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# Permanent Bed Width Has Little Effect on Crop Yield under Rainfed and Irrigated Conditions across Central Mexico

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**Abstract:** In Mexico, conservation agriculture has been mainly implemented using permanent beds, where the top of the raised beds is not tilled, which allows them to obtain the benefits of conservation agriculture for yield and soil quality. However, narrow (0.75–0.80 m width) and wide (1.50–1.60 m width) beds are commonly implemented without scientific evidence available as to whether the width of the beds affects crop yields. The objective of our study was therefore to evaluate two types of permanent beds, in maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), and barley (*Hordeum vulgare* L.) production, in various agro-ecological regions of Mexico. The study included nine sites, of which six were rainfed and three had irrigation. Bed width did not significantly affect crop yield. Therefore, farmers can choose the bed width that best meets their practical needs. Some practical considerations include mechanical weeding (more access in narrow beds), fuel use (lower for reshaping wide beds), irrigation water use (in wide beds similar to irrigating alternate furrows in narrow beds), and residue management (option to concentrate residue in windrows at center of wide beds). Soil texture can also affect this choice, because it affects water infiltration and retention.

**Keywords:** conservation agriculture; conservation tillage; permanent beds; corn; wheat; barley



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## 1. Introduction

Climate change is forecast to strongly affect maize yields in the coming years in Mexico, due to an increase in temperature and a more erratic rainfall pattern [1]. This highlights the importance of adopting production systems that help adapt to the impact of climate change on agriculture, such as conservation agriculture, which is a production system based on three principles: minimum tillage, permanent soil cover, and crop diversification [2]. Several studies have demonstrated the benefits of conservation agriculture, such as improvements in the physical, chemical, and biological properties of soil [3–5], which can lead to higher and more stable crop yields and increased profitability of production systems [6–8]. Although conservation agriculture has been shown to be a climate-smart production system, applicable to a wide range of environments, the practice should be adapted to the conditions of each region, depending on the climate, soil conditions, and production system [9]. Reduced tillage systems can be applied, such as zero tillage, permanent beds, strip tillage, and minimum tillage with implements that do not invert the soil [7,10].

In Mexico, conservation agriculture has been implemented mainly under a system of permanent beds, where the movement of soil is limited to the reformation of the furrows of raised beds when necessary, while the top of the bed is not tilled [2,11]. This has allowed for greater adoption of reduced tillage systems in Mexico, because planting in elevated beds has long been used for various crops in the conventional system, where the beds are tilled after each harvest and reformed with several tillage operations (subsoil, plow, or disc harrow) before the planting of the new crop [2]. Therefore, permanent beds are more readily accepted by farmers than conservation agriculture with zero tillage and direct seeding. In areas with surface or furrow irrigation, the furrows are used to apply irrigation, while, under rainfed conditions, they help drain excess water. On sloping terrain, ridges along the contours of the slope reduce erosion [12,13]. Planting in permanent beds helps to reduce soil compaction through controlled traffic if traffic is confined to the furrows; it also allows for the use of mechanical methods for weed control and facilitates management of stubble on the soil [2,11,14].

The width of the permanent beds depends mainly on the width between the tractor wheels [2]. For maize and small grains, in central Mexico, this usually ranges from 0.75 to 0.85 m; in some regions of the Mexican Bajío, wide beds are used, which equate to two narrow beds (1.5 to 1.7 m width). In other crops, mainly in vegetables, beds of 1 m width are sometimes used. Generally, the distance between planting lines does not change in wide or narrow beds. However, the design of the planting beds can have an effect on the production of the crop by greater moisture conservation, especially in the deeper layers of soil [15]. In the implementation of permanent beds, there are practical differences between wide and narrow beds. If no machinery with cutting discs to cut the residue during furrow reformation is available, wide beds can be more practical as they allow for more residues on the top of the bed that will not hinder when reforming the furrows and will allow the bed to have a greater area of soil cover. In wide beds, the consumption of diesel required for bed reform is also lower, as there are fewer furrows to reform. In narrow beds, it is possible to perform better mechanical control of weeds by means of mechanical weeding, which is a common practice in conventional systems, and water conservation measures such as tied ridges or chiseling at the bottom of the furrow can be applied more intensely [16]. In irrigated conditions, irrigating alternating furrows (in narrow beds) can greatly reduce water use; wide beds could thus allow for a similar reduction in irrigation water use [17].

The optimal bed width under furrow irrigation conditions likely depends on soil texture, water movement, and crop requirements [18]. However, to date, permanent beds have been implemented according to the preference of farmers and farm advisors, but whether or not the width of the bed affects crop yields has not been evaluated. This has led to doubts among farmers, farm advisors, and scientists on how to best implement permanent beds. Therefore, treatments comparing narrow and wide permanent beds have been included in many of the field trials across Mexico by collaborators in the agri-food innovation system coordinated by the International Maize and Wheat Improvement Center (CIMMYT) [16,19]. The objective of this study was to determine the effect of permanent bed width on the yield of maize and small grain cereals under different environmental conditions and soil types in central Mexico by analyzing the results of these adaptive trials.

