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VERMICOMPOST APPLICATION IMPROVING SEMIARID-GROWN CORN GREEN EAR AND GRAIN YIELDS[1]

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ABSTRACT – Intensive corn farming quickly depletes soil organic matter in the nutrient-poor soils of the Brazilian semiarid region. Application of vermicompost, an excellent organic fertilizer, could help solve that problem. This study evaluated the effect of applying *Eisenia fetida* vermicompost in the seeding furrows, at 0, 2, 4, 6, 8, and 10 Mg.ha^{-1} application rates, on the green ear yield and grain yield of two corn cultivars. Treatments were replicated five times with split-plots (vermicompost application rates within plots) in a completely randomized block design. The number of mature ears, number of kernels per ear (cultivar BR 106), and 100-kernel weight (cultivar AG 1051) were not affected by vermicompost application rate. However, vermicompost application increased total number and weight of unhusked and husked marketable green ears as well as grain yield. Total number of green ears was higher in cultivar BR 106 than in cultivar AG 1051. Conversely, grain yield and total ear weight and marketable weight of unhusked and husked green ears was higher in cultivar AG 1051, but responses in the latter two traits were dose-dependent.

Key words: Humus. Earthworm. *Zea mays*. *Eisenia fetida*. Cultivars.

APLICAÇÃO DE VERMICOMPOSTO ELEVA OS RENDIMENTOS DE ESPIGAS VERDES E DE GRÃOS DE MILHO NO SEMIÁRIDO

RESUMO - A exploração intensiva do milho reduz rapidamente os já considerados baixos teores de matéria orgânica dos solos do semiárido brasileiro. A aplicação de vermicompostos, considerados excelentes adubos orgânicos, poderia contribuir para a solução desse problema. O objetivo do presente trabalho foi avaliar os efeitos da aplicação, nos sulcos de semeadura, de doses (0, 2, 4, 6, 8 e 10 Mg ha^{-1}) de vermicomposto de *Eisenia fetida*, obtido a partir de esterco bovino, sobre os rendimentos de espigas verdes e de grãos de cultivares de milho (AG 1051 e BR 106). Utilizou-se o delineamento de blocos ao acaso com cinco repetições e parcelas subdivididas (vermicomposto nas parcelas). A aplicação de doses de vermicomposto não influenciou o número de espigas maduras, número de grãos espiga^{-1} (na cultivar BR 106) e massa de 100 grãos (na cultivar AG 1051). Mas a aplicação do vermicomposto aumentou os números e as massas de espigas verdes, totais e comercializáveis, empalhadas e despalhadas, e o rendimento de grãos. A cultivar BR 106 foi superior à cultivar AG 1051 quanto ao número total de espigas verdes. O inverso ocorreu nas massas total e de espigas verdes comercializáveis, empalhadas e despalhadas, e no rendimento de grãos. Mas nessas duas últimas características a superioridade da cultivar AG 1051, dependeu da dose do adubo.

Palavras-chave: Húmus. Minhoca. *Zea mays*. *Eisenia fetida*. Cultivares.

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INTRODUCTION

Soils in the Brazilian semiarid region usually have low organic matter content, an important soil quality indicator (MANLAY; FELLER; SWIFT, 2007). Corn crops, grown intensively and under irrigation in the region (often producing up to three harvests per year), tend to quickly deplete organic matter content. In addition, in both irrigated and dryland corn, virtually all plant biomass aboveground is removed to feed cattle after the ears are harvested. Together with the high temperatures in the region, this results in intense mineralization of soil organic matter and crop residues occurs, resulting in decreased soil quality (MARIN et al., 2006; DINESH et al., 2010). Organic fertilizers and/or crop residues, used either alone or in combination with mineral fertilizers, could help minimize these issues (MANLAY; FELLER; SWIFT, 2007).

