

2021 Influence of Phosphorus and Potassium Applications in a Multi-Year Spring Wheat-Soybean Crop Rotation – Year 3

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Layman's Summary (200 words)

Spring wheat and soybeans is a common crop rotation for producers in NW MN. In a ten year period from 2007 to 2017, soybean acres increased from 1.1 million to 1.8 million acres in USDA District 10 in NW MN. Reported wheat yields in 2007 were 50.4 and in 2017 was 65.8 bu/ac, but soybean yields were relatively flat at 35 bu/ac. One of the theories for the flat response in soybean yields was a lack of phosphorus (P) and potassium (K).

The project objective is to determine if elevated levels of P&K will improve wheat and soybean yields compared to standard P&K rates. These wheat and soybean research trials were conducted at two sites with small plot replicated trial methods and five locations with on-farm strip trial methodologies.

Small plot wheat yields ranged from 60 to 84.8 bu/acre and soybean yields ranged from 46 to 54.1 bu/acre. Wheat yields from the low P rate (20) were increased by 12.6 bu/ac and all P rates produced 19.6 bu/ac or more than untreated. Soybean yield were flat, probably due to drought conditions in August. On-farm soybean trials gave a positive response to additional 50 units P&K in 25% of the sites.

Background

In the last decade, soybean acres have increased by 707,000 acres in NW MN. Spring wheat yields have risen from 47.8 in 2011 to 68.5 bu/acre in 2017, while reported soybean yields are relatively flat ranging from 35.7 in 2007 and 34.1 bu/acre in 2017. A 40 bu/acre soybean crop will require 33.6 # P205 and 52 # K20. With increased wheat yields and the potential increase in soybeans yields, P and K may be a limiting factor for plant growth development and yield in a wheat -soybean crop rotation.

A 2017 AGVISE soil survey in northwest MN indicated 67% had Phosphorus (P) levels of < 10 ppm and 39% had Potassium (K) levels < 150 ppm. This soil survey suggests over 2/3 of the soil samples for P and over 1/3 of samples for K may have fertility levels that limit the production of high yield soybean and wheat. The objective of this project is to utilize a combination of small plot replicated research and large on-farm trials to determine if P and K levels are limiting soybean and wheat yields. Field trials will be conducted over four consecutive years in a wheat-soybean cropping sequence in northwest MN. The 2020 growing season will be year 3 of 4 for this project.

Research Objectives

Goal: To determine optimum levels of Phosphorus (P) and Potassium (K) in a high yield, long term sequence of spring wheat and soybeans in northwest Minnesota.

1. Establish long term crop rotation trials (4 year minimum) in wheat and soybeans using a combination of small plot replicated research trials and on-farm research sites
2. Conduct small plot replicated research to determine the influence of elevated levels of P and K on wheat and soybean growth, development and yield
3. Partner with the MN Wheat On-Farm Research Network (OFRN) to evaluate enhanced P and K fertility

utilizing large on-farm research trial methodologies to determine if current P and K recommendations provide adequate fertility in a high yield wheat-soybean crop rotation

Materials and Methods

Small Plots

The objective of this research is to establish two small plot replicated research sites and five on-farm locations in 2019 and continue for four years. A complete analysis will be conducted on collected soil and tissue samples to determine potential nutrient interaction with elevated applied levels of P & K.

- For the small plot experiments, various treatments with 0-46-0 and 0-0-60 and will be applied broadcast and incorporated prior to seeding. Small plot treatments are outlined below in Table 1.
- The small plot treatment rates included 0, 20, 40, 60, 80 and 100 units of P and K and combination of P and K in both wheat and soybeans. The total number of treatments will be 15 plus an untreated for a total of 16 in wheat and soybeans.
- Treatments were arranged in a randomized complete block design with four replications.
- Best management practices were followed for wheat and soybean production.
- Each individual plot was harvested with a small plot combine. Harvest samples were dried, weighted and quality assessments conducted on a sub sample from each plot

Table 1. Small plot P and K fertility treatments.

