CAN MULTI-YEAR FERTILIZER APPLICATIONS IMPROVE PRODUCTIVITY IN A CORN AND SOYBEAN ROTATION?

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ABSTRACT

Corn (*Zea mays* L.) yield responses to fertilizer are often greater when the fertilizer is applied in the same year, while soybean [*Glycine max* (L.) Merr.] yields are typically equivalent or higher when fertilizer was applied in a previous year. Thus, a common fertilization practice in the Midwest is to apply two-crop amounts of phosphorus (P), potassium (K), and sulfur (S) fertilizers during the corn phase of a corn-soybean rotation. However, with rising fertilizer costs, it is important to purchase and apply fertilizer when prices are low, so the objective of this study was to assess the effects of single versus multi-year fertilizer applications on soil nutrient availability and the consequent productivity of corn and soybean. Fertilizer treatments were initiated in the spring of 2021 at Champaign, IL, and consisted of: 1) an untreated control (UTC); 2) an annual application to either crop; 3) a biennial corn-only amount; 4) a biennial two-crop application amount; and 5) a single four-crop amount. All corn treatments were balanced for N (180 lbs/acre), and monoammonium phosphate (11-52-0), muriate of potash (0-0-60), and polyhalite (POLY4, 0-0-14-19S-11.4Ca-3.6Mg), which, in total, provided corn equivalents of 70, 60, and 25 lbs/acre, and soybean equivalents of 30, 60, and 15 lbs/acre of P_2O_5, K_2O, and S, respectively. Although not statistically significant, all fertilized treatments increased year-one corn yields by 4-8 bushels/acre, but the annual application supplied in year two did not increase soybean yield. Differences in soil S levels from the initial 2021 fertilizer applications were no longer detected two years later. All previous or current fertilized treatments of year three increased corn yields, and the two-crop application resulted in the highest yields across each of the first three years, likely due to greater soil P, K, and S availability, which was detected in the root zone postharvest. In year four, all fertilized treatments produced 4-5 bushels/acre more soybean. These findings suggest that farmers could apply nutrients biennially before corn with sufficient nutrient availability for both crops in a standard corn-soybean rotation.

INTRODUCTION

Phosphorus, K, and S are essential macronutrients that are often limiting in corn and soybean production and, thus, are the most applied. In 2021, 75% of corn acres in the U.S. received phosphate fertilizer, averaging 64 lbs/acre and totaling 2.05 million tons. There were 2.15 million tons of potash applied to 65% of U.S. corn acres, averaging 77 lbs/acre. Sulfur applications averaged 19 lbs/acre across 34% of corn acres, totaling 0.25 million tons (USDA-NASS, 2022). For the 2023 U.S. soybean crop, 44% of acres received phosphate (57 lbs/acre; 1.02 million tons), 46% received potash (88 lbs/acre; 1.64 million

tons), and 14% received S (20 lbs/acre; 115 thousand tons) (USDA-NASS, 2024). A typical Midwest fertilization strategy is to apply enough fertilizer before planting corn to meet the nutrient needs of both the corn and soybean crops.

As yields have increased, more nutrients are removed from the soil, increasing the demand for fertilizer application (Bender et al., 2013). Optimizing the timing and rate of these nutrients is crucial to be more efficient, as nutrients can become unavailable for crop uptake if applied too early. Soybean has often yielded similarly or greater when fertilizer is applied in previous years, while corn responded more consistently to same-year fertilization (Boring et al., 2018). Rising demand for corn and soybean has driven the need for higher yields and more fertilizer, resulting in increased fertilizer prices (Jones & Nti, 2022). Thus, farmers have questioned whether they should apply fertilizer each year or if they should apply multi-year rates when prices are relatively low to reduce input costs. The objective of this research was to quantify the effects of different allocations of multi-year fertilizer applications on yield and soil nutrient availability in a corn and soybean rotation over a four-year period.

MATERIALS AND METHODS

The trial was initiated in 2021 at the Crop Sciences Research and Education Center at Champaign, IL with first-year corn and continued through 2024 in a corn-soybean rotation. Prior to trial implementation, a composite soil sample was taken to determine initial fertility levels and consisted of 10 cores at a depth of 0–6 inches sampled in a grid pattern across the trial area and analyzed by A&L Great Lakes Laboratories, Inc. (Fort Wayne, IN) using Mehlich III-extraction. The selected site was a Drummer silty clay loam (fine-silty, mixed, superactive, mesic typic endoaquolls) with initial levels of 3.8% soil organic matter, a pH of 6.7, and P, K, and S levels of 62, 198, and 6 ppm, respectively.

