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Impact of corn residue on yield of cool-season crops

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Abstract

Synergy between dry pea and corn can reduce the density of corn needed for optimum yield. Lower crop density may accrue an additional benefit, as after-harvest residues of corn lying on the soil surface can reduce yield of crops planted the next year. This study evaluated impact of corn residue levels on growth and yield of three cool-season crops in no-till. Corn was grown at two densities, 52,000 and 73,000 plants ha^{-1}, leading to after-harvest residue levels designated as low and high residue. Residue quantity on the soil surface differed by 21%. Controls were included for each residue level by burying residue with tillage. Spring wheat, dry pea and red clover were planted the following year. Grain yield of spring wheat and dry pea and forage yield of red clover were reduced 13–33% by residue on the soil surface. However, yield of cool-season crops were 10–18% higher in the low-residue treatment compared with high residue. Furthermore, yield loss because of weed interference in spring wheat and red clover was greater with high residue. Of the three crops, spring wheat was the least affected by corn residue on the soil surface. One contributing factor to lower yield with high residue was reduced crop seedling establishment. Producers may be able to reduce the negative impact of corn residue on following crops in no-till systems by using synergistic crop sequences in the rotation.

Key words: crop diversity, synergy, systems design, weed tolerance

Introduction

Success with no-till practices has stimulated producers and scientists to reconsider rotation design and the diversity of crops grown in rotation. One reason for this change is the awareness that crop diversity can improve soil functioning, and consequently, crop productivity[1]. For example, changes in soil biology because of crop diversity can reduce the need for inputs such as fertilizers and pesticides[2]. Hobbs[3] noted that integrating crop diversity with no-till management enhances soil biological benefits and improves efficient use of natural resources.

One benefit of crop diversity in no-till is that synergistic relationships may exist between crops and the biological component of soils[4]. An example of this synergy occurs between dry pea (*Pisum sativum* L.) and corn (*Zea mays* L.). When corn follows dry pea in sequence, corn yields more because of changes in the microbial community that improve resource-use efficiency of corn[5,6]. Improved resource-use efficiency also increases corn tolerance of drought stress and weed interference. For instance, corn yielded twofold more following dry pea than following soybean [*Glycine max* (L.) Merr.] when a uniform weed infestation was present[6]. A second benefit of this synergy is that plant density of corn needed for optimum yield is lower when corn follows dry pea than following soybean. Corn yielded similarly at 52,000 plants ha^{-1} following dry pea as at 73,000 plants ha^{-1} following soybean[5].

Our interest in corn density is related to the sometimes detrimental impact of crop residues on following crops in no-till. In the Northern Corn Belt, corn and soybean yields have been reduced 10–25% in no-till systems relative to conventional tilled systems when spring soil conditions are cooler and wetter[7]. The cause of this yield loss, which is especially prominent in high-residue situations, has been attributed to various factors such as cool soil temperatures delaying seedling growth, residues interfering with seed placement in soil during corn planting, or changes in the soil microbial community[8–10]. Other factors proposed as contributors to residue suppression of crop growth are decreased soil air-filled porosity[11] or allelopathy from residue decomposition injuring seedlings[12]. Vyn and Hooker[13] suggested that residue suppression of crop yield probably involves an interaction of several factors.

Management options have been developed that reduce the impact of crop residues on crop growth. For example, strip tillage and row cleaners that move residue away from the planted row can alleviate some of the difficulties observed with residues[11,14,15]. If a producer prefers a no-till system, an option may be growing cool-season crops such as spring wheat (*Triticum aestivum* L.) in high-residue situations; these crops may tolerate cool soil temperatures more readily. Diversifying the corn–soybean rotation with cool-season crops may minimize the detrimental impact of corn residues on yields of following crops, and facilitate adoption of no-till.