Vermicomposts - the end-product of the breakdown of organic matter by earthworms (ALVAREZ et al., 2004) - are finely divided materials with high porosity, aeration, drainage, water-holding capacity and microbial activity, stabilized by interactions between earthworms and microorganisms in a non-thermophilic process (ARANCON et al., 2004a). Vermicomposts release nutrients in plant-available forms after mineralization in the soil, and have large particulate surface areas that provide sites for microbial (fungi, bacteria, and actinomycetes) activity and nutrient retention, improving crop growth and yield (ARANCON; GALVIS; EDWARDS, 2005). In recent years, a large number of studies investigated the effects of vermicompost application on crops such as rice, sorghum, and corn (PATIL; SHEELAVANTAR, 2006; SUJATHA et al., 2008; BRITO et al., 2009; LAZCANO et al., 2011; TEJADA; BENITEZ, 2011), likely due to a growing worldwide concern for the sustainability of agricultural systems (GUTIÉRREZ-MICELI et al., 2008). In general, these studies have found positive effects of vermicompost application on crop yields.

The objective of this study was to evaluate the effect of a range of vermicompost application rates on green ear yield and grain yield for two corn cultivars grown under irrigation in the Brazilian semi-arid region.

MATERIAL AND METHODS

The study was conducted from August to November 2009 at Rafael Fernandes Experimental Farm, Universidade Federal Rural do Semi-Arido (UFERSA), located 20 km from Mossoró, RN, Brazil (5°11' S and 37°20' W, 18 m elevation). Climate information for the region was summarized by Carmo Filho and Oliveira (1989).

The experiment was sprinkler-irrigated. The depth of water required by corn (5.6 mm) was calculated based on the actual depth of the root system (0.4 m). Irrigation duration was based on the water retained by the soil at a tension of 0.04 Mpa. A one-day irrigation schedule was established. Irrigation was started after seeding and was suspended one day before each harvest. The soil in the area is Arenic Hapludult (red yellow argisol or PVA) (EMBRAPA, 2006). Soil analysis results for the study area are presented in Table 1.

The soil was tilled by two harrowing operations. Before seeding, 30 $kg.ha^{-1}$ N (ammonium sulfate), 60 $kg.ha^{-1}$ P_2O_5 (single superphosphate), and 30 $kg.ha^{-1}$ K_2O (potassium chloride) were applied as base fertilizers. The fertilizers were applied by hand in furrows at a depth of approximately 20 cm. The furrows were ploughed deeper than usual to allow in-furrow application of fertilizers. Vermicompost, prepared using cattle manure mixed with *Eisenia fetida* (Savigny) worms, was applied by hand over the chemical fertilizers (0, 2, 4, 6, 8, and 10 $Mg. ha^{-1}$) and the furrows were later covered with soil using a hoe. Fertilizers and vermicompost were applied in furrows, rather than by broadcasting, to reduce the amount of vermicompost used. The vermicompost analysis results (EMBRAPA, 1999) are presented in Table 1.

Hand seeding was performed on 07/29/2009 at 1.0 m × 0.4 m spacing with four seeds/pit at an approximate depth of 5.0 cm in pits opened at the furrow walls. Thinning was performed 20 days after seeding (DAS), leaving the two more vigorous plants in each pit, resulting in a density equivalent to 50,000 plants ha^{-1} in the experimental stand. Two corn cultivars were evaluated: BR 106 and AG 1051. BR 106 is a free-pollination, medium-cycle, medium-sized, flint type, reddish-yellow variety. Corn cultivar AG 1051 is a short-sized, super-early double hybrid with yellow dent grain.

Pest control was done by spraying deltamethrin (250 $mL.ha^{-1}$) at seven and 14 DAS. Weeds were removed with a hoe 20 and 45 DAS. After each weeding, the stand was fertilized with 30 $kg.ha^{-1}$ N (ammonium sulfate).

Table 1. Chemical analysis results for the soil and vermicompost utilized in the experiment[1].

Attributes	Units	Soil analysis	Vermicompost analysis
Organic matter	g kg^{-1}	0.76	10.50
pH	-	6.5	-
C	%	0.44	6.31
P	mg dm^{-3}	1.00	3.22
Na^+	$cmol_c$ dm^{-3}	0.11	38.41
K^+	$cmol_c$ dm^{-3}	0.07	5.90
Ca^{2+}	$cmol_c$ dm^{-3}	1.20	61.25
Mg^{2+}	$cmol_c$ dm^{-3}	0.72	71.66
Al^{3+}	$cmol_c$ dm^{-3}	0.00	0.66
H + Al	$cmol_c$ dm^{-3}	0.74	1.28
SB	$cmol_c$ dm^{-3}	2.10	0.72
CEC	$cmol_c$ dm^{-3}	2.84	-
t	$cmol_c$ dm^{-3}	2.10	-
m	%	0.00	-
V	%	73.9	-

[1]Analyses conducted according to EMBRAPA (1999).

