

Yield Response to Fertilization Strategies in No-Tillage Soybean, Corn and Common Bean Crops

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ABSTRACT

Two research fields were conducted on a Haplohumox from 1998 and to 2005. The study aimed to evaluate the strategies for starter fertilizer application on corn, soybean and common bean yield as well as the accumulation of earlier dry matter for corn in a no-tillage crop rotation system in south of Brazil. There was no increase in the yield of soybean with phosphorus and potassium application for at least seven seasons, while corn and common bean showed increased yields with phosphorus, potassium and nitrogen application. For soybean, corn and common beans in no-tillage systems with high levels of phosphorus and medium of potassium, the starter fertilizer can be applied in any of the methods evaluated and in any of the period considered. The presence or absence of potassium in the furrow, phosphorus sources and row preparation components provided similar yields to corn, soybean and common bean.

Key words: Starter fertilizer, application technique, fertilizer management, crop rotation, no-till

INTRODUCTION

Fertilizers in soybean, common bean and corn generally are applied in furrows, when sowing. This strategy, besides increasing cost, increases the time necessary to sow which can affect the use of potential soil moisture and the most adequate period to sow; it also demands more machinery and concentrates labor efforts. Furrowers more commonly used to incorporate fertilizers in no-tillage system are double-disc opener and coulter opener and can make furrows about 70 mm and 150 mm deep, respectively, positioning fertilizer under seeds (Coelho, 1998; Silva, 2003).

Generally the increases in yield due to furrow fertilizer application occur when P and K contents in the soil are low (Yibirin, et al., 1993; Prado et al., 2001). But it can happen in soils with high or very high nutrient contents (Gordon, 1999; Bundy and Andraski, 2001). In conditions where inhibition of P and K adsorption can occur; like hydric deficit (Borges and Mallarino, 2000; Broch and Chueiri, 2005), low temperatures and excessive moisture during the crop development can be advantageous to furrow application. The weather can affect the results of different kinds of fertilizer application what makes to carry out long-term studies very important.

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The adoption of no-tillage system decreases the soil, water and nutrient losses by erosion (Cogo et al., 2003; Guadagnin et al., 2005) and increases the nutrient and organic matter concentration in superficial layers (Eckert and Johnson, 1985; Merten and Mielniczuk, 1991; Pauletti et al., 1995). There is high root concentration (Yibirin et al., 1993) and hyphae and mycorrhiza spores (Kabir et al., 1998) in the first centimeters in the superficial layer in no-tillage systems which increases the possibility of absorption of nutrients applied or accumulated in this layer. In no-tillage, the superficial nutrient application has propitiated similar yields to the furrow application in several crops (Oliveira et al., 1992, Kochhann et al., 1998; Bordoli and Mallarino, 1998; Borges and Mallarino 2000; Heckman and Kamprath, 1992; Sguario Jr., 2000, Howard et al., 2002) or even superior (Buah et al., 2000), but can vary according to crop (Pöttker, 1999).

This long period study aimed to evaluate the effect of strategies in the starter fertilizer application on grain yield and its components in corn, soybeans and common beans in rotation and no-tillage system.

MATERIALS AND METHODS

The experiment was carried out in the Experimental and Demonstrative Field belonging to the ABC Foundation, in Castro, PR state, latitude 24°51'44.35" S, longitude 49°56'0.40"W

and altitude of 1030 m, south Brazil. According to Köppen, the climate of this region is Cfb (IAPAR, 2005). Table 1 shows the monthly average temperature during the study and the average of the last 30 years. The historical average temperatures of the colder months (May to August) varied from 12.4 to 14.2°C and in the warmer months (December to April) from 17.5 to 20.4°C. The annual average was 16.2°C. During this study, the average temperatures varied from 14.3 to 17.3°C in the colder months and between 20.6 and 22.5°C in the warmer months, with an annual average of 19°C.

In Table 2 the monthly average data of precipitation are shown for the period of study and the average of the last 30 years. The average annual rainfall was 1,573 mm; the drier months varied from 84 to 115 mm and the rainy months varied from 142 to 193 mm, which did not define a dry season. The average rainfall (September to April) varied from 134 to 213; the sum of these months was from 934 mm (1999/2000) to 1,455 mm (1998/99), with an average of 1,232 mm.

