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Long-term response planting method on wheat under conservation agriculture

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ABSTRACT

Objective: To compare different bed planting systems: narrow beds, wide beds, and flat soil, on the growth and yield of wheat under conservation system.

Design/methodology/approach: Treatments were established on a complete block design with three replicates. Also, wheat crop was grown during five seasons. Treatments were as follow: wide beds (100 cm), narrow beds (80 cm) flat soil. Response variables were dry weight of 50 stems, weight of 1000 grains, number of spikes (m^2), harvest index and yield. Also, the relationship between relative yield and cold units and degree-days were measured.

Results: The flat beds treatment reached the highest stem weight, while the narrow beds had the highest number of spikes m^2. Yield was the same between flat beds and narrow beds. No differences were found in the harvest index between the evaluated treatments. When the variables were compared in the years evaluated, the dry weight of 50 stems increased and the harvest index was reduced, negatively affecting yield. A negative association was identified between the reduction of chilling hours and crop yield.

Study limitations/implications: The use of wide planting beds reduced the yield of the wheat crop, and its use is not recommended.

Findings/conclusions: The performance was the same between the treatment of flat beds and narrow beds. The reduction in yield was mainly associated with the reduction in cold hours that occurred in each year of production.

Keywords: climate; environment; grain yield; plant density; topological arrangement.

INTRODUCTION

The Mexicali valley is located in the state of Baja California in Northwest Mexico. It has an approximate area of 105,000 irrigated hectares, of which 98,000 hectares are crops of wheat (*Triticum aestivum* L.) cultivated during the months of November through May

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(SIAP, 2014). Traditionally, most growers employ the flat planting system for wheat under conventional tilling practices. The system includes the subsoiling, disking and mould board plough. Besides, straw is usually burned after harvest, which substantially affects microbial activity in soils (Wuest *et al.*, 2005).

Wheat grain yield attained by the use of this technology has reached an average of 6.8 Mg ha^{-1} (Salinas-Zavala, Salvador, Lluch-Cota & Fogel, 2006). However, it can be enhanced by increasing the number of irrigations (Kakar & Iqbal, 2015) and employing different management practices such as bed planting system. Additionally, profitability of this crop can be increased by employing conservation tillage system (minimum tillage, crop rotation, straw incorporation) (Govaerts *et al.*, 2009).

In conservation agriculture system, the soil is ploughed as in conventional system during the first year. After that time, soil is not disturbed; crop rotation and all crop remains are incorporated over the surface. The planting method consists of raised beds (80-100 cm) with two or three rows on the top of the bed (Limon-Ortega, Sayre, Drijber, & Francis, 2002).

With conservation agriculture, growers can achieve fuel costs savings up to 30% (Lal, 2004), increase nitrogen concentration, organic matter content (Zuber *et al.*, 2015)and keep stable yield (Kassam *et al.*, 2009). Fahonga, Xuqinga & Sayre (2004) mention that bed planting system provides advantages in water saving (30%) when compared to flat soil planting. They also indicate that soil crusting problems are reduced because the seed bed surface improves physical structure. Besides, N use efficiency is increased up to 30%, microclimate favors crop stand, reduces lodging and presence of plant diseases. Weed management and fertilization timing practices are substantially improved (Govaerts, Sayre, & Deckers, 2005).

The use of bed planting in wheat crops has been recommended for more than a decade in the Yaqui valley (state of Sonora) as well as in high valleys of central Mexico (Govaerts *et al.*, 2005). Nevertheless, the use of this technology in Mexicali valley is under research due to different cropping systems (type of soil, irrigation water quality and environment) which are contrasting to the places above mentioned. In that sense, a study was conducted during five years in order to compare different bed planting systems (flat soil, wide beds (100 cm) and narrow beds (80 cm) on the growth and yield of wheat under conservation system.

MATERIALS AND METHODS

The research was carried out at the experimental platform for conservation agriculture located at the agricultural science institute (32° 24’ 12.34” N; 115° 11’ 47.37” W). The weather of this region is arid with periods of rain in winter (BW [h’] hs [x´] [e’]; (Ruiz-Corral *et al.*, 2006), summer temperatures up to 50 °C and winter temperatures of −7 °C, the mean annual temperature is 22.3 °C and the mean annual precipitation is 58 mm.