Treatments were replicated five times with split-plots (vermicompost application rate within plots) in a complete randomized block design. Each experimental unit consisted of four 6.0 m-long rows. The usable area was the two central rows, discarding plants from one pit at each end. One usable row was selected to evaluate green ear yield and the other was used to assess grain yield and its components.

Green ear harvesting was performed every two days (as the grain reached the "green corn" stage), during the period from 70 to 76 days after seeding. The total number and weight of unhusked green ears and the number and weight of marketable green ears, either unhusked or husked were evaluated. Unhusked marketable ears were >22 cm in length, had good visual appearance, and were free of blemishes or holes from pests. Husked marketable ears were >17 cm that displayed grain set and health suitable for commercialization.

Ripe ears were harvested 105 days after sowing, when the grain showed a water content of approximately 20%. Next, the ears were husked and left to dry in the sun for approximately 72 hours, when they were threshed by hand. After weighing the grain, a 100 g sample was taken to estimate water content. Based on the water content thus determined, grain weight was corrected to a water content of 15.5%. The number of kernels per ear was estimated based on 20 ears, and the 100-kernel weight was estimated based on five samples of 100 kernels.

The data were submitted to analysis of variance using SAEG-software developed by Universidade Federal de Viçosa (RIBEIRO JÚNIOR, 2001), while regression analyses were made with the software developed by Jandel (1992). The data were tested for homogeneity of variance prior to the analyses (BARTLETT, 1937). The regression models were selected based on the following criteria: biological explanation of the phenomenon, testing of model parameters by the Student's t test at 5%, and model simplicity.

RESULTS AND DISCUSSION

Analysis of variance indicated an effect of cultivar (C), vermicompost rate (V), and the C × V interaction on the total number of green ears. Regression analysis indicated a positive effect on the total number of green ears as well as on the number of marketable ears, unhusked and husked (Table 2). Differences between the two types of analyzes are frequent (PIMENTEL-GOMES, 2009). Cultivar BR 106 was superior to cultivar AG 1051 with regard to total number of green ears (Table 2). As for the number of marketable husked green ears, cultivar AG 1051 was better than cultivar BR 106 at smaller doses of vermicompost, but the two cultivars did not differ at higher doses of fertilizer (Table 2).

With respect to total number of green ears in cultivars AG 1051 and BR 106, and number of marketable husked ears in cultivar BR 106, the positive effects of the application of vermicompost doses occurred up to certain rates (7.37, 5.79, and 5.13 Mg.ha^{-1}, respectively) (Table 2). Higher vermicompost rates resulted in yield reductions. However, with regard to number of marketable unhusked green ears in both cultivars and number of marketable husked ears in cultivar AG 1051, the maximum yields were obtained with the highest vermicompost rate (Table 2). Some authors (ARANCON et al., 2004a; SILVA et al., 2006) found no significant effects of vermicompost doses on some crop traits, similarly to this study.

Table 2. Mean numbers of green ears of corn cultivars as a response to the application of vermicompost rates, obtained from cattle manure[1].

Vermicompost rates ($Mg\ ha^{-1}$) (x)	Number of ears ha^{-1}								
	Total			Marketable unhusked			Marketable husked		
	Cultivars			Cultivars			Cultivars		
	AG 1051	BR 106	Means	AG 1051	BR 106	Means	AG 1051	BR 106	Means
0	49039	47893	48466	44969	44635	44802	43046 a	35022 b	39034
2	49183	54964	52074	45195	49566	47381	40071 a	44370 a	42221
4	50035	59452	54744	47498	48184	47841	45465 a	43553 a	44509
6	50909	54486	52698	50909	49931	50420	49432 a	43950 b	46691
8	51631	53009	52320	48415	49936	49176	47646 a	42142 b	44894
10	50000	54869	52435	50000	51030	50515	47692 a	41720 b	44706
Means	50133 b	54112 a	-	47831 a	48878 a	48355	-	-	-

