Effects of Different Nitrogen Fertilizer Sources, Placements , and Rates on Agronomic Traits of Barley Grown at the Landscape-Scale

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Introduction

Direct seeding or a one-pass placement of seed and fertilizer into untilled land is increasing in popularity in western Canada. Primarily granular or liquid forms of nitrogen (N) fertilizer are used in direct seeding. More research is needed, however, before recommending direct seeding with anhydrous ammonia (AA) (Hultgreen and Leduc, 1995). Evidence suggests that placement of AA at seeding may be possible as demonstrated by the numerous trials conducted throughout western Canada (Hnatowich, 1995). Varvel(l982) observed that AA can be safely side banded with seeds of spring wheat *(Triticum aestivum* L.) and barley (Hordeum vulgare L.) if a good separation is provided. Recently, several openers and packing systems have been developed for direct seeding. These openers need to be evaluated for their siutability in placing AA and their subsequential influence on grain yield, grain protein and nitrogen fertilizer use efficiency. Further, farm soils are highly variable across knolls, shoulders, and footslopes and may respond differently to AA application. Therefore, by placing fertilizer treatments on shoulders and footslopes we will be able to evaluate the effectiveness of two types of openers on their placement of nitrogen fertilizers on different landform positions. Accordingly, the objectives of this study were: 1) to compare urea (U) and ammonium nitrate (AN) with AA placement during seeding at the landscape-scale level and, 2) to evaluate at the landscape-scale level the effectiveness of two widely differing openers in placing AA during seeding and their effects on barley grain yield, gram percent protein, and nitrogen use efficiency.

Materials and Methods

A 3.75 ha area was selected in a representative section of a farm field at Wakaw and St. Louis, Saskatchewan (Conservation Learning Center). The Digital Elevation Model classified the area in shoulders and footslopes. The experiment was a split-plot design with fertilizer treatments as main plots and shoulders and footslopes as subplots. Treatments were laid out in a randomized complete block design replicated five times. Repeated measures analysis was used to compare shoulders with footslopes and to determine the magnitude of the landform by treatment, and the location by landform by treatment interactions. The Azallini and Cox test for crossover interaction was used to determine change in ranking of barley grain yield, grain protein and nitrogen use efficiency induced by nitrogen fertilizer treatments (Baker, 1988).

On the shoulders at St. Louis the soil was a Black Orthic Chemozem silty clay loam to silty clay. The Ap horizon thickness was about 15 cm. Footslope soils were characterized as a Black Eluviated Chemozem silt loam to silt clay loam. The Ap horizon thickness was about 30 cm. The total precipitation from seeding to harvesting was 199 mm. Soil bulk density was 1.13 g cm^{-3} on the shoulders and 0.99 g cm^{-3} on the footslopes. Soil water content, cation exchange capacity, available soil nitrogen before fertilizer application, total organic carbon, and clay content for both locations are presented in Table 1.

At Wakaw the soil of the shoulders was a Black Rego Chernozem with significant areas of Black Calcareous Chernozem loam. The Ap horizon was about 12 cm in thickness. The soil at the footslopes was a Black Eluviated Chemozem silt loam. The Ap horizon thickness was about 20 cm. The total precipitation from seeding to harvesting was 180 mm. Soil bulk density was 1.20 g cm^{-3} on the shoulders and 1.17 g cm^{-3} on the footslopes.

At both locations nine fertilizer treatments were applied to barley cv. Harrington seeded at a rate of 80 kg ha^{-1} on May 30, 1995 (Table 2). Triple super-phosphate (0-45-O) was seed placed at a rate of 20 kg P_2O_5 ha^{-1} at both locations. Seeding depth was 3.5-cm at Wakaw and 3.0-cm at St. Louis. Barley was seeded on barley stubble at St. Louis and on canola stubble at Wakaw. Plot size was 2.5-m wide by 20-m long. Barley grain was harvested with a small plot combine, and cleaned and weighed to determine grain yields. Grain samples were air dried under forced air at 40^0C to constant weight and ground using a cyclone mill (0.4-mm screens). Grain percent nitrogen was determined on a continuous-flow isotope ratio mass spectrometer (CF-IRMS)(Europa Scientific, Crewe, England) interfaced with a RoboPrep Sample converter (Europa Scientific). Grain percent protein was calculated by multiplying the grain percent nitrogen by 6.25. Nitrogen use efficiency (NUE) was calculated by the following formula:

