VARIABILITY IN WHEAT CROP PRODUCTION BASED ON MANAGEMENT ZONES IN HUMID PAMPAS REGION, ARGENTINA

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ABSTRACT

Crop productivity within fields is heterogeneous and it responds to the variation in crop patterns associated to crop management, previous crop management practices, as well as random and natural crop management factors. The methodologies for delimitation of management zones (MZ) within production fields differ based on their application objectives. The objectives of the present study were (i) to quantify the coincidence of defined areas based on 8 methodologies for zone delimitation, (ii) to quantify differences in yields and nitrogen use in wheat crops (*Triticum aestivum L.*) among MZ in relation to the 8 selected methodologies, and (iii) using one methodology selected in (ii) to quantify differences in wheat productivity in MZ in relation to N-fertilization levels (0 and 160 kg N ha-1). In 3 wheat production fields in the Humid Pampas region (Argentina) high (H), medium (M) and low (L) productivity MZ were defined based on previous crop yield mapping (YM), elevation, normalized vegetation index (NDVI) of crops, NDVI of Gramineae, previous crop management practices, soil mapping (SM), photo-interpretation of satellite images (PhSI), and standardized sums of YM and SM. Out of 23 analyzed combinations of zone delimitation methodologies, 5 displayed coincidences higher than 60 %. Wheat production was determined in each MZ based on 5 N fertilization levels. When MZ productivity increased, maximum yields were obtained with lower levels of N available (soil + fertilizer). Considering productivity and nitrogen use, higher differences among productivity MZ were found based on PhSI, productivity MZ H was higher than productivity MZ L in minimum and maximum yields (44 % and 7 %), and in N use efficiency (59 %). Productivity MZ H yield was a 26 and 15 % higher than productivity MZ L based on N fertilization, which was 0 and 160 kg of N ha-^{1}. In lower nitrogen levels, differences between MZ increased. Forty percent of the difference in wheat production between MZ H and MZ L decreased with the application of 160 kg N ha-^{1}.

Key words: Site-specific Management – Nitrogen – Wheat - Fertilization

INTRODUCTION

Crop productivity within fields is heterogeneous, and it responds to the variation in crop patterns caused by: (i) crop management, and previous crop management practices (human intervention), (ii) random natural factors (rainfall, hail, pest), and (iii) natural stable factors (soil types and edaphic processes, biological attributes). In the case of wheat crops (*Triticum aestivum L.*) its yields present a close relation to various soil properties, such as nutrient and organic matter contents, texture, and moisture retention capacity. Nitrogen is one of the nutrients that most frequently limits yields of wheat crops in the Pampas region (Argentina); and the levels of soil properties that display any variation within production fields are considered in diagnosing and recommending fertilization needs (Zubillaga *et al.* 1991 and 2006. Gregoret *et al*. 2005).

Whereas understanding yield variability and characterizing the factors that produce yields within relatively uniform defined areas allow for crop management strategic planning, the methodologies for defining these management zones (MZ) are not consistent. Among these the most frequently used methods are soil sampling and soil mapping, photo-interpretation of satellite images, altimetry, yield mapping, and the recognition of previous crop management practices. The methodologies for the definition of environments within production fields vary in accordance with their application objectives, such as studying nutrient supply variability in relation to soil types (Chang *et al*. 2003), minimizing production variability based on previous crop results (Taylor *et al.* 2007), or minimizing errors (or variability) when fertilization recommendations are formulated (Fleming *et al.* 2000. Scharf *et al.* 2005).

Therefore, differences in defining MZ could affect parameters considered for diagnosing and recommending, for instance, N fertilization needs, and crop response to this practice.

The objectives of the present study were (i) to quantify the coincidence of defined areas based on 8 methodologies for zone delimitation, (ii) to quantify differences in yield and nitrogen use in wheat crops (*Triticum aestivum L.*) between MZ in relation to the 8 selected methodologies, and (iii) based on one methodology selected in (ii) to quantify differences in wheat crop productivity between MZ in relation to N-fertilization levels (0 and 160 kg N ha-1).

