Spring Wheat Production and Associated Pests in Conventional and Diversified Cropping Systems in North Central Montana

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Abstract

Producers in the northern plains are diversifying and intensifying traditional wheat (*Triticum aestivum* L.)-based cropping systems by reducing summer fallow and including legume and oilseed crops. This study examined the influence of diversification and intensification on spring wheat yield and quality and associated insects, diseases, and weeds. Research was conducted during the 1998 through 2000 period in farm fields in north central Montana. Conventional rotations included either hard red spring wheat–spring barley (*Hordeum vulgare* L.)–fallow or spring wheat–fallow. Diversified rotations included replacement of fallow with either annual pulse crops or cool-season oilseeds. Preplant soil water was less in diversified rotations, but residual nitrate was not influenced by rotation type. Insect pests and beneficial arthropods were in greater numbers in conventional rotations. Incidence and severity of crown and root rots of wheat were similar between rotation types, but foliar leaf spot diseases were greater for wheat in conventional rotations. Weed densities were not influenced by rotation type. Spring wheat yield, tiller density, and test weight were greater in conventional rotations. Spring wheat in diversified rotations had greater drought stress. Diversification and intensification of spring wheat systems may reduce pests and decrease wheat productivity, particularly when precipitation is inadequate.

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Abbreviations: GPS, global positioning system.

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Previous Research on Intensified and Diversified Wheat Cropping

INTENSIFIED CROPPING SYSTEMS that incorporate pulse and oilseed crops adapted to local growing conditions increase cropping system diversity offering producers greater economic choices in enterprise selection (27) and the flexibility to adapt to variable environmental conditions (8). Use of no-till has permitted intensification from crop–fallow to crop–crop–fallow in the northern Plains where summer rains are likely to sustain growth of a second crop through the summer (21). No-till with crop intensification improves soil and air quality (17,23) and enhances efficient use of water and nutrient contents of soil (7,24). No-till systems have become increasingly popular in this region where summer precipitation is dominant and helps sustain crop growth through the warmest period of the year.

Including a pulse crop in the rotation is seen as a viable option for enhancing the efficiency of N fertilizer use and improving net return from grain production. In Montana, a crop rotation with winter lentil (*Lens culinaris* Medik.), green manure, and winter wheat produced greater grain yield and protein content at lower N input levels, indicating a greater N benefit from pulses (4). In neighboring Saskatchewan, wheat grain yields after pulses were increased 56% compared to wheat after wheat (9). This difference was attributed to increased N availability. In addition, cereals grown after broadleaf crops generally yield more than those grown after other cereals (2,10). A survey of 33 experiments in Australia suggested that the yield of wheat following canola (*Brassica napus* L.) was 19% greater than wheat following wheat (2,9). Crop rotation benefits from oilseeds are attributed to reduction in soil-borne diseases (11), arthropods (20), or weeds (1).

Evaluation of crop and pest management strategies often is done with small-plot studies, but farmer acceptance of results from small-plot studies can be poor. In addition, results obtained from small-plot studies may not always be representative of farm fields (26), particularly for mobile insects. Crop rotation benefits are well documented in numerous small plot studies; however, few studies have explicitly examined the influence of cropping diversification and intensification on grain quality and yield at the field scale.

The primary focus of this study was to determine impacts of diversification and intensification of the spring wheat–fallow system on spring wheat production, pests, and pest interactions at the field scale. Specific objectives were to determine the influence of dryland cropping system diversification and intensification on (i) spring wheat grain yield and quality, (ii) pest and edaphic factors that impact spring wheat yield, and (iii) comparative crop–pest interactions among cropping systems. The cropping systems were assessed over a 3 yr period (1998–2000) at the field scale with grower–producer participation under semiarid conditions in north central Montana.

Materials and Methods

Paired spring wheat fields grown in conventional and diversified cereal rotations were selected for study with active participation by producer–cooperators in north central Montana. Individual fields (plots) ranged in size from 27.5 to 80 acres; 19 fields were 40 acres. Six fields were monitored in 1998 while eight fields were monitored in 1999 and 2000. The three general locations were approximately 42 miles northwest of Havre, MT (48°50.3′ N, 110°3.6′ W), two miles west of Box Elder, MT (48°19.6′ N, 110°4.8′ W), and 17 miles west of Big Sandy, MT (48°10.6′ N, 110°27.8′ W). Soils at the three sites are predominantly frigid Aridic Argiustolls (Telstad, Joplin, Hillon, and Evanston loams) derived from glacial till or alluvial outwash.

