# Even-sowing pattern strategies for a low-input organic system in forage maize

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**Abstract:** The objective of this study was to verify the effectiveness of new patterns of sowing and to achieve a low-input organic system in two different environments (northern and southern Europe). The study was motivated by the hypothesis that more even sowing patterns (triangular and square) would significantly enhance the growth and yield of forage maize under widely varying conditions, compared with traditional mechanised rectangular seed patterns. An experiment was conducted in Madrid and duplicated in Copenhagen during 2010. A random block design was used with a 2 × 2 factorial arrangement based on two seed-sowing patterns: traditional (rectangular) and new (even) and two weed-management conditions (herbicide use and a low-input system). In both weed-management conditions and locations, the production of aerial maize biomass was greater for the new square seed patterns. In addition, the new pattern showed a greater effectiveness in the control of weeds, both at the initial crop stages (36% and 33% fewer weeds $m^{-2}$ at the 4- and 8-leaf stages, respectively, in the Copenhagen field experiment) and at the final stage. The final weed biomass for the new pattern was 568 kg $ha^{-1}$ lower for the Copenhagen experiment and 277 kg $ha^{-1}$ lower in Madrid field experiments. In the light of these results, the new pattern could potentially reduce the use of herbicides. The results of the experiments support the hypothesis formulated at the beginning of this study that even-sowing patterns would be relatively favourable for the growth and yield of the maize crop. In the near future, new machinery could be used to achieve new seed patterns for the optimisation of biomass yield under low-input systems. This approach is effective because it promotes natural crop-weed competition.

**Keywords:** weed-control strategies, alternative seed patterns, precision agriculture, environmental management

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## 1 Introduction

Maize (*Zea mays* L.) is a basic food crop for great numbers of people, as well as livestock feed and for industrial use. It has been widely distributed and is grown worldwide in a great range of climates (Maiti and Wesche-Ebeling, 1998). It is currently the most important forage crop in the European Union for dairy cattle (Bertoia, 2010) and it is grown throughout Europe, from Spain and other countries in the south having a Mediterranean climate to Denmark and other northern countries having a temperate climate. Many environmental, biological or socioeconomic factors can affect the plant. Furthermore, productivity of maize is influenced by different biotic and abiotic factors,

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including transpiration, water-use efficiency and a variety of other plant processes (Maiti and Wesche-Ebeling, 1998).

In different types of climates, and therefore under different management policies, one factor is common to almost all silage maize cultivars in all countries: the distance between plants in a row and the distance between cultivation lines (rows), owing to the use of traditional means of mechanisation. The term seed pattern (SP) is used to refer to these features of maize cultivation (Griepentrog et al., 2009). Previous studies have investigated the effects of seed pattern on maize plants (Bullock et al., 1988; Cox and Cherney, 2001; Barbieri et al., 2008; Götz and Bernhardt, 2010; Robles et al., 2012; Novacek et al., 2013). The common distance between rows for silage maize varies from 70 to 80 cm, and the density of plants varies from 6 to 12 plants $m^{-2}$ (usually from 9 to 12 plants $m^{-2}$ for new hybrids). Therefore, the within-row plant spacing distance for new hybrids can be between 13 and 15 cm (Guerrero, 1999; Lopez Bellido, 1991). Presently a traditional seed pattern for forage maize at a high plant density (10-12 plants $m^{-2}$) would allow 75 cm between rows and 13-15 cm between plants. These dimensions determine a rectangular SP.

