THE INTERNATIONAL SOCIETY OF PRECISION AGRICULTURE PRESENTS THE
13th INTERNATIONAL CONFERENCE ON
PRECISION AGRICULTURE
July 31-August 4, 2016 • St. Louis, Missouri USA

Positioning strategy of maize hybrids adjusting plant population by management zones

Anselmi, A. A.[1]; Molin, J. P.[1]; Trevisan, R. G.[1]; Eitewein, M. T[1]; Colaço, A. F[1]

[1]University of São Paulo, 'Luiz de Queiroz' College of Agriculture, Biosystems Department, Piracicaba-SP, Brazil.

A paper from the Proceedings of the
13th International Conference on Precision Agriculture
July 31 – August 4, 2016
St. Louis, Missouri, USA

Abstract. *Choice of hybrid and accurate amount of plants per area determines grain yield and consequently net incomes. Local field adjustment in plant population 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 response of hybrids by levels of plant population across management zones (MZ). Six different hybrids and five rates of plant populations were analyzed starting with a local recommended seeding rate (55000 pl ha^{-1}) and offsetting it in 40% and 20% below and above this reference. Three field experiments were conducted in commercial fields from 2012 to 2015 in Brazil tropical region (Maracaju – MS) where corn is grown as a secondary crop following soybean. MZ were establish by cluster analysis of soil electrical conductivity (ECa), yield maps (YM) and elevation. Long strip tests with fix rate of plants were carry out crossing different zones. High yielding MZ reached higher average yield compared to the low yielding MZ. The optimal plant population can vary by up to 5743 pl ha^{-1} across MZ within the same field, depending on hybrid. Responsive hybrids to plant population are key to achieving positive results using variable rate seeding (VRS). Grain yield achieved by farmers in the second crop is limited by use of low plant population density, about 25% away from the optimal plant density. Years with lower yield averages have a narrow optimal plant population interval. Although, further studies are required to understand the potential of VRS within fields also considering levels of fertilization and different planting dates. However, to increase the adoption of VRS it is necessary to facilitate the process of MZ setting and optimal plant population choice.*

Keywords. *Management zones (MZ); variable rate seeding (VRS); corn yield; spatial variability*

Introduction

Recent advances in information technology have enabled farmers to register large amount of georeferenced data, in order to reduce uncertainty in decision making (National Reserarch Cunciliun, 1997; Blackmore, 2000). In Brazil yield maps (YM) are still poorly adopted, although they show the spatial and temporal variability of production that is important information for decision making (Molin, 2011) especially for the adoption of variable rate seeding (VRS).

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, it is necessary establish some parameters that can guide VRS strategy. Prior studies point out PA tools that have great potential to guide VRS. Historical yield maps (YM), soil sensing like apparent electrical conductivity maps (ECa) 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, Khosla et al., 2008). ECa is used in agriculture to qualitatively identify the spatial variability of soil attributes. Texture, moisture and salt content are the key factors that influence the action of ECa (Griffin, 2010; Sudduth et al., 1998). It is noteworthy that in soils with low concentration of salts the largest contribution of ECa is related to soil moisture and its texture (Brevik; Fenton, 2002)

Yield maps (YM) carry information from a large number of factors that affect the crop development and can be understood as a good parameter for comparison of the yield obtained in different parts of field (King et al., 2005). Due to the influence of atypical years on YM suggests associating maps soil attributes or a set of productivity maps over the years to minimize temporal variability order thus to define homogeneous areas (Godwin et al., 2003; Shanahan et al 2004;. King et al, 2005).

Due to increasing size of cultivated areas and spatial variability occurrence in the fields arises the need to measure and specialize fields' attributes to determine sizes smaller management units relative to the whole field (Khosla et al., 2008). Approaches to delimit MZ in a field may vary. Over the past two decades, physical and chemical soil properties have been used as the main factors to delimit the MZ and treat the spatial variability. However, to facilitate the environmental characterization process, information obtained from proximal sensors and remote sensors are increasingly used due to high density of data collected and agility during the data collection process (Khosla et al., 2010). In this sense, yield map sequences and ECa maps are considered as potentially cost-effective getting data methods for identifying and mapping MZ (King et al., 2005).