The soil is characterized as Haplohumox typical, clayey texture, with smooth waved relief (EMBRAPA, 2002). Soil samples were collected before the experiment implantation and analyzed according the method described by Raij et al. (1987). According to Raij et al. (1996) the content of P, extracted with resin, was high (41 to 80 mg dm⁻³) and medium for K (1.6 a 3 mmol_c dm⁻³) in the layer 0-20 cm (Table 3). The field was under no-tillage system for more than 10 years.

Table 1 - Monthly average temperature (°C) from 1998 to 2005 and monthly average of the last 30 years in Castro, PR state, ABC Foundation.

Month	Year								Average	Average 30 Years
	1998	1999	2000	2001	2002	2003	2004	2005		
Jan	23.4	22.5	22.0	22.6	21.9	22.8	22.6	22.4	22.5	20.4
Feb	22.6	22.6	21.5	23.0	21.4	23.8	23.0	23.5	22.7	19.8
Mar	21.3	22.4	20.5	22.9	23.4	22.6	22.4	24.7	22.5	19.6
Apr	19.4	19.0	19.1	20.8	22.2	21.1	21.2	22.6	20.7	17.1
Mai	15.4	13.9	15.4	15.0	17.0	16.8	16.0	19.3	16.1	14.2
Jun	13.4	13.1	15.9	13.1	16.4	17.6	16.2	18.2	15.5	12.5
Jul	14.6	14.4	11.4	14.2	13.8	15.7	16.1	17.0	14.6	12.4
Aug	16.7	15.1	14.3	16.1	17.1	14.9	18.8	18.8	16.5	13.7
Sep	16.1	17.7	16.3	16.2	16.2	18.2	21.8	16.0	17.3	14.1
Oct	17.9	17.6	21.0	18.9	21.3	19.5	19.9	20.0	19.5	16.3
Nov	19.9	18.3	20.7	20.5	20.8	21.2	21.5	21.5	20.6	16.6
Dez	21.7	20.6	21.7	20.6	22.1	21.6	22.7	22.3	21.7	17.5
Average	18.5	18.1	18.3	18.7	19.5	19.7	20.2	20.5	19.0	16.2

Table 2 - Monthly average precipitation (mm) from 1998 to 2005 and monthly average of the last 30 years in Castro, PR state, ABC Foundation.

Month	Year								Average 30 Years	
	1998	1999	2000	2001	2002	2003	2004	2005		
Jan	267	227	120	193	213	181	261	245	213	193
Feb	270	229	313	275	113	200	104	34	192	156
Mar	458	121	104	141	68	152	185	63	162	142
Apr	196	103	19	72	29	145	228	103	112	111
Mai	67	91	45	176	192	44	328	160	138	125
Jun	97	83	153	171	9	42	97	111	95	127
Jul	76	144	92	127	68	115	173	70	108	90
Aug	183	5	141	73	119	24	18	67	79	84
Sep	334	110	174	114	201	87	88	285	174	126
Oct	236	78	185	265	185	120	256	258	198	146
Nov	28	76	172	144	214	215	128	95	134	116
Dez	177	113	215	174	149	235	162	48	159	158
Total	2,388	1,382	1,733	1,925	1,558	1,558	2,027	1,539	1,764	1,573

Table 3 - General chemical and textural analyses of the area, prior to the experiment implantation (1998).

Depth	pH	P [†]	OC [‡]	K	Ca	Mg	V [§]	Al	Clay [¶]	Sand [¶]	Silt [¶]
cm	CaCl ₂	mg dm ⁻³	g dm ⁻³	mmol _c dm ⁻³			%		g kg ⁻¹		
0-5	5.9	122	38	4.0	66	39	78	0	607	136	257
5-10	5.4	43	34	2.6	56	32	64	0	622	136	242
10-30	5.1	11	28	1.4	34	16	47	1,9	627	150	223
0-20	5.2	51	30	2.2	43	30	60	0	616	131	253

[†]Anionic resin; [‡]Organic Carbon; [§]Basis saturation; [¶]Pipette method.

