, *22*, 219–238.
125. Andersen, I.L.; Nævdal, E.; Bøe, K.E. Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs (*Sus scrofa*). *Behav. Ecol. Sociobiol.* **2011**, *65*, 1159–1167, doi:10.1007/s00265-010-1128-4.
126. Ocepek, M.; Newberry, R.C.; Andersen, I.L. Trade-offs between litter size and offspring fitness in domestic pigs subjected to different genetic selection pressures. *Appl. Anim. Behav. Sci.* **2017**, *193*, 7–14, doi:10.1016/j.applanim.2017.03.008.
127. Velarde, A.; Fàbrega, E.; Blanco-Penedo, I.; Dalmau, A. Animal welfare towards sustainability in pork meat production. *Meat Sci.* **2015**, *109*, 13–17, doi:10.1016/j.meatsci.2015.05.010.
128. Röö, E.; Mie, A.; Wivstad, M.; Salomon, E.; Johansson, B.; Gunnarsson, S.; Wallenbeck, A.; Hoffmann, R.; Nilsson, U.; Sundberg, C.; et al. Risks and opportunities of increasing yields in organic farming. A review. *Agron. Sustain. Dev.* **2018**, *38*, 14.
129. Etterlin, P.E.; Ytrehus, B.; Lundeheim, N.; Heldmer, E.; Österberg, J.; Ekman, S. Effects of free-range and confined housing on joint health in a herd of fattening pigs. *BMC Vet. Res.* **2014**, *10*, 208, doi:10.1186/s12917-014-0208-5.
130. Gourdine, J.L.; de Greef, K.H.; Rydhmer, L. Breeding for welfare in outdoor pig production: A simulation study. *Livest. Sci.* **2010**, *132*, 26–34, doi:10.1016/j.livsci.2010.04.017.
131. Killbride, A.L.; Mendl, M.; Statham, P.; Held, S.; Harris, M.; Cooper, S.; Green, L.E. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. *Prev. Vet. Med.* **2012**, *104*, 281–291, doi:10.1016/j.prevetmed.2011.11.011.
132. Turner, S.P.; Camerlink, I.; Baxter, E.M.; D'Eath, R.B.; Desire, S.; Roehe, R. Breeding for pig welfare: Opportunities and challenges, In *Herd and Flock Welfare, Advances in Pig Welfare*; Špinka, M., Ed.; Woodhead

- Publishing: Cambridge, England, **2018**; pp. 399–414, ISBN 9780081010129, doi:10.1016/B978-0-08-101012-9.00012-5.
133. Rydhmer, L.; Canario, L. Behavioural Genetics in Pigs and Relations to Welfare. In *Genetics and the Behaviour of Domestic Animals*, 2nd Ed.; Grandin, T., Deesing, M.J., Eds.; Academic Press: Cambridge, Massachusetts USA, **2014**; pp. 397–434, doi:10.1016/B978-0-12-394586-0.00011-1.
 134. Chu, Q.; Liang, T.; Fu, L.; Li, H.; Zhou, B. Behavioural genetic differences between Chinese and European pigs. *J. Genet.* **2017**, *96*, 707–715.
 135. De Melo, R.L.C.; Dutra Júnior, W.M.; Palhares, L.O.; de Moura Ferreira, D.N.; de Aquino, R.S.; Cavalcanti Manso, H.E.C. Behavioural and physiological evaluation of sows raised in outdoors systems in the Brazilian semiarid region. *Trop. Anim. Health Prod.* **2019**, *51*, 1057–1063, doi:10.1007/s11250-018-1780-7.
 136. Tozawa, A.; Tanaka, S.; Sato, S. The Effects of Components of Grazing System on Welfare of Fattening Pigs. *Asian-Australas. J. Anim. Sci.* **2016**, *29*, 428–435, doi:10.5713/ajas.15.0190.
 137. McLennan, K.M. Why Pain Is Still a Welfare Issue for Farm Animals, and How Facial Expression Could Be the Answer. *Agriculture* **2018**, *8*, 127, doi:10.3390/agriculture8080127.
 138. Veissier, I.; Boissy, A. Stress and welfare: Two complementary concepts that are intrinsically related to the animal's point of view. *Physiol. Behav.* **2007**, *92*, 429–433.
 139. Hötzel, M.J.; Pinheiro Machado, L.C.F.; Machado Wolf, F.; Dalla Costa, O.A. Behaviour of sows and piglets reared in intensive outdoor or indoor systems. *Appl. Anim. Behav. Sci.* **2004**, *86*, 27–39, doi:10.1016/j.applanim.2003.11.014.
 140. Nakamura, K.; Tanaka, T.; Nishida, K.; Uetake, K. Behavioural indexes of piglet welfare: Comparison of indoor and outdoor housing systems. *Anim. Sci. J.* **2011**, *82*, 161–168, doi:10.1111/j.1740-0929.2010.00806.x.
 141. Temple, D.; Manteca, X.; Velarde, A.; Dalmau, A. Assessment of animal welfare through behavioural parameters in Iberian pigs in intensive and extensive conditions. *Appl. Anim. Behav. Sci.* **2011**, *131*, 29–39, doi:10.1016/j.applanim.2011.01.013.
 142. Yonezawa, T.; Takahashi, A.; Imai, S.; Okitsu, A.; Komiyama, S.; Irimajiri, M.; Matsuura, A.; Yamazaki, A.; Hodate, K. Effects of outdoor housing of piglets on behaviour, stress reaction and meat characteristics. *Asian-Australas. J. Anim. Sci.* **2012**, *25*, 886–894, doi:10.5713/ajas.2011.11380.
 143. Studnitz, M.; Jansen, K.H.; Jorgensen, E.; Jansen, K.K. The effect of nose ringing on explorative behaviour in gilts. *Anim. Welf.* **2003**, *12*, 109–118.
 144. Pedersen, L.J. Overview of commercial pig production systems and their main welfare challenges. In *Herd and Flock Welfare, Advances in Pig Welfare*; Špinka, M., Ed.; Woodhead Publishing: Cambridge, England, **2018**; pp. 3–25, ISBN 9780081010129, doi:10.1016/B978-0-08-101012-9.00001-0.
 145. Bracke, M.B.M. Review of wallowing in pigs: Description of the behaviour and its motivational basis. *Appl. Anim. Behav. Sci.* **2011**, *132*, 1–13, doi:10.1016/j.applanim.2011.01.002.
 146. Gegner, L. Considerations in Organic Hog Production. ATTRA's Organic Matters Series. Available online: [http://www.organiccentre.ca/Docs/ATTRA/hog production2001.pdf](http://www.organiccentre.ca/Docs/ATTRA/hog%20production2001.pdf) (accessed on 13 April 2020).
 147. Madzingira, O. Animal Welfare Considerations in Food-Producing Animals, IntechOpen Limited: London, UK, **2018**. Available online: <https://www.intechopen.com/books/animal-welfare/animal-welfare-considerations-in-food-producing-animals> (accessed on 20 December 2019).
 148. Simmons, M. *Environmental Management of Outdoor Pigs for Protein, Plough and Pest Control*; Nuffield Australia Project No: 1213; Nuffield Australia: Moama, NSW Australia, **2013**; p.43. Available online: <https://nuffieldinternational.org/live/Report/AU/2012/matthew-simmons> (accessed on 12 December 2019).
 149. Callaway, T.R.; Morrow, J.L.; Johnson, A.K.; Dailey, J.W.; Wallace, F.M.; Wagstrom, E.A.; Mcglone, J.J.; Lewis, A.R.; Dowd, S.E.; Poole, T.L.; et al. Environmental Prevalence and Persistence of *Salmonella* spp. in Outdoor Swine Wallows. *Foodborne Pathog. Dis.* **2005**, *2*, 263–273.
 150. Eckert, K.D.; Keiter, D.A.; and Beasley, J.C. Animal Visitation to Wild Pig (*Sus scrofa*) Wallows and Implications for Disease Transmission. *J. Wildl. Dis.* **2019**, *55*, 488–493.
 151. Hernández, M.; Gómez-Laguna, J.; Luque, I.; Herrera-León, S.; Maldonado, A.; Reguillo, L.; Astorga, R.J. *Salmonella* prevalence and characterization in a free-range pig processing plant: Tracking in trucks, lairage, slaughter line and quartering. *Int. J. Food Microbiol.* **2013**, *162*, 48–54, doi:10.1016/j.ijfoodmicro.2012.12.026.
 152. Andersen, H.M.; Schild, S.L.A.; Jakobsen, M. Inclusion of Trees in Pasture-Based Systems Reduces Heat Load of Sows. **2017**. Available online: <http://icrofs.dk/en/aktuelt/nyheder/viewnews/artikel/shade-for-outdoor-pigs-is-important/> (accessed on 13 December 2019).

153. Andersen, H.M.L.; Kongsted, A.G.; Jakobsen, M. Pig elimination behaviour — A review. *Appl. Anim. Behav. Sci.* **2020**, *222*, doi:10.1016/j.applanim.2019.104888.
154. Roepstorff, A.; Mejer, H. Strategies for parasite control in organic pigs. In Proceedings of the 5th NAHWOA Workshop, Rodding, Denmark, 11–13 November 2001; pp. 72–78.
155. Vermeer, H.M.; Altena, H.; Vereijken, P.F.G.; Bernardus, M.; Bracke, M. Rooting area and drinker affect dunging behaviour of organic pigs. *Appl. Anim. Behav. Sci.* **2015**, *165*, 66–71, ISSN 0168-1591, doi:10.1016/j.applanim.2015.01.007.
156. Wischner, D.; Kemper, N.; Krieter, J. Nest-building behaviour in sows and consequences for pig husbandry, *Livest. Sci.* **2009**, *124*, 1–8, doi:10.1016/j.livsci.2009.01.015.
157. Yun, J.; Swan, K.; Oliviero, C.; Peltonniemi, O.; Valros, A. Effects of pre-partum housing environment on abnormal behaviour, the farrowing process, and interactions with circulating oxytocin in sows. *Appl. Anim. Behav. Sci.* **2015**, *162*, 20–25, doi:10.1016/j.applanim.2014.11.006.
158. Jarvis, S.; Calvert, S.K.; Stevenson, J.; van Leeuwen, N.; Lawrence, A.B. Pituitary-adrenal activation in pre-parturient pigs (*Sus scrofa*) is associated with behavioural restriction due to lack of space rather than nesting substrate. *Anim. Welf.* **2002**, *11*, 371–384.
159. Baxter, E.; Alistair, L.; Edwards, S. Alternative farrowing systems: Design criteria for farrowing systems based on the biological needs of sows and piglets. *Animal* **2011**, *5*, 580–600, doi:10.1017/S1751731110002272.
160. Baxter, E.M.; Jarvis, S.; Sherwood, L.; Robson, S.K.; Ormandy, E.; Farish, M.; Smurthwaite, K.M.; Roehe, R.; Lawrence, A.B.; Edwards, S.A. Indicators of piglet survival in an outdoor farrowing system. *Livest. Sci.* **2009**, *124*, 266–276.
161. Lidfors, L.; Berg, C.; Bo Algers, B. Integration of Natural Behaviour in Housing Systems. *AMBIO* **2005**, *34*, 325–330, doi:10.1579/0044-7447-34.4.325.
162. Li, Y.; Zhang, H.; Johnston, L.J.; Martin, W. Understanding Tail-Biting in Pigs through Social Network Analysis. *Animals* **2018**, *8*, 13, doi:10.3390/ani8010013.
163. Rodríguez-Estévez, V.; Sánchez-Rodríguez, M.; Gómez-Castro, A.G.; Edwards, S.A. Group sizes and resting locations of free range pigs when grazing in a natural environment. *Appl. Anim. Behav. Sci.* **2010**, *127*, 28–36, doi:10.1016/j.livsci.2010.11.015.
164. Greenwood, E.C.; Dickson, C.A.; Van Wettene, W.H.E.J. Feeding Strategies Before and at Mixing: The Effect on Sow Aggression and Behaviour. *Animals* **2019**, *9*, 23, doi:10.3390/ani9010023.
165. Pittman Elmore, M.R.; Garner, J.P.; Johnson, A.K.; Kirkden, R.D.; Richert, B.T.; Pajor, E.A. Getting around social status: Motivation and enrichment use of dominant and subordinate sows in a group setting. *Appl. Anim. Behav. Sci.* **2011**, *133*, 154–163, doi:10.1016/j.applanim.2011.05.017.
166. Remience, V.; Wavreille, J.; Canart, B.; Meunier-Salaün, M.C.; Prunier, A.; Bartiaux-Thill, N.; Nicks, B.; Vandenheede, M. Effects of space allowance on the welfare of dry sows kept in dynamic groups and fed with an electronic sow feeder. *Appl. Anim. Behav. Sci.* **2008**, *11*, 284–296, doi:10.1016/j.applanim.2007.07.006.
167. Walker, P.K.; Bilkei, G. Tail-biting in outdoor pig production. *Vet. J.* **2006**, *171*, 367–369, ISSN 1090-0233, doi:10.1016/j.tvjl.2004.10.011.
168. Van de Weerd, H.A.; Day, J.E.L. A review of environmental enrichment for pigs housed in intensive housing systems. *Appl. Anim. Behav. Sci.* **2009**, *116*, 1–20.
169. Valros, A. Tail biting. In *Advances in Pig Welfare*; Spinka, M., Ed.; Elsevier: Amsterdam, The Netherlands, 2018; pp. 137–166.
170. Vermeer, H.M.; Dirx-Kuijken, N.C.P.M.M.; Bracke, M.B.M. Exploration Feeding and Higher Space Allocation Improve Welfare of Growing-Finishing Pigs. *Animals* **2017**, *7*, 36 <https://doi.org/10.3390/ani7050036>.
171. Studnitz, M.; Jensen, M.; Pedersen, L. Why do pigs root and in what will they root: A review on the exploratory behaviour of pigs in relation to environmental enrichment. *Appl. Anim. Behav. Sci.* **2007**, *107*, doi:10.1016/j.applanim.2006.11.013.
172. Valros, A.; Heinonen, M. Save the pig tail. *Porc. Health Manag.* **2015**, *1*, 2, doi:10.1186/2055-5660-1-2.
173. Seibert, L.; Norwood, F.B. Production Costs and Animal Welfare for Four Stylized Hog Production Systems. *J. Appl. Anim. Welf. Sci.* **2011**, *14*, 1–17, doi:10.1080/10888705.2011.527596.
174. Deen, J.; Anil, S.S.; Anil, L. Sow housing: Opportunities, constraints, and unknowns. *J. Am. Vet. Med. Assoc.* **2005**, *226*, 1331–1334, doi:10.2460/javma.2005.226.1331.

175. Greenwood, E.C.; Plush, K.J.; van Wettere, W.H.E.J.; Hughes, P.E. Hierarchy formation in newly mixed, group housed sows and management strategies aimed at reducing its impact. *Appl. Anim. Behav. Sci.* **2014**, *160*, 1–11, doi:10.1016/j.applanim.2014.09.011.
176. Coutellier, L.; Arnould, C.; Boissy, A.; Orgeur, P.; Prunier, A.; Veissier, I.; Meunier-Salaün, M.C. Pig's responses to repeated social regrouping and relocation during the growing-finishing period. *Appl. Anim. Behav. Sci.* **2007**, *105*, 102–114, doi:10.1016/j.applanim.2006.05.007.
177. Sapkota, A.; Marchant Forde, J.N.; Richert, B.T.; Lay Jr., D.C. Including dietary fiber and resistant starch to increase satiety and reduce aggression in gestating sows. *J. Anim. Sci.* **2016**, *94*, 1–11, doi:10.2527/jas2015-0013.
178. Guy, J.H.; Burns, S.E.; Barker, J.M.; Edwards, S.A. Reducing post-mixing aggression and skin lesions in weaned pigs by application of a synthetic maternal pheromone. *Anim. Welf.* **2009**, *18*, 249–255.
179. Marchant-Forde, J.N.; Marchant-Forde, R.M. Minimizing inter-pig aggression during mixing. *Pig News Infor.* **2005**, *26*, 63–71.
180. Sutherland, M.A. Welfare implications of invasive piglet husbandry procedures, methods of alleviation and alternatives: A review. *N. Z. Vet. J.* **2015**, *63*, 52–57, doi:10.1080/00480169.2014.961990.
181. Marchant-Forde, J.N.; Lay, D.C.; McMunn, K.A.; Cheng, H.W.; Pajor, E.A.; Marchant-Forde, R.M. Postnatal piglet husbandry practices and well-being: The effects of alternative techniques delivered separately. *J. Anim. Sci.* **2009**, *87*, 1479–1492, doi:10.2527/jas.2008-1080.
182. Marchant Forde, J.N.; Lay, D.C., Jr.; McMunn, K.A.; Cheng, H.; Marchant-Forde, R.M.; Pajor, E.A. Postnatal piglet husbandry practices and well-being: The effects of alternative techniques delivered in combination. *J. Anim. Sci.* **2014**, *92*, 1150–1160.
183. Parois, S.; Bonneau, M.; Chevillon, P.; Larzul, C.; Quiniou, N.; Robic, A.; Prunier, A. Odeurs indésirables de la viande de porcs mâles non castrés: Problèmes et solutions potentielles. *INRA Prod. Anim.* **2018**, *31*, 23–36.
184. Von Borell, E.; Baumgartner, J.; Giersing, M.; Jäggin, N.; Prunier, A.; Tuytens, F.A.; Edwards, S.A. Animal welfare implications of surgical castration and its alternatives in pigs. *Animal* **2009**, *3*, 1488–1496, doi:10.1017/S1751731109004728.
185. Čandek-Potokar, M.; Škrlep, M.; Zamaratskaia, G. Immunocastration as Alternative to Surgical Castration in Pigs. In Payan Carreira, R., Ed *Theriogenology Intechopen*; IntechOpen Limited: London, UK, **2017**, Available online: doi:10.5772/intechopen.68650. (accessed on 20 December 2019)
186. Holinger, M.; Früh, B.; Hillmann, E. Group composition for fattening entire male pigs under enriched housing conditions—Influences on behaviour, injuries and boar taint compounds. *Appl. Anim. Behav. Sci.* **2015**, *165*, 47–56, doi:10.1016/j.applanim.2015.01.016.
187. Bonneau, M.; Weiler, U. Pros and Cons of Alternatives to Piglet Castration: Welfare, Boar Taint, and Other Meat Quality Traits. *Animals* **2019**, *9*, 884, doi:10.3390/ani9110884.
188. Kress, K.; Weiler, U.; Schmucker, S.; Čandek-Potokar, M.; Vrecl, M.; Fazarinc, G.; Škrlep, M.; Batorek-Lukač, N.; Stefanski, V. Influence of Housing Conditions on Reliability of Immunocastration and Consequences for Growth Performance of Male Pigs. *Animals* **2019**, *10*, 27, doi:10.3390/ani10010027.
189. Kress, K.; Verhaagh, M. The Economic Impact of German Pig Carcass Pricing Systems and Risk Scenarios for Boar Taint on the Profitability of Pork Production with Immunocastrates and Boars. *Agriculture* **2019**, *9*, 204.
190. Tallet, C.; Brilloüet, A.; Meunier-Salaün, M.C.; Paulmier, V.; Guérin, C.; Prunier, A. Effects of neonatal castration on social behaviour, human–animal relationship and feeding activity in finishing pigs reared in a conventional or an enriched housing. *Appl. Anim. Behav. Sci.* **2013**, *145*, 70–83, doi:10.1016/j.applanim.2013.03.001.
191. Heyrman, E.; Millet, S.; Tuytens, F.A.M.; Ampe, B.; Janssens, S.; Buys, N.; Wauters, J.; Vanhaecke, L.; Aluwé, M. On farm intervention studies on reduction of boar taint prevalence: Feeding strategies, presence of gilts and time in lairage. *Res. Vet. Sci.* **2018**, *118*, 508–516, doi:10.1016/j.rvsc.2018.05.008.
192. Hortos, M.; García-Regueiro, J.A.; Esteve, E.; Lizardo, R.; Quintanilla, R.; Sais, N.; Diestre, A.; Knap, P.; Matthews, N.; Fields, B.; et al. *Preventive Measures to Reduce Boar Taint: The Use of Feeding Benefits on Boar Taint Reduction in Pork from Entire Males Sired from Boars Genetically Characterized for High and Low Boar Taint*; IRTA Final Report; IRTA: Girona, Spain **2015**, SANCO/2012/G3/SI2.640072;

193. Øverland, M.; Kjos, N.K.; Fauske, A.K.; Teige, J.; Sørum, H. Easily fermentable carbohydrates reduce skatole formation in the distal intestine of entire male pigs. *Livest. Sci.* **2011**, *140*, 206–217, doi:10.1016/j.livsci.2011.03.032.
194. While, S.G.; Kjos, N.P.; Sørum, H.; Overland, M. Feeding Jerusalem artichoke reduced skatole level and changed intestinal microbiota in the gut of entire male pigs. *Animal* **2012**, *6*, 807–814.
195. Strathe, A.B.; Velander, I.H.; Mark, T.; Ostensen, T.; Hansen, C.; Kadarmideen, H.N. Genetic parameters for male fertility and its relationship to skatole and androstene in Danish Landrace boars. *J. Anim. Sci.* **2013**, *91*, 4659–4668.
196. Chevillon, P. Les meilleures pratiques d'élevage de mâles entiers décryptées. *Tech. Porc.* **2019**, *270*, 38–40.
197. De Briyne, N.; Berg, C.; Blaha, T.; Palzer, A.; Temple, D. Phasing out pig tail docking in the EU - present state, challenges and possibilities. *Porc. Health Manag.* **2018**, *4*, 27, doi:10.1186/s40813-018-0103-8.
198. Horrell, R.I.; A'Ness, P.J.; Edwards, S.A.; Eddison, J.C. The Use of Nose-Rings in Pigs: Consequences for Rooting, Other Functional Activities, and Welfare. *Anim. Welf.* **2001**, *10*, 3–22.
199. Edge, H.L.; Bornett, H.L.I.; Newton, E.; Edwards, S.A. Alternatives to nose-ringing in outdoor sows: 2. The provision of edible or inedible overground enrichment. *Anim. Welf.* **2004**, *13*, 233–237.
200. Edge, H.L.; Bulman, C.A.; Edwards, S.A. Alternatives to nose ringing in outdoor sows: The provision of root crops. *Appl. Anim. Behav. Sci.* **2005**, *92*, 15–26.
201. Campbell, J.M.; Crenshaw, J.D.; Polo, J. The biological stress of early weaned piglets. *J. Anim. Sci. Biotechnol.* **2013**, *4*, 19, doi:10.1186/2049-1891-4-19.
202. Schrey, L.; Kemper, N.; Fels, M. Behaviour and Skin Injuries of Piglets Originating from a Novel Group Farrowing System Before and After Weaning. *Agriculture* **2019**, *9*, 93, doi:10.3390/agriculture9050093.
203. Oostindjer, M.; Bas Kemp, B.; van den Brand, H.; Bolhuis, J.E. Facilitating 'learning from mom how to eat like a pig' to improve welfare of piglets around weaning. *Appl. Anim. Behav. Sci.* **2014**, *160*, 19–30, doi:10.1016/j.applanim.2014.09.006.
204. Hötzel, M.J.; Machado, L.C.P.; Irgang, R.; Alexandre, L. Short-term behavioural effects of weaning age in outdoor-reared piglets. *Animal* **2010**, *4*, 102–107, doi:10.1017/S1751731109990875.
205. Gentry-Carter, J.G.; Li, Y.; Pajor, E. *Welfare Issues at the Time of Weaning*; PIG 05-06-02; Pig Information Gateway: Clive, Iowa USA, **2012**.
206. Hovi, M.; Sundrum, A.; Thamsborg, S.M. Animal health and welfare in organic livestock production in Europe: Current state and future challenges. *Livest. Prod. Sci.* **2003**, *80*, 41–53.
207. Riart, G.R. Some Aspects of Outdoor Pig Production in Argentina. Ph.D. Thesis, University of Aberdeen, Aberdeen, UK, 2002; p. 221. ISBN:0000 0001 3515 3638.
208. Kongsted, A.G.; Hermansen, J.E. Sow body condition at weaning and reproduction performance in organic piglet production. *Acta Agric. Scand. Sect. A Anim. Sci.* **2009**, *59*, 93–103, doi:10.1080/09064700903071768.
209. Lau, Y.Y.W.; Pluske, J.R.; Fleming, P.A. Does the environmental background (intensive v. outdoor systems) influence the behaviour of piglets at weaning? *Animal* **2015**, *9*, 1361–1372, doi:10.1017/S1751731115000531.
210. Poppenga, R.H. Poisonous plants. In *Molecular, Clinical and Environmental Toxicology*; Luch, A., Eds.; Experientia Supplementum; Birkhäuser Basel: Basel Switzerland **2010**; Volume 100, pp. 123–175, doi:10.1007/978-3-7643-8338-1_4.
211. Jakobsen, M.; Kongsted, A.G.; Hermansen, J.E. Foraging behaviour, nutrient intake from pasture and performance of free-range growing pigs in relation to feed CP level in two organic cropping systems. *Animal* **2015**, *9*, 2006–2016, doi:10.1017/S1751731115001585.
212. López-García, A.; García-Casco, J.M.; Muñoz, M.; Martínez-Torres, J.M.; Fernández-Barroso, M.A.; González-Sánchez, E. Backfat Fatty Acid Profile after Growing Period. In *Iberian Pigs Fed With Olive Cake in a Dry or Wet (Silage) Form*. In Proceedings of the 11th International Symposium Modern Trends in Livestock Production, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, **2017**; pp. 169–177, ISBN 978-86-82431-73-2. Available online: <http://istocar.bg.ac.rs/en/simpozijum/11th-international-symposium-modern-trend-in-livestock-production-11th-13-th-october-2017-belgrade-serbia/> (accessed on 17 May 2019).
213. Spencer, J.D.; Gaines, A.M.; Berg, E.P.; Allee, G.L. Diet modifications to improve finishing pig growth performance and pork quality attributes during periods of heat stress. *J. Anim. Sci.* **2005**, *83*, 243–254, doi:10.2527/2005.831243x.

214. Scott, K.; Binnendijk, G.P.; Edwards, S.A.; Guy, J.H.; Kiezebrink, M.C.; Vermeer, H.M. Preliminary evaluation of a prototype welfare monitoring system for sows and piglets (Welfare Quality® project). *Anim. Welf.* **2009**, *18*, 441–449.
215. Temple, D.; Courboulay, V.; Manteca, X.; Velarde, A.; Dalmau, A. The welfare of growing pigs in five different production systems: Assessment of feeding and housing. *Animal* **2012**, *6*, 656–667, doi:10.1017/S1751731111001868.
216. Turner, S.P.; White, I.M.S.; Brotherstone, S.; Farnworth, M.J.; Knap, P.W.; Penny, P.; Mendl, M.; Lawrence, A.B. Heritability of post-mixing aggressiveness in grower-stage pigs and its relationship with production traits. *Anim. Sci.* **2006**, *82*, 615–620.
217. Karg, H.; Bilkei, G. Causes of sow mortality in Hungarian indoor and outdoor pig production units. *Berl. Munch. Tierarztl. Wochenschr.* **2002**, *115*, 366–368.
218. Presto, M.H.; Andersson, H.K.; Wallgren, P.; Lindberg, J.E. Influence of dietary amino acid level on performance, carcass quality and health of organic pigs reared indoors and outdoors. *Acta Agric. Scand. Sect. A* **2007**, *57*, 61–72.
219. Osava, C.F.; Castro Rodrigues, A.; Neto, H.V.R.; Pascoal, J.O.; Yokosawa, J.; Martins, M.M.; Szabó, M.P.J.; Ramos, V.N. *Amblyomma sculptum* (*Amblyomma cajennense* complex) tick population maintained solely by domestic pigs. *Vet. Parasitol. Reg. Stud. Rep.* **2016**, *6*, 9–13, doi:10.1016/j.vprsr.2016.11.002.
220. Kochanowski, M.; Karamon, J.; Dąbrowska, J.; Dors, A.; Czyżewska-Dors, E.; Cencek, T. Occurrence of intestinal parasites in pigs in Poland- the influence of factors related to the production system. *J. Vet. Res.* **2017**, *61*, 459–466.
221. Lindgren, K.; Lindahl, C. Mobile and stationary systems for organic pigs—Animal Welfare assessment in the fattening period. Researching Sustainable Systems. In Proceedings of the First Scientific Conference of the International Society of Organic Agriculture Research (ISO FAR), Adelaide, Australia, 21–23 September 2005. Köpke, U., Niggli, U., Neuhoﬀ, D., Cornish, P., Lockeretz, W., Willer, H., Eds.; 15th IFOAM Organic World Congress. 2005.
222. Katakam, K.K.; Thamsborg, S.M.; Dalsgaard, A.; Kyvsgaard, N.C.; Mejer, H. Environmental contamination and transmission of *Ascaris suum* in Danish organic pig farms. *Parasites Vectors* **2016**, *9*, 80, doi:10.1186/s13071-016-1349-0.
223. Venglovsky, J.; Sasakova, N.; Gregova, G.; Papajova, I.; Toth, F.; Szaboova, T. Devitalisation of pathogens in stored pig slurry and potential risk related to its application to agricultural soil. *Environ. Sci. Pollut. Res.* **2018**, *25*, 21412–21419, doi:10.1007/s11356-017-0557-2.
224. Andersen, I.L.; Berg, S.; Bøe, K.E. Crushing of piglets by the mother sow (*Sus scrofa*)—Purely accidental or a poor mother? *Appl. Anim. Behav. Sci.* **2005**, *93*, 229–243, doi:10.1016/j.applanim.2004.11.015.
225. Borgsteede, F.H.M.; Gaasenbeek, C.P.H.; van Krimpen, M.M.; Maurer, V.; Mejer, H.; Spoolder, H.A.M.; Thamsborg, S.M.; Vermeer, H.M. Studies on preventive strategies and alternative treatments against roundworm in organic pig production systems. *NJAS Wagening. J. Life Sci.* **2011**, *58*, 173–176, doi:10.1016/j.njas.2011.09.008.
226. Valdivieso-Ugarte, M.; Gomez-Llorente, C.; Plaza-Díaz, J.; Gil, Á. Antimicrobial, Antioxidant, and Immunomodulatory Properties of Essential Oils: A Systematic Review. *Nutrients* **2019**, *11*, 2786, doi:10.3390/nu11112786.
227. Wang, L.; Shi, Z.; Shi, B.; Shan, A. Effects of dietary stevioside/rebaudioside A on the growth performance and diarrhea incidence of weaned piglets. *Anim. Feed Sci. Tech.* **2014**, *187*, 104–109.
228. Casal-Plana, N.; Manteca, X.; Dalmau, A.; Fàbrega, E. Influence of enrichment material and herbal compounds in the behaviour and performance of growing pigs. *Appl. Anim. Behav. Sci.* **2017**, *195*, 38–43, ISSN 0168-1591, doi:10.1016/j.applanim.2017.06.002.
229. Wen-Chao, L.; Hyeok-Min, Y.; Seung-Ho, P.; In-Ho, K. Supplementing lactation diets with herbal extract mixture during Summer improves the performance of Sows and nursing piglets. *Ann. Anim. Sci.* **2017**, *17*, 835–847, doi:10.1515/aoas-2016-0084.
230. Dearlove, B.A.; Kind, K.L.; Gatford, K.L.; van Wettere, W.H.E.J. Oral caffeine administered during late gestation increases gestation length and piglet temperature in naturally farrowing sows. *Anim. Reprod. Sci.* **2018**, *198*, 160–166, doi:10.1016/j.anireprosci.2018.09.015.
231. EFSA. Scientific Opinion of the Panel on Animal Health and Welfare on a request from the Commission on Animal health and welfare aspects of different housing and husbandry systems for adult breeding boars, pregnant, farrowing sows and unweaned piglets. *EFSA J.* **2007**, *572*, 1–13.

232. Schild, S.L.A.; Rangstrup-Christensen, L.; Thorsen, C.K.; Bonde, M.K.; Pedersen, L.J. The course of parturition in two sow genotypes and two hut designs under free-range conditions. *Appl. Anim. Behav. Sci.* **2019**, *213*, 55–64, doi:10.1016/j.applanim.2019.02.005.
233. Baxter, E.M.; Jarvis, S.; Sherwood, L.; Farish, M.; Roehe, R.; Lawrence, A.B.; Edwards, S.A. Genetic and environmental effects on piglet survival and maternal behaviour of the farrowing sow. *Appl. Anim. Behav. Sci.* **2011**, *10*, 28–41, doi:10.1016/j.applanim.2010.11.020.
234. Vieuille, C.; Berger, F.; Le Pape, G.; Bellanger, D. Sow behaviour involved in the crushing of piglets in outdoor farrowing huts—A brief report. *Appl. Anim. Behav. Sci.* **2003**, *80*, 109–115, doi:10.1016/S0168-1591(02)00211-3.
235. Johnson, A.K.; McGlone, J.J. Fender design and insulation of farrowing huts: Effects on performance of outdoor sows and piglets. *J. Anim. Sci.* **2003**, *81*, 955–964.
236. Queensland Government Department of Agriculture and Fisheries, Basic Housing Requirements. 2018. Available online: <https://www.daf.qld.gov.au/business-priorities/agriculture/animals/pigs/piggery-management/housing/basic-housing> (accessed on 19 April 2020).
237. Randolph, C.E.; O’Gorman, A.J.; Potter, R.A.; Jones, P.H.; Miller, B.G. Effects of insulation on the temperature within farrowing huts and the weaning weights of piglets reared on a commercial outdoor pig unit. *Vet. Rec.* **2005**, *157*, 800–805, doi:10.1136/vr.157.25.800.
238. Schild, S.L.A.; Rangstrup-Christensen, L.; Bonde, M.; Pedersen, L.J. The use of a shaded area during farrowing and lactation in sows kept outdoors. *Appl. Anim. Behav. Sci.* **2018**, *209*, 22–29, doi:10.1016/j.applanim.2018.08.019.



© 2020 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Paper III

Pietrosevoli, S.; Raczowski, C.; Green, J.T.; Villamide Diaz, M.J. **2020, Effect of growing-finishing pig stocking rates on bermudagrass ground cover and soil properties.** *Animals*, 2020; 10(9):1666. <https://doi.org/10.3390/ani10091666>

Effects of growing-finishing pig stocking rates on bermudagrass ground cover and soil properties

Silvana Pietrosevoli ^{1,2,*}, Charles Raczkowski ³, James T. Green, Jr. ⁴ and Maria Jesús Villamide ²

¹ Department of Animal Science, College of Agriculture and Life Sciences, North Carolina State University, Raleigh, 27695-7621 NC, USA Silvana_pietrosevoli@ncsu.edu

² Departamento de Producción Agraria, E.T.S.I. Agronómica, Alimentaria y de Biosistemas, Universidad Politécnica de Madrid, Madrid 28040, Spain; mariajesus.villamide@upm.es

³ Department of Natural Resources and Environmental Design, College of Agriculture and Environmental Sciences, North Carolina Agricultural and Technical State University, Greensboro, NC 27411, USA; charlesraczkowski@gmail.com

⁴ Department of Crop and Soil Science, College of Agriculture and Life Sciences, North Carolina State University, Raleigh, 27695-7621 NC, USA; jim_green@ncsu.edu

* Correspondence: silvana_pietrosevoli@ncsu.edu; Tel.: +01-919-515-0814

Received: date; Accepted: date; Published: date

Simple Summary: A common challenge for most livestock industries is to identify more productive, efficient and sustainable pasture-based production systems that have a positive effect on animal welfare, biodiversity, and long-term operation profitability without negatively influencing the environment. Implementing best management practices allows producers to achieve profitability and environmental goals. Maintaining an appropriate ground cover, minimizing the use of external inputs as fertilizers and pesticides, and adopting agroecological approaches are key for sustainable pasture management. Pasture-based pig production systems are considered animal welfare and environmentally friendly. However, the number of animals grazing can influence the vegetation ground cover, and the amount of nutrients imported to the systems. This study compared the effects of four different pig stocking rates (37, 74, 111 or 148 pigs ha⁻¹) during two 14-week grazing periods, on the vegetation ground cover and soil properties of bermudagrass paddocks. Increasing the number of animals aggravated the damage to the vegetative ground cover, and raised the amount of nutrients deposited on the soil. For conservation purposes, the number of pigs grazing bermudagrass should be equal to or less than 37 pigs ha⁻¹.

Abstract: This study compares four stocking rates (37, 74, 111 and 148 pigs ha⁻¹) for growing to finishing pigs (18.4±0.5 kg and 118.5±2.0 kg, and 35.7±2.1 kg and 125.7±2.3 kg initial and final BW for grazing periods 1 and 2, respectively) and their effect on ground cover and soil traits in bermudagrass (*Cynodon dactylon* [L.] Pers) pastures, over two 14-week grazing periods (July-September and May- August). The study was conducted at the Center for Environmental Farming systems at the Cherry Research Station, Goldsboro North Carolina. A continuous stocking method was implemented to manage the pasture. The percent ground cover was estimated with a

modified step point technique. Soil samples were collected in three sampling positions (center, inner and outer areas of the paddocks) and two soil sampling depths (0-30 and 30-90 cm). The experimental design was a completely randomized block with three field replicates. Data were analyzed using the PROC GLIMMIX procedure of SAS/STAT® Version 9.4. Greater ground cover and lesser soil nutrient concentrations were registered in bermudagrass paddocks managed with 37 pigs ha⁻¹. The results of this study validated also the existence of a spatial pattern of soil properties, which differed among sampling positions and depths.

Keywords: Pasture pigs; Bermudagrass; Stocking rates; Soil sampling position; Soil depth; Ground cover; Soil properties; Soil nutrients; Nutrients distribution; Outdoor pigs.

1. Introduction

A common challenge for most livestock industries is to identify more productive, efficient and sustainable pasture-based production systems that have a positive impact on animal welfare, biodiversity, and long-term operation profitability without negatively affecting soil health. The way that the available resources (land, forage species, animals, infrastructure, and climate) are organized and used to achieve the goals of the operation is key for sustainable animal production. Grazing management allows for more efficient use of resources by structuring how we make a better utilization of them. Franzluebbers et al. [1] listed the traits that describe well managed pasture systems. They include: maintaining an appropriate ground cover, minimizing the use of external inputs as fertilizers and pesticides, and adopting agroecological approaches. Production systems having these characteristics could provide a profit to farmers while maintaining diverse ecosystem services to the community. Recently, a renewed interest in pasture-based production systems has been observed [2], but information related to sound management practices oriented toward conservation of the resources is scarce. Pietrosemoli and Green [3] indicated that pasture pig production systems are confronted with a double challenge: to produce quantity and quality of forage year-around and to assure forage persistence. Under this approach, the list from Franzluebbers et al. [1], could be complemented with aspects pertinent to pasture pig systems to incorporate: minimizing the soil nutrient load, enhancing the dispersal of soil nutrients along the paddocks, and reducing soil compaction.

Management strategies have a direct effect on the environmental outcome of pasture-based livestock operations. Stocking rates particularly may influence animal grazing behavior and performance as well as pasture characteristics and soil properties [4-6]. Profitability has been associated with the number of animals per unit area or stocking rate. Therefore, intensification of the grazing management via the implementation of high stocking rates has been considered a way to increase production and profitability of livestock operations, but this strategy could involve environmental risks, especially in pasture pig systems. Pasture pigs have a better opportunity to express natural behavior compared to pigs raised indoors [7]. Nonetheless, if left uncontrolled behavior expressions such as grazing, rooting, trampling, wallowing and selecting dunging areas could trigger damages to the vegetation and the soil. Reduced ground cover leaves the soil exposed to weather elements and prone to erosion. Additionally, high soil nutrient concentrations in selected dunging areas could surpass the utilization capacity of the vegetation, increasing nutrient losses and becoming a water pollution source [3]. In contrast, areas with lesser nutrient loads may lead to reduced fertility.

The objectives of this study were to evaluate the effect of growing to finishing pig stocking rates on the vegetative ground cover, the soil properties, and to establish the existence of a spatial pattern of

soil properties in bermudagrass (*Cynodon dactylon* L. Pers) paddocks grazed with pigs during two 14-week periods, thus providing for a better understanding of soil nutrient dynamics, leading ultimately to the improvement of the management practices.

2. Materials and Methods

2.1 Experimental site description

The grazing studies were conducted at the Center for Environmental Farming System (CEFS, Cherry Research Station, lat. 35°24'5"N, long. 78°1'53"W) in Goldsboro North Carolina, USA. Three soil taxonomies were identified: Johns sandy loam (fine-loamy over sandy or sandy-skeletal, siliceous, semi-active, thermic Aquic Hapludults), Kenansville loamy sand (siliceous, sub-active, thermic Arenic Hapludults), and Lakeland sand loamy (Thermic, coated Typic Quartzipsamments). [8]. The landscape was almost flat with less than 1% slope. The climate of the area is classified as humid subtropical (Trewartha climate classification) with warm and humid summers and mild winters and occasional snow. In this climate, the average total annual precipitation is 1,465mm, the average temperature varies between 10.8 and 22.5°C and the growing season generally extends from early May to mid-October. The experiment was replicated twice (two pig grazing periods, 1st: July to September - Year 1, and 2nd: May to August - Year 2), while maintaining the same paddock conformation and field replicates. The paddocks were allowed to rest for 32 weeks between pig groups.

2.2 Forage

One hectare of well-established (10+ yr) bermudagrass previously intensively grazed with dairy cattle was used for the experiment. Three blocks were demarcated using a temporary electric fence. In each block, four square-shaped paddocks were proportionally sized to equal the stocking rates under evaluation. The four stocking rates were 37, 74, 111 and 148 pigs ha⁻¹, and the paddocks size ranged between 1350 m² and 340 m² with a grazing pressure between 10756 and 2689 kg of body weight ha⁻¹ (Table 1). The paddocks contained a shelter, a feeder and a drinking and cooling station. The shelter, without flooring, and the drinking/cooling station were located in the center of the paddock, while the feeders were positioned along one of the fences to facilitate feed delivery. Service structures were kept in the same emplacement during both pig grazing periods. Groups of pigs were randomly assigned to each paddock, which was managed under a continuous stocking system. Paddocks were winter fallow.

Table 1. Stocking rates under evaluation.

Stocking rate		Paddock size
Pigs ha ⁻¹	Kg BW ha ⁻¹	m ²
37	2689	1350
74	5378	675
111	8067	450
148	10756	340

Kg BW: kg body weight estimated as a function of the average weight

(Final weight – Initial weight) of the two groups of pigs

Vegetative ground cover estimation

Ground cover was estimated weekly following a modified step-point method [9]) along transects lines evenly spaced in each paddock. The presence of living vegetation, vegetation residues and bare soil were recorded every three steps on 6, 7, 9 and 12 transects 18.35, 21.21, 26.0 and 36.58 m long, for the paddocks managed with 148, 111, 74 and 37 pigs ha⁻¹, respectively. The transects were identified using 1.20 m PVC pipes (1.3-cm diameter) permanently located in two parallel lines at the sides of the paddocks. Ground cover was estimated adding living vegetation plus vegetation residues cover. During the first grazing period, ground cover data were recorded weekly up to week 5, following with estimations on a biweekly basis. Through the second growing period the information was registered weekly. Only ground cover data for weeks 1, 5, 10 and 14 were analyzed.

2.3 Animals

All animal related methods and protocols followed the guidelines developed by the North Carolina State University Institutional Animal Care and Use Committee (IACUC 09-021-A). A total of 120 pigs (castrated male and female) were included in the experiment. Animals used in the first grazing period (July to September, 14-week) were different from those used in the second period (May to August, 14-week). The first batch of pigs included 60 purebred Yorkshire (18.4 ± 0.5 kg and 118.5 ± 2.0 kg initial and final BW, respectively) that had been born and raised at the CEFS swine unit in a deep straw system. The second group (35.7 ± 2.1 kg and 125.7 ± 2.3 kg initial and final BW, respectively) was genetically more heterogeneous, with pure Yorkshire from CEFS (37% of the animals used), and crosses (Landrace x Duroc) and (Landrace x Hampshire) bought at a commercial operation. Pigs were not nose-ringed. Before starting the experiment, both groups of pigs were kept in an outdoor training paddock for two weeks, to let them get accustomed to the new environment and electric fences. Pigs were allotted to 12 groups of five pigs each such that all the groups had the same average total initial weight. The groups were then randomly assigned to the paddocks. Pigs on all groups were managed in a similar manner.

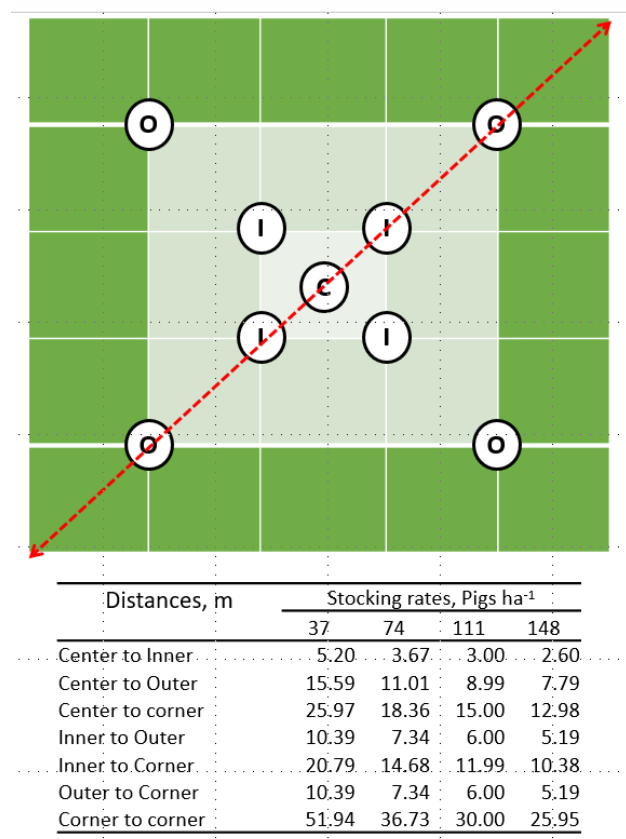
In the paddocks, pigs had access to an open shelter structure, a nipple drinker and a two-opening self-feeder (Figures 2 and 3). The creation of wallow areas was not encouraged, but a water valve was installed in the top of the pipe where the drinker was mounted and was used as a cooling station during the hottest times of the day. Pigs had *ad libitum* access to a home mix grain mixture (containing corn, soybean, minerals and vitamin mixes averaging 168 g kg⁻¹ crude protein and 2463 kcal kg⁻¹ net energy) and were individually weighed at the beginning and at the end of the grazing period, in the morning, without feed or water withdrawal. Feed offered was weighed twice a week for each paddock, and feed leftover in the feeder was collected at the end of the trial and weighed. Feed waste was not estimated. Feed offered and daily gain averaged 2.94 kg pig⁻¹ d⁻¹ and 0.907 kg pig⁻¹ d⁻¹, respectively.

2.4 Soil sampling

Soil samples were collected on three different dates. The initial sampling (before grazing pigs) followed a grid pattern of 16 equally-spaced sampling points per paddock. Samples were collected to a depth of 90 cm in the increments 0 to 30 and 30 to 90 cm, resulting in two samples per point that were used to establish the baseline soil property condition. The second and third soil samples from the same two soil depth layers were collected after removing the first and second group of pigs from the paddocks, respectively. A different sampling protocol was implemented for these two sampling times: nine sampling points were established within each paddock. Sampling points were classified according to their position relative to the center of the plot to monitor the distribution of soil disturbance within the paddocks: center, inner and outer (1, 4 and 4 samples, respectively,

Figure 1). These points were located along transects used to estimate ground cover and positioned proportionally at the same distance and the same location in the different size plots.

The initial soil samples were collected with a hand-held auger. The soil samples collected after the first group of pigs were collected with a hydraulic sampling device (Model GSRPS Giddings Machine Company, Windsor, CO) that had a 3.2-cm diameter coring tube. The day of sampling the soil was moist and no evidence of soil compaction was observed as the tube penetrated to the 90 cm depth. The coring device allowed for the determination of soil bulk density. Small subsamples of the 45°C oven-dried samples were collected and dried at 105°C to determine soil bulk density on a dry basis. The soil was dry when the second group of pigs was removed from the paddocks and the soil was being compacted inside the sampling tube when using the hydraulic sampling device. Therefore, samples were collected with the hand-held auger device used during the initial sampling. Bulk density data corresponding to the second sampling were not included in the analyses. All soil samples collected in the study were oven dried (45°C) for 24 h, passed through a 2-mm sieve to remove coarse organic fragments and gravel, then ground and sent to the laboratory for nutrient analysis.



C: Center; I: Inner; O: Outer; Distances among sampling points were estimated using Pythagoras' theorem [10].

Figure 1. Soil sampling positions.

2.5 Soil laboratory Analysis

Soil samples were analyzed at the North Carolina Agricultural and Technical State University soil laboratory for bulk density, nitrate (NO₃-N), ammonium (NH₄⁺-N), Total-N, PO₄-P and Total-P concentrations. Soil chemical forms of nitrogen and phosphorous were determined in each soil core sample. The inorganic forms of soil nitrogen (NO₃-N and NH₄⁺-N) were extracted with a 2M KCL

solution in a 1:10 soil-solution ratio. The concentration of each N form in filtrates were determined spectrophotometrically with a Flow Injection Analyzer (LACHAT Instrument Quick Chem. 8000). A CHNS/O Analyzer (Perkin-Elmer Model 2400) was used to analyze for total nitrogen. Soil phosphorus was extracted with a Bray-1 solution in a 1:7 soil-solution ratio. Concentrations of extractable phosphorus and total phosphorus in the filtrate were determined using inductively coupled plasma optical emission spectroscopy (ICP-OES Perkin-Elmer Optima 3300). The concentration of each nutrient form was converted to the amount in weight on a per hectare volume basis using the soil bulk density determined from the core sample.

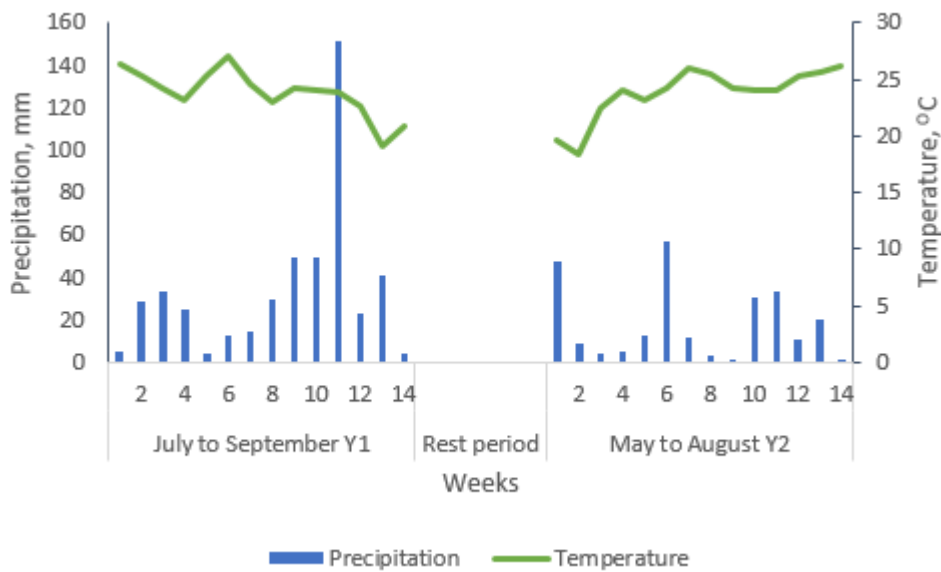
2.6 Statistical analysis

The experimental design was a randomized complete block with three field replications. The paddock was considered the experimental unit. Data analyses were performed through analyses of variance and covariance by means of generalized mixed models using the procedure PROC GLIMMIX of SAS/STAT[®] Version 9.4 (Copyright 2017© SAS Institute Inc., SAS Campus Drive, Cary, North Carolina 27513, USA) [11]. To study ground cover across time, the model included grazing period, stocking rate, week and their interactions as fixed effects. Block was considered a random effect and week a repeated measure. The model for final ground cover (measured on week 14) incorporated grazing period, stocking rate and their interaction as fixed effects, and block as a random effect. Grazing period was analyzed as a repeated measure.

A split-split-split plot analysis was conducted for soil-related variables with grazing periods as the main plot factor, pigs stocking rate (37, 74, 111 and 148 pigs ha⁻¹), soil sampling position (center, inner and outer areas within paddock) and soil sampling depth (0 to 30, and 30 to 90 cm) as sub, sub-sub, and sub-sub-sub plot factors, respectively. Block was considered a random effect, whereas grazing period, stocking rate, sampling position, soil depth, and their interactions were analyzed as fixed effects. Initial soil values were included in the models as covariates. Grazing period and sampling position were analyzed as repeated measures. For all models, the Kenward and Roger option was used to estimate the covariance matrix for the fixed effects and the degrees of freedom for t- and F- tests. The compound-symmetry structure, was selected using the Akaike corrected (AICC) and Schwarz's Bayesian (BIC) criteria. Differences between treatments were determined by the multiple comparison procedure using the SIMULATE adjustment option. Results were considered statistically significant at $P < 0.05$, and are presented as means $\pm$ standard error.

3. Results

During both grazing periods precipitation (472.4 and 247.4 mm for period 1 and 2, respectively) and temperature (23.8 and 23.8 °C for period 1 and 2, respectively) were favorable for bermudagrass growth (Figure 2). During the 32-week rest-period (time-lapse between the two grazing periods when the paddocks were not grazed), 535.4 mm of rain accumulated and the temperature averaged 10.4 °C. Baseline soil properties from samples collected up to 90 cm depth prior to grazing pigs on the site can be found in Table 2.



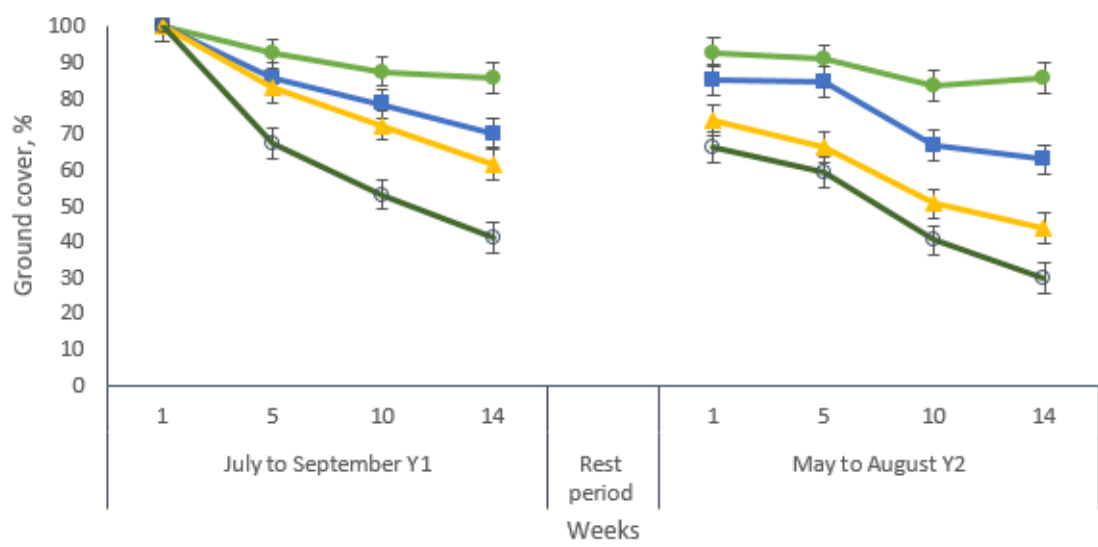
Source: State climate office of North Carolina, North Carolina State University. CRONOS/ECONet Database [12]

Figure 2. Weekly precipitation and temperature during the experimental period.

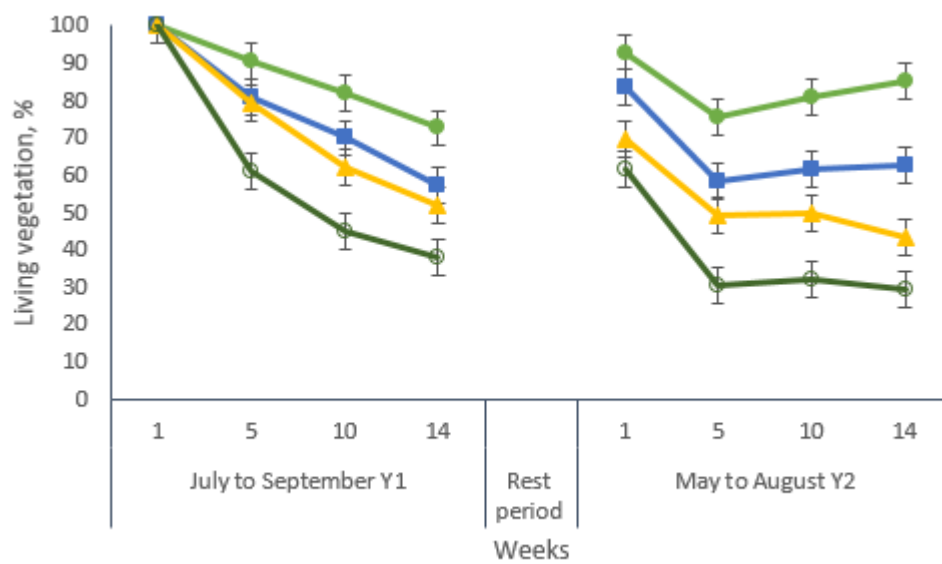
3.1. Ground cover

Ground cover averaged 80% and 68%, respectively, for grazing periods 1 and 2. Interactions grazing period x stocking rate, grazing period x week, and stocking rate x week were observed for ground cover and living vegetation, and week and grazing period x week for vegetation residues. The evolution of the ground cover and its components during the two-pig grazing periods are presented in Figure 3 (a-c). Ground (Figure 3a) and living vegetation cover (Figure 3b) followed a similar decreasing trend from start to end of each grazing period, while vegetation residues cover (Figure 3c) behaved more irregularly, especially during the second grazing period with an initial growth and a final decrease. The ground and living vegetation cover decreased at all stocking rates. However, a greater decrease rate in ground cover was observed for paddocks managed with 148 pigs ha⁻¹ compared with those managed with 37 pigs ha⁻¹. In the first grazing period, vegetation residues increased from week 1 to week 14 for stocking rates of 37, 74, and 111 pigs ha⁻¹ (Figure 3c). In contrast, no cohesive pattern was observed for vegetation residues in paddocks with 148 pigs ha⁻¹. A different trend was observed in the second grazing period, where vegetation residues increased greatly during the first 5 weeks, then declined steadily until the end of the period for all stocking rates. Even though the 32-week rest period between grazing periods allowed for the recuperation of the ground cover, no paddock recovered coverage to 100 % at the beginning of the second period.

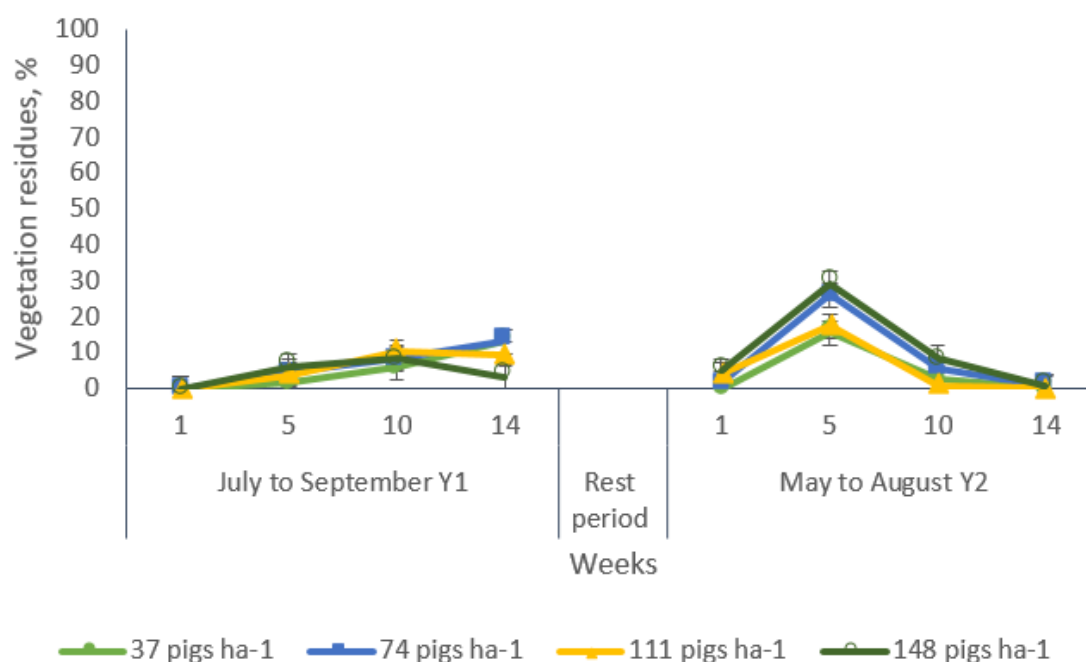
(a)



(b)



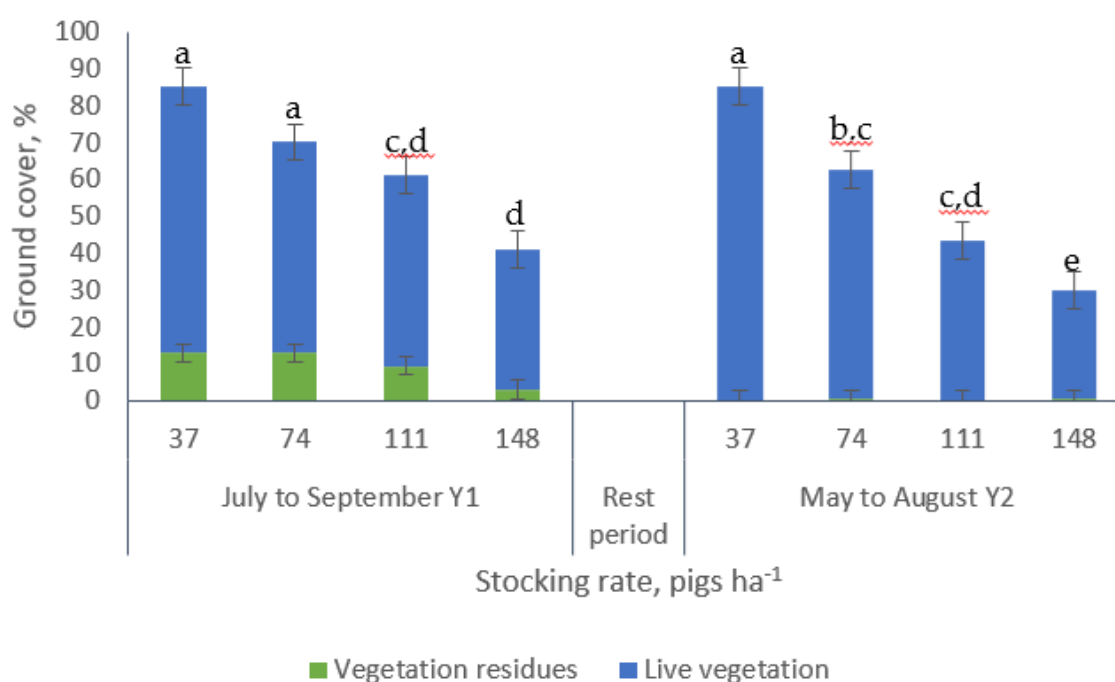
(c)



Data are the means of three field replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 3. Vegetative ground cover (%) in bermudagrass paddocks grazed with pigs during two 14-week grazing periods. (a) Ground cover, (b) Living vegetation and (c) Vegetation residues.