Beres et al. (2008) reported that whole-plant yield was not significantly affected by row spacing, although it was affected by seeding rate, and that forage quality was higher in wide rows and rectangular SPs with plant densities of 7.4, 8.4, 9.4 and 11.4 plants $m^{-2}$. Moreover, it has also been found that reducing row widths to produce squarer seed patterns provides no yield benefits (for 12.5 plants $m^{-2}$) or small benefits that are difficult to detect (for 7.5 and 10 plants $m^{-2}$) because the extent of the possible benefits tends to vary with environmental and hybrid-related factors (Baron et al., 2006; Robles et al., 2012; Novacek et al., 2013). In contrast, an experiment using a plant density of 7.65 plants $m^{-2}$ compared a square SP (35 × 37 cm) with a rectangular SP (70 × 18 cm). The yield from the square SP was 1,500 kg of dry matter per ha greater than the yield from the rectangular SP in the absence of N fertilization (Barbieri et al., 2008). An important result obtained Cox et al. (2006) using 8.65 plants $m^{-2}$ is that narrow-row maize (38 cm, with a 38 × 30 cm SP) yielded 6.6% (1,100 kg $ha^{-1}$) more than conventional-row maize (76 cm, with a 76 × 15 cm SP) and 3% (500 kg $ha^{-1}$) more than twin rows (19 cm on 76 cm centers). In another study (Cox and Cherney, 2001), the authors concluded that the forage and DM (dry matter) yields of maize were 13.9% (9093 kg $ha^{-1}$) and 13.7% (3213 kg $ha^{-1}$) higher, respectively, using 25-cm row-distance SPs compared with 65-cm SPs, averaging across hybrids and plant densities (6.5, 8.5, 10.5 and 12.5 plants $m^{-2}$). The highest forage yield was achieved for 25 × 38 cm SPs. Moreover, in a study (Turgut et al., 2005) performed in Turkey in 2002 and 2003, the forage and DM yields of maize were 13.9% (9093 kg $ha^{-1}$) and 13.7% (3213 kg $ha^{-1}$) higher, respectively, using 25-cm row-distance SPs compared with 65-cm SPs, averaging across hybrids and plant densities (6.5, 8.5, 10.5 and 12.5 plants $m^{-2}$). The highest forage yield was achieved for 25 × 38 cm SPs.

Some weed control problems are likely to occur also in traditional SP because the wide spacing between rows enhances weed growth and causes significant problems for the developing crop. The control of weeds in maize can involve a broad range of options (Cordill and Grift, 2011). Herbicides, tilling and crop rotation are all frequently used to control weeds in maize crops. But the production of weed biomass is also strongly influenced by the choice of different plant population densities, row spacing, SPs and by the intensity of competition with the particular genotype and the crop (Begna et al., 2001). It is interesting to ask how the SP might favour crop plants over weeds in crop-weed competition. A square or triangular SP can be the best and most effective way to maximise weed suppression (Fisher and Miles, 1973). In a comparison of the effectiveness of square and rectangular SPs for weed control Acciaresi and Chidichimo (2007), reported less competition between crop plants and weeds (with a subsequent increase in maize yield) in square SPs than in rectangular SPs. In addition, the results of the study demonstrated more intra- and inter-row uniformity of maize roots, higher water uptake levels, and more PAR (photosynthetically active radiation) interception by maize. Consistent with this finding, an informative trial (Murphy et al., 1996) demonstrated that narrower rows (50 vs. 75 cm) with higher plant densities (10 vs. 7 plants $m^{-2}$) significantly reduced the biomass of late-emerging weeds and generally enhanced competition against weeds. In another study carried out by Begna et al. (2001), the use of narrow row spacing (38 cm) in a square SP produced a decrease of 23% to 29% in weed biomass compared with the values for wide spacing (76 cm) and a rectangular SP at plant densities of 10 plants $m^{-2}$. The experimental treatment was less effective for weed control at higher plant densities. Further research (Mashingaidze et al., 2009) reported that higher values of weed biomass occurred at wider row spacings (90 and 75 cm vs. 60 cm row spacing, for 3, 4 and 6 plants $m^{-2}$ plant densities). The lowest weed biomass in the latter study was found in square seed patterns (60 × 56 cm) with 3 plants $m^{-2}$. This finding was a result of the lower level of PAR interception that occurred under the square maize canopy. In contrast, a weedy plant, Bermuda grass, showed increased aerial biomass and an increased use of soil N at the expense of crop plants in an experiment (Fernández et al., 2002) using a square seed pattern (35 × 35 cm) with 8 plants $m^{-2}$. It is evident that almost all studies performed to evaluate the influence of SPs on weed control have found that a narrower distance between rows, a higher plant density and square SPs produce the best and most effective response.