Two experiments were conducted simultaneously during the seasons 1998/99 to 2004/05. Each experiment had an area of 50x50 m. The objective of having duplicates was to eliminate partially the effect of the year over the crops, since two of the evaluated crops were cultivated each year. The adopted crop rotation was black oat (*Avena strigosa* L.)/soybean/black oat/corn/wheat (*Triticum aestivum* L.)/common bean. The study started with soybean in one of the experiment and corn in the other one. Five seasons of corn, four of soybean and four of common bean were evaluated. In 2000, the data about soybean were not considered due to problems in the plant population. The spacing between the rows was 0.8 m for corn and 0.4 m for soybean and common bean. The corn sowing was done on 10/10/1998, 29/09/1999, 11/10/2001, 28/09/2002 and 22/10/2004. The soybean sowing was done on 03/11/1998, 27/11/2001, 11/12/2003 and 25/11/2004, and the common bean sowing was done on 21/12/1999, 07/12/2000, 27/12/2002 and 05/01/2004.

For each experiment, the same treatment was carried out (Table 4), combining P sources,

furrowing mechanisms and kinds and period of mineral fertilizer application. For corn and common bean, nitrogen (N), phosphorus (P) and potassium (K) were applied; for soybean, just P and K were applied. Urea, KCl and triple superphosphate as N, P and K sources were used, respectively. The exceptions were treatment 4, with natural phosphate instead of triple superphosphate, and treatment 10, without fertilizers. The treatment 10 was conducted to evaluate the effect of fertilizers on crops. The natural phosphate used was from North Carolina, up to the 2001/02 season, after this, phosphate from Gafsa was used, both in the milled form, and the total P content was considered to the determination of quantity to be applied. Immediately before the application, the mixture of these was prepared in order to obtain the necessary quantity per hectare to apply in the furrows during the sowing of each crop (Table 5), according to the treatments.

The furrowing devices were: the coulter opener; made by Semeato, a.k.a. guilhotina (Semeato, 2006), with 2.5 cm at its end, 4.0 cm as the widest portion of the coulter and 11.0 cm of working

depth; and the double disk opener, one of 339 mm (14") and other of 363 mm (15"). Both the furrowing devices worked aligned to the seed furrow, the first device put the fertilizer about 5 or 6 cm below the seeds, while the second (double disk) put the fertilizer about 2 or 3 cm below the seeds.

Since the application strategies were analyzed for the summer crops, to the wheat fertilizers in the winter were spread manually before sowing in all the plots (Table 4). The wheat fertilizer application was based in the reposition of P and K exported by the harvest, according to Pauletti (1998), and additionally the fertilizer to winter on treatments 1,

2, 3 and 4 (Table 4). The black out cover crop did not receive fertilizer application except those proposed to winter in the same treatments 1, 2, 3 and 4.

The experimental design was a randomized block, with four blocks and 10 treatments. The size of each experimental unit (parcel) was 5.55 x 12.5 m, and the useful area was 3.2 x 8.5 m (27.2 m²). All the evaluations were done in the useful area of the plot. The wheat yield was evaluated only to further determination of nutrient exportation; it was obtained harvesting nine rows, spaced 17 cm, 5 meters each.

Table 4 - Period and kind of fertilization and furrowing devices per treatment.

Treatment	Period and kind of nutrient application †			Furrowing mechanism		
	Winter ‡	Summer		Soybeans	Corn	Feijão
	Spread	Furrow	Spread§			
1	NPK	-	-	Double disk	Coulter	Coulter
2	P	NK	-	Double disk	Coulter	Coulter
3	P	-	NK	Double disk	Coulter	Coulter
4	P - FN¶	NK	-	Double disk	Coulter	Coulter
5	-	NPK	-	Double disk	Double disk	Double disk
6	-	NPK	-	Coulter	Coulter	Coulter
7	-	NPK#	-	Double disk	Coulter	Coulter
8	-	-	NPK	Double disk	Coulter	Coulter
9	-	NP	K	Double disk	Coulter	Coulter
10	-	-	-	Double disk	Coulter	Coulter

†In soybean N was not applied; ‡Immediately before sowing, without incorporation; §Immediately after sowing; ¶Natural phosphate of North Carolina up to the crop 2001/02 and Gafsa after this.

Table 5 - Quantity of nutrients applied and cultivars to each crop.

Crop (cultivar)	N†	P ₂ O ₅	K ₂ O	Zn
Corn (XL 214)	30	60	60	3
Soybean(EMBRAPA 133)	00	40	40	
Common bean (regular Carioca)	30	60	40	

†Application of 90 and 35 kg ha⁻¹ N in top dress fertilization in V3/V4, to corn and common bean, respectively, except treatment 10.