MATERIALS AND METHODS

In the year 2007, in three wheat crop production fields with predominance of Typical Argiudolls (Field 1, 2 and 3) (Table 1) located in San Antonio de Areco (Humid Pampas, Argentina) MZ were defined by implementing different methodologies: (i) Cluster analysis of yield maps (YM) of previous wheat, soybean (*Glycine max L. Merrill*), and corn (*Zea mays L.*) crops (Table 2) (Kitchen *et al*. 2004), (ii) Soil Mappings (SM) (INTA 1965), (iii) Photo-interpretation of Satellite Images LandSat, and integrated vegetation indexes of crops described in table 3 (PhSI), (iv) Cluster analysis of Normalized Difference Vegetation Index (NDVI = RNIR–RR)/(RNIR+RR), where R_{NIR} is reflectance in the near infrared band and R_R is reflectance in the red band) of soybean, corn, and wheat (Table 4) (NDVIto), (v) Cluster analysis of NDVI of Gramineae (Table 4) (NDVIgra), (vi) management records based on data provided by the producer (MR), and (vii) Cluster analysis of altimetry and slope (ALT). In addition, a Standardized Sum (SS) was used integrating data from YM and SM, as described by Derby *et al.* (2007).

When yield maps were implemented (YM and SS), errors were removed in yield mapping development based on the proposal of Dobermann *et al.* (2004). The obtained results were grouped into zones H, M, and L based on their productivity estimated according to each of the definition methodologies, being High, Medium and Low, respectively. In MZ definition based on SM and MR, the MZ were two: H and L.

Table 1. Location of experimental sites, soil and management characteristics

Field	Location	Soil type	Variety	Surface (ha)	Year
Field 1	San Antonio de Areco	Typical Argiudoll	Don Mario Cronox	24	2007
Field 2	San Antonio de Areco	Typical Argiudoll	Don Mario Cronox	29	2007
Field 3	San Antonio de Areco	Typical Argiudoll	Don Mario Cronox	70	2007
Field 4	San Antonio de Areco	Typical Argiudoll	Don Mario Cronox	15	2008
Field 5	San Antonio de Areco	Typical Argiudoll	Don Mario Cronox	20	2008
Field 6	San Antonio de Areco	Typical Argiudoll	Don Mario Cronox	34	2008
Field 7	Baradero	Vertic Argiudoll	Don Mario Cronox	49	2008
Field 8	Pehuajó	Typic Hapludoll	Nidera Baguette 10	35	2008
Field 9	Pasteur	Typic Hapludoll	Nidera Baguette 10	30	2008
Field 10	Gonzales Chaves	Typical Argiudoll	Nidera Baguette 10	40	2008

To contrast the coincidence between methods for MZ definition, for each field a grid sample of 10 m side was implemented interpolating each data layer using the Inverse Distance Weighted, a maximum distance of 20 m, and a ratio distance of 0.4. In each square of the grid MZ coincidences were analyzed between methodologies. In each comparison between methodologies, the percentage of coincidences over the total points of the grid was estimated. In comparisons between definition methodologies that presented an uneven number in differentiated zones, H and M zones were grouped both under one zone H.

For processing georeferenced data of YM, PhSI, MR, SS, NDVIto, NDVIgra, ALT, and SM, SMS Basic 1.01 (Ag Leader Technol.) and GeoAgro GIS (GeoAgro) programs were implemented.

Table 2: Crop and harvest year in each yield map implemented for MZ definition in each of the 3 studied fields.

Yield Mapping		
Field 1	Field 2	Field 3
corn 2003	corn 2000	soybean 2004
wheat 2004	soybean 2003	wheat 04
corn 2006	corn 2006	
	soybean 2007	

Table 3: Crop month and year of LandSat images used in photo-interpreting of satellite images in the 3 analyzed fields. Date of images for which some fields have no detail of crop or are marked without crop (W/oC) the image was not used. W/oC = Image used without presence of developing crop.

