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Study on phosphorus concentration of corn hybrids adapted in South Dakota, USA

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Abstract

This research aims to quantify the phosphorus (P) concentration in the commercially adapted ten corn hybrids in South Dakota and to determine if selection can be carried out for these traits to develop useful inbred lines; to determine the effect of planting densities on P concentrations and dry matter (DM) yields. Ten commercially adapted corn hybrids were planted, in randomized complete block design with three replications, in three different locations, and in two planting density. Results showed that hybrid were significantly different for phosphorus concentration. High population density plants contained low mean P concentration in the environments having high mean P concentrations. DM yields were highly dependent on hybrids' genetics but were altered by the environments where they were grown. Based on the results, it is possible to carryout selection based on P concentration without giving up DM yields. However, effect of environments should be considered while establishing a selection program, as P concentration of plants interacts with the environmental effects. It is suggested to include more and diversified germplasm for further study.

Key words: Phosphorus, Corn, Dry matter, phosphorus uptake, South Dakota

Introduction

Phosphorus (P) is vital nutrient elements to living beings for their growth and development (Barber et al., 1967; Jones, 1985, Kim et al., 2011). If it is present in excess amounts either in plants or animal, which in turn will go to the soil, they have an adverse impact to the environment causing eutrophication of water bodies (Wardyn, 2002; Johnson et al., 2007). In addition, it affects animal and human health. Concentration of P in corn plants plays a crucial role in intake of these nutrients by animals. Several studies have been done looking for the concentration of P in corn seeds (Baker et al., 1970; baker et al., 1971; Wardyn, 2002). However, there is no study on the concentrations of P on a whole plant basis for the use of silage.

Due to increase in use of alternative energy, ethanol industry is in the midst of a considerable expansion period in South Dakota and the surrounding states (Tjardes, 2002). There will be change in feeding habit of animals with increase of ethanol processing plants due to increased amounts of a highly nutritive feed byproduct, distillers grain (DG). Therefore, it is imperative to manage the intake of P by animals through silage. Thus development of silage corn plants low in P might be important avenue to reduce P intake.

Average planting rates for corn have been significantly increased in the past decades. Planting density is approaching 74,131 seeds ha^{-1} in some northern Corn Belt states (Paszkiewicz and Butzen, 2003). Significant study on the planting density and its effect on grain and silage yield; and silage quality parameters has been done in the past (Cusicanqui and Lauer, 1999; Roth et al., 2000; Schroeder, 2004). However, there is a dearth of research understanding planting density in terms of P concentrations in the whole plants.

Thus this study was designed to find out which hybrids have low and high concentration of P and to find the line that can be used for further breeding of low-P corn. Specific objectives are; 1) to quantify whole plant P concentration in commercially adapted corn hybrids in South Dakota; 2) to detect variance factors for P concentrations; 3) to identify the relationship between P concentration and DM yield 4) to identify the effect of plant population in P concentration, and DM yield and 5)to determine whether selection of corn varieties can be carried

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out for further development of inbred lines based on whole plant P concentration.

Materials and Methods

Experiment was conducted at the SDSU Agricultural Experimentation Stations at three locations, namely; Brookings Agricultural Research Station, Brookings (BKG), South East Research Station, Beresford (BSF) and North East Research Station at Watertown (WTN) in 2004 and 2005. Soil at all locations was of medium textured or even mixture of sand, silt, and clay. Soil type at Beresford was Egan-Clarno-Trent Complex with 0-6% slopes. Brookings had Vienna-Brookings Complex with 1-6% slopes (NRCS, 2006). Similarly, soil type at Watertown was Brookings Silty Clay Loam with 0-3 percent slopes (SDSU, 2005). Soil pH was approximately in the range required for the efficient uptake of P. Beresford had a pH of 5.9 in both years. Brookings had 6.4 and 7 soil pH in 2004 and 2005, respectively. Watertown had 6 and 5.7 soil pH in 2004 and 2005, respectively.

Ten hybrids that are commonly grown in the region were selected for the experiment. Hybrids used in the study, their relative maturity, recommended planting density, hybrid type and the seed companies which released them are listed in Table 1.

Table 1. Hybrids, their relative maturities, type, recommended planting density and the company which released them.

