OPTIMIZING P AND K MANAGEMENT IN WHEAT-SOYBEAN SYSTEM PRODUCTIVITY

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ABSTRACT

In Oklahoma, wheat-soybean double cropping has been used as a viable system to increase productivity, but its short growing seasons and high nutrient demand create unique phosphorus (P) and potassium (K) management challenges not addressed by Oklahoma's full season recommendation. This study evaluated the effects of P and K application timing (fall, winter, spring, summer) for double-crop soybean and P and K management rates on wheat-soybean productivity at Lake Carl Blackwell, Oklahoma (2024-2025). A split plot design with four replications evaluated four application timings and six P and K management rates (W Only, W + DC P, W + DC K, W + DC P&K, Control, and DC Only) using OSU soil test recommendations. Timing treatments were only applicable to the double-crop soybean, while P and K for wheat were all applied in the fall. The results revealed that P and K management rate, not application timing drove wheat-soybean productivity. Management rate significantly affected wheat yield ($p < 0.01$), and soybean yield ($p = 0.02$), while application timing had no significant effect on either crop yield ($p > 0.1$). Management rates with wheat fertilized significantly outperformed control. Soybean required direct P application for optimal yields, while adding K to soybean beyond wheat fertilization provided no yield benefit. W + DC P and K maximized system yield with W +DC P performing similarly. This initial findings suggest that adequate P and K management rate maximizes wheat-soybean productivity.

INTRODUCTION

Wheat-soybean double cropping has recently become an important form of intensifying agriculture in the Southern Great Plains especially in Oklahoma due to suitable weather patterns that allow the production of two different crops during one growing year (Reed et al., 2022). This system, which involves planting soybeans immediately after winter wheat harvest, maximizes land productivity and economic returns (Alori et al., 2017). The USDA-ERS estimated 1.81 billion bushels of winter wheat produced and 86.1 million acres of soybean planted in the USA in 2024 (USDA-ERS, 2025). The wheat-soybean rotation represents a significant part of U.S. agricultural production. However, the intensified nutrient demands and compressed growing season inherent to double cropping present unique challenges for phosphorus (P) and potassium (K) fertilizer management that remain inadequately addressed by current recommendations.

Current Oklahoma State University recommendations for P and K fertilization were developed for full-season crops and may not adequately meet the specific nutrient requirements of wheat-soybean double cropping systems. Research has consistently demonstrated that double-crop soybeans grown after wheat are frequently limited by P and K availability, particularly when nutrient replacement is insufficient or when unfavorable environmental conditions restrict nutrient uptake (Parvej & Holshouser, 2025). The rapid nutrient cycling characteristic of successive cropping, creates nutritional demands that differ substantially from those of full-season systems. Furthermore, soil test predictions alone often fail to accurately reflect nutrient responsiveness in double-cropped soybeans due to temporal variability in nutrient availability and the complex interactions between soil fertility, application timing, and environmental factors (Yadav, 1998).

The objectives of this study were to evaluate the effect of P and K application timing on wheat and soybean grain yields and compare six fertilizer management rates for optimizing system-level productivity.

MATERIALS AND METHODS

This multi-year study being carried out at Lake Carl Blackwell Agricultural Research Station in Stillwater, Oklahoma addresses these knowledge gaps. This paper presents initial results from 2024-2025 season, using a split plot experimental design with four blocks. Each block was subdivided into four plots representing different fertilizer application timings, with each plot further divided into six subplots representing different fertilizer rate treatments, resulting in 96 total experimental units.

Experimental Treatments

Application Timing (Whole plot factor): Four fertilizer application timings were evaluated for the double-crop soybean component only (fall pre-wheat planting, winter wheat top-dress, spring wheat top-dress, summer pre-soybean planting). All wheat P and K applications were applied in the fall, irrespective of timing treatment to ensure adequate wheat nutrition.

Fertilizer Rate Treatments (Subplot Factor):

Wheat Fertilized Only (W Only): Wheat receives P & K, double-crop receives none.

