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Agronomic performance of maize with different fertilizers in winter crop succession

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The aim of this study was to evaluate the effect of temperate climate plant species and two different types of fertilizer on the yield components related to summer maize crop productivity in an area with a history of 5 years of soybean/black oat succession cropping in a no-tillage system in ArenitoCaiua, Northwestern Paraná State, Brazil. The experiment was conducted in split blocks, with 6 blocks and 16 treatments (8 winter crops and 2 types of fertilizer). The maize hybrid used was DKB 390PRO. The following yield components were evaluated: plant height and height of first-ear insertion; final plant population; ear length and diameter; number of rows per ear, number of grains per row and number of grains per ear; weight of 100 grains and yield. It can be concluded that all succession systems are agronomically viable for maize production in the ArenitoCaiua region, in conjunction with adequate crop nutrition management, especially the winter common vetch/summer maize succession system fertilized with poultry litter which produced the best maize yield.

Key words: Green manure, poultry litter, commercial formulation, yield component, *Zea mays*.

INTRODUCTION

The production of maize (*Zea mays* L.) is one of the most important economic activities in Brazilian agribusiness due to its various forms of use, ranging from human and animal nutrition to high technology industrial uses, as well as its importance in social and economic terms. In terms of primary production alone, maize accounts for around 37% of the grain produced in Brazil (Brasil, 2007).

The Brazilian 2010/2011 summer maize crop occupied an area of 7.92 million hectares, producing 35.93 million metric tons of grain. The State of Paraná is the main Brazilian producer, accounting for 9.70% of the cropping area (768,000 ha) and 16.83% of domestic yield (6.05 million metric tons) (CONAB, 2012). However, the average maize yield figure of 4,500 kg ha^{-1} (CONAB, 2012) is considered low when compared to other producer countries such as Argentina (7,800 kg ha^{-1}) and the United States (10,000 kg ha^{-1}) (FAO, 2012).

Over and above the favorable climatic conditions and the production system used, the optimization of Brazil's maize production potential depends on adequate soil fertility. Nitrogenated fertilizer plays an important role, since nitrogen is one of the most efficient nutrients for

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boosting maize yield (Kappes et al., 2009).

With the advent of agricultural systems aimed at sustainable soil management, conservation practices have become more widespread. The no-tillage system is one of the best alternatives for conserving natural resources, in conjunction with crop rotation and green manures that increase organic matter content, helping conserve and improve the structure of the soil (Calegari et al., 2006). These management strategies optimize fertilizer use since they increase biological activity in the soil (Calegari et al., 2006). In addition, the combined use of mineral fertilizers and green manure is aimed at conserving the environment while maintaining high crop yields (Arf et al., 1999).

Results indicate that legumes are capable of supplying significant quantities of nitrogen to maize planted in succession, due to their capacity to biologically fix atmospheric nitrogen and the high decomposition rate of crop residues (Aita et al., 2001; Heinrichs et al., 2001). The same applies to oil seed radish (*Raphanus sativus* L. var. *oleiferus* Metzg.), which has a high capacity for nitrogen cycling (Amado et al., 2002), and oats (genus *Avena* L.) that accumulate a lower quantity of nitrogen in the plant biomass and subsequently release it slowly after harvesting (Aita et al., 2001).

Therefore, the aim of this study was to examine the effects of temperate climate plant species and 2 fertilizers on the yield components related to the productivity of the summer maize crop in an area with a history of 5 years of soybean/black oat succession in a no-tillage system in the ArenitoCaiua region, northwestern Paraná State, Brazil.

MATERIALS AND METHODS

The experiment was conducted during the 2010/2011 growing season on the Experimental Farm at the State University of Maringá in Umuarama, Paraná (23º47'25"S; 53º15'32"W; elevation: 405 m). The Köppen climate classification is Cfa (humid subtropical). The soil in the experimental area is typical dystrophic acrisol (Brazilian classification: *Argissolo vermelho* Distrofico) with a sandy texture. Chemical soil analysis in the 0 to 20 cm layer presented the following results: pH (H_2O) 5.0; organic matter 15 g kg^{-1}; P (Mehlich-1) and K 3.5 and 78 mg dm^{-3}; Ca 1.0 cmol$_c$ dm^{-3}; Mg 0.4 cmol$_c$ dm^{-3}; H+Al 3.2 cmol$_c$ dm^{-3}; SB 49 cmol$_c$ dm^{-3}; CEC 4.8 cmol$_c$ dm^{-3} and V = 34%.