NUE = (total N yields in treatment - total N yields in control)/N rate x 100

Description of openers

Two openers representing the extremes produced in soil disturbance during operation were chosen for evaluation. The Flexi-Coil Stealth LS Paired Row Double Shoot opener is a narrow bolt-on knife opener which causes minimal soil disturbance on use. The opener produces two rows of seed with a horizontal separation of 5 cm. The fertilizer is placed midway between the seed rows and approximately 2.5 cm below. The Sweep Wing Tip System, by D.J. Manufacturing, uses a 35 cm shovel in which the AA tubes are split and extended to the wing tip section of the shovel. Anhydrous ammonia tubes are attached to every second shank; therefore this system simulates a midrow fertilizer application. The AA is applied at the same depth as the seed. Shovels were equipped with Froc seed boots which scatter the seed creating a seedrow approximately 12.5 - 20 cm wide. This is a high soil disturbance system. Anhydrous ammonia was applied in a liquefied forrn.

Results and Discussion

Grain yield

Grain yields of barley were higher, on average, on the footslopes than on the shoulders (Tables 3, 4 and 5). Yields ranged from a high of 2.89 t ha^{-1} on the shoulders of St. Louis (Table 4) to a low of 1.01 t ha^{-1} on the footslopes of Wakaw (Table 5). At St. Louis, where the residual mineral nitrogen was high (Table 1), nitrogen fertilizers had no affect on grain yield (Tables 3 and 4). At Wakaw, where the residual mineral nitrogen was low nitrogen fertilizers increased grain yield by more than 100% on the shoulders compare with the control (Table 5).

The grain yield of barley was not affected by nitrogen sources at Wakaw (Tables 3 and 5). Similarly, Varvel(l982) observed minor reduction in wheat and barley seedling stands with no negative effects on grain yield. In contrast, barley fertilized with U and AN yielded 0.14 t ha^{-1} higher than when fertilized with AA at St. Louis. It is unknown if this yield reduction was caused by AA toxicity or volatilization losses.

The significant location by treatment interaction for grain yield was caused by changes in the magnitude of the response to AA placement (Table 3). At Wakaw, barley fertilized with 35 kg N ha^{-1} of AA applied using the sweep/froc boot opener yielded 0.7 t ha^{-1} higher than when fertilized with 35 kg N ha^{-1} of AA applied using the paired row opener, whereas at St. Louis grain yield differences were much lower. In addition, contrast analysis indicated that barley fertilized with 35 kg N ha^{-1} of AA applied using the paired row opener yielded higher than barley fertilized with 105 kg N ha^{-1} of AA applied using the paired row opener at St. Louis (Table 3). While at Wakaw the reverse occurred (Tables 3 and 5). This suggested that the performance of openers in placing AA varied across landform-complexes and AA rates. The AA losses were probably greater at St. Louis due to high soil clay and high soil moisture content. Johnston et al. (1995) also reported high losses of N from AA applied to wet clay soils.

The response of barley grain yield varied with the type of opener. The shoulders or footslopes at Wakaw which were fertilized with 35 kg N ha“ of AA applied using the paired row opener procured grain yields similar to the control. In contrast, barley fertilized with 35 kg N ha^{-1} of AA applied using the sweep/froc boot opener yielded 39% higher on the shoulders and 90% higher on the footslopes compared with the control. This suggested that at Wakaw the sweep/froc boot opener was superior to the paired row opener.