Photo-interpretation of Satellite Images				
Month	Year	Field 1	Field 2	Field 3
January	2000			Corn
June	2000	W/oC		W/oC
September	2000			W/oC
November	2000	Corn		
January	2001	Corn	Soybean	Corn
February	2001	Corn	Soybean	Corn
March	2001	Corn	Soybean	Corn
April	2001	W/oC		W/oC
May	2001	W/oC	W/oC	W/oC
August	2001	W/oC		
September	2001			Wheat
October	2001	W/oC		Wheat
November	2001	Soybean		Wheat
December	2001	Soybean		
January	2002	Soybean		Soybean
April	2002	Soybean		Soybean
May	2002	W/oC	W/oC	
June	2002	W/oC		
August	2002		W/oC	
October	2002		W/oC	
December	2002	Corn	Soybean corn	
January	2003	Corn	Soybean corn	Sorghum corn
March	2003	Corn	Soybean corn	
October	2003		Corn Soybean	
December	2003	Soybean	Corn Soybean	
March	2007		Soybean	Soybean

In each field (Field 1, 2 and 3) and defined MZ based on the 8 methodologies (YM, PhSI, NDVIto, NDVIgra, SM, MR, ALT, SS) tests were conducted in randomized blocks with four repetitions, and 5 N fertilization treatments with a ratio of 0, 40, 80, 120 and 160 kg ha-1 of N-urea applied at crop sowing. Experimental units were 30 furrows by 10 m, and in every case these were fertilized at sowing with P 30 kg ha^{-1}. Crop production was determined based on physiological maturity by mechanical harvest of the central part of each experimental unit. Aerial dry matter contents, number of spikes, and thousand-kernel weight, number of grains, yield and protein-content in grains. In Zadoks et al. (1974). Flag leaves status was assessed with Minolta SPAD.

Grain production depending on applied N dosage was adjusted in each field based on quadratic models. Applied N levels to reach maximum yields (Nmax) were taken from the first derivative from corresponding quadratic models, and based on these data; maximum yields (MAXY) were estimated. Minimum yields (MINY) were taken from the ordinate intercept. N-use efficiency (NUE) was estimated based on the ratio between MAXY and MINY and the Nmax level.

Table 4. Harvest and crop year of each vegetation index (NDVI = (RNIR–RR)/(RNIR+RR), where R_{NIR} is reflectance in the near-infrared band and R_R is reflectance in the red band) implemented for management zone delimitation in each of the 3 study fields. + = vegetation index implemented for management zone definition in all crops. * = vegetation index implemented for management zone definition with gramineae.

Field 1	Field 2	Field 3
soybean 2002+	soybean 2001+	corn 2001+*
corn 2003+*	soybean 2003+	wheat 2001+*
soybean 2004+	corn 2004+*	soybean 2004+
wheat 2004+*	soybean 2005+	wheat 2004+*
corn 2006+*	corn 2006+*	soybean 2007+
soybean 2007+	soybean 2007+	

At sowing, composited soil samples were taken from the soils in each MZ (0 to 0.2 M) to determine total organic carbon, Bray and Kurtz I extractable phosphorous, water pH, and texture. N-NO_3 was determined to 0.4 m depth. Soil N-levels to 0.4 m depth were estimated based on N-NO_3 (0 to 0.2 + 0.2 to 0.4 m) contents and taking into account an apparent mean density of 1.3 Mg m^{-3}. Available N was estimated by the sum of soil N to 0.4 m depth, and fertilized N (Table 5).

Table 5. Summary of edaphic properties in 3 wheat crop production fields in Argiudolls. OC = organic carbon. Average data, more less Standard Deviation.

	Water pH	OC	Sand	Silt	Clay	N-NO3
		------------------------------------		(g kg^{-1})	-------------------------	(kg ha^{-1})
Field 1	553±1.32	17.39±4.61	131.8±35.5	549.3±133.9	266.4±63.5	37.2±2.72
Field 2	5.53±1.11	16.37±3.18	125.3±26.5	566.7±114.1	259.7±57.2	54.16±11.12
Field 3	6.18±0.41	15.65±2.42	165.9±22.1	546.7±38.6	287.4±46.3	33.75±6.80

Based on the studies conducted in fields 1, 2, and 3, one zone delimitation methodology was selected with higher differentiation of productivity parameters in wheat crops; and in 10 wheat production fields during 2007 and 2008 campaigns (Table 1), MZ of H, M, and L productivity were defined.

