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Possible Causes of Dry Pea Synergy to Corn

Randy L. Anderson*

Dry pea improves corn yield and tolerance to weed interference compared with soybean, spring wheat, or canola as preceding crops. To understand this synergy between dry pea and corn, growth and nutrient concentration of corn were examined following dry pea or soybean in sequence. Each corn plot was split into weed-free and weed-infested subplots, with foxtail millet established at one density to provide uniform weed interference. Compared with soybean, dry pea improved corn grain yield 10% in weed-free conditions and corn tolerance to weed interference more than twofold. Dry pea synergy to corn in weed-free conditions was not related to differences in corn development, height, or nutrient status of corn seedlings. When foxtail millet was present, dry pea increased corn height and rate of development late in the growing season compared with soybean. Improved corn tolerance to weed interference was not related to seedling emergence or growth of foxtail millet, as these parameters did not vary with preceding crop. Other biological factors must be involved in dry pea synergy to corn.

Nomenclature: Canola, *Brassica napus* L.; corn, *Zea mays* L.; dry pea, *Pisum sativum* L.; foxtail millet, *Setaria italica* (L.) Beauv.; soybean, *Glycine max* (L.) Merr.; spring wheat, *Triticum aestivum* L.

Key words: Crop diversity, crop sequence, crop tolerance to interference, rotation effect.

El guisante mejora el rendimiento del maíz y su tolerancia a la interferencia de las malezas, comparado con la soya, el trigo de primavera y la colza usados como cultivos anteriores. Para entender la sinergia entre el guisante y el maíz, se examinó el crecimiento y la concentración de nutrientes del maíz sembrado secuencialmente después de guisante o soya. Cada parcela de maíz fue dividida en sub-parcelas: libre o infestada con malezas, con *Setaria italica* establecida a una sola densidad para proveer una interferencia uniforme de malezas. En comparación con la soya, el guisante mejoró el rendimiento en grano del maíz 10% en condiciones libres de malezas y la tolerancia del maíz a la interferencia de malezas incrementó en más de dos veces. La sinergia del guisante y el maíz en condiciones libres de malezas no estuvo relacionada a diferencias en el desarrollo del maíz, su altura o el estatus nutricional de las plántulas de maíz. Cuando *S. italica* estuvo presente, el guisante incrementó la altura del maíz y la tasa de desarrollo al final del ciclo de crecimiento en comparación con la soya. La mejor tolerancia del maíz a la interferencia de las malezas no estuvo relacionada a la emergencia de las plántulas o al crecimiento de *S. italica*, ya que estos parámetros no variaron con el cultivo anterior. Otros factores biológicos deben estar involucrados en la sinergia entre el guisante y el maíz.

Scientists and producers are expanding their perspective of cropping systems. In addition to production and economics, ecological aspects are now considered when designing these systems (Swinton et al. 2007). For example, producers would like to accentuate biological mechanisms that can reduce the need for inputs such as fertilizers and pesticides (Dore et al. 2011). Increasing crop diversity in rotations is especially favorable for enhancing ecological benefits in agriculture (Vereijken 2002).

One benefit of crop diversity is increased yields due to the rotation effect. For example, corn yielded 15 to 18% more when soybean preceded corn compared with continuous corn; this yield gain was attributed to soybean eliminating a negative factor of corn following corn (Crookston et al. 1991). Corn responded even more favorably to dry pea than soybean as a preceding crop; corn yielded 12 to 15% more in weed-free conditions following dry pea than following soybean (Anderson 2011a). Dry pea also improved corn tolerance of weed interference; a uniform infestation of foxtail millet reduced grain yield approximately 75% when corn followed soybean, spring wheat, or canola, but only 48% when dry pea preceded corn (Anderson 2011b). Furthermore, corn population required for maximum yield was 30% lower following dry pea compared with soybean or spring wheat as preceding crops (Anderson 2011a).

In earlier research, dry pea improved resource-use efficiency of winter wheat, which we termed synergism (Anderson 2011a). Water-use efficiency of winter wheat was 10 to 15% higher following dry pea compared with canola, proso millet (*Panicum miliaceum* L.), or spring wheat preceding winter wheat (Anderson 2005; Lafond et al. 2006). Winter wheat was more tolerant of weed interference following dry pea because of this improved resource-use efficiency (Anderson 2009a).

