Original Paper Open Access

Maize (*Zea mays* L) cultivars nutrients concentration in leaves and stalks

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Abstract

There is pressure for crop residue removal for use as biofuel, animal feed, animal bedding and many other functions which may increase nutrient export. However, there is little information about nutritional composition of maize stover considering the wide variability of cultivars used. The aim of this study was to evaluate the influence of maize cultivar on macronutrient (P, K, Ca, and Mg), micronutrient (Fe, Mn, Zn, and Cu) and Na concentration in leaves and stalks. We selected five pairs of cultivars, ranging from creole to high potential hybrid (creole, commercial variety, single, double and triple cross hybrid). The cultivars were cropped under field conditions in high fertile Rhodic Ferralsol Eutric during two growing seasons. The first was characterized by severe drought (2005/2006) while the second with an abundant water supply (2006/2007). The leaf and stalk concentrations of P, K, Ca, Mg, Fe, Mn, Na, Zn, Cu, and C/P ratio were quantified at maturation stage. The results indicated that the P concentration in leaves and stalks was inversely related to the technological level when simple hybrid was compared to creole cultivars. Similar behavior was observed for K in the leaf and stalk tissues. For Ca, Mg, Fe, Mn, Zn, Cu, and Na, it was not possible to establish the influence of maize selection. The C/P ratio of leaves and stalks underwent influence of the technological level with high values for simple hybrids. Maize selection seems to decrease P and K concentration for two major residue fractions, leaves and stalks.

Keywords: biofuel, macronutrients, micronutrients, genetic selection, C/P ratio

Introduction

The replacement of traditional cultivars by genetically modified hybrids, is one the most important tools to increase maize yield (Santos et al, 2012). In general, over the last 10 years, hybrids represented most of maize cultivars available for farmers, while commercial varieties and creole represented a small fraction of the area planted with maize in Brazil.

The great enhancement in maize yield observed in recent years has resulted in an increase of the amount of crop residue on the field. In addition, competition provided by globalization and occurrence of economic crises has been driving the farmers to use crop residue as a potential extra source of income (Wilhelm et al, 2004). The maize residues also have been used for cattle grazing under the integrated crop-livestock system (Sulc and Tracy, 2007). In this case the knowledge of the residue nutrients concentration is important to establish the animal nutrition. However, different from the harvesting and selling process, grazing provides a return of the majority of the nutrients to the soil in the form of liquid and solid animal waste. There is a great concern, however, involving the economic aspect given by the increase of necessary fertilizer as result of the increase of the amount nutrient extraction from the field (Avila-Segura et al, 2011). Also, soil conservation needs to be evaluated since crop residues are essential for conservation systems, such as the no-till (Wilhelm et al, 2004; Blanco-Canqui and Lal, 2009).

On one hand, the nutrient grain concentration and the productivity can be used to determine the nutrient extraction and exportation, which is important to establish the necessity of nutrient reposition by fertilizer (Heckman et al, 2003). On the other hand, the nutrient concentration and amount of leftovers, as crop residues, can determine the amount of nutrients returned to the soil by washing or decomposition processes, with a high importance for nutrient cycling (Moschler et al, 1972). For the nutrients that have their cycle associated to the organic fraction such as N, P, and S, their relative concentration with C in the crop residue is important, determining the predominance of the immobilization and mineralization process (Zibilske

RECEIVED 12/20/2013

Table 1 - Chemical properties of soil (0 - 10 cm) before planting in the growing season of 2005/2006 and 2006/2007.

Growing season	pH ($CaCl_2$)	OM ($g\ dm^{-3}$)	P ($mg\ dm^{-3}$)	Ca	Mg	K ($cmol_c\ dm^{-3}$)	Na	Al	H+Al	V (%)	Mn	Fe	Cu ($mg\ dm^{-3}$)	Zn
2005/2006	6.0	28.4	24.5	10.6	3.4	1.0	0	0	3.2	82	268	86	33	13
2006/2007	5.9	29.1	40.3	6.5	2.6	0.8	0	0	3.1	76	308	67	24	12

pH ($CaCl_2$ 0,01 mol L^{-1}); organic matter (OM) (Walkley-Black); P, K, Na, Mn, Fe, Cu, and Zn (Mehlich-1 extraction); Ca, Mg, Al (extracted with KCl 1 mol L^{-1}); H + Al (calcium acetate 0,5 mol L^{-1} extraction)

and Materon, 2005) and, consequently, their short or long term availability to the plants.