The analysis corresponding to final ground cover (measured at the end of the grazing periods-week 14), showed significant differences among grazing periods, stocking rates and for the interaction grazing period $\times$ stocking rate (Figure 4). In both periods, the greater final ground cover was recorded in paddocks managed with 37 pigs ha⁻¹ (110 % and 187 % more ground cover at the end of the grazing periods 1 and 2, respectively) compared to the ground cover found in paddocks managed with 148 pigs ha⁻¹. Paddocks managed with a stocking rate of 111 pigs ha⁻¹ showed no differences in ground cover with the most intensive treatment (148 pigs ha⁻¹) at the end of grazing period 1. However, at the end of grazing period 2, it was possible to detect differences in the ground cover from paddocks managed with 37, 74, and 111 pigs ha⁻¹ and the ground cover estimated in paddocks grazed with 148 pigs ha⁻¹.



a, b, c, d, e: means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. The Letters display does not reflect all significant comparisons. The following additional pairs are significantly different: (GP1 SR111 vs GP2 SR111; (GP1 SR148 vs GP2 SR148; where GP: grazing period, and SR: stocking rate). Data are the means of three replicates. Errors bars represent plus or minus one standard error of the mean.

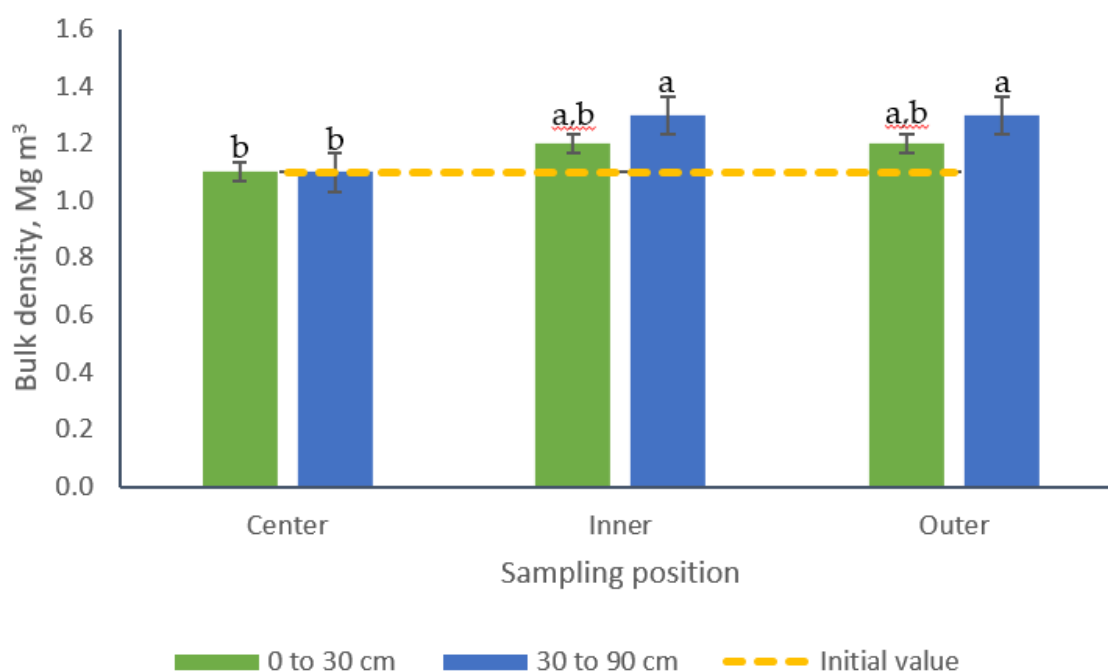
Figure 4. Effect of the interaction grazing period x stocking rate on the ground cover of bermudagrass paddocks at the end of the grazing periods.

3.2 Soil properties

Initial values for soil properties were similarly distributed across stocking rates but soil bulk density and the concentrations of Total-N, PO₄-P and Total-P varied along the soil profile, generally showing lesser values deeper in the profile (30 to 90 cm). Previous history of the paddocks, which were intensively grazed with dairy cows, could have influenced the soil values observed in the collected samples. Changes in soil properties over time toward an increase compared to average initial figures were also observed. The inclusion of initial values as covariates in the different models resulted significant for bulk density, and PO₄-P (Table 2).

Bulk density

All paddocks had similar bulk density before pig introduction, averaging 1.12 Mg m⁻³ and ranging from 1.0 to 1.25 Mg m⁻³, data not shown. No differences were established in bulk density among samples from paddocks managed with different stocking rates (average 1.20 Mg m⁻³, data not shown). Significant interactions were observed, however, for the interaction sampling position x sampling depth. The samples collected in the center position of the paddocks (both depths) showed lesser bulk density (1.1 Mg m⁻³) compared with those collected in the inner or in the outer positions (30 to 60 cm soil layer) which did not differ and averaged 1.3 Mg m⁻³ (Figure 5).



a, b: means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. Data correspond to the first grazing period, and are the means of three field replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 5. Effect of the interaction sampling position x sampling depth on soil bulk density (Mg m⁻³) of bermudagrass paddocks grazed with pigs during one grazing period.

Soil Nutrients

Results of the analyses conducted to soil nutrients data are presented on Table 2. Greater concentrations (+ 41%) of Total-N were found in the first grazing period (July to September Y1). Conversely, greater amounts (+ 87%) of PO₄-P were recorded in the second grazing period. Stocking rate showed a trend ($P=0.0727$) toward an increase in NO₃⁻-N (Table 2), with greater concentrations recorded on paddocks managed with 148 pigs ha⁻¹ (+159%) than in paddocks managed with 37 pigs ha⁻¹).

Table 2. Soil nutrients (kg ha⁻¹) in bermudagrass paddocks grazed with pigs during two 14-week grazing periods.

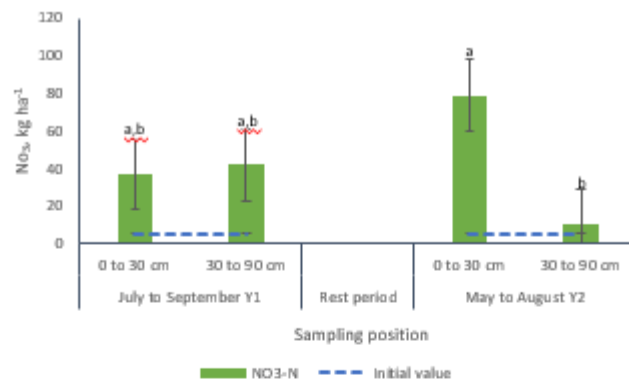
		NO ₃ -N	NH ₄ -N	Total-N	PO ₄ -P	Total-P
		(kg ha ⁻¹)				
INITIAL VALUE		5 ± 1	41 ± 2	1493 ± 49	391 ± 21	1695 ± 91
MEAN		42 ± 4	79 ± 9	1244 ± 76	630 ± 44	1345 ± 73
Grazing Period GP	July to Sept Y1	39	52	1456 a	438 b	1496
	May to Aug Y2	44	107	1032 b	821 a	1193
	SE	17	31	101	86	193
	Prob	0.8338	0.2068	0.0398	0.0263	0.2724
Stocking Rate SR	37 pigs ha ⁻¹	22 b	55	1126.0	495	1260
	74 pigs ha ⁻¹	37 a,b	83	1313.0	744	1395
	111 pigs ha ⁻¹	51 a,b	85	1232.0	746	1355
	148 pigs ha ⁻¹	57 a	94	1304.0	535	1369
	SE	15	31	140	126	203
	P	0.0727	0.376	0.7537	0.3708	0.9075
Sampling Position SP	CENTER	36	97	1000 b	495 b	1035 b
	INNER	40	78	1359 a	710 a	1482 a
	OUTER	49	63	1372 a	685 a	1517 a
	SE	14	29	87	79	170
	P	0.3796	0.1213	<.0001	<.0001	<.0001
Sampling Depth SD	0 – 30 cm	58	46	1978 a	356 b	1976 a
	30 – 90 cm	26	113	510 b	904 a	713 b
	SE	16	33	99	90	189
	P	0.1735	0.1839	<.0001	0.0062	0.0213
GP x SR	P	0.5200	0.2101	0.9816	0.8352	0.6534
GP x SP	P	0.6109	0.3297	0.0782	0.2183	0.4372
GP x SD	P	<.0001	<.0001	0.0365	<.0001	<.0001
SR*SP	P	0.0236	0.5374	0.4181	0.5919	0.7388
SR x SD	P	0.2578	0.3246	0.2481	0.0028	0.7049
SP x SD	P	0.8504	0.2825	0.0022	0.2670	0.0501
GP x SR x SP	P	0.3333	0.5550	0.5790	0.2552	0.8892
GP x SR x SD	P	0.0416	0.2979	0.9975	0.6200	0.1073
GP x SP x SD	P	0.5591	0.4674	0.9936	0.0891	0.0554
SR x SP x SD	P	0.4990	0.5918	0.9789	0.1221	0.9884
GP x SR x SP x SD	P	0.9031	0.4125	0.5531	0.2570	0.9257
Initial value - covariate	P	0.3991	0.8028	0.8942	0.0002	0.2370

NO₃-N: Nitrate-N, NH₄-N: Ammonium-N, Total-N, PO₄-P: Phosphate-P, Total-P, SE: Standard Error, P: Probability, a, b: means having the same letter in common are not significantly different at the 5% level of probability as indicated by Multiple Comparisons test using the Simulate option. Data are the means of three field replicates.

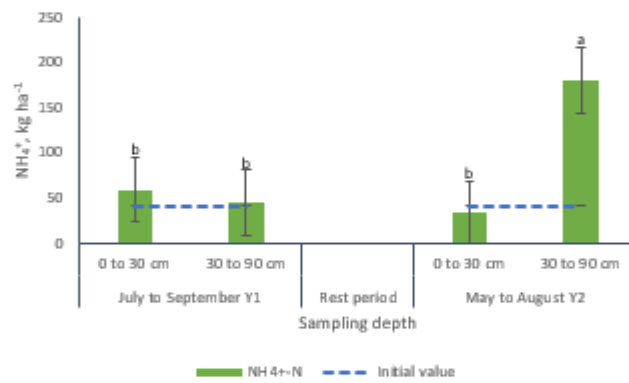
Differences in the concentrations of Total-N, PO₄-P, and Total-P were observed among soil samples collected from different positions in the paddocks (Table 2). The inner and outer positions registered 37, 41 and 45% more Total-N, PO₄-P, and Total-P, respectively, compared to samples from the center of the paddocks. No differences were observed, however, among samples collected in the inner and outer positions. Differences related to sampling depth were also observed for these nutrients, with increases of 288 % Total-N and 177% Total-P in samples collected from the top soil layer (0 to 30 cm). Conversely, samples from the 30 to 90 cm soil strata contained 154% more PO₄-P than samples collected in the upper layer (Table 2).

The existence of a trend ($P=0.0782$) for Total-N was found for the interaction grazing period x sampling position. For all the nutrients under evaluation, differences were observed for the interaction grazing period x sampling depth (Table 2, Figures 6 and 7). No differences were observed in NO₃-N concentrations in samples collected at different depths during the first grazing period. Conversely, greater concentrations of NO₃-N (+ 690%) were found in samples from the 0 to 30 cm layer during the second grazing period (Figure 6 (a)).

(a)



(b)



(c)

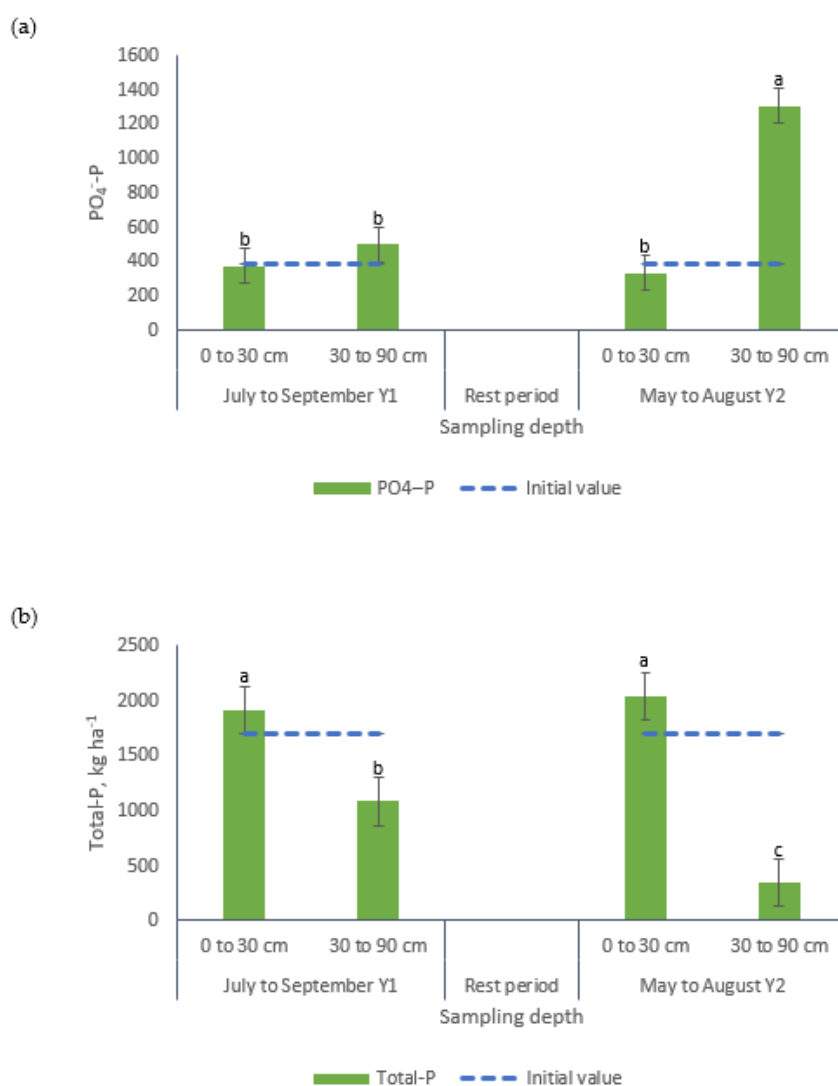


a, b, c: means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. Data are the means of three field replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 6. Effects of the interaction grazing period x sampling depth on the concentrations of (a) NO_3^- -N, (b) NH_4^+ -N and (c) Total-N (kg ha^{-1}) in soil samples from bermudagrass paddocks managed with different pig stocking rates during two 14-week grazing periods

During the first grazing period, no differences were observed in the concentration of NH_4^+ -N among samples from both sampling depths (Figure 6b). During the second grazing period, however, greater NH_4^+ -N values were found in samples gathered in the bottom layer (30 to 90 cm, a value 440 % greater than the value registered in the top layer, and 225% greater than the value registered in the first period). Similarly, greater Total-N levels were found in samples from the top soil, which were not different among the grazing periods and averaged $1978 \text{ kg Total-N ha}^{-1}$ (Figure 6c).

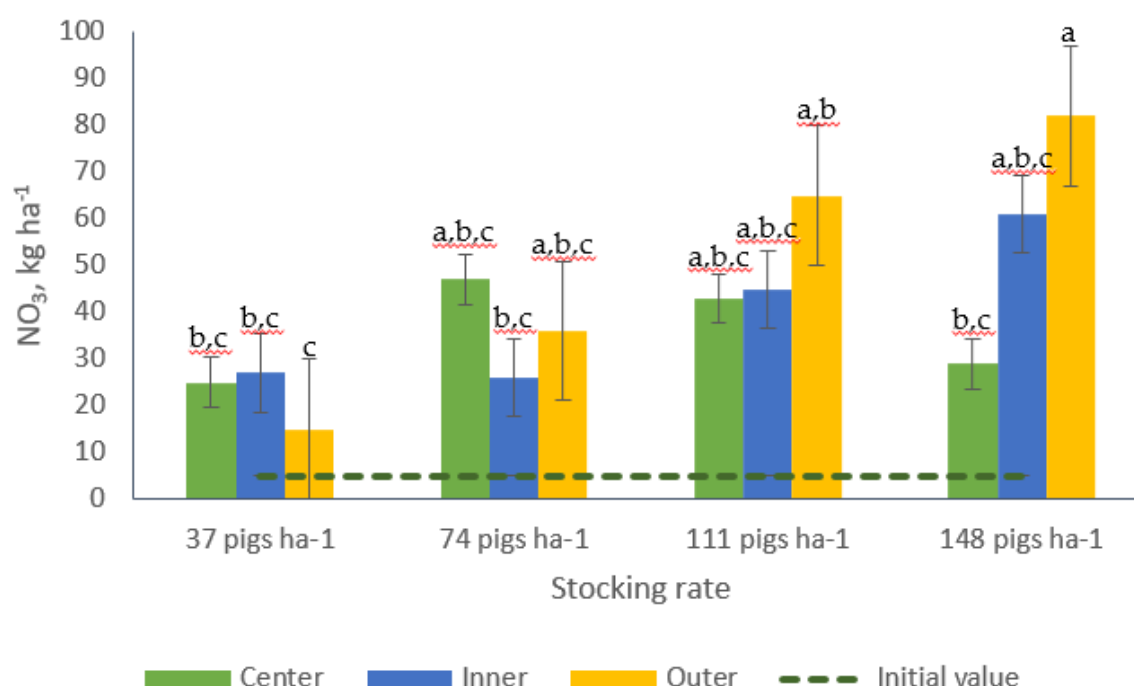
Greater concentrations of PO_4 -P were recorded in samples collected following the second grazing period in the 30 to 90 cm soil layer (1308 kg ha^{-1}), whereas the other group of samples did not differ and showed 224% less PO_4 -P (Table 2, Figure 7a). The Total-P levels in the upper soil layer did not present differences among grazing periods (average 1976 kg ha^{-1}) but that value was greater than the values registered for the samples collected in the bottom soil layer (+82 and 476%) in the first and second grazing period, respectively, (Figure 7b).



a, b, c: Means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. Data are the means of three replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 7. Effects of the interaction grazing period x sampling depth on the concentrations of (a) $\text{PO}_4\text{-P}$, (b) Total-P (kg ha^{-1}) in soil samples from bermudagrass paddocks managed with different pig stocking rates during two 14-week grazing periods

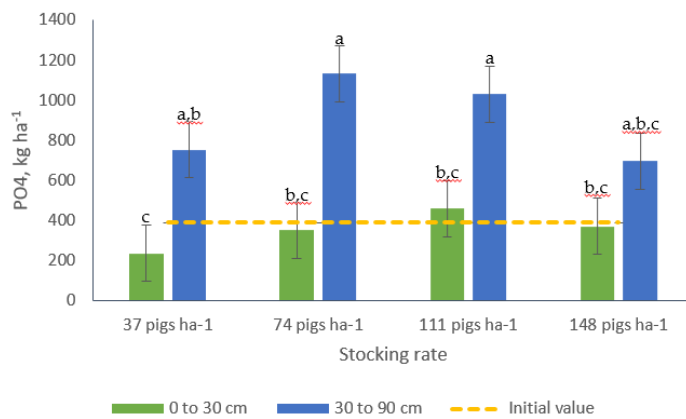
A significant interaction stocking rate x sampling position was detected for $\text{NO}_3\text{-N}$ concentrations (Table 2). No differences were observed among samples collected from the different sampling positions from paddocks managed with 37, 74 or 111 pigs ha^{-1} . Samples from paddocks managed with 148 pigs ha^{-1} collected from the outer position, however, contained greater concentrations of $\text{NO}_3\text{-N}$, 183% more than the concentrations found in samples collected from the center of the same paddocks. Similarly, samples from the outer position from paddocks with 148 pigs ha^{-1} showed greater $\text{NO}_3\text{-N}$ (+267%) than the concentrations found in samples collected from the three sampling positions in paddocks managed with 37 pigs ha^{-1} , and 215% more than the concentrations found in samples collected from the inner position in paddocks with 74 pigs ha^{-1} (Table 2, Figure 8).



a, b, c: For each grazing period, means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. Data are the means of three field replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 8. Effect of the interaction stocking rate x sampling position on soil $\text{NO}_3\text{-N}$ (kg ha^{-1}) in bermudagrass paddocks grazed with pigs during two grazing periods.

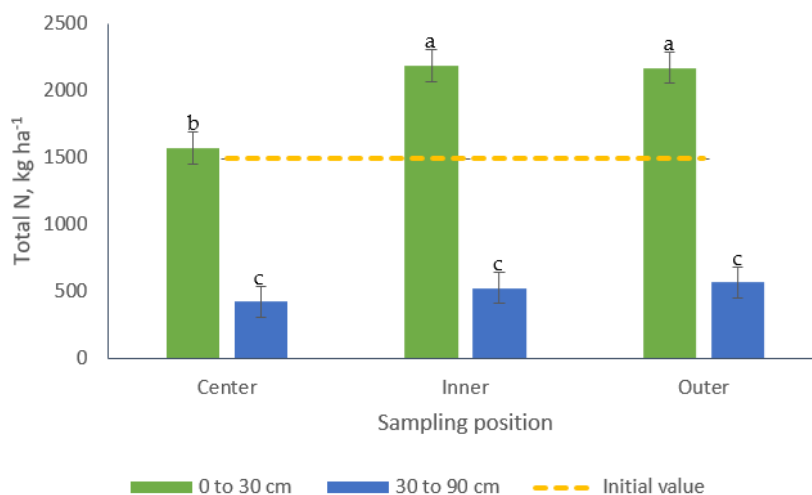
Similarly, the interaction stocking rate x sampling depth proved significant for $\text{PO}_4\text{-P}$ (Table 2). Greater concentrations of that nutrient (+154 %) were found in the bottom soil layer, with no differences among stocking rate. A comparable pattern was observed in samples collected in the 0 to 30 cm soil profile (Figure 9).



a, b, c: Means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. The Letter display does not reflect all significant comparisons. The following additional pairs are significantly different: (SR148 SD2, SR148 SD1; where SR: stocking rate, and SD: sampling depth). Data are the means of three replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 9. Effect of the interaction stocking rate x sampling depth on soil PO₄-P (kg ha⁻¹) in bermudagrass paddocks grazed with pigs during two grazing periods.

Total-N patterns resulted in a significant interaction for sampling position x sampling depth (Table 2). Differences in Total-N concentrations were observed in samples from the 0 to 30 cm soil depth. Samples collected from the center of the paddocks contained 39% less Total-N in comparison to samples gathered at the inner and outer positions which were similar (average 2181 kg Total-N ha⁻¹). Lesser Total-N concentrations were found in samples collected from the soil bottom layer, with no difference among the positions (average 510 kg Total-N ha⁻¹) (Figure 10).

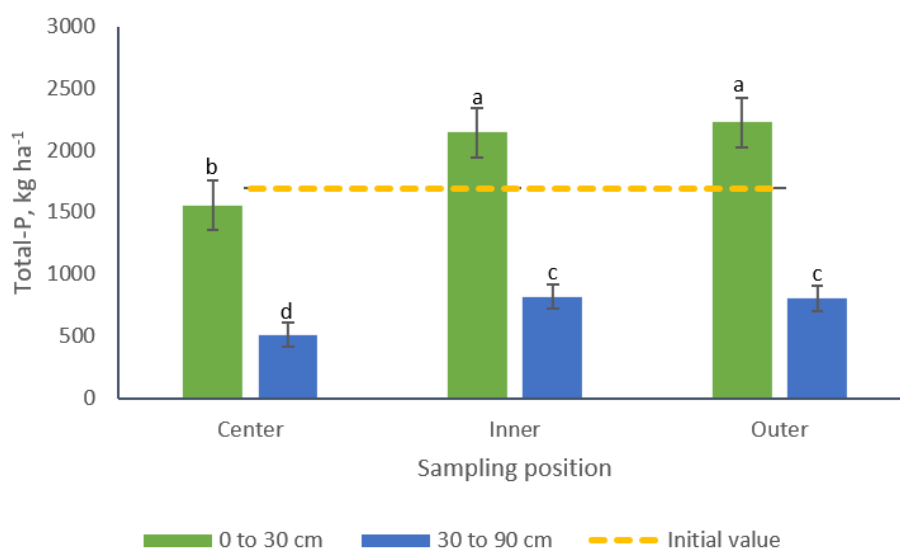


a, b, c: Means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. Data are the means of three replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 10. Effect of the interaction sampling position x sampling depth on soil Total-N (kg ha⁻¹) in bermudagrass paddocks grazed with pigs during two grazing periods.

Similarly, a significant interaction for sampling position x sampling depth was detected for Total-P (Table 2). More elevated concentrations of Total-P were found in the top layer of the soil (0 to 30 cm) but similar patterns were observed across positions for both soil depths. Concentrations were

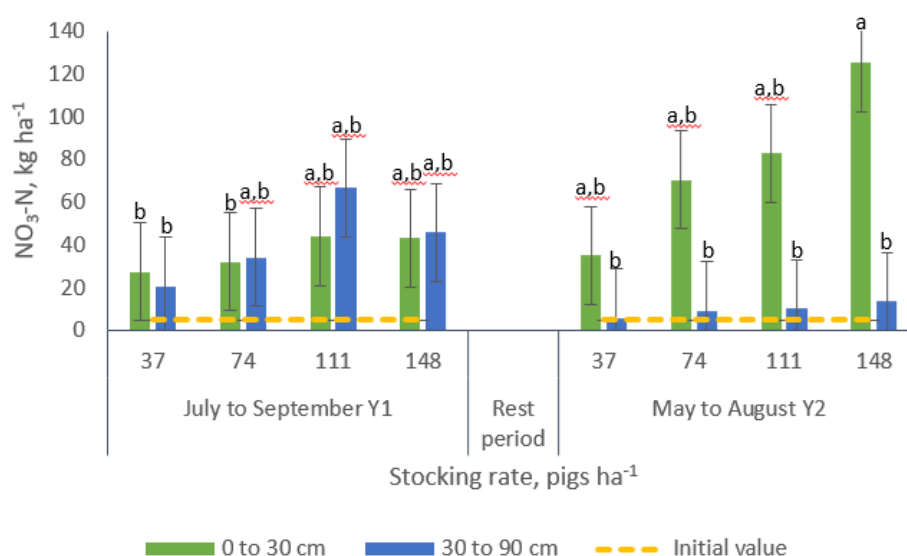
similar in the inner and outer positions, averaging 2185 and 813 kg Total-P for the upper and bottom layers, respectively. The latter Total-P concentrations were respectively 40 and 59% greater than those collected from the center of the paddocks (Figure 11).



a, b, c, d: Means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. Data are the means of three replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 11. Effect of the interaction sampling position x sampling depth on soil Total-P (kg ha⁻¹) in bermudagrass paddocks grazed with pigs during two grazing periods.

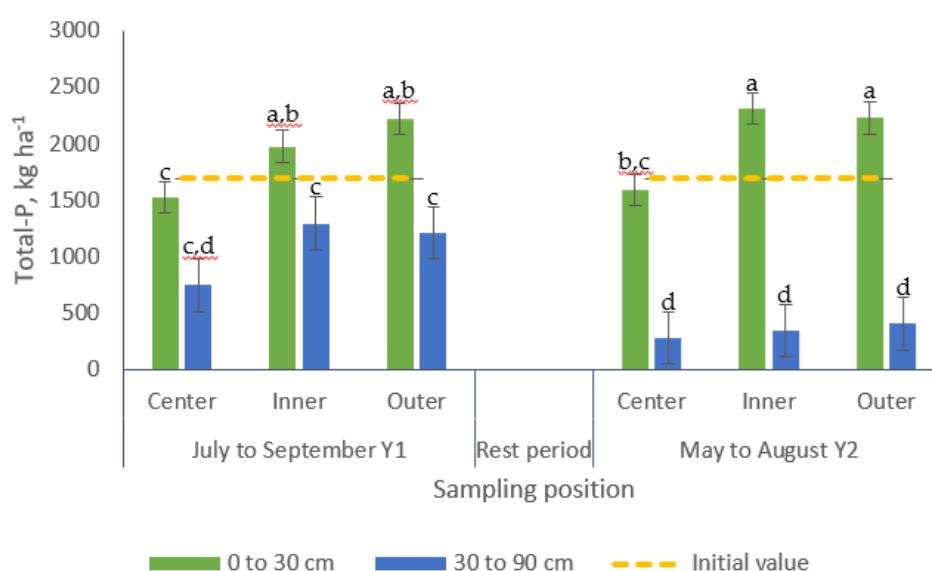
An interaction grazing period x stocking rate x sampling depth was observed for NO₃-N (Table 2). No differences were noted in samples collected following the first grazing period from paddocks managed with different stocking rate at neither soil layers. However, samples collected after the second grazing period depicted differences among samples collected in the 0 to 30 cm soil layer from paddocks managed with a stocking rate of 148 pigs ha⁻¹ compared to samples collected in the 30 to 90 cm soil layer for all the stocking rates under evaluation (Figure 12).



a, b: means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. The Letters display does not reflect all significant comparisons. The following additional pairs are significantly different: (GP2 SR148 SD1, GP2 SR37 SD1; where GP: grazing period, SR: stocking rate, and SD: sampling depth). Data are the means of three replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 12. Effect of the interaction grazing period x stocking rate x sampling depth on soil Total-N (kg ha^{-1}) in bermudagrass paddocks grazed with pigs during two grazing periods.

An interaction grazing period x sampling position x sampling depth was identified for Total-P levels (Table 2). Both grazing periods showed a similar pattern with greater levels of Total-P in the upper soil layer (0 to 30 cm). In this soil strata, greater concentrations of Total-P were found in samples from the inner and the outer positions of the paddocks, which did not differ and averaged 2101 and 2270 kg ha^{-1} for the first and the second grazing period, respectively). Comparatively, samples collected from the center positions presented 1527 and 1591 kg ha^{-1} for the first and the second grazing period, respectively. Conversely the effect of sampling position was not observed on the bottom soil layer (30 to 90 cm) (Figure 13).



a, b, c, d: Means having the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. The Letter display does not reflect all significant comparisons. The following additional pairs are significantly different: (GP1 SP-C SD1, GP1 SP-C SD2), (GP1 SP-I SD2, GP1 SP-C SP2), (GP1 SP-O SD2, GP1 SP-C SD2); where GP: grazing period, SP: Sampling position, SD: sampling depth; C: center, I: Inner, O: Outer. Data are the means of three replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 13. Effect of the interaction grazing period x sampling position x sampling depth in soil Total-P (kg ha^{-1}) in bermudagrass paddocks grazed with pigs during two grazing periods.

4. Discussion

4.1. Ground cover

In pasture pig operations, an appropriate grazing management is necessary to prevent damage to the pasture and, consequently, soil degradation. The amount of ground cover in a certain pasture will be dependent on a variety of factors including the pasture species, climate, soil, pasture management [13], and seasonal variability [14]. The establishment of an adequate stocking rate is a key management component to assure the preservation of ground cover levels required to avoid negative environmental consequences. In 2007, North Carolina USDA Natural Resource Conservancy Service (NRCS) conservationists established that for conservation purposes, outdoor pig operations should retain a ground cover of 75% or more [15]. Maintaining an appropriate

ground cover level offers a wide array of benefits including animal welfare, forage supply, protection against erosion and runoff, and ultimately against soil and water pollution [3, 7]. Greater nutrient losses (N and P) have been associated with bare soil conditions [16,17]. Similarly, Dourmad and Casabianca [18] highlighted the role of ground cover in minimizing ammonia emissions. The importance of the presence of ground cover in pasture pig systems is associated with its role of trapping and recycling the nutrients deposited through manure [19] and avoiding their losses to the system via runoff and leaching [20].

In the present study, a reduction of ground cover and of its indicators was observed over time. A similar declining response had been reported by Bordeaux et al. [21], using a cover of sudangrass (*Sorghum bicolor*) and a mixture of cereal rye (*Secale cereale*) and ryegrass (*Lolium multiflorum*) at a stocking rate equivalent of 74 pigs ha⁻¹. Pigs can have a direct effect on ground cover when they graze, but also an indirect effect due to trampling and rooting activities. Trampling has been associated with higher soil compaction, damaged soil aggregates, decreased water infiltration and increased run-off [22,23]. In the study herein, the 32-week rest period between pig grazing periods allowed the ground cover to recover but did not reach the initial ground cover values, a situation that could be an indicator of damage to the vegetation and(or) to the soil structure. Rooting has been linked to a reduction in ground cover as a consequence of the damage to the aerial and radicular portions of the vegetation [24]. It could be also possible that the first grazing period ended too late (last week of September), and the second grazing period started too early (second week of May), therefore not allowing the bermudagrass to completely develop the structures (roots, rhizomes, shoots, tillers, stolons) needed for regrowth and growth, consequently impairing its spring recover [25].

The results of this study showed differences in ground cover measured during the last experimental week among paddocks managed under different stocking rates (Figure 4). Only paddocks managed with the lowest stocking rate (37 pigs ha⁻¹) maintained the ground cover level recommended by North Carolina NRCS [15]. Similar trends have been observed by Thomsen et al. [4], who reported 31, 57 and 76% ground cover on mixed pastures of *Poa trivialis*, *Dactylis spp.* and *Bromus spp.* for stocking rates equivalent to 100, 42 and 17 pigs ha⁻¹, respectively. Conversely, using growing pigs (20 to 100 kg body weight) managed at a stocking rate equivalent of 100 pigs ha⁻¹, Hermansen et al. [26], reported no survival of ground cover. Investigating the effects of stocking rates (244 vs 86 pigs ha⁻¹) and animal categories (growers: 25 to 40 kg body weight vs finishers: 80 to 105 kg) on *Bromus catharticus* Vahl, Campagna et al. [27], reported significant effects of both factors on the ground cover, with greater ground cover with the lower stocking rate (62 vs 25%, and 65 vs 45%, respectively). Furthermore, more ground cover damage was observed in paddocks managed with growers at the highest stocking rate. Overstocked conditions will lead to the complete destruction of the vegetation cover with the aforementioned environmental effect.

Greater stocking rates will produce more damage to the cover due to trampling [28]. Additionally, the damage caused to the vegetation is exacerbated when grazing is coupled with rooting. Rooting pressure has been indicated as the cause of loss of vegetation, the starting point for erosion and runoff, and a risk factor for ground water pollution [4]. An effect of stocking rate on pigs eating behavior has been reported, with greater frequency of rooting in the low stocking rate treatment (0.57 vs 0.39% for 100 or 200 pigs ha⁻¹, respectively), while more foraging was observed at the high stocking rate (0.17 vs 0.11% for 200 or 100 pigs ha⁻¹, respectively) [29,30]. Accordingly, the strong influence of wild boar rooting in an Argentinian desert ecosystem has been highlighted, resulting in a reduction of the vegetative ground cover and of the species richness [31]. Forage species traits, such as their growth and reproductive habits (erect or prostrate, bunch or sod forming), nutritive value, and palatability, can favor rooting behavior [28, 32] and affect the ability of the forage to survive [33]. Bermudagrass, with its decumbent growth habit and its rhizomatous and stoloniferous reproductive structures has the potential to withstand the foraging behavior of pigs [33]. Greater

deterioration of the vegetation cover as a consequence of rooting and trampling behavior in areas close to the location of the service structures, and along paddock fences, have been reported by previous researchers [34-36]. In addition to the adjustment of the stocking rate, other practices can be implemented to reduce damage to the vegetative cover. These practices include the selection of forage species that can resist rooting and trampling by pigs [3, 37], and avoiding feed restriction [28,37].

4.2. Soil properties.

There is evidence regarding the effect of grazing pigs on different soil physical (soil structure, [23, 33, 36], water infiltration, [33] bulk density, [24,31]) and chemical properties (inorganic N and exchangeable K concentration, [39]; N, P, K, Cu, Zn, [31,40-42]). In addition, the effect of grazing pigs on soil biological properties such as soil respiration, abundance of different functional groups of microorganisms and direct cell counts have been demonstrated [31]. Furthermore, a faster N mineralization rate in wild boar-disturbed patches has also been reported [24,31]. Those patches were linked to physical soil degradation, litter incorporation and increased aeration as a consequence of rooting activity [24, 31].

The effects of pigs on the soil will vary in function of soil moisture, amount of ground cover, soil texture and topography. The damage caused by pigs on sandy soils is mainly a consequence of rooting behavior which disturbs and mixes the soil superficial strata, whereas in heavy soils the damage is caused by trampling action [28]. More damage will be exerted in sloped conditions [43]. Negative effects on the physical traits of soil such as increases in soil bulk density and compaction, a decline in porosity, and reduction in water infiltration will also affect microbiological soil activity by reducing the microbial biomass, and changing the microbial community composition [23, 28], which in turn influences the decomposition of organic matter, and the mineralization of organic N [24].

The stocking rate, which is the number of animals grazing, rooting, trampling and defecating per area per a definite time scale [44], is an important factor in the management of pasture systems, and may have effects on soil organic matter, soil biological activity, nutrient loads, nutrient cycling, water infiltration, runoff and erosion [38, 43, 45]. A greater intensity of management, and consequently a greater stocking rate, has been associated with a greater effect on ground cover and soil properties [5, 36, 43]. Greater pig stocking rates involve the use of more supplemental feed, raising the load of nutrients imported to the system and the threat of losses to the environment [6, 20, 27].

Deterioration of physical soil characteristics, such as increases in soil bulk density, have been related to grazing management intensity and animal trampling behavior [22]. Even though an increment (+9.1%) in soil bulk density was reported in this study after one pig grazing period, no difference was associated with stocking rate. These results differed from those reported by Campagna et al. [27] who found lesser soil bulk density in paddocks that were managed with grower vs finisher pigs at the lesser stocking rate (86 vs 244 pigs ha⁻¹). In the study herein, the soil sand concentration (average 86.9 %), the length of the rest period between successive paddock occupation, and pig rooting activity could have contributed to counteracting the trampling impact, thus preventing bulk density to reach critical values that could compromise vegetation growth.

The difference in bulk density found in samples from the center of the paddocks compared to those from the inner and outer sampling positions could be a consequence of greater rooting activity in this position where the shelter and water structures were located. The overturning and mixing of soil in this area could have neutralized the trampling effect which was more evident in other areas of the paddocks. Similarly, lesser bulk densities have been recorded in soil patches disturbed by

wild boars [31]. These findings, and the existence of a significant sampling position x sampling depth interaction, suggest the existence of a spatial heterogeneity in the horizontal and vertical dimensions of the soil attribute measured in paddocks grazed by pigs.

Other authors have found differences in soil physical characteristics in different sections of paddocks managed with pigs which coincide with the findings of this study. Greater damage to soil structure in the wallow areas followed by the shelter and then the feeding areas has been recorded [38]. Similarly, reductions in medium and narrow pore sizes and increases in wide and fine pore sizes with the impact limited to the 0 to 7 cm soil layer in the proximity of feeders have been reported [35]. Monteverde and Del Pino [46], determined higher soil density in the service areas where the huts were located, than in the grazing areas. Similarly, Bordeaux et al. [21], observed greater compaction on interior subplots of paddocks with permanent shade and drinking structures. Differences among samples collected at different sampling depths, recording greater values with increased depth were also found [46].

Woodland areas with a low density of wild boars supported an increase in soil organic matter concentrations, and an improvement in soil properties as a result of the incorporation of manure and plant residues, and a stimulation of soil oxygenation and microbiological activity [47]. In the present study, lesser soil nutrient concentrations were associated with the lowest stocking rate. The results obtained herein support previous research that have linked greater stocking rates with increments in soil nitrates and phosphorus, and greater N concentrations and N surpluses in soils [27, 33, 39, 46]. Similarly, the adoption of greater stocking rates (40 to 50 pigs ha⁻¹ vs 1 to 2 pigs ha⁻¹) in a hilly area of Tuscany resulted in damage of soil physical and chemical properties, including a decrease in carbon concentrations, lesser chemical parameters linked to organic matter and increased mineralization, and impaired soil fertility and quality [43].

Pig density per unit of area has been identified as one factor that disrupts the excretory behavior of pigs housed indoors [48]. In these systems, a direct relationship between pen size and the size of the area dedicated to defecation has been reported, the latter being larger in larger pens [49]. The size of the paddocks used in the present study (340, 450, 675 vs 1350 m² for 148, 111 and 74 vs 37 pigs ha⁻¹, respectively) could have limited the expression of the excretory behavior linked with the natural behavior of selecting or avoiding certain areas for excretion [50]. As previously reported, pigs prefer dunging areas 5 to 15 m away from their resting areas [40,51] or in the proximity to fences [52]. In the study herein, there were 5 or more meters between the center and the inner sampling point (Figure 1) only in paddocks with the lowest stocking rate (37 pigs ha⁻¹), therefore the urinating or defecating locations could be more a consequence of the paddock design than an expression of the natural behavior of the pigs [53].

The results reported herein validated the influence of the sampling positions on the concentration of soil nutrients and, in consequence, the existence of a spatial pattern in their distribution. Greater concentrations of Total-N, PO₄-P, and Total-P were found in samples from the inner and the outer positions, farther than the shelters and drinking stations, but closer to the feeders and fences (Table 2, Figures 10, 11, and 13). The buildup of these nutrients may be related to greater fecal deposition in these areas compared to the center. Defecating pigs tend to walk a longer distance from the resting and feeding areas than when urinating [54], which could lead to differential nutrient accumulation. Irregular distribution of nutrients in paddocks managed with pigs has been previously reported [21,42,55].

In pasture systems, the distribution of wild-boar sow feces followed a spatial aggregated pattern. A binomial distribution has been used to describe the pattern [56]. Similarly, in paddocks of grass and clover, pigs defecation was conducted 50, 10 and 40%, and urination 41, 27 and 31%, in newly allotted area (50 m² group⁻¹ d⁻¹), the transfer area, and in the service area (including huts, water

structure and wallows (200 m² group⁻¹), respectively; soil nutrients concentrations followed the same pattern as for defecation [57]. Correspondingly, differences in excretory activity performed during day or night hours have been reported for fattening pigs reared in confinement, who exhibited a preference for defecating in corners away from their feeding and lying areas [58].

It has been estimated that pigs deposit manure in 4 to 24% of the total area of the paddock, which would be the preferred area for defecation, thus concentrating 43 to 95% of the nutrients that would be excreted. Furthermore, Phosphorus concentrations in the topsoil of these preferred areas could be as high as 4 times the concentrations registered in other sections of the paddock [40]. A heterogeneous soil spatial distribution of P has been reported for pig paddocks, and has been explained as a consequence of pig excretory behavior, paddock slope and feed input. In addition, more concentration of soil organic-P was found under nearby shade trees [59]). Similar results to those obtained in this study were reported by Bordeaux et al. [21], who indicated that greater concentrations of inorganic N were found in the exterior versus the interior areas of paddocks grazed by growing pigs.

The interaction grazing period x sampling depth showed significance for all soil nutrients under evaluation (Table 2, Figures 6 and 7). Only NH₄⁺-N and PO₄-P presented their greater values in samples collected after the second grazing period and in the bottom soil layer, which may indicate accumulation of these nutrients (Figures 6 (b) and 10 (a)). Perhaps, these nutrients moved from the upper depths to zones below 30 cm, a situation that could represent a water quality environmental risk. Previous research has reported decreases in P concentrations with soil sampling depth [52].

The interaction stocking rate and sampling position resulted significant for NO₃-N. Greater concentrations of this nutrient were found in samples collected in the outer sections (areas contiguous to the fence and where the feeders were located) of paddocks managed with 148 pigs ha⁻¹ in comparison with the NO₃-N concentrations registered in samples collected in paddocks managed with 37 pigs ha⁻¹, indistinctly of the position of collection (Table 2, Figure 8). These findings corroborate the results reported by Bordeaux et al. [21], who indicated that greater concentrations of inorganic N were found in the exterior versus the interior areas of paddocks grazed by growing pigs. Similarly, Monteverde and Del Pino [46], reported greater concentrations of NO₃-N, Available-P, and Electrical Conductivity in soil collected from paddocks managed under the greater stocking rate in areas where feeders and drinking points were located.

Additionally, the results herein point out the existence of an interaction sampling position by sampling depth for bulk density, Total-N, and Total-P soil concentrations (Figures 5, 10, and 11). These findings coincide with the results of Scharifi et al. [42] who suggested that the concentration of soil nutrients in paddocks individually grazed with lactating sows showed a marked spatial (horizontal and vertical) pattern along four areas. According to these authors, the pattern varied among soil nutrients and also among the form of the nutrients, which presented an uneven pattern in both the vertical and horizontal dimensions of the soils. For example, the concentration for P (Olsen) in the 0 to 15 cm soil layer was higher in the feeding area followed by the wallow, then the huts and finally the grazing areas, while in the 15 to 30 cm soil layer the pattern was huts followed by wallows, then feeding areas and last grazing areas.

Pigs tend to concentrate their activities in certain areas of the paddocks such as the vicinity of shelters, shades, feeders, water structures and fences. As a consequence of grazing, rooting and trampling behavior, the survival of the vegetation in these areas may be compromised. Damaged ground cover can result in a reduction of nutrient removal and in an increased potential of runoff and erosion. Higher numbers of animals can increase the eventuality of environmental hazards. To minimize the effects that grazing pigs could have on the environment, best management practices of animals and pastures should be implemented. Adjustment of stocking rates [20, 28, 35, 55, 60],

service infrastructure rotation [20, 21, 35], and adoption of rotational stocking [55, 60] are measures that have proven effective.

5. Conclusions

This study provides insight on the effects of the intensity of use of bermudagrass paddocks by growing-finishing pigs. Greater ground cover and lesser soil nutrient concentrations were found in the paddocks managed with the lesser pig-stocking rates. Additionally, soil properties differed among sampling points and depths, with differences in the spatial pattern followed for each soil traits. The results suggest that a moderate stocking rate would likely be an effective management tool to improve the environmental sustainability of pasture-based pig production systems. Considering conservation goals and the results obtained, stocking rates for growing to finishing pigs should not be higher than 37 pigs ha⁻¹. Further research is needed to examine the long-term effects of pig stocking rates on the productivity and sustainability of pasture-based pig production systems.

Author Contributions: Conceptualization J.T.G.; C.R.; S.P. and M.J.V.; methodology, J.G.; C.R. and S.P.; investigation, J.T.G.; C.R.; S.P. and M.J.V.; resources, J.T.G. and C.R.; data curation, S.P.; writing—original draft preparation, S.P.; writing—review and editing, J.T.G.; C.R.; M.J.V. and S.P.; supervision, J.T.G.; project administration, S.P.; funding acquisition, J.T.G. and C.R. All authors have read and agreed to the published version of the manuscript.

Funding: The project was funded through USDA- NRCS (69-3A75-795) and USDA-SARE grants, and the W.K. Kellogg foundation endowment.

Acknowledgments: The authors would like to thank CEFS field staff for their assistance on this project, and Mrs Marsha McGraw for soil collection and laboratory analysis support. The authors gratefully acknowledge Dr. Jean-Marie Luginbuhl, and the reviewers for their valuable comments and suggestions to improve the quality of this manuscript.

Conflicts of Interest: We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

6. References

1. Franzluebbers, A.J.; Paine, L.K.; Winsten, J.R.; Krome, M.; Sanderson, M.A.; Ogles, K.; and Thompson, D. Well-managed grazing systems: A forgotten hero of conservation. Publications from USDA-ARS /UNL Faculty. 2012. Paper 1460. <http://digitalcommons.unl.edu/usdaarsfacpub/1460>
2. NC CHOICE. NC Statewide Niche Meat Survey. Available online at: <https://cefs.ncsu.edu/resources/nc-statewide-niche-meat-survey-results-by-county-2016/> 2016 (Accessed on Sept 1st 2019)
3. Pietrosemoli, S.; Green, J.T. Pasture systems for pigs. In *Achieving sustainable production of pig meat*. Julian Wiseman ed. Burleigh Dodds: Philadelphia, USA, 2018; Volume 3. Animal health and welfare, pp. 151-202. ISBN-13: 9781786760968 doi:10.19103/as.2017.0013.21
4. Thomsen, L.E.; Mejer, H.; Wendt, S.; Roepstorff, A.; Hindsbo, O. The influence of stocking rate on transmission of helminth parasites in pigs on permanent pasture during two consecutive summers, *Vet. Parasitol.*, **2001**, 99(2), 129-146, [https://doi.org/10.1016/S0304-4017\(01\)00454-X](https://doi.org/10.1016/S0304-4017(01)00454-X).
5. Rachunyo, H.A.; Pond, W.G.; McGlone, J.J. Effects of stocking rate and crude protein intake during gestation on ground cover, soil-nitrate concentration, and sow and litter performance in an outdoor swine production system. *J. Anim. Sci.*, **2002**, 80(6), 1451–61.
6. Sikala, K. Free-range organic pigs foraging Jerusalem artichokes (*Helianthus tuberosus*)- effect of feeding strategy on feed intake, feed conversion, growth, animal behavior, nutrient balances and profitability. MSc. Thesis. 2012. Aarhus University, Department of agroecology. 70 p.
7. Pietrosemoli, S.; Tang, C. Animal Welfare and Production Challenges Associated with Pasture Pig Systems: A Review. *Agriculture*, **2020**, 10(6), 1-34 <https://www.mdpi.com/2077-0472/10/6/223/>

8. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at: <http://websoilsurvey.sc.egov.usda.gov/>. (Accessed on 12 December, 2017).
9. Coulloudon, B.; Eshelman, K.; Gianola, J.; Habich, N.; Hughes, L.; Johnson, C.; Pellant, M.; Podborny, P.; Rasmussen, A.; Robles, B.; Shaver, P.; Spehar, J.; Willoughby, J. Sampling vegetation attributes. Interagency Technical Reference. [pdf] Denver, Colorado. Bureau of Land Management's National Applied Resource Sciences Center BLM/RS/ST-96/002+1730. *Technical Reference 1734-4*. **1999**. 171 pags Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044175.pdf
10. Watson, E.K. Pythagoras, Measurement, and the Geoboard. *Teaching Children Mathematics*, **2007**, 13(7), 369-375 Available online at: <http://www.jstor.com/stable/41198968> (Accessed on 20 August 2020)
11. SAS Institute Inc. SAS/STAT(R) 9.3 User's Guide. J. Copyright © **2017** SAS Institute Inc. https://support.sas.com/documentation/cdl/en/statug/63962/HTML/default/viewer.htm#statug_glimmix_a0000001463.htm
12. State Climate Office of North Carolina, NC State University. CRONOS (internet database) Available online at: <http://climate.ncsu.edu/cronos/>. (Accessed on 17 September, 2019).
13. Lang, D.; McDonald, G.W. Maintaining groundcover to reduce erosion and sustain production, *Agfact*, **2005**, P2.1.14. https://www.dpi.nsw.gov.au/_data/assets/pdf_file/0018/162306/groundcover-for-pastures.pdf (Accessed on 2 October, 2019)
14. Monteiro, E.D.C.; Burak, D.L.; Cunha, A.D.M.; Passos, R.R.; Mendonça, E.D.S. Visual assessment of pasture degradation: validation by ground cover and seasonal variation. *Rev. Ciência Agrônôm.*, **2018**, 49(1), 174-182.
15. NC-NRCS. Conservation planning guidelines for outdoor swine operations. **2007**. [(PDF)] Available online: <https://efotg.sc.egov.usda.gov/references/Delete/2008-7-12/OSOTECHNOTE.pdf> [(Accessed 12 November, 2017)]
16. Butler, D.M.; Franklin, D.H.; Ranells, N.N.; Poore, M.H.; Green J.T. Ground cover impacts on sediment and phosphorus export from manured riparian pasture. *J Environ Qual.* **2006**, 35(6), 2178-2185. DOI: 10.2134/jeq2005.0351
17. Butler D.M.; Ranells N.N.; Franklin D.H.; Poore M.H.; Green J.T. Ground cover impacts on nitrogen export from manured riparian pasture. *J Environ Qual.* **2007**, 36(1), 155-62. DOI: 10.2134/jeq2006.0082
18. Dourmad, J-Y.; Casabianca, F. Effect of husbandry systems on the environmental impact of pig production. *Acta agriculturae Slovenica*, **2013**, Supplement 4, 197-204. Available at: <http://prodinra.inra.fr/record/253477> (Accessed on 10 June, 2020)
19. Rachunonyo, H.A.; McGlone, J.J. Impact of Outdoor Gestating Gilts on Soil Nutrients, Vegetative Cover, Rooting Damage, and Pig Performance, *J. Sustain. Agric.*, **2007**, 29 (3), 69-87, DOI: 10.1300/J064v29n03_07
20. Eriksen, J.; Hermansen, J.E.; Strudsholm, K.; Kristensen, K. Potential loss of nutrients from different rearing strategies for fattening pigs on pasture. *Soil Use Manag.* **2006**, 22, 256-266. DOI: 10.1111/j.1475-2743.2006.00035.
21. Bordeaux, C.; Grossman, J.; White, J.; Osmond, D.; Poore, M.; Pietrosemoli, S. Effects of rotational infrastructure within pasture-raised pig operations on ground cover, soil nutrient distribution, and bulk density. *J. Soil Water Conserv.* **2014**, 69(2), 120-30. doi:10.2489/jswc.69.2.120.
22. Drewry, J.J. Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: A review. *Agric., Ecos. Environ.*, **2006**, 114, 159-169
23. Hiltbrunner, D.; Schulze, S.; Hagedorn, F.; Schmidt, M.W.I.; Zimmermann, S. Cattle trampling alters soil properties and changes soil microbial communities in a Swiss sub-alpine pasture. *Geoderma*, **2012**, 170, 369-377
24. Palacio, S.; Bueno, C.G.; Azorín, J.; Maestro, M.; Gómez-García, D. Wild-boar disturbance increases nutrient and C stores of geophytes in subalpine grasslands. *Am J Bot.*, **2013**, 100(9), 1790-1799. Doi: 10.3732/ajb.1300002.
25. Pande, T.N.; Valentine, I.; Betteridge, K.; Mackay, A.; Horne, D. Pasture damage and regrowth from cattle treading. *Proceedings of the New Zealand Grassland Association*, **2000**, 62: 155-160
26. Hermansen, J.E.; Strudsholm, K.; Horsted, K. Integration of organic animal production into land use with special reference to swine and poultry. *Livest. Produc. Sci.*, **2004**, 90, 11-26.
27. Campagna, D.; Dichio, L.; Ausilio, A.; Bessón, P. A.; Silva, P.; Spinollo, L. Efectos de la carga animal sobre el tapiz vegetal y el recurso suelo en un sistema de producción porcina al aire libre. In: Barlocco, N. and Vadell, A. (eds). Producción de Cerdos a Campo. Aportes para el desarrollo de tecnologías apropiadas para la producción familiar. [pdf] Montevideo, Uruguay. *Universidad de la República. Facultad de Agronomía*. **2011**, 92-101. Available at: <http://www.upc.edu.uy/images/documents/extension/Publicacion%2015%20anos%20UPC.pdf>

28. Pistoia A.; Ferruzzi G. Impatto ambientale da pascolamento suino. In Allevamento animale e riflessi ambientali. Crovetto G.M. y Sandrucci A. (Eds). *Fondazione Iniziative Zooprofilattiche e Zootecniche*. Brescia, Italia. **2010**, 78, 161-174
29. Andresen, N.; Redbo, I. Foraging behaviour of growing pigs on grassland in relation to stocking rate and feed crude protein level. *Applied animal behavior science*. **1999**, 62(2-3), 183–197. [https://doi.org/10.1016/S0168-1591\(98\)00221-4](https://doi.org/10.1016/S0168-1591(98)00221-4)
30. Andresen, N.; Ciszuk, P.; Ohlander, L. Pigs on grassland: animal growth rate, tillage work and effects in the following winter wheat crop. *Biological Agriculture and Horticulture*, **2001**, 18, 327–343
31. Cuevas, M.F.; Mastrantonio, L.; Ojeda, R.A.; Jaksic, F.M. Effects of wild boar disturbance on vegetation and soil properties in the Monte Desert, Argentina. *Mammalian Biology*, **2012**, 77, 299–306
32. Rachuonyo, H.A.; Allen, V.G.; McGlone, J.J. Behavior, preference for, and use of alfalfa, tall fescue, white clover, and buffalograss by pregnant gilts in an outdoor production system. *J. Anim. Sci.*, **2005**, 83(9), 2225–34.
33. Williams, J.R.; Chambers, B.J.; Hartley, A.R.; Ellis, S.; Guise, H.J. Nitrogen losses from outdoor pig farming systems, *Soil Use Manag.*, **2000**, 16, 237-243
34. Salomon, E.; Benfalk, C.; Lindahl, C.; Lindgren, K. Mobile and stationary systems for pigs – Nutrient excretion, distribution on outdoor areas and environmental impact. In *Researching Sustainable Systems. ISOFAR*, **2005**, 254–7.
35. Quintern, M.; Sundrum, A. Ecological risks of outdoor pig fattening in organic farming and strategies for their reduction - results of a field experiment in the centre of Germany. *Agric., Ecos., Environ.*, **2006**, 117(4), 238–50.
36. Acciaioli, A.; Grifoni, F.; Fontana, G.; Esposito, S.; Franci, O. Evaluation of forest damage derived from the rearing of Apulo-Calabrese pig. In: De Pedro, E. J. (ed.), Cabezas, A. B. (ed.). 7th International Symposium on the Mediterranean Pig. [online] Zaragoza: CIHEAM. Options Méditerranéennes: Série A. Séminaires Méditerranéens; **2012**, 101, 133–6. Available at: <http://om.ciheam.org/om/pdf/a101/00006667.pdf> (Accessed 4 May 2020)
37. Rachuonyo, H.A.; Pond, W.G.; McGlone, J.J. Effects of stocking rate and crude protein intake during gestation on ground cover, soil-nitrate concentration, and sow and litter performance in an outdoor swine production system. *J. Anim. Sci.*, **2002**, 80(6), 1451–61.
38. Menzi, H., Stauffer, W., Zihlmann, U., and Weisskopf, P. Environmental impacts of outdoor pig production. In: Martinez, J. and Maudet, M. N. (eds), 8th International Conference on the Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture (RAMIRAN 98). Rennes. FAO ESCORENA. *Editions Quae*, **1998**, 2, 31–9. ISBN: 978-2-85362-531-9.
39. Eriksen J.; Kristensen K. Nutrient excretion by outdoor pigs: a case study of distribution, utilization and potential for environmental impact. *Soil Use and Management*, **2001**, 17, 21-29.
40. Salomon, E.; Hkerhielm, H.; Lindahl, C.; Lindgren, K. Outdoor pig fattening at two Swedish organic farms-Spatial and temporal load of nutrients and potential environmental impact. *Agric., Ecos. Environ.*, **2007**, 121(4), 407–18.
41. Monteverde, S.; Del Pino, A.; Lladó, B. Cerdos a campo e impactos sobre el suelo. In: *Producción de cerdos a campo. Aportes para el desarrollo de tecnologías apropiadas para la producción familiar*. Eds.Barloco, N y Vadell, A. **2011**, 56-61 pp ISBN: 978 9974-563-85-8
42. Sharifi, M.; Messiga, A.J.; Asefpour Vakilian, K.; Stopford, E.; Hutchinson, T.C. Spatial distribution of soil phosphorous fractions following 1-year farrowing sows in an outdoor hog-rearing farm in Eastern Canada. *Environ Monit Assess*, **2020**, 192, 322. <https://doi.org/10.1007/s10661-020-08260-y>
43. Bondi, G.; Peruzzi, E.; Macci, C.; Masciandaro, G.; Pistoia, A. Changes in soil organic matter associated with pig rearing: Influence of stocking densities and land gradient on forest soils in central Italy, *Agric., Ecos. Environ.*, **2015**, 211, 32-42, ISSN 0167-8809, <https://doi.org/10.1016/j.agee.2015.05.003>.
44. Allen, V.G.; Batello, C.; Berretta, E.J.; Hodgson, J.; Kothmann, M.; Li, X.; McIvor, J.; Milne, J.; Morris, C.; Peeters, A.; Sanderson, M. An international terminology for grazing lands and grazing animals. *Grass Forage Sci.*, **2011**, 66, 2–28. doi:10.1111/j.1365- 2494.2010.00780.x
45. Quintern, M. Integration of organic pig production within crop rotation: Implications on nutrient losses In: *Organic Pig Production in Free Range Systems*. Eds Sundrum, A.; Weißmann, F., **2005**, Special Issue 281, 31-34.
46. Monteverde, S.; Del Pino, A. Variabilidad espacial en las propiedades químicas del suelo en un sistema de producción con cerdos en pastoreo. *Ciencias Agronómicas*. **2014**, Revista XXIII,14,37-45
47. Macci, C.; Doni, S.; Bondi, G.; Davini, D.; Masciandaro, G.; Pistoia, A. Effects of wild boar (*Sus scrofa*) grazing on soil properties in Mediterranean environment. *CATENA*, **2012**, 98, 79–86.

48. Banhazi, T. Modelling and influencing hygiene conditions in Australian livestock buildings. In Aland, A. and Banhazi, T. (Eds) *Livestock housing. Modern management to ensure optimal health and welfare of farm animals*. **2013** DOI: <http://dx.doi.org/10.3920/978-90-8686-771-4>. pp. 377–390 (Accessed 17 FEB 2017) https://eprints.usq.edu.au/23880/2/Banhazi_ch19_2013_PV.pdf
49. Yicui, L.; Baoming, L.; Zhengxiang, Z. Effects of size, shape and partition type of pen on excretory behavior of domestic pigs, *Chinese Society of Agricultural Engineering*, **2008**, 11, 206-211
50. Andersen, H.M.-L.; Kongsted, A.G.; Jakobsen, M. Pig elimination behavior—A review. *App. Anim. Beh. Sci.*, **2020**, 222, 104888. <https://doi.org/10.1016/j.applanim.2019.104888>
51. Stolba A.; Wood-Gush, D.G.M., The behaviour of pigs in a semi-natural environment." *Anim. Prod.*, **1989**, 48(2), 419-425.
52. Watson S, C.; Atkins, T.; Bento, S.; Edwards, A.; Edwards, S. Appropriateness of nutrient budgets for environmental risk assessment: a case study of outdoor pig production. *European Journal of Agronomy*, **2003**, 20(1), 117-126.
53. Andersen, H.M.L.; Pedersen, L.J. The effect of feed trough position on choice of defecation area in farrowing pens by loose sows. *App. Anim. Behav. Sci.*, **2011**, 131(1-2), 48-52.
54. Olsson, A.C.; Jeppsson, K.-H.; Botermans, J.; von Wachenfelt, H.; Andersson, M.; Bergsten, C.; Jørgen Svendsen, J. Pen hygiene, N, P and K budgets and calculated nitrogen emission for organic growing–finishing pigs in two different housing systems with and without pasture access. *Lives. sci.*, **2014**, 165, 138–146. <http://doi.org/10.1016/j.livsci.2014.03.025>
55. Ivanova-Peneva, S.; Aarnink, A.; Verstegen, M. Ammonia and Mineral losses on Dutch Organic farms with pregnant sows. *Biosystems Engineering*, **2006**, 93(2), 221-235
56. Ferretti, F.; Storer, K.; Coats, J.; Massei, G. Temporal and spatial patterns of defecation in wild boar. *Wildlife society bulletin*, **2015**, 39(1), 65–69
57. Stern, S.; Andresen, N. Performance, site preferences, foraging and excretory behaviour in relation to feed allowance of growing pigs on pasture, *Livest. Prod. Sci.*, **2003**, 79(2–3), 257-265, [http://dx.doi.org/10.1016/S0301-6226\(02\)00171-9](http://dx.doi.org/10.1016/S0301-6226(02)00171-9)
58. Guo, Y.; Lian, X.; Yan, P. Diurnal rhythms, positions and behavioural sequences associated with eliminative behaviours in fattening pigs. *Appl. Anim. Beh. Sci.*, **2015**, 168, 18–23
59. Horta, C.; Batista, M.; Roque, N.; Almeida, J. Environmental impact of pig production: soil P forms evolution, spatial distribution and P losses in drainage waters. *Revista de Ciencias Agrarias*. **2012**, 35(1), 36–48. ISSN: 0871-018 X
60. Pietroseoli, S.; Green, J.; Villamide, M. Sows-Gilts stocking rates and their environmental impact in rotationally managed Bermudagrass paddocks. *Animals*, **2020**, 10, Doi: 10.3390/ani10061046



20 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Paper IV

Pietrosemoli, S.; Green, J.T.; Villamide Diaz, M.J. **Sows-Gilts Stocking Rates and Their Environmental Impact in Rotationally Managed Bermudagrass Paddocks.** *Animals*. 2020; 10(6):1046.
<https://doi.org/10.3390/ani10061046>

Article

Sows-Gilts Stocking Rates and Their Environmental Impact in Rotationally Managed Bermudagrass Paddocks

Silvana Pietrosemoli ^{1,2,*}, James T. Green, Jr. ³ and Maria Jesús Villamide ²

¹ Department of Animal Science, College of Agriculture and Life Sciences, North Carolina State University, Raleigh, 27695-7621 NC, USA

² Departamento de Producción Agraria, E.T.S.I. Agronómica, Alimentaria y de Biosistemas, Universidad Politécnica de Madrid, Madrid 28040, Spain; mariajesus.villamide@upm.es

³ Department of Crop and Soil Science, College of Agriculture and Life Sciences, North Carolina State University, Raleigh, 27695-7621 NC, USA; jim_green@ncsu.edu

* Correspondence: silvana_pietrosemoli@ncsu.edu; Tel.: +01-919-515-0814

Received: 04 May 2020; Accepted: 12 June 2020; Published: date

Simple Summary: Maintaining a ground cover greater than 75% and controlling nutrient loading and distribution are considered best management practices for pasture pig operations. These practices improve soil health and water quality, by minimizing runoff containing soil, water and nutrients. Those goals are not easily reached when managing pigs on pastures. This study was conducted to evaluate the effect of three sow stocking rates (10, 15 or 25 sows-gilts ha⁻¹) on ground cover and soil nutrient concentrations of bermudagrass (*Cynodon dactylon* L. Pers) paddocks managed in a rotational stocking system. Increasing the Stocking rates were inversely related with the deterioration of vegetative ground cover and directly related to soil nutrient loads in the soil. The stocking rates should be kept in the range of 10 to 15 sows-gilts ha⁻¹ to minimize the environmental impact of sows-gilts managed on bermudagrass.