The corn, soybean and common bean were harvested in four rows, each five meters, weighed and corrected to 13% moisture and transformed per hectare. The a thousand grains mass (TGM) was obtained through accounting and weighting of 250 grains obtained after processing the sample for

the yield determination, with further correction to 13% of moisture and multiplied by four. The total number of plants and ears were obtained by plant and ear counting of the harvested area and further transforming per hectare.

The height of pod insertion in soybeans or ear insertion of corn were determined, measuring the distance between the soil and insertion of the first pod in the main stalk (soybean), or the first ear (corn) in five plants in sequence in two rows, total 10 plants per plot, while the plant height was obtained measuring the distance from the soil to the insertion of the last leaf, for soybean in the main stalk, in the same plants the height of pod and ear insertions were determined.

The biomass production in the beginning of the corn growth in the last crop (2004/05) was determined by cutting five plants in sequence approximately one centimeter from soil, on day 35 and 47 after the emergence and determining the dry matter by putting the plants in a forced air

oven at 65°C until constant weight.

Before statistical analysis the discrepant data (outliers) were eliminated after being identified through the criterion of standard normal distribution, using the criterion of more or less three times the standard deviation. For the statistical treatment of the data, the variance analysis per year and crop was performed individually, using the randomized complete block design. In case of significant variance analysis, the Scheffé test was applied in order to evaluate the contrasts (Montgomery, 2001). A confidence level of 5% was considered. The contrasts are presented in Table 6. The statistical analyses were done in the software R 2.1.1 (R Development Core Team, 2005).

Table 6 - Contrasts used in the evaluation of experimental data and objectives.

Contrast	Objective	Treatments†
I	To evaluate the effect of fertilization	1,2,3,4,5,6,7,8,9 vs 10
II	To evaluate the fertilization in the winter comparing to summer	1 vs 8
III	With P application in the winter, to compare the NK application in the winter with the summer application	1 vs 3
IV	With P application in the winter, to compare the NK in furrow with NK in total area in the summer	2 vs 3
V	To compare P from natural phosphate with soluble P	2 vs 4
VI	To compare NP in furrow with NP out of furrows in summer	5 and 6 vs 7 and 8
VII	To compare furrowing devices	5 vs 6
VIII	To evaluate the K application in furrows comparing to K out of furrows	5 and 6 vs 9
IX	To compare NPK in bands with NPK in total area	7 vs 8

†According to Table 4.

RESULTS AND DISCUSSION

The effect of treatments for soybean variables occurred only in the plant population (Pop) in 1998/99 and 2003/04 and on the TGM in 2003/04 (Table 7). However, the contrast analyses done for this crop did not show significance for all crop yields (Table 8) and for the other variables (data not shown). There was no effect of fertilizer over soybean yields (Table 8), which were higher than Parana state average (from 2,550 to 2,880 kg ha⁻¹) for the period studied (Conab, 2006) as well as the regional yield of the last three agricultural years evaluated in this study, which varied from 2,360 to 3,040 kg ha⁻¹ (SEAB, 2006). The high yields could be related to the climate

conditions, soil fertility and independence of soybean from N fertilizer. The climate conditions was favorable for the crop development with the exception of a slight drought in February 2005, during the reproductive stage for the soybeans, which probably contributed for the average yield to be lowest to this agricultural year (2004/05) for soybean compared to others. The condition of soil fertility was good with low soil acidity, high and medium content of available P and K, respectively. In this condition of P and K soil availability, the average yield increase for soybeans (obtained with fertilization) varied from 1.3 to 11% (Table 8), according with Raij et al. (1996) who observed an increase of 10% for medium soil K.

Table 7 - P-values of variance analyses (ANOVA) for soybean, corn and common bean variables.

Crop	Season						
	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05
Soybeans†							
Yield	0.56	-	-	0.07	-	0.57	0.5
TGM	0.79	-	-	0.6	-	0.03*	0.12
Pop	0.0008***	-	-	0.08	-	0.04*	0.16
Pheight	0.07	-	-	-	-	-	-
Epod	0.88	-	-	-	-	-	-
Corn							
Yield	2.8e-06***	3.2e-09***	-	5.8e-08***	3.4e-10***	-	7.7e-10***
TGM	0.003**	0.001**	-	0.002**	1.8e-09***	-	0.006**
Pop	0.000003***	0.49	-	0.003**	0.89	-	0.39
Ears	1.0e-05***	0.03*	-	0.12	0.84	-	0.16
Pheight	-	0.0002***	-	-	8.1e-06***	-	-
Eheight	-	1.4e-05***	-	-	0.0001***	-	-
DM1	-	-	-	-	-	-	0.006**
DM2	-	-	-	-	-	-	0.0003***
Common bean							
Yield	-	8.9e-06***	0.03*	-	0.1	0.03*	-
TGM	-	0.26	0.03*	-	0.53	0.08	-
Pop	-	0.04*	0.07	-	0.005**	0.002**	-