Hybrids	RM (days)	Recommended planting density	Seed Company	Hybrid type
2D601	106	Medium Low - Medium	Mycogen Seeds	Silage
2R570	104	High	Mycogen Seeds	Grain
34N43	110	34-36,000ppa	Pioneer	Grain
35Y54	105	34-36,000ppa	Pioneer	Grain
DKC50-18	100	Medium-high	DEKALB	Grain
DKC54-51	104	Medium-high	DEKALB	Grain
LG2463Bt	96	26-32,000ppa	LG Seeds	Silage
LG2489Bt	100	28-33,000ppa	LG Seeds	Silage
N67-T4	103	22-30,000ppa	Syngenta Seeds	Dual
N70-T9	112	22-30,000ppa	Syngenta Seeds	Grain

All locations were planted in conventionally tilled, rain-fed systems. Planting dates were determined when the air temperatures averages near 12-15° C (Shaw, 1988). Further, planting was synchronized with the surrounding corn fields' planting dates.

Experimental design was randomized Complete Block design with three replications. Each variety was planted in two rows of 40 seeds per row (73,398 plants ha^{-1}) for low population density and 48 seeds per row (93,910 plants ha^{-1}) for high population density. Length of the row was 6.08 m with row spacing of 0.762 m.

Proper moisture content of corn at harvest for silage is between 60-70%. This is during the stage when milk line is 2/3rd –1/3rd down the kernel (Roth et al., 1995; Bates, 1998). The plants were hand harvested by sickle when the milk line was 1/2nd – 2/3rd down the kernel. Further, harvesting time was synchronized with the surrounding area farmers' silage fields. Ten plants, five from each row, were randomly harvested from each hybrid at ground level. Harvested ten plants of each hybrid were combined and weighed in the field for wet weight. Samples were then cut and put into a sac in order to avoid loss of any plants parts. Plants were dried in a forced-air dryer at 32.2°C for 20-25 days after which dry weight measurement was taken. Dry matter yield was calculated based on wet weight and dry weight and expressed in Mg ha^{-1}. Plants were counted at the time of harvesting for plant stand calculations.

Dried plants were chopped and ground to powder using Wiley® Model 4 mill (Thomas Scientific, Swedesboro, NJ). Samples were then passed through a 1 mm sieve, from which a sub-sample was taken. Phosphorus concentration in samples were analyzed using spectrophotometric method used in SDSU Soil and Plant Analysis Laboratory; Vanado molybdo phosphoric Acid Digestion (VAD) method for P content (Barber et al., 1967; SDSU, 1995). Briefly, ground sample (0.25 g) was digested in nitric acid (5 mL) and percholic acid (2.5 mL) by heating at 200º C until the plant material was completely digested, vortexed and filtered through Whatman #41 filter paper. The extracted material (2.5 mL) was dissolved in 2.5 mL of Barton reagent and 20 mL of distilled water. Phosphorus was analyzed using spectrophotometer at 430 nm wave length. The Barton reagent was prepared as following. Solution A was prepared by dissolving 25g of ammonium molybdate in 400 mL of distilled water. Solution B was prepared by dissolving ammonium metavandate (1.25 g) in 300 mL of boiling water then cooled and 250 mL of concentrated HNO3 was added and cooled again at room temperature. The solutions A and B were mixed and the volume was maintained up to one liter and stored at room temperature. Phosphorus concentrations (in percentage) obtained from lab analysis was used to obtain P (g kg^{-1} DM^{-1}) in whole plants, in terms of dry matter, as by Pollmer et al. (1979). The P of the whole plant was expressed in terms of area and termed as P uptake respectively (Gallais and Hirel, 2004) and expressed in Mg ha^{-1}.

Data from the lab analyses and the field were analyzed by using SAS Ver.9 program. Analysis of variance (ANOVA) procedures were run over all locations for P concentration, dry matter yield, plant stand, and P uptake in 2004 and 2005. Test of homogeneity of error variance was done as per Gomez and Gomez (1984) before doing combined analyses of both years. Mean separation was done using least significance difference (LSD) test. Regression analysis was run for stability analysis of hybrids at each density and Pearson's correlation coefficient was calculated to find out the relatedness of the variables.

Information on weather at the experiment locations was obtained from the South Dakota Office of Climatology, SDSU, Brookings.

Results

Precipitation varied greatly across test locations (Table 2). Beresford received 404.62 mm of total rainfall during the period of April to September 2004. Similarly, Brookings and Watertown received, 524.76 and 546.86 mm total rainfall, respectively during the period of April to September 2004. In 2005, Beresford received 90.03 mm less rainfall than that of 2004 and Brookings received 119.13 mm less rainfall than that of 2004. However, Watertown received 191.26 mm more rainfall in 2005 than 2004 during the period of April to September.

Table 2. Mean DM yield and mean P concentrations at six environments, pooled over densities and hybrids.