Abstract: Ground cover maintenance and nutrients management are key elements to reduce the environmental impact of outdoor swine production. The objective of this study was to determine the effects of sows-gilts stocking rates on vegetative ground cover and soil nutrient concentrations in rotationally stocked bermudagrass (*Cynodon dactylon* L. Pers) pastures. Three stocking rates (10, 15 and 25 sows-gilts ha⁻¹) were compared during three 8-week grazing periods. Increasing the stocking rate from 10 to 25 sows-gilts ha⁻¹ decreased the ground cover of the paddocks from 65 to 48%, and increased soil nutrient concentrations (ammonium 47%; nitrate 129%; phosphorus 53%; zinc 84%; and copper 29%).

Keywords: bermudagrass; sows-gilts; stocking rate; ground cover; soil nutrients; pasture-based pig systems; outdoor pig systems; grazing pigs

1. Introduction

Meat consumers have shown an increasing interest in purchasing products from more sustainable production systems that are considered more respectful of the environment and of animal welfare [1,2]. Those systems reduce the use of agrochemicals and fossil fuels, encourage the rescue of local animal genetic resources, and contribute to the strengthening of local communities [3]. This reorientation promotes the creation and consolidation of niche markets. Niche pork production

systems have the capability of including the attributes that more informed consumers are demanding, and to become a more sustainable approach to meat production [4]. Pasture pig systems fit well into productive systems to provision niche markets, as observed with the renowned popularity achieved by “Iberico” products from Spain. This traditional system is found in a unique ecosystem of the Iberian Peninsula called “La Dehesa”. In the Dehesa, pigs of the ‘Iberico’ heritage breed are managed in a silvopastoral system where grasses, acorns, chestnuts and other local resources contribute to the origination of the dry-cured ham [5]. These market trends oriented to products originated in alternative production systems, should be cultivated to strengthen the consolidation of the pasture-based pork supply chain and its related niche markets. A market-driven approach could include labelling [6]. In Europe exist legal certifications that allow the identification of certain attributes in products oriented to specialized niche markets. Certifications such as IGP (Indication of Geographic Protection) and DOP (Protected Designation of Origin) indicate that quality traits of the product are linked to the place of production, processing or preparation, and that specific age-old traditional protocols have been followed [7]. In these niche markets, sustainable practices that integrate elements relevant to the environment, animal welfare, food safety, and economic viability are drivers for innovation.

To improve the productivity and animal welfare in pasture pig systems, it is convenient to organize and manage the herd in functional groups according to their productive stage (breeding, gestation, farrowing, growers and finishers) [8,9]. Pasture use is an ideal option for managing gestating sows because older animals can make better use of nutrients from forages, and it provides opportunity for a wide range of favorable behavioral activities [10]. Additionally, pasture helps alleviate hunger in sows fed a restricted diet at maintenance levels [11]. Pregnant sows grazing *Lolium perenne* and *trifolium repens* pastures, and managed under supplemental feed restriction strategies presented daily forage intake in the range of 3.4 to 8.2 kg fresh forage + 1.5 kg of supplemental feed, and 6.5 to 8.1 + 3.0 kg of supplemental feed per sow, during spring and summer, respectively [12]. Similarly, lactating sows grazing the same grass and clover mixture but receiving feed supplement *ad libitum* showed lower fresh forage intake (0.2 to 1.6 kg sow⁻¹ d⁻¹) [13].

Reduction of environmental impact is one of the major goals of sustainable livestock production and imposes underlying pressure to farmers. Indeed, farmers face the challenge of how simultaneously integrate environmental goals with production system practices oriented to achieve animal welfare, farm profitability and consumers’ health. Key elements of a successful grazing system include identifying how many animals to incorporate and defining the grazing period that will minimize the environmental impact on the resources. Concentrating too many animals could damage the vegetative ground cover leaving the soil vulnerable to the influence of rainfall, wind and temperature [14].

Best management practices are designed to support farmers in the search of more sustainable ways to produce food. But this goal is not easily achieved with grazing pigs which, if left uncontrolled, could express potentially environmental damaging behavior such as selective grazing, rooting and the use of preferred dunging areas [15]. Combined with the physical effect of their hooves, swine natural behavior could deteriorate the ground cover, and increase bare soil, soil compaction, erosion, and run-off, thus negatively impacting surface and ground water and decreasing pasture production and productivity [16,17]. Additionally, the grazing of pigs involves a high import of nutrients into the system through the feed. Grazing animals deposit manure and urine in certain sections of the paddocks, therefore if the amount of nutrients deposited surpasses the vegetation capacity to use these nutrients there is a risk of environmental pollution [17]. The amount of nutrients that leave a pasture system through erosion, runoff and leaching can be reduced by maintaining an appropriate ground cover, a factor directly linked with the stocking rate and length of access. Indeed, lower ground cover [18–20] and higher soil structural damage [17,21,22] have been related to increased stocking rate.

There are many factors to consider when determining suitable stocking rate for swine on pastures (soil, forage type, weather conditions, animal physiological stage, and management skill) [17]. The effects of stocking rates (ranging from 8 to 92 sows ha⁻¹) has been documented [18,19,23–30]. In some European countries, the stocking rates are established based on the projected annual excretion of N (140 kg N ha⁻¹) [30]. To our knowledge, the rotational stocking management system as used in this work has not been previously evaluated in terms of ground cover maintenance or soil nutrient upload. Ground cover maintenance and nutrient management are key elements to reduce the environmental impact of outdoor swine production [31]. Maintaining a ground cover greater than 75% and controlling nutrient loading and distribution are considered as best management practices for pasture pig operations [32]. These best management practices improve soil health and water quality, by minimizing runoff, soil erosion and water pollution. This study was conducted to evaluate the effect of three stocking rates (10, 15 or 25 sows-gilts ha⁻¹) on ground cover and soil nutrient concentrations of bermudagrass (*Cynodon dactylon* L. Pers) paddocks managed in a weekly rotational stocking system.

2. Materials and Methods

2.1. Study Area

The research was conducted at the Center for Environmental Farming System (CEFS) Field Research, Education, and Outreach Facility at Cherry Research farm, in Goldsboro (35.38291° N, – 78.035846° W), North Carolina (USA). The climate is humid subtropical (Trewartha climate classification), with average temperatures between 10.8 and 22.5 °C and yearly precipitation of 1465 mm. The soils of the experimental site had been classified as Johns sandy loam (Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Aquic Hapludults), and Kenansville loamy sand (Loamy, siliceous, subactive, thermic Arenic Hapludults), based on US Soil Taxonomy [33]. The terrain is mostly flat with 0 to 2% slope. The CEFS swine herd is managed in hoop houses using a deep bedding system. The nucleus of the herd is Yorkshire, and has been kept antibiotic-free for almost 40 years, thus requiring that very strict biosecurity measures must be followed. These biosecurity measures restricted the availability of animals during the calendar year, thus constraining the timing of the experiment. The field experiment was conducted over three grazing periods of 8 weeks each during two consecutive years: January to March of year 1; September to November of year 1; and April to June of year 2. A 24-week rest period was implemented between each grazing period.

2.2. Animals

The study was conducted in accordance with the animal use and care guidelines of North Carolina State University Institutional Animal Care and Use Committee (IACUC 09-021-A). A total of 60 pure Yorkshire sows and gilts were allotted to one of the three treatments according to pre-experimental individual live weight to balance live weight across stocking rates. Three different groups of animals varying in initial live weight (294.2 ± 8.4 , 211.9 ± 6.9 and 186.4 ± 3.0 kg for animals used in grazing period 1, 2 and 3, respectively) and parity were used. Live weight was estimated by weighing the sows when they were turned in and out of the paddocks. The change in live weight during the graze periods was equivalent to 1.2 ± 4.36 , 5.58 ± 3.03 and 5.51 ± 2.87 kg for animals included in grazing period 1, 2 and 3, respectively).

Prior to the experimental period, sows-gilts were kept in straw-bedded hoop barns, but were given two weeks of acclimation to a wooded outdoor paddock with an electrical fence. At the beginning of each grazing cycle, animals were arranged in groups of two, three or five corresponding to the treatments. These groups were randomly assigned to the paddocks where they stayed for the 8-week grazing cycle.

During the graze period the animals had free access to shelter and water drinkers located in the center of the paddock (Figure 1). Shelters were built with repurposed metal grain bins open on one end. Sows were offered daily in the morning a home-mixed feed containing corn, soybean, minerals and vitamin mixes. Feed was allocated according to maintenance requirements which averaged 2.0 kg grain mixture head⁻¹ d⁻¹ plus an additional adjustment of 0.41 kg per every 45 kg of live weight over 180 kg. During the first grazing period when the environmental temperature declined to 12.8 °C, animals received an additional 0.20 kg head⁻¹ d⁻¹ per 5.6 °C decline in temperature. Feed was analyzed for chemical composition by the North Carolina Department of Agriculture and Consumer Services - Farm Feed Testing Service laboratory. On average, the grain mix contained 161.1 g kg⁻¹ crude protein; 43.3 g kg⁻¹ crude fat; and 44.5 g kg⁻¹ ash (8.7 g kg⁻¹ Ca; 5.3 g kg⁻¹ P; 2.0 g kg⁻¹ S; 1.7 g kg⁻¹ Mg; 1.8 g kg⁻¹ Na; 8.4 g kg⁻¹ K; 163 g kg⁻¹ Cu; 281 ppm Fe; 51 ppm Mn; and 139 ppm Zn); net energy was calculated as 2436 kcal kg⁻¹ DM. The daily feed was delivered once day⁻¹ onto mats made from rubber used conveyor belts providing space enough to allow simultaneous access to feed (each sow had 1 lineal m of the mat available, Figure 2).



Figure 1. The service areas with the shelter and a water barrel functioning as a drinker were located in the center of the paddocks. A PVC-coated metal slat was placed under the barrel to reduce damage to the soil structure. (January to March, year 1).



Figure 2. Mats from a repurposed rubber conveyor belt were used daily to offer a farm-made grain mixture. (January to March, year 1). The snow is not frequent in the area and only lasted few days.

2.3. Pasture Management

A 1.25-ha pasture established with Coastal bermudagrass was divided into two blocks, which were further divided into three rectangular paddocks each. The paddocks differed slightly in dimensions among the two blocks (59.4 m × 34 m vs. 66.0 m × 30.6 m, for block 1 and 2, respectively), and measured an average 2019.6 m². Each paddock was divided using plastic step-posts and electrified poly-wire fencing into nine equal-sized sections (Figure 3; Figure 4).

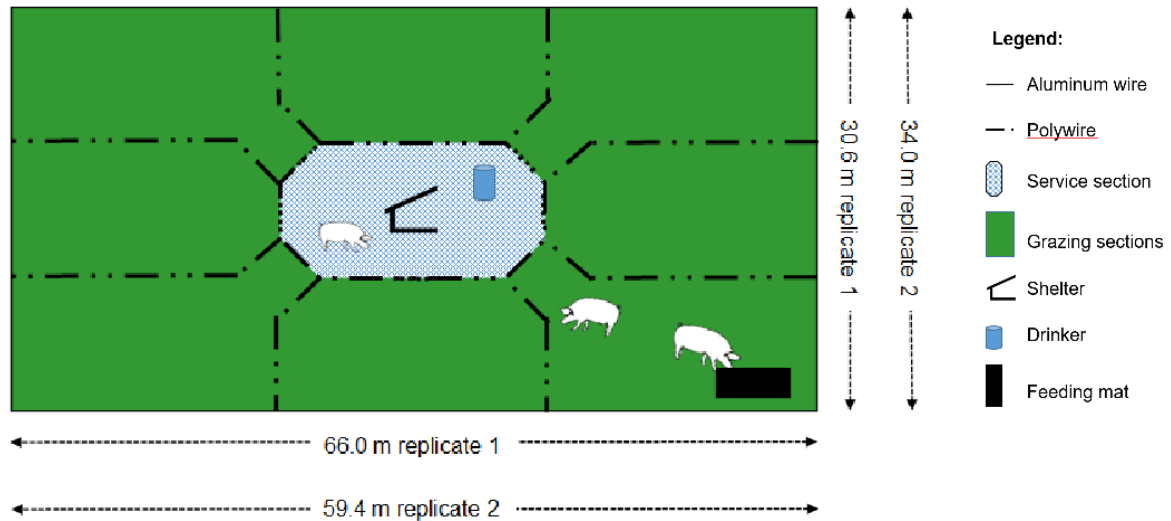


Figure 3. Experimental setup. Paddock dimensions in the field's replicates were slightly different. (Replicate 1: 30.6 m × 66.0 m and Replicate 2: 34.0 m × 59.4 m). The figure is not drawn to scale.



Figure 4. View of one field replicate with three paddocks. The service areas can be identified with the shelters, the barrel-drinkers, and piles of hay. At the far left, four sows in a graze subplot. (January to March, year 1).

The central section (representing 11.1% of the paddock, 224.4 m²) was considered the service section where shelters and water drinkers were located. The other eight sections were managed as graze sections resulting in an eight subplot rotation (Figure 5). Animals had permanent access to the service sections, and simultaneously to one of the grazing sections on a weekly basis. Each of the graze sections was grazed once (7 d of occupation) per grazing period. In the graze section currently in use, the feed was provided over used conveyor belts acting as feeders. The location of these “feeders” changed daily within the respective section. The water was supplied using metal barrels with attached water-cup drinkers. A PVC-coated metal perforated slat (61 cm × 122 cm, 3/8” openings) was placed under each drinker. The stocking density was equivalent to 10, 15 and 25 sows-gilts ha⁻¹ (224.4, 149.6 and 89.8 m² sow-gilt⁻¹ week⁻¹, respectively; Table 1). The paddocks were managed with the same stocking rate treatments during the three grazing periods. Temporary electric fencing was used to control access to the designated sub-section each week. Each of the 8 sub-sections was grazed for 7 days of the 56-day grazed period. Grazing periods were calendar-fixed with a 24-week rest period among consecutive grazing periods. No fertilizer was applied during the course of the experiment.



Figure 5. Gilts in a graze section (September to November, year 1).

Table 1. Stocking rates for sows-gilts grazing bermudagrass for three grazing cycles of eight weeks in an 18-month period.

Grazing Cycle		Stocking Rate, Sows-Gilts ha ⁻¹		
		10	15	25
	m ² head ⁻¹	1000	667	400
1st, Jan to March	Kg Live weight ha ⁻¹	2942	4413	7355
2nd, Sept to Nov	Kg Live weight ha ⁻¹	2119	3179	5298
3rd, Apr to June	Kg Live weight ha ⁻¹	1864	2796	4660

2.4. Ground Cover Estimation

Ground cover estimation was conducted weekly using a modified step point method [34]. The ground cover was differentiated into three components: live vegetation (including grasses, forbs, leaves and stems), dead-dormant vegetation (litter-plant residues, standing dormant and senesced or dead vegetation) and bare soil. To assess ground cover, each paddock was marked with 24 equally spaced transects using pieces of PVC pipes (70 cm long by 1.27 cm diameter). Every other step along the transect represented a sampling point, in each of which the ground cover was characterized and recorded. On average, 28 sampling points were recorded per transect providing 672 points within each treatment paddock. Ground cover was calculated with the following equation: Ground cover = live vegetation + dead-dormant vegetation [34]. Ground cover was determined weekly, but only data corresponding to the last week (8th week) of each grazing period were included in the statistical analysis.

2.5. Soil Samples

Soil samples were collected and assembled before starting the experiment, and following the removal of the animals from the paddocks after the first and third grazing periods. Paddock portions showing evidence of feed waste and manure deposits at the soil surface were excluded in

the sampling process. The initial sampling was conducted using a hand probe (2-cm diameter) to a sampling depth of 30 cm. Five soil cores were taken from each of the nine sections of the paddocks, combined (45 cores) and mixed to form one composite sample per paddock ($n = 6$). One week after the animals were removed at the end of the first grazing period, soil samples were collected using a hand probe to two depths: 0 to 15 and 15 to 30 cm. Each sample was made up of 15 soil cores randomly gathered from each paddock section. Those samples were later combined and mixed per depth to yield a sample corresponding to the service section, and a sample for the graze section (this last one, containing 20 cc subsamples from each of the eight grazing sections). A total of 24 samples were sent to the laboratory. Following the third grazing period (nine days after animal removal) one core soil sample was taken from the center of each of the nine sections of the paddock using a soil coring device (3.2 cm diameter) installed on a truck (Model GSRPS Giddings Machine Company, Windsor, CO). These samples were collected to four sampling depths (0 to 15, 15 to 30, 30 to 60 and 60 to 90 cm) resulting in 216 samples.

Soil samples were air-dried at room temperature, gently crushed, sieved through a 2-mm mesh [35] and sent to the North Carolina Department of Agriculture and Consumer Services Agronomic Division, Soil Testing Section laboratory for standard analysis using Mehlich-3 extraction methodology (Mehlich buffer acidity) for Ca, P, K, Mg, Na, S, Cu, Mn, Zn, and Fe. Samples were also analyzed for ammonium (NH_4^+) and nitrate (NO_3^-) concentrations (1 M KCl soil extracts analyzed on a Quick Chem 8000 LACHAT) [35] at North Carolina State University Environmental and Agricultural Testing Service laboratory. The amount of nutrients imported to the system through animal feed were estimated.

2.6. Experimental Design and Statistical Analysis

A randomized complete block design with a split-split plot arrangement of treatments was used to analyze ground cover data, while soil data were evaluated employing a split plot complete block design with a factorial treatment arrangement. For ground cover, the main plot factor was the grazing period (January to March, year 1, September to November, year 1 and April to June, year 2), stocking rate (10, 15 and 25 sows-gilts ha^{-1}) was the subplot factor and section of the paddock (grazing and service sections) represented the sub-subplot factor. Two independent analyses were conducted for the soil samples collected after the first and the last (third) group of sows. For soil nutrients, stocking rate was considered as the main plot factor and soil sampling depth (0 to 15 and 15 to 30 cm; or 0 to 15; 15 to 30; 30 to 60 and 60 to 90 cm, for the sampling conducted after the first or after the third grazing period, respectively) as the subplot factor. Treatments were randomly assigned to the paddocks and each paddock was considered as the experimental unit. All treatments had two field replicates (blocks).

Statistical data analyses were performed with the software SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) using the PROC GLIMMIX (generalized linear mixed models) [36]. In the models for ground cover, grazing period, stocking rate, section of the paddock and their interactions were treated as fixed effects. Blocks and its interactions with grazing period, stocking rate and section of the paddock were considered random effects. In the models for soil nutrients, block and its interactions with stocking rate and sampling depth were included as random effects and stocking rate, sampling depth and their interaction as fixed effects. Differences were considered significant when $p \leq 0.05$, and $p \leq 0.10$ were noted as a tendency. Mean separation was conducted using least-squares means including the ADJUST and SIMULATE options.

3. Results

The cumulative precipitation and average daily temperature recorded during the experiment are presented in Figure 6. The precipitation was 164.2, 73.5 and 101.70 mm for grazing cycles 1, 2 and 3, respectively. Similarly, the average daily temperature for the same periods were 5.16, 18.2 and 19.9 °C. In addition, the amount of precipitation registered during the first and second rest

periods were 461.80 mm and 468.10 mm, respectively, and the temperature varied from 21.0 to 7.0 °C during those time intervals. Accordingly, the weather conditions during the experimental period did not have a negative impact on bermudagrass growth and survival. Soil disturbance, vegetation damage and leaching of nutrients can be highly related to soil moisture conditions. Only during week eight of the first graze period was the rainfall sufficient to have potentially impacted those parameters.

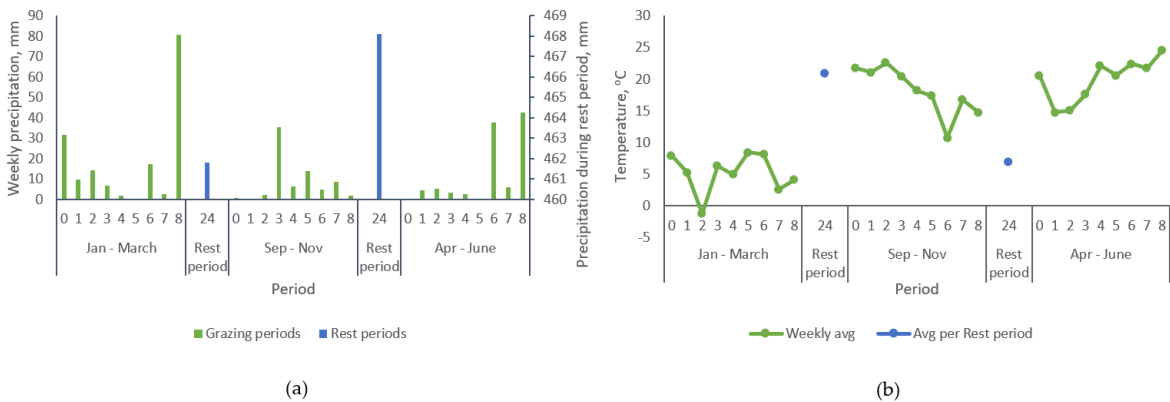


Figure 6. Cumulative precipitation (a) and average temperature (b) registered during the experimental period. Source: CHRONOS database - State Climate Office Of North Carolina [37] and own estimation.

3.1. Ground Cover

This study monitored ground cover changes over time in graze and service areas of the paddocks. Ground cover in the graze sections of the paddocks generally declined weekly throughout each of the grazing cycles, following a similar pattern for all the periods (Figure 7).

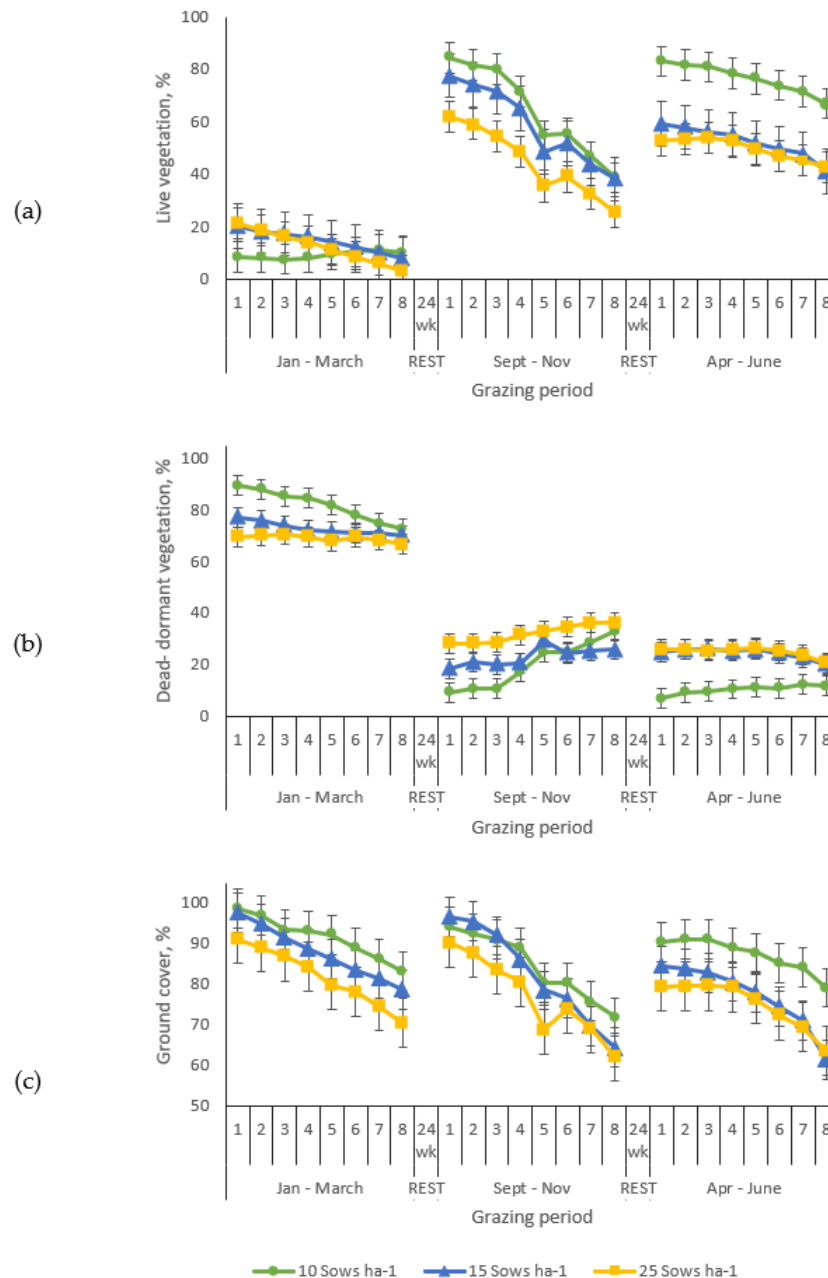


Figure 7. Evolution of the vegetation and the ground cover in the grazing section of bermudagrass paddocks managed with sows-gilts during three grazing periods. (a) Live vegetation, (b) dead-dormant vegetation, (c) ground cover.

During the first two grazing cycles, the ground cover within the graze sections was similar for all stocking rates. However, in the third period, there was less cover in paddocks managed with 15 or 25, compared to those managed with 10 sow ha⁻¹. The mean ground cover values during the experimental period were greater than 65%, even for the paddocks managed with the higher stocking rate. The rest period (168 days) between grazing cycles allowed the ground cover to recover in all the paddocks, reaching 93.8 and 85% at the beginning of the second and third period, respectively.

At the end of each grazing period the ground cover (in both graze and service areas) was affected by the grazing cycle ($p = 0.0011$), the stocking rate ($p = 0.0423$), the paddock section (graze or service) ($p < 0.0001$) and the interaction of grazing cycle $\times$ paddock section ($p = 0.0514$) (Table 2, Figure 8). Ground cover was 72.6% at the end of the first grazed cycle, but only 48.3% at the end of the 2nd and 3rd graze cycles (47.1 and 49.6%, respectively). Paddocks managed with 10 sows-gilts

ha⁻¹ had significantly more (35.4 %) ground cover than paddocks with 25 sows-gilts ha⁻¹ (Table 2). However, there were no significant differences in ground cover between the stocking rates 10 and 15 sows-gilts ha⁻¹ (average 60.7%). The cover was similar also for 15 and 25 sows-gilts ha⁻¹ (average 52.1%). The graze section of the paddocks had 68% more ground cover than the service sections (Table 2) except at the end of the first grazing period, when no differences in ground cover were detected among both sections of the paddocks which averaged 72.8% (Table 2; Figure 8). The interactions grazing cycle x stocking rate, stocking rate x paddock's section, and grazing cycle x stocking rate x paddock's section were found to be not statistically significant ($p > 0.05$).

Table 2. Final vegetative ground cover (%; means and standard error) estimated after animal removal in bermudagrass paddocks managed with sows-gilts during three grazing periods.

Factors	Vegetation (%)		
	Living	Dead-Dormant	Ground Cover
Grazing period			
<i>p</i>	<0.0001	<0.0001	0.0011
Jan to March, year 1	3.7 b	68.9 a	72.6 a
Sept to Nov, year 1	25.3 a	21.8 b	47.1 b
Apr to Jun, year 2	26.4 a	23.2 b	49.6 b
SE	± 3.7	± 8.3	± 11.1
Stocking rate			
<i>p</i>	0.0948	0.4417	0.0427
10 sows ha ⁻¹	23.2	41.8	65.0 a
15 sows ha ⁻¹	18.1	38.2	56.3 a,b
25 sows ha ⁻¹	14.1	33.9	48.0 b
SE	± 3.7	± 8.3	± 11.1
Paddock section			
<i>p</i>	<0.0001	0.4318	<0.0001
Grazing	30.8 a	40.0	70.7 a
Service	6.1 b	36.0	42.1 b
SE	± 3.3	± 7.9	± 10.8

p: Probability, SE: standard error. a,b,c: means in a column followed by a common letter are not significantly different by the *t*-test at the 5% level of significance. Stocking rates expressed as kilograms of live weight ha⁻¹ are equivalents to 2942, 4413 and 7355; 2119, 3179 and 5298; and 1864, 2796 and 4660 kg LW ha⁻¹, for grazing periods 1, 2 and 3, respectively.



Figure 8. Final ground cover (%) estimated after animal removal in grazing and service sections of bermudagrass paddocks managed with sows-gilts during three grazing periods.

3.2. Soil Nutrients

Nutrient concentrations in the soil profile following the first 8-week period were not significantly ($p > 0.05$) affected by stocking rate (Table 3). Nevertheless, concentrations of most soil nutrients were highest ($p < 0.01$) in the upper layer (0–15 cm), with the exceptions of P, NH_4^+ and Na. However, NH_4^+ , B and Na tended to decrease with depth ($p = 0.0843$ and $p = 0.0630$, respectively). Additionally, the interaction of stocking rate x soil sampling depth did not influence ($p > 0.05$) either of the soil nutrients levels.

Significant differences in nutrient concentrations following the third graze period were found among stocking rates for NH_4^+ ($p = 0.0082$), NO_3^- ($p = 0.0177$), P ($p = 0.0002$), K ($p = 0.0544$), Zn ($p = 0.0001$) and Cu ($p = 0.0017$) (Table 4). The lowest soil nutrient levels were found in paddocks grazed with 10 sows-gilts ha^{-1} , with exception of NO_3^- , P, Zn and Cu which were not significantly different between 10 and 15 sows-gilts ha^{-1} . The soil concentrations of K found in paddocks managed with 25 sows-gilts ha^{-1} were not different for those registered in paddocks managed with the other two stocking rates. Soil nutrient concentrations generally declined with depth (NH_4^+ , $p = 0.0002$; P, $p < 0.0001$; K, $p = 0.0013$; Ca, $p < 0.0001$; Mg, $p < 0.0001$; S, $p = 0.0025$; Mn, $p < 0.0001$; Zn, $p < 0.0001$; and Cu, $p < 0.0001$), with a general tendency for higher concentrations in the 0 to 15 cm layer. Conversely, NO_3^- concentrations were similar at all sampling depths. Soil concentrations of Na and Fe were not affected by stocking rate nor sampling depth. The initial soil P level in the upper 30 cm was high (1059 kg ha^{-1}) and similar (1020 kg ha^{-1}) at the end of the experiment. There was not an interaction for stocking rate x sampling depth ($p > 0.05$) following the third graze period.

Table 3. Soil nutrients (mg kg⁻¹) in bermudagrass paddocks following the first eight weeks of grazing with sows-gilts (January to March).

Factors	NH ₄ ⁺	NO ₃ ⁻	P	K	Ca	Mg	S	Mn	Zn	Cu	Na	Fe
(mg kg ⁻¹)												
Initial values	8.5	2.4	470.6	193.7	863.8	182.2	17.8	17.1	9.6	1.0	16.8	1081.2
SE	± 1.1	± 0.5	± 76.6	± 24.9	± 75.4	± 18.9	± 1.1	± 4.6	± 3.2	± 0.2	± 0.8	± 108.9
Stocking rate												
<i>p</i>	0.5845	0.4513	0.6888	0.3215	0.5459	0.3984	0.3218	0.4859	0.3426	0.2753	0.4162	0.2570
10 Sows ha ⁻¹	8.5	3.2	419.4	176.3	779.1	162.0	18.3	15.2	6.5	0.8	20.3	1099.0
15 Sows ha ⁻¹	12.7	5.3	488.3	195.9	888.5	181.8	19.6	18.2	11.6	1.2	25.0	1027.6
25 Sows ha ⁻¹	10.9	5.3	492.4	213.0	851.6	187.5	21.4	18.0	8.2	1.0	25.4	1335.0
SE	± 2.7	± 1.2	± 171.4	± 25.5	± 64.5	± 11.9	± 1.2	± 10.4	± 4.9	± 0.24	± 2.5	± 10.8
Soil depth												
<i>p</i>	0.0843	0.0110	0.6632	<.0001	<.0001	<.0001	0.0050	0.0037	0.0012	0.0025	0.0630	0.0187
0–15 cm	12.8	7.3 a	473.1	238.3 a	976.3 a	212.9 a	21.7 a	19.8 a	11.2 a	1.1 a	25.7	1083.8 b
15–30 cm	8.5	1.9 b	460.4	151.8 b	703.3 b	141.3 b	17.8 b	14.5 b	6.4 b	0.9 b	21.4	1223.9 a
SE	± 2.1	± 1.2	± 164.7	± 24.4	± 40.6	± 8.3	± 0.9	± 10.4	± 4.7	± 0.2	± 1.9	± 67.9
Stocking rate x Soil depth												
<i>p</i>	0.7755	0.5102	0.7760	0.6309	0.5528	0.7962	0.6379	0.7953	0.5683	0.4429	0.5663	0.7556

NH₄⁺: ammonium, NO₃⁻: nitrate, P: Phosphorus, K: potassium, Ca: calcium, Mg: magnesium, S: Sulphur, Mn: manganese, Zn: zinc, Cu: copper, Na: sodium, Fe: Iron. SR: stocking rate, Soil depth: sampling depth. *p*: probability, SE: standard error. Initial values: Composite samples collected in each paddock before grazing with sows, N = 6. a,b,c: means in a column followed by a common letter are not significantly different by the *t*-test at the 5% level of significance. Stocking rates expressed as kilograms of live weight ha⁻¹ are equivalents to 2942, 4413 and 7355 kg LW ha⁻¹.

Table 4. Soil nutrients (mg kg⁻¹, means and standard error) in bermudagrass paddocks following three eight-week periods of grazing with sows-gilts (January to March, year 1; September to November, year 1; April to June, year 2).

Factors	NH ₄ ⁺	NO ₃ ⁻	P	K	Ca	Mg	S	Mn	Zn	Cu	Na	Fe
(mg kg ⁻¹)												
Initial values	8.5	2.4	470.6	193.7	863.8	182.2	17.8	17.1	9.6	1.0	16.8	1081.2
SE	± 1.1	± 0.5	± 76.6	± 24.9	± 75.4	± 18.9	± 1.1	± 4.6	± 3.2	± 0.2	± 0.8	± 108.9
Stocking Rate												
<i>p</i>	0.0082	0.0177	0.0002	0.0544	0.1156	0.6400	0.2184	0.6795	0.0001	0.0017	0.649	0.1167
10 Sows ha ⁻¹	9.0 b	0.7 b	280.6 b	135.9 b	633.0	144.8	14.9	12.6	5.1 b	0.7 b	13.7	1020.3
15 Sows ha ⁻¹	12.1 a	0.8 b	346.1 b	184.0 a	605.6	138.5	18.5	13.6	5.5 b	0.8 b	14.8	1185.2
25 Sows ha ⁻¹	13.2 a	1.6 a	428.9 a	162.9 a,b	677.6	147.7	16.7	13.3	9.4 a	0.9 a	14.2	1163.0
SE	± 1.3	± 0.4	± 172.9	± 23.3	± 51.5	± 29.7	± 2.5	± 9.6	± 3.4	± 0.2	± 1.1	± 58.2
Soil depth												
<i>p</i>	0.0002	0.9014	<0.0001	0.0013	<0.0001	<0.0001	0.0025	<0.0001	<0.0001	<0.0001	0.8271	0.2910
0–15 cm	15.7 a	1.2	443.5 a	204.5 a	939.9 a	194.9 a	16.3 a	18.1 a	12.8 a	1.0 a	13.8	1012.4
15–30 cm	11.8 b	1.0	486.6 a	176.5 a,b	688.0 b	130.1 b	14.2 b	14.5 b	7.4 b	0.8 b	14.0	1129.3
30–60 cm	9.3 b	1.1	315.7 b	150.9 b,c	535.1 c	131.4 b	13.9 b	11.8 b	4.8 b	0.8 b	14.1	1186.5
60–90 cm	9.0 b	1.0	161.6 c	111.8 c	391.9 d	118.2 b	22.2 b	8.3 c	1.8 c	0.6 c	15.0	1163.3
SE	± 1.4	± 0.4	± 173.4	± 24.6	± 53.4	± 30.0	± 2.6	± 9.6	± 3.5	± 0.2	± 1.2	± 67.2
Stocking rate x Soil depth												
<i>p</i>	0.999	0.9911	0.9267	0.9810	0.8897	0.7618	0.8911	0.9792	0.8455	0.8934	0.9976	0.9992

NH₄⁺: ammonium, NO₃⁻: nitrate, P: Phosphorus, K: potassium, Ca: calcium, Mg: magnesium, S: Sulphur, Mn: manganese, Zn: zinc, Cu: copper, Na: sodium, Fe: Iron. SR: stocking rate, Soil depth: sampling depth. *p*: probability, SE: standard error. Initial values: Composite samples collected in each paddock before grazing with sows, N = 6. a,b,c: means in a column followed by a common letter are not significantly different by the *t*-test at the 5% level of significance. Stocking rates expressed as kilograms of live weight ha⁻¹ are equivalents to 2942, 4413 and 7355; 2119, 3179 and 5298; and 1864, 2796 and 4660 kg LW ha⁻¹, for grazing periods 1, 2 and 3, respectively.

3.3. Estimated Excretion of Nutrients into the System

The estimated amount of N and P imported to the system from the feed over the course of the three grazing cycles are presented in Table 5. The estimated N inputs ranged from 113 kg ha⁻¹ (10 sows-gilts ha⁻¹) to 280 kg ha⁻¹ (25 sows-gilts ha⁻¹). Phosphorus input ranged from 23 to 58 kg ha⁻¹ for the 10 to 25 sows-gilts ha⁻¹, respectively.

Table 5. Estimated Total N and Total P (kg ha⁻¹) imported to the system via feed offer.

Stocking rate	Grazing Cycle			
	1st	2nd	3rd	Total
sows-gilts ha ⁻¹	Nitrogen, kg ha ⁻¹			
10	50	33	30	113
15	75	49	45	169
25	124	82	74	280
sows-gilts ha ⁻¹	Phosphorus, kg ha ⁻¹			
10	10	7	6	23
15	15	10	9	34
25	26	17	15	58

4. Discussion

The adoption of the appropriate stocking rate for a pasture system is a critical management decision because it influences animal performance, long-term farm productivity, economic outcomes, wildlife and natural resources. The impact by grazing animals is the result of diverse interrelated compartments including defoliation, treading, trampling, and manure deposition [38]. The implementation of high stocking rates could magnify the undesirable impacts of grazing animals [38]. Previous research has shown the importance of implementing a suitable stocking rate to limit the extent of the damage that grazing pigs could exert to the vegetation and the soil [18,39,40]. The eight-week rotation scheme as evaluated fits in systems where sows-gilts are group-managed in breeding paddocks and moved to gestation paddocks after the second gestation control conducted after the fifth week following mating (38–42d) [41], or in farrowing–lactating paddocks where sows are moved in one week before the farrowing date and removed after weaning [31].

4.1. Ground Cover

Maintaining ground cover in outdoor pig systems is critical to controlling water, soil and nutrient movement off site. In these production systems service areas (feeding, watering, housing) receive the greater impact of the pigs. Therefore, it is necessary to manage the paddock in such a way that those service areas can be buffered by grassed areas to minimize runoff and erosion. The morphological and physiological traits of bermudagrass, a warm season perennial species adapted to different types of soils and climates, that shows aggressive growth, good grazing tolerance, and ability to produce biomass of good quality forage when soil nutrients are not limiting [42], make this grass suitable for this kind of systems. Its growth habit and reproductive mechanisms (rhizomes, stolons, and extensive root mass) allowed it to endure the grazing, rooting, trampling and lounging behaviour of the sows, and to recover

during the rest periods between successive grazings. The final ground cover reported after the three grazing periods (72.6, 47.1 and 49.6% for the first, second and third grazing periods, respectively) demonstrates the potential of bermudagrass inclusion in pasture-based pig systems. The final ground cover, however, was lower than the 75% recommended to minimize runoff and erosion [32,43]. The first period (January to March) coincided with winter months when bermudagrass is dormant. During that season, most of the ground cover consisted of dead-dormant vegetation (69.1%, Figure 7) which was not nutritionally valuable nor palatable, thus limiting sows foraging behavior and their impact on the vegetation. Besides, pigs tend to decrease their activity during the coldest days of winter as a saving-energy strategy [44]. Additionally, the rooting behavior could have been restricted by soil hardness [45–47]. Dormant winter rhizomatous and stoloniferous vegetation (bermudagrass) appears to provide suitable ground cover, even in service areas where animals lounged and drank for eight consecutive weeks. Conversely, the second (September to November) and third (April to June) grazing periods corresponded to fall and spring when the live vegetation accounted on average for 25.8% of the ground cover at the end of each cycle. This fact could have elicited the foraging behavior of the sows attracted by the live vegetation. Softer soil conditions, as a consequence of rainfall, could have made rooting easier [48–50]. Additionally, warmer temperatures could have triggered more rooting for thermoregulation purposes, increasing paddock surface damage [51]. Moreover, it has been noticed that pigs tend to impact already affected areas and enlarge existing bare soil spots. What have been called “grazed patches perpetuating”, showing the lack of random area utilization [52]. Conversely, a greater amount of grass cover during summer than during winter (80 vs. 50%) has been reported in paddocks managed with stocking rate of 32 sows ha⁻¹ indicating the existence of a seasonal pattern [53], and highlighting the effect of local (soil, forage, management) and climatic conditions.

Some authors [54] suggest expressing stocking rates in terms of kg of live weight ha⁻¹ instead of the number of animals ha⁻¹ when analyzing the impacts of grazing animals on the grassland ecosystem. In the current study, the heavier animals were used in the first grazing cycle (38% and 58% heavier than animals in the second and third grazing cycle, respectively), during winter months and showed the greater final ground cover (72.6 vs. 48.3%). In spite of each grazing period corresponded to different season, there was no significant interaction between grazing cycle and stocking rate for ground cover, which decreased from 65.0 to 48.0% for the lowest and the highest stocking rates, respectively. Similar results have been reported for different forages species [18,48,55,56]

In the study herein, differences in ground cover were detected among the sections of the paddocks, with graze areas showing 68% more ground cover than the service sections, which represented 11.1% (1/9) of the paddock area. The lower ground cover of the service sections could represent higher risks for runoff and nutrient leaching. The greater impact on the ground cover observed in the service sections is attributed to the permanent access of sows to this area of the paddocks where drinkers and shelters were located. Conversely, the access to one of the eight graze and feeding sections was sequential, and allocated on a weekly basis determined by the rotation. The grazing sections were occupied only one week during each grazing cycle. It has been previously reported that sows show a tendency to concentrate their activities to the areas adjacent to shelters and huts [39,57]. Estimated weighted averages showed an overall ground cover of 67.5% for the paddocks under evaluation across both sections (service and graze areas) and the three grazing cycles. Similarly, weighted average of final ground cover considering both sections of the paddocks showed that only paddock managed with 10 sows-gilts ha⁻¹ were able to reach the 75% ground cover conservation goal (75.3, 65.8 and 61.6% final ground cover for 10, 15 and 25 sows-gilts ha⁻¹, respectively). To maintain 75% cover on the entire paddock would require an average of 79% ground cover on the 8 graze sections. The rotational system tested in this experiment located the service area in the center of the paddock surrounded by the grazing paddocks, thus minimizing potential runoff that could escape from the service section (Figure 3).

4.2. Soil Nutrient

It could be expected that pastures with a greater number of grazing animals would show an increased probability for manure deposition and in consequence greater soil nutrient loads [58]. The sows grazing in the first grazing cycle (January to March) received a greater allocation of feed. They were bigger than the animals used in the two other grazing cycles, but also were supplied additional feed for thermoregulation to compensate for lower environmental temperatures. However, no differences in nutrient content among soil samples from paddocks managed with different stocking rate was noticed in the soil samples collected after removal of the first group of grazing sows. Differences were only observed among samples collected at different depths showing greater accumulation of nutrients in the upper soil layer, except for NH_4^+ ; P and Na, which did not present differences along the soil profile. Conversely, Fe values were 13% higher in the bottom (15 to 30 cm) layer (Table 3). The paddocks responded similarly to management with different stocking rates and did not show a significant impact of stocking rates on soil nutrients concentrations. The differences in amount of feed and consequently in excretion may have been balanced by bermudagrass uptake [18]. The lack of a more marked effect of stocking rates could also be attributed to the rotational stocking system implemented, which allowed the grass a rest period to recover after one week of grazing, and may have led to better nutrients distribution and utilization [59]. Similarly, it may also be possible that the time lapse between manure deposition during the grazing period and the soil sampling date was not long enough to allow the mineralization of organic matter to take place. As the first grazing period was in winter time, the natural decomposition processes could have been delayed [60]. Similarly, an increase in extractable phosphorus in soils managed with lactating sows for six months it has been reported, P levels kept rising even after animal removal [39].

In contrast, the samples collected in the study herein after the third grazing period differed in soil nutrient concentrations according to stocking rates (Table 4). Paddocks managed with 25 sows-gilts ha^{-1} , showed greater soil concentrations of NH_4^+ ; NO_3^- ; P; Zn and Cu (46.7, 128.6, 52.9, 84.3 and 28.6% more, respectively) than paddocks managed with 10 sows-gilts ha^{-1} . As these nutrients are major components of pig manure, it may be assumed that the variation of these nutrients detected among the paddocks could be reflecting additional manure deposited in the paddocks that were more intensively managed. Paddocks managed with the higher stocking rates received more nutrients to the system via animal feed and mineralization of the soil organic matter [58]. The presence of greater (35%) ground cover in paddocks managed with the lower stocking rate (10 sows-gilts ha^{-1}) could have partially contributed to the reduction in the soil nutrient levels as a consequence of plant uptake [19].

Similarly to the findings of the previous set of samples, the nutrient concentrations varied also according to sampling depth (Table 4) with greater concentrations of NH_4^+ , P, K, Ca, Mg, S, Mn, Zn and Cu in samples collected from the upper soil strata (0 to 15 cm). The amount of P and K did not vary in the first (0 to 15 cm) and second (15 to 30 cm) layers of soil but showed higher values than in deeper soil strata. However the soil P concentrations in the 30 to 60 and 60 to 90 cm layers (315.7 and 161.6 mg kg^{-1} , respectively) are high enough [61] to be considered as evidence of movement through the profile. The relatively low input of P over the course of the three graze cycles resulted in no differences in soil P between the first two layers of soil. While being grazed, the additional organic matter deposited on the soil surface will eventually decay and release its components in the soil profile, circumstance that could increase the concentration of nutrients in the soil upper layer. The differences among nutrients along the soil layers could be indicating what portions of these nutrients may have moved deeper into the soil profile. Irregular dispersion of soil P concentrations in different areas of paddocks managed with pigs have been previously reported, with greater concentrations of P at the deeper soil layers around feeders, huts and wallows [62]. The results obtained herein are in agreement with previous studies where it was indicated an influence of the stocking rates and soil sampling depth on soil nitrate concentrations [20,60,63].

Perennial forages have been included in nutrient management programs to manage soils fertilized with swine manure. In the southeast of the USA, different cultivars of bermudagrass have shown good potential for this purpose. However, differences in the nitrogen use efficiency among cultivars have been found [42]. Previous studies have shown annual uptake values for this species in the range of 314 to 382, and 44 kg ha⁻¹ yr⁻¹ of N and P, respectively. The species has also shown potential for the extraction of Ca, K, Mg, Cu, Fe, Mn, and Zn [64]. Although excessive or prolonged application of manure could cause nutrients accumulation in the soil, with increased environmental risks.

In this study, a simplified N and P balance was conducted, under the assumption that the inputs to the systems were represented by the feed offered to the animals and entering the system by nutrients deposition via sow excreta. Similarly, little nutrients were expected to leave the system because no major changes were observed in animal weight, and there was no removal of bermudagrass biomass from the paddocks. Under these conditions, it could be expected a surplus of N close to the values of the imported N. The estimated N inputs ranged from 113 kg ha⁻¹ to 280 kg ha⁻¹, while P input varied from 23 to 58 kgs ha⁻¹ for the 10 and 25 sows-gilts ha⁻¹, respectively.

Differences in animal breeds, age, weight, physiological stage, health status, diet, forage species and management, soil type, and environmental conditions make it difficult to make comparisons among systems, and these results are found in scientific literature. Recently, in individual paddocks that included trees and were managed with a stocking rate equivalent to 30 or 37 sows ha⁻¹ and seven weeks of occupation, loads of 67 and 78 kg N ha⁻¹ respectively, have been reported [31]. However, in research conducted in Texas, there were no differences found in soil nitrate among the tested stocking rates [40].

Outdoor swine production has been associated with an increased risk of nitrate nitrogen leaching [20], especially in nutrient hot-spot areas [18,25,39,65], and deeper than 60 cm in the soil profile. The nitrate values recorded in soil samples collected after the growing season reveal the net balance of N inputs (feed, manure), plant uptake and losses, and represent the amount of nitrate potentially vulnerable to leaching [66]. In this study, NO₃⁻ levels in the soil profile following the first graze cycle (January to March) (Table 3), were similar for stocking rates, but the concentration in the 0 to 15 cm soil layer was fourfold (7.3 vs. 1.9 mg kg⁻¹) higher than in the 15 to 30 cm layer. The NO₃⁻ concentrations following the first eight weeks of exposure was 93% higher than the initial levels. Bermudagrass was completely dormant during this grazing cycle, therefore nutrient leaching was likely [20,66].

On the contrary, following the third grazing cycle, the paddocks managed with 25 sows-gilts ha⁻¹ contained about 113% more NO₃⁻ than those managed with 10 and 15 sows-gilts ha⁻¹, with no effect of soil depth. The NO₃⁻ concentrations for the 0 to 30 cm soil profile was about 46% of the initial level before sows entered the paddocks. High levels of soil nitrate have been associated with increased N losses [66,67], but the levels of NO₃⁻ herein reported are unlikely to be of concern [67]. The overall relatively low concentrations of NO₃⁻ following the third grazing cycle as compared to the first grazing period could be attributed to differences in the temperature among grazing cycles that increase ammonia volatilization, NO₃⁻ leaching, and forage uptake. In soils similar to those of the experimental area, the bermudagrass has an uptake potential of 22 kg N Mg⁻¹ DM and 2.7 kg P Mg⁻¹ DM [68]. Additionally, the production potential for best management practices on the soils at this site is approximately 11Mg DM ha⁻¹ [68]; however, no crop removal nor animal products were removed from the site, therefore N output from the system as bermudagrass biomass was negligible.

The addition of organic-N or NH₄⁺-N to soils during the nongrowing season presents the risk of leaching into the groundwater [20,66]. In this study, the stocking rate did not affect soil NH₄⁺ after the first grazing cycle. However, following the third graze cycle NH₄⁺ was 40.5% higher in paddocks managed with 15 and 25 sows-gilts ha⁻¹ than in paddocks managed with 10 sows-gilts ha⁻¹, similarly the NH₄⁺ was 56.5% higher in the 0 to 15 cm soil layer than the layers below. The NH₄⁺ concentration in the 0 to 30 cm layer was about 61.8% higher than initial levels. The levels observed after the third graze cycle could indicate a threat of potential loss of nitrogen via nitrification [53] or ammonia volatilization [65]. The

amount of such losses would be related to climatic factors, vegetation, and other management practices [53]. There appeared to be no differences in soil nutrients between grazed and service areas with the exception of NO_3^- that was 148% higher and K that was 29% higher in the service area, indicating that animals may have been depositing more urine there than in the grazed areas.

Reductions of stocking rate and homogenization of the distribution of the manure are best management practices toward reducing the N surplus in sow pasture-based systems [60,63]. Some studies showed a decrease in soil nutrient levels with the increase of distance to the feeding stations [69,70]. Similarly, the service area of paddocks rotationally stocked during 12 years with 3 sows ha^{-1} , exhibited greater bulk density and resistance to penetration, and higher soil concentrations of P, K, and Zn than the areas dedicated to grazing [71,72]. However, contradictory results of the benefits of weekly rotations of shelters, feeders and drinkers on the dispersion of inorganic N in soils has been reported [55]. In the study herein, the feeding mats were located in the currently grazed section of the paddocks, with daily repositioning at feeding time, and shifted to the next grazed section with the animals on a weekly basis, while the shelter and water were permanently located in the central section. The sows were maintained in small areas and recurrent movement of feeders and shelters was performed to create a better distribution of the nutrients in the swine paddocks [39]. It is also important to provide a rest period to the pasture in order to get a regrowth of grass using the nutrients deposited to the soil. Therefore, paddock design and the location of shelters, and feeding and watering points should be taken into consideration for a successful distribution of manure on pasture [31].

A critical issue with the addition of swine manure to soils is the potential risk of increasing the concentration of heavy metals originated from pig feedstuffs and additives [24,69,73]. In the study herein, an increase in the concentrations of zinc and copper in the soil were observed when intensifying the stocking rate from 10 to 25 sows-gilts ha^{-1} ; nonetheless, the values attained remained under the levels for environmental concerns [74].

An additional benefit of the system implemented in this study is the use of a perennial species of forage to minimize nitrate leaching [42,75]. The larger root biomass of perennial forages and their nutrient uptake reduce leachate under the root zone in comparison with annual crops [76].

5. Conclusions

Sustainable pastured pork production systems depend on the implementation of the best management practices, which include (1) applying adequate stocking rates, (2) implementing rotation strategies that match seasonal pasture growth rates, (3) shorter paddock occupation periods, and (4) modifying animal behaviour through the thoughtful placement and movement of feeders in relation to housing and drinking areas.

The rotational system implemented in this study provides insight into management strategies that can be used to intensify the grazing of pasture-based sows and reduce environmental impacts. The combination of perennial forage, higher stocking rates, and short occupation periods lead to maintenance of ground cover and better distribution of nutrients, which could reduce erosion and loss of nutrients. Future research should be geared towards assessing (1) the long-term impact of the proposed stocking rates for sow-gilts or growing pigs and (2) the role of multispecies pastures and feeding strategies in terms of environmental impact.

Author Contributions: Conceptualization, S.P., J.G. and M.J.V.; methodology, S.P. and J.G.; investigation, S.P. and J.G.; resources, J.G.; data curation, S.P.; writing—original draft preparation, S.P.; writing—review and editing, S.P., J.G. and M.J.V.; project administration, S.P.; funding acquisition, J.G. All authors have read and agreed to the published version of the manuscript.

Funding: Financial support for the project was generously provided by: USDA/NRCS-CIG, USDA-SARE and the W.K. Kellogg Foundation.

Acknowledgments: The field technical support of Juan Carlos Guevara and the staff at Cherry Experimental Station is gratefully acknowledged. We are grateful to Sarah Seehaver for assistance with the soil analyses. We also wish to acknowledge Dr Consuelo Arellano for statistical advice. The authors thank three anonymous reviewers for their valuable comments and suggestions that greatly improved previous versions of the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Norwood, F.B.; Lusk, J.L. A calibrated auction-conjoint valuation method: Valuing pork and eggs produced under differing animal welfare conditions. *J. Environ. Econ. Manag.* **2011**, *62*, 80–94.
2. Miranda-de la Lama, G.C.; Estévez-Moreno, L.X.; Sepúlveda, W.S.; Estrada-Chavero, M.C.; Rayas-Amor, A.A.; Villarroel, M.; María, G.A. Mexican consumers' perceptions and attitudes towards farm animal welfare and willingness to pay for welfare friendly meat products, *Meat Sci.* **2017**, *125*, 106–113, doi:10.1016/j.meatsci.2016.12.001.
3. Dumont, B.; Fortun-Lamothe, L.; Jouven, M.; Thomas, M.; Tichit, M. Prospects from agroecology and industrial ecology for animal production in the 21st century. *Animal* **2013**, *7*, 1028–1043, doi: 10.1017/S1751731112002418.
4. Picardy, J.; Pietroseoli, S.; Griffin, T.; Peters, C. Niche pork: Comparing pig performance and understanding producer benefits, barriers and labeling interest. *Renew. Agr. Food Syst.* **2019**, *34*, 42170517000230.
5. Rodríguez-Estévez, V., García, A., Peña, F., & Gómez, A.L. Foraging of Iberian fattening pigs grazing natural pasture in the dehesa. *Livest. Sci.* **2009**, *120*, 135–143, doi:10.1016/j.livsci.2008.05.006. ISSN 1871-1413.
6. Sørensen, J.T.; Schrader, L. Labelling as a Tool for Improving Animal Welfare — The Pig Case. *Agriculture* **2019**, *9*, 123 doi: 10.3390/agriculture9060123.
7. Belletti, G.; Burgassi, T.; Marescotti, A. Il ruolo delle denominazioni geografiche per la sostenibilità delle filiere zootecniche di qualità. *Agriregionieuropa* **2008**, *4*. Available online: <https://agriregionieuropa.univpm.it/en/content/article/31/13/il-ruolo-delle-denominazioni-geografiche-la-sostenibilita-delle-filiere> (accessed on 12 May 2020).
8. Thornton, K. *Outdoor Pig Production; Farming Press Books and Videos (1708)*: Ipswich, UK, 1998; 224p. ISBN-13:9780852361788.
9. Miao, Z.H.; Glatz, P.C.; Ru, Y.J. Review of Production, Husbandry and Sustainability of Free-range Pig Production Systems, *Asian-Australas. J. Anim. Sci.* **2004**, *17*, 1615–1634.
10. Jørgensen, H.; Serena, A.; Hedemann, M.S.; Bach-Knudsen, K.E. The fermentative capacity of growing pigs and adult sows fed diets with contrasting type and level of dietary fibre. *Livest. Sci.* **2007**, *109*, 111–114.
11. D'Eath, R.B.; Jarvis, S.; Baxter, E.M.; Houdijk, J. Mitigating hunger in pregnant sows, In *Herd and Flock Welfare, Advances in Pig Welfare*; Špinko, M., Ed.; Woodhead Publishing: Cambridge, UK, 2018; pp. 199–234, doi:10.1016/B978-0-08-101012-9.00007-1.
12. Rivera-Ferre, M.G.; Edwards, S.A.; Mayes, R.W.; Riddoch, I.; Hovell, F.D.D. The effect of season and level of concentrate on the voluntary intake and digestibility of herbage by outdoor sows. *Animal Sci.* **2001**, *72*, 501–510.
13. Jurjan, S.; Roinsard, A. Ingestion d'herbe et de sol par des truies au pâturage. *Alter Agric.* **2014**, *125*, 27–28.
14. Bear, D.A.; Russell, J.R.; Tufekcioglu, M.; Isenhardt, T.M.; Morrical, D.G.; Kovar, J.L. Stocking Rate and Riparian Vegetation Effects on Physical Characteristics of Riparian Zones of Midwestern Pastures. *Rangeland Ecol. Manag.* **2012**, *65*, 119–128, doi:10.2111/REM-D-11-00133.1.
15. Laister, S.; Konrad, S. Behaviour, performance and carcass quality of three genotypes of growing-finishing pigs in outdoor pig production in Austria: A pilot study. In Sundrum, A., Weißmann, F., Eds, *Organic Pig Production in Free Range Systems*; Bundesforschungsanstalt für Landwirtschaft (FAL): Braunschweig, Germany, **2005**; 13–18 (281), ISBN 3-86576-005-8.
16. Quintern, M.; Sundrum, A. Ecological risks of outdoor pig fattening in organic farming and strategies for their reduction - results of a field experiment in the centre of Germany. *Agric., Ecosyst. Environ.* **2006**, *117*, 238–250.

17. Pietrosevoli, S.; Green, J.T. Pasture systems for pigs. In *Achieving Sustainable Production of Pig Meat*; Wiseman, J., Ed.; Burleigh Dodds: Sawston, UK, **2018**; Volume 3: Animal Health and Welfare; pp. 151-202. doi:10.19103/as.2017.0013.21.
18. Eriksen, J.; Studnitz, M.; Strudsholm, K.; Kongsted, A.G.; Hermansen, J.E. Effect of nose ringing and stocking rate of pregnant and lactating outdoor sows on exploratory behaviour, grass cover and nutrient loss potential. *Livest. Sci.* **2006**, *104*, 91–102, doi:10.1016/j.livsci.2006.03.008. ISSN 1871-1413.
19. Rachuonyo, H.A.; Pond, W.G.; McGlone, J.J. Effects of stocking rate and crude protein intake during gestation on ground cover, soil-nitrate concentration, and sow and litter performance in an outdoor swine production system. *J. Anim. Sci.* **2002**, *80*, 1451–1461.
20. Jørgensen, U.; Thuesen, J.; Eriksen, J.; Horsted, K.; Hermansen, J.E.; Kristensen, K.; Kongsted, A.G.; Nitrogen distribution as affected by stocking density in a combined production system of energy crops and free range pigs. *Agrofor. Syst.* **2018**, *92*, 987–999, doi: 10.1007/s10457-018-0200-3.
21. Bilotta, G.S.; Brazier, R.E.; Haygarth, P.M. The impacts of grazing animals on the quality of soils, vegetation, and surface waters in intensively managed grasslands. *Adv. Agron.* **2007**, *94*, 237–280, doi: 10.1016/S0065-2113(06)94006-1.
22. Palacio, S.; Bueno, C.G.; Azorín, J.; Maestro, M.; Gómez-García, D. Wild-boar disturbance increases nutrient and C stores of geophytes in subalpine grasslands. *Am. J. Bot.* **2013**, *100*, 1790–1799, doi:10.3732/ajb.1300002.
23. Ogel, S. Amenagement des parcs en élevage de truies plein air. In: *Resultats de Recherche en Production Porcine*; Chambre Regionale D'agriculture: Rennes, France, **1997**; pp. 3–5.
24. Menzi, H.; Stauffer, W.; Zihlmann, U.; Weisskopf, P. Environmental impacts of outdoor pig production. In *Proceedings of the 8th International Conference on the Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture* (RAMIRAN 98), Rennes, France, 8–12 September 1998; Martinez, J., Maudet, M.N., Eds.; FAO ESCORENA Editions Quae: Paris, France, **1999**; Volume 2, pp. 31–39, ISBN: 978-2-85362-531-9.
25. Williams, J.R.; Chambers, B.J.; Hartley, A.R.; Ellies, S., Guse, H.S. Nitrogen losses from outdoor pig farming systems. *Soil Use Manag.* **2000**, *16*, 237–243.
26. Honeyman, M.S.; McGlone, J.J.; Kliebstein, J.B.; Larson, B.E. Outdoor pig production. In *Pork Industry Handbook*; PIH-145; Purdue University: West Lafayette, IN, USA, **2001**; p. 9.
27. Gustafson, G.M.; Svensson, L. Ammonia emissions from pigs on deep litter beds and in a strip grazing system. *J. Sustain. Agric.* **2003**, *23*, 41–51, doi: 10.1300/j064v23n02_05.
28. Ciompi, S. *Effetti dell'allevamento al Pascolo Boschivo del Suino Sulla Qualita' dei Prodotti Carnei Trasformati*; Agricoltura Biologica e Multifunzionale; Secon-level degree thesis, Università di Pisa: Pisa, Italy, **2008**; 136p. Tesi etd-04182008-120852.
29. Wheaton, H.N.; Rea, J.C. Forages for swine. Extension University of Missouri. **2018**. Available online: <https://extension2.missouri.edu/g2360> (accessed on 7 January 2020).
30. Kongsted, A.G.; Hermansen, J.E. Organic pig production—with particular reference to Danish production conditions. **2005**. Available online: <https://orgprints.org/6457/1/6457.pdf>. (accessed on 18 May 2020).
31. Jakobsen, M.; Hermansen, J.E.; Andersen, H.M.-L.; Jørgensen, U.; Labouriau, R.; Rasmussen, J.; Kongsted, A.G. Elimination behavior and soil mineral nitrogen load in an organic system with lactating sows—Comparing pasture-based systems with and without access to poplar (*Populus* sp.) trees. *Agroecol. Sust. Food* **2018**, doi:10.1080/21683565.2018.1541039.
32. NC-NRCS. Conservation planning guidelines for outdoor swine operations. **2007**. Available online: <https://efotg.sc.egov.usda.gov/references/Delete/2008-7-12/OSOTECHNOTE.pdf> (accessed 25 January 2020).
33. Soil Survey Staff. *Keys to Soil Taxonomy*, 12th ed.; USDA-Natural Resources Conservation Service: Washington, DC, USA, **2014**; 372p. Available online: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/?cid=nrcs142p2_053580 (accessed on 20 May 2020).
34. Coulloudon, B.; Eshelman, K.; Gianola, J.; Habich, N.; Hughes, L.; Johnson, C.; Pellant, M.; Podborny, P.; Rasmussen, A.; Robles, B.; et al. *Sampling Vegetation Attributes*; Interagency Technical Reference; Bureau of Land Management's National Applied Resource Sciences Center: Denver, CO, USA, **1999**. BLM/RS/ST-96/002+1730.

