CHANGES IN P UPTAKE AND PARTITIONING IN SOYBEAN CULTIVARS RELEASED IN THE LAST 90 YEARS

Péter Kovács and Shaun N. Casteel
Purdue University, West Lafayette, Indiana

Abstract

Historical changes in nutrient uptake and partitioning of soybean [*Glycine max* (L.) Merr.] were not studied. Field studies were conducted in 2011 and 2012 to investigate phosphorus (P) uptake changes and partitioning through the growing season in 25 maturity group (MG) II, and 26 MG III cultivars. Plant samples were taken and partitioned at V4 (four trifoliates), R2 (full bloom), R4 (full pod), R6 (full seed), and R8 (physiological maturity) growth stages. In-season samples were partitioned into leaves, stems, and pods if available, and into grain and stover at physiological maturity. Whole season phosphorus (P) uptake in the most recently released cultivars improved by 59% in MG II, and by 64% in MG III relative to the oldest cultivars. Grain P content changes were contributed the most in the whole plant P uptake changes. The evolution of P content by partitions showed that newer cultivars began to remobilize P from vegetative plant parts later in the growing season than older cultivars, and the P levels remained higher during reproductive growth. The significant changes in P accumulation in modern soybean cultivars, may warrant further research to revisit crop nutrient removal values, and potentially revise fertilizer recommendations.

Introduction

Soybean [*Glycine max* (L.) Merr.] is the second most planted field crop in the U.S. behind corn (*Zea mays* L.). Its yield has nearly quadrupled since 1924, the time since agricultural statistics available for soybean in the U.S. (USDA-NASS, 2014). The observed yield changes were due to genetic and agronomic improvements in soybean production (Egli, 2008; Specht et al., 2014). Recently conducted studies reported historical changes in soybean cultivars released in the last 9 decades, however, these studies focused on genetic improvement or genetic improvement x management interaction on grain yield and yield components of soybean cultivars (Rowntree et al., 2013, 2014; Christenson et al., 2014; Wilson et al., 2014; Koester et al., 2014; Rincker et al., 2014; Suhre et al., 2014). To date, there is no available publication which assessed and compared the changes in nutrient uptake of soybean, other than N, through the growing season among old and recently introduced cultivars. This information would be necessary to assess soybean's P requirement and its nutrition, since this nutrient plays an important role in the life of a (soybean) plant.

The objective of this research was to compare the changes of historical soybean cultivars, released from 1923 until 2011 both in maturity group (MG) II and MG III, in P uptake in whole plant and plant partitions, at various growth stages [V4 (four trifoliate), R2 (full bloom), R4 (full pod), and R6 (full seed) through the growing season and at physiological maturity (R8).

Materials and Methods

Site description and data collection

Twenty-five cultivars from MG II, and twenty-six cultivars from MG III were selected from private and public breeding programs released from 1923 to 2011. These cultivars were selected to represent the decades as equally as possible (Table 1). These cultivars were grown in the 2011 and 2012 growing seasons near West Lafayette, IN (40° 29’ 19” N, 86° 58’ 09” W) on a Toronto-Millbrook soil complex (Toronto series: fine-silty, mixed, superactive, mesic Udollic Epiaqualf) (Millbrook series: fine-silty, mixed, superactive, mesic Udollic Endoaqualf).

Table 1. List of maturity group II and III cultivars, their respective release year and plant introduction (PI) number.

Maturity Group II			Maturity Group III		
Cultivar	**Year of Release**	**PI Number**	**Cultivar**	**Year of Release**	**PI Number**
Korean	1928	PI548360	Dunfield	1923	PI548318
Mukden	1932	PI548391	Illini	1927	PI548348
Richland	1938	PI548406	AK (Harrow)	1928	PI548298
Hawkeye	1947	PI548577	Mandell	1934	PI548381
Harosoy	1951	PI548573	Mingo	1940	PI548388
Lindarin	1958	PI548589	Lincoln	1943	PI548362
Hawkeye 63	1963	PI548578	Adams	1948	PI548502
Amsoy	1965	PI548506	Shelby	1958	PI548574
Corsoy	1967	PI548540	Ford	1958	PI548562
Beeson	1968	PI548510	Ross	1960	PI548612
Wells	1972	PI548630	Wayne	1964	PI548628
Harcor	1975	PI548570	Calland	1968	PI548527
Private 2- 7	1977	n/a	Williams	1971	PI548631
Century	1979	PI548512	Woodworth	1974	PI548632
Elgin	1984	PI548557	Private 3- 1	1978	n/a
Private 2-15	1985	n/a	Williams 82	1981	PI518671
Conrad	1988	PI525453	Chamberlain	1986	PI548635
Jack	1989	PI540556	Private 3- 9	1989	n/a
Private 2- 6	1991	n/a	Thorne	1992	PI564718
Private 2-10	1994	n/a	Macon	1995	PI593258
Dwight	1997	PI597386	Private 3- 7	1999	n/a
Private 2-20	2005	n/a	Private 3- 8	2002	n/a
Private 2-14	2008	n/a	Private 3-13	2004	n/a
Private 2-21	2011	n/a	Private 3-14	2007	n/a
Private 2-22	2011	n/a	Private 3-15	2011	n/a
			Private 3-16	2011	n/a