A split-block experimental design was used, with 6 blocks. The factor A was arranged for 6 winter crops, a plot of intercropped black oats + oilseed radish, and a fallow plot. The 6 winter crops were as follows: black oats 'IAPAR 61 Ibiporã' (*Avena strigosa* Schreb.), chickpea (*Lathyrussativus* L.), common vetch (*Vicia sativa* L.), common bean 'IPR 139' (*Phaseolus vulgaris* L.), oilseed radish 'IPR 116' (*R. sativus* L. var. *oleiferus* Metzg.) and wheat 'CD 117' (*Triticum aestivum* L.). The factor B was arranged so that 2 fertilizers [organic (poultry litter) and chemical (commercial formula)] could be used. The experiment therefore consisted of 96 experimental units (8 factors A × 2 factors B × 6 blocks). Each plot had an area of 5.00 m × 2.70 m.

The winter crops were sown on May 20, 2010, left to grow for 100 days and then cleared. On October 2, 2010, the maize was sown (DKB 390PRO early cycle hybrid), with a row spacing of 0.90 m and density of 65,000 plants per hectare. Basic fertilizer application consisted of 4,000 kg ha^{-1} of poultry litter and 650 kg ha^{-1} of 04-28-16 commercial formula (N-P_2O_5-K_2O), for the respective treatments. The plots treated with the commercial formula also received nitrogen (110 kg ha^{-1}) in the form of urea as top dressing in 3 applications (phenological stages V_3, V_7 and V_{11}). During the experiment, the plants were irrigated by a sprinkler system and weeds controlled by 2 manual clearing operations at 18 and 39 days after emergence of the maize.

The following characteristics were evaluated in each plot: plant height; height offirst-ear insertion; final stand; ear length and diameter; number of rows per ear, number of grains per row and number of grains per ear; weight of 100 grains and grain yield.

For each plot, the plant height and the height offirst-ear insertion were verified on ten plants in full bloom, measuring the distance between the soil surface and first leaf, and the soil surface and height first-ear insertion, respectively. Ear length and diameter were measured on 10 ears collected at random in the useable area (2.70 m²) in each plot, measuring the length with a graduated ruler and the diameter of the middle third with a digital pachymeter. The same 10 ears were used to determine the number of rows, grains per row and grains per ear. The weight of 100 grains was assessed using 2 samples, dried in a fan-assisted oven at a constant temperature of 65ºC for 72 h. For grain yield, the ears in the area used for the final population count were collected manually and after hulling, the grains were weighed to calculate yield (kg ha^{-1}) based on moisture content of 13%.

The data obtained were subjected to analysis of variance and the treatment means compared by Tukey test at 5% and 1% probability, using the Agroestat statistics program (Barbosa and Maldonado Junior, 2011).

RESULTS AND DISCUSSION

Data analysis showed that the winter crops, fertilizers and winter crop × fertilizer interaction had almost no effect on plant height, height first-ear insertion and ear length and diameter. However, winter crop × fertilizer interaction did affect ear diameter (Table 1).

Average plant and ear-insertion heights (Table 1) were around 40 and 30 cm lower than those observed by Shioga et al. (2012) in the state-wide evaluation of maize in the 2011/2012 growing season, involving the cultivation of the DKB 390PRO hybrid at an average population density of 64, 000 plants per hectareunder different edaphoclimatic conditions in the main producer regions of the Paraná State, Brazil.

As well as being genetic characteristics, plant and ear-insertion heights are influenced by plant population and these heights increase in proportion to the population, due to the combined effect of intraspecific competition for light, stimulating apical dominance accordingly (Argenta et al., 2001; Sangoi et al., 2002). This relationship has been observed by Argenta et al. (2001), Marchão et al. (2005) and Demétrio et al. (2008), who reported increased plant and ear-insertion heights as population density increases, suggesting that there is a natural tendency for plant height to increase in high-density situations.

It can therefore be inferred that the population of plants sown with the objective of obtaining a final standof 65,

Table 1. Plant height (PH), height of ear insertion (HEI), ear length (EL) and ear diameter (ED) of summer maize as a function of the winter crop and fertilizer.