Because dry pea improves corn yield and tolerance to weed interference, we wanted to understand the cause of this synergy between dry pea and corn, and thus possibly accentuate this benefit. Several factors could be involved in synergy between crops, such as changes in nutrient availability (Hobbs 2007) or release of growth-promoting substances (Anaya 1999). Also, changes in the microbial community and microbial–crop interactions could result from crop diversity. One microbial entity often associated with the rotation effect is mycorrhizae, which can improve resource-use efficiency by plants (Auge 2004).

We initially speculated that higher N levels in soil may explain the contrasting response between dry pea and soybean as preceding crops, but the dry pea effect on corn yield was

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more prominent in low-yielding environments (years when soil and fertilizer N supply exceeded crop needs) (Anderson 2011a). Thus, we decided to measure parameters of corn growth that may provide insight for identifying the cause of dry pea synergy to corn. For example, different N concentrations in corn seedlings may indicate if temporal N availability varied among preceding crops (Przednowek et al. 2004), whereas higher P, Zn, and Cu concentrations in corn plants may reflect greater colonization of mycorrhizae (Hamel 2004; Lambert et al. 1979).

We are seeking to expand cropping choices in the corn–soybean rotation for the western Corn Belt. Dry pea is one promising option; land area planted to dry pea in the northern Great Plains has increased sevenfold in the last 10 yr (Johnston et al. 2007). Therefore, the objective of this experiment was to identify possible factors involved in the beneficial impact of dry pea on corn compared to soybean as a preceding crop. Our broader goal is to gain knowledge with crop sequencing that will help producers develop more diverse rotations than corn–soybean, and thus improve weed management and crop yield.

Materials and Methods

Site Characteristics. The experiment 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 (84-yr record) is 537 mm. The experiment was established in corn stubble; the cropping history of the site was a no-till corn–soybean–spring wheat rotation.

Treatments and Experimental Design. The experiment involved treatments imposed for 2 yr; the preceding crop (dry pea or soybean) grown in year 1 and corn grown in year 2. Dry pea was planted in early April, whereas soybean was planted in mid-May. Crops were established with no-till and managed with conventional practices used by producers (Table 1). Dry pea was planted in rows spaced 20 cm apart whereas row spacing for soybean was 50 cm. Weeds were controlled by herbicides; weeds surviving herbicide treatments were removed by hand.

In the second year, corn, DK 42-95 RR (DeKalb Seed, Monsanto Agriculture Products Co., St. Louis, MO), was planted at 66,000 seeds ha^{-1} in early May. The planter unit had double disk openers and a row spacing of 50 cm. Fertility management was based on a yield goal of 9,000 kg of grain per ha, and included N credits for the legumes. A band application of 10 kg N + 30 kg P + 50 kg K ha^{-1} as a liquid formulation was applied 5 cm to the side of the seed row and 5 cm deep with a single coulter disk at planting. The remainder of N fertilizer (90 kg N ha^{-1}) was applied broadcast as ammonium nitrate when corn had six leaves fully exposed.

Corn plots were split into two subplots. One subplot was maintained weed-free whereas with the second subplot, foxtail millet was broadcast on the soil surface at 230 seeds m^{-2} immediately before planting. Our purpose for using foxtail millet as a weed was to impose a uniform level of weed interference. Treatments were randomly assigned to subplots. Weeds in the weed-free subplot were controlled by a PRE application of *S*-metolachlor at 1.5 kg ai ha^{-1}, one POST application of glyphosate at 840 g ae ha^{-1}, and hand removal of weeds surviving herbicide treatments. Weeds present at time of planting in both subplots were controlled with glyphosate. The resident weed community density was low due to intensive weed management in preceding years.

Table 1. Cultural practices in establishing and managing dry pea and soybean in the year preceding corn production.

Cultural practice	Dry pea	Soybean
Cultivar	Admiral	Pioneer 91B91
Planting date range	April 1–10	May 15–20
Seeding rate (seeds ha^{-1})	880,000	400,000
Starter fertilizer (kg ha^{-1})	20 P + 7 K	20 P + 7 K
Herbicide	Imazethapyr	Glyphosate
Rate[a] (g ha^{-1})	32	840
Yield range (kg ha^{-1})	3,000–3,360	2,200–2,690

[a] Rate of imazethapyr is expressed as active ingredient, whereas glyphosate is acid equivalent.

The experimental design was a randomized complete block design in a split-plot arrangement, with six replications. Whole-plot size was 7 m by 20 m, with each plot split into 7 m by 10 m subplots. The experiment was conducted three times at different sites in the same field in 2007 to 2008, 2008 to 2009, and 2009 to 2010.

