OPTIMIZATION OF MAIZE YIELD: RELATIONSHIP BETWEEN MANAGEMENT ZONES, HYBRIDS AND PLANT POPULATION

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ABSTRACT

Plant population per unit area is one of the most important aspects under farmer control that can influence maize grain yield. Adjusting plant population in crop fields is a strategy to manage spatial variability and optimize environmental resources that are not under farmer control like soil type and water availability. This study aims to evaluate the strategy of variable rate seeding (VRS) by management zones (MZ) in Brazil. In this study, ten hybrids and five plant populations ranging from 20 to 40% below, and 20 to 40% above the local planting density were analyzed. Three field experiments were conducted during 2012 and 2013 in two regions with distinct growing seasons, both under rain fed and non-tillage system. The attributes used to delineate MZ were apparent soil electrical conductivity (EC_a), yield maps (YM) and elevation. The quality of seed rate (indicator of spacing between plants) was 88% to 95% accurate at all locations. The analyses of variance were significant ($P < 0.05$) for triple interaction between hybrids, plant population, and the MZ. The high MZ reached higher average yield compared to the low MZ and high populations reached higher yield regardless of MZ. Management zones influenced the maximum attainable yield. The optimum plant population varied across zones. However, there is no simple recommendation regarding the optimal plant population.

Keywords: maize; management zone (MZ); plant density; corn yield; spatial variability

INTRODUCTION

Maize (*Zea mays*) is sensitive to variations in plant population and it is one of the most important practices influencing grain yield (Duvick, 1997, Sangoi et al., 2002). Previous knowledge about plant physiology and morphology enables understanding of how the crop productivity interacts with variation in plant population variation. Considering that for each production system there is a population that optimizes the use of available resources, it is necessary to manage plant population such that the crop reaches its optimal grain yield in each particular environment.

Variable rate seeding (VRS) was the most frequent tool listed by farmers from south Brazil who intend to increase adoption of Precision Agriculture (PA) technologies (Anselmi et al., 2014). Another survey among United States agricultural retailers show optimistic projections to VRS (Holland et al., 2013). The highest valued technology was variable rate seeding with 49.6% of respondents who agreed that: "*it is an emerging technology with a promising future*". Dealerships had the largest increase in variable rate seeding offerings, increasing from 36% of respondents in 2011 to 56% in 2013 (Holland et al., 2013). Therefore, it is necessary establish some parameters that can guide variable rate seeding management.

Yield optimization by PA technology is a management strategy that takes advantage of natural spatial variability of fields' characteristics that the producer cannot easily change, like soil texture, soil water content, slope (Molin, 2003). Therefore, soil properties should be mapped to delineate management zones and help farmers in decision making (Khosla et al., 2008). Prior studies point out PA tools that have great potential to guide VRS. Historical yield maps (YM), soil sensing like apparent electrical conductivity maps (EC_a) and elevation are efficient in identifying spatial variability, and can be mapped quickly and with low cost (Sudduth et al., 1998, Godwin et al., 2003, Shanahan et al., 2004).

Genetic improvements have contributed to selection of maize characteristics to improve stresses tolerance, as for example, stress caused by the increase in the number of plants per unit area. Plant density has increased 250% since 1930s and yield ability has improved at a linear rate of about 74 kg ha^{-1} per year (Duvick, 1997). Over the last decade, plant population has been the agronomic management factor that changes the most in response to tolerance acquired by new genotypes (Tollenaar and Lee, 2002). In Iowa, USA, plant densities increased by about 425 plants ha^{-1} per year since 2001 (Abendroth and Elmore, 2007). While modern hybrids tolerate higher plant population (Sangoi et al., 2002), the increase in seed cost requires producers to adjust the rates of seeds depending on soil potential response in order to optimize yield and save seed costs.

Variable rate seeding of maize southern Brazil allowed optimization of plant populations and increased yield. Economic improvements were about 25% in low management zones (LMZ) and 6% in high management zones (HMZ). In LMZ, plant density of 29% below the standard population (70000 plants ha^{-1}) increased yield around 1500 kg ha^{-1}. In HMZ, yield increased by 900 kg ha^{-1} with plant population 13% above standard population (Horbe et al., 2013).

