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Evaluation of Nitrogen and Phosphorus Fertilizer Placement with Strip Tillage for Irrigated Pacific Northwest Corn Production

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Abstract
Nutrient placement options with strip tillage (ST) can potentially improve plant nutrient utilization and increase crop yield compared to conventional fertilizer placement practices under conventional tillage (CT). The effects of tillage practice and N and P placement on grain yield, biomass yield (whole plant, grain + cobs + stover), and N and P uptake of field corn (*Zea mays* L.) were assessed on four sites during 2007 and 2009 at the USDA-ARS Northwest Irrigation & Soils Research Laboratory at Kimberly, ID. During each year, two locations (eroded and not eroded from furrow irrigation) were utilized as study locations. Band placement (15 to 20 cm below the soil surface) of fertilizer with ST increased corn grain yield by 12.5 (689 kg/ha) and 25.9% (1,626 kg/ha) on the eroded locations compared to broadcast N and P and 5 × 5-cm N under CT in 2007 and 2009, respectively. These increased yields also resulted in greater removal of N and P. Reduced tillage costs of ST with associated band placement of N and P could increase the economic productivity of many acres of land in the Pacific Northwest.

Introduction
The use of strip tillage (ST) and other conservation tillage (CT) practices are used to conserve soil and soil water through residue management, and reduce tillage costs in many areas of the Corn Belt. However, in the Pacific Northwest these tillage practices are less common. As presented here, CT refers to any tillage practice that results in the incorporation of most crop residue from a variety of tillage implements (e.g., disc, moldboard plow, roller harrow, and chisel plow). Often multiple passes with different implements are used. Strip tillage is becoming more common in the sugarbeet industry in southern Idaho and due to the high dairy cow populations, the potential use of strip tillage in corn production is increasing. The area under strip tillage in sugarbeet production in the Amalgamated Inc. production area has increased for 0 ha in 2007 to approximately 2,800 ha in 2009. The same growers that used strip tillage in sugarbeet production utilized strip tillage in corn production in over 1,000 ha in 2009 (*personal communication*, Amalgamated Sugar Inc., Boise, ID) The dual use of strip tillage for sugarbeet and corn production will likely continue to develop, increasing the need for ST best management practices in this region.

Strip tillage is a practice that creates a residue free and tilled zone, approximately 15 to 38 cm wide and 15 to 20 cm deep. The remaining portion of the field is not tilled and the residue from the previous crop remains on the soil surface. Corn production under ST has been shown to be comparable to or greater than chisel tillage (3,5,8). However, ST reduced corn yields compared to moldboard plow in southern Ontario (10).

Although ST allows for the deep banding of fertilizers, differences in fertilizer placement must be compared to CT practices in order to assess overall differences between the systems. Many studies have observed mixed results when evaluating fertilizer placement in corn production. Most studies, though, have shown that starter fertilizer placed in a band near the seed can benefit early corn growth (9). However, increases in corn grain yields are less common.

Low initial soil test P concentrations are the most common conditions in which corn grain yields increased as a result of starter fertilizer applications. Corn yield with 5 × 5 (5 cm to the side and 5 cm below the seed) placement of starter fertilizer at planting was found to be better than placement of fertilizer 5 cm below the row in the fall under zone tillage (11). Zone tillage is analogous to strip tillage (11).

The objective of this research was to evaluate corn production under ST and CT, and various N and P fertilizer placements under conditions found in the Pacific Northwest.

Assessing Effects of Tillage Practice and N and P Placement

The field study was conducted at a total of four locations over a two-year period (2007 and 2009) at the USDA-ARS Northwest Irrigation & Soils Research Lab in Kimberly, ID, on a Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthid). The fields have been furrow irrigated for 80 to 100 years and have a 1 to 2% slope. As a result most topsoil has eroded from the top areas of the fields and some has been deposited on the bottom areas of the fields. This erosion process has decreased yields on at least 800,000 ha in the Pacific Northwest (2). During each year of the study two locations were utilized, one located at the top of a field (eroded) and one located at the bottom of a field (not eroded). The two sites in 2007 still utilize furrow irrigation and the two sites in 2009 were under linear move irrigation (converted from furrow irrigation approximately 18 years ago). The study locations were previously cropped to alfalfa (*Medicago sativa* L.) for at least three years prior to the start of the study. In the fall before planting corn, the alfalfa was sprayed with 2,4-D herbicide at a rate of 3.5 liter/ha and glyphosate at a rate of 2.4 liter/ha.