## 2. Materials and Methods

The study was based on results from the network of research platforms of CIMMYT and its collaborators [19]. These platforms perform research across Mexico on conservation agriculture and other sustainable practices. The treatments evaluated in these trials seek to improve the local production system, so they depend on local agro-ecological conditions and are based on the common practices of farmers in the region. This study selected the platform network sites where wide and narrow permanent beds were compared at the same site for at least three consecutive crop cycles. Six trials were selected under rainfed conditions in the states of Querétaro, Guanajuato, Michoacán, and Estado de México, and three more with irrigation, which were located in Guanajuato and Querétaro (Figure 1, Table 1). The sites are representative of the diverse environments and production systems of central Mexico, with soil texture ranging from sandy loam to clay (Table 2).

Although experiments began in different years, data from at least three consecutive evaluation cycles are reported in all cases. Because the sites had between 4 and 32 treatments, from each site we selected the two permanent bed treatments, which had full residue cover and only differed in the width of the bed. All sites have a randomized complete block design, with two, three, or four repetitions. In San Juan del Río I, Cadereyta, Apaseo el Alto, and Indaparapeo, treatments were developed in monoculture of maize; in Texcoco

I and II, maize and wheat rotation was used. In the irrigated sites, maize was rotated in the spring–summer growing season with wheat or barley in the autumn–winter growing season. The first production cycle in conservation agriculture corresponds to a conventional tillage system, and from the second cycle, permanent beds were maintained, with partial or total retention of stubble from the previous crop. Every cycle, only the reformation of the furrows of the permanent beds was carried out. Soil preparation in the permanent beds consisted of the reformation of the bed with an implement with furrowers and cutter discs (Figure 2); the furrow was 15 to 20 cm deep and 25–30 cm wide (Figure 3). Maize row distance was the same in narrow and wide beds at all sites: 80 cm in Cadereyta and 75 cm at all other sites. In all cases, the sowing density was the same in both types of bed. In Texcoco I and II, six rows of small grains were planted in wide beds (with a 20 cm row spacing) and two rows on narrow beds (with 22 to 24 cm between rows). At the irrigated small grain sites (San Juan del Río III, Irapuato I, and Pénjamo, Mexico), row spacing was the same on narrow and wide beds: a row distance of 18 cm between two rows on narrow beds and the same paired row arrangement on wide beds.

**Table 1.** Agroecological characteristics of the sites where the study was carried out.

| Site | State | Latitude (North) | Longitude (West) | Altitude (masl) | Climate | Water Regime | Precipi-tation (mm) |
|---|---|---|---|---|---|---|---|
| Cadereyta | Querétaro | 20.749 | 99.823 | 2000 | Semi-arid | Rainfed | 350 |
| San Juan del Río I | Querétaro | 20.450 | 99.905 | 1972 | Semi-arid | Rainfed | 380 |
| San Juan del Río III | Querétaro | 20.466 | 100.0912 | 1903 | Temperate Semi-dry | Irrigation | 550 |
| Indaparapeo | Michoacán | 19.797 | 100.951 | 1888 | Temperate Subhumid | Rainfed | 800 |
| Irapuato I | Guanajuato | 20.646 | 101.296 | 1720 | Temperate Subhumid | Irrigation | 692 |
| Apaseo el Alto | Guanajuato | 20.360 | 100.567 | 1956 | Temperate Subhumid | Rainfed | 550 |
| Pénjamo | Guanajuato | 20.314 | 101.837 | 1690 | Sub-humid Subhumid | Irrigation | 580 |
| Texcoco I | Estado de México | 19.530 | 98.853 | 2240 | Temperate Subhumid | Rainfed | 625 |
| Texcoco II | Estado de México | 19.530 | 98.853 | 2240 | Temperate Subhumid | Rainfed | 625 |

**Table 2.** Soil type, texture and hydraulic conductivity at the sites.

| Site | Soil Type | Texture | %Clay | %Sand | %Silt | Hydraulic Conductivity (cm $h^{-1}$) |
|---|---|---|---|---|---|---|
| Cadereyta | Vertisol | Clay Loam | 33.3 | 31.0 | 35.8 | 2.7 |
| San Juan del Río I | Phaeozem | Sandy Loam | 41.2 | 20.5 | 38.0 | 2.5 |
| San Juan del Río III | Vertisol | Clay Loam | - | - | - | 2.6 |
| Indaparapeo | Vertisol | Loam | 33.0 | 31.2 | 35.8 | 2.5 |
| Irapuato I | Vertisol | Clay Loam | 38.5 | 27.5 | 34.0 | 2.3 |
| Apaseo el Alto | Vertisol | Clay | 43.8 | 30.5 | 25.8 | 0.7 |
| Pénjamo | Vertisol | Clay | 44.5 | 29.2 | 26.3 | 0.4 |
| Texcoco I | Phaeozem | Clay | 29.0 | 34.2 | 36.8 | 3.7 |
| Texcoco II | Phaeozem | Clay | 29.0 | 34.0 | 37.0 | 4.0 |

Agronomic management was the same for both treatments at each site. Due to the duration of the study, agronomic management may have varied over the years, but was the same for treatments at each site in each year. Management practices were in line with the common conditions and practices of each region, fertilization was defined based on a yield goal (Table 3) agroecological practices were preferred in pest management, and weed control was mainly done with the use of herbicides. In irrigated sites, irrigation was applied as furrow irrigation, in accordance with the conventional practice of the region. There were generally 5 irrigations spaced every 20 or 25 days during the autumn–winter season, depending on the availability of water and precipitation during the development of the crop. In the spring–summer season, one or two supplemental irrigations may be applied, depending on rainfall. Additional details of each site can be found in annual publications of results from CIMMYT's network of research platforms [20].