Experimental units were four-row plots in 30-inch row spacing and were 37.5 feet in length for the corn phase and 36 feet long for soybean. Treatments were arranged in a randomized complete block experimental design with six replications (30 total plots), with the plot arrangement being static over the four years.

For both crops and all years, conventional tillage was done with a disk-ripper in the fall and a soil finisher in the spring, and consistent weed control was maintained throughout the trial period. A SeedPro 360 research plot planter (ALMACO, Nevada, IA) was used for planting in all four years. The corn hybrid DKC64-64 (Bayer Crop Science, Research Triangle Park, NC) was planted on 7 April 2021 and 6 May 2023 at 36,000 plants/acre density, with Force 6.5G applied in-furrow at a rate of 2.3 oz/1000 ft to ensure control against soil-dwelling insects. Due to seed availability, different soybean varieties were used, with AG37XF2 (Bayer Crop Science) being planted on 10 May 2022 and AG38XF3 (Bayer Crop Science) planted on 22 April 2024, both at a density of 140,000 plants/acre.

Fertilizer blends of polyhalite (POLY4; 0-0-14-19S-11.4Ca-3.6Mg; Anglo American Crop Nutrients LTD., U.K.), monoammonium phosphate (MAP, 11-52-0), muriate of potash (MOP, 0-0-60), and urea (46-0-0) were mixed and applied preplant at three

different rates calculated by seasonal nutrient needs of corn and soybean (Bender et al., 2013; Bender et al., 2015). Treatments initiated in the spring of 2021 for the four-year duration were: 1) an untreated control (UTC), 2) a biennial corn-only amount consisting of a 1-year blend applied in study year one and repeated in year three (Corn-Only), 3) an annual application consisting of 1-year blends fertilizing either corn or soybean in each year (Annual), 4) a biennial two-crop application consisting of blends fertilizing the corn in study years one and three with presumably enough nutrition for the following year's soybean crop in the respective years of two and four (Two-Crop), and 5) a single four-crop application in the first year with presumably enough nutrition for growing both corn and soybean over the next four seasons (Four-Crop). All four fertilized treatments were broadcasted with a hand spreader and lightly incorporated with a harrow in the spring before corn planting in 2021, and in 2023, the corn-only, the annual, and the two-crop amounts were reapplied broadcast. In 2022 and 2024, only the annual application was broadcast-applied before soybean and left unincorporated. First-year and four-year total nutrient rates are summarized in Table 1, and the soybean nutritional rates were 30, 60, 15, 9, and 3 lbs/acre of P_2O_5, K_2O, S, Ca, and Mg, respectively. In the two years of the corn phase of the rotation, plots received supplemental urea-nitrogen applications across all treatments for a total balanced nitrogen (N) rate of 180 lbs/acre each season.

Table 1. The nutrient amounts supplied in the first year and the total of a four-year study by five fertilization treatments to evaluate the effect of fertilizer blends applied to a corn-soybean rotation at Champaign, IL in 2021-2024. All corn plots were balanced for 180 lbs N/acre.

	First-Year Rates					Four-Year Total				
Fertilization	**P_2O_5**	**K_2O**	**S**	**Ca**	**Mg**	**P_2O_5**	**K_2O**	**S**	**Ca**	**Mg**
	lbs/acre									
UTC	0	0	0	0	0	0	0	0	0	0
Corn-Only	70	60	25	15	5	140	120	50	30	9
Annual	70	60	25	15	5	200	240	80	48	15
Two-Crop	100	120	40	24	8	200	240	80	48	15
Four-Crop	200	240	80	48	15	200	240	80	48	15

The center two rows of each plot were mechanically harvested using a rotary combine (R1, ALMACO, Nevada, IA) at physiological maturity for grain yield and standardized to bushels per acre at 15.5% moisture for corn and 13% moisture for soybean. Preplant and postharvest soil samples consisting of six cores per plot were taken between 0-6-inch depths, and the composite sample was analyzed for mineral nutrient compositions using Mehlich III extraction by A&L Great Lakes Laboratories, Inc.