This study aims to analyze the relationship between management zones, hybrids and plant population. Specifically, was evaluated if management zones respond to the plant population.

MATERIAL AND METHODS

Fields characterization

This study was conducted at commercial farm sites located in two distinguished regions of Brazil where maize is a usually grown. Each region has different maize growing seasons. The summer season was carried from October to March, in a subtropical region (latitude -24° 22’), 1036 m above sea level (Southern region of Brazil). Fall season (second growing season of the year, at Brazil’s Midwest region) was carried from February to July in a tropical region (latitude -21° 24’), 384 m above sea level. Both sites were rain fed and under non-tillage system. The soil type of the study sites was predominately dystrophic red latosol (Oxisol).

Long strips experiments

Three experiments were conducted during 2012 and 2013 and were referred as Field 1 (subtropical region, during summer 2012/2013); Field 2 (tropical region, second crop, during fall of 2013) and Field 3 (subtropical region, during summer 2013/2014). The treatments were composed by 10 different hybrids (Table 1) and five plant populations ranging from 20 to 40% below, and 20 to 40% above the local plant density (Table 2).

Table 1. Characteristics of maize hybrids used in each experimental field at different geographical regions.

	Hybrid name*	Company	Growing degree days**	Recommended Population (Plants ha^{-1})
Subtropical region (South Brazil) Fields 1 and 3	P30R50	Pioneer	760	70000 - 80000
	P30F53	Pioneer	766	70000 - 80000
	DKB 245	Dekalb	834	65000 - 70000
	DKB 240	Dekalb	826	75000 - 80000
	AS1656PRO2	Agroeste	820	65000 - 75000
	Status	Syngenta	875	60000 - 65000
Tropical region (Midwest Brazil) Field 2	AG 8500	Agroceres	860	50000 - 55000
	AG 9030	Agroceres	795	55000 - 65000
	AG 9040	Agroceres	790	55000 - 60000
	30A37	Agromen	810	50000 - 60000

* All used hybrids were single-cross maize hybrids; ** Growing degree days were calculated: [(maximum temperature + minimum temperature)/2]-10 summed for each day from emergence to flowering. Daily maximum temperatures greater than 30 ^{o}C result in use of 30 ^{o}C in formula. Minimum temperature less than 10 ^{o}C result in use of 10 ^{o}C.

Table 2. Geographical regions and corresponding plant population rates used for each region.

	Plant population rates (plants ha^{-1})				
	40% below	20% below	Standard population	20% above	40% above
Subtropical region (South Brazil)	42000	56000	70000	84000	98000
Tropical region (Midwest Brazil)	33000	44000	55000	66000	77000

Long experimental strips (6 m of width and around 700 m of length) were established across the field such that they cover at least high and low management zones. Each strip was planted in a fixed population rate with three replications along the field. Strips were planted side by side in 12 narrow rows of 0.5 m spacing in between rows. The total experimental area for each experiment ranged from 17 to 26 ha in size.

Quality of seed rate was obtained by measuring the average distance between plants after plant emerges. To determine the quality of seed rate, the frequency of spacing between plants was measured as referred in ISO 7256-1 standard (International Standardization Organization, 1984). Theoretical spacing between seeds, $x_{\mathrm{ref},}$ (planted length divided by number of seeds planted), was compared to actual spacing between plants. The frequency distribution of actual spacing was dived into three groups: (1) multiples [spacing between 0 to 0.5 times x_{ref}], lower than the theoretical spacing; (2) single [between 0.5 to 1.5 times x_{ref}], corresponding to the theoretical spacing; and (3) skip [spacing larges than 1.5 times x_{ref}], larger than theoretical spacing. The plant spacing classified in the second group is considered as a planting with correct spacing.