35. Drinkwater, L.E.; Cambardella, C.A.; Reeder, J.D.; Rice, C.W. Potentially Mineralizable Nitrogen as an Indicator of Biologically Active Soil Nitrogen. In *Methods for Assessing Soil Quality*; Doran, J.W.; Jones, A.J., Eds.; Soil Science Society of America, Inc: Madison, WI, USA, **2015**, doi:10.2136/sssaspecpub49.c13.
36. SAS Institute Inc. *SAS/STAT(R) 9.4 User's Guide*; Copyright © 2020; SAS Institute: Cary, NC, USA, **2018**. Available online: <http://support.sas.com/documentation/94/index.html> (accessed on 11 November 2019).
37. State Climate Office of North Carolina, NC State University. CRONOS (internet database) Available online: <http://climate.ncsu.edu/cronos/>. (accessed on 17 September 2019).
38. Sales-Baptista, E.; d'Abreu, M.C.; Ferraz-de-Oliveira, M.I. Overgrazing in the Montado? The need for monitoring grazing pressure at paddock scale. *Agrofor. Syst.* **2016**, *90*, 57, doi: 10.1007/s10457-014-9785-3.
39. Eriksen, J.; Kristensen, K. Nutrient excretion by outdoor pigs: A case study of distribution, utilization and potential for environmental impact. *Soil Use Manage.* **2001**, *17*, 21–29, doi: 10.1079/SUM 200051.
40. Rachuonyo, A.H.; McGlone, J. Impact of Outdoor Gestating Gilts on Soil Nutrients, Vegetative Cover, Rooting Damage, and Pig Performance. *J. Sustain. Agr.* **2006**, *29*, 69–87. 10.1300/J064v29n03_07.
41. Quiles, A.; Hevia, M.L. Manejo y alimentación de las cerdas gestantes alojadas en grupo. *Produc. Anim.* **2010**, *26*, 6–15.
42. Schneider-Canny, R.; Chekhovskiy, K.; Muñoz, P.; Kwon, S.; Saha, M.C. Characterization of bermudagrass (*Cynodon dactylon* L.) germplasm for nitrogen use efficiency. *Euphytica* **2019**, *215*, 40, doi: 10.1007/s10681-019-2347-z.
43. Lang, R.D. The effect of ground cover on surface runoff from experimental plots (soil erosion). *J. Soil Conserv. Serv. New South Wales*, **1979**. ISSN: 0028-6818.
44. Singer, F.J.; Otto, D.K.; Tipton, A.R.; Hable, C.P. Home ranges, movements, and habitat use of European wild boar in Tennessee. *J. Wildl. Manag.* **1981**, *45*, 343–53.
45. Elledge, A.E.; McAlpine, C.A.; Murray, P.J.; Gordon, I.J. Modelling habitat preferences of feral pigs for rooting in lowland rainforest. *Biol. Invasions* **2013**, *15*, 7, 1523–1535, doi: 10.1007/s10530-012-0387-6.
46. Parrini, S.; Acciaioli, A.; Franci, O.; Pugliese, C.; Bozzi, R. Grazing behaviour of Cinta senese and its crossbreed pigs. *Ital. J. Anim. Sci.* **2019**, *18*, 287–291, doi:10.1080/1828051X.2018.1508376.
47. Sandom, C.J.; Hughes, J.; Macdonald, D.W. Rewilding the Scottish Highlands: Do Wild Boar, *Sus scrofa*, Use a Suitable Foraging Strategy to be Effective Ecosystem Engineers? *Restor. Ecol.* **2013**, *21*, 336–343.
48. Andresen, N.; Redbo, I. Foraging behaviour of growing pigs on grassland in relation to stocking rate and feed crude protein level. *Appl. Anim. Behav. Sci.* **1999**, *62*, 183–197, doi: 10.1016/S0168-1591(98)00221-4.
49. Thomsen, L.E.; Mejer, H.; Wendt, S.; Roepstorff, A.; Hindsbo, O. The influence of stocking rate on transmission of helminth parasites in pigs on permanent pasture during two consecutive summers. *Vet. Parasitol.* **2001**, *99*, 129–146, doi: 10.1016/S0304-4017(01)00454-X.
50. Henney, J. *An Evaluation of the Use of Pigs as a Method of Bracken Control*; MSc. Grazing Animals Project Heritage Grazing Traineeship; Rare Breeds Survival Trust: Warwickshire, UK, **2012**; 40p. Available online: http://www.grazinganimalsproject.org.uk/habitat_land_management.html?publication=1; (accessed on 11 November 2019).
51. Olczak, K.; Nowicki, J.; Klocek, C. Pig behaviour in relation to weather conditions—A review. *Ann. Anim. Sci.* **2015**, *15*, 601–610, doi: 10.1515/aoas-2015-0024.
52. Barnes, M.K.; Norton, B.E.; Maeno, M.; Malecheck, J.C. Paddock size and stocking density affect spatial heterogeneity of grazing. *Rangeland Ecol. Manag.* **2008**, *61*, 380–388.
53. Petersen, S.O.; Kristensen, K.; Eriksen, J. Denitrification Losses from Outdoor Piglet Production: Spatial and Temporal Variability. *J. Environ. Qual.* **2001**, *30*, 1051–1058, doi:10.2134/jeq2001.3031051x.
54. Metera, E.; Sakowski, T.; Sloniewski, S.K.; Romanowicz, B. Grazing as a tool to maintain biodiversity of grassland—A review. *Anim Sci Pap Rep* **2010**, *28*, 315–334.
55. Bordeaux, C.; Grossman, J.; White, J.; Osmond, D.; Poore, M.; Pietroseoli, S. Effects of rotational infrastructure within pasture-raised pig operations on ground cover, soil nutrient distribution, and bulk density. *J. Soil Water Conserv.* **2014**, *69*, 120–130, doi:10.2489/jswc.69.2.120.

56. MAFF. Ministry of Agriculture, Fisheries and Food. *Grass Cover Management on Outdoor Sow Units*; Final Project Report; DEFRA Research Project SP0507; MAFF: London, UK, 2000. Available online: http://randd.defra.gov.uk/Document.aspx?Document=SP0507_426_FRP.doc. (accessed on 14 December 2019).
57. Braund, J.P.; Edwards, S.A.; Riddoch, I.; Buchner, L.J. Modification of foraging behaviour and pasture damage by dietary manipulation in outdoor sows. *Appl. Anim. Behav. Sci.* **1998**, *56*, 173–186.
58. Webb, J.; Broomfield, M.; Jones, S.; Donovan, B. Ammonia and odour emissions from UK pig farms and nitrogen leaching from outdoor pig production: A review. *Sci. Total Environ.* **2014**, *470*, 865–875.
59. Dubeaux, J.C.B.; Sollenberger, L.E. Nutrient cycling in grazed pastures. In *Management Strategies for Sustainable Cattle Production in Southern Pastures*; Rouquette, M., Aiken, G.E., Eds. Academic Press: Cambridge, MA, USA, 2020; pp. 59–76. ISBN: 978-0-12-814474-9.
60. Eriksen, J. Implications of grazing by sows for nitrate leaching from grassland and the succeeding cereal crop. *Grass Forage Sci.* **2001**, *56*, 317–322, doi:10.1046/j.1365-2494.2001.00279.x.
61. Hardy, D.H.; Tucker, M.R.; Stokes, C.E. *Crop Fertilization Based on North Carolina Soil Tests*; N.C. Department of Agriculture and Consumer Services Agronomic Division Circular No. 1; Department of Agriculture and Consumer Services Agronomic Division: Raleigh, NC, USA, 2014. 111p. Available online: www.ncagr.gov/agronomi/pdffiles/oobook.pdf (accessed on 15 May 2020).
62. Sharifi, M.; Messiga, A.J.; Stopford, E.; Hutchinson, T.C. *Spatial Distribution of Soil N and P Forms Following One-Year Farrowing Sows on an Outdoor Hog-Rearing Farm in Eastern Ontario*; Technical report; NSERC Engage; Trent University: Peterborough, ON, Canada, 2014, doi:10.13140/2.1.3468.1122.
63. Eriksen, J.; Petersen, S.O.; Sommer, S.G. The fate of nitrogen in outdoor pig production. *Agronomie* **2002**, *22*, 863–867, doi: 10.1051/agro: 2002045.
64. McLaughlin, M.R.; Fairbrother, T.E.; Rowe, D.E. Nutrient Uptake by Warm-Season Perennial Grasses in a Swine Effluent Spray Field. *Agron. J.* **2004**, *96*, 484–493, doi:10.2134/agronj2004.0484.
65. Sommer, S.G.; Søgaard, H.T.; Møller, H.B.; Morsing, S. Ammonia volatilization from sows on grassland, *Atmosp. Environ.* **2001**, *35*, 2023–2032, doi: 10.1016/S1352-2310(00)00428-3.
66. Redding, M. *Manure and Groundwater Quality. Literature Review*; Washington State Department of Ecology, Environmental Assessment Program: Seattle, WA, USA, 2016. Available online: <https://fortress.wa.gov/ecy/publications/SummaryPages/1603026.html> (accessed on 15 May 2020). Publication No. 16-03-026.
67. *Biosolids Management Guidelines for Washington State. Solid Waste and Financial Assistance Program*; Washington State Department of Ecology: Seattle, WA, USA, 2000. Available online: <https://fortress.wa.gov/ecy/publications/SummaryPages/9380.html> (accessed on 16 May 2020). Publication No. 93-80.
68. North Carolina Interagency Nutrient Management Committee. *Realistic Yields and Nitrogen Application Factors for North Carolina Crops*; North Carolina State University; North Carolina Department of Agriculture and Consumer Services; North Carolina Department of Environment and Natural Resources; Natural Resources Conservation Service: Raleigh, NC, USA, 2014. Available online: <https://realisticyields.ces.ncsu.edu/> (accessed on 3 June 2020).
69. Salomon, E.; Hkerhielm, H.; Lindahl, C.; Lindgren, K. Outdoor pig fattening at two Swedish organic farms-Spatial and temporal load of nutrients and potential environmental impact. *Agric. Ecosys. Environ.* **2007**, *121*, 407–418.
70. Watson, C.; Atkins, T.; Bento, S.; Edwards, A.; Edwards, S. Appropriateness of nutrient budgets for environmental risk assessment: A case study of outdoor pig production. *Eur. J. Agron.* **2003**, *20*, 117–126.
71. Monteverde, S.; Del Pino, A.; Piaggio, J.; Naya, H. Impactos físicos en el suelo por cerdos a pastoreo. In *Proceedings of the VII Jornadas Técnicas Veterinarias. Facultad de Veterinaria*; Universidad de la República: Montevideo, Uruguay, 2011; p. 190 Available online: https://www.academia.edu/1184687/IMPACTOS_FISICOS_EN_EL_SUELO_POR_CERDOS_EN_PASTOREO (accessed on 14 December 2019).
72. Monteverde, S.; Del Pino, A.; Piaggio, J.; Naya, H. Metales pesados en la producción de cerdos a campo. In *Proceedings of the VII Jornadas Técnicas Veterinarias. Facultad de Veterinaria*; Universidad de la República: Montevideo, Uruguay, 2011; p. 191. Available online: <http://smonteverde.blogspot.com/2011/11/metales-pesados-en-la-produccion-de.html> (accessed on 14 December 2019).

73. Formentini, T.A.; Kochem Mallmann, F.J.; Pinheiro, A.; Scapulatempo Fernandes, C.V.; Bender, M.A.; da Veiga, M.; Rheinheimer dos Santos, D.; Doelsch, E. Copper and zinc accumulation and fractionation in a clayey Hapludox soil subject to long-term pig slurry application. *Sci. Total Environ.* **2015**, *536*, 831–839, doi:10.1016/j.scitotenv.2015.07.110. ISSN 0048-9697.
74. Hardy, D.H.; Myers, J.; Stokes, C. *Heavy Metals in North Carolina Soils. Occurrence & Significance*; Department of Agriculture and Consumer Services Agronomic Division: Raleigh, NC, USA, **2008**. Available online: <http://digital.ncdcr.gov/u?/p249901coll22,63754> (accessed on 28 December 2019).
75. Karimi, R.; Akinremi, W.; Flaten, D. Cropping system and type of pig manure affect nitrate-nitrogen leaching in a sandy loam soil. *J. Environ. Qual.* **2017**, *46*, 785–792, doi:10.2134/jeq2017.04.0158.
76. Lasisi, A.A.; Akinremi, O.O.; Tenua, M.; Cattani, D. Below-ground plant biomass and nitrogen uptake of perennial forage grasses and annual crops fertilized with pig manures. *Agric. Ecosyst. Environ.* **2018**, *268*, 1–7, doi:10.1016/j.agee.2018.08.006. ISSN 0167-8809.



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Paper V

Pietrosevoli, S.; Green, J.T.; Villamide Diaz, M.J. **2020, A comparison of stocking methods for pasture-based pig production systems.** *Animals*, 2020, 1010 (10):1885. <https://doi.org/10.3390/ani10101885>

A comparison of stocking methods for pasture-based pig production systems

Silvana Pietrosemoli ^{1,2,*}, James T. Green Jr., ³ and Maria Jesús Villamide ²

¹ Department of Animal Science, College of Agriculture and Life Sciences, North Carolina State University, Raleigh, 27695-7621 NC, USA; silvana_pietrosemoli@ncsu.edu

² Departamento de Producción Agraria, E.T.S.I. Agronómica, Alimentaria y de Biosistemas, Universidad Politécnica de Madrid, Madrid 28040, Spain; mariajesus.villamide@upm.es

³ Department of Crop and Soil Sciences, College of Agriculture and Life Sciences, North Carolina State University, Raleigh, 27695-7620 NC, USA; jim_green@ncsu.edu

* Correspondence: silvana_pietrosemoli@ncsu.edu; Tel.: +01-919-515-0814

Received: date; Accepted: date; Published: date

Simple Summary: A sustainable pasture-based production system should provide benefits to the vegetation, soil and animals while providing means of economic support for the household that operates the system. Best management practices are implemented, thus allowing the development of resilience for the pasture system, and ameliorate the natural resources for present and future generations. Pasture-based pig production represents a production alternative for small scale or limited resources farmers, offering them the possibility to brand their products. It also offers an option for consumers searching for an animal-welfare and environmentally-friendly produced pork, due to the surge of niche markets which are considered a good approximation to sustainable meat production. The implementation of best management practices would allow managers to reach productive and conservation goals. This study was conducted to compare the effects of continuous, rotational and strip-grazing stocking methods for pigs on tall fescue pastures. Stocking methods affected soil bulk density and some soil nutrients, vegetative ground cover, animal weight gain, and feed use efficiency. The rotational and strip grazing stocking methods offer potential to improve the sustainability of pasture-based pig systems.

Abstract: Pasture-based pig production represents a production alternative for small-scale or limited-resources farmers, and the possibility to brand their products, as well as an option for consumers searching for a more animal-welfare and environmentally-friendly produced pork. There is a lack of information of the impact of stocking methods on the sustainability of these systems. In this study, two alternative stocking methods (rotational and strip-grazing) were compared to continuous stocking at the same stocking rate (47 pigs ha⁻¹) in tall fescue pastures. The research was conducted during two twelve-weeks graze periods in North Carolina (USA). A complete randomized block design with three field replicates was used. Data were analyzed by the PROC GLIMMIX procedure of SAS 9.4 (SAS Cary, NC). Greater bulk density, and soil concentrations of NO₃⁻, P, K, Mn, Zn and Cu were observed in paddocks managed continuously, while greater final ground cover was recorded in paddocks managed with the rotational and strip grazing stocking methods. No differences were detected in botanical composition of the paddocks. Better animal performance indicators were registered from animals managed under

rotational stocking. The results indicated the potential of both alternative stocking methods to be implemented in sustainable pasture-based pig production systems.

Keywords: Pasture-based pig production; Stocking methods; Rotational; Continuous; Strip-grazing; Tall fescue (*Schedonorus arundinaceus*); Ground cover; Soil nutrients; Grazing pigs; Environmental impact; Pig performance.

1. Introduction

The sustainability of pasture-based animal production systems has social, environmental and economic implications. Grasslands provide low cost feed for livestock, mainly ruminants, becoming the basis for production and livelihoods in many rural areas of the world [1]. Sustainable grazing systems are grounded on the principles of improving the cycle of nutrients of grassland ecosystems, enhancing the vegetation, increasing the biodiversity, and improving the performance of grazing animals [2]. The adoption of one or another management strategy can represent a significant difference on the productivity, on the environmental impact, and consequently on the sustainability of a production system [1,3]. Adequate management strategies need to be implemented to fulfill the varied functions and services of grassland ecosystems [2]. According to Motta-Delgado et al., a sustainable pasture-based production system should provide benefits to the vegetation, the soil and the animals, while providing means of economic support for the household that operates the system through the implementation of best management practices that allow for the development of resilience of the pasture system, and conserve and ameliorate the natural resources for present and future generations [1].

Pasture-based pig production represents a production alternative to small scale or limited resources farmers due to its relatively low initial investment requirements, and the possibility to brand their products via diversification. It also offers an option for consumers searching for a more animal-welfare and environmentally-friendly produced pork [4,5] due to emerging or niche markets, considered a good approximation to sustainable meat production [6].

Pietrosemoli and Green advocate for a management of grazing pigs that focus on the main impacts that this animal species could cause to pastures [4]. This implies that minimizing ground cover disappearance [7,8] [Pietrosemoli, et al., In press Animals 2020], decreasing the damage to the soil structure [9–11], reducing soil nutrients buildup [8,12,13] [Pietrosemoli, et al., In press Animals 2020], and enhancing soil nutrients distribution [12,14,15] [Pietrosemoli, et al., In press Animals 2020] should be taken into consideration when designing the pasture management plan.

The stocking method most frequently used to keep pigs on pastures is the continuous stocking method [16], where pigs have continuous, unrestricted access to a grazing area, usually for the length of a production cycle. This method is often preferred by farmers because of its lower initial investment in water-supplying systems and fencing [17], and minimum of labor needs. Some alternatives to the continuous stocking such as the rotational stocking methods, provide a rest period to forages that allow recovery and regrowth, potentially improving their productivity and persistence [18,19].

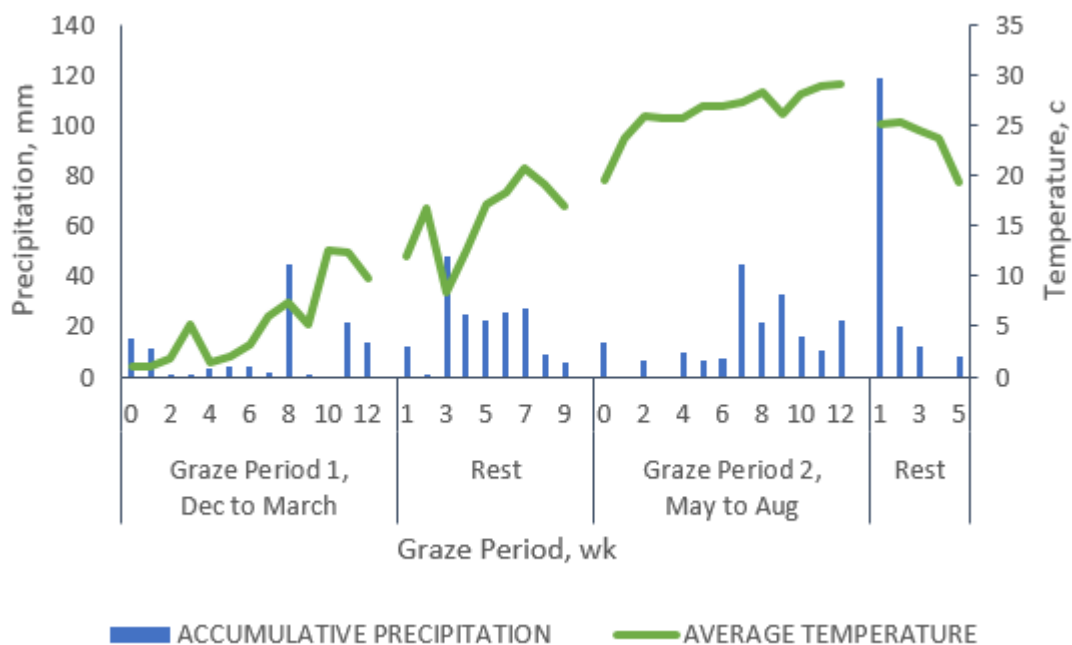
While there is a profusion of information related to stocking methods for other kinds of pasture-based livestock, to our knowledge there is limited information about how growing-finishing pig stocking methods impact soil properties, vegetation and animal performance. The purpose of this research is to contribute to the generation of knowledge about this subject by evaluating the effect of pigs stocking methods on tall fescue pastures. This knowledge would enable improving management practices for

pasture-based pig production, thus reducing pollution and enhancing the environment. In this study, two rotational alternative stocking methods (rotational and strip-grazing) were compared to continuous stocking at the same stocking rate in a tall fescue pasture-based pig system.

2. Materials and Methods

2.1. Study area

The research was conducted during two twelve-week graze periods (December to March and May to August, with 12 weeks of rest among them), in Goldsboro (35.38291° N, -78.035846° W, 24 m above sea level), North Carolina (USA). The farm is the Cherry Research, Education, and Outreach Facility of the Center for Environmental Farming Systems (CEFS). The research site comprised a 1.5 ha tall fescue (*Schedonorus arundinaceus* [Schreb.]) field with no previous history of pastured pigs. The soils were classified as Johns loamy sand (Fine-loamy over sandy or sandy-skeletal, siliceous, semi-active, thermic Aquic Hapludults) with 0 to 2 % slope [20]. According to the Trewartha climate classification, the climate is humid subtropical. Considering as a reference data from the last four years (2016-2020), the average precipitation was 1598 mm with a year round distribution and two peaks, one in April - May and the other in September - October. The average annual temperature was 17.3 °C (11.1 to 22.5 °C), being January the coldest month (0.9 °C) and July (32.7 °C) the warmest (NC CRONOS/ECONet Database and personal estimation) [21]. (Figure 1).



Source: State climate office of North Carolina [21]

Figure 1. Accumulative precipitation and average temperature during the experimental period

2.2. Experimental design and treatments

The experimental design was a randomized complete block design, with three field-replicate blocks (Figure 2). Three pig stocking methods were compared during two twelve-weeks graze periods (Table 1).

The stocking methods were randomly distributed to the paddocks in each block. A split-plot arrangement of treatments was employed to analyze the soil related variables, with stocking method as the main plot factor, and soil sampling depth (0 to 15 or 15 to 30 cm) as the sub-plot factor. For ground cover, the graze period was considered the main plot and stocking method the subplot, while botanical composition was analyzed as a complete block with the stocking method as the source of variation. Regarding animal related variables, the graze period was the main plot and stocking method the subplot.



Figure 2. Satellite view of the experimental site. From left to right replicates 1, 2 and 3. Image courtesy USDA WEB soil survey.

Table 1. Stocking methods under evaluation.

Grazing period	Stocking method	Area in use (%)	Stocking density ($\text{m}^2 \text{ pig}^{-1}$)
Weeks 1 to 8	Continuous	100	211
	Rotational	22.2	47
	Strip	12.5	26
Weeks 9 to 12	Continuous	100	211
	Rotational	33.3	70
	Strip	25	53

The stocking methods under evaluation (Figure 3) consisted of a continuous stocking system where animals were allowed to roam free in the paddocks during the entire graze period (Continuous, Figure 4), and two rotational methods. The first of them was developed by dividing the paddock into nine equally-sized sub paddocks, with the center area acting as the service area where the shelter and water were placed. Pigs had permanent access to the service area, and would graze the other sections on a weekly basis during weeks one to eight, after which they would be allowed to graze two sections per week,

following this pattern during week nine to twelve of the graze period. The feeders were located in the grazing sections, and were moved with the animals (Rotational, Figure 5). For the third stocking method, the paddock was divided into eight strips. All the service structures (shelters, drinkers and feeders) were moved with the pigs. In this treatment, pigs were allowed to graze one strip per week during weeks one to eight and two strips per week during weeks nine to twelve (Strip grazing, Figure 6). A twelve weeks rest period (from March to May) was implemented between graze periods. After being grazed, the sub paddocks for the rotational and strip-grazing treatments were back fenced.

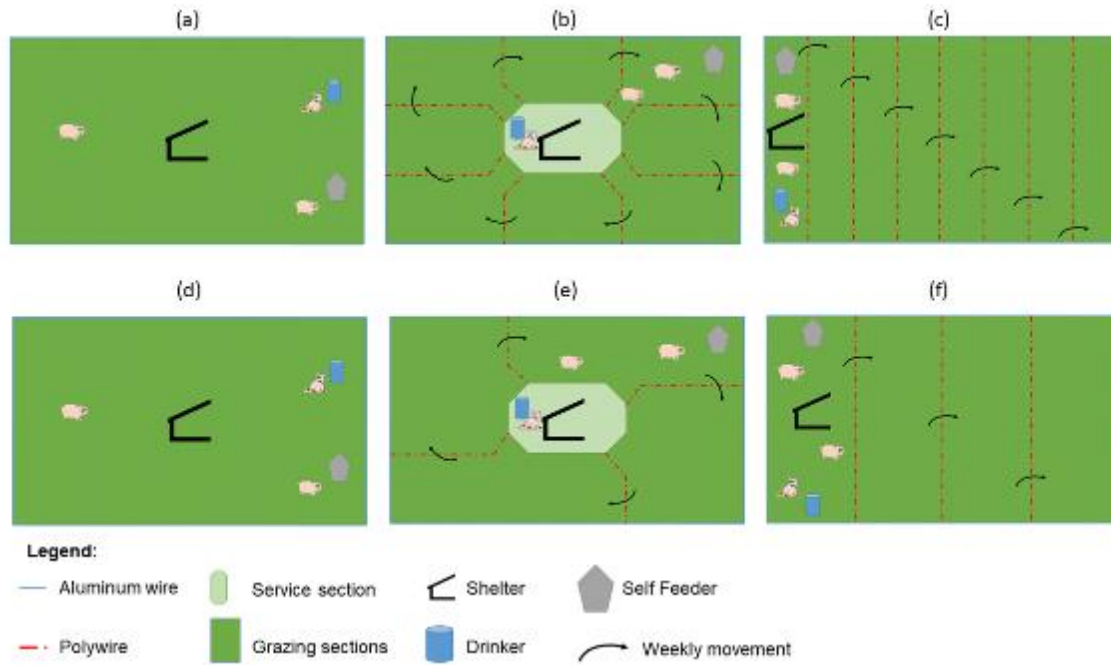


Figure 3. Stocking methods under comparison, weeks 1 to 8: (a) Continuous, (b) Rotational and (c) Strip grazing. Weeks 9 to 12: (d) Continuous, (e) Rotational and (f) Strip grazing.



Figure 4. View of a paddock managed under the continuous stocking method during the first graze period (December to March).



Figure 5. View of a rotationally stocked paddock during the second graze period (May to August). In front, pigs in the grazing sections. Back left, the service section with the shelter and the drinking station.



Figure 6. View of a Strip managed paddock during the first graze period (December to March). In front two two-holes self-feeders, in the center of the strip the shelter, in the back the plastic barrel used as a drinker during winter.

Paddocks were considered the experimental unit for most of the variables evaluated, with the exception of animal live weight and weight gain related variables where each animal was studied as the experimental unit. The treatments were kept in the same paddocks for the entire length of the study.

2.3 Soil sampling

Soil sampling was conducted in December before starting the experiment and in August immediately after animal removal at the end of the second graze period. For the purposes of soil sampling, each paddock was visually divided into nine equally-sized sections using PVC step-posts along the fence line (Figure 7). From each section of the paddocks, 12 core soil samples were randomly collected at two depths (0 to 15 cm and 15 to 30 cm) using a hand auger (Oakfield 36" LS). Additionally, composite samples were also fabricated per paddock and depth. Soil samples were kept at 4 C until analyzed at the North Carolina Department of Agriculture and Consumer's Services (NCDA& CS) soil laboratory where they were analyzed for percent humic matter (HM%), weight volume⁻¹ ratio (BD), cation exchange capacity (CEC), percent base saturation (BS%), exchangeable acidity (AC), pH, and the nutrients P, K, Ca, Mg, S, Mn, Zn, Cu, Na, and Fe following Melich-3 extraction methodology (Mehlich buffer acidity) [22]. A total of 324 samples were sent to the laboratory, 162 for baseline sampling and 162 following the second graze period, respectively. In addition to the above mentioned variables, 36 composite samples (18 from the initial sampling, and 18 following pig removal) were analyzed for nitrate nitrogen [23].

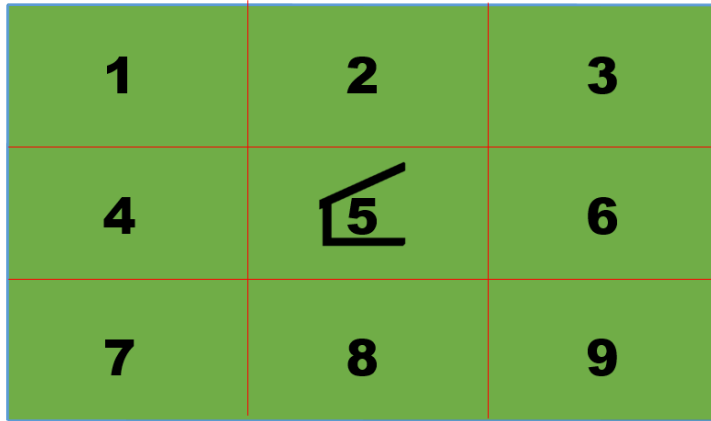


Figure 7. Each paddock was divided into nine equally-sized sections for sampling purposes.

2.4. Pastures

Tall fescue, the forage species established on the experimental site has been described as a cool season perennial forage with good yield potential, drought-resistance, tolerance to close grazing, and showing good persistence [24]. Dry matter yields have been reported in the range of 0.6 to 5.9 Mg ha⁻¹, and nutrients uptake potential of 57.3; 10.4; 75.4; 20.9 and 45.1 kg ha⁻¹ y⁻¹ of N, P, K, Cu and Zn, respectively [25].

The pasture was divided into three blocks which were subdivided into three paddocks each. Due to some irregularities in the field, one of the replicates had slightly different dimensions than the other two (105 m x 48.3 m for replicates 1 and 2, and 93 m x 54.5 m for replicate 3). On average, each paddock measured 1689.8 m². Eight pigs were used in each paddock, to a fixed stocking rate equivalent to 47 pigs ha⁻¹.

All paddocks were furnished with the same set of equipment: a three walls wood and zinc-laminate shelter (5.75 m²) and two two-hole self-feeders. During the first graze period (winter), plastic water barrels were used to supply water, whereas during the second graze period two water nipples coupled to metal pipes were employed (Figure 8). During winter, pigs were provided with bedding (hay), while during summer two of the shelter walls were removed, and additional shade was supplied using a tarp (11.2 m²). Poly-vinyl coated expanded metal slabs (61 cm x 76 cm) were placed under drinkers and feeders.

Two weeks before starting the second graze period, a mower was used to homogenize the height of the forage to 15 cm. The biomass was allowed to decompose on site.



Figure 8. View of the service area of a rotationally managed paddock. The portable shelter, the tarp used to provide additional shade, and the drinking structure with a hose and two nipple drinkers can be seen. Two walls of the shelter were removed.

2.4.1. Vegetative cover.

During each graze period, the vegetative cover was recorded weekly in every paddock along 11 transects permanently identified with plastic PVC pipes (1.3 cm diameter) placed along the longest sides of the paddocks. The two exterior transects were located 0.5 m from the paddock fence while the distance between the other transects were 3.0 m for replicates 1 and 2, and 3.40 m for replicate 3. A modified step point method was used to identify living vegetation, dead-dormant vegetation and bare soil every other step along the transects [26]. In September, four weeks after the end of the second graze period, the vegetative ground cover was estimated again along the same transects. Ground cover data analyzed in this study include data from week 8 and 12 of both periods (moments in which all paddocks had been grazed), and data from the last assessment four weeks after ending the second graze period.

2.4.2. Botanical composition

In September, four weeks after removing the second batch of pigs, the botanical composition of the paddocks was visually assessed by randomly throwing fifteen quadrats (0.5 m by 0.5 m) in each section of the paddocks [27]. The pasture species present were grouped as tall fescue, crabgrass, other grasses, or broad leaves species.

2.5. Animals

The animal-related protocols for this experiment were reviewed and approved by the Institutional Animal Care and Welfare Committee of North Carolina State University (IACUC 09-021-A). A total of 72 pigs were included in each graze period. Crossbred Yorkshire X Berkshire female and castrated male pigs (17.5 ± 0.3 and 78.6 ± 1.8 kg initial and final body weight, respectively) were used during the first graze

period, and Yorkshire/Landrace X Hampshire and Yorkshire/Landrace X Duroc male pigs (29.1 ± 0.8 and 91.0 ± 0.9 kg initial and final body weight, respectively) during the second graze period. The pigs were vaccinated and dewormed prior to moving them to the experimental site. The pigs were ranked according to their live weight and assigned at random to nine groups of eight pigs each, to balance initial total weight among groups. Each group was then assigned at random to the paddocks. Live animal weights were recorded individually at the beginning and at the end of each graze period. Animals were weighed at approximately the same time of day in each event, without overnight fasting. Weight gain was calculated per pig, and daily gain was estimated according to the total weight gain and the days of the graze periods (84 d). Pigs had *ad libitum* access to water and to a homemade grain mix (corn, soybean, vitamins and minerals) which was formulated following NRC nutrient recommendations for pigs [28]. On average, the grain mixes contained 151.8 g kg^{-1} crude protein, 36.2 g kg^{-1} crude fat, and 38.4 g kg^{-1} ash (4.9 g kg^{-1} Ca; 4.9 g kg^{-1} P; 1.6 g kg^{-1} S; 1.6 g kg^{-1} Mg; 0.9 g kg^{-1} Na; 6.4 g kg^{-1} K; 12 mg kg^{-1} Cu; 184 mg kg^{-1} Fe; 32 mg kg^{-1} Mn; and 98.5 mg kg^{-1} Zn), and $2383 \text{ kcal kg}^{-1}$ DM (dry matter) of net energy. Feed samples were collected monthly, composited and analyzed per graze period at the North Carolina Department of Agriculture and Consumer Services NCDA&CS Forage laboratory. Feed disappearance was estimated at the paddock level as feed offered minus feed residues at the end of each graze period. Feed efficiency was calculated for each graze period by dividing animal weight gain for each paddock by paddock dry matter feed disappearance.

2.6. Nutrient balance.

Feed composition data, feed disappearance, and pig weight gain were used to estimate nutrients (N, P, and K) balance as differences between inputs to the system and the outputs as pigs' body components. The coefficient of the retention of the nutrients in the body of pigs used (0.029 , 0.0055 , and 0.0022 kg of N, P, and K kg^{-1} body weight, respectively) were obtained from the literature [29,30].

2.7. Statistical analysis

Stocking methods were compared by way of analysis of variance/covariance fitting generalized mixed models through the PROC GLIMMIX procedure of SAS 9.4 (SAS Institute Inc., Cary, NC) [31]. Differences between means with significant effects were determined by comparing the least-squares means using the PDIF statement with a SIMULATE adjustment for multiple comparisons. Repeated measures were tested using a first-order autoregressive structure (AR (1)). Significance was determined at a level of $P < 0.05$ for main factors and $P < 0.10$ for the interactions. Results presented in tables and figures are arithmetic means and standard errors.

The model statements for soil nutrients included fixed effects of stocking methods and soil sampling depths and their interactions, and initial values as covariates. Blocks and their interactions were considered as random effects. The sampling sections of the paddocks were included as repeated measures. Differences in ground cover were evaluated by treating stocking methods, graze periods, their interactions, and weeks as fixed effects. Blocks, and the interaction blocks x graze periods were analyzed as random effects. Weeks were considered as repeated measures. Final ground cover (considering week 8 and 12) was evaluated including graze periods, stocking methods, their interaction, and weeks nested within graze periods as fixed effects. Blocks and their interactions were included as random effects. To test for significance effects of ground cover estimated four weeks after ending the second graze period, stocking methods were modelled as fixed effects, and blocks as random effects. Similarly, the model for botanical composition estimated at the same time included stocking methods, pasture sections, and their interactions as fixed effects, and blocks as random effects. The section of the paddock was considered as a

repeated measure. In the models used to test animal-related variables (final weight, weight gain, feed disappearance, and gain to feed ratio), graze periods, stocking methods, and their interaction were included as fixed effects, and blocks were evaluated as random effects. Pig initial weight and the animal sexual condition were included as covariates in the models for final weight, total weight gain, and daily weight gain.

3. Results

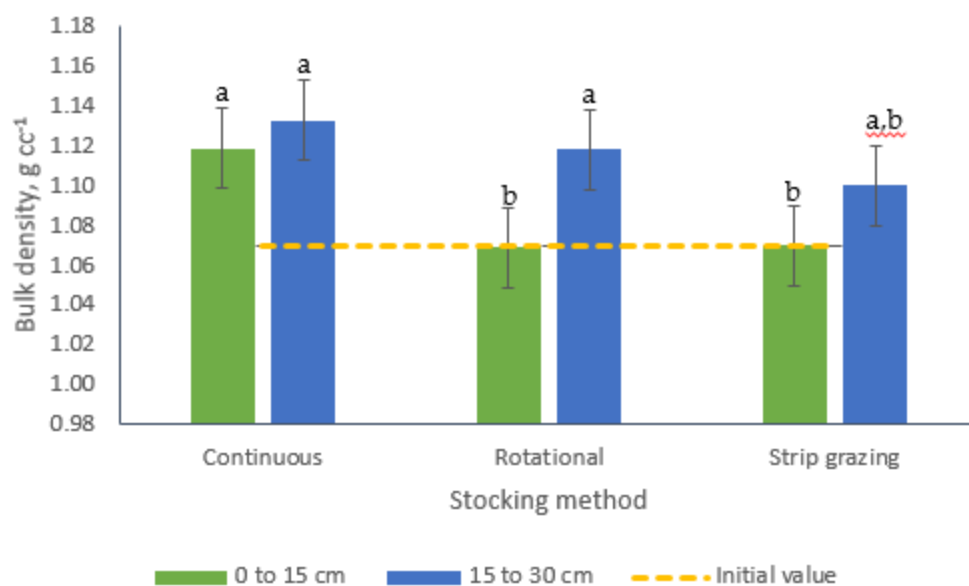
3.1. Soils properties

Stocking method had a significant effect ($P=0.0400$) on soil bulk density estimated as weight volume⁻¹ ratio (Table 2). The bulk density from paddocks under continuous management were greater (2.8%) than those rotationally or strip grazed which did not differ (average: 1.09 g cc⁻¹). Differences among samples from different sampling depths were observed for humic matter ($P=0.0046$), bulk density ($P<0.0001$) and exchangeable acidity ($P=0.0002$). In the studied samples, the upper soil layer (0 to 15 cm) presented 46.2% and 11.6% greater values for humic acid and exchangeable acidic, respectively, and 2.8% lower bulk density than the values recorded from samples collected deeper in the soil profile (15 to 30 cm). Interaction between stocking methods and soil sampling depth (Figure 9) were observed for bulk density ($P<0.0001$) While no differences were observed among soil depth for the samples collected from paddocks managed under continuous stocking (average: 1.13 g cc⁻¹), the samples collected from rotationally managed paddocks showed greater (+4.7%, 1.12 vs 1.07g cc⁻¹) bulk density in the deeper soil layer (15 to 30cm). No differences were detected among bulk densities in samples from the strip grazing stocking method (average: 1.9 g cc⁻¹).

Table 2. Effect of stocking methods and soil sampling depths on the chemical–physical soil properties of tall fescue paddocks managed with pigs.

	HM (%)	BD (g cc ⁻¹)	CEC (Meq 100 cc ⁻¹)	BS (%)	AC (Meq 100 cc ⁻¹)	pH
Initial value						
0 to 15 cm	0.36	1.04	6.33	79.04	1.28	5.61
15 to 30 cm	0.28	1.1	5.13	79.49	1.0	5.6
SE	0.01	0.01	0.12	0.81	0.04	0.05
Stocking method SM						
Continuous	0.33	1.12 a	5.89	79.54	1.13	5.56
Rotational	0.32	1.09 b	5.77	80.9	1.13	5.61
Strip Grazing	0.32	1.08 b	6.05	78.42	1.29	5.64
SE	0.02	0.02	0.19	2.59	0.18	0.07
Soil depth SD						
0 to 15 cm	0.38 a	1.08 b	5.93	79.69	1.25 a	5.57
15 to 30 cm	0.26 b	1.11 a	5.87	79.55	1.12 b	5.64
SE	0.02	0.01	0.17	2.2	0.18	0.04
Stocking method SM						
<i>P</i>	0.6877	0.0400	0.2415	0.6152	0.2703	0.6879
Soil depth SD						
<i>P</i>	0.0046	<.0001	0.5411	0.7865	0.0002	0.1319
SM x SD						
<i>P</i>	0.2454	<.0001	0.6382	0.7641	0.6223	0.6380

N=162; HM: Humic matter; BD: soil density estimated as weight volume⁻¹ ratio; CEC: Cationic exchange capacity; BS: Base saturation; AC: exchangeable acidity; pH. P: Probability, SE: standard error; SM: Stocking method; SD: Soil sampling depth. a, b, c: means in a column followed by a common letter are not significantly different by the *t*-test at the 5% level of significance. Initial values: nutrients in soil from samples collected from each paddock before grazing with pigs



a, b: means displaying the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. Data are the means of three field replicates. Errors bars represent plus or minus one standard error of the means for the interaction.

Figure 9. Effect of the interaction stocking method and soil sampling depth on the bulk density of soils from tall fescue paddocks managed with pigs.

Similarly, significant effects of the stocking method were observed for soil concentrations of $\text{NO}_3\text{-N}$, P, K, Mn, Zn, and Cu, with lower values of these nutrients found in samples from paddocks managed with the rotational stocking method. The soil sampling depth showed significant effects in soil concentrations of $\text{NO}_3\text{-N}$, P, K, S, Mn, Zn, Cu, Na, and Fe.

Table 3. Soil nutrients in tall fescue paddocks managed with pigs during two twelve-week graze periods

	NO ₃ ²	P	K	Ca	Mg	S	Mn	Zn	Cu	Na	Fe
	(mg kg ⁻¹)										
Initial value¹											
0 to 15 cm	3.44	51.8	55.2	698.1	172.1	13.4	62	5.3	2.5	18.5	606
15 to 30 cm	2.33	22.2	26.8	602.6	128.2	10.2	47.7	2.5	1.5	16	654.6
SE	0.8	2	1.5	17.9	5.8	0.4	1.9	0.1	0.1	0.6	11.6
Stocking method SM											
Continuous	21.8 a	49.5 a	92.4 a	643.4	152.3	13.7	45.9 a	4.3 a	1.9 a	22.6	693.9
Rotational	16.9 b	41.0 b	72.4 b	650.3	155.3	13.6	39.3 b	3.6 b	1.7 b	25.2	660.9
Strip Grazing	18.1 a,b	40.1 b	75.9 b	655.1	157.1	13.1	45.8 a,b	3.8 b	1.8 a,b	25.2	670.7
SE	1.5	2.2	4.6	20.8	5.6	0.8	2.7	0.3	0.1	2.3	33.6
Soil depth SD											
0 to 15 cm	25.2 a	50.9 a	109.7 a	654.2	150.3	15.0 a	45.3 a	4.7 a	2.1 a	26.1 a	657.2 b
15 to 30 cm	12.8 b	36.2 b	50.8 b	645.1	159.6	11.9 b	42.1 b	3.1 b	1.5 b	22.5 b	692.9 a
SE	1	2.1	4.6	14.1	6.1	0.8	1.8	0.3	0.1	1.4	27.4
Stocking method SM											
P	0.0627	0.0052	0.0037	0.9195	0.6309	0.6236	0.0701	0.0016	0.0077	0.6879	0.6468
Soil depth SD											
P	<0.0001	<0.0001	<0.0001	0.4807	0.2700	<0.0001	<0.0001	<0.0001	0.0095	0.0003	0.0007
SM x SD											
P	0.8020	0.4003	0.8689	0.3080	0.7000	0.9907	0.5556	0.1329	0.1168	0.2527	0.9256

N=162; NO₃: nitrate, P: Phosphorus, K: potassium, Ca: calcium, Mg: magnesium, S: Sulphur, Mn: manganese, Zn: zinc, Cu: copper, Na: sodium, Fe: Iron. P: Probability, SE: standard error; SM: Stocking method; SD: Soil sampling depth. Initial values: nutrients in soil from composite samples collected from each paddock before grazing with pigs, N=18; ²: composite soil samples collected from each paddock after grazing with pigs.

a, b: means in a column followed by a common letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option.

It was estimated that after the two grazing cycles circa 371, 74 and 98 kg ha⁻¹ of N, P and K, respectively, were imported into the system via concentrate feed. Similarly, approximately 168, 32, and 12 kg ha⁻¹ of N, P and K respectively, were removed as pig body components. The balance resulted in the deposition of 204, 42, and 85 kg ha⁻¹ of N, P and K, respectively, to the paddocks (Table 4). In soils similar to those where the experiment was conducted, tall fescue have shown the potential to produce up to 5600 kg of forage ha⁻¹, and to remove 240 and 39 kg ha⁻¹ of N and P respectively [32].

Table 4. Balance of Nitrogen, Phosphorus and Potassium (kg ha⁻¹), in tall fescue paddocks managed with pigs

	Live Weigh	INPUT			OUTPUT ¹			BALANCE		
	Gain	N	P	K	N	P	K	N	P	K
Grazing period	Kg	(Kg ha⁻¹)²								
December to March	61.0	195	31	49	83	16	6	112	15	43
May to August	62.1	176	43	49	85	16	6	92	27	42
TOTAL		371	74	98	168	32	12	204	42	85

N: Nitrogen; P: Phosphorus; K: Potassium;

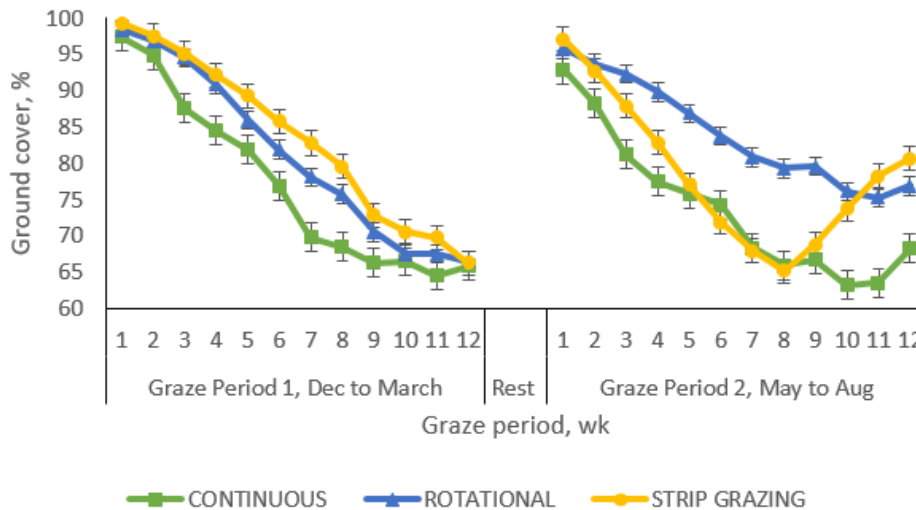
¹Estimated amount of nutrients (N, P, and K) in the body of grower to finisher pigs (30 to 100 kg). Coefficients of retention used 0.029, 0.0055, and 0.0022 kg of N, P, and K kg⁻¹ body weight, were obtained from the literature [29,30].

²Nutrients kg ha⁻¹= Nutrient mg kg⁻¹ x 2.25

The stocking rate was equivalent to 47 pigs ha⁻¹

3.2 Vegetation.

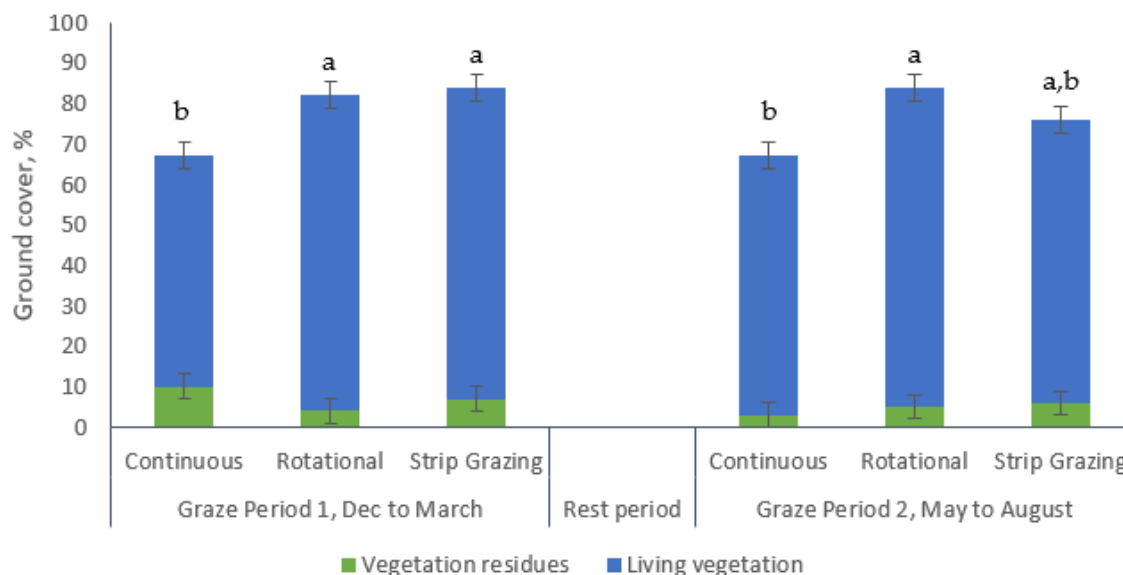
The ground cover of the paddocks declined with time across all treatments (Figure 10). The tendencies in the evolution of the vegetative ground cover were similar for the rotational and strip-grazing stocking, which demonstrated a gradual decline while paddocks managed with the continuous system showed a more marked decrease. By the end of the first graze period the cover reached levels of 73 % on average for all plots, with the plots managed continuously showing 11% less cover than the paddocks managed with the other two treatments. The rest period between the two graze periods allowed the vegetation to recover from the stress inflicted by the animals, however the recovery was not complete and it did not reach 100% ground cover. During the second graze period, the paddocks managed under rotational stocking displayed greater ground cover than the paddocks managed with the other two stocking methods during most of the sampled weeks. However, at the end of this period the ground cover reached on average the level of 74.1%, with the continuous treatment showing 9% lesser ground cover than the other two which did not show differences among them. A sudden downward trend in ground cover was observed for the paddocks managed with the strip-grazing method until week 8 when a reverse trend was observed and maintained until the end of the study.



Data are the means of three field replicates. Errors bars represent plus or minus one standard error of the means.

Figure 10. Evolution of the vegetative ground cover in tall fescue paddocks managed with pigs under three different stocking methods

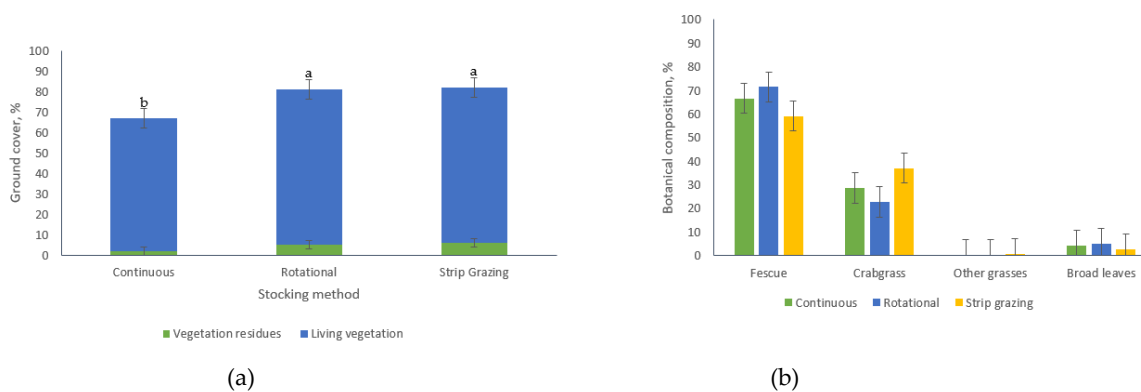
The interaction graze periods x stocking method showed significance ($P=0.0107$) for the ground cover of tall fescue paddocks recorded on week 8 and 12 of the graze periods. In both periods, the rotational method presented greater (+22.1%) ground cover than the paddocks managed with the continuous stocking method (67.1%), but did not differ from the strip grazing-managed paddocks (80.1%) (Figure 11). However, the ground cover during the second period for the strip grazing-managed paddocks showed no statistical difference with the values recorded for the continuous system (average: 70.3%). At the end of both graze periods, the residues (dead or dormant vegetation) represented less than 10% of the ground cover.



a, b: For each graze period, means displaying the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. Data are the means of three field replicates. Errors bars represent plus or minus one standard error of the mean. Data is the average of weeks 8 and 12 of each graze period, moment when all the sections of the paddocks have been grazed.

Figure 11. Final ground cover (%) in tall fescue paddocks managed with pigs.

The ground cover was also evaluated four weeks following the removal of the animals after the second graze period. Stocking methods were significant ($P=0.0064$) with greater (+21%) values in paddocks under the rotational or the strip grazing stocking methods which showed similar (average: 81.1%) (Figure 12 (a)). The botanical composition of the paddocks was also estimated at this time, with no effect of the stocking methods on percent of tall fescue ($P=0.7248$), crabgrass ($P=0.693$), other grasses ($P=0.6209$), and broad leaves species ($P=0.8461$) (Figure 13 (b)).



a, b: means displaying the same letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option. Data are the means of three field replicates. Errors bars represent plus or minus one standard error of the mean.

Figure 12. (a) Ground cover (%) and (b) Botanical composition (%) in tall fescue paddocks four weeks after the second graze period.

3.3 Animal performance.

Initial and final live weight differed among animals used in the two graze periods. Pigs were heavier at the beginning (+66.5 %) and at the end (+15.7%) of the trial during the May to August graze period compared with pigs used in the December to March period (Table 5). Nevertheless, total and daily weight gain were similar among graze periods. Feed disappearance was greater (+7.46%) during the first graze period, whereas the gain to feed ratio was greater (+11.1%) during the second one. Animal weight gains were similar in both graze periods. The stocking method had a significant effect in final weight, total weight gain, daily weight gain, feed disappearance, and gain to feed ratio. In general, animals under rotational stocking performed better, showing an 8.8% higher weight gain than the animals in the other two stocking systems which grew similarly.

Table 5. Effect of stocking method on performance of growing pigs reared in tall fescue paddocks

	Live Weight		Weight Gain		Feed	
	Initial (kg pig ⁻¹)	Final (kg pig ⁻¹)	Total (kg pig ⁻¹)	Daily (kg pig ⁻¹ d ⁻¹)	Disappearance (kg pig ⁻¹ d ⁻¹)	Gain to feed (kg kg ⁻¹)
Grazing period GP						
December to March	17.5 b	78.66 b	60.9	0.73	2.01 a	0.36 b
May to August	29.14 a	90.98 a	62.09	0.74	1.86 b	0.40 a
SE	0.59	1.37	1.66	0.02	0.03	0.01
Stocking method SM						
Continuous	23.18	83.56 a,b	60.37 b	0.72 b	1.99 a	0.37 b
Rotational	23.30	88.29 a	64.99 a	0.77 a	1.98 a	0.40 a
Strip Grazing	23.47	82.60 b	59.13 b	0.70 b	1.83 b	0.39 a,b
SE	0.72	1.68	1.54	0.02	0.04	0.01
Grazing period GP						
P	<0.0001	<0.0001	0.6717	0.6717	0.0100	0.0040
Stocking method SM						
P	0.9585	0.0414	0.0208	0.0208	0.0404	0.0714
GP x SM						
P	0.9975	0.4937	0.3707	0.3707	0.5723	0.3966

a, b: means in a column followed by a common letter are not significantly different at the 5% level of probability as indicated by the Multiple Comparisons test - simulate option.

4. Discussion

Stocking methods are techniques that allow the management of grazing animals according to the pasture area and occupation time to reach a determined objective [18]. More than 12 alternatives of stocking methods derived from the continuous or the rotational stocking methods have been listed [18]. It was hypothesized that different stocking methods to manage pigs on tall fescue pastures would present different impacts on the soil, the vegetation and the animal performance. It was expected that the implementation of rotational stocking methods would enhance soil nutrients distribution within the paddocks, improve ground cover persistence, would sustain appropriate animal performance, and increase soil nutrients uptake by the forage growing on the pastures.

Soils physical-chemical properties

Most of the soil variables did not differ significantly among stocking methods, which could be attributed to having managed all the paddocks with the same stocking rate (47 pigs ha⁻¹). Another possible reason for the lack of differences could be related to the experiment length. Greater differences could become more evident after longer or more grazing periods. The results showed, however, that pig stocking methods influenced soil bulk density. Lower bulk density was observed from the paddocks managed rotationally or under strip grazing. As soil bulk density increases as a result of pig trampling, it could be reasonable to assume that pigs under continuous stocking, being free to use the area at will, would tend to concentrate in already-used areas, thus increasing their bulk density. Pigs tend to concentrate in areas adjacent to shelters, feeders and drinkers, and patch-perpetuating behavior has been previously observed [8]. Similarly, Bordeaux et al. reported greater bulk density in pastures managed with pigs under a stationary scheme, compared to the bulk density of paddocks where service structures (shelter and water) were moved weekly [10]. Likewise, a study comparing stocking methods for cattle reported that lower values for bulk density were recorded in the rotational managed soils [33]. In the study herein, pigs under rotational stocking had access to the grazing areas for only a week while maintaining a permanent access to the service-central area. As the latter represented proportionally a smaller area of the paddock (11.11%) it could have impacted more localized soil areas [34,35]. Conversely, rooting behavior, which has been related to reduction in soil compaction [10,36], could have happened more frequently in the more extensive grazing areas. Additionally, pastures managed under continuous stocking exhibited lower vegetative ground cover than the other two methods. The presence of ground cover could have partially alleviated the direct impact of pig hooves on the soil contributing to a reduction in the soil bulk density of the rotationally stocked paddocks.

Differences were also observed between some of the soil properties in samples collected at different depths. Soil bulk density was greater deeper in the soil, while humic matter concentrations and exchangeable acidity showed higher values in the topsoil layer (0 to 15 cm). These differences could be attributed to the deposition of manure and organic matter to the surface of the ground [8]. The addition of organic matter has also been related with lessened bulk density [37].

Soil nutrients

Soil samples showed differences in their concentrations of NO₃⁻, P, K, Mn, Zn and Cu among paddocks managed with different stocking methods. Greater concentrations of the above-mentioned soil nutrients were found in paddocks managed under continuous stocking. Differences in soil nutrients among continuous and rotationally stocked pastures have been related to the length of graze periods [38]. In the present study, the differences could be attributed to the short occupation period (1 week) that would have allowed the forage to rest and recover from animal disturbances in the rotational and strip grazed paddocks, and the uptake of some of the nutrients deposited through the manure and feed wastage. Conversely, having unrestricted freedom of movement, pigs in the continuous system could have exerted a greater selective pressure on the vegetation of their preference, thus causing localized overgrazing. Recurrent defoliations and soil disturbance have a negative impact on forage root systems, resulting in a reduction of nutrient uptake [38]. In addition, as a consequence of the weekly movement of feeding (rotational and strip grazing) and watering stations and shelters (strip grazing), the elimination behavior of pigs could have been modified [39], causing a better dispersion of nutrients [38,40] and a greater forage uptake, thus leaving lower concentrations of nutrients in the soil. Conversely, in paddocks under continuous stocking the feeding, drinking and resting areas were kept unchanged for the entire length of the graze period. In addition, the short graze periods followed by the rest period could have improved forage nutrient uptake efficiency by supplying nutrients via manure when forages need them

for regrowth [41]. Similar results have been obtained in paddocks grazed with cattle where the stocking methods influenced the concentrations of NO_3^- , P, K, Mg, Ca and S, with lower concentrations of nutrients in recorded in paddocks managed with the shorter occupancy [33].

The concentration of NO_3^- , P, K, S, Mn, Zn, Cu, Na, and Fe varied among the soil layers with greater values found in the top 0 to 15 cm layer for most of the nutrients, but for Fe which presented higher values on the bottom strata of the explored soil profile (15 to 30 cm). Previous studies have reported vertical displacement of soil nutrients [8,33,40]. Grazing pigs deposit dung and urine on the surface of the paddocks. Manure needs to be physically degraded before releasing its components to the soil. However, manure nutrients availability for plant uptake will be dependent on microbial activity [42] and environmental conditions. It is likely that greater concentrations of nutrients in the upper layer would be a consequence of the manure deposition on the topsoil.

When comparing the initial level of nutrients with those in samples collected following the second pig graze period, changes of different magnitudes were observed. Similarly, increases in concentration of inorganic-N forms (53 % more NO_3^- -N and 75% more NH_4^+ -N) were reported in paddocks (ryegrass, white and red clover) managed during two 12-week periods with a stocking rate equivalent to 58 pigs ha^{-1} [43]. In the study herein, rotational stocking methods did not improve the homogeneity of nutrients distribution, most likely due to the short duration of the graze periods.

Vegetation

Ground cover

Accordingly with a 2007 North Carolina-Natural Resources Conservation Service recommendation, to minimize erosion in pasture-based pig production systems ground cover needs to be maintained over 75% [44]. Uncontrolled grazing may lead to reduced ground cover [45]. As a consequence of foraging pigs activity, mainly rooting, ground cover resulted damaged [46]. As in previous studies, the sites where pigs tended to congregate, such as resting, feeding and wallowing areas, showed a greater impact [8]. In the study herein, however, at the end of the 12-week graze periods the ground cover was over 66 %, greater than the ground cover (8 to 27 %) reported by Kongsted and Jakobsen for pigs grazing (338 m^2 pig^{-1} , 30 pigs ha^{-1}) a multispecies pasture including grass-clover, and forage herbs for a similar period of time [46], and greater than the final ground cover recorded for bermudagrass pastures [Pietrosemoli, et al., In press Animals 2020]. It is worth noting that grazing management strategies varied between the above mentioned studies.