Environments	Rainfall (mm)	Rank	Mean DM yield (Mg ha^{-1})	Rank	Mean P concentrations (gm kg^{-1} DM^{-1})	Rank
BSF04	404.62	4	21.211 a†	1	1.771 a†	1
BKG05	405.63	3	14.117 c	4	1.762 a	2
BKG04	524.76	2	11.505 e	6	1.535 b	3
BSF05	314.32	6	15.882 b	2	1.446 c	4
WTN05	355.60	5	14.457 c	3	1.360 d	5
WTN04	546.86	1	13.176 d	5	1.336 d	6
LSD $_{(0.05)}$			0.589		0.076	

†: Means with same lowercase letters within a column are not significantly different.

Phosphorus concentration was significantly different among hybrids ($P<0.0001$) and among plants grown at different environments ($P<0.0001$) in combined 2004-2005 analysis (Table 3). Though the main effect of density was not significant for P concentration, there was a significant ($P = 0.0066$) interaction effect of environment by density indicating that effect of plant density differs by location. Significant interaction of environment by density was due to the significant differences between the mean P concentrations of hybrids at two planting densities at environments BSF05 and BKG04 (data not shown). Similarly, the interaction of environment by hybrids was significant at the 0.05 probability level. BSF04 and BKG05 had the highest mean P concentration and WTN04 had the lowest P concentrations (Table 2). The P concentration of hybrids was not correlated with RM days. But the correlation between P concentration and DM yield was positive and significant (Table 4).

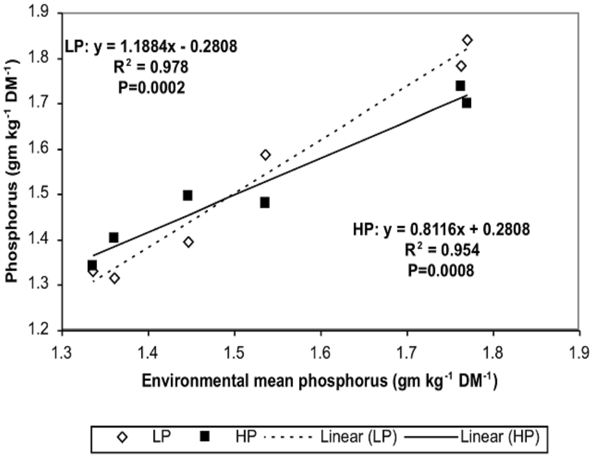

Figure 1. Stability of Phosphorus (P) concentration of corn hybrids in low planting density (LP) and high planting density (HP) across six environments, pooled over hybrids.

Linear regression analysis of P concentration shows the stability of P concentration of two different planting densities across six environments (Fig 1). The results suggest that the environmental mean P concentration is a strong predictor of a hybrid's P concentration for low density (b=1.188) rather than high density (b=0.812). Similarly, plants at higher densities tend to have lower P concentrations if environmental mean P concentration is higher. This is also supported by the significance of the t-test for difference in slopes of two planting densities which is significant at 5% level (P = 0.0173, $t_{0.05}$ = 2.99). Therefore, the mean P concentrations of the different planting densities are not same in all environments.

The main effect of hybrids was highly significant ($P<0.0001$) for plant stand percent (Table 2). Similarly, main effects of environment and density were significant at the 5% level of significance. Interaction of these variables was not significant, indicating that performance of hybrids for plant stand do not differ in different density or environment. The mean plant stand percent of high density was 94.02% and that of low density, 95.18%, with an LSD (0.05) value of 0.987%. In terms of hybrids, DKC54-51 (104 RM days) was the hybrid with the highest and 35y54 (105 RM days) was the hybrid with the lowest plant stand percent (Table 5).

Variation in dry matter yields was significantly impacted by environment ($P<0.0001$) and density treatments ($P<0.0001$, Table 2). The interaction of environment by hybrids was highly significant (P = 0.0002) indicating that the performances of hybrids were significantly different across environments. DM yield was significantly different between hybrids in BKG05 ($P < 0.05$) and in BSF05 ($P < 0.01$) but was non-significant at WTN. Mean dry matter yields was significantly highest in BSF04 and lowest in WTN04 environments (Table 2). High planting densities had a mean dry matter yield of 16 Mg ha^{-1} and low planting densities had a mean dry matter yield of 14.1 Mg ha^{-1}, with a critical $LSD_{(0.05)}$ value of 0.34 Mg ha^{-1}. The correlation between DM yield and RM days was non-significant (Table 4).