Prior to field operations, twenty soil sub-samples were collected at depths of 0 to 30 and 30 to 60 cm across all replications of the study locations. Subsamples from each site and depth were composited. The composited samples were air dried, ground to pass through a 2-mm sieve, and analyzed for organic matter (OM) by combusting a subsample at 400° for 16 h, $CaCO_3$ percentage (8), bicarbonate extractable P and K (6), and NO_3-N and NH_4-N (4).

Treatments were a combination of ST and CT with N and P fertilizer applied either broadcast prior to the final tillage operation (broadcast), placed 5 cm to side and 5 cm below seed at planting (5 × 5), or placed 15 to 20 cm below the soil surface directly below the seed during ST (band). The specific treatment combinations were: (i) ST with band placement of P and broadcast N; (ii) ST with 5 × 5 placement of N and broadcast P; (iii) ST with band placement of N and P; (iv) CT with 5 × 5 placement of N and broadcast P; and (v) CT with broadcast N and P. Total N and P rates of 118 kg N per ha and 65 kg P_2O_5 per ha were applied to all treatments as urea (46-0-0) and mono-ammonium phosphate (11-52-0). Nitrogen fertilizer application rate was based on University of Idaho recommendations for corn grain (1) at a yield goal of 11 Mg/ha and NO_3-N and NH_4-N concentrations in the 0 to 30 and 30 to 60-cm depth in 2007. A 67 kg N per ha alfalfa credit was applied. The same fertilizer rates were used in 2009 for consistency. All treatments were replicated four times in a randomized complete block design.

Conventional tillage treatments consisted of chisel plow, tandem disk, fertilizer application (on broadcast treatments), and roller harrow in the spring. Strip tillage was conducted using a Strip Cat implement developed by Twin Diamond Industries LLC in Minden, NE. Corn (Pioneer 3523, GDD_{50F} = 2530 in 2007; Pioneer 38H66, GDD_{50F} = 2370 in 2009) was planted to the study locations at a seeding rate of 76,600 seed/ha on 24 May and 2 June in 2007 and 2009, respectively. The study locations were irrigated with furrow irrigation in 2007 and sprinkler irrigation in 2009.

Corn grain yield from each plot was determined by harvesting 12.2 m of row on 13 November 2007 and 18.3 m of row on 10 November 2009. Prior to harvest, eight whole plants from each plot were hand-harvested to quantify above ground biomass production (whole plant, grain + cobs + stover) and total N and P content of cobs, stover, and grain. Oven dried grain, stover, and cob samples were ground for total N and P analysis. Total N was determined by combusting 50 mg of sample in a FlashEA1112 (CE Elantech, Lakewood, NJ). Total P was determined using inductively coupled plasma optical emission spectroscopy (ICP-OES) following dry ashing of a 0.5-g sample at 500°C for 6 h and digestion on a hot plate with 10 ml of 1N HNO_3.

Analysis of variance for the comparison of tillage/fertilizer placement treatments for grain yield, biomass yield, and N and P content of grain and biomass was conducted using the Randomized Complete Block Model from Statistix 8 (2003, Analytical Software, Tallahassee, FL). The least significant difference (LSD) method was used for mean separations.

Soil Analysis

For all sites, many soil properties were similar at the 0 to 30 and 30 to 60-cm depths (Table 1). However, compared to the bottom locations, $CaCO_3$ percentage was on average two times greater at both soil depths and OM was about 40% less in the 30 to 60-cm depth in the top locations. These differences resulted from the erosion of topsoil on the top end, exposing the calcareous subsoils associated with many soils in this region. Soil test P ranged from 9.3 to 26.5 mg/kg in the 0 to 30-cm depth over all site years. The soil test P concentrations at three of the sites (2007 top, 2009 top, and 2009 bottom) were considered low to marginal according to the University of Idaho fertilizer recommendations for field corn (1). The recommendations suggested application of 45 to 157 kg P_2O_5 per ha depending on the soil lime content. The soil test K at all sites was considered sufficient.

Table 1. Selected soil chemical properties from top and bottom sites in 2007 and 2009.