The soil from the experimental site is classified as clayed (vertisol), bulk density of 1.16 g cm^3, electrical conductivity (EC) of 4.44 dS m^{-1}, pH 7.83, 33 ppm of phosphorus content, 395 ppm of potassium, 5236 ppm of calcium, 1255 ppm of magnesium and 672 ppm of sodium respectively. Irrigation water flowed from Colorado River, the pH was of

8.18, EC of 1.28 dS m^{-1} and 122.0, 61.4, 154.8, 177.1, 243.5, 421.8 mg L^{-1} of calcium, magnesium, sodium, bicarbonates, chlorides and sulfates approximately.

The experiment was established in a big area of land under conservation agriculture system. The tillage techniques were those recommended by Verhulst *et al.* (2015). The first year of the study (2011-2012), land was ploughed using conventional system (subsoiling, disking and leveling). Subsequently, all treatments were established on a complete block design with three replicates. Plots had a length of 140 m and 12 m wide. Treatments were: A) wide beds (furrows at 100 cm), wheat was planted in twin line (two rows 27 cm apart) (Figure 1) and seed density of 80 kg ha^{-1}; B) narrow beds (furrows at 80 cm) (two rows 27 cm apart) and the same seeding rate; C) flat soil with a seed density of 160 kg ha^{-1}.

Planting and harvest dates were as follow: A) December 6th 2011 and June 15th 2012 first growing season; B) December 15th 2012 and June 15th 2013 second growing season, C) November 15th 2013 and June 7th 2014 third growing season, D) November 22nd 2014 and June 4th 2015 fourth growing season, E) November 25 2015 and June 15th 2016 the fifth growing season. The variety planted was Rio Colorado during all growing seasons.

Planting on wide and narrow beds was realized with a multifunctional seed drill (manufactured by Industrias Vázquez S.A de C.V); flat soil planting system was realized with a special seed drill (Dobladense 290-17®). Fertilization rates were of 276 kg of nitrogen using urea [$CO(NH_2)_2$] and 78 kg of phosphorus using monoammonium phosphate (MAP-11-52-00). Total P and 25% of N were pre-plant applied, 33% of N applied in the first post-plant irrigation, 25% in the second post-plant irrigation while the last 17% in the third post-plant irrigation. Pest and weed management were realized following the guideline provided by Hernández-Vázquez *et al.* (2010).

Response variables were dry weight of 50 stems (season 2013-14; 2014-15 and 2015-16), number of spikes (m^2) (season 2014-15 and 2015-16), weight of 1000 grains (season 2013-14, 2014-15 and 2015-16), harvest index (season 2011-12, 2013-14 and 2015-16) and yield (from 2011 through 2016). It was also identified the ratio of annual yield relative to chill hours and degree-days from planting to February (year). The reason for considering February is because heading usually occurs during this time (Verhulst, Kienle, Sayre, Deckers, & Raes, 2014).

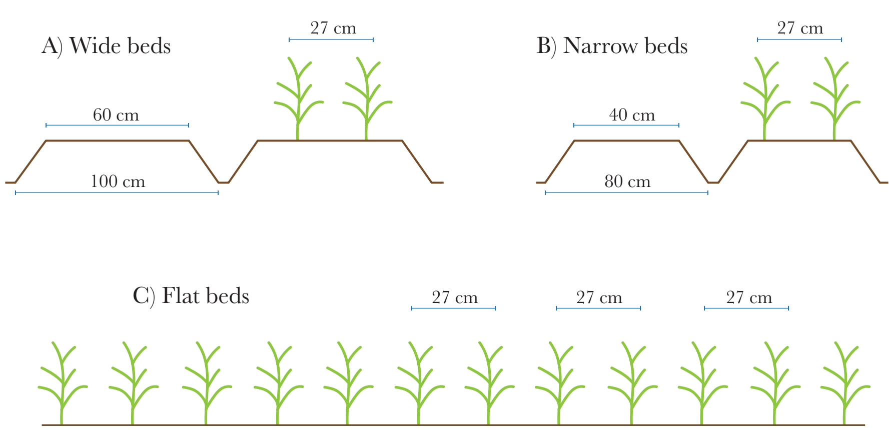

Figure 1. Different planting systems on wheat production.