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).

Previous studies show that optimal plant population can vary ± 12000 pl ha^{-}1 (Abendroth, Elmore 2007). Shanahan et al. (2004) analyzed three years of productivity data (1997, 1998 and 1999), two corn hybrids and four levels of plant population in eastern Colorado (USA) and concluded that the optimal plant density can vary only ± 5000 pl ha^{-1} between zones. In southern Brazil, tests under different levels of water availability, shows the optimal plant population was the highest tested (110000 pl ha^{-1}) when there was no water restriction, which under normal condition of rainfall, the optimum population was 90000 pl ha^{-1}.

While modern hybrids tolerate higher plant population (Sangoi et al., 2002) and the optimal rate of plants per area can vary according the environmental potential, farmers need to adjust the rates of seeds in order to optimize yield and/or save seed costs looking for a more efficient production system. In this sence, this study aims to evaluate the response of hybrids by levels of plant population across MZ. Specifically, we evaluated if optimal plant population differ in each zone.

Material and Methods

This study was conducted in a commercial farm site located in the tropical region of Brazil (Maracaju – MS) where maize is grown as a secondary crop following soybean, at latitude -21°24', 384 m above sea level. Site was rain fed and under non-tillage system. The soil type of the study sites was predominately dystrophic red latosol (Oxisol).

Management zones delineation

The attributes used to delineate MZ were apparent soil electrical conductivity (ECa), 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 yield 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 (Figure 1).

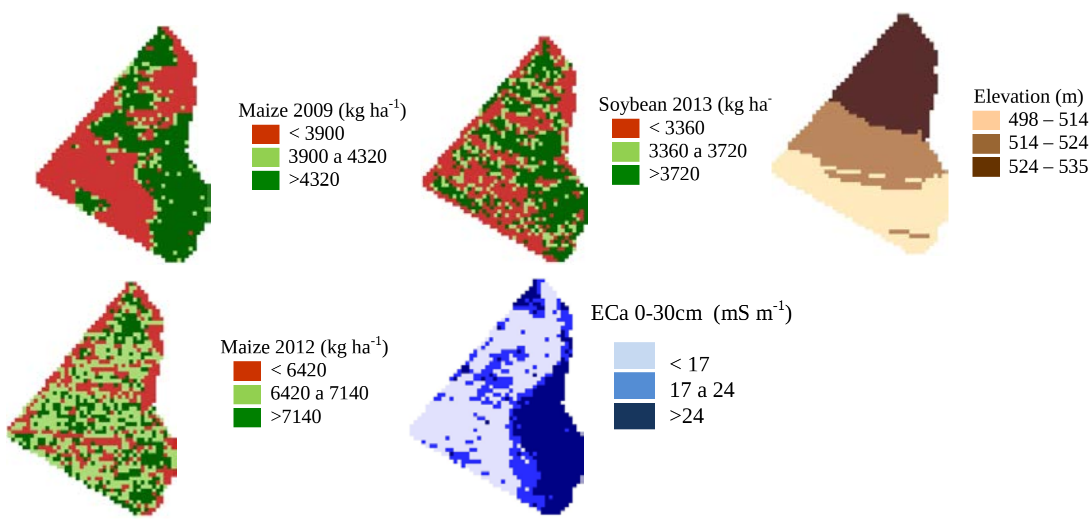

Figure 1. Collection of attributes layers as showed in each map of yield from different years and crops, ECa map and elevation map. Historical data base to delineate management zones.