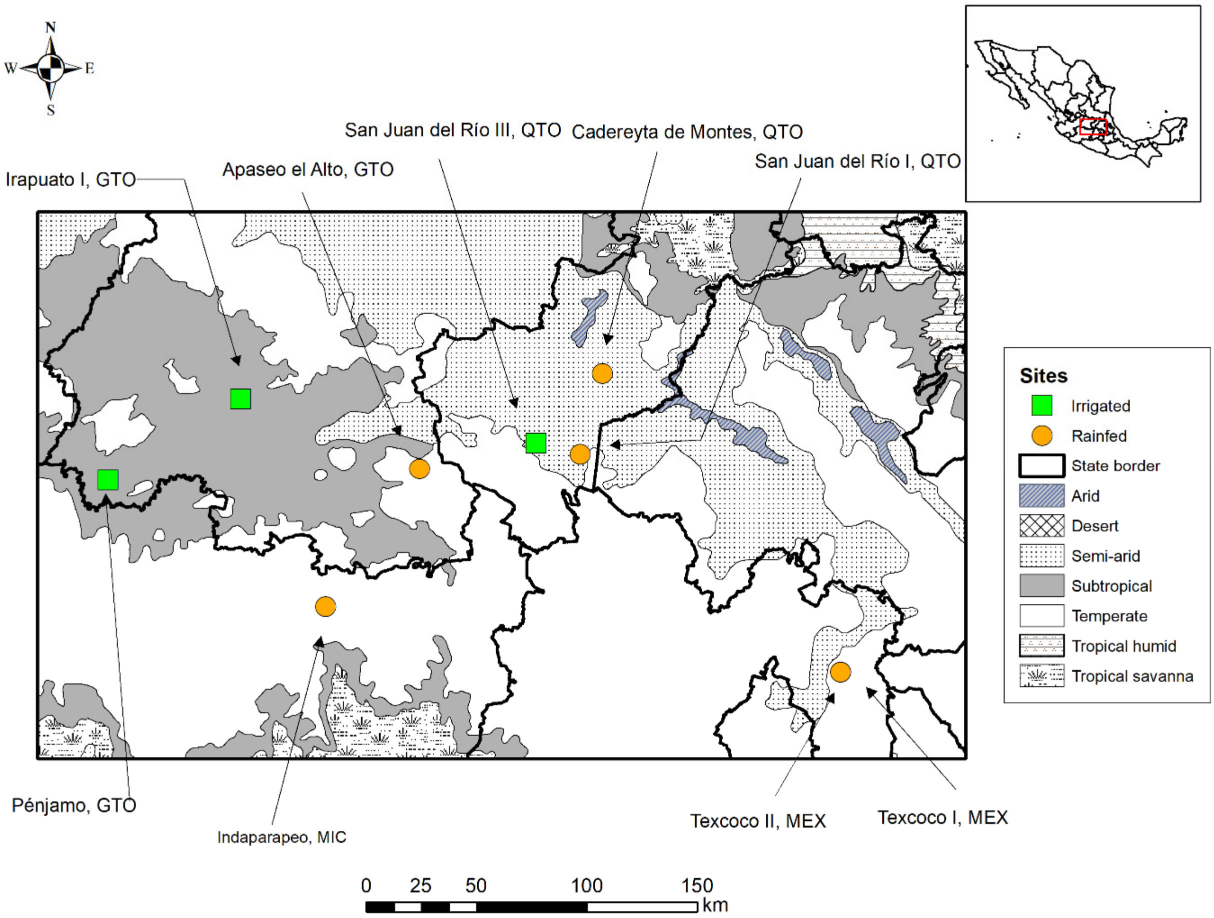


**Figure 1.** Location of the trials used in this study. Texcoco I and Texcoco II are located at the same research station. Abbreviation of states in site names: GTO = Guanajuato; QTO = Querétaro; MIC = Michoacán; MEX = Estado de México.