There are few research works that have studied the influence of maize genetic selection on the residue nutrient concentration, as has been studied for grains. Thus, the objective of this study was to evaluate the influence of the cultivar on the concentration of the macronutrients (P, K, Ca, and Mg), micronutrients (Fe, Mn, Zn, and Cu), and Na from maize leaves and stalks.

Materials and Methods

Field experiments were conducted during the 2005/06 and 2006/07 growing seasons at the Monsanto Company Experimental Station in Rolândia county (23°16'S, 51°28'W, 645 m altitude), Paraná State, southern Brazil. The soil is classified as a Rhodic Ferralsol Eutric (FAO, 2006) and the climate is classified as Cfa according to the Köppen classification.

Before the plantation, samples had been collected until the depth of 10 cm for chemical analyses. The samples were air dried, ground, homogenized, passed through a 2 mm sieve and analyzed chemically. The results are presented in Table 1.

In both years, cultivars were sown in a randomized complete block design with five replications, using six-row plots 10 m in length. Row width was 0.80 m, plant spacing within rows was 0.20 m, and the established plant population was 62,500 plants ha^{-1}. Fertilizer providing 28 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 70 kg K_2O ha^{-1} was applied prior to sowing. Plots were hand-planted at two seeds per hole, and thinned to the desired plant population at the V2 stage. To minimize N restrictions, urea was supplied at 135 kg N ha^{-1} at the four-leaf stage (V4). Plots were kept free of weeds, insects, and diseases following recommended practices for the region.

Five pairs of maize cultivars representing different degrees of breeding selection development were selected. The pairs were: (1) creole [Palotina and Tupy Pyta Sopé (GI045)]; (2) commercial varieties (BR106

Table 2 - Macronutrient concentrations for leaf fractions of ten maize cultivar of five different technological levels in the growing season of 2005/2006 and 2006/2007.

Treatment		P ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)	Ca ($g\ kg^{-1}$)	Mg ($g\ kg^{-1}$)
			2005/2006		
Simple	AG9010	0.44 f	8.9 c	2.81 e	1.37 d
Hybrids	DKB950	0.45 f	9.4 c	2.78 e	1.48 d
Triple	DKB566	0.68 e	13 b	3.03 de	1.93 c
Hybrids	AG5020	1.07 a	14 ab	4.01 a	2.31 b
Double	AG2040	0.91 bc	13 b	3.33 bcd	1.91 c
Hybrids	DKB979	0.75 de	14 ab	3.97 a	1.90 c
Improved	BRS4157	0.81 cd	13 b	3.66 ab	2.69 a
Varieties	BR106	0.86 cd	13 b	3.47 bc	2.11 bc
Creole	GI045	1.09 a	14 ab	3.15 cde	2.31 b
Cultivars	Palotina	1.01ab	14 ab	3.17 cde	2.25 bc
Coefficient of variation		12	9.4	8.9	12.8
			2006/2007		
Simple	AG9010	0.77 c	3.5 d	2.45 b	1.18 c
Hybrids	DKB950	0.88 bc	3.4 d	1.66 b	1.22 bc
Triple	DKB566	1.06 ab	6.2 ab	1.69 b	1.39 abc
Hybrids	AG5020	1.17 a	5.1 bc	4.81a	1.46 abc
Double	AG2040	1.15 a	4.4 cd	3.35 ab	1.84 a
Hybrids	DKB979	1.09 ab	5.5 bc	3.53 ab	1.25 bc
Improved	BRS4157	1.16 a	5.8 abc	3.65 ab	1.71 ab
Varieties	BR106	1.06 ab	5.7 abc	1.71 b	1.24 bc
Creole	GI045	1.21a	6.5 ab	1.77 b	1.49 abc
Cultivars	Palotina	1.26 a	7.0 a	1.47 b	1.28 bc
Coefficient of variation		17.3	19.2	60.9	25.1

Averages followed by the same letter in the column do not differ among themselves by the Duncan test ($p > 0.05$).

and BRS4157); (3) double cross hybrids (AG2040 and DKB979); (4) triple cross hybrids (AG5020 and DKB566); and (5) single cross hybrids (AG9010 and DKB950). Additional information about maize cultivars are available in Santos et al (2012).