Producers are hesitant to add alternative crops to their rotations because of a possible economic penalty. However, ancillary benefits gained with alternative crops, such as lower inputs because of reduced pest infestations or increased yields because of the rotation effect, may compensate for lower gross returns. One benefit is that seed costs can be reduced when corn follows dry pea[5]; planting 21,000 fewer seeds will save US \$54–70 ha^{-1}. Also, lower plant density of corn may lead to smaller amounts of after-harvest residues lying on the soil surface. Another benefit is that rotations including both warm-season and cool-season crops can disrupt weed population dynamics such that cost of weed management is reduced[16]. Thus, diverse rotations with synergistic sequences may lead to similar net returns even though low-value crops are included in the rotation.

Producers are asking for information on favorable crop sequences to plan rotations with more crop diversity. Therefore, the objective of this study was to determine the impact of corn residue levels on productivity of three cool-season crops, red clover (*Trifolium pratense* L.), dry pea and spring wheat. A second objective was to assess if corn residue affected tolerance of cool-season crops to weed interference. Our broader goal is to encourage more crop diversity in rotations, which will lead to more sustainable cropping systems[3,4].

Materials and Methods

Study procedures

The study was established on a Barnes clay loam (Calcic Hapludoll) near Brookings, SD. The soil contained approximately 3% organic matter and had a soil pH of 6.9. Average yearly precipitation (30-year record) is 584 mm. The cropping history of the site prior to the study was a corn–soybean–spring wheat rotation in a no-till system.

The study involved 12 treatments across a 2-year sequence. In the first year, corn was planted at 52,000 and 73,000 seeds ha^{-1}. After harvest, we established four residue treatments:

1. high residue (corn density of 73,000 plants ha^{-1});
2. tilled control (residue of high-residue treatment buried by tillage);
3. low residue (corn planted at 52,000 plants ha^{-1}); and
4. tilled control (residue of low-residue treatment buried by tillage).

In the second year, red clover, dry pea and spring wheat were planted in each of the four residue treatments, resulting in 12 treatments. The 12 treatments were arranged in a randomized complete block design with four replications. Plot size was 7 m ×13 m. The study was conducted twice, during 2009–2010 and 2010–2011.

Table 1. Cultural practices in establishing red clover, spring wheat and dry pea following corn production the previous year.

Cultural practice	Red clover	Spring wheat	Dry pea
Variety	No variety name	Briggs	Admiral
Planting depth (cm)	1.5	4	6
Planting rate (seeds ha^{-1})	2,920,000	3,420,000	880,000
Fertilizer	None	Starter (N + P) Broadcast (N)	Starter (P)
Herbicide	None	Bromoxynil	Imazethapyr
Rate (g a.i. ha^{-1})	–	205	32

Residue levels on the soil surface after corn harvest were determined by randomly placed 1 m^2 quadrats in each of the low- and high-residue plots that were to be tilled for controls. Samples were oven-dried at 60 °C until samples reached a constant weight. After residue assessment, control plots were chisel plowed and disked.

In the following year, red clover, dry pea and spring wheat were established with conventional cultural practices in this region (Table 1). We chose these cool-season crops because their normal planting depth provided a range of depths from 1.5 to 6 cm. Crops were planted with a no-till drill equipped with single disk openers. Phosphorus (35 kg ha^{-1}) was applied with dry pea seed; fertilizer rate for the starter with spring wheat was 8 kg N and 35 kg P ha^{-1}. The remainder of N fertilizer (45 kg N ha^{-1} as ammonium nitrate) for spring wheat was broadcast at the tillering stage. Weeds present at planting were controlled with glyphosate at 840 g ha^{-1}.

The plots during the cool-season crop interval were randomly split into subplots. One subplot was maintained weed-free with herbicides in spring wheat and dry pea (Table 1) and hand weeding with red clover. In each weed-free subplot, stand counts in 0.5 m of row of each crop were recorded at four random sites 4 weeks after emergence (WAE). Crop biomass 6 WAE was measured in 1 m^2 quadrats randomly located in each subplot. Final yield measurements included forage biomass of red clover (harvested at 1/10 bloom; 12 WAE), and grain yield for spring wheat and dry pea. An area, 1.5 m × 13 m, of spring wheat and dry pea was harvested with a plot combine, whereas an area, 1 m × 4 m of red clover, was harvested by hand. Biomass data are expressed as fresh weight.