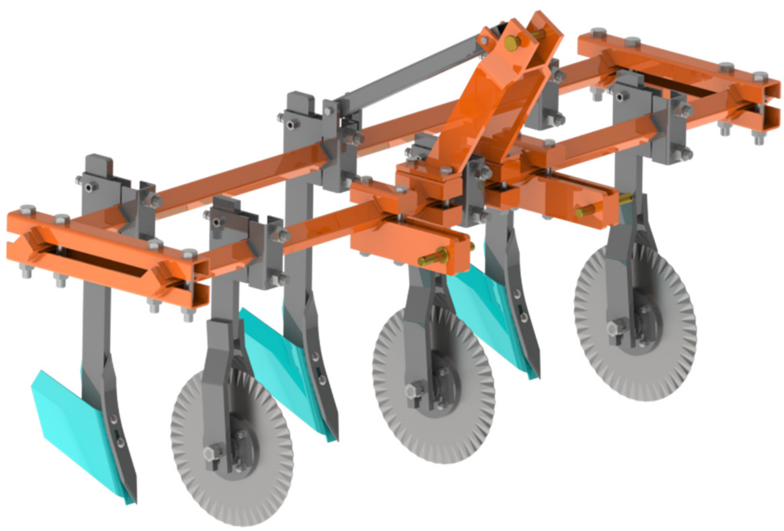

**Figure 2.** Implement with cutter discs and furrowers, employed to reform the furrows between permanent beds.

**Figure 3.** Sowing maize in broad and narrow permanent beds in San Juan del Río, Querétaro, under rainfed conditions.

**Table 3.** Characteristics of the trials and evaluation period at each site.

| Site | Evaluation Period | Cultivation (Cycle) | Bed Width (m) | NPK Fertilization * (kg ha$^{-1}$) |
|---|---|---|---|---|
| Cadereyta | 2015–2019 | Maize (PV) | 0.80 and 1.6 | 11-21-11 |
| San Juan del Río I | 2013–2018 | Maize (PV) | 0.75 and 1.5 | 55-22-11 |
| San Juan del Río III | 2017–2019 | Maize (PV) Barley (OI) | 0.75 and 1.5 | 303-69-60 |
| Indaparapeo | 2014–2018 | Maize (PV) | 0.75 and 1.5 | 175-46-30 |
| Irapuato I | 2012–2018 | Maize (PV)/Wheat (OI) | 0.75 and 1.5 | 418-216-60 |
| Apaseo el Alto | 2014–2018 | Maize (PV) | 0.75 and 1.5 | 156-60-60 |
| Texcoco I | 2007–2019 | Maize/Wheat (PV) | 0.75 and 1.5 | 150-40-00 |
| Texcoco II | 2008–2019 | Maize/Wheat (PV) | 0.75 and 1.5 | 150-40-00 |

* The fertilization formula corresponds to the last reported production cycle and may have changed somewhat throughout the years. PV: Summer; OI: Winter.

Grain yield was determined by harvesting all plants in a central area of at least 1.5 by 5 m, in each plot; the moisture content of the grain was determined by a grain moisture meter or by oven drying a subsample and was subsequently adjusted to 14% for maize and 12% for small grain cereals [21].

Data analysis was performed with the SAS PROC MIXED function (SAS version 9.0, Cary, NC, USA). The variance analysis was first performed as a general analysis for all maize-grown sites by water regime, and later separate analysis was performed for each site. In wheat, the analysis was only performed for each site because there were only two rainfed sites and two sites with irrigation. In barley, a separate analysis was performed for the one site.

For the combined analysis, the model used was:

$$r = m + s + y(s) + t + t * s + t * y(s) + e \quad (1)$$

And for the analysis at each site, the model used was:

$$r = m + y + t + t * y + e \quad (2)$$

where: *r*, variable response; *m*, general mean; *s*, site; *y*, year of evaluation at each site; *t*, bed type; *e*, error. Treatment was considered as a fixed effect and the other variables as random effects. Differences were considered significant at $p \leq 0.05$ and marginally significant at $0.05 < p \leq 0.10$.

## 3. Results

### *3.1. Crop Yield under Rainfed Conditions*

#### 3.1.1. Maize

In the combined analysis of all sites under rainfed conditions, bed width did not significantly affect maize yield ($p = 0.56$) (Table 4); the average yield was 5.0 t ha$^{-1}$ in wide beds and 5.1 t ha$^{-1}$ in narrow beds. Yield varied significantly over the years, mainly due to the amount of rain and its distribution during crop development.

**Table 4.** Combined variance analysis of the maize yield in two bed types, under rainfed conditions.

| Source of Variation | Degrees of Freedom | Sum of Squares | Medium Square | Value of F | Pr > F |
|---|---|---|---|---|---|
| Bed type | 1 | 0.667503 | 0.667503 | 0.35 | 0.5692 |
| Site | 5 | 946.531031 | 189.306206 | 9.35 | <0.0001 |
| Year (Site) | 28 | 556.879938 | 19.888569 | 30.76 | <0.0001 |
| Site × Bed type | 5 | 7.121348 | 1.42427 | 2.19 | 0.0818 |
| Year × Bed type (Site) | 27 | 17.213324 | 0.637531 | 0.6 | 0.9381 |
| Error | 100 | 107.06939 | 1.070694 | | |

At Cadereyta, yield was similar between wide and narrow beds. Average yield was 1.6 t ha$^{-1}$ in wide beds and 1.7 t ha$^{-1}$ in narrow beds (Figure 4), and it fluctuated from 0.2 t ha$^{-1}$ in the driest year to 4.4 t ha$^{-1}$ in the year with the most precipitation. At San Juan del Río I, maize yield was also not affected by bed width, with an average yield of 2.6 t ha$^{-1}$ in the two bed types, fluctuating from 1.5 to 3.8 t ha$^{-1}$ during the five years of the study. At these sites, the average rainfall is less than 400 mm per year and its distribution is very erratic; no differences were observed between the yields of wide or narrow beds in years with greater or lesser precipitation.