A hydraulic motor was installed in the farmers' planters as well as planting monitors in order to automate rate change using vacuum seed meter distributors. Harvesting was performed individually for each strip, in the direction of the slope to avoid errors associated with slippage and angle of combine. The harvester was equipped with a gravimetric yield monitor and the GPS receiver Starfire SF1 (John Deere®). Yield data were collected at 1 Hz frequency. The yield and moisture sensors were calibrated before harvest according to the manufacturer guidelines.

Management zone delineation

The attributes used to delineate MZ were apparent soil electrical conductivity (EC_a), yield maps (YM) and elevation. Apparent electrical conductivity data were collected with Veris3100® (Veris Technologies, Salina, KS, USA) at every 20 m for two depths, shallow 0 - 0.3 m and deep 0 - 0.9 m. The historical databases of yield maps were collected over the years by producers from yield monitor equipped combine. Elevation was obtained by combine onboard GPS, Starfire SF1 with 1Hz frequency of data acquisition.

All raw yields maps were cleaned by removing outliers and possible errors. Datasets were analyzed into a Geographic Information System (GIS) dedicated to precision agriculture, SSToolbox® (SST Development Group, Stillwater, OK, USA). Interpolated maps were created by using Inverse Distance Weighting on the raster format with pixels of 20x20 m.

The layers (yield maps, EC_a map, and elevation map) were normalized by the average of each map according to Molin (2002). After normalization, layers were joined, zones were delineated considering the overall average. Regions above 105% of the overall average were considered high production zones (HMZ), transition zone ranged from 95% - 105% of the average and low production zones (LMZ) were areas under 95% of the average (Figure 1).

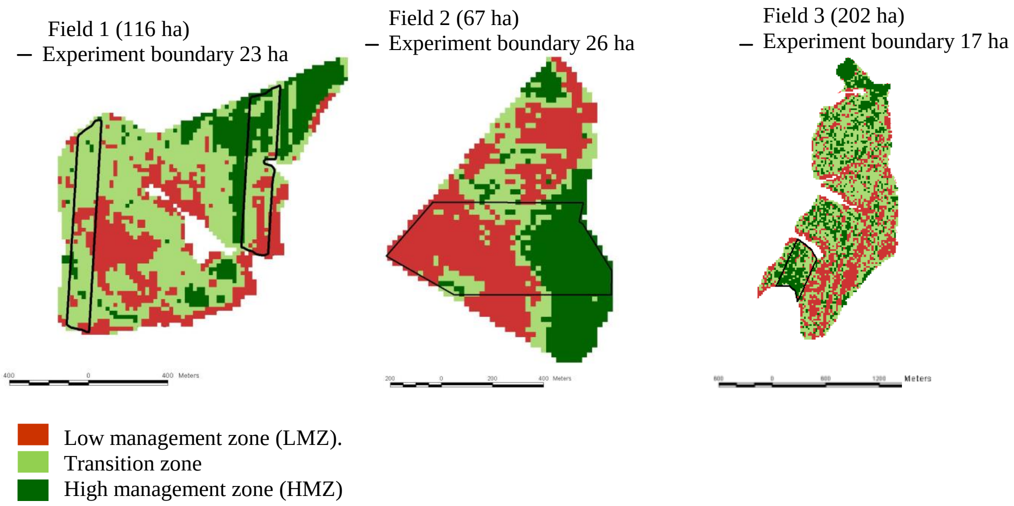

Figure 1. Management zone maps and experiment boundaries, as indicated with black polygons within each field.

Data analysis

Factor analyses were done to test three factors: plant population, hybrids and MZ. The main response variable was yield measured in kg ha^{-1}. Regression analyses and coefficient of determination were performed to predict the response of yield to the factors (management zones, plant populations and hybrids). A descriptive statistical analysis was done to characterize the quality of seed rate. Statistical software R® (R Development Core Team, 2012) was used for all statistical analyses.

RESULTS AND DISCUSSION

Rainfall was close to historical average for Field 1 and below historical average for Field 3, both fields belong to the same region (subtropical) but on different years (Figure 2a).