Greater ground cover was recorded in paddocks managed with the rotational and the strip grazing stocking methods in comparison with the values obtained under continuous stocking. This advantage may be explained by the short occupation period (1 week) and the rest period (7 weeks) in both rotational stocking methods, while the action of the pigs was uninterrupted under continuous stocking, which could have led to the exhaustion and disappearance of forage plants. Similarities in ground cover among both rotational alternatives could be explained by the impact received by the vegetation under the shelter, drinkers and feeding sites which were disturbed with each weekly movement in the strip grazing method, and could be equivalent to the area set to be used as a service area in the rotational method. Corresponding circumstances were described by Bordeaux et al. when comparing the ground cover of sudangrass (*Sorghum bicolor* [L.] Moench) and ryegrass (*Lolium multiflorum*) in pasture-based pig systems managed with stationary or mobile structures [10]. Similarly, the response of tall fescue paddock grazed with beef cattle was affected by the stocking method with paddocks managed rotationally showing greater ground cover [47].

Botanical composition

Paddocks under different stocking methods presented similar botanical composition, with tall fescue maintaining its position as the dominant species (66 % of the species present in the paddocks). Similarly, Michalk asserted that to maintain the competitive position in a pasture, the dominant species (in this case tall fescue) needs to represent at least the 60% of the biomass [48]. Nevertheless, the emergence of species that were not present at the beginning of the study were observed across stocking methods. Pigs grazing and rooting behaviors could have impacted the vegetation, leaving bare soil patches for other species to colonize [45,49]. Seeds of annual opportunistic species such as crabgrass (*Digitaria sanguinalis*) could have been waiting for ideal conditions to sprout. At the moment of the evaluation, crabgrass was the second most important species present in the paddocks (30%), whereas ragweed (*Ambrosia artemisiifolia*) dominated the broad leaves group which represented 4 % of the species present in the paddocks. Differences in botanical composition of paddocks grazed by pigs have been previously reported [50]. Those differences could be partly attributed to the selective grazing behavior exerted by pigs on pasture which tend to select certain plants, and moreover parts within a plant [51], leaving the less preferred species to dominate the stand [45]. Similarly, replacement of the dominant plant species by annual vegetation due to the impact of pigs rooting on species composition have been reported previously [49]. Accordingly, the loss of ground cover would be the initial effect to pigs disturbance, followed by the apparition of annual species that would take advantage not only of the physical removal of competitors but also of the nutrients available in the soil [49].

The values presented across treatments for both ground cover and botanical composition four weeks following animal removal from the paddocks after the second graze period, could be interpreted as that the pasture system possesses resilience, a trait that can promote a quick recovery from the damage inflicted by the pigs.

Animal performance

Feed disappearance

Feed disappearance was 8.06% greater during the first graze period (December to March, winter) than in the second one (May to August, summer). The effect of environmental temperature on feed intake has been previously reported. Voluntary feed intake increased when the temperature was under the lower limit of the comfort zone [52,53], and decreased when the environmental temperature surpassed the upper limit of the temperature comfort zone which decreases as pig age [5,54]. It is important to note the potential exposure of the pigs included in this study to fescue toxicosis, which can cause decreased feed intake [55]. It has also been reported that the effects are more evident during summer than during winter [55]. The tall fescue pastures used in this study were not tested for the presence of the fungal endophyte species (*Epichloë coenophiala* Bacon and Schardl.) involved in the symbiotic relationship with the forage [56].

Considering that higher dry matter intake is expected in pasture-based pigs (15% more than indoor-managed pigs) to balance the increased energy requirements (for thermoregulation and exercise) [57,58], the feed disappearance values registered in this study (2.01 and 1.86 kg pig d⁻¹ for winter and summer, respectively) could seem low when compared with intake values recorded by other researchers, suggesting that tall fescue could have made a contribution to the nutrition of the pigs [58,59]. Intake of forages in grazing pigs represents between 10 and 20% of the total dry matter (DM) intake [60,61]. Greater feed intake values (2.9 kg pig d⁻¹) than those recorded in this study have been reported for pigs managed in a daily strip grazing system [53], or for weekly rotated pigs (3.15 kg DM pig d⁻¹) [43]. These last authors recorded intake of grass of 0.26 kg DM pig d⁻¹ [43]. Jakobsen et al. reported intakes values of

alfalfa in the range of 0.33 to 0.47 kg DM pig d⁻¹ [60] with similar feed intakes to those registered in this study (2.2 kg DM pig d⁻¹),

Previous studies reported no differences in supplementary feed intake (average: 2.4 kg pig d⁻¹) among pigs grazing white clover under different stocking methods [59]. No differences were neither observed in the grazing behavior or pasture intake of European wild boar managed either in a continuous or in a rotational grazing system [17]. The feed efficiency values measured in this study were greater (+8%) in pigs from rotationally managed paddocks than those reported for pigs continuously stocked, while the values obtained from pigs in the strip-grazing treatment were intermediate. Similar values have been registered for Cinta Senese pigs [62], while much lower (-70%) feed efficiency has been reported for grazing pigs in Uruguay [43].

Weight gain

Differences in pigs' final live weight and total and daily weight gain were found among pigs reared in the different stocking methods. Although pigs were offered the same supplemental feed *ad libitum*, it may be that the pasture rotationally stocked had a higher forage quality as reported previously for mixed warm and cool-season grass pastures managed with horses showing differences in concentrations of fiber (ADF, NDF, and lignin), water soluble carbohydrates and sugar, and digestible energy [63]. Additionally, the weekly movement of animals, shelter and feeding and drinking structures in the strip grazing paddocks could have disrupted the daily routine of this group of pigs and potentially imposed some sort of stress on them [5,64]. Contrary to these results, no differences in animal weight gain between pigs grazing white clover managed continuously, alternately or rotationally were reported in Brazil [59].

The total weight gain was similar in both graze periods, and averaged 61.5 kg pig⁻¹, the same weight gain figure reported for rotationally stocked pigs during 12 weeks in Uruguay [43]. The daily weight gain recorded in this study was in the range of values reported for Iberico pigs (0.74 to 0.78 kg pig d⁻¹) [65], and similar to the values registered for Cinta Senese pigs (0.71 to 0.76 kg pig d⁻¹) [62], or for pigs managed in a weekly rotation system (0.73 kg d⁻¹) [52], but are lower than those obtained in strip grazing managed pigs (0.90 kg pig d⁻¹) [53]. The forage species in the pasture has effects in the amount of pigs weight gain. In grass pastures with *ad libitum* access to supplemental feed, daily gains in the range of 0.59 to 0.88 kg d⁻¹ have been reported, whereas for alfalfa pastures the figures were 0.74 to 0.90 kg pig d⁻¹ [60].

In this study, it is hard to ascertain the magnitude of the contribution of tall fescue to pig diets, if any. Pigs had *ad libitum* access to supplemental feed, a factor that has shown to reduce forage intake [66]. Conversely, the possibility of pigs being subjected to toxicity by ingesting endophyte infested fescue cannot be ruled out. Fescue toxicity has been reported to negatively affect animal performance in different livestock species [55].

A practical disadvantage encountered with the strip grazing stocking method was the workload involved in the weekly rotation of the shelters, feeders and drinking structures, which could limit the adoption of this alternative management.

5. Conclusions

The implementation of best management practices is the initial step to reach sustainability with the purpose being to reduce the impact on the environment, and to optimize the efficiency, the productivity and the profitability of pasture-based systems. The results of this study indicated the positive influence of the use of rotational stocking methods in pastured pig systems in terms of soil bulk density, soil

concentrations of NO₃, P, K, Mn, Zn and Cu, vegetation ground cover maintenance and animal performance.

The appearance of spontaneous, less desirable vegetation species in the pastures could lead to reduced pastures quality, underlying the significance of implementing appropriate pasture management practices that consider conservation-oriented stocking rates and stocking methods. Conversely, these less desirable plant species play an important role in biodiversity conservation and as ground cover.

As the impacts of pigs grazing may only be noticed in the long term, longer studies are needed comparing the effects of different stocking rates and stocking methods on forage persistence and soil properties in pasture based pig production systems. However, these short term studies do show that it is possible to maintain ground cover, and they help to develop expected amounts of nutrient loading of pastures. Because very little vegetation is removed from the sites, nutrient loading will be quicker than in other livestock grazing systems. Haying is an approach to decrease nutrients loading over time [67].

As the strip-grazing stocking method showed potential for enhancement of the environmental performance of pasture-based pig systems, it would be interesting to explore alternatives to improve the easiness of performing the rotation of shelters and other structures, which could empower shorter occupation periods. In addition, the impact of scaling up the systems (larger paddocks and herd size) on animal behavior, animal performance and on environmental variables should be examined.

Author Contributions: Conceptualization, Silvana Pietrosemoli, James T. Green Jr. and Maria Jesus Villamide; Data curation, Silvana Pietrosemoli; Formal analysis, Silvana Pietrosemoli and James T. Green Jr.; Funding acquisition, James T. Green Jr.; Investigation, Silvana Pietrosemoli and James T. Green Jr.; Methodology, Silvana Pietrosemoli, James T. Green Jr. and Maria Jesus Villamide; Project administration, Silvana Pietrosemoli; Supervision, James T. Green Jr. and Maria Jesus Villamide; Writing – original draft, Silvana Pietrosemoli; Writing – review & editing, Silvana Pietrosemoli, James T. Green Jr. and Maria Jesus Villamide. All authors have read and agreed to the published version of the manuscript.

Funding: Financial support for the project was generously provided by: USDA/NRCS-CIG, USDA-SARE and the W.K. Kellogg Foundation

Acknowledgments:

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Motta-Delgado, P.A.; Ocaña-Martínez, H.E.; Rojas-Vargas, E.P. Indicadores asociados a la sostenibilidad de pasturas: una revisión. *Ciencia & Tecnología Agropecuaria* **2019**, *20*, 387–408, doi:10.21930/rcta.vol20_num2_art:1464.
2. Boval, M.; Dixon, R.M. The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. *Animal* **2012**, *6*, 748–762, doi:10.1017/S1751731112000304.
3. Bell, L.W.; Hayes, R.C.; Pembleton, K.G.; Waters, C.M. Opportunities and challenges in Australian grasslands: pathways to achieve future sustainability and productivity imperatives. *Crop Pasture Sci.* **2014**, *65*, 489, doi:10.1071/CP13420.
4. Pietrosemoli, S.; Green, J.T. Pasture systems for pigs. In *Achieving sustainable production of pig meat Volume 3*; Burleigh Dodds Science Publishing, 2018; pp. 167–218.
5. Pietrosemoli, S.; Tang, C. Animal Welfare and Production Challenges Associated with Pasture Pig Systems: A Review. *Agriculture* **2020**, *10*, 223, doi:10.3390/agriculture10060223.

6. Picardy, J.A.; Pietrosemoli, S.; Griffin, T.S.; Peters, C.J. Niche pork: Comparing pig performance and understanding producer benefits, barriers and labeling interest. *Renewable Agriculture and Food Systems*; Cambridge **2019**, *34*, 7–19, doi:<http://dx.doi.org/prox.lib.ncsu.edu/10.1017/S1742170517000230>.
7. Acciaioli, A.; Grifoni, F.; Fontana, G.; Esposito, S.; Franci, O. Evaluation of forest damage derived from the rearing of Apulo-Calabrese pig. **2012**, *5*.
8. Pietrosemoli, S.; Green, J.T.; Villamide, M.J. Sows-Gilts Stocking Rates and Their Environmental Impact in Rotationally Managed Bermudagrass Paddocks. *Animals* **2020**, *10*, 1046, doi:10.3390/ani10061046.
9. Horta, C.; Batista, M.; Roque, N.; Almeida, J. Environmental impact of outdoor pig production: soil P forms evolution spatial distribution and P losses in drainage waters. *Revista de Ciências Agrárias* **2012**, *35*, 36–48.
10. Bordeaux, C.; Grossman, J.; White, J.; Osmond, D.; Poore, M.; Pietrosemoli, S. Effects of rotational infrastructure within pasture-raised pig operations on ground cover, soil nutrient distribution, and bulk density. *Journal of Soil and Water Conservation* **2014**, *69*, 120–130, doi:10.2489/jswc.69.2.120.
11. Bondi, G.; Peruzzi, E.; Macci, C.; Masciandaro, G.; Pistoia, A. Changes in soil organic matter associated with pig rearing: Influence of stocking densities and land gradient on forest soils in central Italy. *Agriculture, Ecosystems & Environment* **2015**, *211*, 32–42, doi:10.1016/j.agee.2015.05.003.
12. Eriksen, J.; Hermansen, J.E.; Strudsholm, K.; Kristensen, K. Potential loss of nutrients from different rearing strategies for fattening pigs on pasture. *Soil Use and Management* **2006**, *22*, 256–266, doi:10.1111/j.1475-2743.2006.00035.x.
13. Jakobsen, M.; Hermansen, J.E.; Andersen, H.M.-L.; Jørgensen, U.; Labouriau, R.; Rasmussen, J.; Kongsted, A.G. Elimination behavior and soil mineral nitrogen load in an organic system with lactating sows – comparing pasture-based systems with and without access to poplar (*Populus sp.*) trees. *Agroecology and Sustainable Food Systems* **2019**, *43*, 639–661, doi:10.1080/21683565.2018.1541039.
14. Monteverde, S.; Pino, A.D. Variabilidad espacial en las propiedades químicas del suelo en un sistema de producción con cerdos en pastoreo. *Revista de Investigaciones de la Facultad de Ciencias Agrarias - UNR* **14**, *0*, 037–045.
15. Sharifi, M.; Messiga, A.J.; Asefpour Vakilian, K.; Stopford, E.; Hutchinson, T. Spatial distribution of soil phosphorous fractions following 1-year farrowing sows in an outdoor hog-rearing farm in Eastern Canada. *Environ Monit Assess* **2020**, *192*, 322, doi:10.1007/s10661-020-08260-y.
16. Miao, Z.H.; Glatz, P.C.; Ru, Y.J. Review of Production, Husbandry and Sustainability of Free-range Pig Production Systems. *Asian-Australasian Journal of Animal Sciences* **2004**, *17*, 1615–1634, doi:2004.17.11.1615.
17. Rivero, J.; López, I.; Hodgkinson, S. Pasture consumption and grazing behaviour of European wild boar (*Sus scrofa* L.) under continuous and rotational grazing systems. *Livestock Science* **2013**, *154*, 175–183, doi:10.1016/j.livsci.2013.03.006.
18. Allen, V.G.; Batello, C.; Berretta, E.J.; Hodgson, J.; Kothmann, M.; Li, X.; McIvor, J.; Milne, J.; Morris, C.; Peeters, A.; et al. An international terminology for grazing lands and grazing animals. *Grass and Forage Science* **2011**, *66*, 2–28, doi:10.1111/j.1365-2494.2010.00780.x.
19. Sollenberger, L.E.; Aiken, G.E.; Wallau, M.O. Managing grazing in forage–livestock systems. In *Management Strategies for Sustainable Cattle Production in Southern Pastures*; Elsevier, 2020; pp. 77–100 ISBN 978-0-12-814474-9.
20. Keys to Soil Taxonomy | NRCS Soils Available online: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/taxonomy/?cid=nrcs142p2_053580 (accessed on Aug 13, 2020).

21. Weather and Climate Database | North Carolina Climate Office Available online: <https://climate.ncsu.edu/cronos> (accessed on Aug 13, 2020).
22. Soil Test Methodologies Available online: <http://www.ncagr.gov/agronomi/stmethod.htm> (accessed on Aug 13, 2020).
23. Drinkwater, L.E.; Cambardella, C.A.; Reeder, J.D.; Rice, C.W. Potentially Mineralizable Nitrogen as an Indicator of Biologically Active Soil Nitrogen. In *Methods for Assessing Soil Quality*; John Wiley & Sons, Ltd, 2015; pp. 217–229 ISBN 978-0-89118-944-2.
24. Cougnon, M.; Baert, J.; Waes, C.V.; Reheul, D. Performance and quality of tall fescue (*Festuca arundinacea* Schreb.) and perennial ryegrass (*Lolium perenne* L.) and mixtures of both species grown with or without white clover (*Trifolium repens* L.) under cutting management. *Grass and Forage Science* **2014**, *69*, 666–677, doi:10.1111/gfs.12102.
25. Read, J.J.; Adeli, A.; Lang, D.J.; Oldham, J.L. Nutritive Value and Nutrient Uptake of Summer-Active and Summer-Dormant Tall Fescue under Different Broiler Litter Rates. *Agronomy Journal* **2017**, *109*, 473–482, doi:10.2134/agronj2016.08.0445.
26. Coulloudon, B.; National Applied Resource Sciences Center (U.S.) *Sampling vegetation attributes: interagency technical reference*; Bureau of Land Management : National Business Center [distributor: Denver, Colo., 1999;
27. Murphy, S.; Lodge, G. Ground cover in temperate native perennial grass pastures. I. A comparison of four estimation methods.; 2002.
28. Council, N.R. *Nutrient Requirements of Swine: Eleventh Revised Edition*; 2012; ISBN 978-0-309-48903-4.
29. Fernandez, J.A. Deposition and content of N, P and K in slaughter pigs. *DIAS Report. Animal Husbandry (Denmark)* **1998**.
30. Fernández, J.A.; Poulsen, H.D.; Boisen, S.; Rom, H.B. Nitrogen and phosphorus consumption, utilisation and losses in pig production: Denmark. *Livestock Production Science* **1999**, *58*, 225–242, doi:[https://doi.org/10.1016/S0301-6226\(99\)00011-1](https://doi.org/10.1016/S0301-6226(99)00011-1).
31. SAS 9.4 Product Documentation Available online: <https://support.sas.com/documentation/94/index.html> (accessed on Aug 13, 2020).
32. Realistic Yield Expectations for North Carolina Soils Available online: <https://realisticyields.ces.ncsu.edu/> (accessed on Jul 11, 2020).
33. Northup, B.K.; Starks, P.J.; Turner, K.E. Stocking Methods and Soil Macronutrient Distributions in Southern Tallgrass Paddocks: Are There Linkages? *Agronomy* **2019**, *9*, 281, doi:10.3390/agronomy9060281.
34. Franzluebbers, A.J.; Stuedemann, J.A.; Schomberg, H.H. Spatial Distribution of Soil Carbon and Nitrogen Pools under Grazed Tall Fescue. *Soil Science Society of America Journal* **2000**, *64*, 635–639, doi:10.2136/sssaj2000.642635x.
35. Sigua, G.C.; Myer, R.O.; Coleman, S.W.; Mackowiak, C.; Adjei, M.; Chase, C.C.; Albano, J. Regional Distribution of Soil Phosphorus Across Congregation-Grazing Zones of Forage-Based Pastures with Cow-Calf Operations in Florida. *Journal of Environmental Protection* **2011**, *2*, 408–417, doi:10.4236/jep.2011.24046.
36. Pistoia, A.; Bondi, G.; Balestri, G.; Mani, D.; Masciandaro, G. Soil degradation by grazing pig in Mediterranean environment. **2012**, *6*.

37. Coonan, E.C.; Richardson, A.E.; Kirkby, C.A.; Kirkegaard, J.A.; Amidy, M.R.; Simpson, R.J.; Strong, C.L. Soil carbon sequestration to depth in response to long-term phosphorus fertilization of grazed pasture. *Geoderma* **2019**, *338*, 226–235, doi:10.1016/j.geoderma.2018.11.052.
38. Dubeux, J.C.B.; Sollenberger, L.E.; Vendramini, J.M.B.; Interrante, S.M.; Lira, M.A. Stocking Method, Animal Behavior, and Soil Nutrient Redistribution: How are They Linked? *Crop Science* **2014**, *54*, 2341–2350, doi:10.2135/cropsci2014.01.0076.
39. Andersen, H.M.-L.; Kongsted, A.G.; Jakobsen, M. Pig elimination behavior—A review. *Applied Animal Behaviour Science* **2020**, *222*, 104888, doi:10.1016/j.applanim.2019.104888.
40. Dubeux, J.C.B.; Sollenberger, L.E. Nutrient cycling in grazed pastures. In *Management Strategies for Sustainable Cattle Production in Southern Pastures*; Elsevier, 2020; pp. 59–75 ISBN 978-0-12-814474-9.
41. Wezel, A.; Casagrande, M.; Celette, F.; Vian, J.-F.; Ferrer, A.; Peigné, J. Agroecological practices for sustainable agriculture. A review. *Agron. Sustain. Dev.* **2014**, *34*, 1–20, doi:10.1007/s13593-013-0180-7.
42. Whalen, J.K.; Thomas, B.W.; Sharifi, M. Chapter One - Novel Practices and Smart Technologies to Maximize the Nitrogen Fertilizer Value of Manure for Crop Production in Cold Humid Temperate Regions. In *Advances in Agronomy*; Sparks, D.L., Ed.; Academic Press, 2019; Vol. 153, pp. 1–85.
43. Blumetto, O.; Sanz, S.C.; Barber, F.E.; Villagrà, A.; Torres, A.G. Caracterización productiva y ambiental de un sistema semi-extensivo de engorde de cerdos en condiciones de sequía en Uruguay. *ITEA, información técnica económica agraria: revista de la Asociación Interprofesional para el Desarrollo Agrario (AIDA)* **2012**, 256–274.
44. NC-NRCS. Conservation planning guidelines for outdoor swine operations. 22 pp. 2007. Available online at: <https://efotg.sc.gov.usda.gov/references/Delete/2008-7-12/OSOTECHNOTE.pdf> (accessed on 25 January 2020).
45. Souther, S.; Loeser, M.; Crews, T.E.; Sisk, T. Complex response of vegetation to grazing suggests need for coordinated, landscape-level approaches to grazing management. *Global Ecology and Conservation* **2019**, *20*, e00770, doi:10.1016/j.gecco.2019.e00770.
46. Kongsted, A.G.; Jakobsen, M. Effect of genotype and level of supplementary concentrate on foraging activity and vegetation cover in an organic free-range pig system. *Acta Agriculturae Scandinavica: Section A, Animal Science* **2015**, *65*, 139–147, doi:10.1080/09064702.2016.1156152.
47. Hoveland, C.S.; McCann, M.A.; Hill, N.S. Rotational vs. Continuous Stocking of Beef Cows and Calves on Mixed Endophyte-Free Tall Fescue-Bermudagrass Pasture. *Journal of Production Agriculture* **1997**, *10*, 245–250, doi:10.2134/jpa1997.0245.
48. Michalk, D.L. Sustainability, Biodiversity and Environmental Issues: A Global Perspective for Livestock Production. 18. XXIII International Grassland Congress. New Delhi, India. Available online at: <https://uknowledge.uky.edu/igc/23/plenary/2/> (Accessed on June 28 2020).
49. Wang, H.; Zhang, Y.; Chen, G.; Hettenhausen, C.; Liu, Z.; Tian, K.; Xiao, D. Domestic pig uprooting emerges as an undesirable disturbance on vegetation and soil properties in a plateau wetland ecosystem. *Wetlands Ecol Manage* **2018**, *26*, 509–523, doi:10.1007/s11273-017-9588-1.
50. Sehested, J.; Søgaard, K.; Danielsen, V.; Roepstorff, A.; Monrad, J. Grazing with heifers and sows alone or mixed: herbage quality, sward structure and animal weight gain. *Livestock Production Science* **2004**, *88*, 223–238, doi:10.1016/j.livprodsci.2003.11.008.

51. Rivero, M.J.; Rodríguez-Estévez, V.; Pietrosemoli, S.; Carballo, C.; Cooke, A.S.; Kongsted, A.G. Forage Consumption and Its Effects on the Performance of Growing Swine—Discussed in Relation to European Wild Boar (*Sus scrofa* L.) in Semi-Extensive Systems: A Review. *Animals* **2019**, *9*, 457, doi:10.3390/ani9070457.
52. Blumetto Velazco, O.R.; Calvet Sanz, S.; Estellés Barber, F.; Villagrà García, A. Comparison of extensive and intensive pig production systems in Uruguay in terms of ethologic, physiologic and meat quality parameters. *R. Bras. Zootec.* **2013**, *42*, 521–529, doi:10.1590/S1516-35982013000700009.
53. Gustafson, G.M.; Stern, S. Two strategies for meeting energy demands of growing pigs at pasture. *Livestock Production Science* **2003**, *80*, 167–174, doi:10.1016/S0301-6226(02)00319-6.
54. Nyachoti, C.M.; Zijlstra, R.T.; de Lange, C.F.M.; Patience, J.F. Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. *Can. J. Anim. Sci.* **2004**, *84*, 549–566, doi:10.4141/A04-001.
55. Gupta, R.C.; Evans, T.J.; Nicholson, S.S. Ergot and Fescue Toxicoses. In *Veterinary Toxicology*; Elsevier, 2018; pp. 995–1001 ISBN 978-0-12-811410-0.
56. Leuchtmann, A.; Bacon, C.W.; Schardl, C.L.; White, J.F.; Tadych, M. Nomenclatural realignment of *Neotyphodium* species with genus *Epichloë*. *Mycologia* **2014**, *106*, 202–215, doi:10.3852/13-251.
57. Edwards, S.A. Intake of nutrients from pasture by pigs. *Proc. Nutr. Soc.* **2003**, *62*, 257–265, doi:10.1079/PNS2002199.
58. Kongsted, A.G.; Nørgaard, J.V.; Jensen, S.K.; Lauridsen, C.; Juul-Madsen, H.R.; Norup, L.R.; Engberg, R.M.; Horsted, K.; Hermansen, J.E. Influence of genotype and feeding strategy on pig performance, plasma concentrations of micro nutrients, immune responses and faecal microbiota composition of growing-finishing pigs in a forage-based system. *Livestock Science* **2015**, *178*, 263–271, doi:10.1016/j.livsci.2015.06.010.
59. Leite, D.M.G.; Silva, M.A. da; Medeiros, R.B. de; Saibro, J.C. de; Pavan, M.A.; Barrey, M.A.A. Efeito de diferentes sistemas de pastejo sobre o desempenho de suínos mantidos em pastagem de trevo-branco (*Trifolium repens* L.). *Revista Brasileira de Zootecnia* **2006**, *35*, 792–796, doi:10.1590/S1516-35982006000300022.
60. Jakobsen, M.; Kongsted, A.G.; Hermansen, J.E. Foraging behaviour, nutrient intake from pasture and performance of free-range growing pigs in relation to feed CP level in two organic cropping systems. *Animal* **2015**, *9*, 2006–2016, doi:10.1017/S1751731115001585.
61. Carlson, D.; Lærke, H.N.; Poulsen, H.D.; Jørgensen, H. Roughages for Growing Pigs, with Emphasis on Chemical Composition, Ingestion and Faecal Digestibility. *Acta Agriculturae Scandinavica, Section A — Animal Science* **1999**, *49*, 129–136, doi:10.1080/090647099424033.
62. Aquilani, C.; Sirtori, F.; Franci, O.; Acciaioli, A.; Bozzi, R.; Benvenuti, D.; Čandek-Potokar, M.; Pugliese, C. Effects of Different Protein Levels on the Nitrogen Balance, Performance and Slaughtering Traits of Cinta Senese Growing Pigs. *Animals* **2019**, *9*, 1021, doi:10.3390/ani9121021.
63. Daniel, A.D.; McIntosh, B.J.; Plunk, J.D.; Webb, M.; McIntosh, D.; Parks, A.G. 7 Effects of rotational grazing on water-soluble carbohydrate and energy content of horse pastures. *Journal of Equine Veterinary Science* **2015**, *35*, 385–386, doi:10.1016/j.jevs.2015.03.014.
64. Rutherford, K.M.D.; Haskell, M.J.; Glasbey, C.; Lawrence, A.B. The responses of growing pigs to a chronic-intermittent stress treatment. *Physiology & Behavior* **2006**, *89*, 670–680, doi:https://doi.org/10.1016/j.physbeh.2006.08.006.

65. Rodríguez-Estévez, V.; Sánchez-Rodríguez, M.; García, A.R.; Gómez-Castro, A.G. Average daily weight gain of Iberian fattening pigs when grazing natural resources. *Livestock Science* **2011**, *137*, 292–295, doi:10.1016/j.livsci.2010.11.015.
66. Stern, S.; Andresen, N. Performance, site preferences, foraging and excretory behaviour in relation to feed allowance of growing pigs on pasture. *Livestock Production Science* **2003**, *79*, 257–265, doi:10.1016/S0301-6226(02)00171-9.
67. Renner, B.M. The Effect of Stocking Rate History on Soil Nutrient Levels and Forage Nutrient Uptake in Pasture Hog Production Systems. North Carolina State University. Master of Science Thesis. 2011. 92 pp. Available online: <https://repository.lib.ncsu.edu/bitstream/handle/1840.16/7325/etd.pdf?sequence=2&isAllowed=y> (Accessed on 7 September 2020)



© 2020 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

IV. GENERAL DISCUSSION

In pasture pig operations, an appropriate grazing management is necessary to prevent damage to the pasture and, consequently, soil degradation. The impact that grazing animals exert on the pasture ecosystem is the result of diverse interrelated components including defoliation, treading, trampling, and manure deposition (Sales-Baptista et al., 2016).

The way the resources of the grassland ecosystem are organized to attain a defined objective constitutes the grazing management (Allen et al., 2011). Sollenberger, Aiken, and Wallau, (2020), enumerated grazing intensity, grazing frequency, stocking method, and timing of grazing as the elements that shape the grazing management. According to Aiken (2016), the most important means to reach production goals is the stocking rate, while the way the animals are assigned to the pastures models the stocking method (Allen et al., 2011), which in turn modifies the grazing frequency (Sollenberger, Aiken, and Wallau, 2020).

III.1. Effect of pig stocking rate on vegetative ground cover and soil nutrients.

Adopting the appropriate stocking rate for a pasture system is a critical management decision because it can influence animal performance, long-term farm productivity, economic outcomes, wildlife and natural resources (Sollenberger, Aiken, and Wallau, 2020). The degree of damage that grazing pigs can exert onto the vegetation and the soil can be limited by applying the appropriate stocking rate (Eriksen et al., 2006; Eriksen and Kristensen, 2001; Rachuonyo and McGlone, 2006). Sales-Baptista et al. (2016) advert that the implementation of high stocking rates could magnify the undesirable impacts of grazing animals. A greater intensity of management, and consequently a greater stocking rate, has been associated with greater effects on ground cover and soil properties (Acciaioli et al., 2012; Bondi et al., 2015; Rachuonyo, Pond, and McGlone, 2002).

Maintaining ground cover in outdoor pig systems is critical to controlling water, soil and nutrient movement off site. The amount of ground cover in a certain pasture will be dependent on a variety of factors including the pasture species, climate, soil, pasture management (Lang and McDonald, 2005), and seasonal variability (Monteiro et al., 2018). The establishment of an adequate stocking rate is a key management component to assure the preservation of ground cover levels required to avoid negative environmental consequences. Maintaining an appropriate ground cover level offers a wide array of benefits including animal welfare, forage supply, protection against erosion and runoff, and ultimately against soil and water pollution. In 2007, North Carolina USDA Natural Resource Conservancy Service (NRCS) conservationists established as threshold for conservation purposes, that outdoor pig operations should retain a ground cover of 75% or more (NC-NRCS 2007).

Two studies were conducted to evaluate the effect of stocking rates of growing-finishing pigs (37, 74, 111, and 148 pigs ha⁻¹; 2689; 5378; 8067; and 10756 kg live weigh ha⁻¹, respectively) and sows-gilts (10, 15 and 25 sows-gilts ha⁻¹; 2308; 2531; and 5771 kg live weigh ha⁻¹, respectively) on ground cover and soil properties of bermudagrass paddocks (Field studies 1 and 2, respectively).

Vegetative Ground cover

Pigs can have a direct effect on ground cover when they graze, but also an indirect effect due to trampling and rooting activities (Pistoia and Ferruzzi, 2010). Trampling has been associated with higher soil compaction, damaged soil aggregates, decreased water infiltration and increased run-off

[Drewry, 2006; Hiltbrunner et al., 2012). Rooting has been linked to a reduction in vegetative ground cover as a consequence of the damage to the aerial and radicular portions of the vegetation (Palacio et al., 2013), and has been considered as the starting point for erosion and runoff, and a risk factor for ground water pollution (Thomsen et al., 2001).

The results of the field studies showed differences in ground cover measured during the last experimental week among paddocks managed under different stocking rates (85.5; 66.6; 52.6; 35.6 % final ground cover for 37; 74; 111; and 148 pigs ha⁻¹, respectively, and 78.3; 68.4; and 65.5 % for 10; 15; and 25 sows-gilts ha⁻¹, respectively) . Only paddocks managed with the lowest stocking rate (37 pigs ha⁻¹ or 10 sows ha⁻¹) maintained the ground cover level (75%) recommended by North Carolina NRCS (2007). Reduction of vegetative ground cover following increments in stocking rate have been previously reported (Campagna et al., 2011; Hermansen et al., 2004; Thomsen et al., 2001). Even though in this studies rest periods were implemented between grazing periods, the recovered ground cover did not reach the initial ground cover values, a situation that could be an indicator of damage to the vegetation and(or) to the soil structure. It could be also possible that the first grazing period ended too late in the forage growing cycle, and/or the second grazing period started too early, therefore not allowing bermudagrass to completely develop the structures (roots, rhizomes, shoots, tillers, stolons) needed for growth and regrowth, consequently impairing its spring recover (Pande et al., 2000).

Soil properties

The stocking rate, is a key factor in the management of pasture systems, and may have effects on soil organic matter, soil biological activity, nutrient loads, nutrient cycling, water infiltration, runoff and erosion (Aiken, 2015; Bondi et al., 2015; Quintern, 2005). Greater pig stocking rates involve the use of more supplemental feed, raising the load of nutrients imported to the system and the threat of losses to the environment (Campagna et al., 2011; Eriksen et al., 2006; Sikala, 2012). In both field studies the soil samples collected following animal removal differed in soil nutrient concentrations according to stocking rates. As these nutrients are major components of pig manure, it may be assumed that the variation of these nutrients detected among the paddocks could be reflecting additional manure deposited in the more intensively managed pastures.

The results obtained herein support previous research that have linked greater stocking rates with increments in soil nitrates and phosphorus, and greater N concentrations and N surpluses in soils (Campagna et al., 2011; Eriksen and Kristensen 2001; Monteverde and DelPino, 2014; Williams et al., 2000). Paddocks managed with the higher stocking rates received more nutrients to the system via animal feed and mineralization of the soil organic matter (Webb et al., 2014). Similarly, in individual paddocks that included trees and were managed with a stocking rate equivalent to 30 or 37 sows ha⁻¹ and seven weeks of occupation, were reported loads of 67 and 78 kg N ha⁻¹ respectively (Jakobsen et al., 2018). However, in research conducted in Texas, there were no differences found in soil nitrate among the tested stocking rates (Rachuonyo and McGlone, 2006). The adoption of greater stocking rates (40 to 50 pigs ha⁻¹ vs 1 to 2 pigs ha⁻¹) in a hilly area of Tuscany resulted in damage of soil physical and chemical properties, including a decrease in carbon concentrations, lesser chemical parameters linked to organic matter and increased mineralization, and impaired soil fertility and quality (Bondi et al., 2015). The deterioration of physical soil characteristics, such as increases in soil bulk density, have been related to grazing management intensity and animal trampling behavior (Drewry, 2006).

The presence of greater ground cover in paddocks managed with the lower stocking rate (37 pigs ha⁻¹ and 10 sows-gilts ha⁻¹) could have also partially contributed to the reduction in the soil nutrient levels as a consequence of plant uptake [Rachuonyo, Pond and McGlone, 2002].

A critical issue with the addition of swine manure to soils is the potential risk of increasing the concentration of heavy metals originated from pig feedstuffs and additives (Formentini et al., 2015; Menzi et al., 1999; Salomon et al., 2007). In the study herein, an increase in the concentrations of zinc and copper in the soil were observed when intensifying the stocking rate from 10 to 25 sows-gilts ha⁻¹; nonetheless, the values attained remained under the levels for environmental concerns (Hardy et al., 2008).

Pig density per unit of area has been identified as one factor that disrupts the excretory behavior of pigs housed indoors (Banhazi, 2013). In these systems, a direct relationship between pen size and the size of the area dedicated to defecation has been reported, the latter being larger in larger pens (Yicui, Baoming, and Zhengxiang, 2008). The size of the paddocks used in the growing-finishing pig study (field study 1) (340, 450, 675 vs 1350 m² for 148, 111 and 74 vs 37 pigs ha⁻¹, respectively) could have limited the expression of the excretory behavior linked with the natural behavior of selecting or avoiding certain areas for excretion (Andersen, Kongsted, and Jakobsen, 2020). As previously reported, pigs prefer dunging areas 5 to 15 m away from their resting areas (Salomon et al., 2007; Stolba and Wood-Gush, 1989) or in the proximity to fences (Watson et al., 2003). In the study of the growing finishing pigs, there were 5 or more meters between the center and the inner sampling point only in paddocks with the lowest stocking rate (37 pigs ha⁻¹), therefore the urinating or defecating locations could be more a consequence of the paddock design than an expression of the natural behavior of the pigs (Andersen and Pedersen, 2011).

Impact of pigs' spatial distribution on vegetation and soil properties

Pigs tend to concentrate their activities in certain areas of the paddocks such as the vicinity of shelters, shades, feeders, water structures and fences. As a consequence of grazing, rooting and trampling behavior, the survival of the vegetation in these areas may be compromised. Damaged ground cover can result in a reduction of nutrient removal and in an increased potential of runoff and erosion. Additionally these more impacted areas could potentially become nutrient hot-spot areas (Eriksen et al., 2006; Eriksen and Kristense, 2001; Sommer et al., 2001; Williams et al., 2000), which have been associated with an increased risk of nitrate nitrogen leaching (Jørgensen et al., 2018), especially when the nutrients migrate deeper than 60 cm in the soil profile. Higher numbers of animals can increase the eventuality of environmental hazards.

In the sows stocking rate study (Field study 2), differences in ground cover were detected among the sections of the paddocks, with graze areas showing 68% more ground cover than the service sections. Moreover, it has been noticed that pigs tend to impact already affected areas and enlarge existing bare soil spots. What have been called “grazed patches perpetuating”, showing the lack of random area utilization (Barnes et al., 2008). Similar to these results, greater deterioration of the vegetation cover as a consequence of rooting and trampling behavior in areas close to the location of the service structures, and along paddock fences, have been reported (Acciaioli et al., 2012; Quintern and Sundrum, 2006; Salomon et al 2005; Bordeaux et al 2014). The greater impact on the ground cover observed in the service sections is attributed to the permanent access of sows to this area of the paddocks where drinkers and shelters were located. Conversely, the access to one of the eight graze and feeding sections was sequential, and allocated on a weekly basis determined by the rotation. The

grazing sections were occupied only one week during each grazing cycle. It has been previously reported that sows show a tendency to concentrate their activities to the areas adjacent to shelters and huts (Braund et al., 1998; Eriksen and Kristensen, 2001). The lower ground cover of the service sections could represent higher risks for runoff and nutrient leaching, however in this study, the service sections were located in the center of the paddocks surrounded by the grazing sections which presented greater ground cover and could trap escaping runoff and sediment.

In the growing-finishing pig study (Field study 1), it was found differences in bulk density among samples collected from the center of the paddocks compared to those from the inner and outer sampling positions. This could be a consequence of greater rooting activity in this position where the shelter and water structures were located. The overturning and mixing of soil in this area could have neutralized the trampling effect which was more evident in other areas of the paddocks. Similarly, lesser bulk densities have been recorded in soil patches disturbed by wild boars (Cuevas et al., 2012). These findings, and the existence of a significant sampling position x sampling depth interaction, suggest the existence of a spatial heterogeneity in the horizontal and vertical dimensions of the soil attributes measured in paddocks grazed by pigs. Other authors have also found differences in soil physical characteristics in different sections of paddocks managed with pigs which coincide with the findings of this study. Greater damage to soil structure in the wallow areas followed by the shelter and then the feeding areas has been recorded (Menzi et al., 1998). Monteverde and Del Pino (2014), determined higher soil density in the service areas where the huts were located, than in the grazing areas. Similarly, Bordeaux et al. (2014), observed greater compaction on interior subplots of paddocks with permanent shade and drinking structures. Differences among samples collected at different sampling depths, recording greater values with increased depth were also found (Monteverde and Del Pino, 2014).

The results reported in the growing-finishing pigs study validated the existence of a spatial pattern in soil nutrients distribution. Greater concentrations of Total-N, $\text{PO}_4\text{-P}$, and Total-P were found in samples from the inner and the outer positions, farther than the shelters and drinking stations, but closer to the feeders and fences. The buildup of these nutrients may be related to greater fecal deposition in these areas compared to the center. Similar results to those obtained in this study were reported by Bordeaux et al. (2014), who indicated that greater concentrations of inorganic N were found in the exterior versus the interior areas of paddocks grazed by growing pigs. Defecating pigs tend to walk a longer distance from the resting and feeding areas than when urinating (Olsson et al., 2014), which could lead to differential nutrient accumulation. Irregular distribution of nutrients in paddocks managed with pigs has been previously reported (Bordeaux et al., 2014; Ivanova-Peneva, Aarnink, and Verstegen, 2006; Scharifi et al., 2020). Correspondingly, differences in excretory activity performed during day or night hours have been reported for fattening pigs reared in confinement, who exhibited a preference for defecating in corners away from their feeding and lying areas (Guo, Lian, and Yan, 2015).

In the growing-finishing pig study, greater concentrations of $\text{NO}_3\text{-N}$ were found in samples collected in the outer sections (areas contiguous to the fence and where the feeders were located) of paddocks managed with 148 pigs ha^{-1} in comparison with the concentrations of this nutrient registered in samples collected in paddocks managed with 37 pigs ha^{-1} , indistinctly of the position of collection. The results obtained in both stocking rate studies (growing-finishing pigs and sows-gilts), are in agreement with previous studies where it was indicated an effect of the stocking rates and soil sampling depth on soil nitrate concentrations (Eriksen, 2001; Eriksen, Petersen, and Sommer, 2002; Jørgensen et al., 2018).

Additionally, the results herein point out the existence of an interaction sampling position by sampling depth for bulk density, Total-N, and Total-P soil concentrations. These findings coincide with the results of Scharifi et al. (2020) who suggested that the concentration of soil nutrients in paddocks individually grazed with lactating sows showed a marked spatial (horizontal and vertical) pattern along four areas. According to these authors, the pattern varied among soil nutrients and also among the form of the nutrients, which presented an uneven pattern in both the vertical and horizontal dimensions of the soils. Previous research have indicated also differences in electrical conductivity, and in the concentrations of inorganic-N, and available-P in function to areas of the paddocks. Per example among the exterior and the interior areas of the paddocks (Bordeaux et al., 2014), or the service areas where shelters, feeders, drinking points and wallows were located and the grazing areas (Monteverde and Del Pino, 2014; Sharifi et al., 2014).

In soil samples from both studies the nutrient concentrations varied also according to sampling depth with most of the nutrients showing greater concentrations of most of the nutrients in samples collected from the upper soil strata. While grazing pigs deposit their excreta on the paddock surface. The organic matter deposited in this way will eventually decay and release its components into the soil profile, circumstance that could increase the concentration of nutrients in the soil upper layer. However, for some nutrients such as PO₄-P, NH₄⁺, Total P, Na and Fe, greater concentrations were found in the lower soil strata, sometimes reaching the 60 to 90 cm layer. This can be considered an evidence of the movement of the nutrients through the soil profile, and could represents a water quality environmental risk.

Forage species traits, such as their growth and reproductive habits (erect or prostrate, bunch or sod forming), nutritive value, and palatability, can favor rooting behavior (Pistoia and Ferruzzi, 2010; Rachuonyo, Allen, and McGlone, 2005), and affect the ability of the forage to survive (Williams et al., 2000). The final ground cover reported in our studies, 55 % on average, demonstrates the potential of bermudagrass inclusion in pasture-based pig systems. The morphological and physiological traits of bermudagrass, a warm season perennial species adapted to different types of soils and climates, that shows aggressive growth, good grazing tolerance, and ability to produce biomass of good quality forage when soil nutrients are not limiting (Schneider-Canny et al., 2019), make this grass suitable for this kind of systems. Its decumbent growth habit and reproductive mechanisms (rhizomes, stolons, and extensive root mass) allowed it to endure the grazing, rooting, trampling and lounging behaviour of the pigs, and to recover during the rest periods between successive grazings (Williams et al., 2000).

III.2. Effect of pig stocking methods on soil properties, vegetative ground cover and animal performance.

Stocking methods are techniques that allow the management of grazing animals according to the pasture area and occupation time to reach a determined objective (Allen et al., 2011). It was hypothesized that different stocking methods to manage pigs on tall fescue pastures would present different impacts on the soil, the vegetation and the animal performance. It was expected that the implementation of rotational stocking methods would enhance soil nutrients distribution within the paddocks, improve ground cover persistence, would sustain appropriate animal performance, and increase soil nutrients uptake by the forage growing on the pastures.

The following discussion pertains to field study number 3 comparing the effects of growing-finishing pigs managed either rotationally or under strip-grazing stocking methods to those of continuously-stocked pigs.

Soils physical-chemical properties

Most of the soil variables did not differ significantly among stocking methods, which could be attributed to having managed all the paddocks with the same stocking rate (47 pigs ha⁻¹). Another possible reason for the lack of differences, could be related with the experiment length. Perhaps after longer grazing periods, or more grazing periods greater differences would become evident. The results showed, however, that pig stocking methods influenced soil bulk density. Lower bulk density was observed from the paddocks managed rotationally or under strip grazing. As soil bulk density increases as a result of pig trampling, it could be reasonable to assume that pigs under continuous stocking, being free to use the area at will, would tend to concentrate in already-used areas, thus increasing their bulk density. Similarly, Bordeaux et al. (2014) reported greater bulk density in pastures managed with pigs under a stationary scheme, compared to the bulk density of paddocks where service structures (shelter and water) were moved weekly. A study comparing stocking method for cattle reported that lower values for bulk density were recorded in the rotational managed soils (Northup, Starks, and Turner, 2019).

In the study herein, pigs under rotational stocking had access to the grazing areas for only a week, while maintaining a permanent access to the service-central area. As the latter represented proportionally a smaller area of the paddock (11.11%), pigs could have had a more localized impact on certain soil areas (Franzluebbers, Stuedemann, and Schomberg, 2000; Sigua et al., 2011). Conversely, rooting behavior, which has been related to reduction in soil compaction (Bordeaux et al., 2014; Pistoia et al., 2012), could have happened more frequently in the more extensive grazing areas. Additionally, pastures managed under continuous stocking exhibited lesser vegetative ground cover than the other two methods. The presence of ground cover could have partially alleviated the direct impact of pig hooves on the soil contributing to a reduction in the soil bulk density of the rotationally stocked paddocks.

Soil samples showed differences in their concentrations of NO₃⁻, P, K, Mn, Zn and Cu among paddocks managed with different stocking methods. Greater concentrations of the above-mentioned soil nutrients were found in paddocks managed under continuous stocking. Differences in soil nutrients among continuous and rotationally stocked pastures have been related to the length of graze periods (Dubeaux et al., 2014). In the present study, the differences could be attributed to the short occupation period (1 week) that would have allowed the forage to rest and recover from animal disturbances in the rotational and strip grazed paddocks, and the uptake by the grass of some of the nutrients deposited through the manure and feed wastage. Conversely, having unrestricted freedom of movement, pigs in the continuous system could have exerted a greater selective pressure on the vegetation of their preference, thus causing localized overgrazing. Recurrent defoliations and soil disturbance have a negative impact on forage root systems, resulting in a reduction of nutrient uptake (Dubeaux et al., 2014). In addition, as a consequence of the weekly movement of feeding (rotational and strip grazing) and watering stations and shelters (strip grazing), the elimination behavior of pigs could have been modified (Andersen, Kongsted, and Jakobsen, 2020), causing a better dispersion of nutrients (Dubeaux et al., 2014; Dubeux and Sollenberger, 2020), and a greater forage uptake, thus leaving lower concentrations of nutrients in the soil. Conversely, in paddocks under continuous stocking the feeding, drinking and resting areas were kept unchanged for the entire length of the graze period. In addition, the short graze periods followed by the rest period could have improved forage nutrient uptake efficiency by supplying nutrients via manure in the moment when forages need them for regrowth (Wezel et al., 2014). Similar results have been obtained in paddocks grazed with cattle, where the stocking method influenced the concentration of NO₃⁻, P, K, Mg, Ca and S, with lower

concentration of the nutrients in paddocks managed with the shorter occupancy (Northup, Starks, and Turner, 2019).

Differences were also observed between some of the soil properties in samples collected at different depths. Soil bulk density was greater deeper in the soil, while humic matter concentrations and exchangeable acidity showed higher values in the topsoil layer (0 to 15 cm). The concentration of NO_3^- , P, K, S, Mn, Zn, Cu, Na, and Fe varied among the soil layers with greater values found in the top 0 to 15 cm layer for most of the nutrients, but for Fe which presented higher values on the bottom strata of the explored soil profile (15 to 30 cm). Previous studies have reported vertical displacement of soil nutrients (Dubeux, and Sollenberger, 2020; Northup, Starks, and Turner, 2019). Grazing pigs deposit dung and urine on the surface of the paddocks. Manure needs to be physically degraded before releasing its components to the soil. However, manure nutrients availability for plant uptake will be dependent on microbial activity (Whalen, Thomas, and Sharifi, 2019) and environmental conditions. It is likely that the differences on soil properties, and the greater concentrations of nutrients in the upper layer could be attributed to the deposition of manure and organic matter to the surface of the ground.

When comparing the initial level of nutrients with those in samples collected following the second pig graze period, changes of different magnitudes were observed. For example, the 0 to 15 cm soil layer showed an increase in the concentrations of NO_3^- -N, P and K. Similarly, increases in concentration of inorganic-N forms (53 % more NO_3^- -N and 75% more NH_4^+ -N) were reported in paddocks (ryegrass, white and red clover) managed during two 12-week periods with a stocking rate equivalent to 58 pigs ha^{-1} (Blumetto et al., 2012). In the study herein, rotational stocking methods did not improve the homogeneity of nutrients distribution, most likely due to the short duration of the graze periods.

Vegetation

Uncontrolled grazing leads to reduced ground cover (Souther et al., 2019). As a consequence of foraging-pigs' activities, mainly rooting, ground cover resulted damaged. As in previous studies, the sites where pigs tended to congregate, such as resting, feeding and wallowing, showed a greater impact. In the study herein, however, at the end of the 12-week graze periods the ground cover was over 66 %, greater than the ground cover (8 to 27 %) reported by Kongsted and Jakobsen (2015) for pigs grazing (338 $\text{m}^2 \text{ pig}^{-1}$, 30 pigs ha^{-1}) a multispecies pasture including grass–clover, and forage herbs for a similar period of time, and greater than the final ground cover (55%) recorded for bermudagrass pastures grazed with growing-finishing pigs (field study 1). It is worth noting that grazing management strategies varied between the above mentioned studies which make comparisons difficult.

Greater ground cover was recorded in paddocks managed with the rotational and the strip grazing stocking methods in comparison with the values obtained under continuous stocking. This advantage may be explained by the short occupation period (1 week) and the length of the rest period (7 weeks) in both rotational stocking methods, while the action of the pigs was uninterrupted under continuous stocking, which could have led to the exhaustion and disappearance of forage plants. Similarities in ground cover among both rotational alternatives could be explained by the impact received by the vegetation under the shelter, drinkers and feeding sites which were disturbed with each weekly movement in the strip grazing method, and could be equivalent to the area set to be used as a service area in the rotational method. Corresponding circumstances were described by Bordeaux et al. (2014) when comparing the ground cover of sudangrass (*Sorghum bicolor* [L.] Moench) and ryegrass (*Lolium multiflorum*) in pasture-based pig systems managed with stationary or mobile structures. Similarly, the response of tall fescue paddock grazed with beef cattle was affected by the stocking method with paddocks managed rotationally showing greater ground cover (Hoveland, McCann, and Hill, 1997).

Paddocks under different stocking methods presented similar botanical composition, with tall fescue maintaining its position as the dominant species at the end of the experiment (66 % of the species present in the paddocks). Michalk (2015) asserted that to maintain the competitive position in a pasture, the dominant species (in this case tall fescue) needs to represent at least the 60% of the biomass. Nevertheless, the emergence of species that were not present at the beginning of the study were observed across stocking methods. Pigs grazing and rooting behaviors could have impacted the vegetation, leaving bare soil patches for other species to colonize (Souther et al., 2019, Wang et al., 2018). Seeds of annual opportunistic species such as crabgrass (*Digitaria sanguinalis*) could have been waiting for ideal conditions to sprout. At the moment of the evaluation, crabgrass was the second most important species present in the paddocks (30%), whereas ragweed (*Ambrosia artemisiifolia*) dominated the broad leaves group which represented 4 % of the species in the paddocks. Differences in botanical composition of paddocks grazed by pigs have been previously reported (Sehested et al., 2004). Those differences could be partly attributed to the selective grazing behavior exerted by pigs on pasture which tend to select certain plants and moreover parts within a plant (Wang et al., 2018), leaving the less preferred species to dominate the stand (Souther et al., 2019). Similarly, replacement of the dominant plant species by annual vegetation due to the impact of pigs rooting on species composition have been reported previously (Wang et al., 2018). Accordingly, the loss of ground cover would be the initial effect of pigs disturbance, followed by the apparition of annual species that would take advantage not only of the physical removal of competitors but also of the nutrients available in the soil (Wang et al., 2018).

The values presented across treatments for both ground cover (70.5 % on average), and botanical composition (Fescue 66 %; Crabgrass 30 %, and other broad leaves 4 %) four weeks following animal removal from the paddocks after the second graze period, could be interpreted that the pasture system possesses resilience, a trait that can promote a quick recovery from the damage inflicted by grazing animals, in this case the pigs.

Animal performance

Feed disappearance was 8.1% greater during the first graze period (December to March, winter) than during the second one (May to August, summer). This could be partially explained as the effect of the environmental temperature on pigs' maintenance requirements, and to the nutrients supplied by the pasture, which can present seasonal variations. It has been previously reported that the voluntary feed intake of grazing pigs increased when the temperature was under the lower limit of the comfort zone (Blumetto et al., 2013; Gustafson, and Stern, 2003), and decreased when the environmental temperature surpassed the upper limit of the temperature comfort zone which decreases as pig age (Nyachoti et al., 2004). It is important to note the potential exposure of the pigs included in this study to fescue toxicosis, which can cause decreased feed intake (Gupta, Evans, and Nicholson, 2018). It has also been reported that fescue toxicosis effects are more evident during summer than during winter (Gupta, Evans, and Nicholson, 2018). The tall fescue pastures used in this study were not tested for the presence of the fungal endophyte species (*Epichloë coenophiala* Bacon and Schardl.) involved in the symbiotic relationship with the forage (Leuchtman et al., 2014).

Considering that higher dry matter intake is expected in pasture-based pigs (15% more than indoor-managed pigs) to balance the increased energy requirements (for thermoregulation and exercise) (Edwards, 2003; Kongsted et al., 2015), the feed disappearance values registered in this study (2.01 and 1.86 kg pig d⁻¹ for winter and summer, respectively) could seem low when compared with intake values recorded by other researchers, suggesting that tall fescue could have made a significant contribution to the nutrition of the pigs (Kongsted et al., 2015, Leite et al., 2006). Intake of forages in

grazing growing to finishing pigs represents between 10 and 20% of the total DM intake (Carlson et al., 1999; Jakobsen, Kongsted, and Hermansen, et al., 2015). Greater feed intake values (2.9 kg pig d⁻¹) that those recorded in this study have been reported for pigs managed in a daily strip grazing system (Gustafson, and Stern, 2003), or for weekly rotated pigs (3.15 kg DM pig d⁻¹) (Blumetto et al., 2012). These last authors recorded intake of grass of 0.26 kg DM pig d⁻¹ (Blumetto et al., 2012). Jakobsen et al. (2015) reported intakes values of alfalfa in the range of 0.33 to 0.47 kg DM pig d⁻¹ with similar feed intakes to those registered in this study (2.2 kg DM pig d⁻¹). However, the possibility of reduction in pig feed intake as an effect of fescue consumption and potentially fescue toxicosis cannot be ruled out (Gupta, Evans, and Nicholson, 2018).

Previous studies reported no differences in supplementary feed intake (average: 2.4 kg pig d⁻¹) among pigs grazing white clover under different stocking methods (Leite et al., 2006). No differences were neither observed in the grazing behavior or pasture intake of European wild boar managed either in a continuous or in a rotational grazing system (Rivero, López, and Hodgkinson, 2013). The feed efficiency values measured in this study were greater (+8%) in pigs from rotationally managed paddocks than those reported for pigs continuously stocked, while the values obtained from pigs in the strip-grazing treatment were intermediate. Similar values have been registered for Cinta Senese pigs (Aquilani et al., 2019), whereas a much lower feed efficiency (less than 70% of the values obtained in this study) has been reported for grazing pigs in Uruguay (Blumetto et al., 2012).

Pigs from the rotationally-stocked paddocks showed greater weight gain (8.8% and 8.5% more total and daily weight gain, respectively) when compared with pigs from paddocks managed with the other two stocking methods, which did not differ among them. Although pigs were offered the same supplemental feed *ad libitum*, it may be that the pasture rotationally stocked had a higher forage quality as reported previously for mixed warm and cool-season grass pastures managed with horses showing differences in concentrations of fiber (ADF, NDF, and lignin), water soluble carbohydrates and sugar, and digestible energy (Daniel et al., 2015). Additionally, the weekly movement of animals, shelter and feeding and drinking structures in the strip grazing paddocks could have disrupted the daily routine of this group of pigs and potentially imposed some sort of stress on them (Rutherford et al., 2006). Contrary to these results, no differences in animal weight gain between pigs grazing white clover managed continuously, alternately or rotationally were reported in Brazil (Leite et al., 2006).

The total weight gain was similar in both graze periods, and averaged 61.5 kg pig⁻¹, the same weight gain figure reported for rotationally stocked pigs during 12 weeks in Uruguay (Blumetto et al., 2012). The daily weight gain recorded in this study was in the range of values reported for Iberico pigs (0.74 to 0.78 kg pig d⁻¹) (Rodríguez-Estévez et al., 2011), and similar to the values registered for Cinta Senese pigs (0.71 to 0.76 kg pig d⁻¹) (Aquilani et al., 2019), or for pigs managed in a weekly rotation system (0.73 kg d⁻¹) (Blumetto et al., 2013), but are lower than those obtained in strip grazing managed pigs (0.90 kg pig d⁻¹) (Gustafson and Stern, 2003). The forage species in the pasture impacts the amount of pigs weight gain. In grass pastures with *ad libitum* access to supplemental feed, daily gains in the range of 0.59 to 0.88 kg d⁻¹ have been reported, whereas for alfalfa pastures the figures were 0.74 to 0.90 kg pig d⁻¹ (Jakobsen, Kongsted, and Hermansen, 2015). In this study, it is hard to ascertain the magnitude of the contribution of tall fescue to pig diets, if any. Pigs had *ad libitum* access to supplemental feed, a factor that has shown to reduce forage intake (Stern and Andresen, 2003).

Conclusions

A better knowledge regarding grazing management of pasture pig operations is essential to implement best management practices that would allow reaching conservation goals. Under the umbrella of this report previous studies were reviewed providing evidence that limited information exists concerning best management practices for pasture pig production systems. In addition, three field experiments were conducted to evaluate the effects of stocking rates and stocking methods on vegetative ground cover, soil traits, and animal performance.

The results of the field studies have led to the following conclusions:

Survival of bermudagrass ground cover was related with the stocking rate implemented. Greater ground cover was observed in paddocks managed with the lower stocking rate either in the case of growing-finishing pigs or for sows-gilts systems. Similarly, in these paddocks soil nutrients concentrations were lower than those from paddocks managed with greater stocking rates. Soil nutrients concentrations showed differences in relation to sampling point and soil depth, with individualized spatial patterns.

Pigs tend to concentrate their activities in certain areas of the paddocks such as vicinities of shelters, feeders, drinkers and fences, therefore their impact on reduced ground cover will be more evident in such areas.

For a conservation oriented grazing management of bermudagrass paddocks, the stocking rates for growing to finishing pigs should not be higher than 37 pigs ha⁻¹, whereas for sows-gilts systems the stocking rate could be set between 10 and 15 sows-gilts ha⁻¹.

Paddocks continuously stocked presented less ground cover and higher concentrations of NO₃⁻-N, P, K, S, Mn, Cu and Zn in the soil than paddocks managed with rotational or strip grazing schemes.

Pigs from continuously-stocked paddocks showed greater feed disappearance, lower weight gain, and lower feed efficiency compared with pigs from rotationally-stocked paddocks which showed the best growth performance.

As in pasture-based pig production systems the impacts of grazing pigs may only be noticed in the long term, longer studies are needed comparing the effects of different stocking rates and stocking methods on forage persistence and soil properties.

In summary, this study indicates that the adoption of best management practices, such as the implementation of an appropriate stocking rate, and putting into practice rotational stocking methods, contributes to the reduction of the environmental impact of pasture-based pig production by increasing vegetative ground cover survival, reducing loading of soil nutrients and improving their distribution along the paddock.

References

- Acciaioli, A.; Grifoni, F.; Fontana, G.; Esposito, S.; Franci, O. **2012**. Evaluation of forest damage derived from the rearing of Apulo-Calabrese pig. In: De Pedro, E. J. (ed.), Cabezas, A. B. (ed.). 7th International Symposium on the Mediterranean Pig. [online] Zaragoza: *CIHEAM*. Options Méditerranéennes: Série A. Séminaires Méditerranéens; 101, 133–6. Available at: <http://om.ciheam.org/om/pdf/a101/00006667.pdf> (Accessed on 4 May 2020)
- Agricultural output—Meat consumption—OECD Data*. (n.d.). TheOECD. Available at: <http://data.oecd.org/agroutput/meat-consumption.htm> (Accessed on 15 August 2020)
- Aiken, G.E. **2016**. Invited Review: Grazing management options in meeting objectives of grazing experiments, *Prof. Anim. Scient.*, 32(1), 1-9, <https://doi.org/10.15232/pas.2015-01406>.
- Aiken, G. E. **2015**. Grazing Management Options for Maintaining Optimum Pasture Composition and Utilization. XXIII International Grassland conference. New Delhi, India. Available at: <https://uknowledge.uky.edu/jgc/23/keynote/6/> (Accessed on 28 August 2020)
- Allen, V. G., Batello, C., Berretta, E. J., Hodgson, J., Kothmann, M., Li, X., Mclvor, J., Milne, J., Morris, C., Peeters, A., and Sanderson, M. **2011**. An international terminology for grazing lands and grazing animals. *Grass Forage Sci.*, 66(1), 2–28. <https://doi.org/10.1111/j.1365-2494.2010.00780.x>
- Amory, J.; Wainwright, N. **2018**. Welfare of pigs during finishing. In Achieving Sustainable Production of Pig Meat; Wiseman, J., Ed.; Animal health and welfare; Burleigh Dodds Science Publishing: Cambridge, UK. Volume 3, pp. 255–278.
- Andersen, H.M.-L.; Kongsted, A.G.; Jakobsen, M. **2020**. Pig elimination behavior—A review. *Applied Animal Behaviour Science* 222, 104888, doi:10.1016/j.applanim.2019.104888.
- Andersen, H.M.L.; Pedersen, L.J. **2011**. The effect of feed trough position on choice of defecation area in farrowing pens by loose sows. *App. Anim. Behav. Sci.*, 131(1-2), 48-52.
- Andresen, N. and Redbo, I. **1999**. Foraging behaviour of growing pigs on grassland in relation to stocking rate and feed crude protein level. *Applied Animal Behaviour Science*, 62, 183–97.
- Andresen N., Ciszuk P. and Ohlander L. **2001**. Pigs on grassland – animal growth rate, tillage work and effects in the following winter wheat crop. *Biological Agriculture and Horticulture*, 18 (4), 327–43. DOI:10.1080/01448765.2001.9754896.
- Aquilani, C.; Sirtori, F.; Franci, O.; Acciaioli, A.; Bozzi, R.; Benvenuti, D.; Čandek-Potokar, M.; Pugliese, C. **2019**. Effects of Different Protein Levels on the Nitrogen Balance, Performance and Slaughtering Traits of Cinta Senese Growing Pigs. *Animals*, 9, 1021, doi:10.3390/ani9121021.
- Banhazi, T. **2013**. Modelling and influencing hygiene conditions in Australian livestock buildings. In Aland, A. and Banhazi, T. (Eds) Livestock housing. Modern management to ensure optimal health and welfare of farm animals. DOI: <http://dx.doi.org/10.3920/978-90-8686-771-4>. pp. 377–390 (Accessed 17 FEB 2017) https://eprints.usq.edu.au/23880/2/Banhazi_ch19_2013_PV.pdf
- Barasona, J.A.; VerCauteren, K.C.; Saklou, N.; Gortazar, C.; Vicente, J. **2013**. Effectiveness of cattle operated bump gates and exclusion fences in preventing ungulate multi-host sanitary interaction. *Prev. Vet. Med.* 111, 42–50.
- Barlocco, N. **2005**. Alimentación de cerdos en Crecimiento y engorde en pastoreo permanente. In: Bauza, R. (ed.). Utilización de pasturas en la alimentación de cerdos. [online] Montevideo: Universidad de la Republica.