Conventional rotations in the region are spring wheat–fallow and spring wheat–spring barley–fallow. Diversified rotations in this study included replacement of fallow with field pea (*Pisum sativum* L.), lentil, chickpea (*Cicer arietinum* L.), or yellow mustard (*Sinapis alba* L.) harvested for seed. Specific conventional and diversified rotation paired comparisons are presented (Table 1). Spring wheat crops were planted, managed, and harvested by producer–cooperators. The three cooperators used diverse production systems to raise cereals, pulses, and oilseeds, including organic production, zero tillage, and certified seed production with strong integrated pest management approaches. Paired fields were planted within 1 day of each other using the identical equipment, spring wheat variety, and tillage system.

Grid sampling point density was about 1.6 points per acre in spring wheat crops. Points were located on a regular square grid using an agricultural-grade global positioning system (GPS) receiver. Before planting, soil cores were collected by a truck-mounted, hydraulic-assisted probe at two depths, 0 to 12 inches and 12 to 24 inches. Samples were weighed, oven dried, and reweighed for determination of gravimetric water concentration. Soil samples then were ground, sieved to pass a 2 mm screen, and analyzed for NO_3–N concentration by autoanalyzer at a commercial laboratory (Western Testing Laboratories, Great Falls, MT). Following wheat planting in the spring, individual grid sampling points were marked with numbered lathe.

After crop emergence, wheat plant density was determined by counting plants in 1 yard of row. Weed cover of predominant species, typically kochia [*Bassia prostrata* (L.) A.J. Scott] and Russian thistle (*Salsola kali* L.), was visually estimated (Table 2) at tillering stage, before application of any in-crop herbicide. Insect community, foliar leaf spots, drought stress, and reproductive tiller densities were determined when wheat was at about Feekes growth stage 11.1 (milk stage). Arthropods were sampled by taking five 180° sweeps around each grid point with a standard 15-inch diameter sweep net. Most arthropods were identified to family, genus, or species level and then classified as "beneficial," "pest," or "other" arthropods. Foliar leaf spot diseases, tan spot [causal agent *Pyrenophora tritici-repentis* (Died.) Dreschler] and Septoria blotch (causal agent *Septoria tritici* Roberge in Desmaz.), and drought stress were visually estimated with numerical rating systems (Table 2) based on progression of disease or drought stress symptoms within the crop canopy. Before harvest, 1 yard of spring wheat was sampled at each grid point, and the total numbers of wheat plants, reproductive tillers, and plants with Fusarium crown rot (causal agent *Fusarium pseudograminearum* O'Donnell et. T. Aoki sp. nov.) and

Table 1. Conventional and corresponding diversified rotations with spring wheat for determination of soil water, soil nitrate, weeds, arthropods, diseases, grain production, and grain protein concentration, 1998 through 2000.

Field	Conventional rotations	Field	Paired diversified rotations
1a	wheat–barley–fallow–**wheat**[y]	1b	wheat–barley–lentil–**wheat**
2a	fallow–wheat–fallow–wheat–**wheat**	2b	fallow–wheat–lentil–**wheat**
3a	wheat–barley–fallow–**wheat**	3b	wheat–barley–pea–**wheat**
4a	wheat–fallow–barley–fallow–**wheat**	4b	wheat–fallow–barley–chickpea–**wheat**
5a	wheat–barley–fallow–**wheat**	5b	wheat–barley–pea hay–**wheat**
6a	wheat–fallow–wheat–fallow–**wheat**	6b	wheat–mustard–fallow–**wheat**
7a	wheat–fallow–wheat–fallow–**wheat**	7b	wheat–fallow–wheat–pea–**wheat**
8a	wheat–barley–fallow–**wheat**	8b	wheat–sunflower (*Helianthus annuus* L.)–lentil–**wheat**
9a	wheat–barley–fallow–**wheat**	9b	wheat–barley–pea–**wheat**
10a[x]	wheat–fallow–wheat–fallow–**wheat**	10b[z]	wheat–chickpea–fallow–**wheat**
		10c[z]	wheat–mustard–fallow–**wheat**
		10d[z]	wheat–flax (*Linum usitatissimum* L.)–fallow–**wheat**

[y]Wheat in bold letters is phase used in this study.

[z]These four fields, together making up a contiguous 160 acre block, were sampled in 2000.

common root rot [causal agent *Bipolaris sorokiniana* (Sacc.) Shoemaker] were determined. Wheat stem sawfly [*Cephus cinctus* Norton (Hymenoptera: Cephidae)] infestation was determined by dissecting 40 reproductive tillers from each sample followed by examination for larvae.