An on-site weather station recorded daily air temperature and rainfall throughout each season. Meteorological conditions differed between the two growing seasons. Historical averages of total rainfall in December, January and February are between 200-225 mm, 200-225 mm, and 150-175 mm, respectively. During the 2005/06 season, total rainfall in December, January and February was 80, 56, and 367 mm, respectively. In the 2006/07 season, the respective totals for these months were 226, 398, and 172 mm (Supplementary Figure 1).

At the final harvest, fifteen whole plants were sampled from the second and fifth rows of each plot. Plants were separated into leaf and stalk fractions of the ten maize cultivars, ground and subjected to dry digestion in porcelain crucibles for six hours at 500 °C with solubilization of the ash with HCl 3N. Phosphorus was determined colorimetrically using an UV/VIS Spectrophotometer. Calcium, Mg, Fe, Mn, Zn, and Cu were determined by Atomic Absorption Spectrophotometry while K and Na were determined by Flame Spectrophotometry. Plant tissue samples evaluated were ground in a Wiley mill to pass through a 1.0 mm screen. Subsamples were analyzed in triplicate to determine the C concentration via the dry combustion method using a CN-2000 LECO Instrument (LECO Corporation, St. Joseph, MI). With the values of C and P the C/P ratio was obtained.

As previously stated, the study was a randomized complete block design with five replications. The obtained values were submitted to analysis of variance (ANOVA) and averages compared by the Duncan test with the level of 5 % of variance ($p < 0.05$), to separately characterize the differences between the maize cultivars for each growing season.

Results and Discussion

There was a difference for all macronutrient concentrations among the maize cultivars in both the growing season and plant tissues evaluated (Table 2 and 3).

The genetic selection had a great influence on the P concentration, in general, the rise in the technological level propitiated a decrease in the concentration of this element in leaf and stalk tissue. It was observed that simple hybrids had lower concentrations of P in leaves and stalks than creole cultivars and improved varieties. An exception was observed when the simple hybrid (DKB950) was statistically similar to improved varieties (BR106) for leaf tissue (2006/2007). Thus, by comparing the most selected maize cultivars with massive farm selection confirm the change P concentration. However, when com-

Table 3 - Concentration of macronutrients in the stalk fraction in ten cultivars of maize of five different technological levels in the growing season of 2005/2006 and 2006/2007.

Treatment		P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})
			2005/2006		
Simple	AG9010	0.38 e	17 cd	1.10 b	1.64 ab
Hybrids	DKB950	0.41 e	19 de	1.17 b	1.68 ab
Triple	DKB566	0.59 d	22 bcd	1.08 b	1.23 b
Hybrids	AG5020	0.91 ab	15 e	1.31 ab	1.73 ab
Double	AG2040	0.83 bc	21 cd	1.26 ab	1.66 ab
Hybrids	DKB979	0.54 d	22 bcd	1.20 b	1.36 b
Improved	BRS4157	0.77 bc	27 a	1.48 a	1.83 a
Varieties	BR106	0.74 c	25 abc	1.22 b	1.40 bc
Creole	GI045	0.98 a	26 a	1.24 ab	1.56 abc
Cultivars	Palotina	0.99 a	23 abcd	1.12 b	1.51 abc
Coefficient of variation		14.1	15.1	14.8	16.5
			2006/2007		
Simple	AG9010	0.74 c	21 c	0.50 c	1.00 ab
Hybrids	DKB950	0.71 c	28 abc	0.56 bc	0.99 ab
Triple	DKB566	0.90 bc	34 ab	0.78 abc	0.79 bc
Hybrids	AG5020	0.72 c	26 abc	0.69 abc	1.08 a
Double	AG2040	0.89 bc	23 bc	0.64 abc	0.92 abc
Hybrids	DKB979	1.13 ab	30 abc	0.80 ab	0.96 abc
Improved	BRS4157	1.20 ab	34 a	0.84 a	1.03 ab
Varieties	BR106	1.14 ab	29 abc	0.72 abc	0.95 abc
Creole	GI045	1.27 ab	33 ab	0.66 abc	0.99 ab
Cultivars	Palotina	1.45 a	28 abc	0.55 bc	0.71 c
Coefficient of variation		26.9	25.2	27.8	19.3

Averages followed by the same letter in the column do not differ among themselves by the Duncan test ($p > 0.05$).