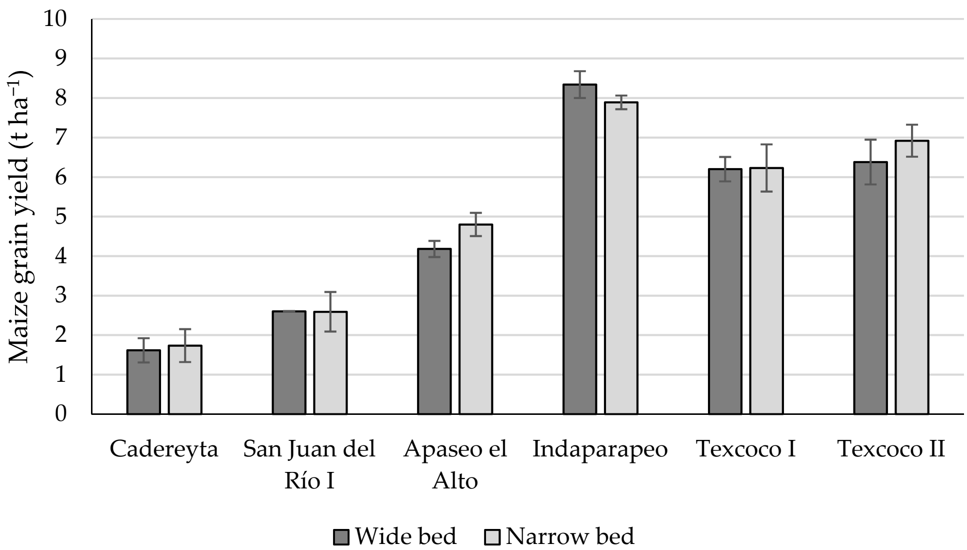


**Figure 4.** Maize yield with planting in wide, narrow beds at six sites in central Mexico. Average yield during the duration of the study; the error bars represent the standard deviation of the mean.

Apaseo el Alto, in Guanajuato, has the soil with the highest clay content of the studied sites and a low average precipitation of 550 mm. In almost all cycles, the highest yield was achieved in narrow beds; the average yield was 4.1 t ha$^{-1}$ in wide beds and 4.8 t ha$^{-1}$ in narrow beds, and this difference was not significant ($p$ = 0.21).

In Texcoco I and Texcoco II, maize and wheat are rotated. In Texcoco I, maize was sown after two years of wheat, so in the evaluation period, maize yield data are available in three cycles in a period of nine years. No yield differences were observed between wide and narrow beds, and the average yield was 6.2 t ha$^{-1}$ on both bed types. In Texcoco II, where an annual rotation is performed, maize yield was, on average, 6.4 t ha$^{-1}$ on wide beds and 6.9 t ha$^{-1}$ on narrow beds, with the crop in narrow beds yielding 0.5 t ha$^{-1}$ more ($p$ = 0.0103). Although the experiment began in 1999, the treatment of wide permanent beds was added in 2007 along with previously conventional tillage, while the narrow permanent beds have been in place since 1999. The difference in yield could be attributed to the period of adaptation of the system and the time required to observe the effects, because the difference has become smaller over time (Figure 5); if the first three years are not considered, the difference was 0.5 t ha$^{-1}$ and was only marginally significant ($p$ = 0.0787).