Some questions may be posed regarding the traditional SP. Could some other SPs improve and increase crop development, growth and yield? Are the rectangular patterns the only possible SP for silage maize cultivation? This study therefore sought to optimise the growth and final yield conditions for forage maize by changing the SP from a rectangular pattern to a squarer, even pattern. The SP investigated in this study incorporated a greater distance between plants and a smaller distance between rows to obtain a preliminary assessment of the added value that would result from the use of small machines to manage the maize crop. The experiment involved a proposed change from a SP consisting of a 75-cm inter-row distance and a 13-15 cm inter-plant distance to an alternative pattern consisting of equal inter-row and inter-plant distances. The use of a new SP will result in new agronomical, ecological, environmental and technical consequences. The main objective of this research is to demonstrate how a new, squarer even seed pattern could optimise the growth and final yield of the maize in ways that could make low-input systems possible.

## 2 Materials and methods

In spring 2010, field experiments with silage maize were conducted in Taastrup Have, Tåstrup (Copenhagen), Denmark and in Madrid, Spain. The technical and design conditions and characteristics differed between the locations. At both locations, one type of plot was planted according to a new SP, and another type of plot was planted according to a conventional SP (Figure 1). Two types of herbicide management were used: management with herbicides, or low-input management. Both emplacements included four different plots: T-herb (traditional SP with herbicide application); T-weeds (traditional SP without herbicide application and with weeds growing naturally); N-herb (new SP with herbicide application); and N-weeds (new seed pattern without herbicide application and weeds growing naturally).

The five-month Copenhagen field experiment ran from May through October. The experiment was conducted in Taastrup Have (55° 40′ 04″ N, 12° 18′ 25″ E, 25 masl), a small city 21 km distant from the centre of the city of Copenhagen, on the experimental fields of the Agricultural and Technology Department of the Faculty of Life Sciences (Copenhagen University). The traditional SP used in the experiment had a 75-cm distance between rows and a 13-cm distance between plants (10.25 plants $m^{-2}$), whereas the new SP had a 32-cm distance between rows and a 32-cm distance between plants (9.8 plants $m^{-2}$). Herbicide was applied to the T-herb and N-herb plots. The low-input plots (T-weeds and N-weeds) did not receive any herbicide. The total area of the experiment was 1,224 $m^2$. The hybrid maize variety NK Bull of Syngenta (FAO cycle 200) was used in the experiment. During the first eight weeks and at harvest, data on the crop, weeds and soil were collected. From the 30$^{th}$ day after sowing (plant emergence) until the 57$^{th}$ day after sowing (week eight), all parameters (crop height, leaf stage, chlorophyll content index, weed infestation in an 0.25-m$^2$ area, soil moisture and soil temperature between rows and between plants) were measured at least once a week. Three measurements per subplot were taken in all plots. At harvest, the final biomass and yield of the crop and weeds were also measured. Additional details are given in Table 1.