P	K	P+K
• 0-46-0 @ 20 units;	0-0-60 @ 20 units;	0-46-0 + 0-0-60 @ 20 units of each
• 0-46-0 @ 40 units;	0-0-60 @ 40 units;	0-46-0 + 0-0-60 @ 40 units of each
• 0-46-0 @ 60 units;	0-0-60 @ 60 units;	0-46-0 + 0-0-60 @ 60 units of each
• 0-46-0 @ 80 units;	0-0-60 @ 80 units;	0-46-0 + 0-0-60 @ 80 units of each
• 0-46-0 @ 100 units;	0-0-60 @ 100 units;	0-46-0 + 0-0-60 @ 100 units of each
• Untreated control		

Large Plots

The large on-farm large trials were conducted in conjunction with small-plot research conducted at the U of MN Magnusson Research Farm near Roseau, MN. The results from the small plot P&K trial can be used to help interpret findings in the large-plot on-farm trials as we continue with this project.

- Five large on-farm research experiments, one soybean and four wheat locations, were harvested near Baudette, Elbow Lake, Roseau, and Ross in 2021.
- Fertilizer was applied by the producer's fertilizer supplier (retailer?) , and plots were harvested by the producer. Individual plots were replicated four to five times and the treatments were one to two passes of the application equipment by the full length of the field.
 - Control - Farmer practice (FP) rate of P and K fertility
 - Treatment - FP rate of P and K, + 50 units P + 50 units K

- At harvest, one combine pass from each plot was weighed in a weigh wagon or a grain cart at harvest and the grain was sampled to test moisture content, test weight, and protein content.

Table 2. Agronomic Information for the Five Large-plot On-Farm Sites in 2021

	Roseau-1	Roseau-2	Roseau-3	Baudette	Elbow Lake
Crop	Wheat	Wheat	Wheat	Wheat	Soybean
Variety	MN-Washburn	Linkert	MN-Washburn	MN-Washburn	LGS0701XF
Planting Date	4/28/2021	4/30/2021	4/27/2021	5/7/2021	5/6/2021
Harvest Date	7/30/2021	7/31/2021	8/9/2021	8/14/2021	9/18/2021
Organic Matter	5.7	3.9	4.4	2.89	4.7
Soil Type	Loam	Sandy Loam	Clay Loam	Clay Loam	Clay Loam
2020 - P ppm	6.5	6	20	17.8	
2020 - K ppm	113	111	379	120.1	
Total rainfall				6.1"	8.1"
*Total rain estimated between planting and harvest using Iteris ClearAg Weather data; Baudette measured with in-field rain gauge after each rain event by cooperator					

Results

Small plot results

Table 3. Initial 2019 Background Soil Test Values for Small Plots Prior to Fertilizer Treatments

0-6" sample	Site 1	Site 2
	2021 wheat plots	2021 soybean plots
OM %	2.8	2.8
PH - 8.2	8.2	7.8
P (Olsen) ppm	6 ppm	23 ppm
K ppm	154 ppm	166 ppm
S ppm	14 lbs/ac	34 lbs/ac
Soluble salts (mmho/cm)	0.23	0.4

Wheat Small Plot Summary (Table 4)

- Soil test values after harvest (untreated) in 2021 for P = 3.7 ppm and K = 120 ppm
- Yields ranged from 60 to 84.8 bu/ac
- All P rates applied alone or in combination with K gave higher wheat yields (0.05% confidence level) than the untreated
- Wheat yields in bu/ac averaged over all P rates = 78 , all K rates = 61.5 and the combination of P&K = 81.2 bu/ac compared to the untreated of 60 bu/ac
- Wheat yields from all K treatments applied alone gave similar yields at the untreated
- Test weight ranged from 61.1 to 62.3 #/bu with no treatment difference
- Wheat protein ranged from 16.6 to 17.1% with no treatment differences
- P applied alone or in combination with K increased soil test levels of P
- P soil test increased from 5.5 ppm at 0-20-0 to 16.8 ppm at 0-100-0
- Soil test levels for P tended to increase as the rate of increased from 20 to 100

- K soil test levels tended to increase only with the highest applied rates of K
- All rates of P increased the levels of P in wheat tissue vs untreated
- K rates of 60, 80 and 100 increased K tissue test levels vs untreated

Table 4. Spring Wheat - Soybean Fertility Rotation Trial U of MN, Magnusson Research Farm Roseau, MN