Uruguay. 15–22. Available at: http://upc.edu.uy/images/documents/extension/Jornada-Taller_Pasturas_dic05.pdf [Accessed 8 June 2016].

Barnes, M.K.; Norton, B.E.; Maeno, M.; Malecheck, J.C. **2008**. Paddock size and stocking density affect spatial heterogeneity of grazing. *Rangeland Ecol. Manag.* 61, 380–388.

Barnett, J.L.; Hemsworth, P.H.; Cronin, G.M.; Jongman, E.C.; Hutson, G.D. **2001**. A review of the welfare issues for sows and piglets in relation to housing. *Aust. J. Agric. Res.*, 52, 1–28.

Barone, C. M. A., Di Matteo, R., Rillo, L., Rossetti, C. E., Pagano F. and Matassino, D. **2015**. Pork quality of autochthonous genotype Casertana, crossbred Casertana x Duroc and hybrid Pen ar Lan in relation to farming systems. *Agronomy Research*, 13(4), 900–6.

Bauza, R. **2005**. Utilización de pasturas en la alimentación de reproductores. In: Bauza, R. (ed.). Utilización de pasturas en la alimentación de cerdos. [pdf] Montevideo: Universidad de la Republica. Facultad de Agronomía. 5–14. Available at: http://upc.edu.uy/images/documents/extension/Jornada-Taller_Pasturas_dic05.pdf [Accessed 8 June 2016].

Bauza, R. **2007**. Alimentos alternativos para animales monogástricos. In: *IX Encuentro de Nutrición y Producción en Animales Monogástricos*. [pdf] Montevideo: Universidad de la Republica, Facultad de Agronomía. 47–55. Available at: <http://upc.edu.uy/ixe/category/23-memorias-delencuentro> [Accessed 8 June 2016] ISBN: 978-9974-0-0399-6.

Bauza, R. and Petrocelli, H. **2005**. Uso de pasturas en el crecimiento-terminación de cerdos: pastoreo con acceso restringido. In: Bauza, R. (ed.). Utilización de pasturas en la alimentación de cerdos. [pdf] Montevideo: Universidad de la Republica. Facultad de Agronomía. 23–32. Available at: http://upc.edu.uy/images/documents/extension/Jornada-Taller_Pasturas_dic05.pdf [Accessed 8 June 2016].

Beinlich, B. and Poschlod, P. **2002**. Low intensity pig pastures as an alternative approach to habitat management. In: Redecker, B., Härdtle, W., Finck, P., Riecken, U. and Schröder, P. (eds). *Pasture Landscapes and Nature Conservation*, pp. 219–26. Publisher Springer Berlin Heidelberg New York. DOI 10.1007/978-3-642-55953-2_16.

Benfalk, C., Lindgren, K., Lindahl, C. and Rungren M. **2005**. Mobile and stationary systems for organic pigs – Animal behavior in outdoor pens. In: Köpke, U., Niggli, U., Neuhoﬀ, D., Cornish, P., Lockeretz, W. and Willer, H. (eds). *Researching Sustainable Systems*. [pdf] ISOFAR, pp. 242–5. Available at: http://orgprints.org/4313/4/4313-Benfalk_etal_4p_revised-ed.pdf [Accessed 8 June 2016].

Benjamins, D. **2002**. Oxford Sandy and Black pigs as a method of weed control. When do they stop being an asset and start becoming a problem? BSc Thesis. De Montfort University, Riseholme School of Agriculture, UK. 43p.

Bikker, P. and Binnendijk, G. P. **2012**. *Grass silage in diets for organic growing-finishing pigs*; Report 603; Wageningen UR Livestock Research: Lelystad, Holland, 22p.

Bisimwa, N.P.; Machuka, E.M.; Githae, D.; Banswe, G.; Amimo, J.O.; Ongus, J.R.; Masembe, C.; Bishop, R.P.; Steinaa, L.; Djikeng, A.; Pelle, R. **2020**. Evidence for the presence of African swine fever virus in apparently healthy pigs in South-Kivu Province of the Democratic Republic of Congo. *Vet. Microb.*, 240, 108521 DOI - 10.1016/j.vetmic.2019.108521

Blumetto Velazco, O.R.; Calvet Sanz, S.; Estellés Barber, F.; Villagrà García, A. **2013**. Comparison of extensive and intensive pig production systems in Uruguay in terms of ethologic, physiologic and meat quality parameters. *R. Bras. Zootec.*, 42, 521–529, doi:10.1590/S1516-35982013000700009.

- Blumetto, O.; Sanz, S.C.; Barber, F.E.; Villagr , A.; Torres, A.G. **2012**. Caracterizaci n productiva y ambiental de un sistema semi-extensivo de engorde de cerdos en condiciones de sequ a en Uruguay. *ITEA, informaci n t cnica econ mica agraria: revista de la Asociaci n Interprofesional para el Desarrollo Agrario (AIDA)*, 256–274.
- Bonde, M.; S rensen, J.T. **2004**. Herd health management in organic pig production using a quality assurance system based on Hazard Analysis and Critical Control Points. *NJAS Wagen. J. Life Sci.*, 52, 133–143.
- Bondi, G.; Peruzzi, E.; Macci, C.; Masciandaro, G.; Pistoia, A. **2015**. Changes in soil organic matter associated with pig rearing: Influence of stocking densities and land gradient on forest soils in central Italy, *Agric., Ecos. Environ.*, 211, 32-42, ISSN 0167-8809, <https://doi.org/10.1016/j.agee.2015.05.003>.
- Bordeaux, C.; Grossman, J.; White, J.; Osmond, D.; Poore, M.; Pietrosemoli, S. **2014**. Effects of rotational infrastructure within pasture-raised pig operations on ground cover, soil nutrient distribution, and bulk density. *J. Soil Water Conserv.*, 69(2), 120-30. doi:10.2489/jswc.69.2.120.
- Bornett, H. L. I., Edge, H. L. and Edwards, S. A. **2003**. Alternatives to nose-ringing in outdoor sows: 1. The provision of a sacrificial rooting area. *Applied Animal Behaviour Science*, 83 (4), 267–76.
- Both, MdC. **2003**. Comportamento e produ  o de su  os mantidos em pastagem e submetidos a diferentes n veis de restri  o alimentar. PHD Thesis. Universidade Federal do Rio Grande do Sul, 127p. Available at: <http://www.lume.ufrgs.br/bitstream/handle/10183/5267/000468021.pdf?sequence=1> [14 June 2016].
- Braund, J.P.; Edwards, S.A.; Riddoch, I.; Buchner, L.J. **1998**. Modification of foraging behaviour and pasture damage by dietary manipulation in outdoor sows. *Appl. Anim. Behav. Sci.*, 56, 173–186.
- Buehrer, K. A. and Grieshop, M. J. **2014**. Postharvest grazing of hogs in organic fruit orchards for weed, fruit, and insect pest management. *Organic Agriculture*, 4, 223–32.
- Butler, D.M.; Franklin, D.H.; Ranells, N.N.; Poore, M.H.; Green J.T. **2006**. Ground cover impacts on sediment and phosphorus export from manured riparian pasture. *J Environ Qual.*, 35(6), 2178-2185. DOI: 10.2134/jeq2005.0351
- Butler D.M.; Ranells N.N.; Franklin D.H.; Poore M.H.; Green J.T. **2007**. Ground cover impacts on nitrogen export from manured riparian pasture. *J Environ Qual.*, 36(1), 155-62. DOI: 10.2134/jeq2006.0082
- Campagna, D.; Dichio, L.; Ausilio, A.; Bess n, P. A.; Silva, P.; Spinollo, L. **2011**. Efectos de la carga animal sobre el tapiz vegetal y el recurso suelo en un sistema de producci n porcina al aire libre. In: Barlocco, N. and Vadell, A. (eds). *Producci n de Cerdos a Campo. Aportes para el desarrollo de tecnolog as apropiadas para la producci n familiar*. [pdf] Montevideo, Uruguay. *Universidad de la Rep blica. Facultad de Agronom a*. 92–101. Available at: <http://www.upc.edu.uy/images/documents/extension/Publicacion%2015%20anos%20UPC.pdf>
- Cano-Terriza, D.; Risalde, M.A.; Rodr guez-Hern ndez, P.; Napp, S.; Fern ndez-Morente, M.; Moreno, I.; Bezos, J.; Fern ndez-Molera, V.; Sa  ez, J.L.; Garc  a-Bocanegra, I. **2018**. Epidemiological surveillance of *Mycobacterium tuberculosis* complex in extensively raised pigs in the south of Spain. *Prev. Vet. Med.*, 159, 87–91.
- Cappaia, S.; Rolesua, S.; Coccollonea, A.; Laddomadab, A.; Loia, F. **2018**. Evaluation of biological and socio-economic factors related to persistence of African swine fever in Sardinia. *Prev. Vet. Med.*, 152, 1–11.
- Carlson, D.; L erke, H.N.; Poulsen, H.D.; J rgensen, H. **1999**. Roughages for Growing Pigs, with Emphasis on Chemical Composition, Ingestion and Faecal Digestibility. *Acta Agriculturae Scandinavica, Section A — Animal Science*, 49, 129–136, doi: 10.1080/090647099424033.
- Castillo-Cuenca, J.C.; D  az-Cao, J.M.; Mart  nez-Moreno, A.; Cano-Terriza, D.; Jim  nez-Ruiz, S.; Almer  a, S.; Garc  a-Bocanegra, I. **2020**. Seroepidemiology of *Toxoplasma gondii* in extensively raised Iberian pigs in Spain. *Prev. Vet. Med.*, 175, 104854.

- Castillo, M, Martín-Orúe, S. M., Anguita, M, Pérez, J. F. and Gasa J., **2007**. Adaptation of gut microbiota to corn physical structure and different types of dietary fibre, *Livestock Science*, 109, 149–152.
- Cecchini, L., Torquati, B., Chiorri, M. **2018**. Sustainable agri-food products: A review of consumer preference studies through experimental economics. *Agricultural Economics (Zemědělská Ekonomika)*, **2018**, 64(12), 554–565. <https://doi.org/10.17221/272/2017-AGRICECON>
- Coulloudon, B.; Eshelman, K.; Gianola, J.; Habich, N.; Hughes, L.; Johnson, C.; Pellant, M.; Podborny, P.; Rasmussen, A.; Robles, B.; Shaver, P.; Spehar, J.; Willoughby, J. **1999**. Sampling Vegetation Attributes; Interagency Technical Reference; Bureau of Land Management's National Applied Resource Sciences Center: Denver, CO, USA.
- Congio, G. F. S., Chiavegato, M. B., Batalha, C. D. A., Oliveira, P. P. A., Maxwell, T. M. R., Gregorini, P., Da Silva, S. C. **2019**. Strategic grazing management and nitrous oxide fluxes from pasture soils in tropical dairy systems. *Science of The Total Environment*, 676, 493–500. <https://doi.org/10.1016/j.scitotenv.2019.04.186>
- Conner, D. S., Oppenheim, D. **2008**. *Demand for Pasture-Raised Livestock Products in Michigan: Results of Consumer Surveys and Experimental Auctions*, (No. 856-2016–57896). Journal of Food Distribution Research., <https://doi.org/10.22004/ag.econ.55603>
- Corbin, M. D., Nave, R. L. G., Bates, G. E., Butler, D. M., & Hawkins, S. A. **2019**. Alternatives to Conventional Nitrogen Fertilization on Tall Fescue and Bermudagrass. *Agron. J.*, 111(1), 275–286. <https://doi.org/10.2134/agronj2018.03.0190>
- Dalla Costa, O.A.; Nelson Morés, N.; Pedroso-de-Paiva, D.; Silva, R.A.M.; Sobestiansky, J.; Monticelli, C.J.; Leite, D.M.G. **2000**. Acompanhamento parasitário de rebanhos suínos no sistema intensivo de suínos criados ao ar livre—SISCAL. CT/253. In Embrapa Suínos e Aves; EMBRAPA: Brasília, DF, Brazil, pp. 1–3, ISBN 0100–8862.
- Daniel, A.D.; McIntosh, B.J.; Plunk, J.D.; Webb, M.; McIntosh, D.; Parks, A.G. **2015**. Effects of rotational grazing on water-soluble carbohydrate and energy content of horse pastures. *Journal of Equine Veterinary Science*, 35, 385–386, doi:10.1016/j.jevs.2015.03.014.
- Danielsen, V.; Hansen, L. L.; Møller, F.; Bejerholm, C. and Nielsen, S. **1999**. Production results and sensory meat quality of pigs fed different amounts of concentrate and ad libitum clover grass or clover grass silage. In Hermansen, J. E., Lund, V. and Thuen, E. (eds), *Ecological Animal Husbandry in the Nordic Countries*, Danish Research Centre for Organic Farming: Tjele, Denmark, pp. 79–86.
- Davies, P.R. **2011**. Intensive Swine Production and Pork Safety. *Foodborne Pathog. Dis.*, 8.
- De Lucia, A.; Rabie, A.; Smith, R.P.; Davies, R.; Ostanello, F.; Ajayi, D.; Petrovska, L.; Martelli, F. **2018**. Role of wild birds and environmental contamination in the epidemiology of Salmonella infection in an outdoor pig farm. *Vet. Microbiol.*, 227, 148–154.
- Demori, A. B., Lovatto, P. A., Andretta, I., Kipper, M., Lehnen, C. R. and Remus, A. **2012**. Criação intensiva de suínos em confinamento ou ao ar livre: estudo meta-analítico do desempenho zootécnico nas fases de crescimento e terminação e avaliação de carcaça e carne no Longissimus dorsi. *Ciência Rural*, 42(7), 1294–9. Available at: <https://dx.doi.org/10.1590/S0103-84782012000700025>.
- Doran, M. **2015**. Multi-Species Grazing Systems. In: Ellsworth, S. (ed.). *Outdoor Hog Production. Best Practices for Resource Conservation in the San Francisco Bay Area*. [pdf] Available at: <http://www.acrcd.org/Portals/0/Multi%20Species%20Grazing.pdf> [18 November 2015.]

Dourmad, J.-Y.; Casabianca, F. **2013**. Effect of husbandry systems on the environmental impact of pig production. *Acta agriculturae Slovenica, Supplement 4*, 197–204. ISSN: 1581-9175 Available at: <http://prodinra.inra.fr/record/253477> [10 June 2016].

Drewry, J.J. **2006**. Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: A review. *Agric., Ecos. Environ.*, *114*, 159–169

Drinkwater, L.E.; Cambardella, C.A.; Reeder, J.D.; Rice, C.W. **2015**. Potentially Mineralizable Nitrogen as an Indicator of Biologically Active Soil Nitrogen. In *Methods for Assessing Soil Quality*; Doran, J.W., Jones, A.J., Eds.; Soil Science Society of America, Inc: Madison, WI, USA.

Dubeux, J.C.B.; Sollenberger, L.E. **2020**. Nutrient cycling in grazed pastures. In *Management Strategies for Sustainable Cattle Production in Southern Pastures*; Elsevier, 59–75 ISBN 978-0-12-814474-9.

Dubeux, J. C. B., Sollenberger, L. E., Muir, J. P., Tedeschi, L. O., Santos, M. V. F. dos, Cunha; M. V. da, Mello; A. C. L. de, DiLorenzo, N. **2017**. Sustainable intensification of livestock production on pastures. *Archivos Latinoamericanos de Producción Animal*, *25*(3–4). https://ojs.alpa.uy/index.php/ojs_files/article/view/2564

Dubeux, J.C.B.; Sollenberger, L.E.; Vendramini, J.M.B.; Interrante, S.M.; Lira, M.A. **2014**. Stocking Method, Animal Behavior, and Soil Nutrient Redistribution: How are They Linked? *Crop Science*, *54*, 2341–2350, doi:10.2135/cropsci2014.01.0076.

Dumont, B., Fortun-Lamothe, L., Jouven, M., Thomas, M.; Tichit, M. **2013**. Prospects from agroecology and industrial ecology for animal production in the 21st century. *Animal*, *7*(6), 1028–1043. <https://doi.org/10.1017/S1751731112002418>

Edge, H. L., Bornett, H. L. I., Newton, E. and Edwards, S. A. **2004**. Alternatives to nose-ringing in outdoor sows: 2.The provision of edible or inedible overground enrichment. *Animal Welfare*, *13*(2), 233–237.

Edge, H. L., Bulman, C. A. and Edwards, S. A. **2005**. Alternatives to nose-ringing in outdoor sows: the provision of root crops. *Applied Animal Behavioural Science*, *92* (1–2), 15–26.

Edwards, S. A. **2003**. Intake of nutrients from pasture by pigs. *Proceedings of the Nutrition Society*, *62*(2), 257–265. <https://doi.org/10.1079/PNS2002199>

Edwards, S. A. **2005**. Product quality attributes associated with outdoor pig production. *Livestock Production Science*, *94*, 5–14.

Edwards, S. **2018**. Welfare of gilts and pregnant sows. In *Achieving Sustainable Production of Pig Meat*; Wiseman, J., Ed.; Animal health and welfare; Burleigh Dodds Science Publishing: Cambridge, UK,; Volume 3, pp. 203–223.

Edwards, S.; Mejer, H.; Prunier, A.; Roepstorff, A. **2011**. Animal health, welfare and production problems in organic pregnant and lactating sows. In *Animal Health and Welfare in Organic Pig Production*; Edwards, S., Ed.; CORE Organic Project: Tjele, Denmark, 1904; p. 109.

Edwards, S.; Mejer, H.; Roepstorff, A.; Prunier, A. **2014**. Animal health, welfare and production problems in organic pregnant and lactating sows. *Org. Agric.*, *4*, 93–105.

EFSA. **2007**. Scientific Opinion of the Panel on Animal Health and Welfare on a request from Commission on the risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems. *EFSA J.*, *6*, 1–13.

EFSA. **2014**. Evaluation of possible mitigation measures to prevent introduction and spread of African swine fever virus through wild boar. *EFSA J.*, *12*, 3616.

Eriksen, J. **2001**. Implications of grazing by sows for nitrate leaching from grassland and the succeeding cereal crop. *Grass & Forage Science*, 56(4), 317–22.

Eriksen, J.; Kristensen, K. **2001**. Nutrient excretion by outdoor pigs: A case study of distribution, utilization and potential for environmental impact. *Soil Use Manage.*, 17, 21–29.

Eriksen, J.; Petersen, S.O.; Sommer, S.G. **2002**. The fate of nitrogen in outdoor pig production. *Agronomie*, 22, 863–867.

Eriksen, J., Hermansen, J. E., Strudsholm, K. and Kristensen, K. **2006a**. Potential loss of nutrients from different rearing strategies for fattening pigs on pasture. *Soil Use Management* 22, 256–66.

Eriksen, J.; Studnitz, M.; Strudsholm, K.; Kongsted, A.G.; Hermansen, J.E. **2006b**. Effect of nose ringing and stocking rate of pregnant and lactating outdoor sows on exploratory behaviour, grass cover and nutrient loss potential. *Livest. Sci.*, 104, 91–102.

Fajardo, D. S. **2009**. Evaluación de dos sistemas de instalaciones y manejo para la etapa de lactancia, comparando la producción porcina tradicional vs la producción al aire libre. BSc Thesis. Universidad de la Salle, Colombia. 125p.

Faner, C. L. **2007**. La pastura de alfalfa como fuente de alimentación para cerdos en crecimiento y terminación. Boletín AACP. Available at: www.produccion-animal.com.ar.

FAO. **2007**. Animal genetic resources and resistance to disease. In: Rischkowsky, B. and Pillin, D. (eds), *The State of the World's Animal Genetic Resources for Food and Agriculture*, FAO, Rome, Italy, pp. 101–12.

Ferretti, F.; Storer, K.; Coats, J.; Massei, G. **2015**. Temporal and spatial patterns of defecation in wild boar. *Wildlife society bulletin*, 39(1), 65–69

Finzel, J.A.; Baldwin, R.A. **2015**. Wild Pigs. UC Cooperative Extension Integrated Pest Management. Publication 74170. Available online: <http://ipm.ucanr.edu/PMG/PESTNOTES/pn74170.html> (accessed on 30 January 2020).

Fleming, P.A.; Dundas, S.J.; Lau, Y.Y.; Pluske, J.R. **2016**. Predation by Red Foxes (*Vulpes vulpes*) at an Outdoor Piggery. *Animals*, 6, 60.

Formentini, T.A.; Kochem Mallmann, F.J.; Pinheiro, A.; Scapulatempo Fernandes, C.V.; Bender, M.A.; da Veiga, M.; Rheinheimer dos Santos, D.; Doelsch, E. **2015**. Copper and zinc accumulation and fractionation in a clayey Hapludox soil subject to long-term pig slurry application. *Sci. Total Environ.*, 536, 831–839.

Fortina, R., Brugiapaglia, A., Tassone, S., Malfatto, V. and Cavallero, A. **2011**. Pasture-Based Swine Management: Behaviour and Performances of Growing-Finishing Pigs. *Animal Science and Biotechnologies*, 44 (1), 37–40.

Franzluebbers, A.J., Paine, L.K., Winsten, J.R., Krome, M., Sanderson, M.A., Ogles, K., & Thompson, D. **2012**. Well-managed grazing systems: A forgotten hero of conservation. *J. Soil and Water Conserv.*, 67(4), 100A–104A. <https://doi.org/10.2489/jswc.67.4.100A>

Franzluebbers, A.J.; Stuedemann, J.A.; Schomberg, H.H. **2000**. Spatial Distribution of Soil Carbon and Nitrogen Pools under Grazed Tall Fescue. *Soil Science Society of America Journal*, 64, 635–639, doi:10.2136/sssaj2000.642635x.

Fredriksson-Ahomaa, M. **2019**. Wild Boar: A Reservoir of Foodborne Zoonoses. *Foodborne Pathog. Dis.*, 16, 163–165.

García-Valverde, R., Nieto, R., Lachica, M. and Aguilera, J. F. **2007**. Effects of herbage ingestion on the digestion site and nitrogen balance in heavy Iberian pigs fed on an acorn-based diet. *Livestock Science*, 112, 63–77.

- Gentry J.G., McGlone J. J.; Blanton J. R.; Miller M.F. **2002a**. Alternative housing systems for pigs: influences on growth, composition, and pork quality. *Journal of Animal Science*, 80(7), 1781–90.
- Gentry, J. G., McGlone, J. J., Miller, M. F. and Blanton, J. R. **2004**. Environmental effects on pig performance, meat quality, and muscle characteristics. *Journal of Animal Science*, 82(1), 209–17.
- Giannone, M. **2001a**. Pascoli di favino per i suini biologici. *Rivista di suinicoltura*. 42, 125–30.
- Giannone, M. **2001b**. Sorgo e barbabietola per i suini biologici. *Rivista di suinicoltura*. 42, 38–42.
- Goh, K.M.; Bruce, G.E. **2005**. Comparison of biomass production and biological nitrogen fixation of multi-species pastures (mixed herb leys) with perennial ryegrass-white clover pasture with and without irrigation in Canterbury, New Zealand. *Agriculture, Ecosystems & Environment*, 110, 230-240, 2005.
- Gourdine, J. L., De Greef, K. H. and Rydhmer, L. **2010**. Breeding for welfare in outdoor pig production: A simulation study. *Livestock Science*. Volume 132(1–3), 26–34. doi:10.1016/j.livsci.2010.04.017
- Griths, I.B.; Douglas, R.G.A. **2000**. Phytophotodermatitis in pigs exposed to parsley (*Petroselinum crispum*). *Vet. Rec.*, 146, 73–74.
- Grosso, L., Barbieri, S., Ferrante, V. and Ferrari, P. **2011**. La producción porcina a campo en Italia. In: Barlocco, N. and Vadell, A. (eds). *Producción de Cerdos a Campo. Aportes para el desarrollo de tecnologías apropiadas para la producción familiar*. Montevideo. Universidad de la república. Facultad de Agronomía. 110–15. Available at: <http://www.upc.edu.uy/images/documents/extension/Publicacion%2015%20anos%20UPC.pdf>
- Guberti, V.; Khomenko, S.; Masiulis, M.; Kerba, S. **2019**. African Swine Fever in Wild Boar Ecology and Biosecurity; *FAO Animal Production and Health Manual No. 22*; FAO: Rome, Italy, p. 97.
- Guo, Y.; Lian, X.; Yan, P. **2015**. Diurnal rhythms, positions and behavioural sequences associated with eliminative behaviours in fattening pigs. *Appl. Anim. Beh. Sci.*, 168, 18–23
- Gupta, R.C.; Evans, T.J.; Nicholson, S.S. **2018**. Ergot and Fescue Toxicoses. In *Veterinary Toxicology*; Elsevier; 995–1001 ISBN 978-0-12-811410-0.
- Gustafson, G.M.; Stern, S. **2003**. Two strategies for meeting energy demands of growing pigs at pasture. *Livestock Production Science*, 80, 167–174, doi: 10.1016/S0301-6226(02)00319-6.
- Gustafson, G. M. and Svensson, L. **2003**. Ammonia emissions from pigs on deep litter beds and in a strip grazing system. *Journal of Sustainable Agriculture*, 23(2), 41–51. DOI: 10.1300/J064v23n02_05.
- Hardy, D.H.; Myers, J.; Stokes, C. **2008**. Heavy Metals in North Carolina Soils. Occurrence and Significance; Department of Agriculture and Consumer Services Agronomic Division: Raleigh, NC, USA,. Available online: <http://digital.ncdcr.gov/u/?p249901coll22,63754>
- Helmerichs, J. **2014**. Paddock management systems for organic growing pigs Effect of land allocation strategies on foraging activity and excretory behavior. MSc Thesis. Aarhus University. Department Of Agroecology. 45p.
- Henney, J. **2012**. An evaluation of the use of pigs as a method of bracken control. In *Grazing Animals Project Heritage Grazing Traineeship; Rare Breeds Survival Trust: Warwickshire, UK*,; p. 40. Available online: http://www.grazinganimalsproject.org.uk/habitat_land_management.html?publication=1;154 (accessed on 9 December 2019).
- Hermansen, J. E. **2005**. Integration of organic pig production into land use. In: Sundrum, A. and Friedrich Weißmann, F. (eds). *Organic Pig Production in Free Range Systems*. [pdf] Braunschweig. FAL Agricultural Research. 281, 3–12. ISSN 0376-0723 ISBN 3-86576-005-8. Available at: <http://orgprints.org/6094/1/6094.pdf> [Accessed 4 June 2016].

Hermansen, J. E., Eriksen, J. and Strudsholm, K. **2005**. Full or partial outdoor rearing of slaughter pigs. Effects on performance, carcass quality and nutrient load. In: Researching Sustainable Systems. [pdf] Adelaide. ISO FAR. 250–3. Available at: http://http://http://orgprints.org/4368/4/4368-Hermansen_etal_4p_revised-ed.pdf [Accessed 4 June 2016].

Hermansen, J.E.; Strudsholm, K.; Horsted, K. **2004**. Integration of organic animal production into land use with special reference to swine and poultry. *Livest. Produc. Sci.*, **90**, 11–26.

Hernández, M.; Gómez-Laguna, J.; Tarradas, C.; Luque, I.; García-Valverde, R.; Reguillo, L.; Astorga, R.J. **2014**. A serological survey of *Brucella* spp., *Salmonella* spp., *Toxoplasma gondii* and *Trichinella* spp. in Iberian fattening pigs reared in free-range systems. *Transbound Emerg. Dis.*, **61**, 477–481.

Heyer, A. H., Andersson, K. and Lundstrom, K. **2006**. Performance, carcass and technological meat quality of pigs in indoor and outdoor production systems. *Acta Agriculturae Scand Section A*. **56**, 55–64. DOI: 10.1080/09064700600670904.

Hilimire, K. **2011**. Integrated Crop/Livestock Agriculture in the United States: A Review. *Journal of Sustainable Agriculture*, **35**(4), 376–93, DOI: 10.1080/10440046.2011.562042

Hill, D.E.; Dubey, J.P.; Baroch, J.A.; Swa_ord, S.R.; Fournet, V.F.; Hawkins-Cooper, D.; Pyburn, D.G.; Schmit, B.S.; Gamble, H.R.; Pedersen, K.; et al. **2014**. Surveillance of feral swine for *Trichinella* spp. and *Toxoplasma gondii* in the USA and host-related factors associated with infection. *Vet. Parasitol.*, **205**, 653–665.

Hiltbrunner, D.; Schulze, S.; Hagedorn, F.; Schmidt, M.W.I.; Zimmermann, S. **2012**. Cattle trampling alters soil properties and changes soil microbial communities in a Swiss sub-alpine pasture. *Geoderma*, **170**, 369–377

Hines, E. **2018**. Keeping Pigs Cool in the Summer Heat. Penn State Extension. Available online: <https://extension.psu.edu/keeping-pigs-cool-in-the-summer-heat> (accessed on 15 December 2019).

Hodgkinson, S. M., Cárcamo, A. and López, I. **2011**. Selective grazing of *Lolium perenne* and *Plantago lanceolata* by growing European wild boar (*Sus scrofa* L.) in a semi-extensive system. *Livestock Science*, **140**, 268–74.

Hodgkinson, S. M., López, I. F. and Navarrete, S. **2009**. Ingestion of energy, protein and amino acids from pasture by grazing European wild boar (*Sus scrofa* L.) in a semi-extensive production system. *Livestock Science* **122**, 222–6

Hodgkinson, S., Schmidt, M. and Ulloa, N. **2008**. Comparison of the digestible energy content of maize, oats and alfalfa between the European wild boar (*Sus scrofa* L.) and Landrace x Large White (*Sus scrofa domestica*). *Animal Feed Science and Technology* **144**, 167–73.

Honeyman, M. S., Pirog, R. S., Huber, G. H., Lammers, P. J., & Hermann, J. R. **2006**. The United States pork niche market phenomenon. *J. Anim. Scie.*, **84**(8), 2269–2275. <https://doi.org/10.2527/jas.2005-680>

Horsted, K., Kongsted, A. G., Jorgesen, U. and Sorensen, J. **2012**. Combined production of free range pigs and energy crops-animal behavior and crop damages. *Livestock Science*, **150**, 200–8. doi:10.1016/j.livsci.2012.09.006.

Horta, C.; Batista, M.; Roque, N.; Almeida, J. **2012**. Environmental impact of pig production: soil P forms evolution, spatial distribution and P losses in drainage waters. *Rev. Ciencias Agrarias*. **35**(1), 36–48. ISSN:0871-018 X

Hoveland, C.S.; McCann, M.A.; Hill, N.S. **1997**. Rotational vs. Continuous Stocking of Beef Cows and Calves on Mixed Endophyte-Free Tall Fescue-Bermudagrass Pasture. *Journal of Production Agriculture*, **10**, 245–250, doi:10.2134/jpa1997.0245.

Hovi, M., Sundrum, A. and Thamsborg, S. M. **2003**. Animal health and welfare in organic livestock production in Europe: current state and future challenges. *Livestock Production Science*, 80, 41–53.

Iowa State University. **2020**. Sunburn and Photosensitization. In Swine Manual Index; Iowa State University of Science and Technology: Ames, IA, USA,. Available online: <https://vetmed.iastate.edu/vdpam/FSVD/swine/index-diseases/photosensitization> (accessed on 15 January 2020).

Ivanova-Peneva, S.; Aarnink, A.; Verstegen, M. **2006**. Ammonia and Mineral losses on Dutch Organic farms with pregnant sows. *Biosystems Engineering*, 93(2), 221-235

Jakobsen, M.; Kongsted, A.G.; Hermansen, J.E. **2015**. Foraging behaviour, nutrient intake from pasture and performance of free-range growing pigs in relation to feed CP level in two organic cropping systems. *Animal*, 9, 2006–2016, doi: 10.1017/S1751731115001585.

Jakobsen, M., Hermansen, J. E., Andersen, H. M.-L., Jørgensen, U., Labouriau, R., Rasmussen, J., & Kongsted, A. G. **2019**. Elimination behavior and soil mineral nitrogen load in an organic system with lactating sows – comparing pasture-based systems with and without access to poplar (*Populus sp.*) trees. *Agroec. and Sust. Food Syst.*, 43(6), 639–661. <https://doi.org/10.1080/21683565.2018.1541039>

Jackson, P.G.G.; Cockcroft, P.D. **2007**. Handbook of Pig Medicine; Elsevier Ltd.: Philadelphia, PA, USA,; p. 296, ISBN 9780702028281

Jensen, A.N.; Baggesen, D.L. **2006**. Salmonella and Campylobacter infections in outdoor organic pigs. In Proceedings of the 1st IFOAM International Conference on Animals in Organic Production, Saint Paul, MN, USA, 23–25 August 2006; Gopalakrishnan, O., Melotti, L., Ostertag, J., Sorensen, N., Eds.; IFOAM: St. Paul, MN, USA, pp. 96–97. Available online: <http://orgprints.org/9159> (accessed on 26 February 2020).

Jensen, A.N.; Dalsgaard, A.; Stockmarr, A.; Nielsen, E.M.; Baggesen, D.L. **2006**. Survival and transmission of *Salmonella enterica* Serovar *Typhimurium* in an outdoor organic pig farming environment. *Appl. Environ. Microbiol.*, 1833–1842.

Johannson, L.M. **2006**. Meningitis and septicemia in a 7-week-old piglet caused by dual streptococcal infection. *Can. Vet. J.* 47, 796–798.

Jørgensen, H.; Serena, A.; Hedemann, M.S.; Bach-Knudsen, K.E. **2007**. The fermentative capacity of growing pigs and adult sows fed diets with contrasting type and level of dietary fibre. *Livestock Science*, 109 (1–3), 111–14.

Jørgensen, U.; Thuesen, J.; Eriksen, J.; Horsted, K.; Hermansen, J.E.; Kristensen, K.; Kongsted, A.G. **2018**. Nitrogen distribution as affected by stocking density in a combined production system of energy crops and free range pigs. *Agrofor. Syst.*, 92, 987–999

Jurjanz, S.; Roinsard, A. **2014**. Ingestion d’herbe et de sol par des truies au pâturage. *Alter. Agric.*, 125, 27–28.

Kambashi, B., Picron, P., Boudry, C., Théwis, A., Kiatoko, H.; Bindelle, J. **2014**. Nutritive value of tropical forage plants fed to pigs in the Western provinces of the Democratic Republic of the Congo. *Animal Feed Science & Technology*, 191, 47–56. DOI:10.1016/j.anifeedsci.2014.01.012.

Kanga, J.S.; Kanengoni, A.T.; Makgothi, O.G.; Baloyi, J.J. **2012**. Estimating pasture intake and nutrient digestibility of growing pigs fed a concentrate-forage diet by n-alkane and acidinsoluble ash markers. *Tropical Animal Health and Production*, 44(7), 1797–802. doi: 10.1007/s11250-012-0141-1.

Karimi, R.; Akinremi, W.; Flaten, D. **2017**. Cropping system and type of pig manure affect nitrate-nitrogen leaching in a sandy loam soil. *J. Environ. Qual.*, 46, 785–792

- Kelly, H. R. C., Browning, H. M., EL Day, J., Martins, A., Pearce, G. P., Stopes, C.; Edwards, S. A. **2007**. Effect of breed type, housing and feeding system on performance of growing pigs managed under organic conditions. *Journal of the Science of Food and Agriculture*, 87(15), 2794–2800
- Killbride, A.L.; Gillman, C.E.; Green, L.E. **2009**. A cross-sectional study of the prevalence of lameness in finishing pigs, gilts and pregnant sows and associations with limb lesions and floor types on commercial farms in England. *Anim. Welf.* 18, 215–224.
- KillBride, A.L.; Mendl, M.; Statham, P.; Held, S.; Harris, M.; Marchant-Forde, J.N.; Booth, H.; Green, L.E. **2014**, Risks associated with pre weaning mortality in 855 litters on 39 commercial outdoor pig farms in England. *Prev. Vet. Med.* 117, 189–199.
- Kijlstra, A.; Eissen, O.A.; Cornelissen, J.; Munniksma, K.; Eijck, I.; Kortbeek, T. **2004**. Toxoplasma gondii Infection in Animal-Friendly Pig Production Systems. *Investig. Ophthalmol. Vis. Sci.* 45, 3165–3169
- Kongsted, A. G., Horsted, K. and Hermansen, J. E. **2013**. Free-range pigs foraging on Jerusalem artichokes (*Helianthus tuberosus* L.) – Effect of feeding strategy on growth, feed conversion and animal behaviour. *Acta Agriculturae Scandinavica*, 63, 76–83.
- Kongsted, A.G.; Jakobsen, M. **2015**. Effect of genotype and level of supplementary concentrate on foraging activity and vegetation cover in an organic free-range pig system. *Acta Agriculturae Scandinavica: Section A, Animal Science*, 65, 139–147, doi:10.1080/09064702.2016.1156152.
- Kongsted, A.G.; Nørgaard, J.V.; Jensen, S.K.; Lauridsen, C.; Juul-Madsen, H.R.; Norup, L.R.; Engberg, R.M.; Horsted, K.; Hermansen, J.E. **2015**. Influence of genotype and feeding strategy on pig performance, plasma concentrations of micro nutrients, immune responses and faecal microbiota composition of growing-finishing pigs in a forage-based system. *Livestock Science*, 178, 263–271, doi:10.1016/j.livsci.2015.06.010.
- Köppel, C.; Knopf, L.; Ryser, M.P.; Miserez, R.; Thür, B.; Stärk, K.D.C. **2007**. Serosurveillance for selected infectious disease agents in wild boars (*Sus scrofa*) and outdoor pigs in Switzerland. *Eur. J. Wildl. Res.*, 53, 212.
- Lagrega, L. and Marotta, E. **2005**. Comportamiento y características ingestivas de forraje en la cerda a campo. In: III Encuentro Latinoamericano de Especialistas en Sistemas de Producción Porcina a Campo. [pdf] Marco Juarez. INTA. Available at: http://www.produccion-animal.com.ar/produccion_porcina/00-produccion_porcina_general/24-comportamiento_ingestivo.pdf [10 June 2016]
- Laister, S.; Konrad, S. **2005**. Behaviour, performance and carcass quality of three genotypes of growing-finishing pigs in outdoor pig production in Austria: A pilot study. In: Organic Pig Production in Free Range Systems. Eds. Sundrum, A., Weißmann, F. Landbauforschung Völkeroode, Special Issue 281. P. 13.
- Lang, D.; McDonald, G.W. **2005**. Maintaining groundcover to reduce erosion and sustain production, *Agfact*, P2.1.14. https://www.dpi.nsw.gov.au/data/assets/pdf_file/0018/162306/groundcover-for-pastures.pdf (Accessed on 2 October, 2019)
- Lasisi, A.A.; Akinremi, O.O.; Tenuta, M.; Cattani, D. **2018**. Below-ground plant biomass and nitrogen uptake of perennial forage grasses and annual crops fertilized with pig manures. *Agric. Ecosyst. Environ.*, 268, 1–7
- Larsen, V. A. and Kongsted, A. G. **1999**. Sows on pasture. In: Hermansen, J. E. and Erling Thuen (eds). Ecological Animal Husbandry in the Nordic Countries. [pdf] Horsens. NJF 303, 99–105. Available at: http://www.darcof.dk/publication/rapport/dar_2.pdf. [Accessed 24 October 2008].
- Lebret, B., Dourmad, J. Y., Mourot, J., Pollet, P. Y. and Gondret, F. **2014**. Production performance, carcass composition and adipose tissue traits of heavy pigs: influence of breed and production system. *Journal of Animal Science*, 92(8), 3543–56.

Lebret, B.; Ecolan, P.; Bonhomme, N.; Méteau, K.; Prunier, A. **2015**. Influence of production system in local and conventional pig breeds on stress indicators at slaughter, muscle and meat traits and pork eating quality. *Animal*, 9(08), 1404–13. doi: 10.1017/S1751731115000609.

Leeb, C.; Hegelund, L.; Edwards, S.; Mejer, H.; Roepstorff, A.; Rousing, T.; Sundrum, A.; Bonde, M. **2014**. Animal health, welfare and production problems in organic weaner pigs. *Org. Agric.* 4, 123–133.

Leite, D.M.G.; Silva, M.A. da; Medeiros, R.B. de; Saibro, J.C. de; Pavan, M.A.; Barrey, M.A.A. **2006b**. Efeito de diferentes sistemas de pastejo sobre o desempenho de suínos mantidos em pastagem de trevo-branco (*Trifolium repens* L.). *Revista Brasileira de Zootecnia*, 35, 792–796, doi: 10.1590/S1516-35982006000300022.

Leite, D., Silva, M., Medeiros, R., Saibro, J., Pavan, M. A., Zanella, J. A. and Barrey, M. A. **2006a**. Comportamento de suínos submetidos a diferentes sistemas de pastejo em pastagem de trevo branco. *R. Bras. Zootec.*, 35(4), 1774–9. Available at: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-35982006000600027&lng=en&nrm=iso (Accessed 14 June 2016). <http://dx.doi.org/10.1590/S1516-35982006000600027>.

Leuchtmann, A.; Bacon, C.W.; Schardl, C.L.; White, J.F.; Tadych, M. **2014**. Nomenclatural realignment of *Neotyphodium* species with genus *Epichloë*. *Mycologia*, 106, 202–215, doi: 10.3852/13-251.

Lindgren, K.; Bochicchio, D.; Hegelund, L.; Leeb, C.; Mejer, H.; Roepstorff, A.; Sundrum, A. **2014**. Animal health and welfare in production systems for organic fattening pigs. *Org. Agric.*, 4, 135–147.

Lindgren, K.; Gunnarsson, S.; Höglund, J. Cecilia Lindahl Allan Roepstorff. **2019**. Nematode parasite eggs in pasture soils and pigs on organic farms in Sweden. *Org. Agric.*

López-García, A.; García-Casco, J.M.; Muñoz, M.; Martínez-Torres, J.M.; Fernández-Barroso, M.A.; González-Sánchez, E. **2017**. Backfat Fatty Acid Profile after Growing Period. In Iberian Pigs Fed With Olive Cake in a Dry or Wet (Silage) Form. In Proceedings of the 11th International Symposium Modern Trends in Livestock Production, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, pp. 169–177, ISBN 978-86-82431-73-2. Available online: <http://istocar.bg.ac.rs/en/simpozijum/11th-international-symposium-modern-trend-in-livestockproduction-11th-13-th-october-2017-belgrade-serbia/> (accessed on 17 May 2019).

Lukovic, Z.; Skorput, D.; Karolyi, D. **2017**. Pig welfare at different production systems. In Proceedings of the 11th International Symposium Modern Trends in Livestock Production, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, 2017; pp. 319–326, ISBN 978-86-82431-73-2. Available online: <http://istocar.bg.ac.rs/en/simpozijum/11th-international-symposium-modern-trend-in-livestockproduction-11th-13-th-october-2017-belgrade-serbia> (accessed on 17 May 2019).

Macci, C., Doni, S., Bondi, G., Davini, D., Masciandaro, G. and Pistoia, A. **2012**. Effects of wild boar (*Sus scrofa*) grazing on soil properties in Mediterranean environment. *CATENA*, 98, 79–86.

Maes, D.; Dewulf, J.; Piñeiro, C.; Edwards, S.; Kyriazakis, I. **2019**. A critical reflection on intensive pork production with an emphasis on animal health and welfare. *J. Anim. Sci.*, 362.

Martens, S. D., Tiemann, T. T., Bindelle, J., Peters, M. and Lascano, C. E., **2012**. Alternative plant protein sources for pigs and chickens in the tropics – nutritional value and constraints: a review. *Journal of Agriculture and Rural Development in the Tropics*, 113, 101–23.

Massey University. **2012**. New Zealand Best Practice Guidelines for Free Range Pork Production; College of sciences. Sustainable farming fund. Crown Copyright—Ministry for Primary Industries: Palmerston North, New Zealand; p. 62.

Meier, R.; Ryser-Degiorgis, M. **2008**. Wild boar and infectious diseases: Evaluation of the current risk to human and domestic animal health in Switzerland: A review. *Schweiz. Arch. Tierheilkd.*, 160, 443–460.

Meng, X.J.; Lindsay, D.S.; Sriranganathan, N. **2009**. Wild boars as sources for infectious diseases in livestock and humans. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 364, 2697–2707.

Menzi, H.; Stauffer, W.; Zihlmann, U.; Weisskopf, P. **1998**. Environmental impacts of outdoor pig production. In *Proceedings of the 8th International Conference on the Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture (RAMIRAN 98)*, Rennes, France, 8–12 September; Martinez, J., Maudet, M.N., Eds.; FAO ESCORENA Editions Quae: Paris, France, 1999; Volume 2, pp. 31–39, ISBN 978-2-85362-531-9.

Miao, Z. H., Glatz, P. C., & Ru, Y. J. **2004**. Review of Production, Husbandry and Sustainability of Free-range Pig Production Systems. *Asian-Australasian J. Anim. Scie.*, 17(11), 1615–1634. <https://doi.org/2004.17.11.1615>

Michalk, D.L. **2015**. Sustainability, Biodiversity and Environmental Issues: A Global Perspective for Livestock Production. 18. XXIII Grassland conference. New delhi, India.

Mkwanazi, M.V.; Ncobela, C.N.; Kanengoni, A.T.; Chimonyo, M. **2019**. Effects of environmental enrichment on behaviour, physiology and performance of pigs—A review. *Asian-Australas. J. Anim.*, 32, 1–13.

Moerman, M. **2019**. L'élevage des Porcs en Agriculture Biologique-Le Bien-Être; Centre Wallon de Recherches Agronomiques: Gembloux, Belgique. pp. 1–43. Available online: <http://www.cra.wallonie.be/fr/lelevage-des-porcs-en-agriculture-biologique-le-bien-etre978-> (accessed on 11 January 2020).

Monteiro, E.D.C.; Burak, D.L.; Cunha, A.D.M.; Passos, R.R.; Mendonça, E.D.S. **2018**. Visual assessment of pasture degradation: validation by ground cover and seasonal variation. *Rev. Ciência Agrônôm.*, 49(1), 174–182.

Monteverde, S. and Del Pino, A. **2014**. Variabilidad espacial en las propiedades químicas del suelo en un sistema de producción con cerdos en pastoreo. *Revista Ciencias Agronómicas* 23, 037–045.

Monteverde, S., Del Pino, A., Piaggio, J. and Nay, H. **2011**. Metales pesados en la producción de cerdos a campo. In: VII Jornadas técnicas de la Facultad de Veterinaria. UDELAR. 190. Available at: <http://www.fvet.edu.uy/?q=tecnolog%C3%ADa-agropecuaria/publicaciones> [Accessed 27 August 2013].

Motta-Delgado, P. A., Ocaña-Martínez, H. E., & Rojas-Vargas, E. P. **2019**. Indicadores asociados a la sostenibilidad de pasturas: Una revisión. *Ciencia & Tecnología Agropecuaria*, 20(2), 387–408. https://doi.org/10.21930/rcta.vol20_num2_art:1464

Mpampouli, S., Abraham, E. M., Kyriazopoulos, A., Fotiadis, G., Parissi, Z. M. and siouvaras, C. N. **2009**. The effects of wild boar grazing on the floristic diversity of a silvopastoral oak system. In *Alternative functions of grassland. Proceedings of the 15th European Grassland Federation Symposium*, Brno, Czech Republic, 7–9 September. Editors Cagaš, B.; Macháč Macháč Czech RepuGrassland Science in Europe, 14, 192–5. ISBN 978-80-86908-15-1 Record Number 20093293375.

Muns, R.; Nuntapaitoon, M.; Tummaruk, P. **2016**. Non-infectious causes of pre-weaning mortality in piglets. *Livest. Sci.*, 184, 46–57.

Muñoz-Mendoza, M.; Marreros, N.; Boadella, M.; Gortázar, C.; Menéndez, S.; de Juan, L.; Bezos, J.; Romero, B.; Copano, M.F.; Amado, J.; et al. **2013**. Wild boar tuberculosis in Iberian Atlantic Spain: A different picture from Mediterranean habitats. *BMC Vet. Res.*, 9, 176.

Murphy, S.; Lodge, G. **2002**. Ground cover in temperate native perennial grass pastures. I. A comparison of four estimation methods.

Murrell, K.D. **2016**. The dynamics of *Trichinella spiralis* epidemiology: Out to pasture? *Vet. Parasitol.*, 231, 92–96.

Nazareno, A.C.; Da Silva, I.J.O.; Nunes, M.L.A.; De Castro, A.C.; Miranda, K.O.S.; Trabachini, A. **2012**. Caracterização bioclimática de sistemas ao ar livre e confinado para a criação de matrizes suínas gestantes. *Rev. Bras. Eng. Agríc. Ambient.*, 16, 314–319.

NC-NRCS. Conservation planning guidelines for outdoor swine operations. **2007**. [(PDF)] Available online: <https://efotg.sc.egov.usda.gov/references/Delete/2008-7-12/OSOTECHNOTE.pdf> (Accessed 12 November, 2017)

Norwood, F. B.; Lusk, J. L. **2011**. A calibrated auction-conjoint valuation method: Valuing pork and eggs produced under differing animal welfare conditions. *Journal of Environmental Economics and Management*, 62(1), 80–94. <https://doi.org/10.1016/j.jeem.2011.04.001>

Northup, B.K.; Starks, P.J.; Turner, K.E. **2019**. Stocking Methods and Soil Macronutrient Distributions in Southern Tallgrass Paddocks: Are There Linkages? *Agronomy*, 9, 281, doi:10.3390/agronomy9060281.

Nunn, L., Embree, C. G., Hebb, D., Bishop, S. D. and Nichols, D. **2007**. Rotationally grazing hogs for orchard floor management in organic apple orchards ISHS. *Acta Horticulturae*, 737(9), 71–78, <http://dx.doi.org/10.17660/ActaHortic.2007.737.9> ISSN: 0567-7572 [Accessed 19 June 2016].

Nyachoti, C.M.; Zijlstra, R.T.; de Lange, C.F.M.; Patience, J.F. **2004**. Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. *Can. J. Anim. Sci.*, 84, 549–566, doi:10.4141/A04-001.

Ocampo-Duran, A. **2011**. Producción porcina tropical: cuando el alimento viene de las alturas. In: Barlocco, N. and Vadell, A. (ed.). *Producción de Cerdos a Campo. Aportes para el desarrollo de tecnologías apropiadas para la producción familiar*. [pdf] Montevideo. Universidad de la Republica, Facultad de Agronomía. 116–20 Available at: <http://www.upc.edu.uy/images/documents/extension/Publicacion%2015%20anos%20UPC.pdf>. [Accessed 12 April 2016]

Ogle, B. **2006**. Forage for pigs: Nutritional, physiological and practical implications. In *Forages for Pigs and Rabbits*; Phnom Penh MEKARN-CeIAgrid: Phnom Penh, Cambodia, Available online: <http://www.mekarn.org/proprf/ogle.htm> (accessed on 13 December 2019).

Olczak, K.; Nowicki, J.; Kloczek, C. **2015**. Pig behaviour in relation to weather conditions—A review. *Ann. Anim. Sci.*, 15, 601–610.

Oliveira Júnior, G.M.; De Ferreira, A.S.; Oliveira, R.F.M.; Silva, B.A.N.; Figueiredo, E.M.; Santos, M. **2011**. Behaviour and performance of lactating sows housed in different types of farrowing rooms during summer. *Livest. Sci.*, 141, 194–201.

Olsson, A.C.; Jeppsson, K.-H.; Botermans, J.; von Wachenfelt, H.; Andersson, M.; Bergsten, C.; Jørgen Svendsen, J. **2014**, Pen hygiene, N, P and K budgets and calculated nitrogen emission for organic growing–finishing pigs in two different housing systems with and without pasture access. *Lives. sci.*, 165, 138–146. <http://doi.org/10.1016/j.livsci.2014.03.025>

Pablos-Tanarro, A.; Ortega-Mora, L.M.; Palomo, A.; Casasola, F.; Ferre, I. **2018**. Seroprevalence of *Toxoplasma gondii* in Iberian pig sows. *Parasitol. Res.*, 117, 1419–1424.

Palacio, S.; Bueno, C.G.; Azorín, J.; Maestro, M.; Gómez-García, D. **2013**. Wild-boar disturbance increases nutrient and C stores of geophytes in subalpine grasslands. *Am J Bot.*, 100(9), 1790-1799. Doi: 10.3732/ajb.1300002.

Pande, T.N.; Valentine, I.; Betteridge, K.; Mackay, A.; Horne, D. **2000**. Pasture damage and regrowth from cattle treading. *Proceedings of the New Zealand Grassland Association*, 62: 155–160

Parois, S.P.; Cabezón, F.A.; Schinckel, A.P.; Johnson, J.S.; Stwalley, R.M.; Marchant-Forde, J.N. **2018**. Effect of Floor Cooling on Behaviour and Heart Rate of Late Lactation Sows Under Acute Heat Stress. *Front. Vet. Sci.*, 5, 223.

Parrini, S.; Acciaioli, A.; Franci, O.; Pugliese, C.; Bozzi, R. **2019**. Grazing behaviour of Cinta senese and its crossbreed pigs. *Ital. J. Anim. Sci.*, 18, 287–291.

Pastiu, A.I.; Györke, A.; Blaga, R.; Mircean, V.; Rosenthal, B.M.; Cozma, V. **2013**. In Romania, exposure to *Toxoplasma gondii* occurs twice as often in swine raised for familial consumption as in hunted wild boar, but occurs rarely, if ever, among fattening pigs raised in confinement. *Parasitol. Res.*, 112, 2403–2407.

Passos, A. A., Andrade, C., Phillips, C. E., Coffey, M.T.; Kim, S.W. **2015**. Nutrient value of spray field forages fed to pigs and the use of feed enzymes to enhance nutrient digestibility. *J Anim. Scien.*, 93(4), 1721–8.

Patridge, G. **2014**. Challenges in feeding high-fiber diets to pigs. *Pig International*. Available online at: www.WATTAgNet.com (Accessed 21 June 2016).

Petersen, S. O., Kristensen, K. and Eriksen, J. **2001**. Denitrification losses from outdoor piglet production. *Journal of Environmental Quality*, 30(3), 1051–8.

Pedersen, P.; Sousa, P.; Andersen, L.; Jensen, K. **2003**. Thermoregulatory Behaviour of Growing/Finishing Pigs in Pens with Access to Outdoor Areas. *Agric. Eng. Int.*, V, 1–14.

Phocas, F., Belloc, C., Bidanel, J., Delaby, L., Dourmad, J. Y., Dumont, B., Ezanno, P., Fortun-Lamothe, L., Foucras, G., Frappat, B., González-García, E., Hazard, D., Larzul, C., Lubac, S., Mignon-Grasteau, S., Moreno, C. R., Tixier-Boichard, M.; Brochard, M. **2016**. Review: Towards the agroecological management of ruminants, pigs and poultry through the development of sustainable breeding programmes: I - selection goals and criteria. *Animal*, 10(11), 1749–1759. <https://doi.org/10.1017/S1751731116000926>

Picardy, J. A., Pietrosemoli, S., Griffin, T. S., & Peters, C. J. **2019**. Niche pork: Comparing pig performance and understanding producer benefits, barriers and labeling interest. *Renewable Agriculture and Food Systems; Cambridge*, 34(1), 7–19. <http://dx.doi.org/prox.lib.ncsu.edu/10.1017/S1742170517000230>

Pistoia, A.; Bondi, G.; Balestri, G.; Mani, D.; Masciandaro, G. **2012**. Soil degradation by grazing pig in Mediterranean environment., 6.

Pistoia A.; Ferruzzi G. **2010**. Impatto ambientale da pascolamento suino. In Allevamento animale e riflessi ambientali. Crovetto G.M. y Sandrucci A. (Eds). *Fondazione Iniziative Zooprofilattiche e Zootecniche*. Brescia, Italia. 78, 161-174

Pistoia, A., Poli, P., Casarosa, L., Balestri, G. and Ferruzzi, G. **2008**. Utilizzo del pascolo boschivo nell'allevamento biologico del suino. In: Paolo Pignattelli, P., Ferrante, V., Mattiello, S., Barbieri, S. and Lolli, S. (eds). *Zootecnia biologica e ricerca: Investire insieme*. VI Convegno Nazionale dell'Associazione Italiana di Zootecnia biologica e biodinamica. [pdf] Arezzo. ZooBioDi, 68–73. ISBN 978-88-903475-0-4. Available at: http://www.zoobiodi.it/doc/ATTI_2008_DEFINITIVI.pdf [Accessed 16 May 2015].

Poppenga, R.H. Poisonous plants. **2010**. In *Molecular, Clinical and Environmental Toxicology*; Luch, A., Ed.; Experientia Supplementum; Birkhäuser Basel: Basel, Switzerland, 100,123–175.

Pugliese, C.; Sirtori, F. **2012**. Quality of meat and meat products produced from southern European pig breeds. *Meat Science*, 90(3), 511–18.

Presto, M. H., Andersson, H. K., Wallgren, P.; Lindberg, J. E. **2007**. Influence of dietary amino acid level on performance, carcass quality and health of organic pigs reared indoors and outdoors. *Acta Agriculturae Scandinavica Section A*, 57, 61–72.

Quijada, R. P., Bitsch, N. I.; Hodgkinson, S. M. **2012**. Digestible energy content of pasture species in growing European wild boar (*Sus scrofa* L.). *Journal of Animal Physiology and Animal Nutrition*, 96(3), 421–7. DOI:10.1111/j.1439-0396.2011.01158.x.

Quintern, M. **2005**. Integration of organic pig production within crop rotation: Implications on nutrient losses In: *Organic Pig Production in Free Range Systems*. Eds Sundrum, A.; Weißmann, F., Special Issue 281, 31–34.

Quintern, M.; Sundrum, A. **2006**. Ecological risks of outdoor pig fattening in organic farming and strategies for their reduction - results of a field experiment in the centre of Germany. *Agric., Ecos., Environ.*, 117(4), 238–50.

Rachuonyo, H.A.; Allen, V.G.; McGlone, J.J. **2005**, Behavior, preference for, and use of alfalfa, tall fescue, white clover, and buffalograss by pregnant gilts in an outdoor production system. *J. Anim. Sci.*, 83(9), 2225–34.

Rachuonyo, A.H.; McGlone, J. **2006**, Impact of Outdoor Gestating Gilts on Soil Nutrients, Vegetative Cover, Rooting Damage, and Pig Performance. *J. Sustain. Agr.* 29, 69–87.

Rachuonyo, H.A.; Pond, W.G.; McGlone, J.J. **2002**, Effects of stocking rate and crude protein intake during gestation on ground cover, soil-nitrate concentration, and sow and litter performance in an outdoor swine production system. *J. Anim. Sci.*, 80, 1451–1461

Ramírez-Restrepo, C.A; Barry, T. N. **2005**. Alternative temperate forages containing secondary compounds for improving sustainable productivity in grazing ruminants. *Animal Feed Science and Technology*, 120(3–4), 179–201.

Régnier, C., Bocage, B., Archimède, H., Noblet, J. and Renaudeau, D., **2013**. Digestive utilization of tropical foliages of cassava, sweet potatoes, wild cocoyam and Erythrina in Creole growing pigs. *Animal Feed Science and Technology*, 180(1), 44–54.

Renner, B.M. **2011**. The Effect of Stocking Rate History on Soil Nutrient Levels and Forage Nutrient Uptake in Pasture Hog Production Systems. North Carolina State University. Master of Science Thesis.. 92 pp. Available online: <https://repository.lib.ncsu.edu/bitstream/handle/1840.16/7325/etd.pdf?sequence=2&isAllowed=y> (Accessed on 7 September 2020)

Rivera Ferre, M.G.; Edwards, S.A.; Mayes, R.W.; Riddoch, I.; Hovell, F.D. **2001**. The effect of season and level of concentrate on the voluntary intake and digestibility of herbage by outdoor sows. *Anim. Sci.*, 72, 501–510.

Rivero, J.; López, I.; Hodgkinson, S. **2013**. Pasture consumption and grazing behaviour of European wild boar (*Sus scrofa* L.) under continuous and rotational grazing systems. *Livestock Science*, 154, 175–183, doi:10.1016/j.livsci.2013.03.006.

Robinson, J. **2013**. Towards a framework for agroecological pig production: maximizing functional roles for pigs within food and farm systems. MSc. Thesis. Norwegian University of Life Sciences. 105 pp.

Rodríguez-Estévez, V., García, A. and Gómez, A. G. **2009a**. Characteristics of the acorns selected by free range Iberian pigs during the montanera season. *Livestock Science*, 122(2–3), 169–76.

Rodríguez-Estévez, V., García, A. and Gómez, A. G. **2009b**. Intrinsic factors of acorns that influence the efficiency of their consumption by Iberian pigs. *Livestock Science*, 122(2–3), 281–5.

- Rodríguez-Estévez, V., García, A., Peña, F. and Gómez, A. G. **2009c**. Foraging of Iberian pigs grazing natural pasture in the dehesa. *Livestock Science*, 120(1), 135–43.
- Rodríguez-Estévez, V., Sánchez-Rodríguez, M., García, A. and Gómez-Castro, A. G. **2010**. Feed conversion rate and estimated energy balance of free grazing Iberian pigs. *Livestock Science*, 132(1), 152–6.
- Rodríguez-Estévez, V., Sánchez-Rodríguez, M., Gómez-Castro, A. G. and Edwards, S. A. **2010**. Group sizes and resting locations of free range pigs when grazing in a natural environment. *Applied Animal Behaviour Science*, 127(1), 28–36.
- Rodríguez-Estévez, V.; Sánchez-Rodríguez, M.; García, A.R.; Gómez-Castro, A.G. **2011**. Average daily weight gain of Iberian fattening pigs when grazing natural resources. *Livestock Science*, 137, 292–295, doi:10.1016/j.livsci.2010.11.015.
- Roepstorff, A. and Mejer, H. **2001**. Strategies for parasite control in organic pigs. In The 5th NAHWOA Workshop, Rodding, 11–13 November. 72–8.
- Roepstorff, A.; Mejer, H.; Nejsun, P.; Thamsborg, S.M. **2011**. Helminth parasites in pigs: New challenges in pig production and current research highlights. *Vet. Parasitol.*, 180, 72–81.
- Roepstorff, A., Monrad, J., Sehested, J. and Nansen, P. **1999**. Mixed grazing with sows and heifers: parasitological aspects. In Ecological animal husbandry in the Nordic countries. Eds Hermansen, J. E., Lund, V. and Thuen, E. Book Proceedings from NJF-seminar No. 303, Horsens, Denmark, pp. 41–4 DARCOF Report No. 2 Record Number 20013092887
- Roinsard, A., Maupertuis, F. and Dubois, A. **2014**. De l'enrubannage pour les truies gestantes. *Atler Agri*, 125, 25–8.
- Ru, Y.J.; Bao, Y.M. **2004**. Feeding dry sows *ad libitum* with high fibre diets. *Asian-Australasian Association of Animal Science*, 17(2), 283–300.
- Rutherford, K.M.D.; Haskell, M.J.; Glasbey, C.; Lawrence, A.B. **2006**. The responses of growing pigs to a chronic-intermittent stress treatment. *Physiology & Behavior*, 89, 670–680, doi:https://doi.org/10.1016/j.physbeh.2006.08.006.
- Sales-Baptista, E.; d'Abreu, M.C.; Ferraz-de-Oliveira, M.I. **2016**. Overgrazing in the Montado? The need for monitoring grazing pressure at paddock scale. *Agrofor. Syst.* 90, 57
- Salakpal, K.; Karolyi, D.; Lukovic, Z. **2013**. Sanitary aspects of outdoor farming systems. *Acta Agric. Slov.*, 4, 109–117.
- Salomon, E.; Benfalk, C.; Lindahl, C.; Lindgren, K. **2005**. Mobile and stationary systems for pigs – Nutrient excretion, distribution on outdoor areas and environmental impact. In *Researching Sustainable Systems. ISOFAR*, 254–257.
- Salomon, E.; Hkerhielm, H.; Lindahl, C.; Lindgren, K. **2007**. Outdoor pig fattening at two Swedish organic farms-Spatial and temporal load of nutrients and potential environmental impact. *Agric. Ecosys. Environ.*, 121, 407–418
- Santos-Ricalde, R.H.; Lean, I.J. **2006**. Digestibility of dried star grass (*Cynodon nlemfuensis*) and consumption of fresh star grass in primiparous pregnant sows. *Animal Feed Science and Technology*, 129, 12–22. doi:10.1016/j.anifeedsci.2005.11.012
- Santos-Ricalde, R.H.; Lean, I.J. **2002**. Effect of feed intake during pregnancy on productive performance and grazing behavior of primiparous sows kept in an outdoor system under tropical conditions. *Livestock Production Science*, 77(1), 13–21.