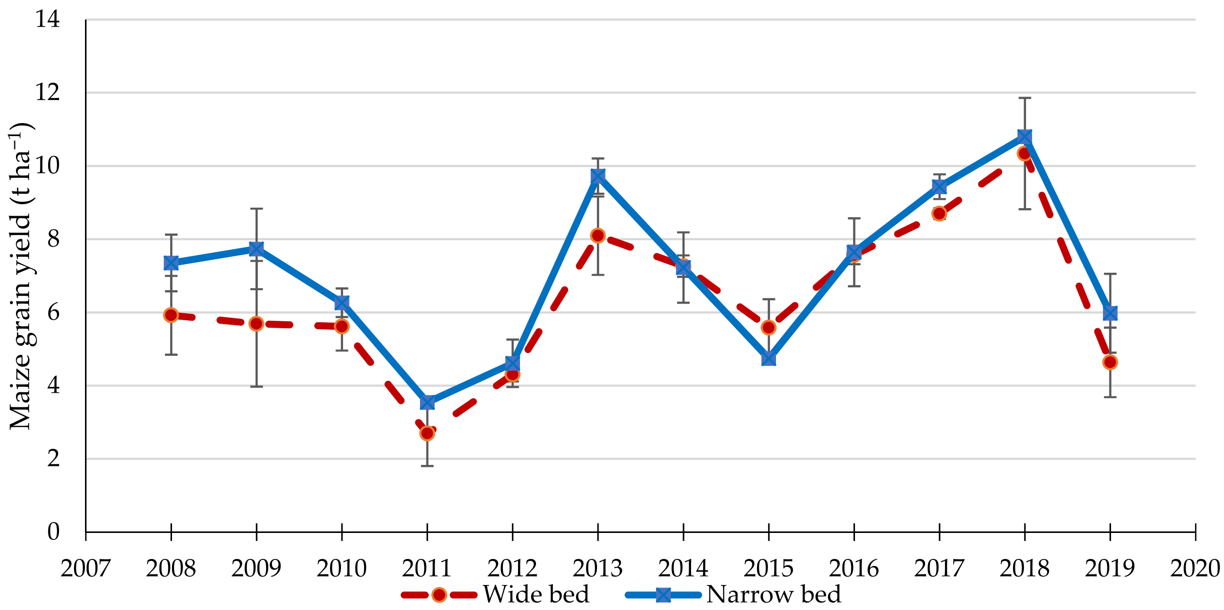


**Figure 5.** Maize yield with planting in wide and narrow beds in Texcoco II. Average yield for each year during the duration of the study; the error bars represent the standard deviation of the mean.

Indaparapeo, in Michoacán, is the site with the highest annual precipitation, which is more than 800 mm, but prolonged periods of drought can be observed. Planting in wide permanent beds achieved the highest yield in five out of six cycles; the average yield was 8.3 t ha$^{-1}$ in wide beds and 7.9 t ha$^{-1}$ in narrow beds, respectively. However, the differences were not significant ($p$ = 0.22). In 2014, the distribution of precipitation was very erratic, and there were prolonged periods of drought, which caused water stress in the crop. Under these conditions, the average yield was 9.7 t ha$^{-1}$ in wide beds and 9.8 t ha$^{-1}$ in narrow beds.

### 3.1.2. Wheat and Barley

The production of small grains in Texcoco I and Texcoco II was not affected by the width of the planting bed. In Texcoco I, the average wheat yield in wide beds was 4.3 t ha$^{-1}$ and 4.1 t ha$^{-1}$ in narrow beds, while in Texcoco II the yield was 4.0 t ha$^{-1}$ and 3.9 t ha$^{-1}$ in wide and narrow beds, respectively. In seven out of twelve cycles, narrow beds had a numerically higher yield (Figure 6), but in no case were significant differences observed. In 2009 and 2010, the Texcoco I site was sown with barley; the average yield was 2.4 t ha$^{-1}$ in wide beds and 2.2 t ha$^{-1}$ in narrow beds, the same difference than in wheat.

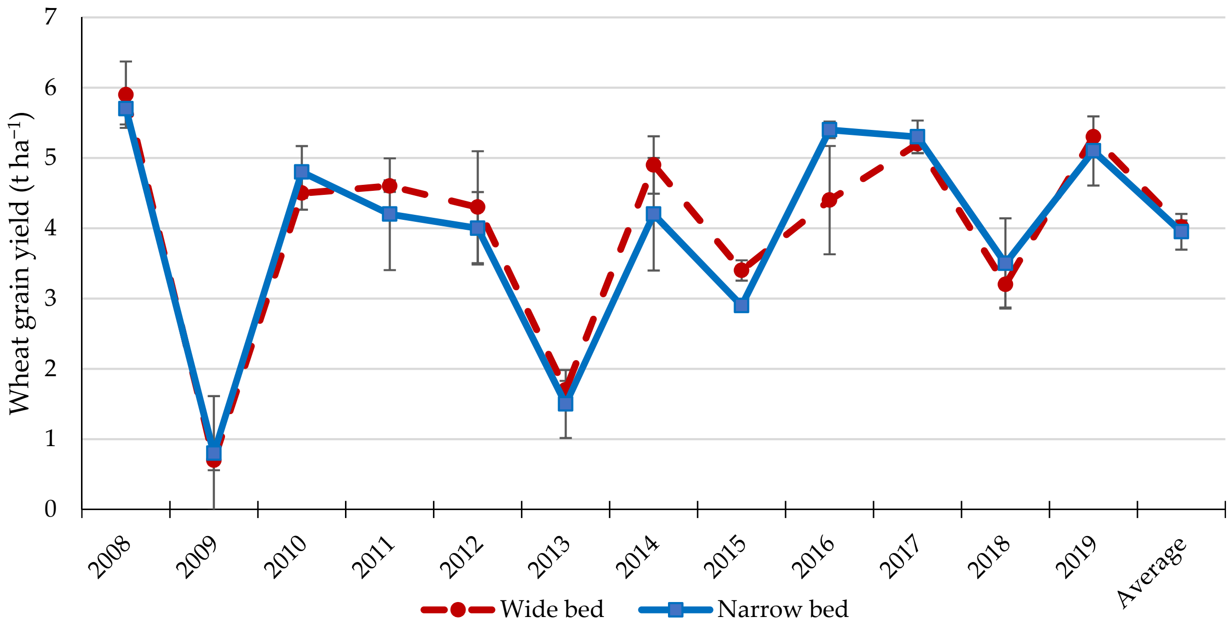


**Figure 6.** Average wheat yield in wide and narrow beds in Texcoco II. Average yield for each year during the duration of the study; the error bars represent the standard deviation of the mean.

### *3.2. Crop Yield under Irrigated Conditions in Two Bed Types*

#### 3.2.1. Maize

In the combined analysis of the irrigated sites, bed type marginally affected maize yield ($p$ = 0.0858). Average yield was 13.5 t ha$^{-1}$ in wide beds and 12.8 t ha$^{-1}$ in narrow beds. The sites represent high productivity systems in the Mexican Bajío, where yields can vary widely (more than 10%) over the years as a result of environmental conditions, but the effect of site was not significant (Table 5).