Producer-operated combine harvesters equipped with calibrated yield monitors and GPS receivers were used to measure and map site-specific spring wheat yields within the fields. Grain samples (about 800 g) were manually taken at the grain bin filling auger every 1 min of combine operation for subsequent laboratory determination of grain protein concentration and test weight. Protein concentration of each grain sample was determined by whole grain near-infrared spectroscopic analysis at the Cereal Quality Laboratory, Montana State University, Bozeman.

Analysis of variance was undertaken with the mixed model procedure (22) with farm and year as random variables, except for categorical data. Percentage data were analyzed following arcsine-square root transformation. The categorical data, foliar disease and drought stress, were rank transformed (12) and then analyzed with Friedman's two-way analysis of variance (6). Pearson's correlation coefficients with spring wheat yield were determined using the nearest yield point from GPS coordinates in yield files.

Results and Discussion

Comparing Spring Wheat in Different Systems

Precipitation was less than the long-term average for most months during the 3 yr of our study (Table 3). In this study, the long-term average was based on long-term weather records (1917–2012) at Fort Assinniboine near Havre, MT, which is climatically similar to the three study sites. Official weather data are not available for the Box Elder site. However, the fields at the Box Elder site were located about 12 to 15 miles north of Big Sandy, the nearest weather station, and weather patterns generally are similar between these sites. A recording weather station was located within 1 to 4 miles of the fields in the North Havre area. Overall, despite the distances among field sites, monthly precipitation patterns were similar among locations each year.

Table 2. Numerical rating systems used for visually estimating weed infestations (0–5) and foliar disease and drought stress (0–3) in spring wheat.

Rating	Weed cover	Foliar disease and drought stress
0	None present	None present
1	1–5%	Present in the lower one-third of canopy
2	6–25%	Present in the middle one-third of canopy
3	26–50%	Present in the upper one-third of canopy
4	51–75%	
5	>76%	

Fields in diversified crop rotations had drier soils within the 0 to 24 inch depth than fields in conventional cereal rotations 1 wk before planting spring wheat (Table 4), reflecting the impact of cropping intensification by replacement of summer fallow with pulse or oilseed crops. The rotational effect of pulses has been shown to elevate soil nitrate compared with nonpulse broadleaf crops (19). However, despite including pulses in diversified rotations, overall preplant soil nitrate concentrations were similar between rotational type, perhaps due to reduced soil moisture that likely decreased N mineralization and nitrification rates (3), residue returned to soil, and N fixation by pulses.

Although stand densities were similar between rotation types, wheat grown in the conventional rotations had more reproductive tillers per unit area (Table 5), similar to other reports from the northern Great Plains (13,14). Wheat grown in diversified rotations

Table 3. Precipitation (inches) for 1998 through 2000 at North Havre, MT, and Big Sandy, MT, versus long-term average precipitation at Fort Assinniboine near Havre, MT.

Month	1998	1999	2000	Long-term average[x]
Big Sandy[y]				
April	1.11	1.98	0.93	1.13
May	1.53	1.07	0.91	2.40
June	3.91	2.96	1.20	2.58
July	1.19	0.98	1.04	1.57
August	0.85	0.71	0.19	1.31
Total (12 mo)	12.67	11.80	6.83	13.42
North Havre[z]				
April	0.28	1.17	0.47	0.94
May	0.10	0.87	0.94	1.77
June	2.12	0.51	1.93	2.56
July	0.71	1.57	0.39	1.50
August	0.22	1.18	0.12	1.22
Total (12 mo)	11.34	12.05	5.75	12.10

[x]Long-term precipitation data from Fort Assinniboine, MT, 1917 through 2012.

[y]Precipitation data for Big Sandy, MT (National Climatic Data Center, National Oceanic and Atmospheric Administration, personal communication, 2013), 1970 through 2000 (missing 1990–1991).

[z]1998 through 2000 precipitation data from site located 42 miles northwest of Havre, MT.

had higher drought stress and concomitantly lower grain yields and higher grain protein concentrations than wheat grown in conventional rotations. The inverse relationship between grain yield and grain protein in semiarid environments has been attributed to moisture stress, which restricts the production of carbohydrates in the grain more than production of seed proteins. Higher grain protein concentration in response to greater drought stress for wheat in more intense cropping systems has been reported previously (13,15). Wheat test weight was lower in diversified and intensified systems, likely due to less available soil water at grain fill. Despite finding reduced yield of winter wheat in diversified systems compared to yield in conventional systems, overall profitability can be greater in the diversified systems provided the net return from the additional crops is greater than the reduction in net return from the subsequent wheat crop, due to reduced wheat yields (16). An economic comparison of the conventional and diversified rotations was beyond the scope of this study. Nevertheless, reports in the literature generally show favorable economic returns from intensification of dryland wheat production systems in the northern Great Plains when soil moisture is adequate (27).