Crop and Weed Data Collection. The rate of corn seedling emergence was determined by recording the emergence date for all plants in a 4-m section of the planted corn row. Three sites were randomly located in each weed-free subplot; sites were evaluated daily until all corn seedlings had emerged.

Plant height and development of corn was recorded on six permanently marked plants randomly selected in each weed-free and weed-infested subplot. The date each plant reached V-6 (six leaves fully emerged), V-9, and V-12 development stage was noted, and height of the highest point of each plant recorded. Date of silking was determined by evaluating six plants per subplot on a daily basis; silking was defined as the time at which four of the six plants had visible ear silks.

At the six-leaf stage of development (before the N fertilizer application), nine plants in each replication were randomly selected, cut at ground level, and combined into one sample for nutrient analysis. Samples were oven-dried at 45 C for 7 d, and then analyzed for N, P, Zn, and Cu concentrations at a professional analysis lab (South Dakota State University Soil and Plant Testing Laboratory, Brookings, SD).

Seedling emergence of foxtail millet was recorded weekly in two 0.5 m^2 quadrats randomly located in each weed-infested subplot. Counting started on May 5 and continued until August 1; after the weekly counting, seedlings were removed by hand. Density and fresh weight of foxtail millet were assessed 7 wk after crop emergence (WAE) by harvesting all plants in four randomly placed 0.5 m^2 quadrats in each weed-infested subplot.

Grain yield was determined by harvesting six rows, 9 m long, in each subplot. Reported yields were adjusted to 15.5% moisture level.

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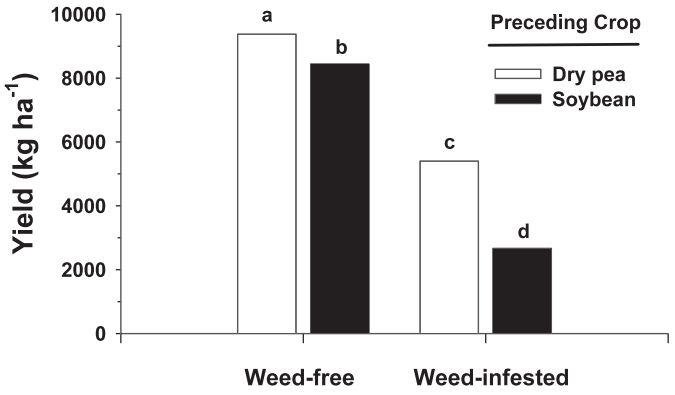


Figure 1. Grain yield of corn as affected by preceding crop and foxtail millet interference. Data averaged across 3 yr. Bars with the same letters are not significantly different as determined by Fisher's Protected LSD (0.05).

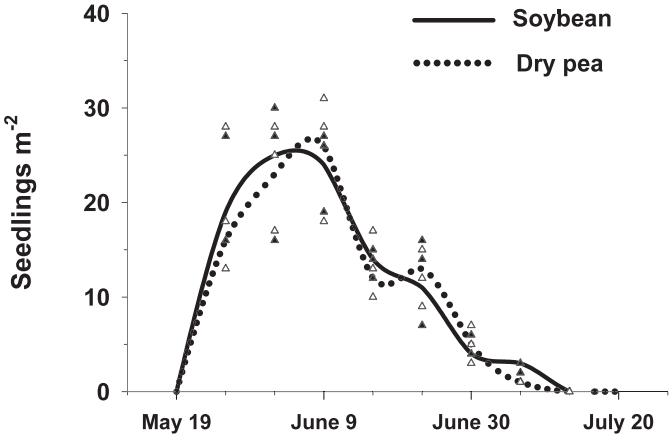


Figure 2. Seedling emergence of foxtail millet in corn as affected by preceding crop. Weekly seedling densities in corn did not differ between preceding crops (soybean or dry pea); data averaged across 3 yr. Symbols (filled triangle for soybean; open triangle for dry pea) represent seedling density for a specific week, averaged across replications and years.

Statistical Analysis. Data were initially examined for homogeneity of variance among years, and then subjected to analysis of variance to determine treatment effects and possible interactions among treatments and years (Statistix Analytical Software. Tallahassee, FL). Main and interaction effects were considered significant at $P \leq 0.05$; treatment means were separated with Fisher's Protected LSD. Data collected in quadrats within a plot were averaged for a plot value before analysis. Mean emergence rate for corn was calculated by averaging days to emergence for each plant across the total number of plants at the sampling site.