Table 4 - Concentration of Cu, Fe, Mn, Zn, and Na in the leaf fraction in ten cultivars of maize of five different technological levels in the growing season of 2005/2006 and 2006/2007.

Treatment		Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Na (mg kg^{-1})
				2005/2006		
Simple	AG9010	11.03 a	141 a	64.7 abc	22.6 a	111.9 a
Hybrids	DKB950	6.92 a	162 a	65.0 abc	17.6 a	81.0 a
Triple	DKB566	7.10 a	197 a	51.6 c	19.4 a	89.9 a
Hybrids	AG5020	7.27 a	195 a	80.7 a	22.4 a	96.3 a
Double	AG2040	8.44 a	159 a	74.5 ab	23.9 a	99.1 a
Hybrids	DKB979	8.14 a	186 a	69.6 ab	19.7 a	94.1 a
Improved	BRS4157	8.99 a	165 a	78.4 a	20.8 a	97.8 a
Varieties	BR106	7.21 a	164 a	60.6 bc	17.5 a	103.7 a
Creole	GI045	8.86 a	179 a	60.8 bc	22.7 a	101.6 a
Cultivars	Palotina	9.63 a	204 a	59.4 bc	22.0 a	93.5 a
Coefficient of variation		40.8	36.6	17.3	25.4	22.2
				2006/2007		
Simple	AG9010	5.68 ab	196 abc	64.4 cd	9.9 a	45.8 a
Hybrids	DKB950	6.17 ab	196 abc	70.3 cd	12.2 a	43.8 a
Triple	DKB566	4.84 ab	181 abc	57.7 d	15.4 a	51.7 a
Hybrids	AG5020	6.42 a	256 ab	84.7 ab	9.7 a	43.8 a
Double	AG2040	6.36 ab	256 ab	69.7 cd	16.3 a	47.8 a
Hybrids	DKB979	5.70 ab	171 bc	68.0 cd	12.8 a	53.7 a
Improved	BRS4157	5.88 ab	301 a	86.5 a	14.0 a	53.7 a
Varieties	BR106	5.14 ab	115 c	76.5 abc	10.5 a	45.8 a
Creole	GI045	4.51 b	152 bc	72.9 bc	11.7 a	49.8 a
Cultivars	Palotina	4.88 ab	191 abc	66.7 cd	11.3 a	43.9 a
Coefficient of variation		22.7	43.8	13.1	48.5	27.4

Averages followed by the same letter in the column do not differ among themselves by the Duncan test ($p < 0.05$).

paring other hybrids (triple and double) with creole cultivars was partially true, result of the high variation within the same selection level.

Working with the same data, Santos et al (2012) obtained higher grain production as a result of plant selection, in the following order: hybrids > improved varieties > creole cultivars. However, the authors found lower concentrations of N in grain and residues of maize selected for high yield. The reduction in the grain nutrient concentration by plant breeding was observed previously for maize (Feil et al, 2005), wheat (Murphy et al, 2008) and barley (Bingham et al, 2012). In short, changes in grain quality in new cultivars also seems to impact on crop waste.

As for P, the diminished leaf K concentration was the result of the genetic improvement provided, simple hybrids having lower values than creole cultivars and improved varieties. In addition, single cross maize hybrids showed the lowest values among hybrids. The effect on the K concentration in stalks was less evident, without influence of technological level, only the cultivar.

The low P and K concentration in leaves and stalks could be associated to better distribution of both elements to the grain or their high use efficiency by new cultivars. Corroborating with these results, Santos et al (2012) found a high C use efficiency for simple hybrids. They verified C harvest index with value of 0.21 and 0.49 for simple hybrids and 0.03 and 0.28 for creole cultivars, for the first and second growing season. The divergence between growing season was due to the first (2005/2006) having undergone water deficiency in reproductive period, drastically reducing grain yield similar to that recorded by Feil et al (2005) and Chimenti et al (2006).