Wheat Fertilized + Double-Crop P (W + DC P): Wheat receives P & K, double-crop receives P only.

Wheat Fertilized + Double-Crop K (W + DC K): Wheat receives P & K, double-crop receives K only.

Wheat Fertilized + Double-Crop P and K (W + DC P&K): Both wheat and the double-crop receive P & K.

Control: No P or K applied to either wheat or the double-crop.

Double-Crop Fertilized Only (DC only): Wheat receives no P nor K, the double-crop receives both P & K.

Phosphorus was applied as triple superphosphate (0-46-0) and potassium as muriate of potash (0-0-60) using broadcast application.

Data Collection

Site Characteristics and Soil Properties: Prior to treatment establishment, composite soil samples (10 cores, 0-6inch depth) were collected from each experimental block and analyzed at the Soil, Water and Forage Analytical Laboratory (SWAFL) at Oklahoma State University. Nitrogen fertilizer was applied uniformly across all blocks. All fertilizer rates varied by block and were based on OSU soil test recommendations to standardize nutrient availability relative to crop requirements.

Table 1. Initial soil fertility by experimental block.

Block	Soil Texture	pH	OM (%)	C (%)	N (%)	Soil P (ppm)	Soil K (ppm)
1	Medium	6.1	1.31	0.76	0.11	21.7	112
2	Coarse	5.8	0.98	0.57	0.10	33.5	133
3	Coarse	5.5	1.10	0.64	0.11	17.4	159
4	Coarse	5.6	0.89	0.52	0.10	17.2	108
Mean		5.8	1.07	0.62	0.11	22.5	128

Note: Fertility classifications based on OSU guidelines.

Crop Management

In December of 2024, winter wheat (cultivar Strad CL+) was sown at a rate of 75 lb/ac, with a row spacing of 7.5" and a seeding depth of 0.5". It was harvested in June of 2025. Seven days after the harvest of wheat, double-cropped soybeans (Asgrow 48XF3) were seeded at a rate of 160,000 seeds/ac, with a row spacing of 15" and a planting depth of 1.0". Soybean was harvested in October 2025.

Wheat and soybean grain yield was obtained using a small-plot combine to harvest approximately 18.3 m² from each of the subplots. The moisture content and protein concentration were determined by using the Near-Infrared Spectroscopy (NIR). The final yield was corrected to a standard of 13% moisture, and then expressed as bushels per acre (bu/ac).

Statistical Analysis

Data were analyzed using R version 4.4.1 with lme4, lmerTest, ggplot2, and emmeans packages. Type III ANOVA was performed using linear mixed-effects models. Timing and rate were modeled as fixed effects, while block, block × timing, and residual error were modeled as random effects. Post-hoc pairwise comparisons used Tukey's HSD ($\alpha = 0.1$). Assumptions were verified using residual plots and Shapiro-Wilk tests.

RESULTS

Wheat Yield: Fertilizer management rate significantly affected wheat yield. Mean wheat yield was 46.86 bu/ac. Mean separation revealed three distinct groupings among fertilizer management rates (Figure 2). The top-performing group (W+DC P&K, W+DC P, and W alone) yielded 48.0-50.8 bu/ac, representing up to 21% increase over the control (42.0 bu/ac). The DC P&K and W+DC K rates showed intermediate performance (45.7 bu/ac each), while the control produced the lowest yield.

Table 2. Analysis of variance for wheat yield in wheat-soybean system.