Regression analysis for total number of green ears (y)				
Cultivars	Equations[1]	x for y max	y max	R^2
AG 1051	$y = 48814.0 + 138.3 x^2 - 12.5 x^3$	7.37	51319	0.94
BR 106	$y^2 = 2422110000 + 271291000 x - 23439000 x^2$	5.79	56631	0.55
Mean	$y^2 = 2398770000 + 163344000 x - 13601000 x^2$	6.00	53751	0.75
Regression analysis for number of marketable unhusked green ears (y)				
Cultivars	Equações[1]	x for y max	y max	R^2
AG 1051	$y^2 = 2025670000 + 52295300 x$	10.00	50484	0.71
BR 106	$y = 45296 + 1814 x^{0.5}$	10.00	51033	0.84
Mean	$y = 44813 + 1793 x^{0.5}$	10.00	50483	0.90
Regression analysis for number of marketable husked green ears (y)				
Cultivars	Equations[1]	x for y max	y max	R^2
AG 1051	$y^2 = 1737180000 + 664075 x$	10.00	49003	0.59
BR 106	$y = 35591 - 112 x^2 + 5223 x^{0.5}$	5.13	44465	0.90
Mean	$y = 38944 + 2034 x - 148 x^2$	6.86	45917	0.96

	Total	Marketable unhusked	Marketable husked
CVplots, %	9.0	9.3	9.2
CVsubplots, %	8.7	11.0	8.4

[1]For each trait, means followed by the same letter, in each row, do not differ from each other at 0.05 probability by Tukey's test. All parameters for all equations were significant at 0.05 probability by the t test.

Regarding total ear weight and weight of marketable, unhusked and husked ears, effects of cultivars (C) and vermicompost rate (V) were observed, but the effects of the C × V interaction on those traits were not significant. Cultivar AG 1051 was superior to cultivar BR 106 for the three traits (Table 3). Vermicompost application increased total ear weight in cultivars AG 1051 and BR 106 up to rates of 7.65 and 6.64 $Mg.ha^{-1}$, respectively, with yield decreasing at higher rates (Table 3). Similarly, for marketable husked ear weight, the vermicompost doses that allowed maximum yield in both cultivars were 7.75 and 5.69 $Mg\ ha^{-1}$, respectively. For marketable unhusked ear weight, maximum yields were obtained with the maximum vermicompost dose under study (Table 3).

Application of vermicompost rate (V), cultivar (C), and the V × C interaction all affected grain yield. Cultivar AG 1051 did not differ from cultivar BR 106, in the three lower vermicompost rates applied, but was superior to the other cultivar for larger doses of fertilizer. Maximum grain yield values for cultivars AG 1051 and BR 106 were obtained with applications of 10.00 and 6.62 $Mg\ ha^{-1}$, respectively (Table 4). The observed increases in those yield values, as indicated by regression analysis, were due to increased numbers of kernels per ear in cultivar AG 1051 and kernel weight in cultivar BR 106, as the application of vermicompost did not influence the number of mature ears in any of the cultivars. For that trait, with an experimental mean of 50369 ears ha^{-1}, the analysis of variance indicated coefficient of variation associated with plots = 2.0%, and coefficient of variation associated with subplots = 2.2%.

The discrepancies reported by different authors for the response to the application of vermicompost doses must be related to genotypic and environmental factors, as well as to vermicompost application rate. For example, tomato (*Lycopersicon esculentum* Mill.) (ZALLER, 2007) and corn cultivars (genotypic differences) (LAZCANO et al., 2011) responded differently to vermicompost application, as observed in this study for some traits of cultivars AG 1051 and BR 106. On the other hand, Arancon et al. (2004b) found that the response of strawberry to vermicompost rate was affected by the location of the experiment.

Table 3. Mean weight of green ears of corn cultivars as a response to the application of vermicompost rates, obtained from cattle manure[1].