On one hand, the low concentration could decrease the impact of the entire residue removed from the field, diminish the nutrient necessity and reposition cost. So, it is important since the extra cost of nutrient reposition might be major key factor for biofuel use of the residue (Avila-Segura et al, 2011). On the other hand, the low concentration for the simple hybrids may decrease the quality of the residue as animal feed under the integrated crop-livestock system as proposed by Sulc and Tracy (2007). However, under all conditions the residue P concentration did not reach the 2.5 g kg^{-1}, necessary to completely supply the animal requirements by using only residue as food (NRC, 1996). Thus, nutrient supplementation will be necessary. The opposite might be observed for K, since the same authors suggest a dry matter value of 4.9 g kg^{-1}. The selection of a cultivar with low P and K concentration might be desirable when the residue will be removed from the field, such as for biofuel use. However, the opposite should be done for direct animal grazing.

Maize selection affected leaf Ca and Mg concentration, since simple hybrids got the lowest values for the first growing season (2005/2006). However, the technological level was not decisive for the values in the stalks, only varying between maize cultivars. A higher concentration of Ca (1.47-4.81 g kg^{-1}) was observed in leaves than Mg (1.18-2.69 g kg^{-1}), in both growing season. In contrast, the Ca concentration (0.50-1.48 g kg^{-1}) in stalks was lower than Mg (0.71-1.83 g kg^{-1}).

Although there was a high variation for all nutrient concentrations, in general, the values obtained for Ca and Mg were lower than average, 3.0 and 2.6 g kg^{-1}, respectively, observed by Avila-Segura et al (2011), combining leaf, stalk and husk residue. The values for observed Mg suggest that the leaves and stalks could meet the requirements for beef cattle since the animal requirement is 1 g Mg kg^{-1} dry mater (NRC, 1996). But, the Ca requirement may not be entirely supplied by leaf and stalk tissue consumption since the requirement is 2.0 to 5.2 g Ca kg^{-1} dry matter (NRC, 1996).

The micronutrients and Na concentrations for leaf fractions (Table 4) indicated that there was a difference among maize cultivars for Mn in the 2005/2006 growing season and Cu, Fe and Mn in 2006/2007. For the stalks (Table 5) there were differences in Fe and Mn concentrations in the 2005/2006 harvest and Fe concentration in the 2006/2007 harvest. Despite the difference among tested cultivars, there was no evidenced of changes resulting from technological levels on concentration of micronutrients and Na in the maize fractions.

The concentration of Fe found in the leaves and stalks was higher than 50 mg kg^{-1} (NRC, 1996) which is the minimum concentration required by cattle. Therefore, both tissues can supply the amount of Fe necessary for animal growth. For Mn, only the stalk fraction had a concentration below of minimum required by cattle (30 mg kg^{-1}). In general, the Cu concentration found in leaf and stalk tissues were below 10 mg kg^{-1}, indicating that supplementation is necessary to meet the animal needs. Also, the results indicated the necessity of Zn and Na supplementation since all values were below 30 and 450 mg kg^{-1} (NRC, 1996).

As P, the C/P ratio of the cultivars varied in both the growing season and evaluated tissues (Table 6). The simple hybrids showed higher a concentration than Creole cultivars and improved varieties, with the exception of C/P in the leaves for BR106 in 2006/2007. This result was the combination of the increase in C concentration (Santos et al, 2012) and decrease in the previously shown P concentration (Table 2 and 3). In general, the second year demonstrated a lower C/P ratio than the first due to P variation in the plant tissue. The values ranging between 343-1200, being close to those observed by Noack et al (2012) for residue (leaf and stalk mixture) of wheat (1106), barley (845), oats (766), rye (859), canola (902), and

Table 5 - Concentration of Cu, Fe, Mn, Zn and Na in the stalk fraction in ten cultivars of maize of five different technological levels in the growing season of 2005/2006 and 2006/2007.