The layers (yield maps, ECa map, and elevation map) were analysed by cluster analyses (Khosla, et al., 2008; Oortega; Santibanez, 2007; King, et al. 2005; Scheppers, et al., 2004) In this case, the groups were defined based on unsupervised clustering method by K-means, "Average Linkage". We previously established the formation of three clusters in order to simplify the practical interpretation of the results. The groups were characterized by High yielding management zone (HMZ), transition zone and Low yielding management zone (LMZ) (Figure 2).

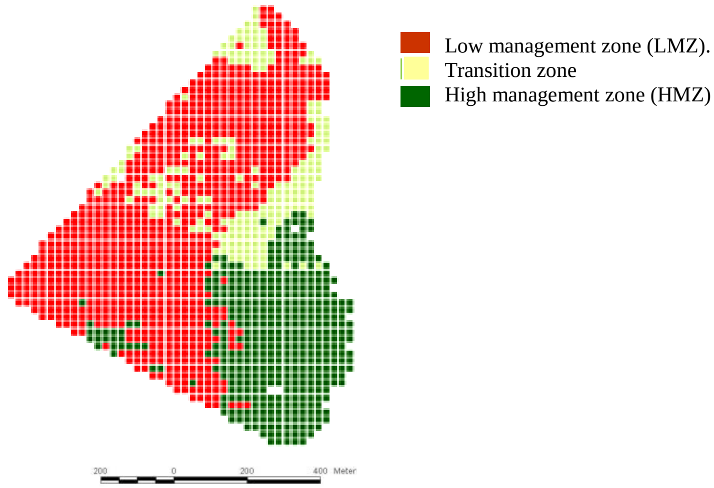

Figure 2. Management zones map.

Long strips experiments

Three experiments were conducted from 2013 to 2015 and the results were referred by years. The treatments were composed by four different hybrids (Table 1) and five rates of plant populations starting with a local standard seeding rate (55000 pl ha^{-1}) and offsetting it in 40% and 20% below above this reference (Table 2).

Table 1. Characteristics of maize hybrids.

Hybrid name*	Company	Growing degree days**	Recommended Population (Plants ha^{-1})
AG 8500	Sementes Agroceres	860	50000 - 55000
AG 9030	Sementes Agroceres	795	55000 - 65000
AG 9040	Sementes Agroceres	790	55000 - 60000
AG 8780	Sementes Agroceres	820	50000 - 55000
DKB 285	Dekalb	795	50000 - 60000
30A37	Morgan Sementes	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
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 yielding 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 was 26 ha in size.