Linear regression analysis of DM yield shows the stability of dry matter yield of two different planting densities across ten hybrids and six environments (Figure 2). The high population densities show a higher yield over low populations across all environments. Though the linear regression analysis was highly significant for both planting densities, the t-test was not significant for the comparison of slopes indicating there is no density by environment interaction. Difference of mean dry matter yields over two planting densities was significantly different. Dry matter yield was increased by 13.46 percent when the planting density was increased from 73,398 to 93,910 plants ha^{-1}.

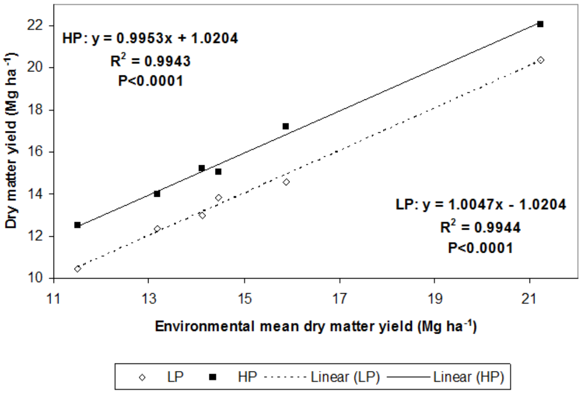

Figure 2. Stability of Dry Matter (DM) yield of corn hybrids in low planting density (LP) and high planting density (HP) across six environments, pooled over hybrids.

Variations in P uptake were significantly impacted by hybrids (P =0.0015), environments ($P<0.0001$) and the density treatment ($P<0.0001$, Table 3). The interaction of environment by density was significant at the five percent level indicating that the impact of plant population on P concentration depends on the environment. Interaction of hybrids with other variables was not significant. Hybrid 35y54 had significantly the highest and 2D601 had the lowest P uptake (Table 4). Environment BSF04 had the highest mean P uptake (37.47 kg ha^{-1}) and BKG04 (17.58 kg ha^{-1}) had the lowest mean P uptake.

Figure 3 shows the stability of P uptake in two different planting densities across six environments. The high population densities showed a higher P uptake compared to that of low populations across all environments. Though the linear regression analysis was highly significant for both planting densities, the t-test was not significant for the comparison of slopes ($t_{0.05}$ = 1.63, P = 0.1416). P uptake was significantly correlated with P concentration and DM yields but not with RM days (Table 4).

Table 3. Combined analysis of variance of P concentration during 2004 and 2005.

		Plant stand	DM yield	P conc	P uptake
Sources	DF	Mean square	Mean square	Mean square	Mean square
Environment	5	51.440*	671.365***	2.226***	3352.166***
Replication (environment)	12	18.015^{NS}	9.738***	0.099*	60.180**
Variety	9	237.303***	4.872^{NS}	0.187***	57.760**
Density	1	119.601*	324.679***	0.026^{NS}	605.927***
Environment*variety	45	24.861^{NS}	5.615**	0.065*	21.346^{NS}
Environment*density	5	21.076^{NS}	3.816^{NS}	0.150**	47.159*
Variety*density	9	12.233^{NS}	2.799^{NS}	0.02^{NS}	12.024^{NS}
Environment*variety*density	45	20.564^{NS}	2.369^{NS}	0.035^{NS}	14.304^{NS}
Error	228	22.563	2.680	0.045	18.595
CV (%)		5.020	10.872	13.845	18.416

* Statistically significant at P <0.05

** Statistically significant at P <0.01

*** Statistically significant at P <0.0001

NS Non-significant at P <0.05

Table 4. Pearson correlation between P, dry matter, P uptake, and RM.

	Dry matter	P uptake	RM
P	0.28713	0.70863	-0.06366
	<0.0001	<0.0001	0.2283
Dry matter		0.87092	-0.03951
		<0.0001	0.4548
P uptake			-0.06115
			0.2472

Table 5. Mean plant stand percent of hybrids during 2004-2005, pooled over densities and environments.

Hybrids	Mean plant stand (%)	Mean P uptake (kg ha^{-1})
DKC54-51	97.251 a†	24.079 abc†
DKC50-18	96.939 ab	24.450 ab
LG2463Bt	96.742 abc	24.318 ab
N67-T4	96.314 abc	22.466 bcd
2R570	95.532 abc	22.666 bcd
N70-T9	94.907 bcd	22.149 cd
2D601	94.549 cd	21.327 d
LG2489Bt	92.818 de	23.625 abc
34n43	91.348 ef	23.514 bc
35y54	89.641 f	25.568 a
LSD$_{(0.05)}$	2.2061	2.0028

†: Means with same lowercase letters within a column are not significantly different.