Parameters were analyzed with the software SAS (version 9.4; SAS Institute, Cary, NC) using the PROC MIXED package. The homogeneity of variance of the residuals were assessed with the Brown-Forsythe modification of the Levene test while their normality of were determined with the Shapiro-Wilk test, QQ-plots, and histograms using the UNIVARIATE and GLM packages in SAS. An outlier analysis was conducted based on visual diagnostics and Pearson residuals to remove any data points that could skew the

data. Means were separated using Fisher's protected LSD test, and significance was declared at the $P \leq 0.1$ level.

RESULTS AND DISCUSSION

Although initial soil tests did not indicate a need to apply P or K fertilizer, all fertilizer treatments tended to increase corn grain yield over the UTC by 4-8 bushels/acre in 2021, suggesting that the increase may have been due to the S application (Table 2). Despite the four-crop amount having the most applied nutrition through the first two years, it did not result in the highest yield in either year. In 2022, the prior-year fertilizer applications increased soybean yield by 2-5 bushels/acre, while the annual application (the only fertility applied in 2022) slightly decreased yield, indicating potential benefit of multi-year fertilization on the two-crop rotation. In 2023, although the four-crop application was applied two years prior, residual fertility effects were still present, generating yields of only 4 bushels/acre less than the two-crop fertilization treatment, but 2 and 4 bushels/acre more than the corn-only and annual treatments, respectively. Fertilizing for two crops produced the greatest yields each year except in 2024, where all applied fertility treatments produced similar soybean yields of 94-95 bushels/acre, exceeding the UTC by 4-5 bushels/acre. These high yields suggest that the two-crop amount applied before corn may be optimal to maximize production.

Table 2. Effect of multi-year fertilizer treatments on corn and soybean grain yield expressed at 15.5% or 13% moisture, for corn and soybean, respectively, at Champaign, IL from 2021-2024.

Treatment	2021 Corn	2022 Soybean	2023 Corn	2024 Soybean
	bushels/acre			
UTC	258	78	262	90
Corn-Only	264	82	270	95
Annual	262	77	269	95
Two-Crop	266	83	276	94
Four-Crop	262	80	272	94
p-value	0.3155	0.2344	0.0002	0.0228
LSD (α = 0.10)	ns	ns	4	3

Phosphorus and K soil nutrient levels followed similar patterns, increasing with applications of the annual, the corn-only, the two-crop blend, and even more so by the four-crop blend at postharvest in the first year [Figures 1(a) and 1(b)]. After the annual treatment application in 2022, fall P and K soil test values rose to the level of the equivalent fertilizer amount of the two-crop treatment applied in 2021, but with numerically higher values for the annual treatment due to less time for nutrients to be bound to the soil. The 2022 preplant and postharvest soil test levels of the plots that had received the four-year blend in 2021 remained the highest for both P and K, but the annual treatment supplied in 2021 and again in 2022 increased P to the same level after the soybean harvest. By fall 2023, after corn, the plots receiving the corn-only, annual, and four-crop treatments had similar soil test P values greater than the UTC, with the two-crop treatment

having the highest P levels due to more fertility applied that season. Potassium levels of the two-crop and the four-crop treated plots were the greatest after corn harvest in 2023, while the corn-only and the annual treatments produced lower and similar K levels.