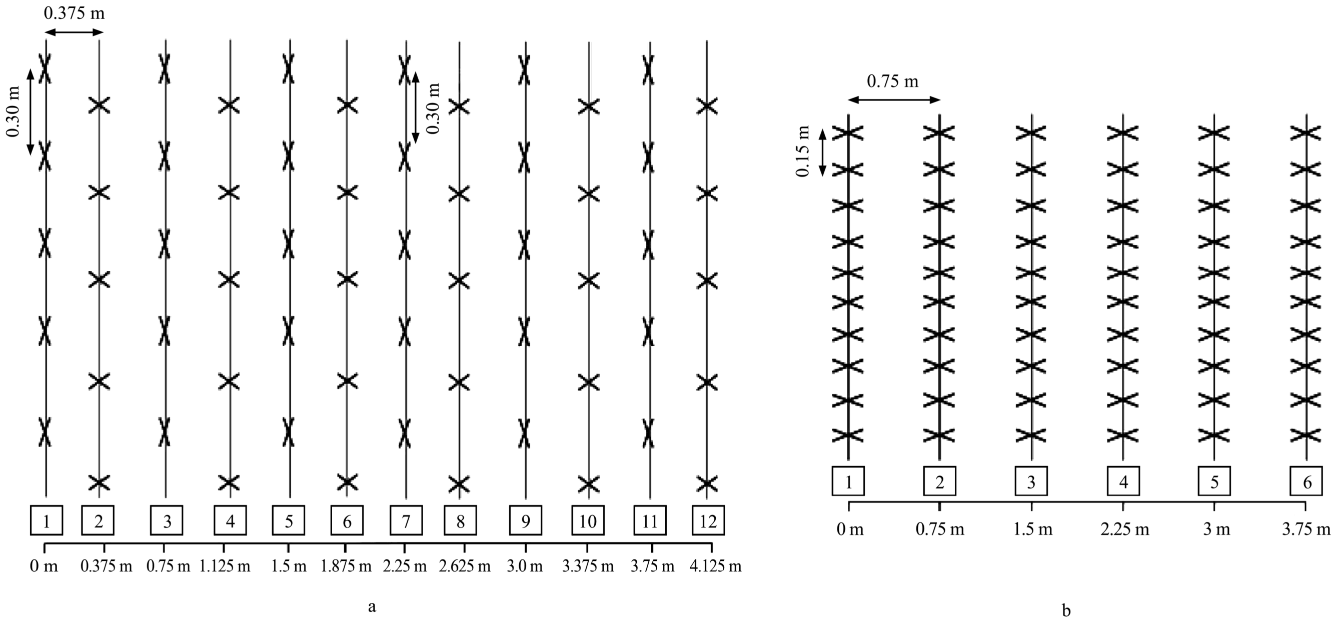



Figure 1 Plot design according to a new even seed pattern (a), and the plot according to a traditional rectangular seed pattern (b)

**Table 1 Management specifications for Copenhagen and Madrid field experiments**

| Labour | Date | Machinery used | Dose | Characteristics |
|---|---|---|---|---|
| | | Copenhagen | | |
| Seedbed preparation | 5-May | Kongskilde Cultivator | | For field leveling and seedbed preparation |
| Sowing | 5-6 May | Stanhay precision seeder | 10.25 (trad. SP) and 9.8 (new SP) plants m$^{-2}$ | Four arms (75 cm distance) for traditional SP plots and two modified arms (32-cm distance) for the new SP plots |
| Fertilization | 26-May | Mechanical plot broadcaster | 400 kg ha$^{-1}$ | NPK 20-10-0 |
| Plant uprooting | 1,2,3 June | Manually | | The three middle maize plants of every 5 were uprooted to achieve the new SP (32 × 32 cm) and plant density |
| Fertilization | 14-Jun | Mechanical plot broadcaster | 400 kg ha$^{-1}$ | NPKS 21-3-10-4 1 Mg |
| Herbicides | 15-Jun | Hydraulic sprayer | 50 L ha$^{-1}$ | Herbicide: Maister (foramsulphuron + iodosulphuron), only in T-herb and N-herb plots |
| Weed harvest | 6-Jul | By hand | | In T-weed and N-weed plots. Two samples of 0.25 m$^2$ in each sub-plot |
| Harvest | 6-Oct | Maize harvest tractor | | |
| | | Madrid | | |
| Seedbed preparation | 12-May | Manually | | For field leveling and seedbed preparation |
| Sowing | 12-May | Manually and Maize traditional seeder | 10 plants m$^{-2}$ | Manually in new SP plots (A, N-weeds and B, N-herb). Seeder with two arms (75 cm distance) for T-seed SP plots (C, T-herb and D, T-weeds) |
| Fertilization | 13-May | Manually | 350 kg ha$^{-1}$ | NPK 13-11-18 |
| Herbicide spraying | 20-May | Knapsack sprayer | 4 L ha$^{-1}$ | Pre-emergence. Only in plots B and C (N-herb and T-herb, respectively). Herbicide: Acetochlor (41%) + Terbuthylazine (19.5%) |
| Herbicide spraying | 15-Jun | Knapsack sprayer | 60 g ha$^{-1}$ | Post-emergence. In the entire field. Herbicide: Rimsulfuron |
| Irrigation | Weekly | Eight sprinklers | 15 mm/ irrigation | Two times per week from sowing to harvest |
| Harvest | 28-Sep | | Maize traditional harvest tractor | |