To determine $DW_{50\ stems}$, plant material was taken at harvest, placed on a forced air-dry oven (65 °C) until constant dry weight. Harvest index (HI) was obtained by the ratio of dry weight of 50 stems relative to grain weight. Number of spikes were also counted (m^2). Yield was estimated by harvesting plants on 2 m^2 segment. Climatic conditions were monitored with a meteorological station located at 840 m from the experimental site during all years of the study. The daily chill hours and degree-days were obtained from a meteorological network station (SIMABC, http://www.simarbc.gob.mx/).

All data obtained was analyzed separately due to different variables measured. Analysis of variance was conducted between treatments, treating years as the fixed factor, ANOVA between years considering treatments as the fixed factor, mean differences between treatments or years, were separated using Tukey's least significance difference (LSD) at $P \leq 0.05$. Additionally, regression models were fitted between accumulated chill hours and degree-days with respect to grain yield.

RESULTS AND DISCUSSION

Table 1 shows the maximum and minimum temperatures during the time of the experiment. It also shows the average monthly maximum and minimum temperatures from 1961 through 2003. It is shown that temperatures obtained during the study were very similar to those recorded from 1962 to 2003. Maximum temperatures registered from January through may increase from 4.9 a 8.7 °C as compared to those registered in the period of 1961 to 2003.

Table 2 shows the monthly Degree-days (DD) and chill hours (CH) accumulation during the study. As the time passed during the period of the experiment, the months from February through March exhibited a reduction in the CH accumulation and increased the DD accumulation.

Table 1. Maximun and minimum temperatures registered on wheat crop under conservation agriculture. Mexicali, Baja California, México.

Month	Year cero (2011-12)		Year two (2012-13)		Year two (2013-14)		Year three (2014-15)		Year four (2015-16)		Average 2011-16		1961-2003†	
	Mínimum	Máximum	Mínimum	Máximum	Mínimum	Máximum	Mínimum	Máximum	Mínimum	Máximum	Mínimum	Máximum	Mínimum	Máximum
November	7.4	24.7	11.8	31.8	9.4	25.3	9.4	27.0	-‡	-	9.5	26.9	9.3	26.0
December	2.6	19.2	4.5	27.5	5.1	22.0	7.1	20.8	-	-	4.8	22.1	6.4	21.4
January	4.6	23.7	3.3	18.8	6.5	24.3	6.4	22.6	5.1	20.8	5.1	26.3	6.4	21.4
February	6.2	24.0	3.7	21.3	8.1	25.7	9.4	27.5	8.3	26.3	7.1	29.7	7.7	23.9
March	7.1	26.6	9.9	28.8	11.3	30.5	11.7	29.2	9.1	27.8	9.8	33.8	9.7	26.4
April	11.5	30.7	11.4	31.0	11.5	31.2	11.7	30.4	12.2	29.4	11.6	36.5	12.0	29.8
May	14.8	36.2	16.1	36.6	15.5	35.2	13.3	31.9	13.7	32.9	14.6	41.3	15.5	33.9
June	19.0	39.5	19.7	39.6	19.6	39.6	19.6	39.9	21.4	39.0	19.8	47.2	19.1	38.5

†: Average from 1961-2001. Ruiz-Corral *et al.*, 2006. ‡: Not determined.

Table 2. Degree-days (DD) and chill hours (CH) accumulation registered on wheat crop under conservation agriculture. Mexicali, Baja California, México[†].

Month/year	2011-12		2012-13		2013-14		2014-15		2015-16	
	CH	DD	CH	DD	CH	DD	CH	DD	CH	DD
November	139	254	0	113	70	292	76	337	267	0
Dicember	375	105	0	0	306	154	211	180	235	59
January	269	206	0	0	195	242	188	211	266	150
February	203	199	195	110	110	269	67	322	107	303
March	139	309	61	392	23	384	36	441	40	365
April	25	446	12	455	12	456	8	442	9	443
May	0	626	0	631	0	602	7	529	0	549
June	0	731	0	747	0	716	0	743	0	767
TOTAL	1150	2876	268	2448	716	3115	593	3205	924	2636

[†]: SIMARBC. 2016. http://www.simarbc.gob.mx/

According to analysis of variance, there were significant differences in variables of dry weight$_{50\ stems}$, spikes (m^2) and yield of crop by the effect of planting methods (Table 3). The greatest weight of 50 stems was registered on flat soil planting. The greatest number of spikes was recorded on narrow bed planting. Lastly, the lowest yield was attained on wide bed planting. However, there were no significant differences on weight of 1000 grains and HI.