Grain Protein

Percent grain protein was 2.8% higher at St. Louis than at Wakaw (Table 3). A residual soil nitrogen about four times higher at this location may have played an important role in determining percent protein (Table 1). Fiez et al. (1994) observed that grain protein was highly correlated with the amount of pre-plant residual soil nitrogen. These researchers concluded that under dryland conditions deep residual soil nitrogen is taken up by the crop late in the growing season. Late uptake of soil and fertilizer nitrogen may have contributed to increased grain protein at St. Louis.

Grain protein obtained from barley grown on shoulders, ranged from 12.8% at St. Louis (Table 4) to 8.0% at Wakaw (Table 5). When averaged across nitrogen fertilizers rates, nitrogen sources had no affect on grain protein at any landform position, or when averaged across landform positions (Tables 3, 4, 5). Whereas at Wakaw, the grain protein of barley grown on the footslopes and fertilized with 70 kg N ha^{-1} of U using a paired row opener was 1.5% higher than the grain protein of barley fertilized with 70 kg N ha^{-1} of AA applied using a similar opener. Similarly, on the footslopes of Wakaw the grain protein of barley fertilized with 70 kg N of AN applied using a paired row opener was 1.3% higher than the grain protein of barley fertilized with 70 kg N ha^{-1} of AA applied with the sweep/froc opener (Table 5). This suggested that nitrogen fertilizer sources affected grain protein of barley at Wakaw. Fertilizer treatments had no affect on percent protein at St. Louis (Tables 3 and 4). At Wakaw, however, a nitrogen fertilizer rate of 105 kg N ha^{-1} of AA applied using the sweep/froc boot opener increased percent protein on the shoulders (1.7%), footslopes (1.9%) or when averaged across landforms (1.7%) compared with the control (Table 5). Therefore, at Wakaw the sweep/froc boot opener was more efficient in increasing grain yield and percent protein than the paired row opener.

Nitrogen use efficiency

Nitrogen use efficiency of barley was 17% higher at Wakaw than at St. Louis, ranging from a low of 6% at St. Louis to a high of 79% at Wakaw (Tables 3, 4, and 5). This decrease in nitrogen use efficiency at St. Louis was consistent with the failure of nitrogen fertilizer to increase barley grain yield. When averaged across landforms and locations nitrogen use efficiency of barley using granular fertilizers (U + AN) was similar to that of AA (Table 3). Nitrogen fertilizer rates affected nitrogen use efficiency differently across landforms. Thus, 35 kg N ha^{-1} of AA applied using the paired row opener at St. Louis resulted in the highest nitrogen use efficiency on the shoulders (50%), while AN applied at a rate of 70 kg ha“ ranked first on the footslopes (53%). The highest nitrogen use efficiency was observed on the footslopes at Wakaw where U was applied at a rate of 70 kg N ha^{-1} using the paired row opener, while a 105-kg N ha^{-1} rate of AA applied using the paired row opener had the highest nitrogen use efficiency on the shoulders. Type of opener did not affect nitrogen use efficiency at Wakaw or on the shoulders at St. Louis (Tables 3, 4, and 5). The nitrogen use efficiency observed on the footslopes at St. Louis was higher using the paired row opener than the sweep/froc boot opener (Table 4). However, this higher nitrogen use efficiency was not reflected in higher grain yield or grain protein.

The nitrogen use efficiency of barley grown at St. Louis and fertilized with 35 kg N ha^{-1} of AA applied using the paired row opener was 3 1.2% higher than the nitrogen use efficiency of barley fertilized with 105 kg N ha^{-1} of AA applied using the same opener. In contrast, the nitrogen use efficiency of barley grown at Wakaw and fertilized with 105 kg N ha^{-1} of AA applied using the paired row opener was 26% higher than the nitrogen use efficiency of barley fertilized with 35 kg N ha^{-1} of AA applied using the same opener.(Table 3). This suggested that the effect of a paired row opener on nitrogen use efficiency was highly variable across landforms.