Wheat-2021				Soil Test Results ⁴		Tissue Test Results ⁵		
Trt.	Added ¹ P & K	Yield ²	Test	P	K	P	K	
		Bu/Acre	Wt./Bu	Protein ³	ppm	ppm	%	%
1	0-20-0	72.6	61.9	16.9	5.5	130	0.36	2.9
2	0-40-0	79.6	62.0	16.8	8.5	125	0.39	3.1
3	0-60-0	78.6	62.0	17.0	9.5	125	0.41	2.8
4	0-80-0	80.0	62.0	16.6	12.5	128	0.45	3
5	0-100-0	79.0	61.4	17.0	16.8	119	0.45	2.7
6	0-0-20	64.3	62.2	17.0	4.0	121	0.33	3
7	0-0-40	63.2	61.9	17.3	5.0	127	0.32	3.3
8	0-0-60	60.3	62.1	17.3	4.5	132	0.32	3.6
9	0-0-80	60.7	62.3	17.4	4.8	147	0.3	3.7
10	0-0-100	59.0	62.2	17.1	3.8	136	0.32	4
11	0-20-20	75.9	62.2	17.1	6.0	126	0.35	3.2
12	0-40-40	80.5	61.8	16.8	10.8	135	0.39	3.3
13	0-60-60	82.4	62.2	17.1	12.5	125	0.43	3.5
14	0-80-80	82.8	62.3	17.1	19.5	130	0.43	3.4
15	0-100-100	84.8	62.0	17.1	19.8	139	0.44	3.5
16	0-0-0	60.0	61.7	17.0	3.7	120	0.33	3
LSD @5%level		7	0.6	0.7	3.8	12.0	0.05	0.3
LSD @10%level		5.8	0.5	0.6	3.1	10.0	0.04	0.2
CV(%)		6.7	0.6	3.0	28.0	6.0	9.0	7.0

Experimental Design: RCB with 4 reps

Linkert wheat seeded at 120 lbs/ac on 5/06/21

Plots harvested on 07/31/21

Added¹ P&K - P source 0-46-0, and K source 0-0-60

Yield² - Yields correct to 12% moisture

Protein³ - Dry matter basis

Soil test results⁴ - Soil samples taken after harvest on 08/17/21

Background soil test spring of 2019 - OM-2.8%; pH 8.2; P (Olsen) 6 ppm; K 154 ppm

Soil type - Borup silt loam

Tissue samples⁵ - Wheat late tillering on 06/14/21

Plot size= 6' x 15' Harvest area= 5' x 12'

160 pounds of nitrogen applied and incorporated prior to planting

Table 5. Soybean - Spring Wheat Fertility Rotation Trial U of MN, Magnusson Research Farm Roseau, MN

Soybean-2021						Soil Test Results ⁴		Tissue Test Results ⁵	
Trt.	Added ¹ P & K	Yield ²	Test			P	K	P	K
		Bu/Acre	Wt./Bu	Protein ³	Oil ³	ppm	ppm	%	%
1	0-20-0	46.0	59.7	37.7	20.6	17.0	117	0.48	1.9
2	0-40-0	44.3	59.4	37.9	20.9	17.0	112	0.48	1.7
3	0-60-0	46.3	59.4	37.6	20.8	17.2	120	0.5	1.9
4	0-80-0	48.3	59.5	36.5	21.3	20.5	115	0.5	1.9
5	0-100-0	50.9	59.5	38.5	20.6	27.8	129	0.47	2
6	0-0-20	48.3	59.5	37.3	20.2	10.5	113	0.47	1.9
7	0-0-40	50.7	59.3	36.9	20.9	11.5	137	0.45	2.1
8	0-0-60	54.1	59.4	35.5	21.1	10.8	133	0.48	2.3
9	0-0-80	47.2	59.4	37.4	21.1	12.7	129	0.48	2.2
10	0-0-100	51.7	59.2	37.9	20.7	10.0	125	0.49	2.3
11	0-20-20	48.0	59.3	36.4	21.0	13.0	108	0.49	2.1
12	0-40-40	46.4	59.5	38.6	20.9	14.5	118	0.5	2.1
13	0-60-60	48.2	59.3	35.8	21.1	22.2	131	0.5	2.1
14	0-80-80	51.1	59.5	37.6	20.9	20.5	126	0.47	2.1
15	0-100-100	48.2	59.2	36.9	21.3	27.3	124	0.5	2.2
16	0-0-0	46.0	59.4	38.0	21.2	12.5	110	0.49	1.9
LSD @5%level		7.5	0.4	1.4	0.8	6.0	11	0.03	0.2
LSD @10%level		6.2	0.3	2.0	0.6	5.0	9	0.02	0.1
CV(%)		10.8	0.5	3.5	2.6	26	6	5	6
Experimental Design: RCB with 4 reps									
Soybean variety - AG005x1 seeded at 1.4 units/ac; 172,000 PLS/ac on 05/13/21									
Plots harvested on 09/13/21									
Added ¹ P&K - P source 0-46-0 and K source 0-0-60									
Yield ² - Yields correct to 13% moisture									
Protein and oil ³ - Dry matter basis									
Soil test results ⁴ - Soil samples taken after harvest on 09/14/21									
Soil type - Zippel very fine sandy loam									
Background soil test taken spring of 2019: OM 2.8%; pH 7.8; P (Olsen) 23 ppm: K 166 ppm									
Tissue samples ⁵ - Soybeans sampled at early flowering on 07/05/21									
Plot size= 6' x 15'		Harvest area= 5' x 12'							