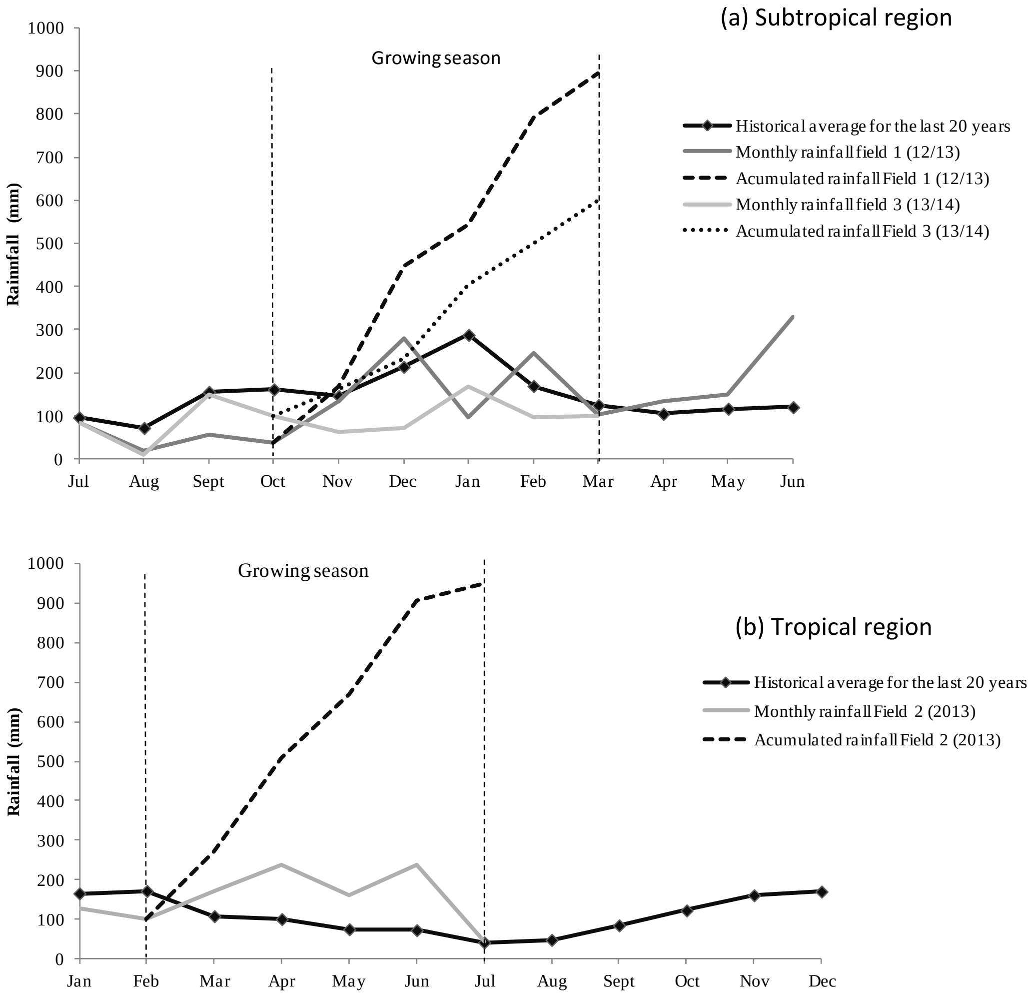

Figure 2. Monthly rainfall distribution for the experiments compared to historical average for the last 20 years, and accumulated rainfall during growing season; (a) Field 1 and Field 3 in a subtropical region; (b) Field 2 in a tropical region.

Harvest of Field 1 was delayed by weather instability, heavy rain and wind, harming the crop just before harvest. The second crop at tropical region (Field 2) is characterized by climatic risks, especially yield losses due to drought. Nevertheless, rainfall of Field 2 was above the historical average of the last 20 years, characterizing excellent condition for crop development (Figure 2b).