†TGM: thousand grain mass; Pop: plants per ha, Ears: ears per ha; Pheight: plant height; Epod: height of first pod insertion; AltEsp: height of ear insertion; DM1 and DM2: dry matter of 3 plants day 35 and 47 after emergence, respectively.

Table 8 - Effect of fertilization in the yields (kg ha⁻¹) of corn, soybean and common bean (contrasts using the Scheffé test).

Crop	Contrast†	Season						
		1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05
Soybeans								
	Trat 10	3,130	-	-	3,211	-	3,180	2,869
	vs.	ns‡			ns		ns	ns
	Other trat	3,171	-	-	3,564	-	3,245	3,031
Corn								
	Trat 10	4,355	5,997	-	6,165	6,004	-	4,051
	vs.	*	*		*	*		*
	Other trat	7,328	10,450	-	10,280	10,215	-	8,330
Common bean								
	Trat 10	-	2,488	2,724	-	2,612	2,138	-
	vs.		*	ns		ns	ns	
	Other trat	-	3,615	3,246	-	3,012	2,723	-

†Treat 10: average of the treatment without fertilizer; others treatments: average over all treatments, except the treatment 10; ‡ P: * <0.05, ns: not significant.

No difference among fertilizer application methods was also obtained by Oliveira et al. (1992) and Lantmann et al. (1996). Working with a Rhodic Ferralsol with high P and K content, Lantmann et al. (1997) found that in the succession wheat/soybean the application of 50 kg ha⁻¹ of P₂O₅ and 30 kg ha⁻¹ of K₂O only in the

wheat crop was enough to keep the yield similar to the treatment that had fertilizer for soybean (60 kg ha⁻¹ of P₂O₅ and 100 kg ha⁻¹ of K₂O) and in the wheat (50 kg ha⁻¹ of P₂O₅ and 30 kg ha⁻¹ of K₂O) during four years. In the areas with 10 years of no-tillage system and in rotation corn/soybean, Buah et al. (2000) observed equal or higher yields for

soybeans when P and K were applied superficially compared to the furrow application, suggesting that corn and soybean fertilizer could be performed totally in the corn for soil with high or very high nutrients availability. These results indicated that in the areas with high content of P and K, the system fertilization can be implemented for soybean, where nutrient application could be performed independent on its kind (furrow or surface) and in precedent crops, supporting Parana state recommendation (EMBRAPA, 2006).

No difference between no-fertilized (treatment 10) and fertilized soybean crop (Tables 8) even after seven years suggested a high extraction capacity for residual fertilization of this crop. In contrast, Lantmann et al. (1996) found that it was possible to relinquish the soybean fertilization only when the wheat was fertilized. What can explain the difference in the obtained results is the kind of soil in these studies, due to the different P and K availability for the plants. Martins et al. (2004) observed a great variation in the potential supply of K from non-exchangeable form to wheat plants in soils of the region from actual work, where up to 54% was absorbed by the plants. In their study, in Haplohumox, the non-exchangeable K contributed with 10%.

The superficial nutrient concentration and the higher moisture in this layer due to the presence of straw (Muzzili 1983; Stecker et al., 1988) could also contribute positively to the nutrient absorption by the soybean and consequently affect the absence of effects of the fertilizer application, besides the favorable climatic conditions during the crops (Tables 1 and 2). Lack of significant difference occurred between the furrow devices over yield and other variables, possibly indicating the absence of physical limitation.

Like soybean, the yields for common bean were superior to the average of the Parana state that varied from 850 to 1,340 kg ha⁻¹ in the same period in which this study was done (Conab, 2006) or in this region, from 1,290 to 1,840 kg ha⁻¹ in the last two agricultural years this study evaluated (SEAB, 2006), respectively. Considering that the common bean yield in the treatment without fertilizer was always inferior (Table 8), although there was no significance in the crops 2000/01, 2002/03 and 2003/04. This difference also could be due to N application considering that the treatment without fertilizer (Treatment 10) this nutrient was not applied. On average, the treatment

propitiated yields 27% higher than the one without fertilizers.