Soybean Small Plot Summary (Table 5)

- Soil test values after harvest (untreated) in 2021 for P = 12.5 ppm and K = 110 ppm
- Yields ranged from 46 to 54.1 bu/ac
- Yields generally similar from all treatments compared to the untreated
- Yields in bu/ac averaged over all P rates = 47.2 , all K rates = 50.4 and the combination of P&K = 48.4 bu/ac compared to the untreated of 46 bu/ac
- No treatment difference in test weight, protein and oil vs untreated
- P applied alone or in combination generally increased soil test levels for P
- P soil test levels increased with rate
- K soil test levels tended to or increased with all K rates
- No treatment effect in P tissue test levels vs untreated

Applied K generally increased K tissue levels in the plants

Large-plot Results

Table 6. Yield, protein, test weight, and harvest moisture for the 2021 large plot wheat locations.

	Roseau-1	Roseau-2	Roseau-3	Baudette	Combined
Treatment	----- Yield (bu/acre) -----				
Control	41.7 b	48.4 -	64.4 -	78.0 -	57.7 -
Extra 50 u P + K	47.0 a	49.6 -	63.1 -	78.9 -	59.4 -
LSD 90% CL	0.3	6.0	7.0	11.2	3.6
CV (%)	0.3	7.4	4.6	8.6	7.1
	----- Protein (%) -----				
Control	14.2 b	--	16.8 -	11.8 -	14 -
Extra 50 u P + K	14.4 a	--	17 -	11.7 -	14 -
LSD 90% CL	0.1	NS	--	NS	--
CV (%)	1.0	6.0	--	0.9	--
	----- Test Weight (lb/bu) -----				
Control	63 -	61 -	60 -	62.5 -	61.6 -
Extra 50 u P + K	63 -	61 -	60 -	62.5 -	61.6 -
LSD 90% CL	NS	NS	NS	NS	NS
CV (%)	--	--	--	0.4	--

* Lowercase letters (a, b) indicate a treatment is significantly different from other treatments with a different letter at the same location at the 90% confidence level.

Table 7. Soybean yield and quality at Elbow Lake in 2021.

Treatment	Yield (bu/ac)	Protein (%)	Oil (%)	Moisture (%)	TW (lbs/bu)
Control	46.0 -	35.2 a	18.4 -	10.7 b	56.3 a
Treated	47.7 -	34.5 b	16.1 -	10.9 a	54.4 b
LSD 90% CL	NS	0.4	NS	0.1	1.8
CV (%)	3.3	0.6	20.7	0.4	1.9
Base rate fertility: 130-100-50-10S					

* Lowercase letters (a, b) indicate a treatment is significantly different from other treatments with a different letter at the same location at the 90% confidence level.