Winter crop (WC)	PH	HEI	EL	ED
	--------------------	cm	--------------------	-- mm --
Oats + oilseed radish	170.4^a	98.6^a	19.7^a	53.72^a
Black oats	178.4^a	103.0^a	20.0^a	54.27^a
Chickpea	183.3^a	103.8^a	20.5^a	55.72^a
Common vetch	171.3^a	97.9^a	20.3^a	54.65^a
Common bean	178.5^a	104.0^a	19.7^a	54.59^a
Oilseed radish	173.8^a	98.2^a	19.9^a	54.53^a
Fallow	179.6^a	105.3^a	20.2^a	55.09^a
Wheat	164.3^a	98.8^a	19.3^a	52.88^a
F-test	1.41^{ns}	0.91^{ns}	1.24^{ns}	1.82^{ns}
CV (%)	10.28	11.06	5.84	4.04
Fertilizer (FZ)				
Organic	173.5^a	100.8^a	19.7^a	54.56^a
Chemical	173.4^a	101.6^a	20.2^a	54.29^a
F-test	0.38^{ns}	0.15^{ns}	3.56^{ns}	0.67^{ns}
CV (%)	13.41	9.69	6.99	2.98
F-test (WC × FZ)	1.57^{ns}	1.51^{ns}	1.16^{ns}	2.83*
CV (%)	5.58	5.77	5.74	3.17

Means followed by the same letter are not differentby Tukey test at 5%level of significance.* = significant at 5%.ns = not significant at 5%. CV=coefficient of variation.

000 plants per hectare was one of the factors that contributed to the difference in plant height and height of first-ear insertion, since the total number of plants did not reach 50,000 plants per hectare, a shortfall of approximately 23% (Table 4). This probably occurred because of the high precipitation on the day after sowing, causing soil surface sealing, a mechanical restriction imposed by covering the soil and providing strong resistance to seedling emergence (Amaral et al., 2008).

Splitting the interaction between winter crop × fertilizer for ear diameter showed that the common bean + organic fertilizer combination significantly increased the ear diameter of maize. The average diameter of maize ears for the aforesaid treatment was 3.73 mm higher than oats + oilseed radish with organic fertilizer treatment (Table 2). The chemical fertilizer × oats + oilseed radish increased the average ear diameter of maize by 2.73 mm while the organic fertilizer + common bean reduced the diameter by 2.98 mm. Out of all other parameters tested, maize yield showed significant difference only for winter crop × fertilizer interaction. All other measurements, viz. rows per ear, grains per row and grains per ear, plant population, weight of 100 grains did not show any significant results for any of the factors tested.

The length, diameter and number of ears per unit area and weight of grains are characteristics for determining the yield potential of maize (Ohland et al., 2005). Ear length (Table 1) and average diameter (Table 2) were greater than those reported by Marchão et al. (2005). This could also be related to the number of plants in the final stand, since Dourado Neto et al. (2003) reported that, in populations of between 30,000 and 60,000 plants per hectare, maize genotypes exhibited increased ear length as a function of the spatial arrangement. However, ear length and diameter play only an indirect role in increasing grain weight (Okumura et al., 2011).

The figures for rows perear, grains per row and grains per ear (Table 3) were higher than those reported by Demétrio et al. (2008). These results may be related to inter-specific competition for environmental resources, since in view of the lower population density, there was a greater area for the plants to exploit for water, light and

Table 2. The mean separations of average summer maize ear diameter by winter crop and type of fertilizer.

Winter crop	Fertilizer		
	Organic	Chemical	F-test
	mm		
Oats + oilseed radish	52.35^{Bb}	55.08^{Aa}	7.62**
Black oats	54.88^{Aab}	53.65^{Aa}	1.55^{ns}
Chickpea	55.70^{Aab}	55.73^{Aa}	0.00^{ns}
Common vetch	55.25^{Aab}	54.05^{Aa}	1.47^{ns}
Common bean	56.08^{Aa}	53.10^{Ba}	9.08**
Oilseed radish	54.35^{Aab}	54.70^{Aa}	0.12^{ns}
Fallow	55.38^{Aab}	54.80^{Aa}	0.35^{ns}
Wheat	52.52^{Aab}	53.23^{Aa}	0.52^{ns}
F-test	3.07**	1.35^{ns}	

Means followed by the same letter in line (capital letter) and in column (lower case) for each variable are not different by Tukey test at 5% level of significance. * = significant at 5%. ns = not significant at 5%.

Table 3. Number of rows per ear (NRE), number of grains per row (NGR) and number of grains per ear (NGE) of summer maize as a function of winter crop and fertilizer.