The quality of seed rate (indicator of spacing between plants) was close to 95% of single spacing in field 3 and was not affected by the seed rate used. The average CV was 28% and planting speed was 1.5 m s^{-1}. However, high seed rates reduced the number of single spacing in two of three fields analyzed (Figure 3).

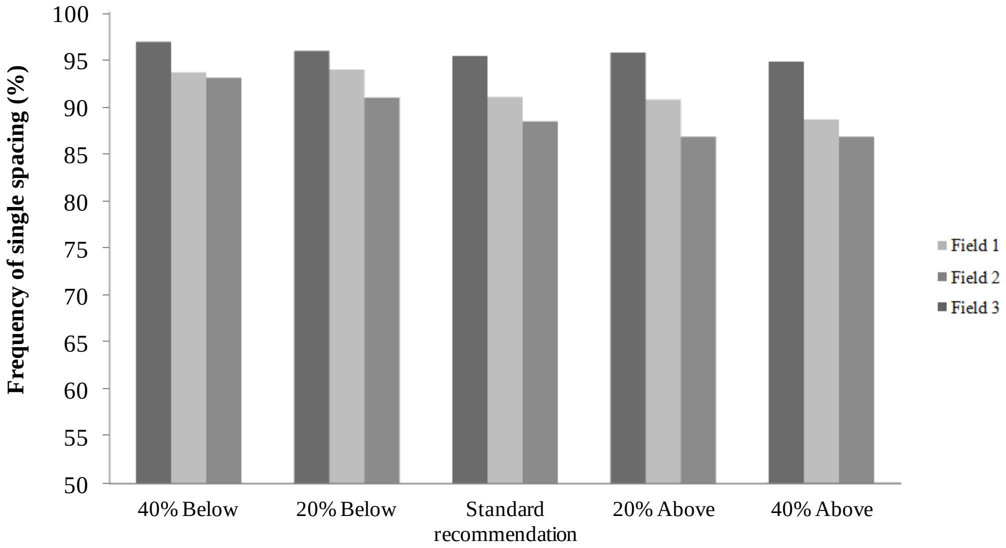

Figure 3. Frequency distribution of plant spacing for three different fields.

At Field 2, the frequency of single spacing decreased with plant population increase. The average CV for plant spacing was 34% and the planting speed was 2.0 m s^{-1}. At Field 1, the large amount of straws from no tillage system was an issue and hampered planting operation affecting the quality of seed rate.

The analysis of variance at Field 2 was significant ($P < 0.05$) for triple interaction between hybrids, plant population and MZ. The HMZ reached higher average yield compared to the LMZ and high populations reached higher yield regardless of MZ (Figure 4).

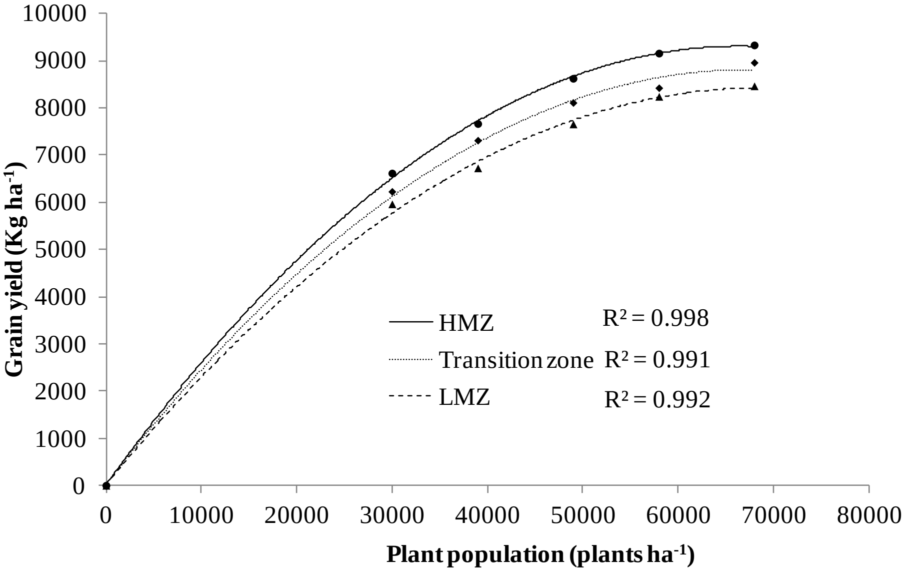

Figure 4. Effect of plant population density on maize grain yield in different MZ. Each symbol represents the average value of three replicates of four hybrids. Field 2, second crop in a tropical region.