Table 5. Mean (SE) stand and reproductive tiller densities, grain protein, yield, and drought stress rating of spring wheat in conventional or diversified crop rotations, 1998 through 2000.

Spring wheat	Conventional	Diversified	*P* > *F*
Plants, no./foot^2	13.6 (0.9)	13.3 (0.9)	0.79
Tillers, no./foot^2	26.4 (1.8) a[y]	23.6 (1.7) b	0.07
Drought stress[z]	0.8 (0.6) b	1.7 (0.9) a	0.07
Grain yield, pound/acre	1852 (262) a	1359 (258) b	0.01
Grain protein, %	14.6 (1.4) b	16.1 (1.3) a	0.03
Test weight, no./bushel	57.7 (0.8) a	56.7 (0.8) b	0.05

[y]Means within rows followed by different letters differ significantly at $P = 0.05$.

[z]Results from 2 yr, 1998 and 1999.

Pest insects outnumbered beneficial arthropods (insects and spiders) in nearly all paired comparisons. Wheat grown in conventional rotations had higher infestations by wheat stem sawfly and other insect pests compared to wheat grown in diversified rotations (Table 4). Both insect pest and arthropod beneficial

Table 4. Mean (SE) arthropod, plant disease and weed ratings, preplant soil water, and soil nitrate from 22 spring wheat fields in conventional or diversified rotations, 1998 through 2000.

Parameter	Conventional	Diversified	*P* > *F*
Preplant soil water 0–12 inches, %	13.0 (1.5)	12.0 (1.2)	0.25
Preplant soil water 12–24 inches, %	13.0 (1.5) a[x]	10.2 (1.3) b	0.01
Preplant soil water 0–24 inches, %	13.0 (1.4) a	11.0 (1.1) b	0.02
Preplant soil nitrate 0–12 inches, pound/acre	11.8 (1.9)	13.0 (1.7)	0.63
Preplant soil nitrate 12–24 inches, pound/acre	6.7 (2.6)	6.5 (2.5)	0.95
Preplant soil nitrate 0–24 inches, pound/acre	18.8 (4.3)	19.3 (4.0)	0.88
Insect pests, no./5 sweeps	7.5 (2.1) a	4.3 (2.1) b	0.02
Wheat stem sawfly, % infested stems	4.3 (2.2) a	2.4 (1.6) b	0.03
Beneficial arthropods, no./5 sweeps	3.5 (1.1) a	2.1 (1.1) b	0.03
Common root rot, % diseased plants	11.6 (2.5)	10.6 (3.0)	0.75
Fusarium crown rot, % diseased plants[y]	2.6 (1.0)	6.0 (2.8)	0.58
Foliar leafspots[z]	1.5 (0.6) a	1.1 (0.9) b	0.05
Russian thistle, % cover[z]	3.2 (2.2)	5.6 (2.3)	0.34
Kochia, % cover[z]	5.3 (2.8)	2.7 (2.0)	0.41
Total weeds, % cover[z]	10.5 (3.6)	12.9 (3.3)	0.29

[x]Means within a row followed by different letters differ significantly at $P = 0.05$.

[y]Results from 1 yr, 1999.

[z]Results from 2 yr, 1998 and 2000.

numbers were both greater in sweep samples from wheat in conventional rotations (Table 4). Insect pests most commonly occurring were wheat stem sawfly, stink bugs (Pentatomidae), thrips (Thripidae), and various leafhoppers (Cicadellidae). Beneficial arthropods included various spiders (Aranae) and wasps (Hymemoptera: "Parasitica"). Due to the lack of aphids (Aphididae) in wheat during the duration of this study, lady bird beetles (Coccinellidae) were largely absent from all fields (data not presented).