Differences in foxtail millet emergence between preceding crop treatments were analyzed and evaluated for each weekly assessment. Seasonal emergence of foxtail millet for each preceding crop was characterized by converting seedling density per week to a percentage of the total seasonal emergence (May 5 to August 1), and then developing emergence curves by cubic spline interpolation (Sigma Plot, Jandel Scientific. Point Richmond, CA).

Results and Discussion

Treatment effects did not interact with years for any parameter; thus, data were averaged across years.

Corn Yield Was Affected by Preceding Crop and Weed Interference. As shown previously (Anderson 2011b), dry pea improved corn tolerance to foxtail millet interference. Corn yielded twofold more following dry pea than following soybean when foxtail millet was present (Figure 1). In weed-free conditions, corn yielded 9,380 kg ha^{-1} following dry pea, an increase of 10% compared to corn following soybean. This trend agrees with previous research where dry pea increased weed-free corn yield compared to soybean across 7 yr (Anderson 2011a).

Foxtail Millet Emergence Did Not Differ in Stubble of Dry Pea and Soybean. One possible factor that could alter the interaction between weeds and corn is that weed seedling emergence can differ between residues of preceding crops (Teasdale and Mohler 2000). In our study, however, seedling emergence of foxtail millet in corn did not vary between preceding crops (Figure 2). Furthermore, foxtail millet density and fresh weight in corn 7 WAE were the same regardless of preceding crop (Table 2). Improved corn tolerance to weed interference was not due to differences in emergence or growth of foxtail millet.

Corn Development and Height Was Not Affected by Preceding Crop When Weed-Free. Greater grain yield and tolerance to weeds may reflect dry pea increasing corn growth early in the growing season. However, corn seedlings emerged similarly in stubble of both preceding crops, whereas rate of development and plant height of corn in weed-free conditions did not vary whether dry pea or soybean was the preceding crop (Table 2). When foxtail millet interfered with corn growth, differences in development and plant height due to preceding crop only occurred late in the growing season. Corn silking was delayed by weed interference when corn followed soybean (Table 2). Also, corn height at the nine-leaf stage was reduced by foxtail millet interference when corn followed

Table 2. Corn development as affected by preceding crop, and density and biomass (fresh weight) of foxtail millet. Data averaged across 3 yr, and across weed-free and weed-infested treatments, except with silking.[a]

	Preceding crop	
	Soybean	Dry pea
Corn development		
Mean emergence rate (d)	14.0 a	14.3 a
Leaf stage V-6 (d after June 1)	23 a	24 a
Leaf stage V-9 (d after July 1)	4 a	5 a
Leaf stage V-12 (d after July 1)	12 a	12 a
Silking (d after July 1)		
Weed-free	29 a	28 a
Weed-infested	33 b	31 ab
Foxtail millet		
Density (plants m^{-2})	88 a	86 a
Fresh weight (g m^{-2})	720 a	700 a

[a] Means within a row followed by the same letter do not differ based on Fisher's Protected LSD (0.05). The four means for silking were compared across weed-infestation levels.

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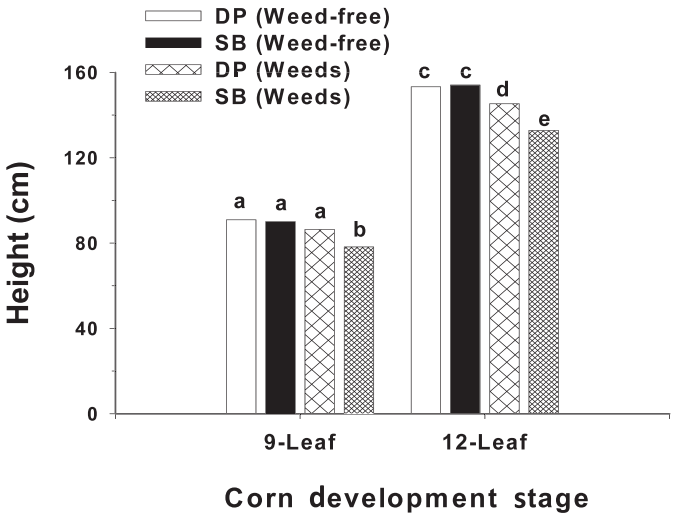


Figure 3. Corn height at the nine-leaf and 12-leaf developmental stages as affected by preceding crop and foxtail millet interference. Data averaged across 3 yr; bars within a leaf-stage with the same letters are not significantly difference as determined by Fisher's Protected LSD (0.05).

soybean and at the 12-leaf stage when corn followed either dry pea or soybean (Figure 3). Corn height was suppressed more by weed interference when following soybean than following dry pea.