Winter crop (WC)	NRE	NGR	NGE
	Number		
Oats + oilseed radish	16.9^{a}	35.1^{a}	593.8^{a}
Black oats	16.6^{a}	36.0^{a}	597.1^{a}
Chickpea	17.0^{a}	36.2^{a}	612.7^{a}
Common vetch	16.7^{a}	36.3^{a}	601.8^{a}
Common bean	16.8^{a}	35.4^{a}	593.2^{a}
Oilseed radish	16.8^{a}	35.9^{a}	601.1^{a}
Fallow	17.2^{a}	37.1^{a}	627.1^{a}
Wheat	16.3^{a}	35.7^{a}	578.9^{a}
F-test	1.56^{ns}	1.03^{ns}	1.45^{ns}
CV (%)	4.60	6.03	6.85
Fertilizer (FZ)			
Organic	16.7^{a}	35.5^{a}	591.2^{a}
Chemical	16.9^{a}	36.4^{a}	610.2^{a}
F-test	0.96^{ns}	3.45^{ns}	4.57^{ns}
CV (%)	4.22	7.16	7.26
F-test (WC × FZ)	1.22^{ns}	1.07^{ns}	1.69^{ns}
CV (%)	4.73	5.87	6.32

Means followed by the same letter are not different by Tukey test at 5% level of significance.ns = not significant at 5% level of significance. CV = coefficient of variation.

nutrients, contributing to greater plant development (Argenta et al., 2001; Sangoi et al., 2002). It has already been reported that row spacing does not affect the number of grains per ear (Penariol et al., 2003), whereas at high population densities, this component can be reduced because of the abortion of fertilized ovules at the beginning of the grain filling stage (Sangoi, 2000). This occurs more often at the tip of the ear, the last to be fertilized and lowest in preference in terms of demand for carbohydrates and nitrogen compounds (Sangoi et al., 2001).

In terms of the weight of 100 grains, the mean value

Table 4. Average plant population, weight of 100 grains and yield of summer maize as a function of winter crop and fertilizer.

Winter crop (WC)	Population	Weight of 100 grains	Yield
	- Plants ha^{-1} -	---- g ----	--- kg ha^{-1} ---
Oats + oilseed radish	47,840^{a}	33.28^{a}	8,345^{a}
Black oats	51,221^{a}	34.42^{a}	9,071^{a}
Chickpea	50,000^{a}	36.80^{a}	10,032^{a}
Common vetch	50,000^{a}	34.92^{a}	9,229^{a}
Common bean	47,840^{a}	34.35^{a}	9,007^{a}
Oilseed radish	49,383^{a}	34.46^{a}	8,641^{a}
Fallow	45,371^{a}	35.26^{a}	9,419^{a}
Wheat	49,691^{a}	33.02^{a}	8,459^{a}
F-test	0.47^{ns}	1.14^{ns}	0.90^{ns}
CV (%)	10.68	11.06	22.33
Fertilizer (FZ)			
Organic	48,688^{a}	34.97^{a}	8,868^{a}
Chemical	49,151^{a}	34.16^{a}	9,182^{a}
F-test	1.26^{ns}	3.83^{ns}	0.71^{ns}
CV (%)	9.43	5.88	20.19
F-test (WC × FZ)	1.18^{ns}	0.40^{ns}	3.54**
CV (%)	13.27	9.72	18.33

Means followed by the same letter in column for each variableare not differentbyTukey test at 5% level of significance. ** = significant at 1%. ns = not significant at 5%. CV = coefficient of variation.

was 34.56 g, and the factors studied had no effect on this parameter (Table 4). Santos et al. (2010) report an interaction between green manures × nitrogen, with increments in the weight of 100 grains related to nitrogenated fertilizer (14.2%) and the green manure crop (*Crotalaria spectabilis* Roth.) (26.9%). This component is influenced by the amount of radiation intercepted by the leaf canopy, plant metabolic efficiency and translocation of leaf and stem photosynthates to the grains during grain development stages (Tollenaar, 1977).

Among these characteristics, it is possible that the ear diameter contributed to the higher maize yield of the crop following common vetch (organic fertilizer), by comparison with the intercropped oats + oilseed radish with organic fertilizer and common vetch with chemical fertilizer. This parameter is strictly related to grain filling and the number of rows per ear, which is also influenced by the genotype (Ohland et al., 2005).