Vermicompost rates ($Mg\ ha^{-1}$) (x)	Ear weight ($kg\ ha^{-1}$)								
	Total			Marketable unhusked			Marketable husked		
	Cultivars			Cultivars			Cultivars		
	AG 1051	BR 106	Means	AG 1051	BR 106	Means	AG 1051	BR 106	Means
0	10409	9192	9801	10027	8926	9477	6008	4600	5304
2	11682	11593	11638	11231	9013	10122	6508	6227	6368
4	12791	12234	12513	12488	11363	11926	7759	6489	7124
6	15092	12041	13567	15092	11382	13237	9035	6378	7707
8	13318	11816	12567	13128	11286	12207	8180	6335	7258
10	13716	12058	12887	13716	11462	12589	8283	6380	7332
Means	12835 a	11489 b	-	12614 a	10935 b	-	7629 a	6068 b	-

Regression analysis for total weight of green ears (y)				
Cultivars	Equations[1]	x for y max	y max	R^2
AG 1051	$y^2 = 104072000 + 23552900 x - 1538700 x^2$	7.65	13936	0.82
BR 106	$y^2 = 89762900 + 19089500 x - 1437100 x^2$	6.64	12376	0.87
Mean	$y = 9888 + 949 x - 67 x^2$	7.04	13229	0.93
Regression analysis for weight of marketable unhusked green ears (y)				
Cultivars	Equations[1]	x for y max	y max	R^2
AG 1051	$y^2 = 97348500 + 31260000 x^{0.5}$	10.00	14007	0.73
BR 106	$y = 8711 + 942 x^{0.5}$	10.00	11689	0.76
Mean	$y^2 = 84178100 + 18179700 x - 1085700 x^2$	8.37	12660	0.87
Regression analysis for weight of marketable husked green ears (y)				
Cultivars	Equations[1]	x for y max	y max	R^2
AG 1051	$y = 6150 + 136 x^2 - 12 x^3$	7.75	8877	0.87
BR 106	$y = 4617 - 328 x + 1565 x^{0.5}$	5.69	6483	0.99
Mean	$y = 5311 + 627 x - 44 x^2$	7.19	7568	0.97

	Total	Marketable unhusked	Marketable husked
CVplots, %	17.0	18.2	19.8
CVsubplots, %	10.3	11.8	13.2

[1]For each trait, means followed by the same letter, in each row, do not differ from each other at 0.05 probability by Tukey's test. All parameters for all equations were significant at 0.05probability by the t test.

Cultivar AG 1051 responded better to vermicompost application than cultivar BR 106 (Tables 2, 3 and 4). In general, the maximum yields in cultivar AG 1051 were obtained with higher vermicompost doses than those obtained with cultivar BR 106. With regard to environmental factors, it was observed that the response to vermicompost applications was dependent upon the material used in vermicomposting (TEJADA; BENITEZ, 2011), soil type (MANTOVANI et al., 2003), location (ARANCON et al., 2004b), year soil tillage and fertilizers (PATIL; SHEELAVANTAR, 2006), among others factors.

Similarly to this study, other authors observed linear responses for some traits and quadratic responses for others under increased vermicompost rates (SOUZA et al., 2003). Moreover, as in this work, other authors (MANTOVANI et al., 2003) also verified that crops responded negatively to high vermicompost rates and positively to low application rates (Tables 2 to 4).

The fact that crop responses to vermicompost applications depend on several factors makes it difficult to explain their effects. Vermicompost may influence plant growth directly or indirectly, through different chemical, physical and biological mechanisms. For instance, vermicompost has a wide range of indirect effects on plant growth, such as the mitigation or suppression of plant diseases (LAZCANO; DOMÍNGUEZ, 2011). Cavender, Atiyeh and Knee (2003) propose that a positive influence of vermicompost on sorghum growth was due more to improved physical and chemical soil properties than to improved soil biological properties. Vermicompost applications increased total organic carbon, total N, P, K, Ca, Zn, and Mn contents, and decreased soil pH (AZARMI; GIGLOU; TALESHMIKAIL, 2008). Soil density and porosity also improved when vermicompost was added to the soil (AZARMI; GIGLOU; TALESHMIKAIL, 2008).