Differently from the results for soybeans, the treatment affected the common bean yield in three of the four evaluated crops (Table 7). The same occurred to the final plant population while the TGM was affected only in the crop 2002/03. However, in the contrast analysis (Table 8), only the yield in the first agricultural year was significant to the contrast I, which compared the treatment without fertilizer (treatment 10) with the other ones.

In general, the common bean plant is considered as highly affected by P (Fageria et al., 2004) and lowly affected by K (Sguário Jr., 2000). This suggests that the fertilization effects were especially due to P or even N. Common bean yield response to N application has been shown to be variable with positive results (Silveira and Damasceno, 1993; Barbosa Filho and Silva, 2000) or no effect (Arf et al., 1999). It is important to define which is the minimum P dose demanded for each season and the remainder can be applied in other culture or in the same season, considering the crop rotation adopted.

Corn was the only crop in which the yield and TGM were affected by the treatments in all the evaluated years (Table 7). The yields (Table 8) were highly superior to the state average (from 3,780 to 5,600 kg ha⁻¹) in the same period in which this data was developed (Conab, 2006), and higher than the regional yield in the last three years of this study which varied from 6,360 to 6,700 kg ha⁻¹ (SEAB, 2006). This demonstrates the high productive potential of this crop in the region. Yield and TGM increased with fertilization according to the contrast analyses presented in Tables 8 and 9, without significant difference between the application strategies (data not shown).

Just as for the common beans, these results could be attributed partially to N, which was not applied in the treatment without fertilizers, since corn was highly affected to the application of this nutrient (Pauletti and Costa, 2000; Fontoura, 2005). The lack of a treatment in which the covering N rate were kept, did not allow the quantification the isolate effects in the absence of N in the fertilization in the sowing. Furthermore, the need of higher N level during the sowing under no-tillage is well documented (Sá, 1995b; Fontoura, 2005), without causing seed damage (Fontoura et al., 1999; Tessaro et al., 2000).

Table 9 - Effect of fertilization on the thousand grain mass (g) for corn (contrasts using the Scheffé test).

Contrast†	Season				
	1998/99	1999/00	2001/02	2002/03	2004/05
Trat 10	257	322	346	311	273
vs.	*‡	*	*	*	*
Other trat	290	369	392	393	307

†Trat 10: average of the treatment without fertilizer; Other trat: average of all treatments, except the treatment 10; ‡ P: * <0.05.

Working with a clayey oxisol with high P content under no-tillage and in the same region of actual work, Sá (2004) obtained increases between 8 and 19% in the accumulated yield of two corn crops in rotation with wheat and soybean when applying P in furrows. This yield increment was far below than near 70% observed in this work (Table 8) what reinforced the possibility of larger effects of N. Nevertheless, considering other comparisons among the treatments, one could infer that the starter fertilization in the corn crop could be performed with furrowing devices, period and application ways, in agreement with Bordoli and Mallarino (1998) who studied P and with Pavinato and Ceretta (2004) who studied the ways and periods of P and K application in a succession of wheat/corn.

Similarity of response between P sources evaluated could be related to extractable P level since high P contents in soil generally favor equality between the soluble sources and natural phosphates (Sousa and Lobato, 2004).

The presence of the K application in furrows also did not interfere in the yield and other evaluated variables, disagreeing with Fancelli and Dourado Neto (2005), who did not recommend to apply doses up to 50 kg ha⁻¹ of K₂O through KCl due to its saline effect. Heckman and Kamprath (1992), working in sandy soil with high K content where K was broadcast applied and incorporated, with or without complementary application in the sowing

furrow, obtained an increase in the corn yield with K application only when there was hydric deficit with no difference for the way of application.

The abundance of straw on the soil surface of experimental area also could influence the nutrient availability for corn, as observed by Yibirin et al. (1993). The authors found reduction of K response and plant demand by this nutrient applied in the furrows, where a larger amount of straw was found on the surface due to the higher root growth in those plants.