- At the (0.05%) confidence level, there was a 5.5 bu/ac yield advantage from the Plus 50 compared to the farmer practice at the Roseau-1 location. The soil P at this location was 6.5 (low). In 2021, one of four wheat sites (25%) gave a positive response to additional P&K.
- The combined analysis did not show significant differences between treatments at the (0.10) confidence level.
- This trial will be conducted again in 2022. Several more years of research in various environments at additional locations are needed before any conclusions can be drawn from this elevated P&K fertility trial.

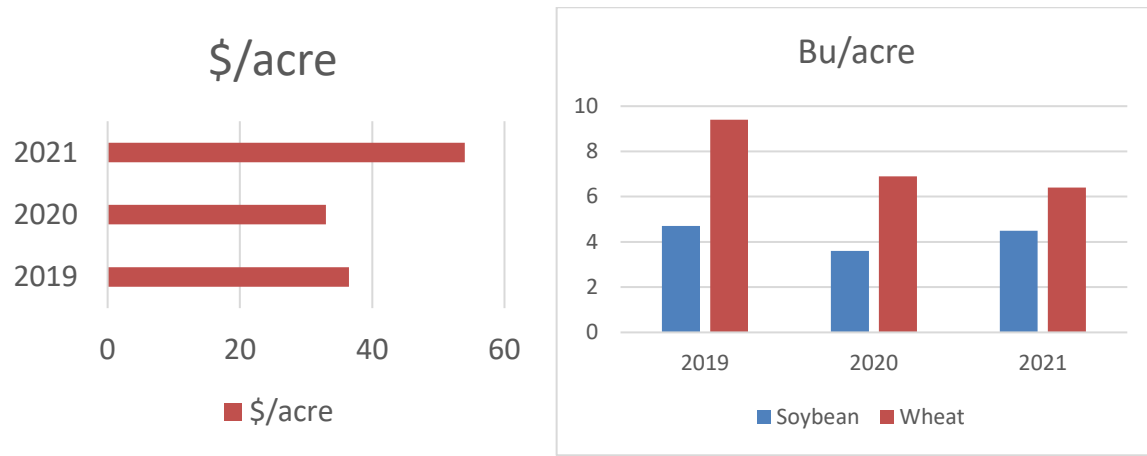


Figure 1. Cost of adding an extra 50 units P and K in the elevated fertility treatment over the farmer's practice control from 2019-2021 (left), and the increase in wheat and soybean yield needed to breakeven on the added cost of fertilizer (right).

- The cost of the elevated fertility treatment to the farmer ranged from an extra \$33/acre in 2019 to \$54/acre in 2021, and will continue to rise in 2022.
- The increase in bushels needed to cover the extra fertilizer cost ranged from 3.6-4.7 bu/acre for soybeans, and 6.4-9.4 bu/acre for wheat based on the cost of fertilizer in the spring and market price at harvest. In 2021, one location showed a 5.3 bu increase in the elevated treatment over the control, which was enough to offset the added cost of the fertilizer. In all other locations over the three years of the experiment, there have not been significant differences in yield between the elevated fertility and the farmer's standard practice to cover the cost of the fertilizer. This indicates that farmers in these locations generally have been using a rate of P&K that is not limiting to wheat and soybean yields.