Nutrient Concentrations of Corn Seedlings Did Not Increase Following Dry Pea. Nitrogen concentration of corn seedlings at the six-leaf stage differed between weed-free and weed-infested conditions, but not between preceding crops (Table 3). Thus, dry pea did not appear to alter N dynamics in soil compared with soybean to affect N status of corn seedlings. Weed interference reduced N concentration in seedlings 9 to 14%, but this effect did not vary with preceding crop.

One benefit of mycorrhizal association with crops is increased absorption of nutrients such as P, Zn, and Cu (Lambert et al. 1979). Neither preceding crop nor weed interference affected P or Cu concentration in corn seedlings (Table 3). Zn concentration did vary, but Zn levels in corn seedlings of both weed-free and weed-infested conditions were higher following soybean than dry pea. Thus, the favorable impact of dry pea on corn growth was not related to increased N, P, Zn, or Cu levels in corn seedlings. We speculate that mycorrhizal association with corn was not affected by the preceding crop.

Possible Causes of Dry Pea Synergy to Corn. Our goal with this study was to gain insight into identifying the cause of dry pea synergy to corn. The factors examined in our experiment, however, did not appear to explain the favorable interaction between dry pea and corn. Changes with microbial dynamics in soil could be a cause of synergy. Lupwayi et al. (2004), exploring the rotational benefit of dry pea with small grains, found that small grain crops often have higher density of rhizobacteria present on their roots when following dry pea. Similarly, Riggs et al. (2001) found that corn yield increased with higher densities of rhizobacteria on its roots.

Table 3. Impact of preceding crop on nutrient status of corn. Corn was assessed when six leaves were developed. Data averaged across 3 yr.[a]

Preceding Crop	Weed management	Nutrient			
		N	P	Zn	Cu
		g kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}
Soybean	Weed-free	3.5 a	0.31 a	22.1 a	11.1 a
	Weed-infested	3.0 b	0.30 a	18.2 b	10.1 a
Dry pea	Weed-free	3.4 a	0.32 a	18.5 b	10.0 a
	Weed-infested	3.1 b	0.30 a	15.3 c	9.5 a

[a] Means within a column followed by the same letter do not differ based on Fisher's Protected LSD (0.05).

Rhizobacteria improve resource-use efficiency and stress tolerance of plants (Dobbelaere et al. 2003); thus, dry pea may improve corn yield and tolerance to weeds by increasing rhizobacterial levels on corn roots. Yet, Sturz and Christie (2003), examining rhizobacterial effect on crop growth, found that identifying causal relationships was extremely difficult because of the complexity of plant–soil–microbial interactions.

Other possible causes could be dry pea residues releasing a growth-promoting compound (Anaya 1999) or affecting gene expression in corn to alter plant physiology and hence, resource-use efficiency (Kumar et al. 2004). However, results often are inconclusive when research focuses on one factor in assessing crop interactions (Kirkegaard et al. 2008). Bashan and de-Bashan (2010) encouraged scientists to consider multiple factors when examining interactions among crops. We suggest that dry pea affects corn physiology in some way to improve resource-use efficiency, and consequently, increase grain yield and tolerance to weeds (Anderson 2011a).

Implications for Agricultural Sustainability. Even though we may not know why corn responds favorably to dry pea, this synergy can improve crop production. Producers and scientists worldwide are interested in developing cropping systems that require fewer inputs to achieve successful crop yields (Bastiaans et al. 2000; Dore et al. 2011). In the semiarid Great Plains, producers increased land productivity without increasing inputs by including dry pea and corn in no-till rotations with other crops (Anderson 2011a; Beck 2011). Producers in eastern South Dakota could benefit similarly by expanding the corn–soybean rotation to include dry pea and other crops. Diversifying the corn–soybean rotation can increase grain yield of corn and soybean (Anderson 2009b; Katsvario et al. 2002), and also reduce inputs for insect and disease management (Krupinsky et al. 2002; Vereijken 2002). Furthermore, with more crop diversity, producers in eastern South Dakota may be able to manage weeds with less herbicide input, similar to producers in the semiarid Great Plains (Anderson 2008).

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