The incidence and severity of root and foliar diseases were lower than expected, perhaps due to the overall lower wheat crop productivity and resulting crop residue during the study period. Incidence of Common root rot and Fusarium crown rot on spring wheat did not differ between conventional and intensified, diversified crop rotations (Table 4). The foliar leaf spot diseases, tan spot and Septoria blotch, were rated in 2 yr only because they were not present on spring wheat grown in 2000, a year with less rainfall. For the 2 yr foliar disease data were available, wheat in diversified rotations had less foliar diseases than wheat grown in conventional rotations (Table 4). Wheat in diversified rotations had foliar leaf spots that were largely restricted to the lower plant canopy and did not progress into the flag leaf. Wheat in conventional rotations probably had more infected wheat residue from previous crops that served as initial inoculum source to infect wheat seedlings. Wheat grown in diversified rotations may be delayed in initial infection as wind-blown spores are more important for primary inoculum. Higher grain yields and increased foliar disease are often correlated under high moisture growing conditions.

Weed cover ratings taken before application of the first and only in-crop herbicide application did not differ for Russian thistle, kochia, or total weeds between the two wheat rotation types (Table 4). Russian thistle and kochia were the predominant weeds encountered in most fields; however, fields 10a through 10d also had downy brome (*Bromus tectorum* L.) present in numerous patches, but differences in weed cover did not exist between systems (results not presented).

Correlations of Wheat Yield with Soil Water and Residual Nitrate

Most fields used in this study were 40 acres in size and were sampled for soil and pest parameters on about 65 points of a regular square sampling grid. However, fields 5a and 5b were 27.5 acres each and had about 35 sampling points per field. Field 2b was 80 acres and had 130 points. Our sampling design provided the opportunity to investigate associations between different pairs of crop and soil variables that had been sampled within the fields. If an association was found between X and Y, one can infer that that variation in X may cause variation in Y or that variation of some other factor causes variation in both X and Y (18).

Spring wheat yield was positively correlated with preplant soil water content in at least one depth increment for seven fields in conventional rotation systems and five fields in diversified systems (Table 6). The strong relationship between wheat yield and soil water content in semiarid environments is well documented for conventional and diversified wheat production systems (5,7,14). The correlation between wheat yield and preplant soil nitrate was modest and both positive and negative for single fields in conventional wheat systems (Table 6). For wheat in diversified, intensified systems, 4 of 10 fields had yield correlated with preplant nitrate. Three fields showed yield negatively correlated with yield while one field had a positive correlation between yield and preplant soil nitrate content (Table 6). Soil nitrate accumulations vary for several reasons. Soils with greater organic matter content typically have greater N cycling, resulting in greater nitrate evolution. Pulse crop residues have lower C to N ratios than cereal residues, providing for faster breakdown and greater N availability if soil moisture is adequate. Drought conditions compromising the ability of a previous crop to utilize use all available N also can result in a greater accumulation of nitrate (15).

Correlations of Spring Wheat Yield with Pests

Spring wheat yield was negatively correlated with weed cover ratings in 4 of 10 fields in conventional cropping systems (Table 7). Competition for water from denser weed cover may be the primary reason for their possible relationship. One wheat field in a conventional system had a positive correlation of wheat yield with weed cover. For wheat in diversified, intensified systems, only 1 field of 10 had a correlation between wheat yield and weed cover, and that correlation was negative (Table 7), indicating that weed cover in this system had little impact on yield within the range of measured values.

Results for correlations for Fusarium crown root and Common root rot with wheat yields were similar between the conventional and diversified systems (Table 7). The majority of fields did not have significant correlation between root and crown rots and yield, but when correlations were significant, they always were negative, indicating that increased root and crown disease may decrease yield. The foliar leaf spot diseases tan spot and Septoria blotch were negatively correlated with spring wheat yield in two fields in both management systems while one field had a positive correlation between yield and foliar disease, which we are unable to explain. Foliar diseases infrequently affect yield of spring wheat in the northern Great Plains (25).

Wheat stem sawfly infestations and beneficial arthropods were rarely correlated with wheat yield in either management system (Table 7). Total pest arthropods were correlated with yield in 4 of 10 fields in diversified systems; however, trends with yield were inconsistent with two fields each with negative and positive correlations.

Table 6. Significant Pearson correlation coefficients of spring wheat yield vs. soil water and nitrate for 22 fields, 1998 through 2000.