The effect of zones was stronger for higher plant densities. It is probably caused by high plant population that leads to increased competition for natural resources (water and nutrients). When competition between plants is low both zones can perform well. However, LMZ has less available resources and did not reach the same yield of HMZ when the competition increases.

Regressions were fitted to model the performance of hybrids in relation to population in each MZ. The regressions were highly significant and the best models adjusted for population and yield were quadratic (Figure 5a; 5b).

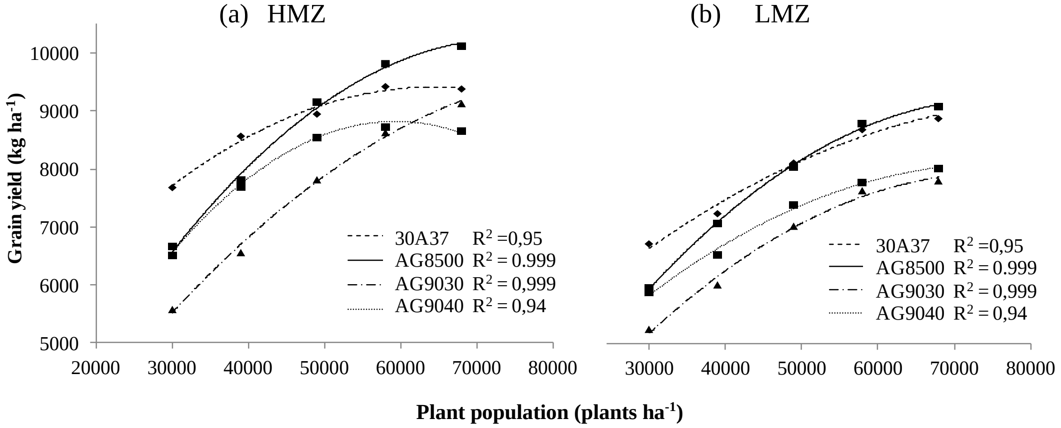

Figure 5. Effect of plant population on maize grain yield for following hybrids, 30A37, AG 8500, AG9030 and AG9040, and two management zones. (a) High management zone (HMZ); (b) Low management zone (LMZ). Each symbol represents the average value of three replicates. Field 2, second crop in a tropical region.

All treatments achieved higher yields in HMZ even though the percentage yield increase of plant population was almost the same for both zones, 41% for the HMZ and 42% for LMZ. The increased plant density from 30000 to 68000 pl ha^{-1} promoted an increase in yield of 63% for the hybrid AG9030 in HMZ, while in LMZ the increase was 49%. On the other hand, the hybrid 30A37 had only 27% of yield increase on average between zones. Shanahan et al., (2004) found that increasing plant population can increase yield by 50% in HMZ and 25% in LMZ.

Some hybrids were more responsive to both plant population and MZ than others. Therefore it is relevant to consider the interaction among environment, hybrids and populations within a crop field. The management zones influence the maximum attainable yield and the optimum population can vary between zones to reach the maximum grain yield. Such finding support to the concept of site-specific management of hybrids and plants populations.

Due to favorable climatic conditions, high populations had the best growth performance regardless of MZ. However, in years where rainfall rates are lower it is possible that higher populations cannot lead to higher yield.

There is risk related to high plant densities. The threshold between improve yield or loose yield is narrow. Strong wind and heavy rain can lead to plant lodging and damage yield. At Field 1, the experiment was lost due to heavy rainfall and high wind few days before harvest (Figure 6a, 6b). Even so, we analyzed the data obtained by the combine sensor and compared it with manual harvest to show the actual result of harvesting affected by adverse conditions (Figure 7).