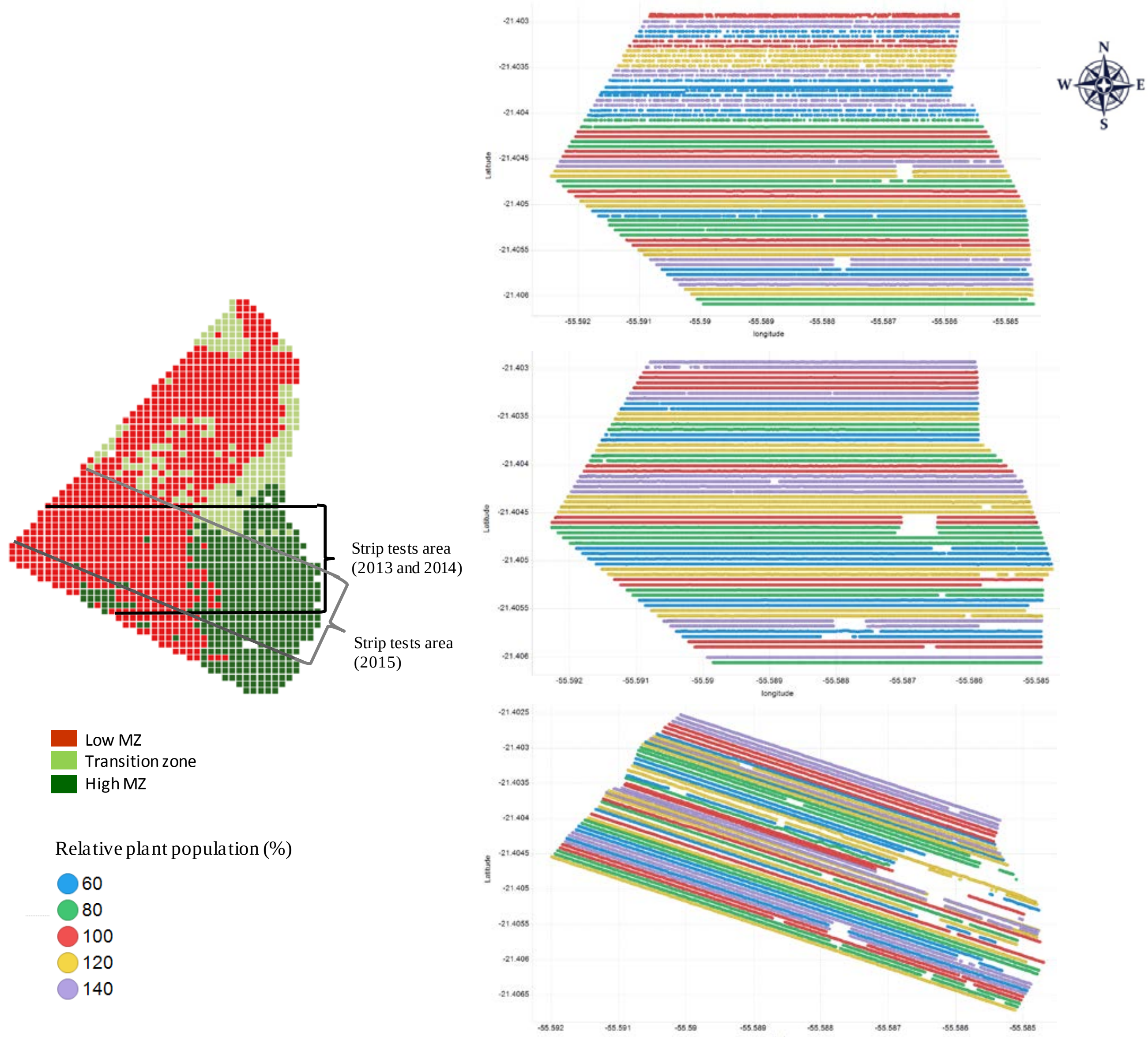

Figure 3. Field experiment design showing long strips of fix plant population rates across management zones.

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_{ref}, (planted length divided by number of desired seeds), 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' planter as well as planting monitor 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 misalignment of the 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.

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 and software Spotfire® (TIBCO software Inc, 2016) was used for the figures.

Results and discussion

The second crop at tropical region is characterized by climatic risks, especially yield losses due to drought periods. Nevertheless, rainfall was above the historical average of the last 20 years, characterizing excellent condition for crop development in 2013 and 2014, while in 2015 rainfall was close to the historical average.

The quality of longitudinal plant distribution vary depending on seed rate. Single spacing (indicator of right spacing between plants) was 86% on average, varying from 90% to 81%. High seed rates reduced the number of single spacing and the average reduction was 2.25% for increase of 10000 pl ha^{-1}.

The grouping method used was efficient in separate areas with different yield potential. The difference in productivity between HMZ and LMZ reached 1655.7 kg ha^{-1}. The change from the average of the field productivity reached 29% considering the plot as a whole. By subdividing field in management zones the CV of each zone reduced compared to the CV of the whole field. The ECa CV was 40%. The management zones setting method provided greater internal homogeneity to the zones compared to general average of the field (Table 3).

Table 3. Descriptive statistic of attributes layers (yield, ECa, and elevation) for management zones and whole field.