Rotation type and field number	Soil water			Soil nitrate		
	0–12 inches	12–24 inches	0–24 inches	0–12 inches	12–24 inches	0–24 inches
Conventional						
1a[x]	ns[y]	0.328[z]	ns	ns	ns	ns
2a	ns	ns	ns	ns	ns	ns
3a	ns	–	–	ns	–	–
4a	ns	0.271*	ns	ns	ns	ns
5a	ns	0.308*	ns	ns	0.286[z]	ns
6a	ns	0.440***	0.388**	ns	ns	ns
7a	0.392**	0.470***	0.486***	–0.332**	–0.264*	–0.319*
8a	ns	0.290[z]	ns	ns	ns	ns
9a	ns	ns	ns	ns	ns	ns
10a	0.404**	0.467***	0.467***	ns	ns	ns
Diversified						
1b	ns	ns	ns	ns	ns	ns
2b	ns	ns	ns	ns	ns	ns
3b	0.423**	ns	0.329*	ns	–0.304*	ns
4b	0.708***	0.711***	0.738***	ns	ns	ns
5b	ns	ns	ns	ns	ns	ns
6b	0.356*	0.296*	0.327*	0.332*	ns	0.383**
7b	ns	ns	ns	ns	ns	ns
8b	ns	ns	ns	ns	ns	ns
9b	ns	0.431**	ns	ns	ns	ns
10b	0.369*	0.280[z]	0.393**	ns	ns	ns
10c	ns	ns	ns	–0.380*	–0.510***	–0.511***
10d	ns	ns	ns	–0.257[z]	–0.294*	–0.305*

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

***Significant at the 0.001 probability level.

[x]Field numbers correspond to spring wheat in rotations listed in Table 1.

[y]ns, not significant.

[z]Significant at the 0.10 probability level.

Summary

Diversified, intensified cropping systems consistently reduced the soil water content available for the subsequent spring wheat crop under below average rainfall in north central Montana. Spring wheat in conventional and diversified cropping systems did not differ in incidences of root disease and infestations of weeds, but conventional systems harbored greater populations of both beneficial and predatory insects. Results from our study show that at field scale, pest–pest and pest–edaphic factor correlations occur, and that correlations of pest and edaphic factors with spring wheat yield can vary between conventional cereal and diversified crop rotations. Additionally, results with field-scale plots closely resemble results from smaller plot studies for soil water (14), residual nitrate (15), weed community (13), arthropods (20), Fusarium crown rot (10), and spring wheat yield and quality (14) when conducted under similar environmental conditions, validating the utility of both large- and small-plot research (9). In the northern Great Plains, producers may find that diversification and intensification of spring wheat systems will decrease wheat productivity, particularly when precipitation is inadequate, despite decreased losses from arthropod and disease pests. During periods of drought, strategic use of summer fallow is warranted in the northern Great Plains. Diversification of crops and the resulting economic benefits largely will be dependent on the long term climate and available soil moisture rather than pest and disease complexes.

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Table 7. Significant Pearson correlation coefficients of spring wheat yield vs. root and foliar diseases, weed cover, and beneficial and pest arthropods from 22 fields, 1998 through 2000.

	Diseases			Arthropods		
Rotation type and field number	Root and crown rots	Foliar leafspots	Weed cover	Beneficials	Pests	Wheat stem sawfly
Conventional						
1a[x]	ns [y]	ns	−0.347[z]	ns	ns	ns
2a	ns	ns	−0.317*	ns	ns	ns
3a	ns	ns	ns	–	–	ns
4a	ns	−0.244 [z]	ns	ns	ns	ns
5a	−0.307*	ns	0.316*	−0.327*	ns	ns
6a	−0.300**	ns	−0.199*	ns	ns	−0.322***
7a	ns	−0.340**	−0.209[z]	ns	ns	ns
8a	ns	–	ns	0.327*	ns	ns
9a	ns	–	ns	ns	ns	ns
10a	ns	–	ns	ns	ns	ns
Diversified						
1b	ns	ns	ns	ns	−0.253[z]	ns
2b	−0.212*	ns	ns	ns	ns	ns
3b	ns	0.368**	ns	ns	ns	ns
4b	ns	−0.562***	−0.353**	ns	ns	ns
5b	ns	ns	ns	ns	ns	ns
6b	−0.418**	ns	ns	ns	ns	0.296*
7b	ns	ns	ns	ns	ns	ns
8b	ns	–	ns	ns	ns	ns
9b	ns	–	ns	ns	ns	ns
10b	ns	–	ns	ns	0.265[z]	ns
10c	−0.271[z]	–	ns	ns	0.301[z]	ns
10d	ns	–	ns	ns	−0.301*	−0.376**

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

***Significant at the 0.001 probability level.

[x]Field numbers correspond to spring wheat in rotations listed in Table 1.

[y]ns, not significant.

[z]Significant at the 0.10 probability level.

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