The other subplot was used to estimate crop tolerance to weeds as affected by residue management. Oat (*Avena sativa* L.) in red clover and dry pea, and canola (*Brassica napus* L.) for spring wheat, were used as indicator weeds. Two micro-plots, 3 m × 3 m, were established; 100 seeds m^{-2} of the indicator weed were broadcast on the soil surface in one micro-plot before planting the cool-season crops. Other weeds emerging in either micro-plot were removed by hand weeding. Four WAE, stand counts and biomass of indicator weeds were determined in a 1 m^2 quadrat for each weed-infested micro-plot of spring wheat and dry pea. Grain yield of spring wheat and dry pea was determined by hand harvesting an area of 1.5 m × 1.5 m in both weed-free and weed-infested micro-plots of each treatment and processing the samples with a stationary bundle thresher (Kincaid Equipment Manufacturing, Haven, KS 67543). Yield loss resulting from weed interference was determined by dividing the difference in sample weights between weed-infested and weed-free micro-plots by yield of the weed-free sample and expressing data as a percentage. Oat density in red clover was determined 4 WAE; biomass of red clover and oat were collected by hand harvesting 1.5 m × 1.5 m in weed-free and weed-infested micro-plots at the one-tenth bloom stage of red clover.

Statistical analysis

Data were initially examined for homogeneity of variance among years, and then subjected to analysis of variance to determine treatments effects and possible interactions among treatments and years. Main and interaction effects were considered significant at $P \leq 0.05$; treatment means were separated with Fisher's Protected LSD.

Yield differences compared with tilled controls were expressed as a percentage and analyzed across crops. Data for the specific agronomic parameters with red clover, dry pea, and spring wheat were analyzed separately for each crop, with the four treatments in a crop analyzed as a randomized complete block design. The reason for separate analysis among crops was because different yield parameters were collected (grain or forage yield) and different plant species were used for indicator weeds (oat or canola).

Results and Discussion

Crop yield was reduced in all crops by corn residue preserved on the soil surface with no-till (Fig. 1). Grain yield of spring wheat and dry pea was 13–29% less in residue treatments compared with tilled controls, whereas forage yield of red clover was reduced 18–33% by residue treatments. Yield loss was greater with high residue, which we attribute to a higher quantity of crop residue remaining on the soil surface. Residue quantity was 725 g m^{-2} with the high-residue treatment, but only 575 g m^{-2} with low residue, a difference of 21%.

Residue suppression of crop yield and other agronomic parameters was consistent across studies; therefore, data were averaged across years. Response to residue varied among the crops; yield of red clover and dry pea was reduced more by high residue than spring wheat (Fig. 1). High residue reduced yield of spring wheat less than 20%.

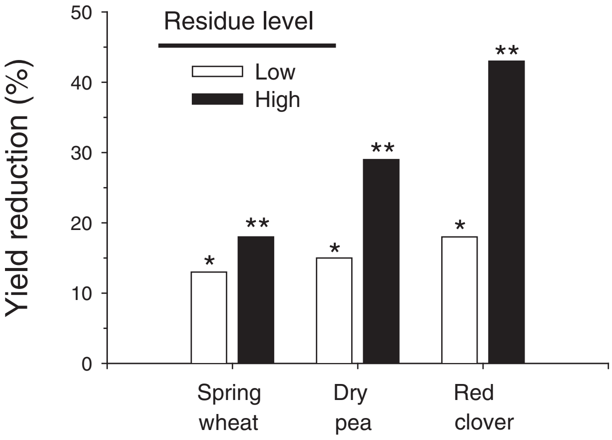

Figure 1. Yield loss in red clover, spring wheat and dry pea as affected by corn residue level on the soil surface. The low-residue treatment followed corn planted at 53,000 seeds ha^{-1} and the high-residue treatment followed corn planted at 73,000 seeds ha^{-1}. Yield loss was determined by comparison with tilled controls. Bars with the same number of asterisks are not significantly different as determined by Fisher's LSD (0.05). All means differed from tilled controls for each crop.