			Maize 2009 (Kg ha^{-1})	Maize 2012 (Kg ha^{-1})	ECa 0-30cm (mS m^{-1})	Elevation (m)
Sub Field	High MZ	average	5120.3	6901.4	29.8	512.0
		CV (%)	19	10	21	1.1
	Transition zone	average	4683.6	6555.0	26	526
		CV (%)	24	9	17	1
	Low MZ	average	3464.6	6796.6	14.6	521.0
		CV (%)	25	8	19	1.5
Whole Field		average	4098.3	6793.3	20.5	519.0
		CV (%)	29	9	40	1.6
		Maximum	7525.8	8669.4	45.6	535
		Minimum	1887.4	5056.4	7.7	497

Schepers et al. (2004) obtained productivity difference in results between MZ up to 25%. The same authors point out that in adverse years productivity gap may be less than 5% between MZ. In this case, the inconsistency in temporal variability can be a serious limiting for the adoption of different management strategies by zones.

There is a productivity increased with increasing plant population to a point where productivity is maximized from which productivity starts to decline. The best model adjusted for population and productivity was quadratic, regardless of the year or the MZ study. The difference in productivity between management zones is greater as increasing the plant population. When used low populations, 33000 pl ha^{-1} (40% below recommended for MS region) the difference between the ZM is less evident. Also, years with lower yield averages seems to have a narrow optimal plant population interval (Figure 4).

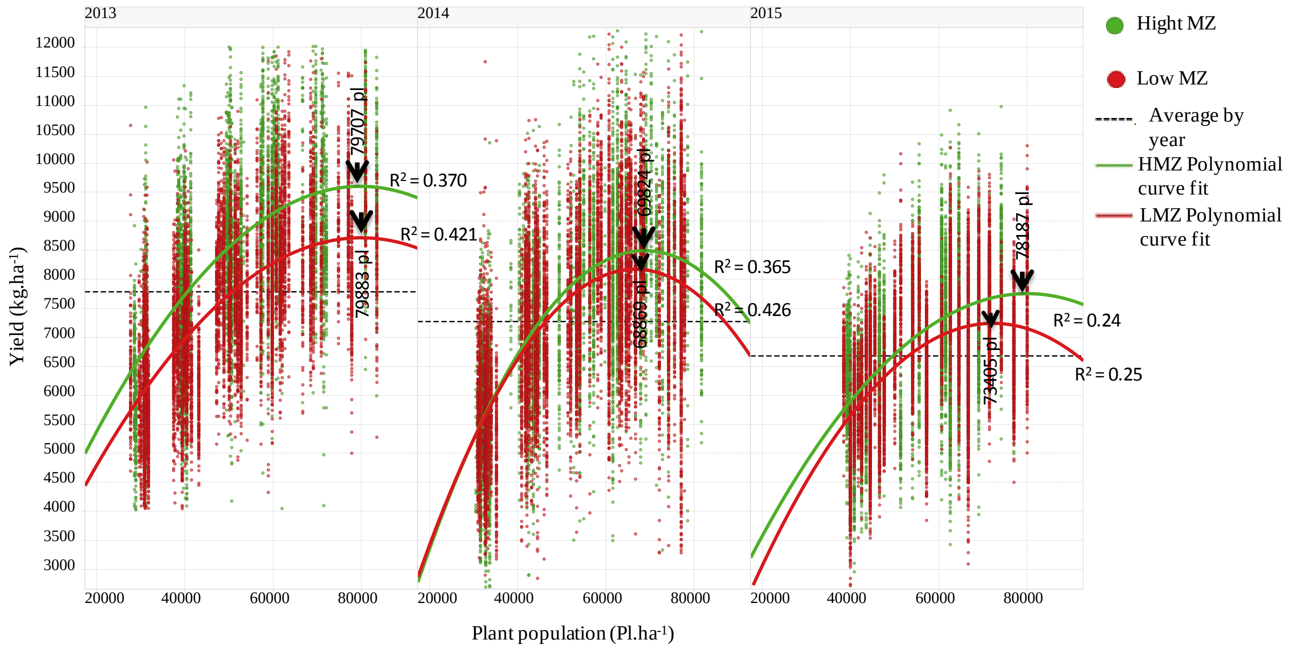

Figure 4. Effect of plant population density on maize grain yield in different years and two different management zones, High yielding management zone (HMZ) and Low yielding management zone (LMZ). Cloud of points represents four hybrids and three replicates in each year