Other authors, however, attribute the positive responses of crops to vermicompost applications to improved soil biological characteristics (ARANCON et al., 2004b; TEJADA; BENITEZ, 2011). Two important contributions of vermicompost are increased microbial populations and activity, which are key factors in soil nutrient cycling rates, producing substances that influence growth; and increased plant resistance or tolerance to disease (ARANCON; EDWARDS; BIERMAN, 2006). Increased microbial populations with increasing vermicompost doses would be the factor responsible for higher crop growth and yield. Microorganisms can produce materials that may affect plant growth, such as substances that act as plant hormones or growth regulators. Microorganisms such as bacteria, fungi, actinomycetes and algae may produce plant growth regulators such as auxins, gibberellins, cytokinins, ethylene, and abscisic acid (ARANCON et al., 2004a). Increased amounts of humic materials would also be responsible for increases in crop growth and yield. Those humic substances occur naturally in rotted animal manure and in other organic materials, but vermicomposting can increase their amounts and production rates (ARANCON et al., 2004a). Positive effects of humic substances on several corn traits have been recently demonstrated (EYHERAGUIBEL; SILVESTRE; MORARD, 2008).

Table 4. Mean values for grain yield of corn cultivars, number of kernels ear^{-1}, and 100-kernel weight as a response to the application of vermicompost doses, obtained from cattle manure[1].

Vermicompost doses (Mg ha^{-1}) (x)	Grain yield (kg ha^{-1})			Number of kernels ear^{-1}			100-kernel weight (g)		
	Cultivars			Cultivars			Cultivars		
	AG 1051	BR 106	Means	AG 1051	BR 106	Means	AG 1051	BR 106	Means
0	4972 a	4829 a	4901	340	352	346	29.5	28.6	29.1
2	5440 a	4889 a	5165	357	342	350	28.2	30.1	29.2
4	5558 a	5120 a	5339	370	342	356	28.0	33.5	30.8
6	6919 a	5416 b	6168	419	367	393	32.8	31.6	32.2
8	6936 a	5200 b	6068	408	367	388	32.0	32.0	32.0
10	7163 a	4789 b	5976	414	323	369	32.8	30.6	31.7
Means	-	-	-	385 a	349 b	-	30.5 a	31.0 a	30.8
Regression analysis for grain yield (y)									
Cultivars	Equations[1]						x for y max	y max	R^2
AG 1051	$y = 4964 + 240x$						10.00	7365	0.90
BR 106	$y = 4802 + 37x^2 - 3.7x^3$						6.62	5342	0.95
Mean	$y = 4903 + 58x^2 - 4.7x^3$						8.14	6180	0.93
Regression analysis for number of kernels ear^{-1} (y)									
Cultivars	Equations[1]						x for y max	y max	R^2
AG 1051	$y = 344 + 8.2x$						10.00	425	0.84
BR 106	$y = 349$						-	-	-
Mean	$y = 341.4 + 2.6x^2 - 0.23x^3$						7.49	389	0.88
Regression analysis for 100-kernel weight (y)									
Cultivars	Equations[1]						x for y max	y max	R^2
AG 1051	$y = 30.5$						-	-	-
BR 106	$y^{-1} = 0.0352 - 0.0025x + 0.0007x^{1.5}$						5.47	32.6	0.78
Mean	$y = 28.97 + 0.162x^2 - 0.014x^3$						7.95	32.4	0.96
CVplots, %		17.8			14.3			8.2	
CVsubplots, %		13.5			12.8			9.8	

[1]For each trait, means followed by the same letter, in each row, do not differ from each other at 0.05 probability by Tukey's test. All parameters for all equations were significant at 0.05 probability by the t test.

In this study, the application of vermicompost application may have contributed to improving soil biological, chemical (Table 2), and physical properties, including higher moisture retention. Even though the experiment was irrigated, the prevailing weather conditions during the study period, which included high temperatures and insolation and lack of rain, suggest that the retention of additional moisture in the soil may have been beneficial to corn. Baumhardt and Lascano (1996) reported that mean cumulative rainfall infiltration was lowest in bare soil and increased curvilinearly with increasing residue amounts.

The factors responsible for the negative responses of crops from a given vermicompost dose include high concentrations of soluble salts, toxicity for heavy metals (ARANCON et al., 2004a), and antagonistic effects of microorganisms that are present in the vermicompost (CAVENDER; ATIYEH; KNEE, 2003).

CONCLUSIONS

Vermicompost application increased total and marketable number and weight of green ears, both unhusked and husked, as well as grain yield.

Total number of green ears was higher in cultivar BR 106 than in cultivar AG 1051. The opposite occurred for total weight and marketable weight of green ears, both unhusked and husked, as well as for grain yield. However, in those last two traits the superiority of cultivar AG 1051 was dependent upon fertilizer rate.

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