Spring wheat

We attribute reduced plant density by corn residue on the soil surface as contributing to lower crop yield in the residue treatments. Wheat density was 44% less in high residue compared with the tilled control, but only 13% less in the low-residue treatment (Table 2). Spring wheat compensated somewhat for fewer plants per area by tillering, as yield loss in high residue was only 18%. Crop biomass at 6 WAE was also reduced by residues on the soil surface. Considering all parameters, suppression of spring wheat growth and yield was less with low residue. Spring wheat yielded 9% less in high residue compared with low residue, 2880 versus 2630 kg ha^{-1}. The quantity of corn residue incorporated by tillage did not affect any parameter of wheat growth (comparing the two tilled control treatments).

Weed interference by canola was increased by high residue; yield loss of spring wheat in high residue was 20%, or 7% higher than any other treatment (Table 2). We attribute this increased interference with high residue because of greater canola growth in the less dense spring wheat canopy. Fewer canola plants established in this treatment, but biomass was 16–24% higher than other treatments and reduced yield more. Weed interference did not differ among the other three treatments.

Dry pea

Dry pea density did not vary among treatments (Table 3). This trend may reflect the target planting depth of 6 cm; the down pressure of the drill ensured that crop seed would be placed sufficiently deep in soil to germinate. However, dry pea biomass at 6 WAE was 16–33% less

Table 2. Agronomic response of spring wheat to corn residue management and weed interference. Low residue is after-harvest residue of corn at 52,000 plants ha^{-1}; high residue is after-harvest residue of corn at 73,000 plants ha^{-1}. WAE refers to weeks after emergence. Data averaged across 2 years; means within a column followed by identical letters are not significantly different based on Fisher's LSD (0.05).

				Tolerance to weed interference		
	Spring wheat			Canola		
Residue management	**Seedling density no. m^{-2}**	**Biomass (6 WAE) g m^{-2}**	**Grain yield kg ha^{-1}**	**Density no. m^{-2}**	**Biomass g m^{-2}**	**Yield loss %**
Low residue	280b	810b	2880b	53ab	292b	12b
Tilled control	320a	895a	3350a	63a	302b	13b
High residue	182c	635c	2630c	47b	363a	20a
Tilled control	325a	870ab	3210a	59a	313b	10b

Table 3. Agronomic response of dry pea to corn residue management and weed interference. Low residue is after-harvest residue of corn at 52,000 plants ha^{-1}; high residue is after-harvest residue of corn at 73,000 plants ha^{-1}. WAE refers to weeks after emergence. Data averaged across 2 years; means within a column followed by identical letters are not significantly different based on Fisher's LSD (0.05).

				Tolerance to weed interference		
	Dry pea (weed-free)			Oat		
Residue management	**Seedling density no. m^{-2}**	**Biomass (6 WAE) g m^{-2}**	**Grain yield kg ha^{-1}**	**Density no. m^{-2}**	**Biomass g m^{-2}**	**Yield loss %**
Low residue	25a	640b	2620b	41a	360a	78a
Tilled control	27a	760a	3080a	44a	350a	74a
High residue	23a	580b	2280c	43a	395a	79a
Tilled control	25a	720a	3230a	46a	375a	83a

Table 4. Agronomic response of red clover to corn residue management and weed interference. Low residue is after-harvest residue of corn at 52,000 plants ha^{-1}; high residue is after-harvest residue of corn at 73,000 plants ha^{-1}. Biomass is expressed as fresh weight. WAE refers to weeks after emergence. Data averaged across 2 years; means within a column followed by identical letters are not significantly different based on Fisher's LSD (0.05).