The corn dry mass at the beginning of the crop development was influenced significantly by the treatments (Table 7), with lower values occurring in the treatment without fertilizer (Table 10). But the contrast analysis, therefore, was not significant (data not shown), which disagreed with several studies that although did not find differences in corn yield, obtained significant biomass accumulation in the initial phases of the crop development when the fertilizer was applied locally (Anghinoni, 1992; Model and Anghinoni, 1992; Silva et al., 1993; Bordoli and Mallarino, 1998; Mallarino et al., 1999; Kaiser et al., 2005). The high P and medium K contents in the soil and the superficial concentrations of these nutrients, associated to the high initial moisture due to regular rainfalls occurred in the beginning of the crop development (Table 2- year 2004 and 2005), could justify the difference of this study compared to the others.

Table 10 -Average dry mass per corn plant (DM), due to the strategy of fertilization.

Trat	1	2	3	4	5	6	7	8	9	10
	Dry mass - g plant ⁻¹									
DM1†	5.7	6.7	6.7	6.3	8.4	7.8	7.6	6.6	6.6	4.9
DM2†	25.2	30.3	33.1	24.6	33.9	28.7	35.3	29.9	27.4	20.7

†Dry mass per plant in the 35 (DM1) and 47 (DM2) days after emergence.

The final number of plants was lower in the treatment without fertilizers (treatment 10) compared to other treatments only in the season 1998/99 and 2001/02, while the final number of ears was lower in treatment 10 compared to the others only in the season 1998/99 (Table 11), possibly due to the less nutrient availability to the plants in treatment 10. The plant height and ear insertion for corn were also influenced in the two seasons in which these variables were measured (Table 7), differences occurring only with applying fertilizers (Table 11). Possibly these higher values for the number of plants and ears

and plant height are related mainly to the N covering application.

The temperature (Table 1) seemed to have no effect in the methods of application, as suggested by Stecker et al. (1988).

Considering the data obtained in this work, the fertilization in the no-tillage system can be performed independent of period and method of application, using natural phosphate as P source and with or without the application of K in furrows for the studied region when the P content was high and K content was medium in the soil.

Table 11 - Effect of fertilization in the plant number (Pop) and ears (Ears) per hectare and in the plant height (Pheight) and ear insertion (Eheight) for corn (contrasts using the Scheffé test).

Contrast†	Season		Contraste†	Season	
	1998/99	2001/02		1999/00	2002/03
	Value	Value		cm	cm
Pop			Pheight		
Trat 10	43438	48750	Trat 10	200	190
vs.			vs.	*	*
Other trat	59462	61904	Other trat	217	217
Ear			Eheight		
Trat 10	43750	56250	Trat 10	90	91
vs.	*	ns	vs.	*	*
Other trat	57836	61319	Other trat	109	113

††Trat 10: average of the treatment without fertilizer; Other trat: average of all treatments, except the treatment 10.

‡ P: * <0.05; ns= not significant

CONCLUSIONS

The results obtained in this study indicated that the soybean crop was not affected by fertilization with P and K for at least seven years when the contents of P and K were high and medium in the soil, respectively. The corn and common bean yield were increased by nitrogen, phosphorus and potassium application. The application of fertilizers for soybean, corn and common bean in the established no-tillage system and with high P content and medium K content could be performed independent of the localization (furrow or total area) and period (winter and summer). Although there was medium K content, there was no need to apply this in the sowing furrow, not even the presence of this nutrient in the furrow interfered negatively on the yields of corn, common bean and

soybean. The natural phosphate provided the same yield as triple superphosphate provides for these crops. The furrowing devices with double disk or coulter had similar results for corn, common bean and soybean. The corn dry mass in the beginning of the crop development was not influenced by the localization and period of fertilizer application.

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RESUMO

Dois ensaios foram conduzidos simultaneamente a campo entre os anos de 1998 e 2005, em um Latossolo bruno, no sul do Brasil. O objetivo foi avaliar o efeito de estratégias de aplicação de adubo mineral de semeadura sobre a produtividade de milho, soja e feijão, bem como sobre o acúmulo inicial de matéria seca no milho, em uma rotação de culturas e no sistema plantio direto. A ausência de aplicação de fósforo e potássio por sete anos não diminuiu a produtividade da soja, mas a aplicação destes nutrientes e nitrogênio aumentou a produtividade de milho e feijão. Para soja, milho e feijão, sob sistema plantio direto e altos teores de fósforo e médios de potássio, a adubação de semeadura pode ser realizada de todas as formas avaliadas e em qualquer época considerada. A presença ou não de potássio no sulco, as fontes de fósforo e os mecanismos sulcadores proporcionaram produtividades semelhantes de milho, soja e feijão.

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