**Table 5.** Combined variance analysis for the maize yield variable in two bed types, under irrigated conditions.

| Source of Variation | Degrees of Freedom | Sum of Squares | Medium Square | Value of F | Pr > F |
|---|---|---|---|---|---|
| Bed type | 1 | 7.022311 | 7.022311 | 4.88 | 0.0858 |
| Site | 2 | 157.523394 | 78.761697 | 1.59 | 0.2557 |
| Year (Site) | 9 | 396.698389 | 44.077599 | 32.77 | <0.0001 |
| Site × Bed type | 2 | 3.507335 | 1.753667 | 1.40 | 0.3150 |
| Year × Bed type (Site) | 9 | 12.106804 | 1.345200 | 0.63 | 0.7626 |
| Error | 58 | 122.896504 | 2.118905 | | |

No significant differences were observed in the analysis of each site, but in two sites, planting in wide beds achieved a numerically higher yield (Figure 7). In Irapuato I, the average yield was similar in the two bed types, with an average yield of 14.2 t ha$^{-1}$. In Pénjamo, the average yield was 10.5 t ha$^{-1}$ on narrow beds and 11.7 t ha$^{-1}$ on wide beds, but the difference was not significant ($p$ = 0.42). In San Juan del Río III, the average yield on narrow beds was 13.5 t ha$^{-1}$ and 14.3 t ha$^{-1}$ in wide beds, but the difference was not significant ($p$ = 0.33).

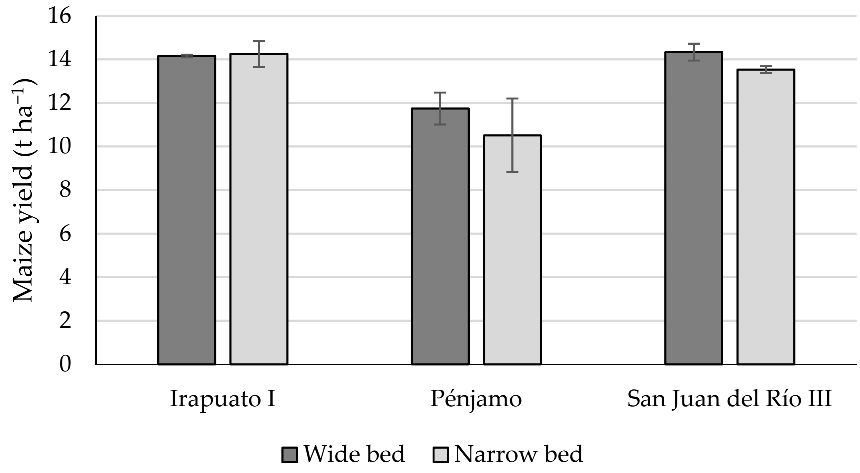


**Figure 7.** Yield of maize with planting in wide and narrow beds under irrigated conditions at three sites in central Mexico. Average yield during the duration of the study; error bars represent the standard deviation of the mean.

### 3.2.2. Wheat and Barley

The irrigated sites were sown with small grains in the autumn–winter cycle; two sites were sown with wheat and one with barley. Overall, the yield was slightly higher in narrow beds (Figure 8), but the differences were not significant. Wheat yield in Irapuato I was 6.8 t $ha^{-1}$ in narrow beds and 6.4 t $ha^{-1}$ in wide beds ($p$ = 0.23). In Pénjamo, the result was similar, with a yield of 6.9 t $ha^{-1}$ in narrow beds and 6.4 t $ha^{-1}$ in wide beds ($p$ = 0.52). Barley in San Juan del Río III averaged 3.9 t $ha^{-1}$ in narrow beds and 3.8 t $ha^{-1}$ in wide beds ($p$ = 0.64).