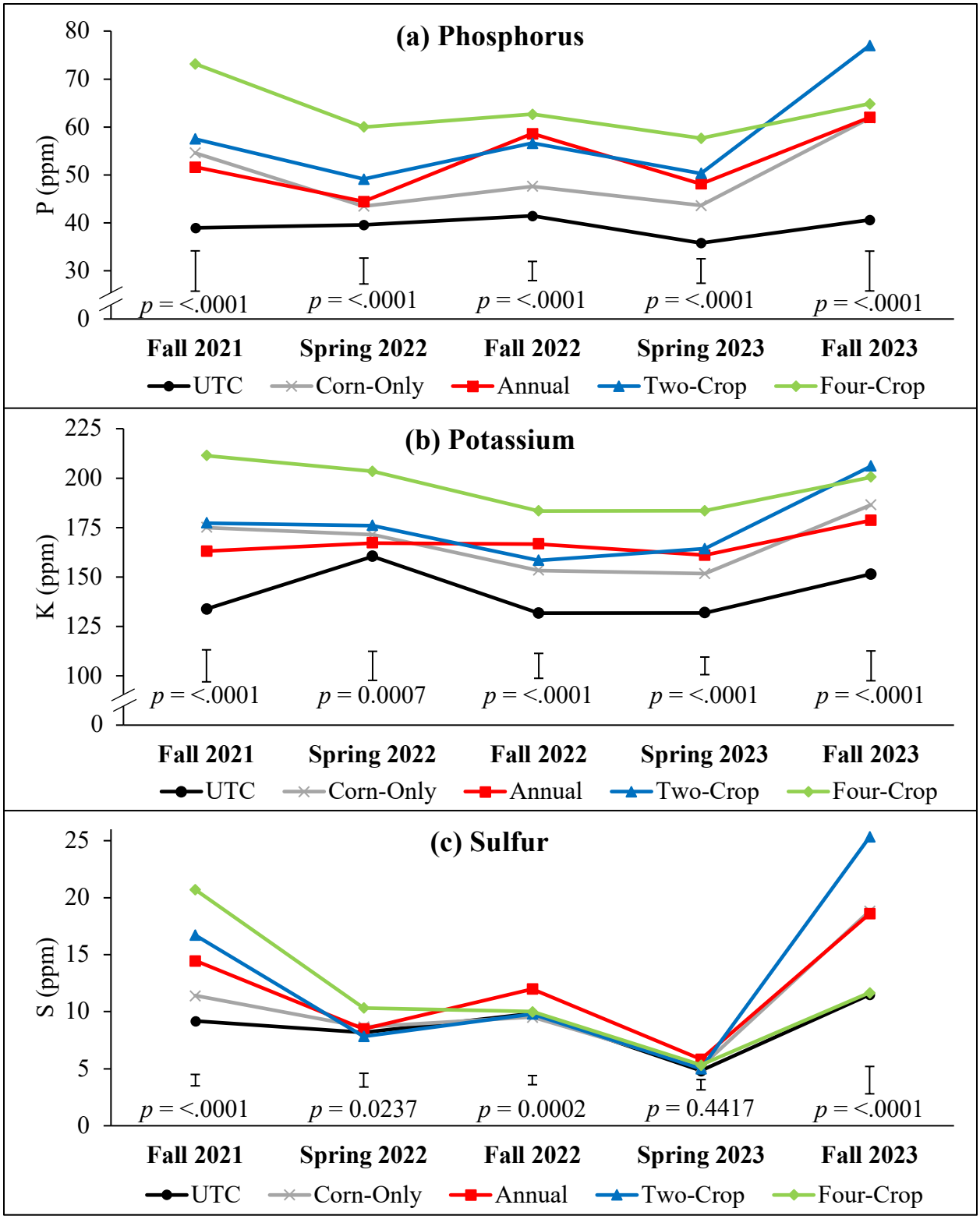

Figure 1. Effect of fertilizer treatments on soil nutrient levels (a) P, (b) K, and (c) S at 0-6 inch depth at Champaign, IL during 2021-2024. Corn was planted in 2021 and 2023, and soybean in 2022 and 2024. Vertical bars represent the least significant difference within a sample timing using the Fisher test at p = 0.1.

In the fall after trial initiation, as S rates were increased with the multi-year blends, the soil test value also increased [Figure 1(c)]. However, in the spring of 2022, S had likely been immobilized or leached from the rooting zone since the corn-only, annual, and two-crop amounts had levels similar to the UTC. Soil test S values were highest in the four-crop treatment plots at this time, likely due to the greater POLY4 application at the time of sampling, as well as POLY4's sustained release properties where it has not yet been wholly leached out of the soil sampling depth, immobilized, or taken up by the crop. At postharvest in 2022, the annual fertilizer application resulted in the highest S level, while the four-year application fell to the level of the other treatments, likely due to the application timing, as the annual fertilizer application was the only treatment applied that year. By spring 2023, all S levels were similar, but after application of the corn-only, annual, and two-crop amounts, fall soil test S values were increased, with the two-crop treatment plots exhibiting the greatest increase, attributed to this blend's greater S application rate that season.

This study suggests farmers could apply nutrients biennially before corn with sufficient nutrient availability for soybean in a corn-soybean rotation, as it consistently produced the highest yields, and its timing and rate provided better residual fertility over four years. While other applications provided "short-term" benefits, they generally resulted in lower yields or inconsistent nutrient availability throughout the trial period.

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