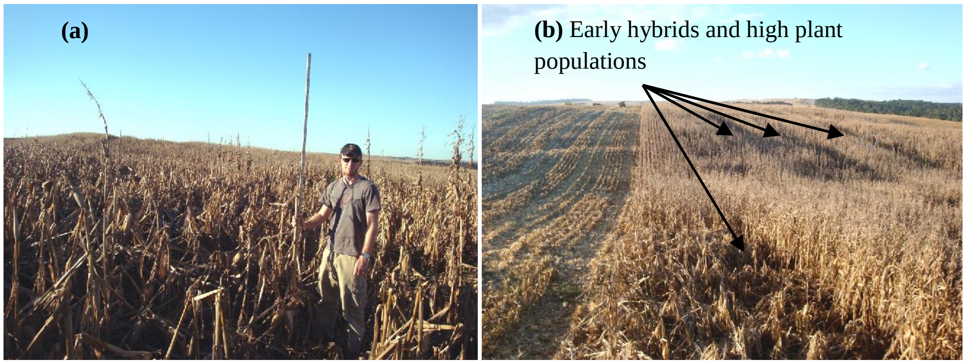

Figure 6. Partial view of the Field 1 at harvest. (a) Evidence of plant lodging; (b) Impacts on earlier hybrids and high plant populations. Field 1. Subtropical region.

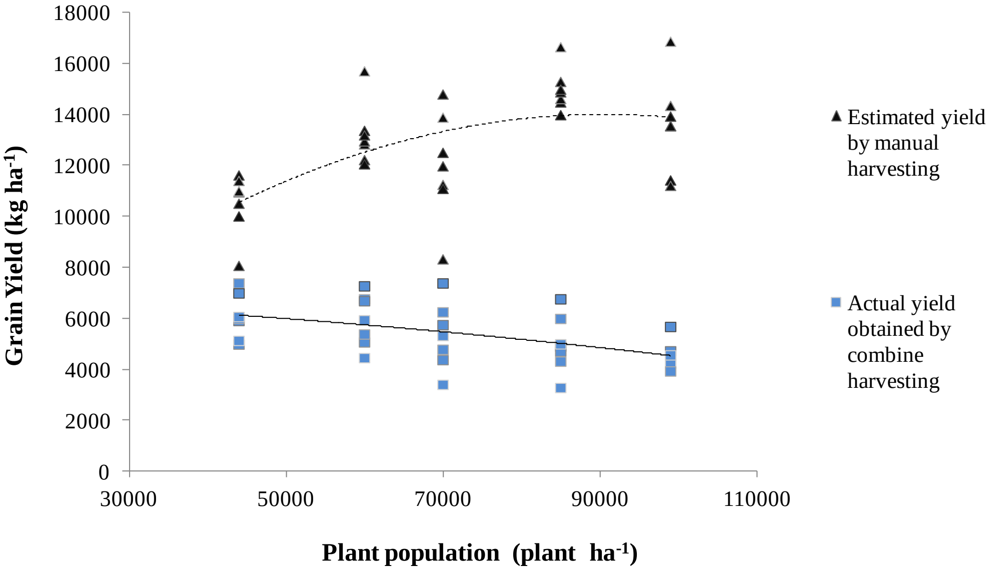

Figure 7. Effect of plant population on maize grain yield for combine harvesting affected by adverse climatic conditions and manual harvesting in Field 1 (subtropical region). Each triangle represents the average per hybrid over six data points (2 zones x 3 replications). Each square represents the average per hybrid over several data points from the yield map (2 zones x 3 replications). Solid and dashed lines illustrate regression functions.

Because of plant lodging, the amount of grain harvested decreased with increasing plant population for all genotypes tested. Nevertheless, manual harvesting made possible to see that yield increased with the population but these grains could no longer be harvested by the combine due to plant lodging. The yield recorded by the combine sensor was on average 42% lower than that estimated by manual sampling. Losses were higher for earlier cycle hybrids and higher densities of plants. At high densities (99000 plants ha^{-1}) losses reached 54%, while for lower densities (44000 plants ha^{-1}) losses were 23% (Figure 6b).