There is an indication that, when the environment is more restrictive to productivity or years with lower productivity average, population interval that maximizes the productivity is narrower and the producer needs to be more assertive in density of plants for the best performance, on pain of lost productivity. This effect can be explained by the increase in the number of plants per area, increase demand for natural resources, water, light and nutrients (Sangoi, et al, 2002;. Duvick.1997), therefore the supply of these resources is lower in environments with lower potential.

Noteworthy is the gap that exists between the optimal plant density where productivity is maximized and plant density normally used by local farmers. The population practiced the second summer harvest (55000 pl ha^{-1}) may be up to 27% below the optimum population for the hybrid. The opportunity for gain in productivity due to the adjustment of the optimum population can reach 1272 kg ha^{-1}, however this gain depends on the responsiveness of the hybrid to the increase in population and the potential response to the environment.

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 5). Quadratic adjustments and significant coefficients of determination for population growth and corn yield are also presented by Sangoi et al. (2006) Shanahan et al. (2004), Tokatlidis; Koutroubas (2004), Sangoi et al, (2002) and Duvick (1997).

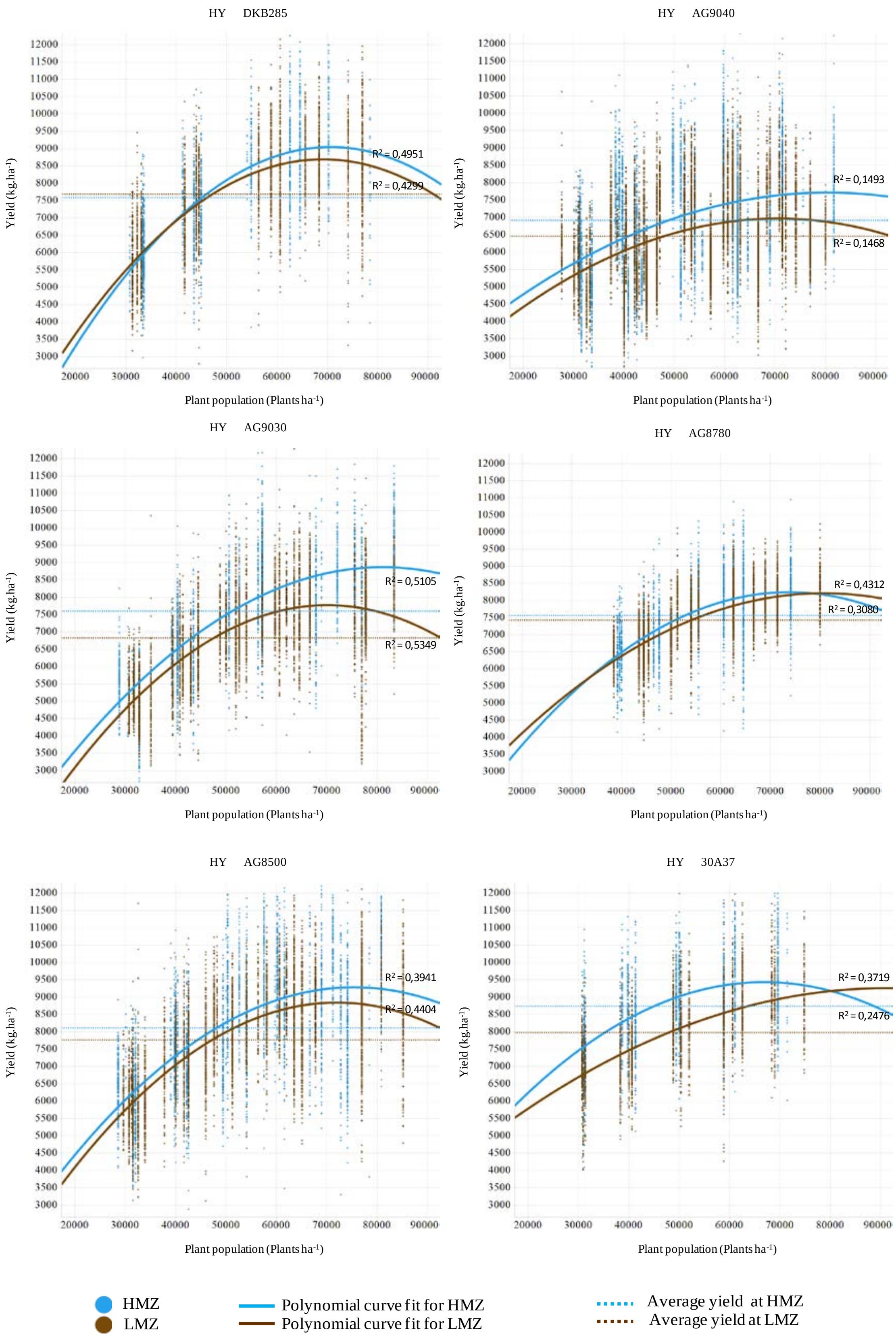

Figure 5. Effect of plant population density on maize grain yield for hybrids 30A37, AG8500, AG9030, AG8780, AG9040 and DKB285, and two different management zones, High yielding management zone (HMZ) and Low yielding management zone (LMZ). Cloud of points represents three replicates and three years of tests for hybrid AG9040, three replicates and two years of tests for hybrids AG8500 and AG9030, and three replicates and one year of test for hybrids 30A37, AG8780 and DKB285.