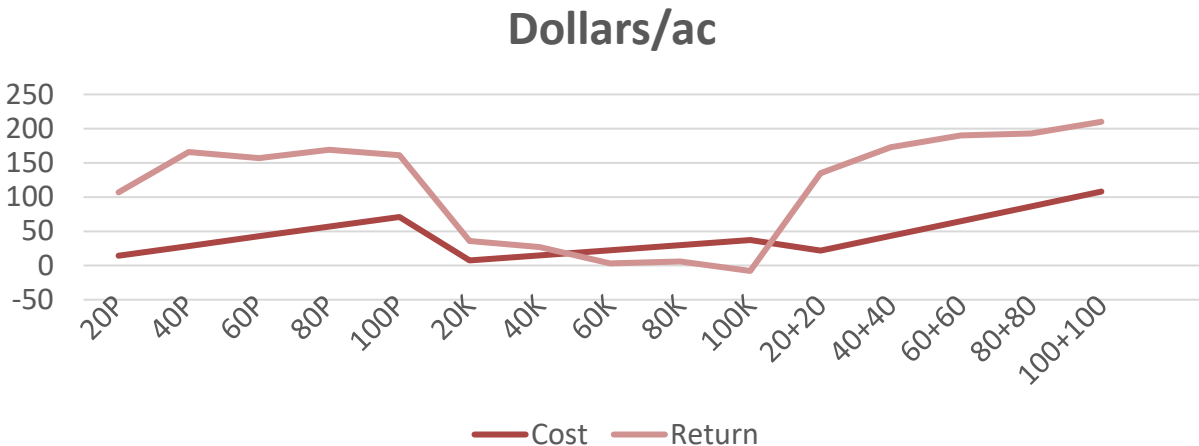


Figure 2. Return on fertilizer investment for the wheat small plot treatments over the unfertilized control for the 2021 season.

- Adding extra P increased yield and revenue in all of the P treatments, while adding K did not. At this site P test after harvest in the untreated was 3.7 ppm (Olsen) which is low. The K test was 120 ppm which is in the medium category.
- As would be expected as the rate of P and K increased the cost to the grower increased. This site was low in P and medium in K. The return/acre was over \$100/ac from a P rate of 20 and over \$150/ac from a P rate of 40 or more. K applied alone gave a flat to negative return with the high rates of K. However, the combination of P&K gave the highest return to the grower, especially with rates of P&K greater than 40 of each product.
- At this low testing P site, P alone at 40 gave over \$150/ac return. However, the combination of P&K at 60 of each gave a return to the grower of close to \$200/acre.
- The results of this wheat trial suggest that in low testing P soils, P alone at 40 and P& K in combination at 60 of will optimize the return to the grower.

Application/Use:

With the recent increase in wheat yield trends and the potential to increase in soybean yield trends, the soil levels of P and K may be a limiting factor for plant growth, development, and yield, however thus far we have seen a limited response to increased fertility in medium to high testing soils for P&K. In low testing P soils the small plots the wheat results indicate the wheat responded to P rates of up to 40 and P&K rates of up to 60 of P&K In the large on-farm trials elevated P&K have given a positive response when soil test P is low.

Recommended Future Research:

We plan to continue this project for at least the 2022 season or until each site completes four years of the experiment.

Outreach

- These data were published in the 2021 Wheat Research Review booklet and distributed at producer meetings throughout the winter.
 - o Prairie Grains Conference, December 8-9th, 2022, Grand Forks, ND, ~600 attendees
 - o Small Grains Updates meetings January 25-28th, 2022, Dilworth, Crookston, Ada, Lancaster, Roseau, and St. Hilaire, MN - 247 attendees
 - o Best of the Best meetings, Grand Forks, ND, February 2 and Moorhead, MN, February 3rd, 2022, ~200 attendees
 - o Available online at <https://mnwheat.org/council/wheat-research-reports/>
- Data were published in the annual On-Farm Research Report booklet, available online at <https://mnwheat.org/council/farm-research-network/>
 - o The annual report booklets were distributed at the above meetings along with the Wheat Research Review booklet
- Data were presented during the 9th Annual On-Farm Research Summit on December 8th, 2021, to about 75 attendees.
- Data were presented during the Soybean Research Reporting Session during the 2021 Prairie Grains Conference on December 9th, 2022.
- Results presented by Dave Grafstrom at the UMN Nutrient Management Conference in Mankato, MN, on February 8th, 2022, to a total of 334 people (69 in-person and 265 attended on-line).
- P&K wheat and soybean rotation trials were mentioned at the annual Grass Seed Field Day at the U of MN Magnusson Research Farm is held in June each year with approximately 80 people in attendance.

Photos



Figure 1. Small plot wheat trial at Magnussen Research Farm in Roseau, MN, 6-2-22. Photo by Dave Grafstrom.



Figure 2. Small plot soybean trial at Magnussen Research Farm in Roseau, MN, 6-8-22. Photo by Dave Grafstrom.



Figure 3. Small plot soybean trial at Magnussen Research Farm in Roseau, MN, late August/early September. Photo by Dave Grafstrom.



Figure 3. Small plot soybean harvest at Magnussen Research Farm in Roseau, MN. Photo by Dave Grafstrom.



Figure 4. Large plot treatment applications with spreader. Photo by Dave Grafstrom.



Figure 5. Large plot harvest with combine and weigh wagon, photos by Dave Grafstrom.