In each field and MZ, tests were conducted in randomized blocks with four repetitions, and 5 N fertilization treatments with a ratio of 0, 40, 80, 120 and 160 kg ha-1 of N-urea applied at crop sowing. Experimental units were 30 furrows by 10 m, and in every case these were fertilized at sowing with P 30 kg ha^{-1}. Crop production was determined based on physiological maturity by mechanical harvest of the central part of each experimental unit. Aerial dry matter contents, number of spikes, and thousand-kernel weight, number of grains, yield and protein-content in grains. In Zadoks *et al* (1974). Flag leaves status was assessed with Minolta SPAD.

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Table 6: Summary of edaphic properties in 10 wheat production fields in the subhumid central pampas region. e-P= extractable Phosphorous. OC= organic carbon. Average data more less standard deviation.

e-P	Water pH	OC	Sand	Silt	Clay	N NO_3 0 to 0.4 m
(mg kg^{-1})		------------------------------- -----		(g kg^{-1})	--------------------------	(kg ha^{-1})
16.7±4.2	5.9±0.3	18.0±2.5	142.3±18.8	587.5±24.7	270.1±11.8	41.3±8.5

The statistic analysis contemplated different models in accordance with the objectives of the study: (i) in order to analyze the degree of coincidence of definition methodologies, a 3 repetition model (fields) and one main factor (delimitation methods) was considered, (ii) for studying differences in yield and nitrogen use in relation to definition methodologies and productivity zones, a randomized block design with 3 repetitions and 2 main factors: H, M and L productivity MZ, and delimitation methodologies (YM, (YM, PhISI, NDVIto, NDVIgra, SM, MR, ALT, SS) were considered; and (iii) when studying productivity differences based on management zones with different levels of applied N, the model taken into account was randomized blocks design with 10 repetitions (sites), and one main factor MZ of H, M and L productivity. In all cases the protected ANOVA ($p<0.10$) and Fisher's test for mean differences (InfoStat 2003) were used.

RESULTS

The coincidence between methodologies varied between 12.9 and 98.1 %, with an average of 57.3, 41.6, and 47.2 % in the fields 1, 2, and 3, respectively. The selected methodology was significant in MZ delimitation, only 5 out of 23 combinations presented in average coincidences higher than 60 % (Table 7).

Wheat crop yields ranged between 600 and 6091 kg ha^{-1}, with an average of 3668 and 3223 kg ha^{-1} during the 2007 and 2008 campaign, respectively. The number of grains and yields presented in all fields and MZ responses of decreasing increases, adjusted to quadratic models based on available N levels.

On average for all methodologies, MAXY were 20 and 8 % higher in MZ H and M, than in MZ L; while the MINY in the same management zones were also higher in MZ L in a 30 and a 16 %, respectively (Table 8). When MZ productivity increased, maximum yields were obtained with lower levels of N fertilization (Table 8). Higher levels of N fertilization were required to reach the MAXY in MZ defined based on SS. The MAXY were higher in MZ H than in MZ L defined by MR. The definitions based on SI, NDVIto, and YM determined zones with differences in the MINY; and in the case of PhSI and NDVIgra, zones with differences in the NUE; while YM defined zones determined zones with differences in the MAXY. These three methodologies (PhSI, NDVIto, and YM) are the ones that allowed the determination of higher differences between management zones in relation to the analyzed properties in wheat crop production. The use of photo-interpretation of satellite images made it possible to differenciate with lower levels of error productivity zones associated to the 4 properties of wheat crop productivity determined in the present study (NEU, Nmax, MINY, and MAXY).

By implementing PhSI the variations in crop productivity between MZ varied in relation to applied N level at fertilization time. The MZ H presented higher number of spikes (>25%), dry matter (>29%), grains (>26%) and yield (>887 kg ha^{-1}) than MZ L, and higher dry matter than (>20%) ZM M when it was not fertilized with nitrogen. When the crop was fertilized 160 kg de N ha^{-1}, the number of grains of MZ H were higher (>22%) than in MZ L. When MZ M was not fertilized with nitrogen, it presented a higher number of spikes (>20%), grains (>21%) and yield (>17%) than MZ L (Table 9).