Treatment		Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Na (mg kg^{-1})
			2005/2006			
Simple	AG9010	10.58 a	181 ab	14.4 b	23.8 a	133.0 a
Hybrids	DKB950	12.44 a	78 b	11.2 b	26.9 a	145.8 a
Triple	DKB566	8.35 a	202 ab	10.7 b	13.0 a	121.2 a
Hybrids	AG5020	11.94 a	82 b	11.3 b	15.3 a	118.2 a
Double	AG2040	14.65 a	438 a	23.5 a	23.5 a	137.3 a
Hybrids	DKB979	10.73 a	220 ab	12.7 b	15.5 a	120.0 a
Improved	BRS4157	12.86 a	222 ab	17.6 ab	19.2 a	132.6 a
Varieties	BR106	8.56 a	177 a	10.8 b	14.4 a	130.7 a
Creole	GI045	14.13 a	375 ab	17.2 ab	20.7 a	139.9 a
Cultivars	Palotina	9.53 a	236 ab	12.3 b	19.1 a	124.9 a
Coefficient of variation		39.1	92.9	41.6	49.4	23.6
			2006/2007			
Simple	AG9010	4.49 a	89 b	18.1 a	10.1 a	61.7 a
Hybrids	DKB950	4.13 a	95 b	19.1 a	10.2 a	63.6 a
Triple	DKB566	5.11 a	130 ab	19.1 a	8.5 a	67.5 a
Hybrids	AG5020	5.37 a	111 ab	20.2 a	8.9 a	63.7 a
Double	AG2040	5.17 a	119 ab	19.0 a	11.9 a	53.7 a
Hybrids	DKB979	5.14 a	93 b	18.0 a	11.2 a	67.6 a
Improved	BRS4157	5.27 a	102 b	20.3 a	12.0 a	67.6 a
Varieties	BR106	4.77 a	129 ab	20.1 a	10.9 a	67.6 a
Creole	GI045	5.45 a	149 a	19.5 a	9.8 a	67.8 a
Cultivars	Palotina	5.51 a	105 ab	18.4 a	11.2 a	59.9 a
Coefficient of variation		31.1	28	10.6	25.7	15.7

Averages followed by the same letter in the column do not differ among themselves by the Duncan test ($p < 0.05$)

Table 6 - Carbon and phosphorus ratio in the leaf and stalk fractions of ten cultivars of maize of five different technological levels in the growing season of 2005/2006 and 2006/2007.

Treatment		Leaves		Stalks	
		2005/2006	2006/2007	2005/2006	2006/2007
Simple Hybrids	AG9010	1021 a	592 a	1200 a	647 a
	DKB950	954 a	533 ab	1089 a	661 a
Triple Hybrids	DKB566	641 b	404 c	727 bc	514 abc
	AG5020	397 d	376 c	480 c	628 ab
Double Hybrids	AG2040	471 cd	374 c	525 c	537 abc
	DKB979	575 bc	407 c	945 ab	406 c
Improved Varieties	BRS4157	516 bcd	374 c	560 c	458 bc
	BR106	506 bcd	426 bc	576 c	414 c
Creole Cultivars	GI045	392 d	362 c	434 c	353 c
	Palotina	430 cd	353 c	425 c	343 c
Coefficient of variation		17	20	30	27

Averages followed by the same letter in the column do not differ among themselves by the Duncan test ($p< 0.05$)

peas (1102), but lower than beans (2227) and lupin (2087).

The values obtained for C/P for leaves and stalks were far above the 300/1 value from which the domain of the immobilization process in soil initiates and indicates the possibility of this process (Havlin et al, 1999). On the other hand, Noack et al (2012) emphasize that the P release prediction, using the C/P ratio is different from analogous predictions of N based on the C/N ratio. As the P be found in significant quantities in inorganic forms and that organic forms of P show higher diversity, both differing from predominant N-compounds in plants. However, the high C/P ratio could compromise the short-term P availability for plants and might lead to a decrease in yield for the subsequent crop, as was observed by Mukuralinda et al (2009).

Conclusions

The results obtained in this research indicated that the concentration of P and K decreased in two major residues, leaves and stalks, which may be associated to better efficiency of simple cross hybrids. For Ca, Mg, Fe, Mn, Zn, Cu, and Na, it was not possible to establish the influence of maize selection.

The observed increase in the C/P ratio for the simple hybrids should potentially the immobilization process which may compromise the P availability for subsequent crops. Further research is necessary to evaluate the influence of crop residue on P availability and velocity of residue decay.

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