SAS Institute Inc. **2018**. SAS/STAT(R) 9.4 User's Guide; Copyright © 2020; SAS Institute: Cary, NC, USA;; Available online: <http://support.sas.com/documentation/94/index.html> (accessed on 11 November 2019).

Scasta, J.D.; Stam, B.; Windh, J.L. **2017**. Rancher-reported efficacy of lethal and non-lethal livestock predation mitigation strategies for a suite of carnivores. *Sci. Rep.*, **7**, 14105.

Schneider-Canny, R.; Chekhovskiy, K.; Muñoz, P.; Kwon, S.; Saha, M.C. **2019**. Characterization of bermudagrass (*Cynodon dactylon* L.) germplasm for nitrogen use efficiency. *Euphytica*, **215**, 40

Scipioni, R.; Martelli, G.; Volpelli, L.A. **2009**. Assessment of welfare in pigs. *Ital. J. Anim. Sci.*, **8**, 117–137.

Sehested, J.; Sørensen, K.; Danielsen, V.; Roepstorff, A.; Monrad, J. **2004**. Grazing with heifers and sows alone or mixed: herbage quality, sward structure and animal weight gain. *Livestock Production Science*, **88**, 223–238, doi:10.1016/j.livprodsci.2003.11.008.

Sharifi, M.; Messiga, A.J.; Asefpour Vakilian, K.; Stopford, E.; Hutchinson, T.C. **2020**. Spatial distribution of soil phosphorous fractions following 1-year farrowing sows in an outdoor hog-rearing farm in Eastern Canada. *Environ Monit Assess*, **192**, 322. <https://doi.org/10.1007/s10661-020-08260-y>

Sharifi, M.; Messiga, A.J.; Stopford, E.; Hutchinson, T.C. **2014**. Spatial Distribution of Soil N and P Forms Following One-Year Farrowing Sows on an Outdoor Hog-Rearing Farm in Eastern Ontario; Technical report; NSERC Engage; Trent University: Peterborough, ON, Canada,

Sigua, G.C.; Myer, R.O.; Coleman, S.W.; Mackowiak, C.; Adjei, M.; Chase, C.C.; Albano, J. **2011**. Regional Distribution of Soil Phosphorus Across Congregation-Grazing Zones of Forage-Based Pastures with Cow-Calf Operations in Florida. *Journal of Environmental Protection*, **2**, 408–417, doi:10.4236/jep.2011.24046.

Sikala, K. **2012**. Free-range organic pigs foraging Jerusalem artichokes (*Helianthus tuberosus*)- effect of feeding strategy on feed intake, feed conversion, growth, animal behavior, nutrient balances and profitability. MSc. Thesis. Aarhus University, Department of agroecology. 70 p.

Sirtori, F., Crovetto, A., Meo Zilio, D., Pugliese, C., Acciaioli, A., Campodoni, G., Bozzi, R. and Franci, O. **2011**. Effect of sire breed and rearing system on growth, carcass composition and meat traits of Cinta Senese crossbred pigs, *Italian Journal of Animal Science*, **10**(4), p.e47. <http://dx.doi.org/10.4081/ijas.2011.e47>.

Smith, R.P.; Andres, V.; Dormer, L.; Gosling, R.; Oastler, C.; Davies, R.H. **2017**. Study of the impact on Salmonella of moving outdoor pigs to fresh land. *Epidemiol. Infect.*, **145**, 1983–1992.

Sørensen, K.; Sehested, J.; Danielsen, V. **2000**. Mixed grazing with heifers and pregnant sows. *Grassland Science in Europe*, **5**, 359–61.

Soil Survey Staff. **2014**. Keys to Soil Taxonomy, 12th ed.; USDA-Natural Resources Conservation Service: Washington, DC, USA; 372p. Available online at: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/?cid=nrcs142p2_053580 (accessed on 20 May 2020).

Sollenberger, L.E.; Aiken, G.E.; Wallau, M.O. **2020**. Chapter 5 - Managing grazing in forage–livestock systems, Eds: Rouquette, M.; Aiken, G.E. *Management Strategies for Sustainable Cattle Production in Southern Pastures*, Academic Press, 77–100, <https://doi.org/10.1016/B978-0-12-814474-9.00005-0>.

Sollenberger, L. E., Newman, Y. C., & Macoon, B. **2020**. Pasture Design and Grazing Management. In *Forages*, (pp. 803–814). John Wiley & Sons, Ltd. <https://doi.org/10.1002/9781119436669.ch44>

Sommer, S.G.; Sørensen, H.T.; Møller, H.B.; Morsing, S. **2001**. Ammonia volatilization from sows on grassland. *Atmosp. Environ.*, **35**, 2023–2032

Souther, S.; Loeser, M.; Crews, T.E.; Sisk, T. **2019**. Complex response of vegetation to grazing suggests need for coordinated, landscape-level approaches to grazing management. *Global Ecology and Conservation*, 20, e00770, doi:10.1016/j.gecco.2019.e00770.

Stampa, E., Schipmann-Schwarze, C., & Hamm, U. **2020**. Consumer perceptions, preferences, and behavior regarding pasture-raised livestock products: A review. *Food Quality and Preference*, 82, 103872. <https://doi.org/10.1016/j.foodqual.2020.103872>

Stanojković, A.; Gogić, M.; Ostojić-Andrić, D.; Petrićević, M.; Nišavić, J.; Nešić, K. **2017**. Wild pigs—The source of zoonotic *Streptococcus suis* strains. In Proceedings of the 11th International Symposium Modern Trends in Livestock Production, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, 2017; pp. 253–259. Available online: <http://istocar.bg.ac.rs/en/simpozijum/11th-internationalsymposium-modern-trend-in-livestock-production-11th-13-th-october-2017-belgrade-serbia/> (accessed on 17 May 2019).

Stolba A.; Wood-Gush, D.G.M., **1989**. The behaviour of pigs in a semi-natural environment." *Anim. Prod.*, 48(2), 419-425.

Stern, S.; Andresen, N. **2003**, Performance, site preferences, foraging and excretory behaviour in relation to feed allowance of growing pigs on pasture, *Livest. Prod. Sci.*, 79(2–3), 257-265, [http://dx.doi.org/10.1016/S0301-6226\(02\)00171-9](http://dx.doi.org/10.1016/S0301-6226(02)00171-9)

Stelzer, S.; Basso, W.; Benavides Silván, J.; Ortega-Mora, L.M.; Maksimov, P.; Gethmann, J.; Conraths, F.J.; Schares, G. **2019**. *Toxoplasma gondii* infection and toxoplasmosis in farm animals: Risk factors and economic impact. *Food Waterborne Parasitol.*, 15.

Stolba, A.; Wood-Gush, D. G. M. **1989**. The behaviour of pigs in a semi-natural environment. *Animal Production*, 48(2): 419–425.

Suescún-Ospina, S.T.; Ocampo-Duran, A. **2015**. Comportamiento y desempeño productivo de cerdas de cría a campo abierto en condiciones de Piedemonte, Orinoquia Colombiana. *Revista Orinoquia*. 19(1), 35–40. ISSN: 0121-3709.

Sutherland, M.A.; Webster, J.; Sutherland, I. **2013**. Animal Health and Welfare Issues Facing Organic Production Systems. *Animals*, 3, 1021–1035.

Thomas, L.F.; de Glanville, W.A.; Cook, E.A.; Fèvre, E.M. **2013**. The spatial ecology of free-ranging domestic pigs (*Sus scrofa*) in western Kenya. *BMC Vet. Res.*, 9, 46.

Thomsen, L.E.; Mejer, H.; Wendt, S.; Roepstorff, A.; Hindsbo, O. **2001**. The influence of stocking rate on transmission of helminth parasites in pigs on permanent pasture during two consecutive summers, *Vet. Parasitol.*, 99(2), 129-146, [https://doi.org/10.1016/S0304-4017\(01\)00454-X](https://doi.org/10.1016/S0304-4017(01)00454-X).

Urriola, P. E., Cervantes-Pahm, S. K. and Stein, H. H. **2013**. Fiber in swine nutrition, In: Chiba, L. I. (ed.), *Sustainable Swine Nutrition*, pp. 255–76. John Wiley&Sons, Inc., USA.

Vallentine, J.F. **2000**. *Grazing Management*. Elsevier.San Diego.

Van der Giessen, J.; Fonville, M.; Bouwknecht, M.; Langelaar, M.; Vollema, A. **2007**. Seroprevalence of *Trichinella spiralis* and *Toxoplasma gondii* in pigs from different housing systems in The Netherlands. *Vet. Parasitol.*, 148, 371–374.

Vico, J.P.; Mainar-Jaime, R.C. **2011**. Salmonellosis in wild birds and its relationship with the infection in finishing pigs. In Proceedings of the 9th International Conference on the Epidemiology and Control of Biological, Chemical

and Physical Hazards in Pigs and Pork: SAFEPORK 2011, Maastricht, The Netherlands, 19–22 June 2011; pp. 264–267. Available online: <http://hdl.handle.net/10532/1666> (accessed on 17 May 2020).

Vittoz, P. and Hainard, P. **2002**. Impact of free-range pigs on mountain pastures in the Swiss Jura. *Applied Vegetation Science*, 5(2), 247–54.

Volker, M. **2015**. The control of classical swine fever in wild boar. *Front. Microbiol.*, 6.

Wallander, C.; Frössling, J.; Dórea, F.C.; Uggla, A.; Vågsholm, I.; Lundén, A. **2016**. Pasture is a risk factor for *Toxoplasma gondii* infection in fattening pigs. *Vet. Parasitol.*, 224, 27–32.

Watson, C.; Atkins, T.; Bento, S.; Edwards, A.; Edwards, S. **2003**. Appropriateness of nutrient budgets for environmental risk assessment: a case study of outdoor pig production. *Eur. J. Agron.*, 20(1), 117–126.

Webb, J.; Broomfield, M.; Jones, S.; Donovan, B. **2014**. Ammonia and odour emissions from UK pig farms and nitrogen leaching from outdoor pig production: A review. *Sci. Total Environ.*, 470, 865–875.

Wegner, K.; Lambertz, C.; Das, G.; Reiner, G.; Gauly, M. **2014**. Climatic effects on sow fertility and piglet survival under influence of a moderate climate. *Animal*, 8, 1526–1533.

Wezel, A.; Casagrande, M.; Celette, F.; Vian, J.-F.; Ferrer, A.; Peigné, J. **2014**. Agroecological practices for sustainable agriculture. A review. *Agron. Sustain. Dev.*, 34, 1–20, doi:10.1007/s13593-013-0180-7.

Wang, H.; Zhang, Y.; Chen, G.; Hettenhausen, C.; Liu, Z.; Tian, K.; Xiao, D. **2018**. Domestic pig uprooting emerges as an undesirable disturbance on vegetation and soil properties in a plateau wetland ecosystem. *Wetlands Ecol Manage*, 26, 509–523, doi:10.1007/s11273-017-9588-1.

Whalen, J.K.; Thomas, B.W.; Sharifi, M. **2019**. Chapter One - Novel Practices and Smart Technologies to Maximize the Nitrogen Fertilizer Value of Manure for Crop Production in Cold Humid Temperate Regions. In *Advances in Agronomy*; Sparks, D.L., Ed.; Academic Press; Vol. 153, pp. 1–85.

Williams, J.R.; Chambers, B.J.; Hartley, A.R.; Ellis, S.; Guise, H.J. **2000**. Nitrogen losses from outdoor pig farming systems, *Soil Use Manag.*, 16, 237–243

Williamson, S.; Woodger, N.; Higgins, R.H.; Hands, I. **2009**. Ataxia associated with sunburn in outdoor gilts: A case report. *Pig J.* 62, 84–87.

Wu, N.; Abril, C.; Thomann, A.; Grosclaude, E.; Doherr, M.G.; Boujon, P.; Ryser-Degiorgis, M.P. **2012**. Risk factors for contacts between wild boar and outdoor pigs in Switzerland and investigations on potential *Brucella suis* spill-over. *BMC Vet. Res.*, 8, 116.

Yicui, L.; Baoming, L.; Zhengxiang, Z. **2008**. Effects of size, shape and partition type of pen on excretory behavior of domestic pigs, *Chinese Society of Agricultural Engineering*, 11, 206–211

Yunes, M.C., Von Keyserlingk, M.A.G., Hötzel, M. J. **2017**. Brazilian Citizens' Opinions and Attitudes about Farm Animal Production Systems. *Animals*, 7(10), 75. <https://doi.org/10.3390/ani7100075>

IV. GENERAL DISCUSSION

In pasture pig operations, an appropriate grazing management is necessary to prevent damage to the pasture and, consequently, soil degradation. The impact that grazing animals exert on the pasture ecosystem is the result of diverse interrelated components including defoliation, treading, trampling, and manure deposition (Sales-Baptista et al., 2016).

The way the resources of the grassland ecosystem are organized to attain a defined objective constitutes the grazing management (Allen et al., 2011). Sollenberger, Aiken, and Wallau, (2020), enumerated grazing intensity, grazing frequency, stocking method, and timing of grazing as the elements that shape the grazing management. According to Aiken (2016), the most important means to reach production goals is the stocking rate, while the way the animals are assigned to the pastures models the stocking method (Allen et al., 2011), which in turn modifies the grazing frequency (Sollenberger, Aiken, and Wallau, 2020).

IV.1. Effect of pig stocking rate on vegetative ground cover and soil nutrients.

Adopting the appropriate stocking rate for a pasture system is a critical management decision because it can influence animal performance, long-term farm productivity, economic outcomes, wildlife and natural resources (Sollenberger, Aiken, and Wallau, 2020). The degree of damage that grazing pigs can exert onto the vegetation and the soil can be limited by applying the appropriate stocking rate (Eriksen et al., 2006; Eriksen and Kristensen, 2001; Rachuonyo and McGlone, 2006). Sales-Baptista et al. (2016) advert that the implementation of high stocking rates could magnify the undesirable impacts of grazing animals. A greater intensity of management, and consequently a greater stocking rate, has been associated with greater effects on ground cover and soil properties (Acciaioli et al., 2012; Bondi et al., 2015; Rachuonyo, Pond, and McGlone, 2002).

Maintaining ground cover in outdoor pig systems is critical to controlling water, soil and nutrient movement off site. The amount of ground cover in a certain pasture will be dependent on a variety of factors including the pasture species, climate, soil, pasture management (Lang and McDonald, 2005), and seasonal variability (Monteiro et al., 2018). The establishment of an adequate stocking rate is a key management component to assure the preservation of ground cover levels required to avoid negative environmental consequences. Maintaining an appropriate ground cover level offers a wide array of benefits including animal welfare, forage supply, protection against erosion and runoff, and ultimately against soil and water pollution. In 2007, North Carolina USDA Natural Resource Conservancy Service (NRCS) conservationists established as threshold for conservation purposes, that outdoor pig operations should retain a ground cover of 75% or more (NC-NRCS 2007).

Two studies were conducted to evaluate the effect of stocking rates of growing-finishing pigs (37, 74, 111, and 148 pigs ha⁻¹; 2689; 5378; 8067; and 10756 kg live weigh ha⁻¹, respectively) and sows-gilts (10, 15 and 25 sows-gilts ha⁻¹; 2308; 2531; and 5771 kg live weigh ha⁻¹, respectively) on ground cover and soil properties of bermudagrass paddocks (Field studies 1 and 2, respectively).

Vegetative Ground cover

Pigs can have a direct effect on ground cover when they graze, but also an indirect effect due to trampling and rooting activities (Pistoia and Ferruzzi, 2010). Trampling has been associated with higher soil compaction, damaged soil aggregates, decreased water infiltration and increased run-off [Drewry, 2006; Hiltbrunner et al., 2012]. Rooting has been linked to a reduction in vegetative ground

cover as a consequence of the damage to the aerial and radicular portions of the vegetation (Palacio et al., 2013), and has been considered as the starting point for erosion and runoff, and a risk factor for ground water pollution (Thomsen et al., 2001).

The results of the field studies showed differences in ground cover measured during the last experimental week among paddocks managed under different stocking rates (85.5; 66.6; 52.6; 35.6 % final ground cover for 37; 74; 111; and 148 pigs ha⁻¹, respectively, and 78.3; 68.4; and 65.5 % for 10; 15; and 25 sows-gilts ha⁻¹, respectively) . Only paddocks managed with the lowest stocking rate (37 pigs ha⁻¹ or 10 sows ha⁻¹) maintained the ground cover level (75%) recommended by North Carolina NRCS (2007). Reduction of vegetative ground cover following increments in stocking rate have been previously reported (Campagna et al., 2011; Hermansen et al., 2004; Thomsen et al., 2001). Even though in this studies rest periods were implemented between grazing periods, the recovered ground cover did not reach the initial ground cover values, a situation that could be an indicator of damage to the vegetation and(or) to the soil structure. It could be also possible that the first grazing period ended too late in the forage growing cycle, and/or the second grazing period started too early, therefore not allowing bermudagrass to completely develop the structures (roots, rhizomes, shoots, tillers, stolons) needed for growth and regrowth, consequently impairing its spring recover (Pande et al., 2000).

Soil properties

The stocking rate, is a key factor in the management of pasture systems, and may have effects on soil organic matter, soil biological activity, nutrient loads, nutrient cycling, water infiltration, runoff and erosion (Aiken, 2015; Bondi et al., 2015; Quintern, 2005). Greater pig stocking rates involve the use of more supplemental feed, raising the load of nutrients imported to the system and the threat of losses to the environment (Campagna et al., 2011; Eriksen et al., 2006; Sikala, 2012). In both field studies the soil samples collected following animal removal differed in soil nutrient concentrations according to stocking rates. As these nutrients are major components of pig manure, it may be assumed that the variation of these nutrients detected among the paddocks could be reflecting additional manure deposited in the more intensively managed pastures.

The results obtained herein support previous research that have linked greater stocking rates with increments in soil nitrates and phosphorus, and greater N concentrations and N surpluses in soils (Campagna et al., 2011; Eriksen and Kristensen 2001; Monteverde and DelPino, 2014; Williams et al., 2000). Paddocks managed with the higher stocking rates received more nutrients to the system via animal feed and mineralization of the soil organic matter (Webb et al., 2014). Similarly, in individual paddocks that included trees and were managed with a stocking rate equivalent to 30 or 37 sows ha⁻¹ and seven weeks of occupation, were reported loads of 67 and 78 kg N ha⁻¹ respectively (Jakobsen et al., 2018). However, in research conducted in Texas, there were no differences found in soil nitrate among the tested stocking rates (Rachuonyo and McGlone, 2006). The adoption of greater stocking rates (40 to 50 pigs ha⁻¹ vs 1 to 2 pigs ha⁻¹) in a hilly area of Tuscany resulted in damage of soil physical and chemical properties, including a decrease in carbon concentrations, lesser chemical parameters linked to organic matter and increased mineralization, and impaired soil fertility and quality (Bondi et al., 2015). The deterioration of physical soil characteristics, such as increases in soil bulk density, have been related to grazing management intensity and animal trampling behavior (Drewry, 2006).

The presence of greater ground cover in paddocks managed with the lower stocking rate (37 pigs ha⁻¹ and 10 sows-gilts ha⁻¹) could have also partially contributed to the reduction in the soil nutrient levels as a consequence of plant uptake [Rachuonyo, Pond and McGlone, 2002].

A critical issue with the addition of swine manure to soils is the potential risk of increasing the concentration of heavy metals originated from pig feedstuffs and additives (Formentini et al., 2015; Menzi et al., 1999; Salomon et al., 2007). In the study herein, an increase in the concentrations of zinc and copper in the soil were observed when intensifying the stocking rate from 10 to 25 sows-gilts ha⁻¹; nonetheless, the values attained remained under the levels for environmental concerns (Hardy et al., 2008).

Pig density per unit of area has been identified as one factor that disrupts the excretory behavior of pigs housed indoors (Banhazi, 2013). In these systems, a direct relationship between pen size and the size of the area dedicated to defecation has been reported, the latter being larger in larger pens (Yicui, Baoming, and Zhengxiang, 2008). The size of the paddocks used in the growing-finishing pig study (field study 1) (340, 450, 675 vs 1350 m² for 148, 111 and 74 vs 37 pigs ha⁻¹, respectively) could have limited the expression of the excretory behavior linked with the natural behavior of selecting or avoiding certain areas for excretion (Andersen, Kongsted, and Jakobsen, 2020). As previously reported, pigs prefer dunging areas 5 to 15 m away from their resting areas (Salomon et al., 2007; Stolba and Wood-Gush, 1989) or in the proximity to fences (Watson et al., 2003). In the study of the growing finishing pigs, there were 5 or more meters between the center and the inner sampling point only in paddocks with the lowest stocking rate (37 pigs ha⁻¹), therefore the urinating or defecating locations could be more a consequence of the paddock design than an expression of the natural behavior of the pigs (Andersen and Pedersen, 2011).

Impact of pigs' grazing distribution on the spatial pattern of vegetation and soil properties

Pigs tend to concentrate their activities in certain areas of the paddocks such as the vicinity of shelters, shades, feeders, water structures and fences. As a consequence of grazing, rooting and trampling behavior, the survival of the vegetation in these areas may be compromised. Damaged ground cover can result in a reduction of nutrient removal and in an increased potential of runoff and erosion. Additionally these more impacted areas could potentially become nutrient hot-spot areas (Eriksen et al., 2006; Eriksen and Kristense, 2001; Sommer et al., 2001; Williams et al., 2000), which have been associated with an increased risk of nitrate nitrogen leaching (Jørgensen et al., 2018), especially when the nutrients migrate deeper than 60 cm in the soil profile. Higher numbers of animals can increase the eventuality of environmental hazards.

In the sows stocking rate study (Field study 2), differences in ground cover were detected among the sections of the paddocks, with graze areas showing 68% more ground cover than the service sections. Moreover, it has been noticed that pigs tend to impact already affected areas and enlarge existing bare soil spots. What have been called "grazed patches perpetuating", showing the lack of random area utilization (Barnes et al., 2008). Similar to these results, greater deterioration of the vegetation cover as a consequence of rooting and trampling behavior in areas close to the location of the service structures, and along paddock fences, have been reported (Acciaioli et al., 2012; Quintern and Sundrum, 2006; Salomon et al 2005; Bordeaux et al 2014). The greater impact on the ground cover observed in the service sections is attributed to the permanent access of sows to this area of the paddocks where drinkers and shelters were located. Conversely, the access to one of the eight graze and feeding sections was sequential, and allocated on a weekly basis determined by the rotation. The

grazing sections were occupied only one week during each grazing cycle. It has been previously reported that sows show a tendency to concentrate their activities to the areas adjacent to shelters and huts (Braund et al., 1998; Eriksen and Kristensen, 2001). The lower ground cover of the service sections could represent higher risks for runoff and nutrient leaching, however in this study, the service sections were located in the center of the paddocks surrounded by the grazing sections which presented greater ground cover and could trap escaping runoff and sediment.

In the growing-finishing pig study (Field study 1), it was found differences in bulk density among samples collected from the center of the paddocks compared to those from the inner and outer sampling positions. This could be a consequence of greater rooting activity in this position where the shelter and water structures were located. The overturning and mixing of soil in this area could have neutralized the trampling effect which was more evident in other areas of the paddocks. Similarly, lesser bulk densities have been recorded in soil patches disturbed by wild boars (Cuevas et al., 2012). These findings, and the existence of a significant sampling position x sampling depth interaction, suggest the existence of a spatial heterogeneity in the horizontal and vertical dimensions of the soil attributes measured in paddocks grazed by pigs. Other authors have also found differences in soil physical characteristics in different sections of paddocks managed with pigs which coincide with the findings of this study. Greater damage to soil structure in the wallow areas followed by the shelter and then the feeding areas has been recorded (Menzi et al., 1998). Monteverde and Del Pino (2014), determined higher soil density in the service areas where the huts were located, than in the grazing areas. Similarly, Bordeaux et al. (2014), observed greater compaction on interior subplots of paddocks with permanent shade and drinking structures. Differences among samples collected at different sampling depths, recording greater values with increased depth were also found (Monteverde and Del Pino, 2014).

The results reported in the growing-finishing pigs study validated the existence of a spatial pattern in soil nutrients distribution. Greater concentrations of Total-N, $\text{PO}_4\text{-P}$, and Total-P were found in samples from the inner and the outer positions, farther than the shelters and drinking stations, but closer to the feeders and fences. The buildup of these nutrients may be related to greater fecal deposition in these areas compared to the center. Similar results to those obtained in this study were reported by Bordeaux et al. (2014), who indicated that greater concentrations of inorganic N were found in the exterior versus the interior areas of paddocks grazed by growing pigs. Defecating pigs tend to walk a longer distance from the resting and feeding areas than when urinating (Olsson et al., 2014), which could lead to differential nutrient accumulation. Irregular distribution of nutrients in paddocks managed with pigs has been previously reported (Bordeaux et al., 2014; Ivanova-Peneva, Aarnink, and Verstegen, 2006; Scharifi et al., 2020). Correspondingly, differences in excretory activity performed during day or night hours have been reported for fattening pigs reared in confinement, who exhibited a preference for defecating in corners away from their feeding and lying areas (Guo, Lian, and Yan, 2015).

In the growing-finishing pig study, greater concentrations of $\text{NO}_3\text{-N}$ were found in samples collected in the outer sections (areas contiguous to the fence and where the feeders were located) of paddocks managed with 148 pigs ha^{-1} in comparison with the concentrations of this nutrient registered in samples collected in paddocks managed with 37 pigs ha^{-1} , indistinctly of the position of collection. The results obtained in both stocking rate studies (growing-finishing pigs and sows-gilts), are in agreement with previous studies where it was indicated an effect of the stocking rates and soil sampling depth on soil nitrate concentrations (Eriksen, 2001; Eriksen, Petersen, and Sommer, 2002; Jørgensen et al., 2018).

Additionally, the results herein point out the existence of an interaction sampling position by sampling depth for bulk density, Total-N, and Total-P soil concentrations. These findings coincide with the results of Scharifi et al. (2020) who suggested that the concentration of soil nutrients in paddocks individually grazed with lactating sows showed a marked spatial (horizontal and vertical) pattern along four areas. According to these authors, the pattern varied among soil nutrients and also among the form of the nutrients, which presented an uneven pattern in both the vertical and horizontal dimensions of the soils. Previous research have indicated also differences in electrical conductivity, and in the concentrations of inorganic-N, and available-P in function to areas of the paddocks. Per example among the exterior and the interior areas of the paddocks (Bordeaux et al., 2014), or the service areas where shelters, feeders, drinking points and wallows were located and the grazing areas (Monteverde and Del Pino, 2014; Sharifi et al., 2014).

In soil samples from both studies the nutrient concentrations varied also according to sampling depth with most of the nutrients showing greater concentrations of most of the nutrients in samples collected from the upper soil strata. While grazing pigs deposit their excreta on the paddock surface. The organic matter deposited in this way will eventually decay and release its components into the soil profile, circumstance that could increase the concentration of nutrients in the soil upper layer. However, for some nutrients such as PO₄-P, NH₄⁺, Total P, Na and Fe, greater concentrations were found in the lower soil strata, sometimes reaching the 60 to 90 cm layer. This can be considered an evidence of the movement of the nutrients through the soil profile, and could represents a water quality environmental risk.

Forage species traits, such as their growth and reproductive habits (erect or prostrate, bunch or sod forming), nutritive value, and palatability, can favor rooting behavior (Pistoia and Ferruzzi, 2010; Rachuonyo, Allen, and McGlone, 2005), and affect the ability of the forage to survive (Williams et al., 2000). The final ground cover reported in our studies, 55 % on average, demonstrates the potential of bermudagrass inclusion in pasture-based pig systems. The morphological and physiological traits of bermudagrass, a warm season perennial species adapted to different types of soils and climates, that shows aggressive growth, good grazing tolerance, and ability to produce biomass of good quality forage when soil nutrients are not limiting (Schneider-Canny et al., 2019), make this grass suitable for this kind of systems. Its decumbent growth habit and reproductive mechanisms (rhizomes, stolons, and extensive root mass) allowed it to endure the grazing, rooting, trampling and lounging behaviour of the pigs, and to recover during the rest periods between successive grazings (Williams et al., 2000).

IV.2. Effect of pig stocking methods on soil properties, vegetative ground cover and animal performance.

Stocking methods are techniques that allow the management of grazing animals according to the pasture area and occupation time to reach a determined objective (Allen et al., 2011). It was hypothesized that different stocking methods to manage pigs on tall fescue pastures would present different impacts on the soil, the vegetation and the animal performance. It was expected that the implementation of rotational stocking methods would enhance soil nutrients distribution within the paddocks, improve ground cover persistence, would sustain appropriate animal performance, and increase soil nutrients uptake by the forage growing on the pastures.

The following discussion pertains to field study number 3 comparing the effects of growing-finishing pigs managed either rotationally or under strip-grazing stocking methods to those of continuously-stocked pigs.

Soils physical-chemical properties

Most of the soil variables did not differ significantly among stocking methods, which could be attributed to having managed all the paddocks with the same stocking rate (47 pigs ha⁻¹). Another possible reason for the lack of differences, could be related with the experiment length. Perhaps after longer grazing periods, or more grazing periods greater differences would become evident. The results showed, however, that pig stocking methods influenced soil bulk density. Lower bulk density was observed from the paddocks managed rotationally or under strip grazing. As soil bulk density increases as a result of pig trampling, it could be reasonable to assume that pigs under continuous stocking, being free to use the area at will, would tend to concentrate in already-used areas, thus increasing their bulk density. Similarly, Bordeaux et al. (2014) reported greater bulk density in pastures managed with pigs under a stationary scheme, compared to the bulk density of paddocks where service structures (shelter and water) were moved weekly. A study comparing stocking method for cattle reported that lower values for bulk density were recorded in the rotational managed soils (Northup, Starks, and Turner, 2019).

In the study herein, pigs under rotational stocking had access to the grazing areas for only a week, while maintaining a permanent access to the service-central area. As the latter represented proportionally a smaller area of the paddock (11.11%), pigs could have had a more localized impact on certain soil areas (Franzluebbers, Stuedemann, and Schomberg, 2000; Sigua et al., 2011). Conversely, rooting behavior, which has been related to reduction in soil compaction (Bordeaux et al., 2014; Pistoia et al., 2012), could have happened more frequently in the more extensive grazing areas. Additionally, pastures managed under continuous stocking exhibited lesser vegetative ground cover than the other two methods. The presence of ground cover could have partially alleviated the direct impact of pig hooves on the soil contributing to a reduction in the soil bulk density of the rotationally stocked paddocks.

Soil samples showed differences in their concentrations of NO₃⁻, P, K, Mn, Zn and Cu among paddocks managed with different stocking methods. Greater concentrations of the above-mentioned soil nutrients were found in paddocks managed under continuous stocking. Differences in soil nutrients among continuous and rotationally stocked pastures have been related to the length of graze periods (Dubeaux et al., 2014). In the present study, the differences could be attributed to the short occupation period (1 week) that would have allowed the forage to rest and recover from animal disturbances in the rotational and strip grazed paddocks, and the uptake by the grass of some of the nutrients deposited through the manure and feed wastage. Conversely, having unrestricted freedom of movement, pigs in the continuous system could have exerted a greater selective pressure on the vegetation of their preference, thus causing localized overgrazing. Recurrent defoliations and soil disturbance have a negative impact on forage root systems, resulting in a reduction of nutrient uptake (Dubeaux et al., 2014). In addition, as a consequence of the weekly movement of feeding (rotational and strip grazing) and watering stations and shelters (strip grazing), the elimination behavior of pigs could have been modified (Andersen, Kongsted, and Jakobsen, 2020), causing a better dispersion of nutrients (Dubeaux et al., 2014; Dubeux and Sollenberger, 2020), and a greater forage uptake, thus leaving lower concentrations of nutrients in the soil. Conversely, in paddocks under continuous stocking the feeding, drinking and resting areas were kept unchanged for the entire length of the graze period. In addition, the short graze periods followed by the rest period could have improved forage nutrient uptake efficiency by supplying nutrients via manure in the moment when forages need them for regrowth (Wezel et al., 2014). Similar results have been obtained in paddocks grazed with cattle, where the stocking method influenced the concentration of NO₃⁻, P, K, Mg, Ca and S, with lower

concentration of the nutrients in paddocks managed with the shorter occupancy (Northup, Starks, and Turner, 2019).

Differences were also observed between some of the soil properties in samples collected at different depths. Soil bulk density was greater deeper in the soil, while humic matter concentrations and exchangeable acidity showed higher values in the topsoil layer (0 to 15 cm). The concentration of NO_3^- , P, K, S, Mn, Zn, Cu, Na, and Fe varied among the soil layers with greater values found in the top 0 to 15 cm layer for most of the nutrients, but for Fe which presented higher values on the bottom strata of the explored soil profile (15 to 30 cm). Previous studies have reported vertical displacement of soil nutrients (Dubeux, and Sollenberger, 2020; Northup, Starks, and Turner, 2019). Grazing pigs deposit dung and urine on the surface of the paddocks. Manure needs to be physically degraded before releasing its components to the soil. However, manure nutrients availability for plant uptake will be dependent on microbial activity (Whalen, Thomas, and Sharifi, 2019) and environmental conditions. It is likely that the differences on soil properties, and the greater concentrations of nutrients in the upper layer could be attributed to the deposition of manure and organic matter to the surface of the ground.

When comparing the initial level of nutrients with those in samples collected following the second pig graze period, changes of different magnitudes were observed. For example, the 0 to 15 cm soil layer showed an increase in the concentrations of NO_3^- -N, P and K. Similarly, increases in concentration of inorganic-N forms (53 % more NO_3^- -N and 75% more NH_4^+ -N) were reported in paddocks (ryegrass, white and red clover) managed during two 12-week periods with a stocking rate equivalent to 58 pigs ha^{-1} (Blumetto et al., 2012). In the study herein, rotational stocking methods did not improve the homogeneity of nutrients distribution, most likely due to the short duration of the graze periods.

Vegetation

Uncontrolled grazing leads to reduced ground cover (Souther et al., 2019). As a consequence of foraging-pigs' activities, mainly rooting, ground cover resulted damaged. As in previous studies, the sites where pigs tended to congregate, such as resting, feeding and wallowing, showed a greater impact. In the study herein, however, at the end of the 12-week graze periods the ground cover was over 66 %, greater than the ground cover (8 to 27 %) reported by Kongsted and Jakobsen (2015) for pigs grazing (338 $\text{m}^2 \text{ pig}^{-1}$, 30 pigs ha^{-1}) a multispecies pasture including grass–clover, and forage herbs for a similar period of time, and greater than the final ground cover (55%) recorded for bermudagrass pastures grazed with growing-finishing pigs (field study 1). It is worth noting that grazing management strategies varied between the above mentioned studies which make comparisons difficult.

Greater ground cover was recorded in paddocks managed with the rotational and the strip grazing stocking methods in comparison with the values obtained under continuous stocking. This advantage may be explained by the short occupation period (1 week) and the length of the rest period (7 weeks) in both rotational stocking methods, while the action of the pigs was uninterrupted under continuous stocking, which could have led to the exhaustion and disappearance of forage plants. Similarities in ground cover among both rotational alternatives could be explained by the impact received by the vegetation under the shelter, drinkers and feeding sites which were disturbed with each weekly movement in the strip grazing method, and could be equivalent to the area set to be used as a service area in the rotational method. Corresponding circumstances were described by Bordeaux et al. (2014) when comparing the ground cover of sudangrass (*Sorghum bicolor* [L.] Moench) and ryegrass (*Lolium multiflorum*) in pasture-based pig systems managed with stationary or mobile structures. Similarly, the response of tall fescue paddock grazed with beef cattle was affected by the stocking method with paddocks managed rotationally showing greater ground cover (Hoveland, McCann, and Hill, 1997).

Paddocks under different stocking methods presented similar botanical composition, with tall fescue maintaining its position as the dominant species at the end of the experiment (66 % of the species present in the paddocks). Michalk (2015) asserted that to maintain the competitive position in a pasture, the dominant species (in this case tall fescue) needs to represent at least the 60% of the biomass. Nevertheless, the emergence of species that were not present at the beginning of the study were observed across stocking methods. Pigs grazing and rooting behaviors could have impacted the vegetation, leaving bare soil patches for other species to colonize (Souther et al., 2019, Wang et al., 2018). Seeds of annual opportunistic species such as crabgrass (*Digitaria sanguinalis*) could have been waiting for ideal conditions to sprout. At the moment of the evaluation, crabgrass was the second most important species present in the paddocks (30%), whereas ragweed (*Ambrosia artemisiifolia*) dominated the broad leaves group which represented 4 % of the species in the paddocks. Differences in botanical composition of paddocks grazed by pigs have been previously reported (Sehested et al., 2004). Those differences could be partly attributed to the selective grazing behavior exerted by pigs on pasture which tend to select certain plants and moreover parts within a plant (Wang et al., 2018), leaving the less preferred species to dominate the stand (Souther et al., 2019). Similarly, replacement of the dominant plant species by annual vegetation due to the impact of pigs rooting on species composition have been reported previously (Wang et al., 2018). Accordingly, the loss of ground cover would be the initial effect of pigs disturbance, followed by the apparition of annual species that would take advantage not only of the physical removal of competitors but also of the nutrients available in the soil (Wang et al., 2018).

The values presented across treatments for both ground cover (70.5 % on average), and botanical composition (Fescue 66 %; Crabgrass 30 %, and other broad leaves 4 %) four weeks following animal removal from the paddocks after the second graze period, could be interpreted that the pasture system possesses resilience, a trait that can promote a quick recovery from the damage inflicted by grazing animals, in this case the pigs.

Animal performance

Feed disappearance was 8.1% greater during the first graze period (December to March, winter) than during the second one (May to August, summer). This could be partially explained as the effect of the environmental temperature on pigs' maintenance requirements, and to the nutrients supplied by the pasture, which can present seasonal variations. It has been previously reported that the voluntary feed intake of grazing pigs increased when the temperature was under the lower limit of the comfort zone (Blumetto et al., 2013; Gustafson, and Stern, 2003), and decreased when the environmental temperature surpassed the upper limit of the temperature comfort zone which decreases as pig age (Nyachoti et al., 2004). It is important to note the potential exposure of the pigs included in this study to fescue toxicosis, which can cause decreased feed intake (Gupta, Evans, and Nicholson, 2018). It has also been reported that fescue toxicosis effects are more evident during summer than during winter (Gupta, Evans, and Nicholson, 2018). The tall fescue pastures used in this study were not tested for the presence of the fungal endophyte species (*Epichloë coenophiala* Bacon and Schardl.) involved in the symbiotic relationship with the forage (Leuchtmann et al., 2014).

Considering that higher dry matter intake is expected in pasture-based pigs (15% more than indoor-managed pigs) to balance the increased energy requirements (for thermoregulation and exercise) (Edwards, 2003; Kongsted et al., 2015), the feed disappearance values registered in this study (2.01 and 1.86 kg pig d⁻¹ for winter and summer, respectively) could seem low when compared with intake values recorded by other researchers, suggesting that tall fescue could have made a significant contribution to the nutrition of the pigs (Kongsted et al., 2015, Leite et al., 2006). Intake of forages in

grazing growing to finishing pigs represents between 10 and 20% of the total DM intake (Carlson et al., 1999; Jakobsen, Kongsted, and Hermansen, et al., 2015). Greater feed intake values (2.9 kg pig d⁻¹) that those recorded in this study have been reported for pigs managed in a daily strip grazing system (Gustafson, and Stern, 2003), or for weekly rotated pigs (3.15 kg DM pig d⁻¹) (Blumetto et al., 2012). These last authors recorded intake of grass of 0.26 kg DM pig d⁻¹ (Blumetto et al., 2012). Jakobsen et al. (2015) reported intakes values of alfalfa in the range of 0.33 to 0.47 kg DM pig d⁻¹ with similar feed intakes to those registered in this study (2.2 kg DM pig d⁻¹). However, the possibility of reduction in pig feed intake as an effect of fescue consumption and potentially fescue toxicosis cannot be ruled out (Gupta, Evans, and Nicholson, 2018).

Previous studies reported no differences in supplementary feed intake (average: 2.4 kg pig d⁻¹) among pigs grazing white clover under different stocking methods (Leite et al., 2006). No differences were neither observed in the grazing behavior or pasture intake of European wild boar managed either in a continuous or in a rotational grazing system (Rivero, López, and Hodgkinson, 2013). The feed efficiency values measured in this study were greater (+8%) in pigs from rotationally managed paddocks than those reported for pigs continuously stocked, while the values obtained from pigs in the strip-grazing treatment were intermediate. Similar values have been registered for Cinta Senese pigs (Aquilani et al., 2019), whereas a much lower feed efficiency (less than 70% of the values obtained in this study) has been reported for grazing pigs in Uruguay (Blumetto et al., 2012).

Pigs from the rotationally-stocked paddocks showed greater weight gain (8.8% and 8.5% more total and daily weight gain, respectively) when compared with pigs from paddocks managed with the other two stocking methods, which did not differ among them. Although pigs were offered the same supplemental feed *ad libitum*, it may be that the pasture rotationally stocked had a higher forage quality as reported previously for mixed warm and cool-season grass pastures managed with horses showing differences in concentrations of fiber (ADF, NDF, and lignin), water soluble carbohydrates and sugar, and digestible energy (Daniel et al., 2015). Additionally, the weekly movement of animals, shelter and feeding and drinking structures in the strip grazing paddocks could have disrupted the daily routine of this group of pigs and potentially imposed some sort of stress on them (Rutherford et al., 2006). Contrary to these results, no differences in animal weight gain between pigs grazing white clover managed continuously, alternately or rotationally were reported in Brazil (Leite et al., 2006).

The total weight gain was similar in both graze periods, and averaged 61.5 kg pig⁻¹, the same weight gain figure reported for rotationally stocked pigs during 12 weeks in Uruguay (Blumetto et al., 2012). The daily weight gain recorded in this study was in the range of values reported for Iberico pigs (0.74 to 0.78 kg pig d⁻¹) (Rodríguez-Estévez et al., 2011), and similar to the values registered for Cinta Senese pigs (0.71 to 0.76 kg pig d⁻¹) (Aquilani et al., 2019), or for pigs managed in a weekly rotation system (0.73 kg d⁻¹) (Blumetto et al., 2013), but are lower than those obtained in strip grazing managed pigs (0.90 kg pig d⁻¹) (Gustafson and Stern, 2003). The forage species in the pasture impacts the amount of pigs weight gain. In grass pastures with *ad libitum* access to supplemental feed, daily gains in the range of 0.59 to 0.88 kg d⁻¹ have been reported, whereas for alfalfa pastures the figures were 0.74 to 0.90 kg pig d⁻¹ (Jakobsen, Kongsted, and Hermansen, 2015). In this study, it is hard to ascertain the magnitude of the contribution of tall fescue to pig diets, if any. Pigs had *ad libitum* access to supplemental feed, a factor that has shown to reduce forage intake (Stern and Andresen, 2003).

V. GENERAL CONCLUSIONS

A better knowledge regarding grazing management of pasture pig operations is essential to implement best management practices that would allow reaching conservation goals. Under the umbrella of this report previous studies were reviewed providing evidence that limited information exists concerning best management practices for pasture pig production systems. In addition, three field experiments were conducted to evaluate the effects of stocking rates and stocking methods on vegetative ground cover, soil traits, and animal performance.

The results of the field studies have led to the following conclusions:

Survival of bermudagrass ground cover was related with the stocking rate implemented. Greater ground cover was observed in paddocks managed with the lower stocking rate either in the case of growing-finishing pigs or for sows-gilts systems. Similarly, in these paddocks soil nutrients concentrations were lower than those from paddocks managed with greater stocking rates. Soil nutrients concentrations showed differences in relation to sampling point and soil depth, with individualized spatial patterns.

Pigs tend to concentrate their activities in certain areas of the paddocks such as vicinities of shelters, feeders, drinkers and fences, therefore their impact on reduced ground cover will be more evident in such areas.

For a conservation oriented grazing management of bermudagrass paddocks, the stocking rates for growing to finishing pigs should not be higher than 37 pigs ha⁻¹, whereas for sows-gilts systems the stocking rate could be set between 10 and 15 sows-gilts ha⁻¹.

Paddocks continuously stocked presented less ground cover and higher concentrations of NO₃⁻-N, P, K, S, Mn, Cu and Zn in the soil than paddocks managed with rotational or strip grazing schemes.

Pigs from continuously-stocked paddocks showed greater feed disappearance, lower weight gain, and lower feed efficiency compared with pigs from rotationally-stocked paddocks which showed the best growth performance.

As in pasture-based pig production systems the impacts of grazing pigs may only be noticed in the long term, longer studies are needed comparing the effects of different stocking rates and stocking methods on forage persistence and soil properties.

In summary, this study indicates that in pasture pig systems the maintenance of ecosystem multifunctionality is related to the adoption of best management practices. The implementation of an appropriate stocking rate and rotational stocking methods would support vegetative ground cover survival, reduce soil nutrients load and improve nutrient distribution along the paddocks, contributing to the reduction of their environmental impact.

VI. REFERENCES

- Acciaioli, A.; Grifoni, F.; Fontana, G.; Esposito, S.; Franci, O. **2012**. Evaluation of forest damage derived from the rearing of Apulo-Calabrese pig. In: De Pedro, E. J. (ed.), Cabezas, A. B. (ed.). 7th International Symposium on the Mediterranean Pig. [online] Zaragoza: *CIHEAM*. Options Méditerranéennes: Série A. Séminaires Méditerranéens; 101, 133–6. Available at: <http://om.ciheam.org/om/pdf/a101/00006667.pdf> (Accessed on 4 May 2020)
- Agricultural output—Meat consumption—OECD Data*. (n.d.). TheOECD. Available at: <http://data.oecd.org/agroutput/meat-consumption.htm> (Accessed on 15 August 2020)
- Aiken, G.E. **2016**. Invited Review: Grazing management options in meeting objectives of grazing experiments, *Prof. Anim. Scient.*, 32(1), 1-9, <https://doi.org/10.15232/pas.2015-01406>.
- Aiken, G. E. **2015**. Grazing Management Options for Maintaining Optimum Pasture Composition and Utilization. XXIII International Grassland conference. New Delhi, India. Available at: <https://uknowledge.uky.edu/jgc/23/keynote/6/> (Accessed on 28 August 2020)
- Allen, V. G., Batello, C., Berretta, E. J., Hodgson, J., Kothmann, M., Li, X., McIvor, J., Milne, J., Morris, C., Peeters, A., and Sanderson, M. **2011**. An international terminology for grazing lands and grazing animals. *Grass Forage Sci.*, 66(1), 2–28. <https://doi.org/10.1111/j.1365-2494.2010.00780.x>
- Amory, J.; Wainwright, N. **2018**. Welfare of pigs during finishing. In Achieving Sustainable Production of Pig Meat; Wiseman, J., Ed.; Animal health and welfare; Burleigh Dodds Science Publishing: Cambridge, UK. Volume 3, pp. 255–278.
- Andersen, H.M.-L.; Kongsted, A.G.; Jakobsen, M. **2020**. Pig elimination behavior—A review. *Applied Animal Behaviour Science* 222, 104888, doi:10.1016/j.applanim.2019.104888.
- Andersen, H.M.L.; Pedersen, L.J. **2011**. The effect of feed trough position on choice of defecation area in farrowing pens by loose sows. *App. Anim. Behav. Sci.*, 131(1-2), 48-52.
- Andresen, N. and Redbo, I. **1999**. Foraging behaviour of growing pigs on grassland in relation to stocking rate and feed crude protein level. *Applied Animal Behaviour Science*, 62, 183–97.
- Andresen N., Ciszuk P. and Ohlander L. **2001**. Pigs on grassland – animal growth rate, tillage work and effects in the following winter wheat crop. *Biological Agriculture and Horticulture*, 18 (4), 327–43. DOI:10.1080/01448765.2001.9754896.
- Aquilani, C.; Sirtori, F.; Franci, O.; Acciaioli, A.; Bozzi, R.; Benvenuti, D.; Čandek-Potokar, M.; Pugliese, C. **2019**. Effects of Different Protein Levels on the Nitrogen Balance, Performance and Slaughtering Traits of Cinta Senese Growing Pigs. *Animals*, 9, 1021, doi:10.3390/ani9121021.
- Banhazi, T. **2013**. Modelling and influencing hygiene conditions in Australian livestock buildings. In Aland, A. and Banhazi, T. (Eds) Livestock housing. Modern management to ensure optimal health and welfare of farm animals. DOI: <http://dx.doi.org/10.3920/978-90-8686-771-4>. pp. 377–390 (Accessed 17 FEB 2017) https://eprints.usq.edu.au/23880/2/Banhazi_ch19_2013_PV.pdf
- Barasona, J.A.; VerCauteren, K.C.; Saklou, N.; Gortazar, C.; Vicente, J. **2013**. Effectiveness of cattle operated bump gates and exclusion fences in preventing ungulate multi-host sanitary interaction. *Prev. Vet. Med.* 111, 42–50.
- Barlocco, N. **2005**. Alimentación de cerdos en Crecimiento y engorde en pastoreo permanente. In: Bauza, R. (ed.). Utilización de pasturas en la alimentación de cerdos. [online] Montevideo: Universidad de la Republica.

Uruguay. 15–22. Available at: http://upc.edu.uy/images/documents/extension/Jornada-Taller_Pasturas_dic05.pdf [Accessed 8 June 2016].

Barnes, M.K.; Norton, B.E.; Maeno, M.; Malecheck, J.C. **2008**. Paddock size and stocking density affect spatial heterogeneity of grazing. *Rangeland Ecol. Manag.* 61, 380–388.

Barnett, J.L.; Hemsworth, P.H.; Cronin, G.M.; Jongman, E.C.; Hutson, G.D. **2001**. A review of the welfare issues for sows and piglets in relation to housing. *Aust. J. Agric. Res.*, 52, 1–28.

Barone, C. M. A., Di Matteo, R., Rillo, L., Rossetti, C. E., Pagano F. and Matassino, D. **2015**. Pork quality of autochthonous genotype Casertana, crossbred Casertana x Duroc and hybrid Pen ar Lan in relation to farming systems. *Agronomy Research*, 13(4), 900–6.

Bauza, R. **2005**. Utilización de pasturas en la alimentación de reproductores. In: Bauza, R. (ed.). Utilización de pasturas en la alimentación de cerdos. [pdf] Montevideo: Universidad de la Republica. Facultad de Agronomía. 5–14. Available at: http://upc.edu.uy/images/documents/extension/Jornada-Taller_Pasturas_dic05.pdf [Accessed 8 June 2016].

Bauza, R. **2007**. Alimentos alternativos para animales monogástricos. In: *IX Encuentro de Nutrición y Producción en Animales Monogástricos*. [pdf] Montevideo: Universidad de la Republica, Facultad de Agronomía. 47–55. Available at: <http://upc.edu.uy/ixe/category/23-memorias-delencuentro> [Accessed 8 June 2016] ISBN: 978-9974-0-0399-6.

Bauza, R. and Petrocelli, H. **2005**. Uso de pasturas en el crecimiento-terminación de cerdos: pastoreo con acceso restringido. In: Bauza, R. (ed.). Utilización de pasturas en la alimentación de cerdos. [pdf] Montevideo: Universidad de la Republica. Facultad de Agronomía. 23–32. Available at: http://upc.edu.uy/images/documents/extension/Jornada-Taller_Pasturas_dic05.pdf [Accessed 8 June 2016].

Beinlich, B. and Poschlod, P. **2002**. Low intensity pig pastures as an alternative approach to habitat management. In: Redecker, B., Härdtle, W., Finck, P., Riecken, U. and Schröder, P. (eds). *Pasture Landscapes and Nature Conservation*, pp. 219–26. Publisher Springer Berlin Heidelberg New York. DOI 10.1007/978-3-642-55953-2_16.

Benfalk, C., Lindgren, K., Lindahl, C. and Rungren M. **2005**. Mobile and stationary systems for organic pigs – Animal behavior in outdoor pens. In: Köpke, U., Niggli, U., Neuhoﬀ, D., Cornish, P., Lockeretz, W. and Willer, H. (eds). *Researching Sustainable Systems*. [pdf] ISOFA, pp. 242–5. Available at: http://orgprints.org/4313/4/4313-Benfalk_etal_4p_revised-ed.pdf [Accessed 8 June 2016].

Benjamins, D. **2002**. Oxford Sandy and Black pigs as a method of weed control. When do they stop being an asset and start becoming a problem? BSc Thesis. De Montfort University, Riseholme School of Agriculture, UK. 43p.

Bikker, P. and Binnendijk, G. P. **2012**. *Grass silage in diets for organic growing-finishing pigs*; Report 603; Wageningen UR Livestock Research: Lelystad, Holland, 22p.

Bisimwa, N.P.; Machuka, E.M.; Githae, D.; Banswe, G.; Amimo, J.O.; Ongus, J.R.; Masembe, C.; Bishop, R.P.; Steinaa, L.; Djikeng, A.; Pelle, R. **2020**. Evidence for the presence of African swine fever virus in apparently healthy pigs in South-Kivu Province of the Democratic Republic of Congo. *Vet. Microb.*, 240, 108521 DOI - 10.1016/j.vetmic.2019.108521

Blumetto Velazco, O.R.; Calvet Sanz, S.; Estellés Barber, F.; Villagrà García, A. **2013**. Comparison of extensive and intensive pig production systems in Uruguay in terms of ethologic, physiologic and meat quality parameters. *R. Bras. Zootec.*, 42, 521–529, doi:10.1590/S1516-35982013000700009.

- Blumetto, O.; Sanz, S.C.; Barber, F.E.; Villagr , A.; Torres, A.G. **2012**. Caracterizaci n productiva y ambiental de un sistema semi-extensivo de engorde de cerdos en condiciones de sequ a en Uruguay. *ITEA, informaci n t cnica econ mica agraria: revista de la Asociaci n Interprofesional para el Desarrollo Agrario (AIDA)*, 256–274.
- Bonde, M.; S rensen, J.T. **2004**. Herd health management in organic pig production using a quality assurance system based on Hazard Analysis and Critical Control Points. *NJAS Wagen. J. Life Sci.*, 52, 133–143.
- Bondi, G.; Peruzzi, E.; Macci, C.; Masciandaro, G.; Pistoia, A. **2015**. Changes in soil organic matter associated with pig rearing: Influence of stocking densities and land gradient on forest soils in central Italy, *Agric., Ecos. Environ.*, 211, 32-42, ISSN 0167-8809, <https://doi.org/10.1016/j.agee.2015.05.003>.
- Bordeaux, C.; Grossman, J.; White, J.; Osmond, D.; Poore, M.; Pietrosevoli, S. **2014**. Effects of rotational infrastructure within pasture-raised pig operations on ground cover, soil nutrient distribution, and bulk density. *J. Soil Water Conserv.*, 69(2), 120-30. doi:10.2489/jswc.69.2.120.
- Bornett, H. L. I., Edge, H. L. and Edwards, S. A. **2003**. Alternatives to nose-ringing in outdoor sows: 1. The provision of a sacrificial rooting area. *Applied Animal Behaviour Science*, 83 (4), 267–76.
- Both, MdC. **2003**. Comportamento e produ  o de su  os mantidos em pastagem e submetidos a diferentes n veis de restri  o alimentar. PHD Thesis. Universidade Federal do Rio Grande do Sul, 127p. Available at: <http://www.lume.ufrgs.br/bitstream/handle/10183/5267/000468021.pdf?sequence=1> [14 June 2016].
- Braund, J.P.; Edwards, S.A.; Riddoch, I.; Buchner, L.J. **1998**. Modification of foraging behaviour and pasture damage by dietary manipulation in outdoor sows. *Appl. Anim. Behav. Sci.*, 56, 173–186.
- Buehrer, K. A. and Grieshop, M. J. **2014**. Postharvest grazing of hogs in organic fruit orchards for weed, fruit, and insect pest management. *Organic Agriculture*, 4, 223–32.
- Butler, D.M.; Franklin, D.H.; Ranells, N.N.; Poore, M.H.; Green J.T. **2006**. Ground cover impacts on sediment and phosphorus export from manured riparian pasture. *J Environ Qual.*, 35(6), 2178-2185. DOI: 10.2134/jeq2005.0351
- Butler D.M.; Ranells N.N.; Franklin D.H.; Poore M.H.; Green J.T. **2007**. Ground cover impacts on nitrogen export from manured riparian pasture. *J Environ Qual.*, 36(1), 155-62. DOI: 10.2134/jeq2006.0082
- Campagna, D.; Dichio, L.; Ausilio, A.; Bess n, P. A.; Silva, P.; Spinollo, L. **2011**. Efectos de la carga animal sobre el tapiz vegetal y el recurso suelo en un sistema de producci n porcina al aire libre. In: Barlocco, N. and Vadell, A. (eds). *Producci n de Cerdos a Campo. Aportes para el desarrollo de tecnolog as apropiadas para la producci n familiar*. [pdf] Montevideo, Uruguay. *Universidad de la Rep blica. Facultad de Agronom a*. 92–101. Available at: <http://www.upc.edu.uy/images/documents/extension/Publicacion%2015%20a os%20UPC.pdf>
- Cano-Terriza, D.; Rialde, M.A.; Rodr guez-Hern ndez, P.; Napp, S.; Fern ndez-Morente, M.; Moreno, I.; Bezos, J.; Fern ndez-Molera, V.; Sa  ez, J.L.; Garc  a-Bocanegra, I. **2018**. Epidemiological surveillance of *Mycobacterium tuberculosis* complex in extensively raised pigs in the south of Spain. *Prev. Vet. Med.*, 159, 87–91. [
- Cappaia, S.; Rolesua, S.; Coccollonea, A.; Laddomadab, A.; Loia, F. **2018**. Evaluation of biological and socio-economic factors related to persistence of African swine fever in Sardinia. *Prev. Vet. Med.*, 152, 1–11.
- Carlson, D.; L rke, H.N.; Poulsen, H.D.; J rgensen, H. **1999**. Roughages for Growing Pigs, with Emphasis on Chemical Composition, Ingestion and Faecal Digestibility. *Acta Agriculturae Scandinavica, Section A — Animal Science*, 49, 129–136, doi:10.1080/090647099424033.
- Castillo-Cuenca, J.C.; D  az-Cao, J.M.; Mart  nez-Moreno, A.; Cano-Terriza, D.; Jim  nez-Ruiz, S.; Almer  a, S.; Garc  a-Bocanegra, I. **2020**. Seroepidemiology of *Toxoplasma gondii* in extensively raised Iberian pigs in Spain. *Prev. Vet. Med.*, 175, 104854.

Castillo, M, Martín-Orúe, S. M., Anguita, M, Pérez, J. F. and Gasa J., **2007**. Adaptation of gut microbiota to corn physical structure and different types of dietary fibre, *Livestock Science*, 109, 149—152.

Cecchini, L., Torquati, B., Chiorri, M. **2018**. Sustainable agri-food products: A review of consumer preference studies through experimental economics. *Agricultural Economics (Zemědělská Ekonomika)*, **2018**, 64(12), 554–565. <https://doi.org/10.17221/272/2017-AGRICECON>

Coulloudon, B.; Eshelman, K.; Gianola, J.; Habich, N.; Hughes, L.; Johnson, C.; Pellant, M.; Podborny, P.; Rasmussen, A.; Robles, B.; Shaver, P.; Spehar, J.; Willoughby, J. **1999**. Sampling Vegetation Attributes; Interagency Technical Reference; Bureau of Land Management's National Applied Resource Sciences Center: Denver, CO, USA.

Congio, G. F. S., Chiavegato, M. B., Batalha, C. D. A., Oliveira, P. P. A., Maxwell, T. M. R., Gregorini, P., Da Silva, S. C. **2019**. Strategic grazing management and nitrous oxide fluxes from pasture soils in tropical dairy systems. *Science of The Total Environment*, 676, 493–500. <https://doi.org/10.1016/j.scitotenv.2019.04.186>

Conner, D. S., Oppenheim, D. **2008**. *Demand for Pasture-Raised Livestock Products in Michigan: Results of Consumer Surveys and Experimental Auctions*, (No. 856-2016–57896). *Journal of Food Distribution Research*, <https://doi.org/10.22004/ag.econ.55603>

Corbin, M. D., Nave, R. L. G., Bates, G. E., Butler, D. M., & Hawkins, S. A. **2019**. Alternatives to Conventional Nitrogen Fertilization on Tall Fescue and Bermudagrass. *Agron. J.*, 111(1), 275–286. <https://doi.org/10.2134/agronj2018.03.0190>

Dalla Costa, O.A.; Nelson Morés, N.; Pedroso-de-Paiva, D.; Silva, R.A.M.; Sobestiansky, J.; Monticelli, C.J.; Leite, D.M.G. **2000**. Acompanhamento parasitário de rebanhos suínos no sistema intensivo de suínos criados ao ar livre—SISCAL. CT/253. In *Embrapa Suínos e Aves*; EMBRAPA: Brasília, DF, Brazil, pp. 1–3, ISBN 0100–8862.

Daniel, A.D.; McIntosh, B.J.; Plunk, J.D.; Webb, M.; McIntosh, D.; Parks, A.G. **2015**. Effects of rotational grazing on water-soluble carbohydrate and energy content of horse pastures. *Journal of Equine Veterinary Science*, 35, 385–386, doi:10.1016/j.jevs.2015.03.014.

Danielsen, V.; Hansen, L. L.; Møller, F.; Bejerholm, C. and Nielsen, S. **1999**. Production results and sensory meat quality of pigs fed different amounts of concentrate and ad libitum clover grass or clover grass silage. In Hermansen, J. E., Lund, V. and Thuen, E. (eds), *Ecological Animal Husbandry in the Nordic Countries*, Danish Research Centre for Organic Farming: Tjele, Denmark, pp. 79–86.

Davies, P.R. **2011**. *Intensive Swine Production and Pork Safety*. Foodborne Pathog. Dis., 8.

De Lucia, A.; Rabie, A.; Smith, R.P.; Davies, R.; Ostanello, F.; Ajayi, D.; Petrovska, L.; Martelli, F. **2018**. Role of wild birds and environmental contamination in the epidemiology of Salmonella infection in an outdoor pig farm. *Vet. Microbiol.*, 227, 148–154.

Demori, A. B., Lovatto, P. A., Andretta, I., Kipper, M., Lehen, C. R. and Remus, A. **2012**. Criação intensiva de suínos em confinamento ou ao ar livre: estudo meta-analítico do desempenho zootécnico nas fases de crescimento e terminação e avaliação de carcaça e carne no Longissimus dorsi. *Ciência Rural*, 42(7), 1294–9. Available at: <https://dx.doi.org/10.1590/S0103-84782012000700025>.

Doran, M. **2015**. Multi-Species Grazing Systems. In: Ellsworth, S. (ed.). *Outdoor Hog Production. Best Practices for Resource Conservation in the San Francisco Bay Area*. [pdf] Available at: <http://www.acrcd.org/Portals/0/Multi%20Species%20Grazing.pdf> [18 November 2015.]

Dourmad, J.-Y.; Casabianca, F. **2013**. Effect of husbandry systems on the environmental impact of pig production. *Acta agriculturae Slovenica, Supplement 4*, 197–204. ISSN: 1581-9175 Available at: <http://prodinra.inra.fr/record/253477> [10 June 2016].