DISCUSSION

Given the conditions of the present study it can be observed that the coincidences of the covered areas by MZ within 3 wheat crop production fields based on 8 methodologies of delimitation were in average 48.7 %. The coincidence differs depending on the methodology for delimitation, and in 5 out of 23 studied combinations degrees of similarities were determined on an average higher than 60 %. There are few studies in which coincidence between delimitation methodologies is contrasted. The absence of differences in similarities between methods was determined by Derby *et al*. (2007) using methods of definition based on classification of bare soil color data, and cluster analysis of soil N, apparent electric conductivity, yield and elevation in North Dakota in artificially irrigated fields. Khosla *et al*. (2006) in the Northeast Region of Colorado contrasted two methods of integrated data with a witness (three year corn crop yield cluster analysis) finding differences that supported a method which integrated data based on images from a crop less soil, altimetry, and knowledge of the producer compared to images of soil without vegetation, organic carbon contents, cation exchange capacity, texture, and crop yield.

Table 7. Coincidence (%) between methodologies for MZ delimitation. Different letters show differences (LSD Fisher, p<0.10) between comparisons. YM= Yield mapping SM= Soil Mapping; PhSI= Photo-interpretation of Satellite images, SS= Standardized Sums of SM and YM; MR= Management Records, ALT=

Altimetry, NDVIto= Normalized Difference Vegetation Index used in the delimitation of MZ with all crops. NDVIgra= Normalized Difference Vegetation Index used in the delimitation of MZ with Gramineae crops.

Methodologies	Coincidence (%)
SM - SS	92.1 A
SM - SI	71.5 AB
SM - NDVIto	69.4 ABC
NDVIto – NDVIgra	66.3 BCD
SM - ALT	63.3 BCDE
ALT - SI	58.8 BCDEF
SM - YM	57.6 BCDEFG
SM - NDVIgra	56.9 BCDEFGH
ALT - SS	51.6 BCDEFGHI
SI - SS	49.7 BCDEFGHI
YM - SI	49.2 BCDEFGHI
NDVIto - YM	47.7 CDEFGHI
NDVIgra - YM	47.3 CDEFGHI
NDVIto - SI	46.0 CDEFGHI
YM - ALT	45.8 DEFGHI
MR- SS	45.6 DEFGHI
NDVIto - SS	45.0 DEFGHI
MR - ALT	43.5 DEFGHI
SM - MR	43.3 DEFGHI
MR - YM	40.0 EFGHI
MR - NDVIto	39.5 FGHI
NDVIto - ALT	39.2 FGHI
MR - SS	38.1 FGHI
HM - SI	36.4 FGHI
NDVIgra - SI	35.9 FGHI
NDVIgra - ALT	34.6 GHI
NDVIgra - SE	34.1 HI
MR - NDVIgra	31.2 I

Table 8: Wheat yields and response parameters to N fertilization in the humid pampas (Argentina) based on 8 methodologies of MZ definition (MZ). Different letters show differences (LSD Fisher, p<0.10) between MZ based on delimitation methods.

MZ	NEU (kg grain kg Nf^{-1})		N Max Dosis	Minimum Yield		Maximum Yield	
			------ (kg ha^{-1}) ------				
			Altimetry				
High	4.82		133	3282		3936	
Medium	7.01		137	2830		3827	
Low	8.74		155	2370		3698	
p	*0.55*		*0.23*	*0.49*		*0.61*	
			Previous Crop Management				
High	4.46		147	3460		4152	A
Low	7.85		146	2591		3714	B
p	*0.49*		*0.88*	*0.38*		*0.08*	
			Photo-interpretation of Satellite Images				
High	4.29	B	129	3435	A	4000	
Medium	6.10	AB	144	3156	A	4020	
Low	10.53	A	182	1935	B	3708	
p	*0.08*		*0.11*	*0.03*		*0.31*	
			Yield Mapping				
High	4.01		114	3656	A	4187	A
Medium	7.30		130	2890	AB	3875	AB
Low	9.48		199	2129	B	3683	B
p	*0.30*		*0.26*	*0.08*		*0.07*	
			Soil Mapping				
High	3.80		140	3431		3952	