For the organic fertilizer, in terms of the effect of winter crop × fertilizer on maize yield, the common vetch treatment exceeded the intercropped oats + oilseed radish by some 3,500 kg ha^{-1} (Table 5). This is attributable to the higher C/N ratio of the intercropped plant biomass by comparison with common vetch (Aita and Giacomini, 2003), since the legume is capable of supplying significant quantities of nitrogen to the succeeding crop due to its capacity to biologically fix atmospheric nitrogen and its high crop residue decomposition rate (Aita et al., 2001; Heinrichs et al., 2001). Since oats accumulate less nitrogen in the plant biomass and release it slowly, it affects nutrient supply and grain yield (Aita et al., 2001). This also applies to oilseed radish, which although it has a higher decomposition rate and faster nutrient release from crop residues by comparison with oats, is similar to the Poaceae in its capacity to absorb nitrogen from the soil and produce plant biomass (Medrado et al., 2011).

Analyzing the fertilizer used in each winter crop, the effect of the fertilizer is notable in 3 treatments: oats + oilseed radish, common vetch and common bean. Chemical fertilizer was most effective on maize yield in the oats + oilseed radish treatment, exceeding by

Table 5. Mean separations of summer maize yield by winter crop and type of fertilizer.

	Fertilizer		
Winter crop	**Organic**	**Chemical**	**F-test**
	-------------- mm --------------		
Oats + oilseed radish	$6{,}816^{B\ b}$	$9{,}874^{Aa}$	9.98**
Black oats	$8{,}813^{Aab}$	$9{,}330^{Aa}$	0.28^{ns}
Chickpea	$9{,}854^{Aab}$	$10{,}210^{Aa}$	0.14^{ns}
Common vetch	$10{,}378^{Aa}$	$8{,}080^{Ba}$	5.64*
Common bean	$10{,}111^{Aab}$	$7{,}902^{Ba}$	5.21*
Oilseed radish	$7{,}925^{Aab}$	$9{,}357^{Aa}$	2.19^{ns}
Fallow	$8{,}905^{Aab}$	$9{,}934^{Aa}$	1.13^{ns}
Wheat	$8{,}145^{Aab}$	$8{,}773^{Aa}$	0.42^{ns}
F-test	2.63*	1.30^{ns}	

Means followed by the same letter in line (capital letter) and in column (lower case) for each variable are not different by Tukey test at 5% level of significance. ** = significant at 1%. * = significant at 5%. ns = not significant at 5%.

around 3,000 kg ha^{-1} the effect of organic fertilizer (Table 5). One possible hypothesis for explaining this difference is the fact that organic fertilizers are less soluble than chemicals, since they are dependent on organic matter mineralization to gradually make the nutrients available (Castoldi et al., 2011).

In the common vetch and common bean treatments, the yield of the maize fertilized with poultry litter exceeded that produced using chemical fertilizer by around 2,300 kg ha^{-1} (common vetch) and 2,200 kg ha^{-1} (common bean) (Table 5). Assessing the application of mineral fertilizer and poultry litter for cropping maize in the municipality of Santa Helena, Paraná State, Brazil, Silva et al. (2012) obtained increased maize yield using 100% poultry litter. Since the area had been under no-tillage for five years, decomposition of plant residues and mineralization of organic matter could have released quantities of nitrogen and other nutrients (Aita et al., 2001). Furthermore, common vetch and common bean (Fabaceae) are nitrogen fixing species, making this element available in sufficient quantity to meet the needs of the maize crop, regardless of the type of fertilizer used (Medrado et al., 2011).

Even with the restrictions imposed on intensive agriculture by the soils of the ArenitoCaiua region, made up of sandy materials consisting mainly of quartz (85 to 90%), with low organic matter content (around 1%), poor in nutrients and highly susceptible to erosion (Sambatti et al., 2003), the maize yields obtained in our study indicate that the region is suitable for maize cropping, as observed by Gerage and Shioga (1999).

Yields of around 8,300 kg ha^{-1} were obtained under common vetch/maize succession in the municipality of Castro, a primary plateau region in Paraná State (Carvalho et al., 2007), and 9,900 kg ha^{-1} in the central region of the State of Rio Grande do Sul (Argenta et al., 2003). In the common bean/maize + organic fertilizer succession system, the maize yield was some 1,000 kg ha^{-1} higher than that produced using chemical fertilizer (Andreola et al., 2000). This shows that it is possible to obtain high maize yields (> 10,000 kg ha^{-1}) in winter crop succession systems, especially using legumes, combined with adequate fertilizing and conservationist soil practices, such as no-tillage, in the ArenitoCaiua region.

Conclusion

All the succession systems, in conjunction with adequate crop nutritional management, were agronomically viable for producing maize in the ArenitoCaiua region. The highest maize yield was produced by common vetch/maize succession with poultry litter fertilizer.

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