The location by treatment interaction for nitrogen use efficiency was a crossover interaction. At St. Louis, the nitrogen use efficiency of barley fertilized with 35 kg N ha^{-1} of AA using the paired row opener was 24% higher than the nitrogen use efficiency of barley fertilized with 70 kg N ha^{-1} of U. While at Wakaw the reverse occurred. In addition, the location by landform by treatment interaction for nitrogen use efficiency was also a crossover interaction (Table 3). The nitrogen use efficiency of barley fertilized with 35 kg N ha^{-1} of AA applied using the sweep/froc opener was 17% higher than 70 kg N ha^{-1} of U applied using the paired row opener on the footslopes at St. Louis, whereas on the footslopes at Wakaw the reverse occurred (Tables 4 and 5). Therefore, the ranking of nitrogen fertilizer treatments for nitrogen use efficiency of barley was highly variable across landform complexes and locations.

Summary

At Wakaw, the grain yield of barley fertilized with anhydrous ammonia was similar to the grain yield of barley fertilized with urea or ammonium nitrate. At St. Louis, barley fertilized with urea or ammonium nitrate yielded higher than of barley fertilized with anhydrous ammonia. It is not known if this reduction in grain yield was caused by seedlings damage or volatilization losses of anhydrous ammonia. At Wakaw, the sweep/froc boot opener increased barley grain yield at low and high nitrogen fertilizer rates and increased grain percent protein at high levels of nitrogen fertilization on shoulders and footslopes. At St. Louis a similar response was not observed. Therefore, at Wakaw the sweep/froc boot opener was more efficient than the paired row opener in increasing grain yields and grain protein. The effects of nitrogen fertilizer sources and openers types on grain yield, grain protein, and nitrogen use efficiency was inconsistent. This suggest that more research is needed to determine the conditions under which anhydrous ammonia is as safe as using granular nitrogen fertilizers and the most efficient opener type to use under zero-tillage conditions in western Canada.

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Table 1. Soil properties of each location (O-20 cm).

Locations	Soil Moisture (%)	CEC[w] (me 100 g^{-1})	Residual N[x] (kg N ha^{-1})	Organic Matter (%)	Soil Texture
St. Louis					
Footslopes	29	38	30	6.9	Silty clay loam
Shoulders	27	37	24	6.9	Silty clay
Wakuw					
Footslopes	16	24	6	3.4	Silty loam
Shoulders	17	23	6	5.2	Loam

[w] CEC = Cation Exchange Capacity
[x] N = Nitrogen

Table 2. Fertilizer treatments, fertilizer types, fertilizer rates, and opener types used on barley grown in 1995.

Fertilizer Treatments	Fertilizer Types	Fertilizer Rates kg N ha^{-1}	Openers Types
Control	No fertilizer	0	Paired row (PR)
U70PR	Urea (U)	70	Paired row
AN70PR	Ammonium nitrate (AN)	70	Paired row
AA35PR	Anhydrous ammonia (AA)	35	Paired row
AA70PR	Anhydrous ammonia	70	Paired row
AA105PR	Anhydrous ammonia	105	Paired row
AA35SFB	Anhydrous ammonia	35	Sweep/froc boot (SFB)
AA70SFB	Anhydrous ammonia	70	Sweep/froc boot
AA105SFB	Anhydrous ammonia	105	S weep/froc boot

Table 3. Means, combined analysis of variance, and contrasts for grain yield, grain protein, and nitrogen use efficiency of barley grown at St. Louis and Wakaw in 1995.