The Madrid field experiment was conducted near the city of Madrid (40º 26' 31.49" N, 3º 44' 29.18" W, 594 masl) during the period May through September (nearly five months). The coordinate specified give the Madrid location of the experimental fields of the Crop Production Department of Escuela Técnica Superior de Ingenieros Agrónomos (School of Agricultural Engineers of the Technical University of Madrid). The traditional SP used in the experiment had a 75-cm distance between rows and a 15-cm distance between plants (8.9 plants $m^{-2}$), whereas the new SP had a 37.5-cm distance between rows and a 30-cm distance between plants (8.9 plants $m^{-2}$). Pre-emergence herbicide application was used in the T-herb and N-herb plots. Post-emergence herbicide application was used in all plots, including the low-input T-weeds and N-weeds plots.

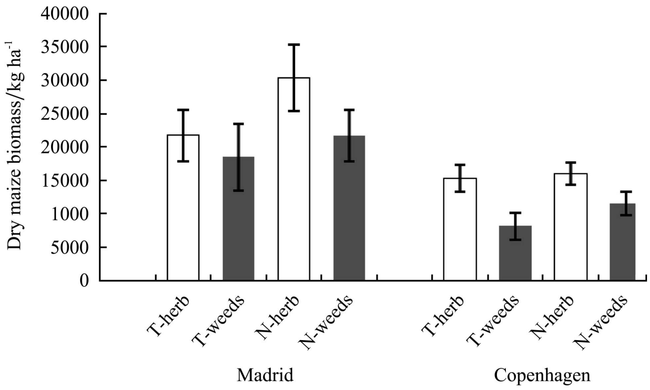
The total area of the experiment was 529 $m^2$. The maize variety used was PR33Y74 (Pioneer Seeds Ltd. Spain). This FAO 600 cycle variety is usually used in Spain. During the first six weeks and at harvest, data on the crop, weeds and soil were collected. During the first six weeks of the crop, measurements of total green cover (% soil cover) were made using RGB photographs. Later, an image analysis of each of the three photographs of each plot for each day was analysed with the dedicated routines in MATLAB 7.0 (Mathworks Inc.). For the final data collection in the experimental fields in Madrid, each plot was sampled at the time of harvest to assess crop final biomass and yield, weed final biomass and yield, plant height and grain yield. Additional details are given in Table 1.

## 3 Results and discussion

In both field experiments, the highest yield (kg $ha^{-1}$ dry whole-plant biomass) was obtained from the new SP with herbicide application. It is important to emphasise that either with or without herbicide treatment, the new SPs always yielded more than the traditional SPs. The results of the study therefore indicate that the whole-plant yield can be significantly affected by the seed pattern.

In Copenhagen, the combination of the new SP and herbicide application produced the highest yield, 16,023 kg $ha^{-1}$. The next-highest yield was obtained from the traditional SP with herbicides (15,353 kg $ha^{-1}$). The new SP without herbicides yielded 11,585 kg $ha^{-1}$, and the traditional SP without herbicides yielded 8,195 kg $ha^{-1}$. Compared with the traditional SP, the new SP yielded 41% more biomass without herbicides and 4% more with herbicides.