The analysis of variance at Field 3 was significant ($P < 0.05$) for zones and population. The interaction between zones and population was not statistically significant (Figure 8). Considering the good quality of seed rate achieved for this field and the drier growing season than normal, it was expected to observe a stronger zone effect. Indeed, when water is limiting crop growth, this emphasizes the differences between zones of higher and lower electrical conductivity, which often translates the organic matter content and the soil texture. On the other hand, lower rainfall may have also impacted yield, manly at higher populations, which resulted in lower amplitude on yield between plant populations.

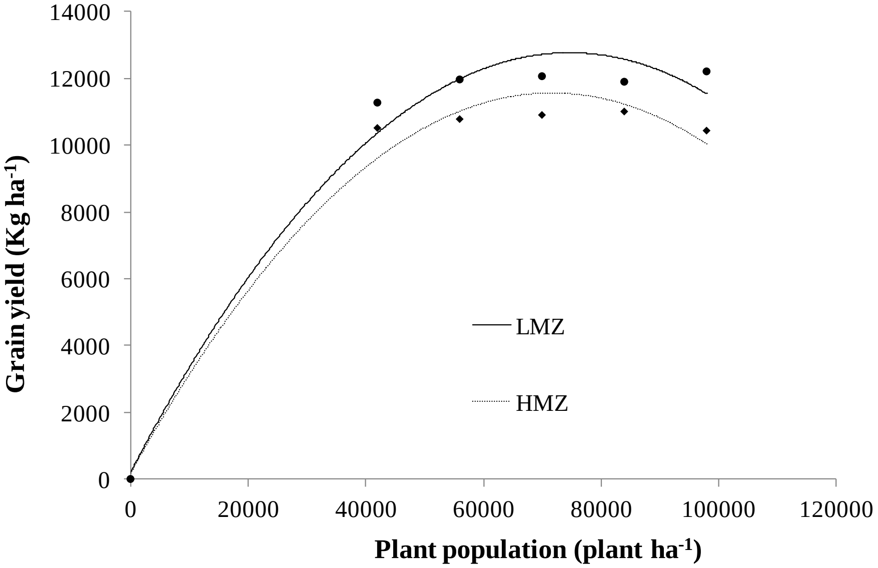

Figure 8. Effect of plant population density on maize grain yield in different management zones of Field 3 (subtropical region). Each symbol represents the average value over six hybrids.

Surprisingly LMZ reached significantly higher average yield compared to HMZ. These results may be related to the delineation of management zones. The zones in Field 3 were not as clear as the ones in Field 2. Management zone delineation is a first step and key factor to apply variable rate seeding. Although not tested in this study, when the zones pattern is not clear or it is not stable in time, potential benefits of VRS may decrease.

Therefore, it is not easy to establish a standard rule for variable rate seeding and zone delineation. Also, it is preferable that a high degree of variability exists within the field to delineate zones and implement variable rate seeding. In favorable years, when rain is not a limiting factor, yield can be improved using plant population above the usual recommendation in both management zones (HMZ and LMZ). Another important aspect is related to the performance of the planters, which may affect negatively the quality of seed rate (mainly in high populations), preventing higher yields. Even with results pointing that MZ influences plant population performance, caution is required to make inference about optimal plant population.

CONCLUSIONS

Management zones affecting the maximum attainable yield and the optimum population can vary between zones to reach the maximum grain yield.

There is no simple recommendation to achieve increase in yield by managing plant population. Even though variable rate seeding management has a different potential between regions and growing seasons, it appears as a good strategy to manage spatial variability.

It is necessary to point out that plant population performance by management zones depends on several factors, genotype (HB) (e.g., high responsiveness to population); environment (MZ) (e.g., water holding capacity) and management practices interaction (e.g., quality of seed rate to guaranty a regular spacing between plants).

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