Significant differences were found in variables of $DW_{50\ stems}$, $DW_{1000\ grains}$, HI and yield of crop during the years of the study (Table 4). The highest value of $DW_{50\ stems}$ was attained during the season 2015-2016. The yield and HI decreased as the time passed. In addition, $DW_{1000\ grains}$ decreased on the season 2014-15 as compared to seasons 2013-14 and 2015-16. Furthermore, the number of spikes (m^2) was not affected during the time of the experiment.

Table 4 shows the analysis of variance and mean comparison for the variables of $DW_{50\ stems}$, spikes m^2, $DW_{1000\ grains}$, HI and yield in five years of study. It was observed that as time passed, $DW_{50\ stems}$ significantly increased ($P>0.01$) to double the weight attained during the season 2013-14 as compared to season 2015-16. However, there were no significant differences on the number of spikes (m^2) during the years of study ($P>0.05$). The highest value of $DW_{1000\ grains}$ was attained on the seasons 2013-14 and 2015-16 as compared to season 2014-15. HI increased on seasons 2011-12 and 2013-14,

Table 3. Effect of planting method on dry weight of 50 stems, spikes (m^2), weight of 1000 grains, HI and yield of wheat crop (2011-12 through 2015-16).

Planting method	$DW_{50\ stems}$ (g)	Spikes m^2	$DW_{1000\ grains}$ (g)	HI	Yield (Ton ha^{-1})
Flat soil	193.54 a	270 b	77.61	0.393	6.45 a
Narrow beds	158.83 b	370 a	73.73	0.385	6.40 a
Wide beds	176.21 b	255 b	76.66	0.398	5.23 b
Significance	**	*	NS	NS	*

NS: non significant; *, **. Significant at $P<0.05$, $P<0.01$, respectively.

Table 4. Mean comparison of yield components on wheat in five growing seasons (2011 to 2016).

Year	$DW_{50\ stems}$ (g)	spikes m^2	$DW_{1000\ grains}$ (g)	HI	Yield (t ha^{-1})
2011-12	-	-	-	0.433 a	6.87 a
2012-13	-	-	-	-	6.98 a
2013-14	117.07 c	-	83.22 a	0.414 a	6.03 a
2014-15	160.93 b	298	63.12 b	-	5.33 ab
2015-16	250.58 a	309	81.66 a	0.327 b	4.94 b
Significance	**	NS	*	*	*

NS: non significant; *, **, ***. Significant at P<0.05, P<0.01, y P<0.001 respectively.

but it decreased on season 2015-16. The same tendency was observed when analyzing yield between years. Yield potential significantly decreased as time passed.

The regression model showed that yield increased as the number of cold units also increased (R^2=0.4355, P<0.007; Figure 2). The regression equation indicated that yield increased 1.35 ton ha^{-1} for every 100 units accumulated to February. A different behavior was observed with respect to degree-days accumulation and yield (Figure 3). The regression equation showed that yield decreased 0.94 ton ha^{-1} for every 100 degree-days accumulated to February (R^2=0.4487; P<0.006).

It is estimated that conservation agriculture system worldwide is growing at a rate of 5.3 million of hectares per year (Kassam, Friedrich, Shaxson & Pretty, 2009). Recently, number of studies show the benefits of this production system. This practice involves the evaluation of climatic and edaphic conditions for each region and the crop response to them (Verhulst, Kienle, Sayre, Deckers, Limon-Ortega, Tijerina-Chavez & Govaerts, 2011). It is observed that yield of wheat under raised bed planting system has not exceed the yield obtained under flat planting system in regions with arid climate and soil saline conditions (Saifuzzaman *et al.*, 2011). However, when there is an increase in yield, it has been associated to improvement in soil conditions (incorporation of crop remains) (Limón-Ortega *et al.*, 2011).