Different hybrids show a specific performance according plant density and MZ characteristics. Some hybrids were more responsive to plant population while others respond better to the environment. Hybrids such as AG9030, AG9040 and 30A37 showed the greatest differences in average productivity between areas. While hybrids like DKB285, AG9030 and AG8500 showed the highest productivity amplitudes in response to the increase in plant population per area. Hybrids responsive to plant population and to the environment are key to achieving positive results using variable rate seeding (VRS).

Certainly, management zones influence the maximum attainable and a generic recommendation for plant population can also restrict yield. Although the relative increase of productivity has been very similar to the environments tested in this study (HMZ and LMZ), there is a difference in the performance of hybrids environmental effect as increasing the plant population per area. At low population, close to 33000 pl ha^{-1} (40% below recommended for MS region), the productivity difference was significant ($P < 0.05$) only for hybrids AG9030 and 30A37.

Conclusions

Hybrids have a specific performance according to plant density and environment and it drives the potential benefit of site specific positioning of hybrids by VRS and MZ.

The optimal plant population can vary by up to 5743 pl ha^{-1} across MZ within the same field and for the same hybrid in a year growing season.

Grain yield achieved by farmers in the second crop is limited by use of low plant population density, about 20% away from the optimal plant density.

Further studies are required to understand the potential of VRS within fields also considering levels of fertilization and different planting dates. However, to increase the adoption of VRS it is necessary to facilitate the process of MZ setting and optimal plant population choice

References

Abendroth, L.; Elmore, R. 2007. Corn seeding rates and variable-rate seeding. 2007. http://www.ipm.iastate.edu/ipm/icm/2007/4-9/seedingrate.html (Accessed 01 February. 2016).

Blacmore, S. Developing the principles of Precision Farming. In: ICETS 2000: Proceedings of the ICETS (China Agricultural University, Beijing, China), 2000. p. 11-13.

Brevic, E.C.; Fenton, T.E. Influence of soil water content, clay, temperature, and carbonate minerals on electrical conductivity readings taken with an EM-38. Soil Survey Horizons, Dickinson, v.43, p. 9-13, 2002.