Source	Df	F-value	p-value
Timing	3	1.98	0.19
Rate	5	4.91	< 0.01***
Timing × Rate	15	1.19	0.30

*Note: *** $p < 0.001$; Model statistics: Whole plot CV = 9.15%; Subplot CV = 11.82%; Marginal $R^2 = 0.08$; Conditional $R^2 = 0.9$*

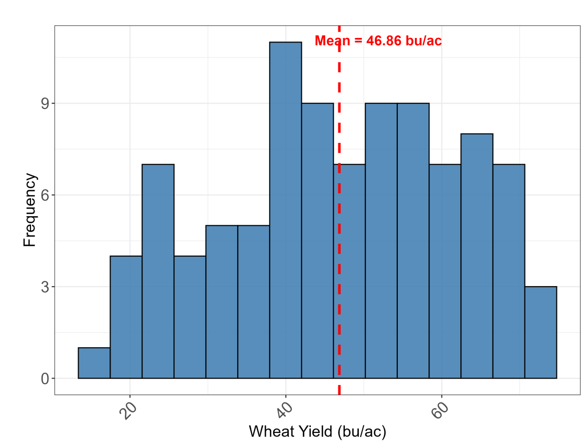

Figure 1: Wheat Yield Distribution

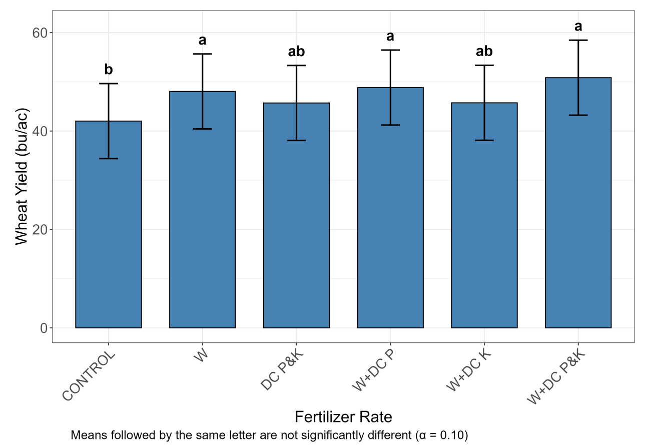

Figure 2: Wheat Yield by Fertilizer rate

Similar to wheat, soybean yield was significantly influenced by fertilizer management rate. Mean soybean yield was 32.7 bu/ac. Mean separation revealed two groupings among fertilizer strategies for soybean yield (Figure 4). The DC P&K strategy produced the highest yield at 34.9 bu/ac, representing a 17% increase over the control (29.8 bu/ac). This strategy, along with W+DC P&K (34.1 bu/ac) and W+DC P (34.0 bu/ac), formed the top-performing group. The W+DC K and W strategies showed intermediate performance (32.0 and 31.7 bu/ac, respectively), while the control produced significantly lower yields than the top three strategies. The absence of significant timing effects for both crops allows growers to have operational flexibility in scheduling P and K applications based on weather, labor availability, and equipment logistics without yield penalty.

Table 3. Analysis of variance for soybean yield in wheat-soybean system.

Source	Df	F-value	p-value
Timing	3	0.97	0.45
Rate	5	3.00	0.02*
Timing × Rate	15	1.05	0.42

*Note: * $p < 0.05$; Model statistics: Whole plot CV = 15.4%; Subplot CV = 13.6%; Marginal $R^2 = 0.19$; Conditional $R^2 = 0.6$*