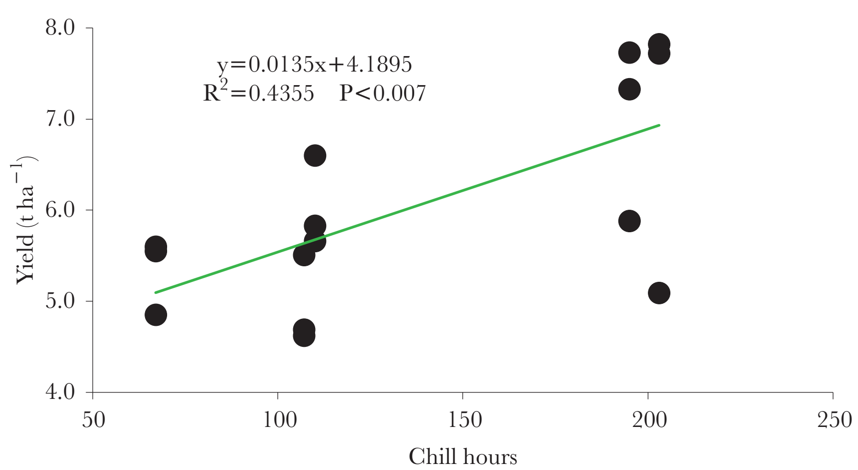

Figure 2. Relationship between chill hours accumulation and yield of wheat in five years.

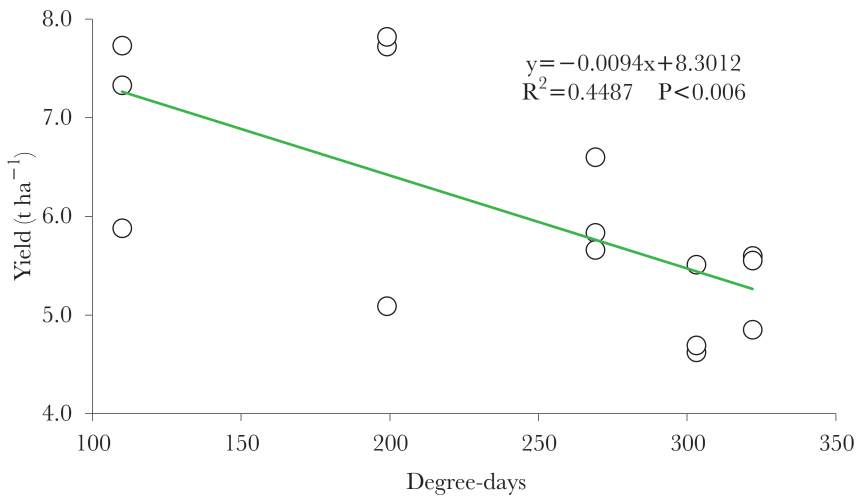

Figure 3. Relationship between degree-days accumulation and yield of wheat in five years.

This study evaluated three planting systems on the growth and yield of wheat under environmental conditions of Mexicali Baja California. The flat planting and the narrow bed planting system provided the same yield; while the yield under wide bed planting system was reduced. It is possible that decrease in yield on this system was due to spacing between them. Fischer *et al.* (2019) have also documented this response. Nevertheless, they stated that yield could fluctuate between years because of low temperatures at the time of planting and crop emergence. They also mentioned that wheat late plantings (past January) lead to better yields.

It was identified a significant relationship between yield drop and increase of temperatures on February ($P<0.006$). According to Verhulst *et al.* (2011), it is just the period for completing the stage of heading and beginning of stem elongation. This process could have modified the pattern of dry matter partitioning to stems, leading to a decrease in harvest index (Banerjee and Krishnan, 2015). The hypothesis is contrasting because of the increase in chill hours during the same month (February). Nuttall *et al.* (2018) indicated that heat waves in period before flowering affected the yield. On the other hand, Calderini *et al.* (1999) exhibited that lowering yields are associated to temperature drop between stages of growth.

CONCLUSIONS

The dry weight of the stems, the number of spikes and the yield of the wheat crop were affected by the sowing method. The lowest yield resulted from planting in wide beds. Likewise, the weight of the grain and the harvest index were not modified with the sowing method. On the other hand, the weight of the stems increased and the harvest index was reduced due to the effect of the years of study. An association between performance and hot or cold hours in February was identified. In general, the use of narrow beds can be a management practice in wheat cultivation because the yield is not affected.

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