Duvick, D.N., What is yield? 1997. *In: Edmeades, G.O., et al. (Ed.), Developing Drought and Low N-tolerant maize.* CIMMYT, El Batan, Mexico, pp. 332–335. 1997

Godwin, R. J. et al. Precision Farming of Cereal Crops: a Review of a Six Year Experiment to develop Management Guidelines. Biosystems Engineering, v. 84, n. 4, p. 375-391, 2003.ISSN 1537-5110.

Horbe, T.A.N., Amado, T.J.C., Ferreira, A.O., Alba, P.J. 2013. Optimization of Corn Plant Population According to Management Zones in Southern Brazil. Precision Agriculture, v.14, p.450–465, 2013.

International Standardization Organization. 1984. Sowing equipment—Test methods—Part 1: Single seed drills (precision drills), 7256/1. Geneva, Switzerland: ISO.

Khosla, R. et al. 2008. A synthesis of multi-disciplinary research in precision agriculture: site-specific management zones in the semi-arid western Great Plains of the USA. Precision Agriculture, v.9, n.1, p. 85-100, 2008.

King, J. A. Bradley, R.I.; Dampney, P. M. R.; Lark, R. M.; Mayr, T. R.; Wheeler, H. C.. Mapping Potential Crop Management Zones within Fields: Use of Yield-map Series and Patterns of Soil Physical Properties Identified by Electromagnetic Induction Sensing. Precision Agriculture, Dordrecht, v. 6, n. 2, p. 167-181. 2005. ISSN 1385-2256. Disponível em: <http://dx.doi.org/10.1007/s11119-005-1033-4 >.

Molin, J.P. Agricultura de precisão: situação atual e perspectivas. In: Fancelli, A. L.; Dourado-Neto, D. Milho: estratégias de manejo para alta produtividade. Piracicaba: Editora, 2003. 208p.

Molin, J.P. Agricultura de precisão. In: Ministério da Agricultura, Pecuária e Abastecimento. Secretaria de Desenvolvimento Agropecuário e Cooperativismo. Agricultura de precisão:.ed. Brasília : MAPA, 2011. 36p. (boletim técnico.2)

National Research Council - Board on Agriculture, Committee on Assessing Crop Yield.Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management Washington, D. C : National Academy Press, 1997. 168p

Ortega, R.A.; Santibanez, O.A. Determination of management zones in corn (Zea mays L.) based on soil fertility. Computers and Electronics in Agriculture,cidade, v. 58, n. 1, p. 49-59, Aug 2007. ISSN 0168-1699. Disponível em: <GotoISI>://WOS:000247360600006>.

Sangoi, L., Gracietti, M.A., Rampazzo, C., Bianchetti, P. 2002. Response of Brazilian maize hybrids from different eras to changes in plant population. Field Crops Res. 79, 39–51. 2002.

Shanahan et al. Feasibility of Site-Specific Management of Corn Hybrids and Plant Densities in the Great Plains. 2004. Precision Agriculture 5: 207, 2004.

Schepers, A. R.; Shanahan, J. F.; Liebig, M. A.; Shepers, J. S.; Johnson, S. H.; Luchiari, A. Appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. Agronomy Journal, v. 96, n. 1, p. 195-203, Jan-Feb 2004. ISSN 0002-1962. Disponível em: <<Go to ISI>://WOS:000188437400022 >.

Sudduth, K. A., Kitchen, N. R., Drummond, S. T. 1998. Soil conductivity sensing on clayplan soil: Comparison of electromagnetic induction and direct methods. *In: 4th International Conference on Precision Agriculture.* p. 979–990. 1998

Tollenaar, M., Lee, E.A. 2002. Yield potential, yield stability and stress tolerance in maize. Field Crops Research, Amsterdam, v.75, p.161-169Tokatlidis, I. S.; Koutroubas, S.D. A review of maize hybrids' dependence on high plant populations and its implications for crop yield stability. Field Crop Research, v.88, p.103–114, 2004.