Soil depth (cm)	Analyte	2007		2009	
		top	bottom	top	bottom
0 to 30.5	Organic matter (%)	1.8	1.6	1.8	2.0
	$CaCO_3$ (%)	20.1	10.4	20.5	10.0
	pH	8.0	8.3	8.0	8.1
	EC (µS/cm)	350	265	312	324
	Bicarbonate P (mg/kg)	11.3	26.5	9.3	10.1
	Exchangeable K (mg/kg)	142	254	147	141
	NO_3-N (mg/kg)	13.1	19.8	5.2	3.7
	NH_4-N (mg/kg)	8.0	5.3	3.4	3.7
30.5 to 61	Organic matter (%)	1.0	1.6	1.0	1.7
	$CaCO_3$ (%)	20.3	8.8	19.7	9.0
	pH	7.9	8.1	8.4	8.1
	EC (µS/cm)	426	354	288	340
	Bicarbonate P (mg/kg)	3.2	9.2	1.2	1.9
	Exchangeable K (mg/kg)	126	229	148	129
	NO_3-N (mg/kg)	3.3	8.2	2.3	3.1
	NH_4-N (mg/kg)	3.5	4.3	2.8	4.3

Grain Yield and Biomass

Based on grain yields in 2007 and 2009, N was supplied in adequate quantities and N deficiencies were not likely. Analysis of variance of treatment effects on corn grain yield and biomass were conducted for each field location separately in 2007 and 2009. There were grain yield differences in treatments at the top locations in 2007 and 2009 (Table 2). At the top location in 2007, treatment 3 (ST-band P-band N) was 12.5% (689 kg/ha) greater than the average of the CT treatments (4 and 5). At the top location in 2009, treatments

3 (ST-band P-band N) and 1 (ST-band P-broadcast N) were on average 25.9% (1,626 kg/ha) greater than the average of the CT treatments. A direct comparison of tillage effects on grain yield could be made between treatments 2 (ST-5 × 5 N-broadcast P) and 4 (CT-5 × 5 N-broadcast P) due to the treatments having the same fertilizer placements. Similar grain yields for the two treatments during both years of the study indicate that there was no effect of tillage on grain yield. Any differences in this study were likely due to band placement of fertilizers with ST. In 2007 and 2009, the placement of N in the CT treatments did not affect grain yield under CT at the top location.

Table 2. Grain yield and biomass (dry matter basis) and analysis of variance in 2007 and 2009 for the top and bottom sites.

		2007		2009	
	Treatment[w]	**top**[x]	**bottom**	**top**	**bottom**
Grain yield (kg/ha)	1. ST-band P-broadcast N	5840 ab	6193	7821 a	8058
	2. ST-broadcast P-5 × 5 N	5870 ab	6313	7188 ab	7923
	3. ST-band P-band N	6193 a	6291	7963 a	8313
	4. CT- broadcast P-5 × 5 N	5371 b	6308	6409 b	7029
	5. CT-broadcast P-broadcast N	5638 b	6287	6123 b	7740
	Mean	**5782**	**6278**	**7101**	**7813**
	ANOVA[y], P>0.05, Treatment	0.0119	0.9972	0.0142	0.3205
Bio-mass[z] (Mg/ha)	1. ST-band P-broadcast N	20.4	23.3	18.9	17.7
	2. ST-broadcast P-5 × 5 N	20.7	23.2	17.6	17.9
	3. ST-band P-band N	21.3	23.3	19.0	19.1
	4. CT- broadcast P-5 × 5 N	19.1	22.8	17.5	16.3
	5. CT-broadcast P-broadcast N	20.6	23.4	17.8	16.5
	Mean	**20.2**	**23.2**	**18.2**	**17.5**
	ANOVA[y], P>0.05, Treatment	0.2324	0.4969	0.5173	0.2532

[w] ST = strip tillage, CT = conventional tillage.

[x] For each year and location rows with the same letter are not significantly different.

[y] Analysis of Variance conducted separately for each location in each year.

[z] Biomass = grain + cobs + stover mass.

At the bottom locations in 2007 and 2009, there were no grain yield differences among treatments. Although not statistically compared, the trend for greater grain yields at the bottom locations compared to the top locations was likely due to differing soil properties resulting from irrigation induced erosion at the top locations (Table 1). Previous research on these types of soils in this region has shown yield reductions on the eroded areas of furrow irrigated fields (2). Research has shown a greater immobilization of applied P in these eroded soils due to greater amounts of $CaCO_3$ (7). In this study, greater $CaCO_3$ percentage at the top locations likely resulted in the advantage of applying P in a concentrated band under ST.

There was no influence of soil water differences between CT and ST on corn grain or biomass yield (*data not shown*). In 2007 both sites were furrow irrigated on a regular basis to meet crop ET demand. In 2009, the soil water content in the top 1 m soil depth was statistically the same for both tillage practices throughout the growing season (*data not shown*). Plant populations also did not influence differences among treatments. In 2007, plant populations averaged 69,800 and 71,400 plants/ha at the top and bottom locations, respectively. In 2009, plant populations averaged 73,500 and 73,100 plants/ha at the top and bottom locations, respectively.