Low	9.13		162		2442		3851
p	*0.20*		*0.16*		*0.28*		*0.75*
			NDVIgra				
High	6.55		140		2942		3873
Medium	4.17		122		3522		4043
Low	9.24		193		2204		3701
p	*0.21*		*0.43*		*0.12*		*0.26*
			NDVIto				
High	6.68	AB	135		2979	AB	3884
Medium	3.70	B	130		3557	A	4032
Low	10.35	A	166		1986	B	3665
p	*0.05*		*0.36*		*0.06*		*0.24*
			Standardized Sum				
High	3.53		124	B	3486		3965
Medium	6.99		134	B	2893		3841
Low	8.89		176	A	2288		3722
p	*0.26*		*0.05*		*0.26*		*0.58*

The differences in productivity within production fields respond to detectable patterns based on the application of different delimitation methodologies. These findings are coincidental to those described in other studies (Fleming *et al.* 2000. Scharf *et al.* 2005. Taylor *et al*. 2007), and would respond to the occurrence of differences on MZ edaphic properties as well as to other attributes reflected in previous crop productivity determined by yield mapping, photo-interpretation of satellite images, and knowledge of previous management practices. Nonetheless, the use of photo-interpretation of satellite images facilitates the differentiation of productivity zones and N use in wheat crops with a lower level of errors. The data analyzed is not sufficient to generalize grouping among production fields, being convenient analyzing individually the environments when N fertilization recommendations are formulated.

The response of wheat crops to nitrogen supply in terms of fertilization doses responded to models of decreasing increases, obtaining maximum yields with lower doses of N fertilization in areas of higher productivity rather than in those of lower yields. This behavior would indicate that part of yield variability between management zones can be better explained in relation to N availability and differs from Bongiovanni et al. (2007) suggestion to Manfredi (Córdoba) where given the minor production the applicable N dosis would have to be lower than in higher yield areas. Low production sites could have also presented lower indexes of mineralization that would limit the soil's natural occurring N supply (Zubillaga et al. 2005).

Table 9. Crop properties in different productivity wheat zones in the humid pampas (Argentina) based on two levels of fertilized nitrogen: without fertilization and with 160 kg of N ha^{-1}. TKW= Thousand-kernel weight. HI= Harvest index. Different letters show differences between productivity zones (LSD Fisher, p<0.10).

	Management Zones			
	High Productivity	Medium Productivity	Low Productivity	*p* Value
	Without N fertilization			

Spikes	(spikes.m^{-2})	393 A	369 A	295 B	0.01
Dry Matter	(g.m^{-2})	883 A	706 B	625 B	0.06
Grains	(grains.m^{-2})	10628 A	10010 A	7833 B	0.01
TKW	(g)	31.2	31.5	30.7	0.87
Yield	(kg.ha^{-1})	3493 A	3170 A	2606 B	0.01
HI		0.34	0.36	0.32	0.24
Spad N160		40.3	40.7	40.4	0.94
Protein	(g.kg^{-1})	111.6	105.9	109.9	0.29
N fertilization 160 kg of N.ha^{-1}					
Spikes	(spikes.m^{-2})	454	379	355	0.19
Dry Matter	(g.m^{-2})	974	747	706	0.21
Grains	(grains.m^{-2})	12530 A	11272 AB	9783 B	0.07
TKW	(g)	27.8	29.25	28.6	0.65
Yield	(kg.ha^{-1})	3870	3591	3318	0.25
HI		0.29	0.32	0.28	0.48
Spad N160		44.7	43.3	45.7	0.37
Protein	(g.kg^{-1})	131.8	132.4	135.5	0.81

CONCLUSIONS

The data presented suggests the relevance of the selection of delimitation methodology based on the objective for delimitation of management zones. When the objective is to define zones differing in productivity and nitrogen use in wheat crops, the analyzed methodology that is most suitable for zone delimitation is photo-interpretation of satellite images.

When MZ productivity in defined zones increases, N needs in terms of doses of fertilization decrease. Therefore, the instrumentation of strategies for diagnosing and recommending N fertilization needs in wheat crops based on photo-interpretation of satellite images defined zones would be a recommended strategy for the efficient use of this nutrient, improving its productive return, and reducing the environmental risks associated with its overdosing.

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