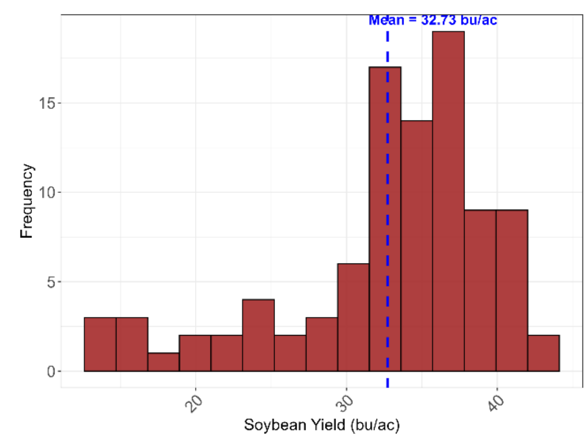

Figure 3: Soybean Yield Distribution

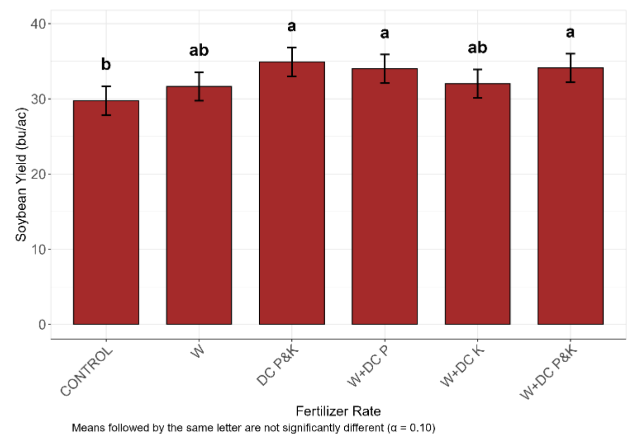

Figure 4: Soybean Yield by Fertilizer Rate

System-level Productivity

System-level productivity, evaluated by summing wheat and soybean grain yields, ranged from 71.8 bu/ac (control) to 84.9 bu/ac (W+DC P&K), representing an 18% increase through appropriate nutrient management. The consistent pattern of significant rate effects, non-significant timing effects, and absent timing × rate interactions (Table 2 and 3) across both crops highlights the primacy of fertilizer management rate over application timing. Although both crops responded to fertilization, numerically higher soybean yields were observed under DC only (34.9 bu/ac), while the highest system-level productivity (84.9 bu/ac) was observed under (W + DC P&K), with P nutrition for soybean (W + DC P) performing similarly. These pattern suggest the importance of whole-system nutrient management. Under-fertilization resulted in yield penalties of 4-6 bu/ac for wheat, 3-5 bu/ac for soybean, and 13.1 bu/ac at the system level, highlighting the potential importance of adequate P & K for crop productivity.

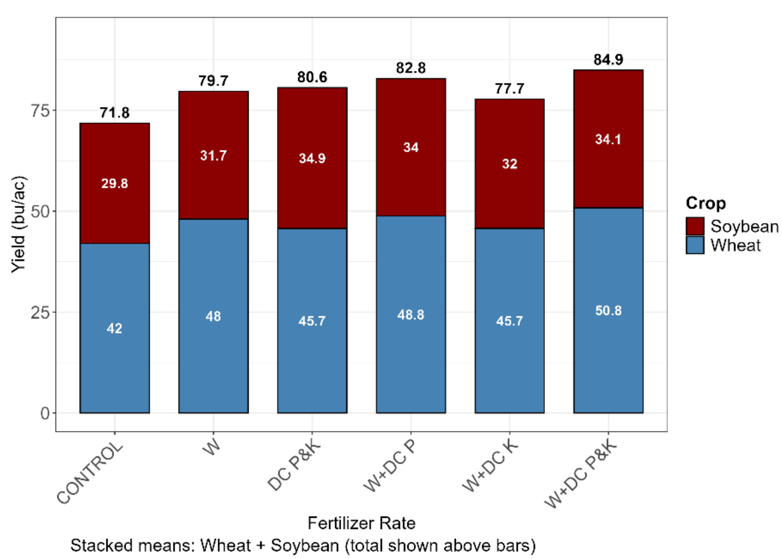

Figure 5: System Productivity (Combined Wheat and Soybean)

Fertilizer management rate, not application timing, drove wheat-soybean productivity, as evidenced by significant rate effects, non-significant timing effects, and the absence of timing × rate interactions. This operational flexibility suggests that producers can schedule fertilizer applications based on weather conditions, labor availability, and equipment logistics without yield penalty. Model performance differed between crops, with wheat explaining 89% of variation (CV = 9-12%) compared to soybean's 67% (CV = 14-15%), reflecting greater environmental sensitivity in double-crop soybean due to late planting, compressed growing season, and potential moisture stress. Future research will examine multi-year consistency of these patterns, evaluate residual nutrient effects across cropping cycles, and incorporate soil moisture at multiple depth as a covariate to account for water availability effects on nutrient response.

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