Discussion

Interaction of hybrids and planting density was non-significant for all variables studied indicating that response of hybrids will be similar across planting densities for P concentration and uptake, and DM yield. Maturity days also did not have impact on any variable under study. This suggests the P concentration in corn hybrids depends on its genetics and environments where it is grown. Though planting density does not impact P concentration in a single environment, results may not be same when grown in different environments. Unlike Furlani et al. (2002) where they found negative correlation of P concentration with the DM yield in soybeans, it was positively correlated and significant in our case.

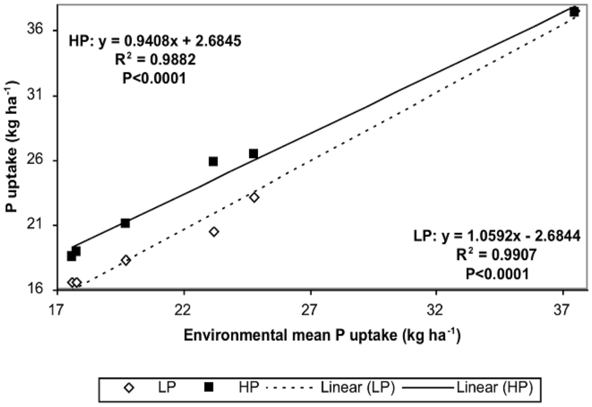

Figure 3. Stability of Phosphorus (P) uptake of corn hybrids in low planting density (LP) and high planting density (HP) across six environments, pooled over hybrids.

Plant stand percentage at the time of harvest was basically dependent on the hybrid and the environment where it is grown. However, plant stand percentage tends to be lower in high density mainly due to competition of more number of plants for the same amount of available resources. DM yield was also dependent on environments and plant populations. DM yield also differed based on the environment where it is grown. Our result of insignificant impact of hybrid genetics on DM yield agrees with the findings of Cusicanqui and Laurel (1999). However, the result contrasts with the result obtained by Yilmaz et al. (2007), where thy reported difference in DM yields in different genotypes of corn. High density population had significantly more DM yield production than from plants in low density populations, this might be due to the higher number of plants per given area. This result agrees with Turgut and Acikgoz (2005) where they reported higher DM yield in high plant density (above 85,000 plants ha^{-1}) compare to low plant density (65,000 plants ha^{-1}). The increase of 13.6% in DM yield in high population density compared to low plant density was 6% higher than results obtained by Rutger and Crowder (1967) when plant density was increased from 50,000-88,000 plants ha^{-1}. In contrary, a recent study by Carpici et al. (2010) do not agree with our result. Carpici et al. (2010) reported no significant increase in DM yield when plant density was increased from 60,000-100,000 plants ha^{-1} in Turkey.

P uptake was dependent on hybrids', environments and planting densities. P uptake was significantly higher in high populations, which might be due to the higher number of plants per area resulting in greater DM yields. However, the differences between P uptake of high and low density populations continued to decrease when the mean environmental P uptake increased. Mean P uptakes of hybrids' were much higher than the P uptake found by Barber and Olson (1968) in corn stover which was eight kg ha^{-1}. However, it was lower than the P concentration found in grain (31 kg ha^{-1}). Similarly, P uptake was in lieu with Eghball et al. (2003), where they reported that the phosphorus removal by various corn hybrids ranged from 24.3 to 35 kg ha^{-1} in 1999 and 16.6 to 25.7 kg ha^{-1} in 2000. When P concentration was related with the rainfall received in each environment, our results agree with Metwally and Pollard (2006), and Mackay and Barber (1985) in that P concentration uptake increases with increased soil moisture in the beginning but decreases later on.

Hybrids 2D601, N67-T4, N70-T9 and DKC54-51 were better in terms of overall performance. On an average, they had P concentration and uptake on lower range; DM yield, and plant stand percentage in the higher range. Though 2D601 had the lowest stand percentage, it had the highest DM yields and P in lower range. Hybrids 35y54, LG2489Bt and 34n43 were in the higher range of P concentrations, and P uptake. They were also variable in DM yields, basically towards lower range. While, the Pioneer brand seeds were worst in terms of high nutrient concentrations, low yields and low stand percentage, Syngenta and Mycogen seeds were advantageous in terms of all characters measured.

Conclusion

Based on the results, it can be inferred that hybrids are variable in terms of P concentrations and uptake. Therefore, it is possible to carryout selection based on these parameters. However, effect of environments should be considered while establishing selection programs, as P concentration and uptake of plants varies with the environmental where they are grown. Further, selection based on P concentrations can be carried out without giving up the DM yields. It is suggested to include more germplasm for further study.

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