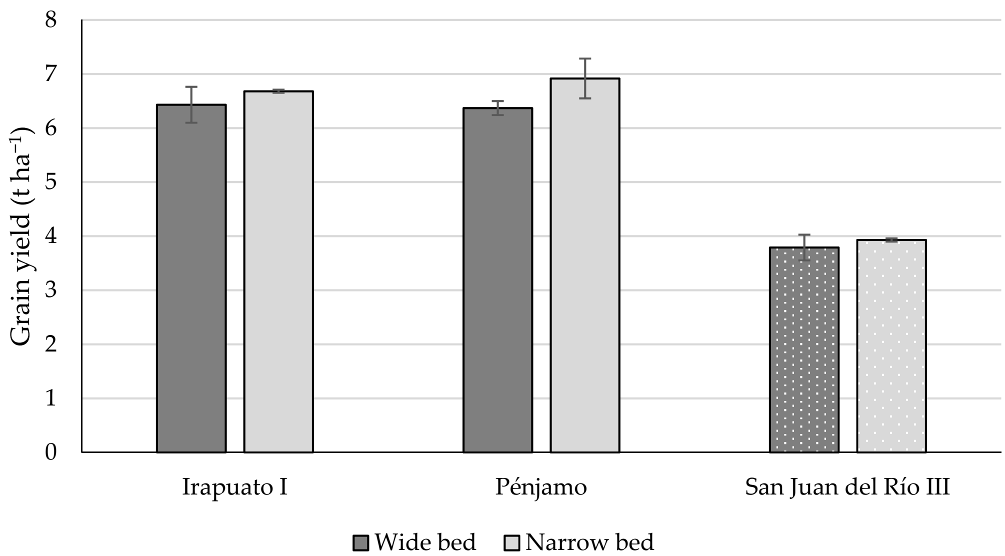


**Figure 8.** Wheat and barley yield, with planting in wide and narrow beds, under irrigated conditions in three sites in central Mexico. Average yield during the duration of the study; the error bars represent the standard deviation of the mean. Dotted bars indicate barley.

## 4. Discussion

This study evaluated the effect of planting bed width on maize, wheat, and barley yield under irrigated and rainfed conditions in various agro-ecological regions of central Mexico. No significant differences in yield were observed between narrow and wide permanent beds, except for in Texcoco II, where it may have been caused by the difference of age between both types of beds. At this site, yield differences between conventionally managed plots and conservation agriculture are high in long term trials, especially in dry years [5,7] which may have increased the difference between the two types of beds in the first years after the inclusion of permanent wide beds. Similarly, no differences were observed in five other trials in the network, which did not qualify to be included in the study due to a lack of consistency in the treatments [20]. Overall, the choice for either type of bed would thus not significantly affect production.

We did observe some trends that could be agronomically relevant and guide farmers in choosing between wide or narrow permanent beds. In San Juan del Río I and Cadereyta, the two sites with the lowest precipitation, maize yield was similar in the two bed types, probably because the greatest benefit of planting beds is observed in places where excess water can be better distributed on the plot or drained by the furrows [22]. The main benefits of using permanent beds instead of zero tillage under those conditions are the controlled traffic and easier mechanical sowing. In a bean monoculture in a semi-arid region, narrow beds yielded more because they could be combined better with water conserving measures such as tied ridges or vertical tillage in the furrows, which is necessary in a bean monoculture as the crop does not produce enough residue to generate the soil cover necessary for conservation agriculture [16]. Furthermore, narrow beds can be combined better with mechanical weed control, which can substantially reduce production costs. In Apaseo el Alto, there was a trend of higher yields in narrow beds than in wide beds, which could be attributed to improved infiltration and drainage in narrow beds, because the soil has a high clay content and low hydraulic conductivity (Table 2) [18]. In narrow beds, a higher proportion of the soil is moved during bed reformation, which facilitates the lateral movement of the water from the edge to the center of the bed [23]. In Indaparapeo, intense rains are frequently followed by dry spells; at this site there was a trend towards higher yields in wide beds than in narrow beds. This trend could be due to the capacity of wide beds to drain excess water and to retain enough moisture by reduced soil evaporation from undisturbed, residue covered soil [24]. Wheat yield may be sensitive to row spacing [25]; however, we did not observe a significant difference in yield with different row spacing for wide and narrow beds in Texcoco I and Texcoco II. This may be attributable to the use of highly tillering cultivars in the trial, which may have compensated the effect of wider spacing with narrow beds. In maize, a reduced distance between rows may contribute to increased yield [26]. In this case, wide beds may be more suitable to allow different planting patterns.

Under irrigated conditions, the maize yield was marginally significantly higher in wide beds than in narrow beds. This could be due to more efficient use of irrigation water, as in the region it is common to apply heavy irrigations followed by long periods of up to 25 days until the next irrigation, due to the absence of rains and water for irrigation. This irrigation practice can lead to soil saturation as well as drought stress, both of which may be reduced in wide beds due to their higher buffering capacity. Although our study did not evaluate the amount of water applied in the two types of beds, other studies have reported that, in wide beds, up to 40% less water is applied compared to narrow beds [27,28]; besides, irrigation in alternating furrows (similar to wide beds), reduces salinization at the top of beds and improves crop development [29].

However, during the autumn–winter cycle, the availability of water depends almost exclusively on irrigation. Under these conditions, there is less infiltration and availability of water in wide beds, because the center of the bed is not wetted completely due to a lower lateral flow and the lower amount of water applied, so the crop rows in the center of the bed do not receive the required amount of water [2,28,30]. This could explain the trend towards lower yield of wheat on wide permanent beds in Irapuato I and Pénjamo. However, the lower wheat yield in Irapuato I and Pénjamo was compensated by the higher maize yield, so the choice of beds would not impact the total grain production. On loamy soils, there is a greater lateral flow of water [18], and a wide bed could be used without affecting small grain yield as seen in San Juan del Río III. Because excessive quantities of crop residues on the soil may affect the performance of furrow openers at planting, in high yielding cereals systems, crop residues can be concentrated into windrows at the center of wide beds for a successful crop establishment.

## 5. Conclusions

Bed width did not significantly affect crop yield; therefore, farmers should use the type of bed that best suits their practical needs. Under surface irrigated conditions or high rainfall, the use of wide beds may be recommended for conditions similar to those reported in this study, except for soils with low hydraulic conductivity.

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