In Madrid, the greatest difference in yield between the new and the traditional SP was found for the plots with herbicide applications (40% higher yield with herbicides, 17% higher yield without herbicides). The combination of the new SP and herbicide application again produced the highest yield, 30,335 kg $ha^{-1}$. The traditional SP with herbicides yielded 21,731 kg $ha^{-1}$, the new SP without herbicides yielded 21,685 kg $ha^{-1}$, and the traditional SP without herbicides yielded 18,529 kg $ha^{-1}$. The results of both field experiments and the details of the ANOVA analyses used with the data are shown in Figure 2 and Table 2.




Note: T-herb: traditional seed pattern (SP) with herbicide application; T-weeds: traditional SP without herbicide application and with weeds growing naturally; N-herb: new SP with herbicide application; and N-weeds: new seed pattern without herbicide application and with weeds growing naturally

Figure 2 Dry maize plant biomass yield (kg $ha^{-1}$) results in Copenhagen and Madrid

These results are consistent with some previous findings. A new, nearly square SP with a 25-cm distance between rows increased the yield of forage maize by 13.9% (9,000 kg $ha^{-1}$), compared with that obtained using a traditional SP (Turgut et al., 2005). Higher amounts of total plant dry weight (g $m^{-2}$) were obtained (Bullock et al., 1988) for equidistant seed patterns (38 × 30 cm) than for conventional ones (76 × 19 cm). Barbieri et al. (2008) reported that dry matter production of maize crops was higher for 38-cm wide rows than for 75-cm wide rows (with a plant density of 7.65 plants $m^{-2}$). Other authors (Cox and Cherney, 2001) reported that forage maize yielded 7.5% (1,400 kg $ha^{-1}$) more for 38-cm wide rows than for 76-cm wide rows.

**Table 2 Two-way (dry maize plant biomass yield (kg ha$^{-1}$)) and one-way (dry weeds biomass yield (kg ha$^{-1}$)) ANOVA results for Copenhagen and Madrid field experiments; Three-way ANOVA results for weed level infestation (weeds m$^{-2}$) in Copenhagen field experiment during the first eight weeks after sowing**

| | Copenhagen | | Madrid | |
|---|---|---|---|---|
| Dry maize biomass | F | p | F | P |
| Seed Pattern | 6.8 | * | 11.7 | ** |
| Treatment | 55.7 | ** | 11.9 | ** |
| SP × T | 3.1 | ns | 2.9 | ns |
| Dry weeds biomass | | | | |
| Seed Pattern | 3.2 | ns | 0.05 | ns |
| Weed level infestation | | | | |
| DAS | 4.8 | ** | | |
| Seed pattern | 30.3 | ** | | |
| Treatment | 36.4 | ** | | |
| DAS × SP | 2.1 | ns | | |
| DAS × T | 9 | ** | | |
| SP × T | 16.7 | ** | | |
| DAS × SP × T | 0.5 | ns | | |

Note: ns, not significant; * $p<0.05$; ** $p<0.01$;
DAS: Days after sowing; SP: Seed Pattern; T: Herbicide application treatment.

The previous results cited above are all consistent with the results of this study. However, the increases in yield obtained in this study using the new SP greatly exceed the value of 7.5% given in a previous report (Cox and Cherney, 2001). Likewise, they greatly exceed the 6.6% (1,100 kg ha$^{-1}$) and 3% (500 kg ha$^{-1}$) increases found in a study (Cox et al., 2006) that compared a squarer SP with traditional and twin row SPs, respectively (with a 8.65 plants m$^{-2}$ plant density). In contrast, whole-plant yield was not significantly affected by row spacing but was influenced by seeding rate in field experiments with silage maize in southern Alberta (Canada) (Beres et al., 2008). Although plant yield was unaffected, these last authors reported that the forage quality of the maize was higher for wide-row SPs than for narrow-row SPs. Other researchers (Baron et al., 2006) concluded that square SPs did not increase maize yield.