n/a not available

Cultivars were arranged within each MG in randomized complete blocks with 3 replications. Corn was grown in both preceding years followed by fall chisel plowing and spring field cultivation. Cultivars were seeded to target 150,000 viable seeds A^{-1}. However, plant stand were about 57,000 plant A^{-1} higher in 2012 relative to 2011 due to seed treatment and better environmental conditions for germination and seedling emergence. Plots were planted in May 18, 2011 and May 15, 2012 using a 4-row John Deere 7000 series planter (John Deere, Moline, IL) with cone distributers on each row. Each plot was 8 rows wide with 30-inch row width, and 20-feet in length.

Plant samples were taken from a 40-inch section of an interior row at R2 (full bloom), R6 (full seed), and R8 (physiological maturity) growth stages, and from 80-inch section of an interior row at V4 (four trifoliates), and R4 (full pod) growth stages. The in-season samples were partitioned into leaves, stems (including petioles), and pods if they were available, while R8 samples were separated into seed and stover partitions. Samples were dried until they reached constant weight, then samples were weighed, and ground. Phosphorus concentrations were determined by a commercial laboratory (A&L Great Lakes, Fort Wayne, IN) via the inductively coupled argon plasma spectrometry method (AOAC International, 2000) for each plant partition. Nutrient uptake for each plant parts at each growth stages were calculated as a product of dry weight of the samples and respective phosphorus concentration of the partitions.

Phosphorus uptake dynamics was constructed for the growing season displaying each available plant partitions. The mean of three cultivars across the two growing seasons were used for cultivars released in the 1930s (Korean, Mukden, Richland), 1960s (Amsoy, Corsoy, Beeson), 1980s (Elgin, Private 2-15, Conrad), and 2010s (Private 2-14, Private 2-21, Private 2-22) in MG II, and for cultivars released in 1920s [Dunfield, Illini, AK(Harrow)], 1960s (Wayne, Calland, Williams), 1980s (Williams 82, Chamberlain, Private 3-9), and 2010s (Private 3-14, Private 3-15, Private 3-16) in MG III.

Results and Discussion

Evolution of P uptake and partitioning changes through the growing season is shown in Fig. 1. Phosphorus uptake were slow at the beginning of the growing season in both MGs. Cultivars from MG II took up P sharply from R2 growth stage onward, whereas MG III cultivars increased P content earlier (V4 growth stage, Fig. 1) in each age group. Enhanced P uptake pattern during reproductive growth was reported from previous studies (Togari et al., 1955; Ohlrogge, 1960; Hanway and Weber, 1971). Accumulation of P until the R2 growth stages was unchanged in both MG across release years. Starting from the R2 growth stage, whole plant P uptake increased in modern cultivars (i.e., recent release years). Maximum whole plant P uptake increased from 12 lbs P A^{-1} (27.5 lbs P_2O_5 A^{-1}) in cultivars from the 1920s to nearly 19.1 lbs P A^{-1} (43.8 lbs P_2O_5 A^{-1}) in cultivars released in the 2010s in MG II, and from 11.6 lbs P A^{-1} (26.6 lbs P_2O_5 A^{-1}) to nearly 17.4 lbs P A^{-1} (39.9 lbs P_2O_5 A^{-1}) in MG III (Fig. 1). Looking at the dynamics of P accumulation pattern one can also observe that the maximum whole plant P accumulation was at R6 growth stages, then slightly declined or remained about the same in cultivars from the 1920s, 1960s, and 1980s. However, P accumulation continued beyond R6 growth stage in cultivars released in the 2010s. Fig. 1 also illustrates that maximum P uptake into the vegetative partitions (leaves and stems) did not change substantially, but the remobilization of P from these organs,