				Tolerance to weed interference		
	Red clover			Red clover biomass		
Residue management	**Seedling density no. m^{-2}**	**Biomass (6 WAE) g m^{-2}**	**Biomass (one-tenth bloom) g m^{-2}**	**Oat-free g m^{-2}**	**Oat-infested g m^{-2}**	**Oat biomass g m^{-2}**
Low residue	920b	260b	1010b	1040b	460a	660a
Tilled control	1090a	350a	1250a	1210a	500a	655a
High residue	510c	150c	860c	760c	240b	600a
Tilled control	1050a	370a	1310a	1200a	450a	615a

in the residue treatments. Also, grain yield was less in both residue treatments compared with tilled controls, with yield loss ranging from 15 to 29%. Comparing the two residue treatments, grain yield was 13% lower in high residue.

As corn residue on the soil surface did not affect stand establishment, other factors must be affecting dry pea growth. Crop growth can be restricted by situations where high soil water content reduces soil aeration[11]. Also, corn residue can be allelopathic to following crops, especially in situations with cool temperatures and high water content in soil[7,13].

Density and biomass of oat, the indicator weed in dry pea, were not affected by residue management (Table 3). Dry pea was not competitive with oat in any treatment; yield loss ranged from 74 to 83%. Dry pea is not competitive with weeds because of slow seedling growth and canopy development[17].

Red clover

Red clover density was reduced at both levels of residue on the soil surface, with reduction being 51% at high residue (Table 4). This impact may be related to seeding depth, as red clover was planted only 1.5 cm deep. High levels of corn residue can interfere with seed placement and seedling establishment[8,9]. Red clover biomass at 6 WAE and one-tenth bloom was reduced similarly by residue. Red clover compensated somewhat for the lower initial plant density; biomass at one-tenth bloom was reduced 33% by high residue when plant density was reduced 51%.

Neither oat density (data not shown) nor oat biomass (Table 4), the indicator weed for red clover, were affected by residue treatment. However, the combination of oat interference and high residue reduced red clover biomass 80% compared with oat-free biomass of red clover in the tilled controls. The multiple stresses of corn residue and oat interference were extremely detrimental to red clover growth.

Summary

Corn residues and no-till suppressed yield of following crops in no-till, even when cool-season crops were grown. Crop yield was reduced 13–33%, but the level of yield loss was related to quantity of residue on the soil surface. Grain yield of spring wheat and dry pea was 10 and 15% higher, respectively, in the low-residue treatment compared with high residue (Tables 2 and 3). Also, red clover biomass was 18% higher with low residue (Table 4).

One reason for reduced yields was that corn residue interfered with crop establishment of spring wheat and red clover. However, residue affects crop growth in other ways; dry pea yield was reduced even though crop establishment was not affected by corn residue. Despite extensive research, the reasons for yield suppression by corn residues are still not understood[7]. Vyn and Hooker[13] proposed that yield loss may be because of multiple stress factors.

Synergy between dry pea and corn may help producers minimize the negative impact of corn residues in no-till. Corn yields similarly at lower densities following dry pea compared with soybean as a preceding crop[5]; in our study, quantity of after-harvest residue on the soil surface was 21% less with the lower planting density. Producers may be able to further reduce impact of corn residue on yield of following crops by adding K and S to starter fertilizers with N and P[15]. Planting alternative crops after soybean rather than corn may be an option, as quantity of after-harvest soybean residue is considerably less than corn residue[18]. Another approach would be to remove corn residue for use as biofuels; however, Wilhelm et al.[19] noted that soil health could be damaged by removing crop residue from croplands.

Scientists and producers are viewing rotation design from a broader perspective, and are seeking multi-functional rotations[20]. To achieve this goal, Kirschenmann[4] suggested designing more complex production systems to accentuate biological synergies inherent in multi-species rotations. Crop diversity provides a multitude of benefits, such as higher crop yields and improved pest management[3,16,21]. For example, producers in the Great Plains have increased land productivity as well as reduced fertilizer and herbicide inputs with more diverse crop rotations[5,16]. An additional benefit of crop diversity is that synergy, such as found between dry pea and corn, may enable producers to reduce corn density[5] and ameliorate the negative impact of corn residues on following crop yield.

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