In both locations, the weed biomass yield (kg ha$^{-1}$) was lower for the new SP than for the traditional SP (Figure 3). In Copenhagen, the total amount of weeds (kg ha$^{-1}$) was nearly 21% (568 kg ha$^{-1}$) lower for the new SP. In Madrid, weed production was 11% (277 kg ha$^{-1}$) less for the new SP. The ANOVA for both field experiments is shown in Table 2.

The levels of early weed infestation (weeds m$^{-2}$) found in the Copenhagen experiment confirm the effectiveness of the new SP for weed control (Figure 3). The ANOVA for this analysis is shown in Table 2.

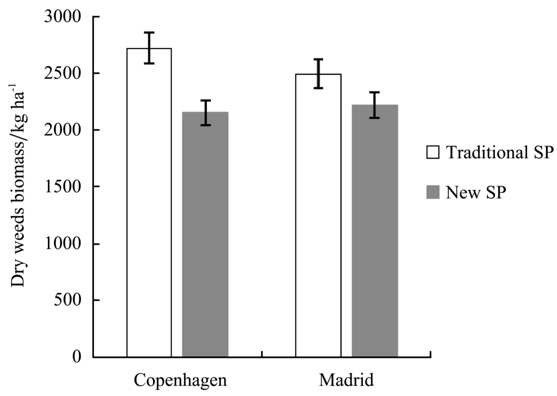



Figure 3 Dry weeds biomass yield (kg ha$^{-1}$) results in Copenhagen and Madrid field experiments of traditional seed pattern and new seed pattern

At both the 4-leaf and 8-leaf stages, the new SP resulted in relatively fewer weeds per m$^2$ than the traditional SP for both weed control strategies. With herbicides, the weed infestation was 12.6% and 11.6% less in the 4- and 8-leaf stages, respectively. Without herbicides, the weed infestation was 36% and 33% less in the 4 and 8 leaf stages, respectively. The difference between the new and traditional SPs was especially significant in the plots without herbicides (Figure 4).

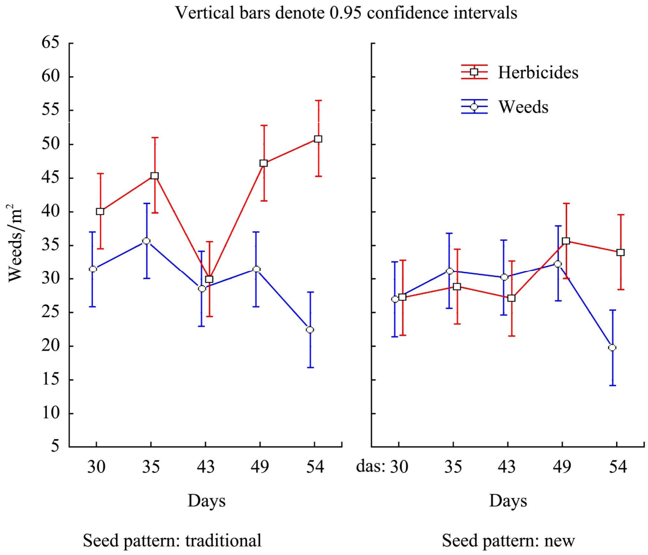



Figure 4 Weed level infestation (weeds m$^{-2}$) results during first maize stages (30, 35, 43, 49 and 54 days after sowing (das)) in Copenhagen field experiment in traditional and new seed patterns and with both herbicide treatments: with (herbicides) and without (weeds)

The results reported in this study are not in agreement with some other findings. For example, one field experiment reported by Fernández et al. (2002) showed that the use of a square SP increased the aerial biomass of Bermuda grass (g $m^{-2}$) as well as the N uptake from soil (to the disadvantage of crop plants), compared with rectangular seed patterns (at an 8 plants $m^{-2}$ density). However, more in keeping with our results, a higher weed biomass was found for a rectangular SP than for a square SP (60 × 56 cm, with 3 plants $m^{-2}$) (Mashingaidze et al., 2009). Moreover, other investigators (Fisher and Miles, 1973; Acciaresi and Chidichimo 2007) have suggested and emphasised from a theoretical perspective that greater effectiveness against weeds can be achieved by using equidistant or even (square and triangular) patterns because these patterns offer crop plants a higher uptake of nutrients, a higher availability of water or light availability and lower interplant competition compared with rectangular seed patterns.