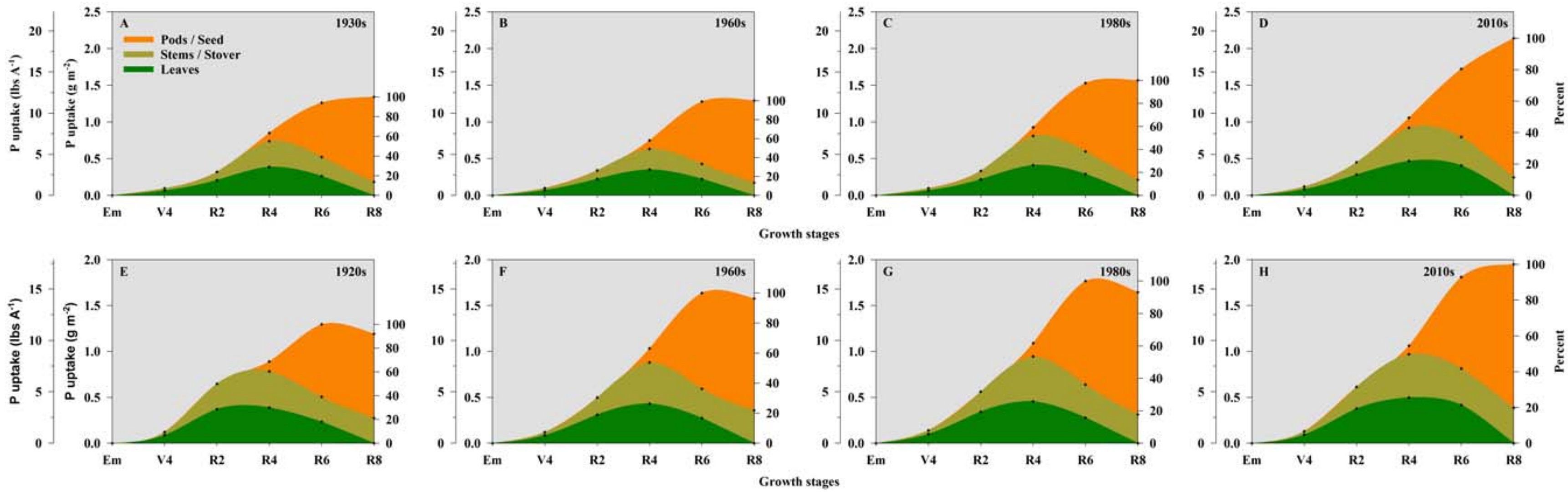

Fig. 1. Evolution of P uptake through the growing season for cultivars (A - D) in maturity group (MG) II and (E - H) in MG III. Graphs represent the mean of 3 cultivars released (A, E) in the 1920s, (B, F) 1960s, (C, G) 1980s, and (D, H) in the 2010s. Accumulation of P for the leaves represented by green, the stems (stover at physiological maturity) with olive-green, and the pods (seeds at physiological maturity) fraction with orange. Percentage of the plant partitions relative to the maximum P accumulation within respective panels shown on the right axis of each panel.

especially from the leaves, started later in the growing season in modern cultivars compared to older cultivars in both MGs. Later remobilization can also suggest that the leaf photosynthetic capability remained functional longer, and helped to maintain seed fill, and nutrient uptake progress. Previous studies reported longer canopy duration (Rincker et al., 2014) and higher light interception and energy conversion (Koester et al., 2014) with newer cultivars relative to older ones. Sharp decline in leaf P content after R6 growth stage was also likely due to senescing and falling leaves, which were not collected.

Whole plant P uptake at physiological maturity (R8) increased by 60% in MG II and by 63% in MG III for the cultivar groups from 2010s compared to the oldest group of cultivars (Fig. 1). The accompanying grain yield level increased from 27.7 bu A^{-1} to 52.2 bu A^{-1} in MG II, and from 23.3 bu A^{-1} to 45.1 bu A^{-1} in MG III in the same comparison (Long, 2013). Phosphorus accumulation increased in both stover and grain as newer cultivars were released (Fig. 1), and the grain was higher. The best regression to describe P accumulation across release years was an upward quadratic (data not shown). Grain and whole plant P content gain accelerated starting from 1955 release year in MG II, while the regression line was beyond its inflection point for MG III (data not shown). Grain P concentration decreased in the newer cultivars, while stover P concentration remained unchanged (data not shown).

Previous studies also identified similar inflection points, and observed accelerated grain yield improvement in recently released cultivars (Voldeng et al., 1997; Long, 2013; Specht et al., 2014). Specht et al. (2014) associated this yield improvement with more investment from private companies in soybean breeding programs due to the Plant Variety Protection Act. Dilution of grain P concentration indicated that grain P accumulation was driven by increasing dry matter production in newer cultivars as it was reported by Long, 2013. Similarly, decreasing grain N concentration with increased N uptake was also reported for newer soybean cultivars and for newer corn hybrids relative to older cultivars/hybrids (Kollman et al., 1974; Ciampitti and Vyn, 2013; Long, 2013).

Summary

Decades of breeding effort increased soybean yield levels, and with that also increased P uptake by more than 50%. The study also demonstrated that P remobilization from the leaves began later in the growing season in modern cultivars compared to older cultivars. With significant increase in grain and aboveground P accumulation in modern soybean cultivars, further research warranted to revisit crop nutrient removal values, and potentially revise fertilizer recommendations.

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James L Camberato
Purdue University
915 W State St.
West Lafayette, IN 47907
(765) 496-9338
jcambera@purdue.edu

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