At the top and bottom locations in 2007 and 2009, there were no differences in biomass among treatments. Grain yield was affected more by soil properties and fertilizer placement than other components of plant biomass (stalks, leaves, and cobs) (Table 2).

Plant N and P Removal

In 2007 and 2009, there were differences in grain N removal between treatments at the top locations (Table 3). At the top locations, treatments 3 (ST-band P-band N) and 1 (ST-band P-broadcast N) had 13 and 14% greater grain N removal compared to the CT treatments (4 and 5) in 2007 and 2009, respectively (Table 3). At the top locations, there were no differences in total biomass N removal among treatments. At the bottom locations, there were no differences in grain or biomass N removal among treatments (Table 2).

Table 3. Total N and P removal (kg/ha) in corn grain and biomass and analysis of variance in 2007 and 2009 for the top and bottom sites.

Constituent	Site	Treatment[x]	2007 Grain	2007 Total	2009 Grain	2009 Total
			Total N and P removal (kg/ha)			
N	top	1. ST-band P-broadcast N	76.8 a[y]	164.9	119.1 a	188.3
		2. ST-broadcast P-5 × 5 N	71.1 ab	153.3	106.3 bc	168.2
		3. ST-band P-band N	75.7 a	161.5	116.0 ab	180.2
		4. CT- broadcast P-5 × 5 N	65.0c	141.7	102.5 c	178.3
		5. CT-broadcast P-broadcast N	67.4 bc	136.3	99.5 c	176.1
		ANOVA[z], P>0.05, Treatment	0.0032	0.1123	0.0165	0.2714
	bottom	1. ST-band P-broadcast N	79.7	213.0	115.5	184.3
		2. ST-broadcast P-5 × 5 N	78.7	193.9	118.4	193.8
		3. ST-band P-band N	83.5	210.4	117.9	192.8
		4. CT- broadcast P-5 × 5 N	767	182.7	112.4	184.6
		5. CT-broadcast P-broadcast N	78.3	177.8	115.8	194.6
		ANOVA[z], P>0.05, Treatment	0.7794	0.0850	0.9830	0.8488
P	top	1. ST-band P-broadcast N	14.0 ab	22.1 ab	22.3 ab	27.5 a
		2. ST-broadcast P-5 × 5 N	13.7 ab	22.1 ab	19.2 bc	24.45 ab
		3. ST-band P-band N	14.6 a	23.1 a	23.2 a	28.3 a
		4. CT- broadcast P-5 × 5 N	11.7 c	17.6 c	19.1 bc	24.1 ab
		5. CT-broadcast P-broadcast N	13.0 bc	19.5 bc	17.1 c	22.2 b
		ANOVA[z], P>0.05, Treatment	0.011	0.0162	0.0283	0.0471
	bottom	1-ST-band P-broadcast N	15.7	28.8	22.7	27.3
		2-ST-broadcast P-5 × 5 N	14.2	25.4	21.4	26.7
		3-ST-band P-band N	16.6	28.2	22.5	28.3
		4-CT- broadcast P-5 × 5 N	15.6	27.6	19.1	23.3
		5-CT-broadcast P-broadcast N	15.8	27.2	221	26.9
		ANOVA[z], P>0.05, Treatment	0.7523	0.7190	0.6398	0.7857

[x] ST = strip tillage, CT = conventional tillage.

[y] For each year and location rows with the same letter are not significantly different.

[z] Analysis of Variance conducted separately for each location and each year.

In 2007 and 2009, there were differences in grain and biomass P removal among treatments at the top locations (Table 3). In 2007 and 2009, at the top locations, treatment 3 (ST-band P-band N) had greater grain P removal compared to the CT treatments (4 and 5). In 2007 and 2009, grain N removal for treatment 3 were 16 and 22% greater than the average of CT treatments, respectively (Table 3). At the top location in 2007, treatment 3 had greater biomass P removal compared to the CT treatments. At the bottom location in 2007 and 2009, no differences were found in grain or biomass P removal among treatments (Table 3).

Conclusions

Many soils in southern Idaho and other areas of the Pacific Northwest have been eroded to various degrees due to furrow irrigation. This study shows that on some eroded soils, band placement of fertilizers, especially P, can increase corn grain yields. In this study, the grain yield increase was between 700 and 1,600 kg/ha. Fertilizer placement did not affect grain yields on less eroded and thus more productive soils. Band placement of fertilizer with ST did not affect biomass irrespective of the soil property differences resulting from erosion.

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