Drewry, J.J. **2006**. Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: A review. *Agric., Ecos. Environ.*, *114*, 159–169

Drinkwater, L.E.; Cambardella, C.A.; Reeder, J.D.; Rice, C.W. **2015**. Potentially Mineralizable Nitrogen as an Indicator of Biologically Active Soil Nitrogen. In *Methods for Assessing Soil Quality*; Doran, J.W., Jones, A.J., Eds.; Soil Science Society of America, Inc: Madison, WI, USA.

Dubeux, J.C.B.; Sollenberger, L.E. **2020**. Nutrient cycling in grazed pastures. In *Management Strategies for Sustainable Cattle Production in Southern Pastures*; Elsevier, 59–75 ISBN 978-0-12-814474-9.

Dubeux, J. C. B., Sollenberger, L. E., Muir, J. P., Tedeschi, L. O., Santos, M. V. F. dos, Cunha; M. V. da, Mello; A. C. L. de, DiLorenzo, N. **2017**. Sustainable intensification of livestock production on pastures. *Archivos Latinoamericanos de Producción Animal*, *25*(3–4). https://ojs.alpa.uy/index.php/ojs_files/article/view/2564

Dubeux, J.C.B.; Sollenberger, L.E.; Vendramini, J.M.B.; Interrante, S.M.; Lira, M.A. **2014**. Stocking Method, Animal Behavior, and Soil Nutrient Redistribution: How are They Linked? *Crop Science*, *54*, 2341–2350, doi:10.2135/cropsci2014.01.0076.

Dumont, B., Fortun-Lamothe, L., Jouven, M., Thomas, M.; Tichit, M. **2013**. Prospects from agroecology and industrial ecology for animal production in the 21st century. *Animal*, *7*(6), 1028–1043. <https://doi.org/10.1017/S1751731112002418>

Edge, H. L., Bornett, H. L. I., Newton, E. and Edwards, S. A. **2004**. Alternatives to nose-ringing in outdoor sows: 2.The provision of edible or inedible overground enrichment. *Animal Welfare*, *13*(2), 233–237.

Edge, H. L., Bulman, C. A. and Edwards, S. A. **2005**. Alternatives to nose-ringing in outdoor sows: the provision of root crops. *Applied Animal Behavioural Science*, *92* (1–2), 15–26.

Edwards, S. A. **2003**. Intake of nutrients from pasture by pigs. *Proceedings of the Nutrition Society*, *62*(2), 257–265. <https://doi.org/10.1079/PNS2002199>

Edwards, S. A. **2005**. Product quality attributes associated with outdoor pig production. *Livestock Production Science*, *94*, 5–14.

Edwards, S. **2018**. Welfare of gilts and pregnant sows. In *Achieving Sustainable Production of Pig Meat*; Wiseman, J., Ed.; Animal health and welfare; Burleigh Dodds Science Publishing: Cambridge, UK,; Volume 3, pp. 203–223.

Edwards, S.; Mejer, H.; Prunier, A.; Roepstorff, A. **2011**. Animal health, welfare and production problems in organic pregnant and lactating sows. In *Animal Health and Welfare in Organic Pig Production*; Edwards, S., Ed.; CORE Organic Project: Tjele, Denmark, 1904; p. 109.

Edwards, S.; Mejer, H.; Roepstorff, A.; Prunier, A. **2014**. Animal health, welfare and production problems in organic pregnant and lactating sows. *Org. Agric.*, *4*, 93–105.

EFSA. **2007**. Scientific Opinion of the Panel on Animal Health and Welfare on a request from Commission on the risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems. *EFSA J.*, *6*, 1–13.

EFSA. **2014**. Evaluation of possible mitigation measures to prevent introduction and spread of African swine fever virus through wild boar. *EFSA J.*, *12*, 3616.

Eriksen, J. **2001**. Implications of grazing by sows for nitrate leaching from grassland and the succeeding cereal crop. *Grass & Forage Science*, 56(4), 317–22.

Eriksen, J.; Kristensen, K. **2001**. Nutrient excretion by outdoor pigs: A case study of distribution, utilization and potential for environmental impact. *Soil Use Manage.*, 17, 21–29.

Eriksen, J.; Petersen, S.O.; Sommer, S.G. **2002**. The fate of nitrogen in outdoor pig production. *Agronomie*, 22, 863–867.

Eriksen, J., Hermansen, J. E., Strudsholm, K. and Kristensen, K. **2006a**. Potential loss of nutrients from different rearing strategies for fattening pigs on pasture. *Soil Use Management* 22, 256–66.

Eriksen, J.; Studnitz, M.; Strudsholm, K.; Kongsted, A.G.; Hermansen, J.E. **2006b**. Effect of nose ringing and stocking rate of pregnant and lactating outdoor sows on exploratory behaviour, grass cover and nutrient loss potential. *Livest. Sci.*, 104, 91–102.

Fajardo, D. S. **2009**. Evaluación de dos sistemas de instalaciones y manejo para la etapa de lactancia, comparando la producción porcina tradicional vs la producción al aire libre. BSc Thesis. Universidad de la Salle, Colombia. 125p.

Faner, C. L. **2007**. La pastura de alfalfa como fuente de alimentación para cerdos en crecimiento y terminación. Boletín AACP. Available at: www.produccion-animal.com.ar.

FAO. **2007**. Animal genetic resources and resistance to disease. In: Rischkowsky, B. and Pillin, D. (eds), *The State of the World's Animal Genetic Resources for Food and Agriculture*, FAO, Rome, Italy, pp. 101–12.

Ferretti, F.; Storer, K.; Coats, J.; Massei, G. **2015**. Temporal and spatial patterns of defecation in wild boar. *Wildlife society bulletin*, 39(1), 65–69

Finzel, J.A.; Baldwin, R.A. **2015**. Wild Pigs. UC Cooperative Extension Integrated Pest Management. Publication 74170. Available online: <http://ipm.ucanr.edu/PMG/PESTNOTES/pn74170.html> (accessed on 30 January 2020).

Fleming, P.A.; Dundas, S.J.; Lau, Y.Y.; Pluske, J.R. **2016**. Predation by Red Foxes (*Vulpes vulpes*) at an Outdoor Piggery. *Animals*, 6, 60.

Formentini, T.A.; Kochem Mallmann, F.J.; Pinheiro, A.; Scapulatempo Fernandes, C.V.; Bender, M.A.; da Veiga, M.; Rheinheimer dos Santos, D.; Doelsch, E. **2015**. Copper and zinc accumulation and fractionation in a clayey Hapludox soil subject to long-term pig slurry application. *Sci. Total Environ.*, 536, 831–839.

Fortina, R., Brugiapaglia, A., Tassone, S., Malfatto, V. and Cavallero, A. **2011**. Pasture-Based Swine Management: Behaviour and Performances of Growing-Finishing Pigs. *Animal Science and Biotechnologies*, 44 (1), 37–40.

Franzluebbers, A.J., Paine, L.K., Winsten, J.R., Krome, M., Sanderson, M.A., Ogles, K., & Thompson, D. **2012**. Well-managed grazing systems: A forgotten hero of conservation. *J. Soil and Water Conserv.*, 67(4), 100A–104A. <https://doi.org/10.2489/jswc.67.4.100A>

Franzluebbers, A.J.; Stuedemann, J.A.; Schomberg, H.H. **2000**. Spatial Distribution of Soil Carbon and Nitrogen Pools under Grazed Tall Fescue. *Soil Science Society of America Journal*, 64, 635–639, doi:10.2136/sssaj2000.642635x.

Fredriksson-Ahomaa, M. **2019**. Wild Boar: A Reservoir of Foodborne Zoonoses. *Foodborne Pathog. Dis.*, 16, 163–165.

García-Valverde, R., Nieto, R., Lachica, M. and Aguilera, J. F. **2007**. Effects of herbage ingestion on the digestion site and nitrogen balance in heavy Iberian pigs fed on an acorn-based diet. *Livestock Science*, 112, 63–77.

- Gentry J.G., McGlone J. J.; Blanton J. R.; Miller M.F. **2002a**. Alternative housing systems for pigs: influences on growth, composition, and pork quality. *Journal of Animal Science*, 80(7),1781–90.
- Gentry, J. G., McGlone, J. J., Miller, M. F. and Blanton, J. R. **2004**. Environmental effects on pig performance, meat quality, and muscle characteristics. *Journal of Animal Science*, 82(1), 209–17.
- Giannone, M. **2001a**. Pascoli di favino per i suini biologici. *Rivista di suinicoltura*. 42, 125–30.
- Giannone, M. **2001b**. Sorgo e barbabietola per i suini biologici. *Rivista di suinicoltura*. 42, 38–42.
- Goh, K.M.; Bruce, G.E. **2005**. Comparison of biomass production and biological nitrogen fixation of multi-species pastures (mixed herb leys) with perennial ryegrass-white clover pasture with and without irrigation in Canterbury, New Zealand. *Agriculture, Ecosystems & Environment*, 110, 230-240, 2005.
- Gourdine, J. L., De Greef, K. H. and Rydhmer, L. **2010**. Breeding for welfare in outdoor pig production: A simulation study. *Livestock Science*. Volume 132(1–3), 26–34. doi:10.1016/j.livsci.2010.04.017
- Griths, I.B.; Douglas, R.G.A. **2000**. Phytophotodermatitis in pigs exposed to parsley (*Petroselinum crispum*). *Vet. Rec.*, 146, 73–74.
- Grosso, L., Barbieri, S., Ferrante, V. and Ferrari, P. **2011**. La producción porcina a campo en Italia. In: Barlocco, N. and Vadell, A. (eds). *Producción de Cerdos a Campo. Aportes para el desarrollo de tecnologías apropiadas para la producción familiar*. Montevideo. Universidad de la república. Facultad de Agronomía. 110–15. Available at: <http://www.upc.edu.uy/images/documents/extension/Publicacion%2015%20anos%20UPC.pdf>
- Guberti, V.; Khomenko, S.; Masiulis, M.; Kerba, S. **2019**. African Swine Fever in Wild Boar Ecology and Biosecurity; *FAO Animal Production and Health Manual No. 22*; FAO: Rome, Italy, p. 97.
- Guo, Y.; Lian, X.; Yan, P. **2015**. Diurnal rhythms, positions and behavioural sequences associated with eliminative behaviours in fattening pigs. *Appl. Anim. Beh. Sci.*, 168, 18–23
- Gupta, R.C.; Evans, T.J.; Nicholson, S.S. **2018**. Ergot and Fescue Toxicoses. In *Veterinary Toxicology*; Elsevier; 995–1001 ISBN 978-0-12-811410-0.
- Gustafson, G.M.; Stern, S. **2003**. Two strategies for meeting energy demands of growing pigs at pasture. *Livestock Production Science*, 80, 167–174, doi:10.1016/S0301-6226(02)00319-6.
- Gustafson, G. M. and Svensson, L. **2003**. Ammonia emissions from pigs on deep litter beds and in a strip grazing system. *Journal of Sustainable Agriculture*, 23(2), 41–51. DOI:10.1300/j064v23n02_05.
- Hardy, D.H.; Myers, J.; Stokes, C. **2008**. Heavy Metals in North Carolina Soils. Occurrence and Significance; Department of Agriculture and Consumer Services Agronomic Division: Raleigh, NC, USA,. Available online: <http://digital.ncdcr.gov/u/?p249901coll22,63754>
- Helmerichs, J. **2014**. Paddock management systems for organic growing pigs Effect of land allocation strategies on foraging activity and excretory behavior. MSc Thesis. Aarhus University. Department Of Agroecology. 45p.
- Henney, J. **2012**. An evaluation of the use of pigs as a method of bracken control. In *Grazing Animals Project Heritage Grazing Traineeship; Rare Breeds Survival Trust: Warwickshire, UK*,; p. 40. Available online: http://www.grazinganimalsproject.org.uk/habitat_land_management.html?publication=1;154 (accessed on 9 December 2019).
- Hermansen, J. E. **2005**. Integration of organic pig production into land use. In: Sundrum, A. and Friedrich Weißmann, F. (eds). *Organic Pig Production in Free Range Systems*. [pdf] Braunschweig. FAL Agricultural Research. 281, 3–12. ISSN 0376-0723 ISBN 3-86576-005-8. Available at: <http://orgprints.org/6094/1/6094.pdf> [Accessed 4 June 2016].

Hermansen, J. E., Eriksen, J. and Strudsholm, K. **2005**. Full or partial outdoor rearing of slaughter pigs. Effects on performance, carcass quality and nutrient load. In: Researching Sustainable Systems. [pdf] Adelaide. ISO FAR. 250–3. Available at: http://http://http://orgprints.org/4368/4/4368-Hermansen_etal_4p_revised-ed.pdf [Accessed 4 June 2016].

Hermansen, J.E.; Strudsholm, K.; Horsted, K. **2004**. Integration of organic animal production into land use with special reference to swine and poultry. *Livest. Produc. Sci.*, *90*, 11–26.

Hernández, M.; Gómez-Laguna, J.; Tarradas, C.; Luque, I.; García-Valverde, R.; Reguillo, L.; Astorga, R.J. **2014**. A serological survey of *Brucella* spp., *Salmonella* spp., *Toxoplasma gondii* and *Trichinella* spp. in Iberian fattening pigs reared in free-range systems. *Transbound Emerg. Dis.*, *61*, 477–481.

Heyer, A. H., Andersson, K. and Lundstrom, K. **2006**. Performance, carcass and technological meat quality of pigs in indoor and outdoor production systems. *Acta Agriculturae Scand Section A*. *56*, 55–64. DOI: 10.1080/09064700600670904.

Hilimire, K. **2011**. Integrated Crop/Livestock Agriculture in the United States: A Review. *Journal of Sustainable Agriculture*, *35*(4), 376–93, DOI: 10.1080/10440046.2011.562042

Hill, D.E.; Dubey, J.P.; Baroch, J.A.; Swa_ord, S.R.; Fournet, V.F.; Hawkins-Cooper, D.; Pyburn, D.G.; Schmit, B.S.; Gamble, H.R.; Pedersen, K.; et al. **2014**. Surveillance of feral swine for *Trichinella* spp. and *Toxoplasma gondii* in the USA and host-related factors associated with infection. *Vet. Parasitol.*, *205*, 653–665.

Hiltbrunner, D.; Schulze, S.; Hagedorn, F.; Schmidt, M.W.I.; Zimmermann, S. **2012**. Cattle trampling alters soil properties and changes soil microbial communities in a Swiss sub-alpine pasture. *Geoderma*, *170*, 369–377

Hines, E. **2018**. Keeping Pigs Cool in the Summer Heat. Penn State Extension. Available online: <https://extension.psu.edu/keeping-pigs-cool-in-the-summer-heat> (accessed on 15 December 2019).

Hodgkinson, S. M., Cárcamo, A. and López, I. **2011**. Selective grazing of *Lolium perenne* and *Plantago lanceolata* by growing European wild boar (*Sus scrofa* L.) in a semi-extensive system. *Livestock Science*, *140*, 268–74.

Hodgkinson, S. M., López, I. F. and Navarrete, S. **2009**. Ingestion of energy, protein and amino acids from pasture by grazing European wild boar (*Sus scrofa* L.) in a semi-extensive production system. *Livestock Science* *122*, 222–6

Hodgkinson, S., Schmidt, M. and Ulloa, N. **2008**. Comparison of the digestible energy content of maize, oats and alfalfa between the European wild boar (*Sus scrofa* L.) and Landrace x Large White (*Sus scrofa domestica*). *Animal Feed Science and Technology* *144*, 167–73.

Honeyman, M. S., Pirog, R. S., Huber, G. H., Lammers, P. J., & Hermann, J. R. **2006**. The United States pork niche market phenomenon. *J. Anim. Scie.*, *84*(8), 2269–2275. <https://doi.org/10.2527/jas.2005-680>

Horsted, K., Kongsted, A. G., Jorgesen, U. and Sorensen, J. **2012**. Combined production of free range pigs and energy crops-animal behavior and crop damages. *Livestock Science.*, *150*, 200–8. doi:10.1016/j.livsci.2012.09.006.

Horta, C.; Batista, M.; Roque, N.; Almeida, J. **2012**. Environmental impact of pig production: soil P forms evolution, spatial distribution and P losses in drainage waters. *Rev. Ciencias Agrarias*. *35*(1), 36–48. ISSN:0871-018 X

Hoveland, C.S.; McCann, M.A.; Hill, N.S. **1997**. Rotational vs. Continuous Stocking of Beef Cows and Calves on Mixed Endophyte-Free Tall Fescue-Bermudagrass Pasture. *Journal of Production Agriculture*, *10*, 245–250, doi:10.2134/jpa1997.0245.

Hovi, M., Sundrum, A. and Thamsborg, S. M. **2003**. Animal health and welfare in organic livestock production in Europe: current state and future challenges. *Livestock Production Science*, 80, 41–53.

Iowa State University. **2020**. Sunburn and Photosensitization. In Swine Manual Index; Iowa State University of Science and Technology: Ames, IA, USA,. Available online: <https://vetmed.iastate.edu/vdpam/FSVD/swine/index-diseases/photosensitization> (accessed on 15 January 2020).

Ivanova-Peneva, S.; Aarnink, A.; Verstegen, M. **2006**. Ammonia and Mineral losses on Dutch Organic farms with pregnant sows. *Biosystems Engineering*, 93(2), 221-235

Jakobsen, M.; Kongsted, A.G.; Hermansen, J.E. **2015**. Foraging behaviour, nutrient intake from pasture and performance of free-range growing pigs in relation to feed CP level in two organic cropping systems. *Animal*, 9, 2006–2016, doi:10.1017/S1751731115001585.

Jakobsen, M., Hermansen, J. E., Andersen, H. M.-L., Jørgensen, U., Labouriau, R., Rasmussen, J., & Kongsted, A. G. **2019**. Elimination behavior and soil mineral nitrogen load in an organic system with lactating sows – comparing pasture-based systems with and without access to poplar (*Populus sp.*) trees. *Agroec. and Sust. Food Syst.*, 43(6), 639–661. <https://doi.org/10.1080/21683565.2018.1541039>

Jackson, P.G.G.; Cockcroft, P.D. **2007**. Handbook of Pig Medicine; Elsevier Ltd.: Philadelphia, PA, USA,; p. 296, ISBN 9780702028281

Jensen, A.N.; Baggesen, D.L. **2006**. Salmonella and Campylobacter infections in outdoor organic pigs. In Proceedings of the 1st IFOAM International Conference on Animals in Organic Production, Saint Paul, MN, USA, 23–25 August 2006; Gopalakrishnan, O., Melotti, L., Ostertag, J., Sorensen, N., Eds.; IFOAM: St. Paul, MN, USA, pp. 96–97. Available online: <http://orgprints.org/9159> (accessed on 26 February 2020).

Jensen, A.N.; Dalsgaard, A.; Stockmarr, A.; Nielsen, E.M.; Baggesen, D.L. **2006**. Survival and transmission of Salmonella enterica Serovar Typhimurium in an outdoor organic pig farming environment. *Appl. Environ. Microbiol.*, 1833–1842.

Johannson, L.M. **2006**. Meningitis and septicemia in a 7-week-old piglet caused by dual streptococcal infection. *Can. Vet. J.* 47, 796–798.

Jørgensen, H.; Serena, A.; Hedemann, M.S.; Bach-Knudsen, K.E. **2007**. The fermentative capacity of growing pigs and adult sows fed diets with contrasting type and level of dietary fibre. *Livestock Science*, 109 (1–3), 111–14.

Jørgensen, U.; Thuesen, J.; Eriksen, J.; Horsted, K.; Hermansen, J.E.; Kristensen, K.; Kongsted, A.G. **2018**. Nitrogen distribution as affected by stocking density in a combined production system of energy crops and free range pigs. *Agrofor. Syst.*, 92, 987–999

Jurjanz, S.; Roinsard, A. **2014**. Ingestion d’herbe et de sol par des truies au pâturage. *Alter. Agric.*, 125, 27–28.

Kambashi, B., Picron, P., Boudry, C., Théwis, A., Kiatoko, H.; Bindelle, J. **2014**. Nutritive value of tropical forage plants fed to pigs in the Western provinces of the Democratic Republic of the Congo. *Animal Feed Science & Technology*, 191, 47–56. DOI:10.1016/j.anifeedsci.2014.01.012.

Kanga, J.S.; Kanengoni, A.T.; Makgothi, O.G.; Baloyi, J.J. **2012**. Estimating pasture intake and nutrient digestibility of growing pigs fed a concentrate-forage diet by n-alkane and acidinsoluble ash markers. *Tropical Animal Health and Production*, 44(7), 1797–802. doi:10.1007/s11250-012-0141-1.

Karimi, R.; Akinremi, W.; Flaten, D. **2017**. Cropping system and type of pig manure affect nitrate-nitrogen leaching in a sandy loam soil. *J. Environ. Qual.*, 46, 785–792

- Kelly, H. R. C., Browning, H. M., EL Day, J., Martins, A., Pearce, G. P., Stopes, C.; Edwards, S. A. **2007**. Effect of breed type, housing and feeding system on performance of growing pigs managed under organic conditions. *Journal of the Science of Food and Agriculture*, 87(15), 2794–2800
- Killbride, A.L.; Gillman, C.E.; Green, L.E. **2009**. A cross-sectional study of the prevalence of lameness in finishing pigs, gilts and pregnant sows and associations with limb lesions and floor types on commercial farms in England. *Anim. Welf.* 18, 215–224.
- KillBride, A.L.; Mendl, M.; Statham, P.; Held, S.; Harris, M.; Marchant-Forde, J.N.; Booth, H.; Green, L.E. **2014**, Risks associated with pre weaning mortality in 855 litters on 39 commercial outdoor pig farms in England. *Prev. Vet. Med.* 117, 189–199.
- Kijlstra, A.; Eissen, O.A.; Cornelissen, J.; Munniksma, K.; Eijck, I.; Kortbeek, T. **2004**. *Toxoplasma gondii* Infection in Animal-Friendly Pig Production Systems. *Investig. Ophthalmol. Vis. Sci.* 45, 3165–3169
- Kongsted, A. G., Horsted, K. and Hermansen, J. E. **2013**. Free-range pigs foraging on Jerusalem artichokes (*Helianthus tuberosus* L.) – Effect of feeding strategy on growth, feed conversion and animal behaviour. *Acta Agriculturae Scandinavica*, 63, 76–83.
- Kongsted, A.G.; Jakobsen, M. **2015**. Effect of genotype and level of supplementary concentrate on foraging activity and vegetation cover in an organic free-range pig system. *Acta Agriculturae Scandinavica: Section A, Animal Science*, 65, 139–147, doi:10.1080/09064702.2016.1156152.
- Kongsted, A.G.; Nørgaard, J.V.; Jensen, S.K.; Lauridsen, C.; Juul-Madsen, H.R.; Norup, L.R.; Engberg, R.M.; Horsted, K.; Hermansen, J.E. **2015**. Influence of genotype and feeding strategy on pig performance, plasma concentrations of micro nutrients, immune responses and faecal microbiota composition of growing-finishing pigs in a forage-based system. *Livestock Science*, 178, 263–271, doi:10.1016/j.livsci.2015.06.010.
- Köppel, C.; Knopf, L.; Ryser, M.P.; Miserez, R.; Thür, B.; Stärk, K.D.C. **2007**. Serosurveillance for selected infectious disease agents in wild boars (*Sus scrofa*) and outdoor pigs in Switzerland. *Eur. J. Wildl. Res.*, 53, 212.
- Lagrega, L. and Marotta, E. **2005**. Comportamiento y características ingestivas de forraje en la cerda a campo. In: III Encuentro Latinoamericano de Especialistas en Sistemas de Producción Porcina a Campo. [pdf] Marco Juárez. INTA. Available at: http://www.produccion-animal.com.ar/produccion_porcina/00-produccion_porcina_general/24-comportamiento_ingestivo.pdf [10 June 2016]
- Laister, S.; Konrad, S. **2005**. Behaviour, performance and carcass quality of three genotypes of growing-finishing pigs in outdoor pig production in Austria: A pilot study. In: Organic Pig Production in Free Range Systems. Eds. Sundrum, A., Weißmann, F. *Landbauforschung Völkerode, Special Issue* 281. P. 13.
- Lang, D.; McDonald, G.W. **2005**. Maintaining groundcover to reduce erosion and sustain production, *Agfact*, P2.1.14. https://www.dpi.nsw.gov.au/data/assets/pdf_file/0018/162306/groundcover-for-pastures.pdf (Accessed on 2 October, 2019)
- Lasisi, A.A.; Akinremi, O.O.; Tenuta, M.; Cattani, D. **2018**. Below-ground plant biomass and nitrogen uptake of perennial forage grasses and annual crops fertilized with pig manures. *Agric. Ecosyst. Environ.*, 268, 1–7
- Larsen, V. A. and Kongsted, A. G. **1999**. Sows on pasture. In: Hermansen, J. E. and Erling Thuen (eds). *Ecological Animal Husbandry in the Nordic Countries*. [pdf] Horsens. NJF 303, 99–105. Available at: http://www.darcof.dk/publication/rapport/dar_2.pdf. [Accessed 24 October 2008].
- Lebret, B., Dourmad, J. Y., Mourot, J., Pollet, P. Y. and Gondret, F. **2014**. Production performance, carcass composition and adipose tissue traits of heavy pigs: influence of breed and production system. *Journal of Animal Science*, 92(8), 3543–56.

Lebret, B.; Ecolan, P.; Bonhomme, N.; Méteau, K.; Prunier, A. **2015**. Influence of production system in local and conventional pig breeds on stress indicators at slaughter, muscle and meat traits and pork eating quality. *Animal*, 9(08), 1404–13. doi:10.1017/S1751731115000609.

Leeb, C.; Hegelund, L.; Edwards, S.; Mejer, H.; Roepstorff, A.; Rousing, T.; Sundrum, A.; Bonde, M. **2014**. Animal health, welfare and production problems in organic weaner pigs. *Org. Agric.* 4, 123–133.

Leite, D.M.G.; Silva, M.A. da; Medeiros, R.B. de; Saibro, J.C. de; Pavan, M.A.; Barrey, M.A.A. **2006b**. Efeito de diferentes sistemas de pastejo sobre o desempenho de suínos mantidos em pastagem de trevo-branco (*Trifolium repens* L.). *Revista Brasileira de Zootecnia*, 35, 792–796, doi:10.1590/S1516-35982006000300022.

Leite, D., Silva, M., Medeiros, R., Saibro, J., Pavan, M. A., Zanella, J. A. and Barrey, M. A. **2006a**. Comportamento de suínos submetidos a diferentes sistemas de pastejo em pastagem de trevo branco. *R. Bras. Zootec.*, 35(4), 1774–9. Available at: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-35982006000600027&lng=en&nrm=iso (Accessed 14 June 2016). <http://dx.doi.org/10.1590/S1516-35982006000600027>.

Leuchtmann, A.; Bacon, C.W.; Schardl, C.L.; White, J.F.; Tadych, M. **2014**. Nomenclatural realignment of *Neotyphodium* species with genus *Epichloë*. *Mycologia*, 106, 202–215, doi:10.3852/13-251.

Lindgren, K.; Bochicchio, D.; Hegelund, L.; Leeb, C.; Mejer, H.; Roepstorff, A.; Sundrum, A. **2014**. Animal health and welfare in production systems for organic fattening pigs. *Org. Agric.*, 4, 135–147.

Lindgren, K.; Gunnarsson, S.; Höglund, J. Cecilia Lindahl Allan Roepstorff. **2019** Nematode parasite eggs in pasture soils and pigs on organic farms in Sweden. *Org. Agric.*

López-García, A.; García-Casco, J.M.; Muñoz, M.; Martínez-Torres, J.M.; Fernández-Barroso, M.A.; González-Sánchez, E. **2017**. Backfat Fatty Acid Profile after Growing Period. In Iberian Pigs Fed With Olive Cake in a Dry or Wet (Silage) Form. In Proceedings of the 11th International Symposium Modern Trends in Livestock Production, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, pp. 169–177, ISBN 978-86-82431-73-2. Available online: <http://istocar.bg.ac.rs/en/simpozijum/11th-international-symposium-modern-trend-in-livestockproduction-11th-13-th-october-2017-belgrade-serbia/> (accessed on 17 May 2019).

Lukovic, Z.; Skorput, D.; Karolyi, D. **2017**. Pig welfare at different production systems. In Proceedings of the 11th International Symposium Modern Trends in Livestock Production, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, 2017; pp. 319–326, ISBN 978-86-82431-73-2. Available online: <http://istocar.bg.ac.rs/en/simpozijum/11th-international-symposium-modern-trend-in-livestock-production-11th-13-th-october-2017-belgrade-serbia> (accessed on 17 May 2019).

Macci, C., Doni, S., Bondi, G., Davini, D., Masciandaro, G. and Pistoia, A. **2012**. Effects of wild boar (*Sus scrofa*) grazing on soil properties in Mediterranean environment. *CATENA*, 98, 79–86.

Maes, D.; Dewulf, J.; Piñeiro, C.; Edwards, S.; Kyriazakis, I. **2019**. A critical reflection on intensive pork production with an emphasis on animal health and welfare. *J. Anim. Sci.*, 362.

Martens, S. D., Tiemann, T. T., Bindelle, J., Peters, M. and Lascano, C. E., **2012**. Alternative plant protein sources for pigs and chickens in the tropics – nutritional value and constraints: a review. *Journal of Agriculture and Rural Development in the Tropics*, 113, 101–23.

Massey University. **2012**. New Zealand Best Practice Guidelines for Free Range Pork Production; College of sciences. Sustainable farming fund. Crown Copyright—Ministry for Primary Industries: Palmerston North, New Zealand,; p. 62.

Meier, R.; Ryser-Degiorgis, M. **2008**. Wild boar and infectious diseases: Evaluation of the current risk to human and domestic animal health in Switzerland: A review. *Schweiz. Arch. Tierheilkd.*, 160, 443–460.

Meng, X.J.; Lindsay, D.S.; Sriranganathan, N. **2009**. Wild boars as sources for infectious diseases in livestock and humans. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 364, 2697–2707.

Menzi, H.; Stauffer, W.; Zihlmann, U.; Weisskopf, P. **1998**. Environmental impacts of outdoor pig production. In *Proceedings of the 8th International Conference on the Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture (RAMIRAN 98)*, Rennes, France, 8–12 September; Martinez, J., Maudet, M.N., Eds.; FAO ESCORENA Editions Quae: Paris, France, 1999; Volume 2, pp. 31–39, ISBN 978-2-85362-531-9.

Miao, Z. H., Glatz, P. C., & Ru, Y. J. **2004**. Review of Production, Husbandry and Sustainability of Free-range Pig Production Systems. *Asian-Australasian J. Anim. Scie.*, 17(11), 1615–1634. <https://doi.org/2004.17.11.1615>

Michalk, D.L. **2015**. Sustainability, Biodiversity and Environmental Issues: A Global Perspective for Livestock Production. 18. XXIII Grassland conference. New delhi, India.

Mkwanazi, M.V.; Ncobela, C.N.; Kanengoni, A.T.; Chimonyo, M. **2019**. Effects of environmental enrichment on behaviour, physiology and performance of pigs—A review. *Asian-Australas. J. Anim.*, 32, 1–13.

Moerman, M. **2019**. L'élevage des Porcs en Agriculture Biologique-Le Bien-Être; Centre Wallon de Recherches Agronomiques: Gembloux, Belgique. pp. 1–43. Available online: <http://www.cra.wallonie.be/fr/lelevage-des-porcs-en-agriculture-biologique-le-bien-etre978-> (accessed on 11 January 2020).

Monteiro, E.D.C.; Burak, D.L.; Cunha, A.D.M.; Passos, R.R.; Mendonça, E.D.S. **2018**. Visual assessment of pasture degradation: validation by ground cover and seasonal variation. *Rev. Ciência Agrônôm.*, 49(1), 174–182.

Monteverde, S. and Del Pino, A. **2014**. Variabilidad espacial en las propiedades químicas del suelo en un sistema de producción con cerdos en pastoreo. *Revista Ciencias Agronómicas* 23, 037–045.

Monteverde, S., Del Pino, A., Piaggio, J. and Nay, H. **2011**. Metales pesados en la producción de cerdos a campo. In: VII Jornadas técnicas de la Facultad de Veterinaria. UDELAR. 190. Available at: <http://www.fvet.edu.uy/?q=tecnolog%C3%ADa-agropecuaria/publicaciones> [Accessed 27 August 2013].

Motta-Delgado, P. A., Ocaña-Martínez, H. E., & Rojas-Vargas, E. P. **2019**. Indicadores asociados a la sostenibilidad de pasturas: Una revisión. *Ciencia & Tecnología Agropecuaria*, 20(2), 387–408. https://doi.org/10.21930/rcta.vol20_num2_art:1464

Mpampouli, S., Abraham, E. M., Kyriazopoulos, A., Fotiadis, G., Parissi, Z. M. and siouvaras, C. N. **2009**. The effects of wild boar grazing on the floristic diversity of a silvopastoral oak system. In *Alternative functions of grassland. Proceedings of the 15th European Grassland Federation Symposium*, Brno, Czech Republic, 7–9 September. Editors Cagaš, B.; Macháč Machác Czech RepuGrassland Science in Europe, 14, 192–5. ISBN 978-80-86908-15-1 Record Number 20093293375.

Muns, R.; Nuntapaitoon, M.; Tummaruk, P. **2016**. Non-infectious causes of pre-weaning mortality in piglets. *Livest. Sci.*, 184, 46–57.

Muñoz-Mendoza, M.; Marreros, N.; Boadella, M.; Gortázar, C.; Menéndez, S.; de Juan, L.; Bezos, J.; Romero, B.; Copano, M.F.; Amado, J.; et al. **2013**. Wild boar tuberculosis in Iberian Atlantic Spain: A different picture from Mediterranean habitats. *BMC Vet. Res.*, 9, 176.

Murphy, S.; Lodge, G. **2002**. Ground cover in temperate native perennial grass pastures. I. A comparison of four estimation methods.

- Murrell, K.D. **2016**. The dynamics of *Trichinella spiralis* epidemiology: Out to pasture? *Vet. Parasitol.*, 231, 92–96.
- Nazareno, A.C.; Da Silva, I.J.O.; Nunes, M.L.A.; De Castro, A.C.; Miranda, K.O.S.; Trabachini, A. **2012**. Caracterização bioclimática de sistemas ao ar livre e confinado para a criação de matrizes suínas gestantes. *Rev. Bras. Eng. Agríc. Ambient.*, 16, 314–319.
- NC-NRCS. Conservation planning guidelines for outdoor swine operations. **2007**. [(PDF)] Available online: <https://efotg.sc.egov.usda.gov/references/Delete/2008-7-12/OSOTECHNOTE.pdf> (Accessed 12 November, 2017)
- Norwood, F. B.; Lusk, J. L. **2011**. A calibrated auction-conjoint valuation method: Valuing pork and eggs produced under differing animal welfare conditions. *Journal of Environmental Economics and Management*, 62(1), 80–94. <https://doi.org/10.1016/j.jeem.2011.04.001>
- Northup, B.K.; Starks, P.J.; Turner, K.E. **2019**. Stocking Methods and Soil Macronutrient Distributions in Southern Tallgrass Paddocks: Are There Linkages? *Agronomy*, 9, 281, doi:10.3390/agronomy9060281.
- Nunn, L., Embree, C. G., Hebb, D., Bishop, S. D. and Nichols, D. **2007**. Rotationally grazing hogs for orchard floor management in organic apple orchards ISHS. *Acta Horticulturae*, 737(9), 71–78, <http://dx.doi.org/10.17660/ActaHortic.2007.737.9> ISSN: 0567-7572 [Accessed 19 June 2016].
- Nyachoti, C.M.; Zijlstra, R.T.; de Lange, C.F.M.; Patience, J.F. **2004**. Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. *Can. J. Anim. Sci.*, 84, 549–566, doi:10.4141/A04-001.
- Ocampo-Duran, A. **2011**. Producción porcina tropical: cuando el alimento viene de las alturas. In: Barlocco, N. and Vadell, A. (ed.). *Producción de Cerdos a Campo. Aportes para el desarrollo de tecnologías apropiadas para la producción familiar*. [pdf] Montevideo. Universidad de la Republica, Facultad de Agronomía. 116–20 Available at: <http://www.upc.edu.uy/images/documents/extension/Publicacion%2015%20anos%20UPC.pdf>. [Accessed 12 April 2016]
- Ogle, B. **2006**. Forage for pigs: Nutritional, physiological and practical implications. In *Forages for Pigs and Rabbits*; Phnom Penh MEKARN-CeIAgrid: Phnom Penh, Cambodia, Available online: <http://www.mekarn.org/proprf/ogle.htm> (accessed on 13 December 2019).
- Olczak, K.; Nowicki, J.; Kloczek, C. **2015**. Pig behaviour in relation to weather conditions—A review. *Ann. Anim. Sci.*, 15, 601–610.
- Oliveira Júnior, G.M.; De Ferreira, A.S.; Oliveira, R.F.M.; Silva, B.A.N.; Figueiredo, E.M.; Santos, M. **2011**. Behaviour and performance of lactating sows housed in different types of farrowing rooms during summer. *Livest. Sci.*, 141, 194–201.
- Olsson, A.C.; Jeppsson, K.-H.; Botermans, J.; von Wachenfelt, H.; Andersson, M.; Bergsten, C.; Jørgen Svendsen, J. **2014**, Pen hygiene, N, P and K budgets and calculated nitrogen emission for organic growing–finishing pigs in two different housing systems with and without pasture access. *Lives. sci.*, 165, 138–146. <http://doi.org/10.1016/j.livsci.2014.03.025>
- Pablos-Tanarro, A.; Ortega-Mora, L.M.; Palomo, A.; Casasola, F.; Ferre, I. **2018**. Seroprevalence of *Toxoplasma gondii* in Iberian pig sows. *Parasitol. Res.*, 117, 1419–1424.

- Palacio, S.; Bueno, C.G.; Azorín, J.; Maestro, M.; Gómez-García, D. **2013**. Wild-boar disturbance increases nutrient and C stores of geophytes in subalpine grasslands. *Am J Bot.*, 100(9), 1790-1799. Doi: 10.3732/ajb.1300002.
- Pande, T.N.; Valentine, I.; Betteridge, K.; Mackay, A.; Horne, D. **2000**. Pasture damage and regrowth from cattle treading. *Proceedings of the New Zealand Grassland Association*, 62: 155–160
- Parois, S.P.; Cabezón, F.A.; Schinckel, A.P.; Johnson, J.S.; Stwalley, R.M.; Marchant-Forde, J.N. **2018**. Effect of Floor Cooling on Behaviour and Heart Rate of Late Lactation Sows Under Acute Heat Stress. *Front. Vet. Sci.*, 5, 223.
- Parrini, S.; Acciaioli, A.; Franci, O.; Pugliese, C.; Bozzi, R. **2019**. Grazing behaviour of Cinta senese and its crossbreed pigs. *Ital. J. Anim. Sci.*, 18, 287–291.
- Pastiu, A.I.; Györke, A.; Blaga, R.; Mircean, V.; Rosenthal, B.M.; Cozma, V. **2013**. In Romania, exposure to *Toxoplasma gondii* occurs twice as often in swine raised for familial consumption as in hunted wild boar, but occurs rarely, if ever, among fattening pigs raised in confinement. *Parasitol. Res.*, 112, 2403–2407.
- Passos, A. A., Andrade, C., Phillips, C. E., Coffey, M.T.; Kim, S.W. **2015**. Nutrient value of spray field forages fed to pigs and the use of feed enzymes to enhance nutrient digestibility. *J Anim. Scien.*, 93(4), 1721–8.
- Patridge, G. **2014**. Challenges in feeding high-fiber diets to pigs. *Pig International*. Available online at: www.WATTAgNet.com (Accessed 21 June 2016).
- Petersen, S. O., Kristensen, K. and Eriksen, J. **2001**. Denitrification losses from outdoor piglet production. *Journal of Environmental Quality*, 30(3), 1051–8.
- Pedersen, P.; Sousa, P.; Andersen, L.; Jensen, K. **2003**. Thermoregulatory Behaviour of Growing/Finishing Pigs in Pens with Access to Outdoor Areas. *Agric. Eng. Int.*, V, 1–14.
- Phocas, F., Belloc, C., Bidanel, J., Delaby, L., Dourmad, J. Y., Dumont, B., Ezanno, P., Fortun-Lamothe, L., Foucras, G., Frappat, B., González-García, E., Hazard, D., Larzul, C., Lubac, S., Mignon-Grasteau, S., Moreno, C. R., Tixier-Boichard, M.; Brochard, M. **2016**. Review: Towards the agroecological management of ruminants, pigs and poultry through the development of sustainable breeding programmes: I - selection goals and criteria. *Animal*, 10(11), 1749–1759. <https://doi.org/10.1017/S1751731116000926>
- Picardy, J. A., Pietrosemoli, S., Griffin, T. S., & Peters, C. J. **2019**. Niche pork: Comparing pig performance and understanding producer benefits, barriers and labeling interest. *Renewable Agriculture and Food Systems; Cambridge*, 34(1), 7–19. <http://dx.doi.org/prox.lib.ncsu.edu/10.1017/S1742170517000230>
- Pietrosemoli, S.; Green, J. T. **2018**. Pasture systems for pigs. In *Achieving sustainable production of pig meat Volume 3*. Burleigh Dodds Science Publishing.167-218
- Pietrosemoli, S., Green, J. T., Villamide, M. J. **2020**. Sows-Gilts Stocking Rates and their Environmental Impact in Rotationally Managed Bermudagrass Paddocks. *Animals*, 10(6), 1046. <https://doi.org/10.3390/ani10061046>
- Pietrosemoli, S.; Green, J.T.; Villamide Diaz, M.J. 2020**. A comparison of stocking methods for pasture-based growing-finishing pig production systems. *Animals*, 2020, 10 (10):1885. <https://doi.org/10.3390/ani10101885>
- Pietrosemoli, S.; Raczkowski, C.; Green, J.T.; Villamide Diaz, M.J. 2020**. Effect of growing-finishing pig stocking rates on bermudagrass ground cover and soil properties. *Animals*, 2020; 10(9):1666. <https://doi.org/10.3390/ani10091666>
- Pietrosemoli, S., Tang, C. **2020**. Animal Welfare and Production Challenges Associated with Pasture Pig Systems: A Review. *Agriculture*, 10(6), 223. <https://doi.org/10.3390/agriculture10060223>

Pistoia, A.; Bondi, G.; Balestri, G.; Mani, D.; Masciandaro, G. **2012**. Soil degradation by grazing pig in Mediterranean environment., 6.

Pistoia A.; Ferruzzi G. **2010**. Impatto ambientale da pascolamento suino. In Allevamento animale e riflessi ambientali. Crovetto G.M. y Sandrucci A. (Eds). *Fondazione Iniziative Zooprofilattiche e Zootecniche*. Brescia, Italia. 78, 161-174

Pistoia, A., Poli, P., Casarosa, L., Balestri, G. and Ferruzzi, G. **2008**. Utilizzo del pascolo boschivo nell'allevamento biologico del suino. In: Paolo Pignattelli, P., Ferrante, V., Mattiello, S., Barbieri, S. and Lolli, S. (eds). *Zootecnia biologica e ricerca: Investire insieme. VI Convegno Nazionale dell'Associazione Italiana di Zootecnia biologica e biodinamica*. [pdf] Arezzo. ZooBioDi, 68–73. ISBN 978-88-903475-0-4. Available at: http://www.zoobiodi.it/doc/ATTI_2008_DEFINITIVI.pdf [Accessed 16 May 2015].

Poppenga, R.H. Poisonous plants. **2010**. In *Molecular, Clinical and Environmental Toxicology*; Luch, A., Ed.; Experientia Supplementum; Birkhäuser Basel: Basel, Switzerland, 100,123–175.

Pugliese, C.; Sirtori, F. **2012**. Quality of meat and meat products produced from southern European pig breeds. *Meat Science*, 90(3), 511–18.

Presto, M. H., Andersson, H. K., Wallgren, P.; Lindberg, J. E. **2007**. Influence of dietary amino acid level on performance, carcass quality and health of organic pigs reared indoors and outdoors. *Acta Agriculturae Scandinavica Section A*, 57, 61–72.

Quijada, R. P., Bitsch, N. I.; Hodgkinson, S. M. **2012**. Digestible energy content of pasture species in growing European wild boar (*Sus scrofa* L.). *Journal of Animal Physiology and Animal Nutrition*, 96(3), 421–7. DOI:10.1111/j.1439-0396.2011.01158.x.

Quintern, M. **2005**. Integration of organic pig production within crop rotation: Implications on nutrient losses In: *Organic Pig Production in Free Range Systems*. Eds Sundrum, A.; Weißmann, F., Special Issue 281, 31-34.

Quintern, M.; Sundrum, A. **2006**. Ecological risks of outdoor pig fattening in organic farming and strategies for their reduction - results of a field experiment in the centre of Germany. *Agric., Ecos., Environ.*, 117(4), 238–50.

Rachuonyo, H.A.; Allen, V.G.; McGlone, J.J. **2005**, Behavior, preference for, and use of alfalfa, tall fescue, white clover, and buffalograss by pregnant gilts in an outdoor production system. *J. Anim. Sci.*, 83(9), 2225–34.

Rachuonyo, A.H.; McGlone, J. **2006**, Impact of Outdoor Gestating Gilts on Soil Nutrients, Vegetative Cover, Rooting Damage, and Pig Performance. *J. Sustain. Agr.* 29, 69–87.

Rachuonyo, H.A.; Pond, W.G.; McGlone, J.J. **2002**, Effects of stocking rate and crude protein intake during gestation on ground cover, soil-nitrate concentration, and sow and litter performance in an outdoor swine production system. *J. Anim. Sci.*, 80, 1451–1461

Ramírez-Restrepo, C.A; Barry, T. N. **2005**. Alternative temperate forages containing secondary compounds for improving sustainable productivity in grazing ruminants. *Animal Feed Science and Technology*, 120(3–4), 179–201.

Régner, C., Bocage, B., Archimède, H., Noblet, J. and Renaudeau, D., **2013**. Digestive utilization of tropical foliage of cassava, sweet potatoes, wild cocoyam and Erythrina in Creole growing pigs. *Animal Feed Science and Technology*, 180(1), 44–54.

Renner, B.M. **2011**. The Effect of Stocking Rate History on Soil Nutrient Levels and Forage Nutrient Uptake in Pasture Hog Production Systems. North Carolina State University. Master of Science Thesis.. 92 pp. Available online: <https://repository.lib.ncsu.edu/bitstream/handle/1840.16/7325/etd.pdf?sequence=2&isAllowed=y> (Accessed on 7 September 2020)

- Rivera Ferre, M.G.; Edwards, S.A.; Mayes, R.W.; Riddoch, I.; Hovell, F.D. **2001**. The effect of season and level of concentrate on the voluntary intake and digestibility of herbage by outdoor sows. *Anim. Sci.*, 72, 501–510.
- Rivero, J.; López, I.; Hodgkinson, S. **2013**. Pasture consumption and grazing behaviour of European wild boar (*Sus scrofa* L.) under continuous and rotational grazing systems. *Livestock Science*, 154, 175–183, doi:10.1016/j.livsci.2013.03.006.
- Robinson, J. **2013**. Towards a framework for agroecological pig production: maximizing functional roles for pigs within food and farm systems. MSc. Thesis. Norwegian University of Life Sciences. 105 pp.
- Rodríguez-Estévez, V., García, A. and Gómez, A. G. **2009a**. Characteristics of the acorns selected by free range Iberian pigs during the montanera season. *Livestock Science*, 122(2–3), 169–76.
- Rodríguez-Estévez, V., García, A. and Gómez, A. G. **2009b**. Intrinsic factors of acorns that influence the efficiency of their consumption by Iberian pigs. *Livestock Science*, 122(2–3), 281–5.
- Rodríguez-Estévez, V., García, A., Peña, F. and Gómez, A. G. **2009c**. Foraging of Iberian pigs grazing natural pasture in the dehesa. *Livestock Science*, 120(1), 135–43.
- Rodríguez-Estévez, V., Sánchez-Rodríguez, M., García, A. and Gómez-Castro, A. G. **2010**. Feed conversion rate and estimated energy balance of free grazing Iberian pigs. *Livestock Science*, 132(1), 152–6.
- Rodríguez-Estévez, V., Sánchez-Rodríguez, M., Gómez-Castro, A. G. and Edwards, S. A. **2010**. Group sizes and resting locations of free range pigs when grazing in a natural environment. *Applied Animal Behaviour Science*, 127(1), 28–36.
- Rodríguez-Estévez, V.; Sánchez-Rodríguez, M.; García, A.R.; Gómez-Castro, A.G. **2011**. Average daily weight gain of Iberian fattening pigs when grazing natural resources. *Livestock Science*, 137, 292–295, doi:10.1016/j.livsci.2010.11.015.
- Roepstorff, A. and Mejer, H. **2001**. Strategies for parasite control in organic pigs. In The 5th NAHWOA Workshop, Rodding, 11–13 November. 72–8.
- Roepstorff, A.; Mejer, H.; Nejsum, P.; Thamsborg, S.M. **2011**. Helminth parasites in pigs: New challenges in pig production and current research highlights. *Vet. Parasitol.*, 180, 72–81.
- Roepstorff, A., Monrad, J., Sehested, J. and Nansen, P. **1999**. Mixed grazing with sows and heifers: parasitological aspects. In Ecological animal husbandry in the Nordic countries. Eds Hermansen, J. E., Lund, V. and Thuen, E. Book Proceedings from NJF-seminar No. 303, Horsens, Denmark, pp. 41–4 DARCOF Report No. 2 Record Number 20013092887
- Roinsard, A., Maupertuis, F. and Dubois, A. **2014**. De l'enrubannage pour les truies gestantes. *Atler Agri*, 125, 25–8.
- Ru, Y.J.; Bao, Y.M. **2004**. Feeding dry sows *ad libitum* with high fibre diets. *Asian-Australasian Association of Animal Science*, 17(2), 283–300.
- Rutherford, K.M.D.; Haskell, M.J.; Glasbey, C.; Lawrence, A.B. **2006**. The responses of growing pigs to a chronic-intermittent stress treatment. *Physiology & Behavior*, 89, 670–680, doi:https://doi.org/10.1016/j.physbeh.2006.08.006.
- Sales-Baptista, E.; d'Abreu, M.C.; Ferraz-de-Oliveira, M.I. **2016**. Overgrazing in the Montado? The need for monitoring grazing pressure at paddock scale. *Agrofor. Syst.* 90, 57

- Salakpal, K.; Karolyi, D.; Lukovic, Z. **2013**. Sanitary aspects of outdoor farming systems. *Acta Agric. Slov.*, 4, 109–117.
- Salomon, E.; Benfalk, C.; Lindahl, C.; Lindgren, K. **2005**. Mobile and stationary systems for pigs – Nutrient excretion, distribution on outdoor areas and environmental impact. In *Researching Sustainable Systems. ISOFAR*, 254–257.
- Salomon, E.; Hkerhielm, H.; Lindahl, C.; Lindgren, K. **2007**. Outdoor pig fattening at two Swedish organic farms- Spatial and temporal load of nutrients and potential environmental impact. *Agric. Ecosys. Environ.*, 121, 407–418
- Santos-Ricalde, R.H.; Lean, I.J. **2006**. Digestibility of dried star grass (*Cynodon nlemfuensis*) and consumption of fresh star grass in primiparous pregnant sows. *Animal Feed Science and Technology*, 129, 12–22. doi:10.1016/j.anifeedsci.2005.11.012
- Santos-Ricalde, R.H.; Lean, I.J. **2002**. Effect of feed intake during pregnancy on productive performance and grazing behavior of primiparous sows kept in an outdoor system under tropical conditions. *Livestock Production Science*, 77(1), 13–21.
- SAS Institute Inc. **2018**. SAS/STAT(R) 9.4 User's Guide; Copyright © 2020; SAS Institute: Cary, NC, USA,; Available online: <http://support.sas.com/documentation/94/index.html> (accessed on 11 November 2019).
- Scasta, J.D.; Stam, B.; Windh, J.L. **2017**. Rancher-reported efficacy of lethal and non-lethal livestock predation mitigation strategies for a suite of carnivores. *Sci. Rep.*, 7, 14105.
- Schneider-Canny, R.; Chekhovskiy, K.; Muñoz, P.; Kwon, S.; Saha, M.C. **2019**. Characterization of bermudagrass (*Cynodon dactylon* L.) germplasm for nitrogen use efficiency. *Euphytica*, 215, 40
- Scipioni, R.; Martelli, G.; Volpelli, L.A. **2009**. Assessment of welfare in pigs. *Ital. J. Anim. Sci.*, 8, 117–137.
- Sehested, J.; Sjøgaard, K.; Danielsen, V.; Roepstorff, A.; Monrad, J. **2004**. Grazing with heifers and sows alone or mixed: herbage quality, sward structure and animal weight gain. *Livestock Production Science*, 88, 223–238, doi:10.1016/j.livprodsci.2003.11.008.
- Sharifi, M.; Messiga, A.J.; Asefpour Vakilian, K.; Stopford, E.; Hutchinson, T.C. **2020**. Spatial distribution of soil phosphorous fractions following 1-year farrowing sows in an outdoor hog-rearing farm in Eastern Canada. *Environ Monit Assess*, 192, 322. <https://doi.org/10.1007/s10661-020-08260-y>
- Sharifi, M.; Messiga, A.J.; Stopford, E.; Hutchinson, T.C. **2014**. Spatial Distribution of Soil N and P Forms Following One-Year Farrowing Sows on an Outdoor Hog-Rearing Farm in Eastern Ontario; Technical report; NSERC Engage; Trent University: Peterborough, ON, Canada,
- Sigua, G.C.; Myer, R.O.; Coleman, S.W.; Mackowiak, C.; Adjei, M.; Chase, C.C.; Albano, J. **2011**. Regional Distribution of Soil Phosphorus Across Congregation-Grazing Zones of Forage-Based Pastures with Cow-Calf Operations in Florida. *Journal of Environmental Protection*, 2, 408–417, doi:10.4236/jep.2011.24046.
- Sikala, K. **2012**. Free-range organic pigs foraging Jerusalem artichokes (*Helianthus tuberosus*)- effect of feeding strategy on feed intake, feed conversion, growth, animal behavior, nutrient balances and profitability. MSc. Thesis. Aarhus University, Department of agroecology. 70 p.
- Sirtori, F.; Crovetto, A.; Meo Zilio, D.; Pugliese, C.; Acciaioli, A.; Campodoni, G.; Bozzi, R. and Franci, O. **2011**. Effect of sire breed and rearing system on growth, carcass composition and meat traits of Cinta Senese crossbred pigs, *Italian Journal of Animal Science*, 10(4), p.e47. <http://dx.doi.org/10.4081/ijas.2011.e47>.
- Smith, R.P.; Andres, V.; Dormer, L.; Gosling, R.; Oastler, C.; Davies, R.H. **2017**. Study of the impact on Salmonella of moving outdoor pigs to fresh land. *Epidemiol. Infect.*, 145, 1983–1992.

Søgaard, K.; Sehested, J.; Danielsen, V. **2000**. Mixed grazing with heifers and pregnant sows. *Grassland Science in Europe*, 5, 359–61.

Soil Survey Staff. **2014**. Keys to Soil Taxonomy, 12th ed.; USDA-Natural Resources Conservation Service: Washington, DC, USA; 372p. Available online at: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/?cid=nrcs142p2_053580 (accessed on 20 May 2020).

Sollenberger, L.E.; Aiken, G.E.; Wallau, M.O. **2020**. Chapter 5 - Managing grazing in forage–livestock systems, Eds: Rouquette, M.; Aiken, G.E. *Management Strategies for Sustainable Cattle Production in Southern Pastures*, Academic Press, 77–100, <https://doi.org/10.1016/B978-0-12-814474-9.00005-0>.

Sollenberger, L. E., Newman, Y. C., & Macoon, B. **2020**. Pasture Design and Grazing Management. In *Forages*, (pp. 803–814). John Wiley & Sons, Ltd. <https://doi.org/10.1002/9781119436669.ch44>

Sommer, S.G.; Søgaard, H.T.; Møller, H.B.; Morsing, S. **2001**. Ammonia volatilization from sows on grassland. *Atmosp. Environ.*, 35, 2023–2032

Souther, S.; Loeser, M.; Crews, T.E.; Sisk, T. **2019**. Complex response of vegetation to grazing suggests need for coordinated, landscape-level approaches to grazing management. *Global Ecology and Conservation*, 20, e00770, doi:10.1016/j.gecco.2019.e00770.

Stampa, E., Schipmann-Schwarze, C., & Hamm, U. **2020**. Consumer perceptions, preferences, and behavior regarding pasture-raised livestock products: A review. *Food Quality and Preference*, 82, 103872. <https://doi.org/10.1016/j.foodqual.2020.103872>

Stanojković, A.; Gogić, M.; Ostojić-Andrić, D.; Petrićević, M.; Nišavić, J.; Nešić, K. **2017**. Wild pigs—The source of zoonotic *Streptococcus suis* strains. In *Proceedings of the 11th International Symposium Modern Trends in Livestock Production*, Belgrade, Serbia, 11–13 October 2017; Škrbić, Z., Ed.; Institute for Animal Husbandry: Belgrade, Serbia, 2017; pp. 253–259. Available online: <http://istocar.bg.ac.rs/en/simpozijum/11th-international-symposium-modern-trend-in-livestock-production-11th-13-th-october-2017-belgrade-serbia/> (accessed on 17 May 2019).

Stolba A.; Wood-Gush, D.G.M., **1989**. The behaviour of pigs in a semi-natural environment." *Anim. Prod.*, 48(2), 419–425.

Stern, S.; Andresen, N. **2003**, Performance, site preferences, foraging and excretory behaviour in relation to feed allowance of growing pigs on pasture, *Livest. Prod. Sci.*, 79(2–3), 257–265, [http://dx.doi.org/10.1016/S0301-6226\(02\)00171-9](http://dx.doi.org/10.1016/S0301-6226(02)00171-9)

Stelzer, S.; Basso, W.; Benavides Silván, J.; Ortega-Mora, L.M.; Maksimov, P.; Gethmann, J.; Conraths, F.J.; Schares, G. **2019**. *Toxoplasma gondii* infection and toxoplasmosis in farm animals: Risk factors and economic impact. *Food Waterborne Parasitol.*, 15.

Stolba, A.; Wood-Gush, D. G. M. **1989**. The behaviour of pigs in a semi-natural environment. *Animal Production*, 48(2): 419–425.

Suescún-Ospina, S.T.; Ocampo-Duran, A. **2015**. Comportamiento y desempeño productivo de cerdas de cría a campo abierto en condiciones de Piedemonte, Orinoquia Colombiana. *Revista Orinoquia*. 19(1), 35–40. ISSN: 0121-3709.

Sutherland, M.A.; Webster, J.; Sutherland, I. **2013**. Animal Health and Welfare Issues Facing Organic Production Systems. *Animals*, 3, 1021–1035.

- Thomas, L.F.; de Glanville, W.A.; Cook, E.A.; Fèvre, E.M. **2013**. The spatial ecology of free-ranging domestic pigs (*Sus scrofa*) in western Kenya. *BMC Vet. Res.*, 9, 46.
- Thomsen, L.E.; Mejer, H.; Wendt, S.; Roepstorff, A.; Hindsbo, O. **2001**. The influence of stocking rate on transmission of helminth parasites in pigs on permanent pasture during two consecutive summers, *Vet. Parasitol.*, 99(2), 129-146, [https://doi.org/10.1016/S0304-4017\(01\)00454-X](https://doi.org/10.1016/S0304-4017(01)00454-X).
- Urriola, P. E., Cervantes-Pahm, S. K. and Stein, H. H. **2013**. Fiber in swine nutrition, In: Chiba, L. I. (ed.), *Sustainable Swine Nutrition*, pp. 255–76. John Wiley&Sons, Inc., USA.
- Vallentine, J.F. **2000**. *Grazing Management*. Elsevier.San Diego.
- Van der Giessen, J.; Fonville, M.; Bouwknegt, M.; Langelaar, M.; Vollema, A. **2007**. Seroprevalence of *Trichinella spiralis* and *Toxoplasma gondii* in pigs from different housing systems in The Netherlands. *Vet. Parasitol.*, 148, 371–374.
- Vico, J.P.; Mainar-Jaime, R.C. **2011**. Salmonellosis in wild birds and its relationship with the infection in finishing pigs. In *Proceedings of the 9th International Conference on the Epidemiology and Control of Biological, Chemical and Physical Hazards in Pigs and Pork: SAFEPOK 2011*, Maastricht, The Netherlands, 19–22 June 2011; pp. 264–267. Available online: <http://hdl.handle.net/10532/1666> (accessed on 17 May 2020).
- Vittoz, P. and Hainard, P. **2002**. Impact of free-range pigs on mountain pastures in the Swiss Jura. *Applied Vegetation Science*, 5(2), 247–54.
- Volker, M. **2015**. The control of classical swine fever in wild boar. *Front. Microbiol.*, 6.
- Wallander, C.; Frössling, J.; Dórea, F.C.; Uggla, A.; Vågsholm, I.; Lundén, A. **2016**. Pasture is a risk factor for *Toxoplasma gondii* infection in fattening pigs. *Vet. Parasitol.*, 224, 27–32.
- Watson, C.; Atkins, T.; Bento, S.; Edwards, A.; Edwards, S. **2003**. Appropriateness of nutrient budgets for environmental risk assessment: a case study of outdoor pig production. *Eur. J. Agron.*, 20(1), 117-126.
- Webb, J.; Broomfield, M.; Jones, S.; Donovan, B. **2014**. Ammonia and odour emissions from UK pig farms and nitrogen leaching from outdoor pig production: A review. *Sci. Total Environ.*, 470, 865–875.
- Wegner, K.; Lambertz, C.; Das, G.; Reiner, G.; Gauly, M. **2014**. Climatic effects on sow fertility and piglet survival under influence of a moderate climate. *Animal*, 8, 1526–1533.
- Wezel, A.; Casagrande, M.; Celette, F.; Vian, J.-F.; Ferrer, A.; Peigné, J. **2014**. Agroecological practices for sustainable agriculture. A review. *Agron. Sustain. Dev.*, 34, 1–20, doi:10.1007/s13593-013-0180-7.
- Wang, H.; Zhang, Y.; Chen, G.; Hettenhausen, C.; Liu, Z.; Tian, K.; Xiao, D. **2018**. Domestic pig uprooting emerges as an undesirable disturbance on vegetation and soil properties in a plateau wetland ecosystem. *Wetlands Ecol Manage*, 26, 509–523, doi:10.1007/s11273-017-9588-1.
- Whalen, J.K.; Thomas, B.W.; Sharifi, M. **2019**. Chapter One - Novel Practices and Smart Technologies to Maximize the Nitrogen Fertilizer Value of Manure for Crop Production in Cold Humid Temperate Regions. In *Advances in Agronomy*; Sparks, D.L., Ed.; Academic Press; Vol. 153, pp. 1–85.
- Williams, J.R.; Chambers, B.J.; Hartley, A.R.; Ellis, S.; Guise, H.J. **2000**. Nitrogen losses from outdoor pig farming systems, *Soil Use Manag.*, 16, 237-243
- Williamson, S.; Woodger, N.; Higgins, R.H.; Hands, I. **2009**. Ataxia associated with sunburn in outdoor gilts: A case report. *Pig J.* 62, 84–87.

Wu, N.; Abril, C.; Thomann, A.; Grosclaude, E.; Doherr, M.G.; Boujon, P.; Ryser-Degiorgis, M.P. **2012**. Risk factors for contacts between wild boar and outdoor pigs in Switzerland and investigations on potential *Brucella suis* spill-over. *BMC Vet. Res.*, 8, 116.

Yicui, L.; Baoming, L.; Zhengxiang, Z. **2008**. Effects of size, shape and partition type of pen on excretory behavior of domestic pigs, *Chinese Society of Agricultural Engineering*, 11, 206-211

Yunes, M.C., Von Keyserlingk, M.A.G., Hötzel, M. J. **2017**. Brazilian Citizens' Opinions and Attitudes about Farm Animal Production Systems. *Animals*, 7(10), 75. <https://doi.org/10.3390/ani7100075>