The 21% lower production of weeds (kg $ha^{-1}$) found in Copenhagen with the new SP is fully consistent with a previous field experiment in which the authors demonstrated (Begna et al., 2001) that a square SP (38 × 26 cm) caused a 23% to 29% reduction in the production of weed biomass. However, the reduction in weed biomass production in Madrid was lower (11%).

The results of our present study clearly demonstrate that new seed patterns can contribute effectively and thoroughly to improving weed control. However, a new question arises: is this new seed pattern the best one for use with an optimum weed-hoeing tool? The traditional SPs usually used in conventional and commercial fields do not permit simple and effective mechanical hoeing because a large area of uncultivated soil is present between the rows (Götz and Bernhardt, 2010). These authors performed a field experiment in 2008 and compared square SPs (33 × 33 cm, 9.18 plants $m^{-2}$) with traditional ones (75 × 13 cm, 10.25 plants $m^{-2}$). They concluded that cross-compound hoeing (hoeing in two directions) could be used with square patterns and would produce a larger weed-free space in the field (an increase from 66% to 90% weed-free space).

## 4 Conclusions

The results of this study confirm the stated hypothesis that relatively regular seed patterns (triangular and square) are significantly more effective than traditional rectangular seed patterns in promoting the growth and yield of forage maize under widely varying conditions.

Field experiments conducted simultaneously in Madrid and Copenhagen in 2010 showed that the new SPs produced a clear increase in the total amount of aboveground dry forage maize, compared with the yields obtained from the traditional SPs. The extent of the increase varied widely among locations and treatments. The relative increases in yield obtained from the new SPs ranged between 4% and 41%. In Copenhagen, the new seed patterns yielded more in the plots without herbicide treatment. In contrast, in Madrid, the plots treated with herbicide showed the highest yield. An analysis of the possible effects of environmental and climatic factors on the success of new seed patterns would be an interesting research topic for the near future.

The new seed patterns allowed the crop to compete more effectively with weeds in both locations. The dry weight of weeds decreased by 21% (570 kg $ha^{-1}$) in Copenhagen and decreased by 11% (277 kg $ha^{-1}$) in Madrid. The need for herbicides is greater for the traditional seed patterns than for the new ones. The new seed patterns give the maize the best opportunities for successful competition with weeds, especially during the first stages of plant development. In the near future, the crops whose seed patterns permit the use of a lower percentage of agrochemical products will be highly appreciated and promoted. The new seed pattern will probably be fully efficient at meeting the needs of low-input agricultural systems.

The new seed pattern provides higher yields and other benefits as well. For example, it offers environmental advantages. It can generate a better distribution of resources in the soil (through the early provision of vegetal cover) or produce beneficial microclimatic conditions, e.g., by modifying the soil temperature or moisture at the level of the plants. These aspects of the new seed pattern must be addressed. Further studies are needed to raise the awareness of the extent to which whole-plant yields can be affected by different SPs. Improving the spatial distribution of crop plants in the field can have future agronomic and environmental advantages, such as the maintenance of homogeneous growth conditions and the optimal utilisation of available resources for growth.

Future research topics include the analysis of currently used seed patterns in light of the constraints imposed by the mechanisation process. These constraints can be overcome in the coming decades by using small autonomous intelligent machines (robots) to move through the crop under narrower frames and in staggered rows. These machines would then have the ability to apply selective environmentally-friendly weed-control strategies.

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