Treatments	St. Louis	Wakaw	Mean	St. Louis	Wakaw	Mean	St. Louis	Wakaw	Mean
	Grain yield (t ha^{-1})			Grain protein (%)			N^{V} use efficiency (kg ha-‘)		
Control	2.58	1.39	1.98	11.4	8.8	10.1			
U70PR	2.76	2.75	2.76	11.8	9.6	10.7	21.5	61.5	41.5
AN70PR	2.71	2.53	2.62	12.3	9.5	10.9	45.1	41.4	43.2
AA35PR	2.72	1.53	2.13	12.1	8.5	10.3	45.6	32.0	38.8
AA70PR	2.59	2.49	2.54	12.0	9.0	10.5	30.7	36.0	33.4
AA105PR	2.55	2.67	2.61	12.4	9.5	10.9	14.4	58.4	36.4
AA35SFB	2.47	2.23	2.35	11.9	8.5	10.2	24.1	43.9	34.0
AA70SFB	2.56	2.51	2.54	11.8	9.0	10.4	17.8	40.8	29.3
AA105SFB	2.70	2.68	2.69	12.5	10.7	10.5	16.0	39.6	27.8
Mean	2.63	2.31	2.47	12.0	9.2	10.6	26.9	44.2	35.5
SE”	0.08	0.15	1.06	0.4	0.4	0.3	6.6	9.6	5.8
$LSD_{(0.05)}$	NS”	0.42	NS	NS	0.8	0.6	13.6	19.6	11.7
Source			***Probability level***						
Locations (L)			NS			**			*
Landforms (LF)	**	**	**	NS	NS	NS	NS	**	**
Treatments (T)	NS	**	NS	NS	**	*	*	**	**
LF*T	NS	NS	NS	NS	NS	NS	NS	NS	NS
L*T			**			NS			**
L*LF			NS			**			**
L*LF*T			NS			NS			**

Table 3. Continued.

	St. Louis	Wakaw	Mean	St. Louis	Wakaw	Mean	St. Louis	Wakaw	Mean
	Grain yield (t ha-‘)			Grain protein (%)			N use efficiency (kg ha^{-1})		
Contrasts	***Probability level***								
Control vs. N	NS	**	NS	**	NS	NS			
Granularvs.		AA	**	NS	NS	NS	NS	NS NS	NS NS
PR[x] vs. SFB[y]	NS	NS	NS	NS	NS	NS	NS	NS	NS
PR35 vs. 105	*	**	NS	NS	NS	NS	*	NS	NS
SFB35 vs. 105.	NS	NS	NS	NS	**	**	NS	NS	NS

[v] N = Nitrogen.
[u] SE = Standard error.
‘LSD = Least significant difference at the 0.05 probability level.
[w] NS = Not significant.
[x] PR = Paired row.
[y] SFB = Sweep/froc.
*, ** Significant at the 0.05 and 0.01 probability level, respectively.

Table 4. Means, analysis of variance, and contrasts for grain yield, grain protein, and nitrogen use efficiency of barley grown at St. Louis in 1995.

	Footslope	Shoulder	Footslope	Shoulder	Footslope	Shoulder
Treatments	**Grain** yield **(t ha^{-1})**		Grain protein **(%)**		**N[t] use** efficiency **(kg ha^{-1})**	
Control	2.63	2.52	11.4	11.3		
U70PR	2.85	2.67	11.6	12.0	14.9	28.1
AN70PR	2.87	2.55	12.0	12.6	53.4	36.4
AA35PR	2.89	2.55	11.6	12.5	41.5	*49.7*
AA70PR	2.77	2.41	12.2	11.7	46.5	14.9
AA105PR	2.73	2.38	12.0	12.8	22.7	6.1
AA35SFB	2.62	2.33	11.2	12.6	31.8	16.3
AA70SFB	2.68	2.45	11.7	11.8	22.1	13.4
AA105SFB	2.88	2.52	12.2	12.7	8.7	23.2
Mean	2.77	2.45	11.8	12.2	30.3	23.5
SE”	0.11	0.13	0.6	0.6	7.4	10.0
LSD (0.05)	NS”	NS	NS	NS	21.5	NS
Source			***Probability level***			
Treatments (T)	NS	NS	NS	NS	**	NS
Control vs. N	NS	NS	NS	NS		
Granular vs. AA[x]	NS	NS	NS	NS	NS	NS
PR[y] vs. SFB[z]	NS	NS	NS	NS	*	NS
PR35 vs. 105	NS	NS	NS	NS	NS	**
SFB35 vs. 105	NS	NS	NS	NS	*	NS

[t] N = Nitrogen.
[u] SE = Standard error.
[v] LSD = Least significant difference at the 0.05 probability level.
[w] NS = Not si nificant.
[x] AA = Anhydrous ammonia.
[y] PR = Paired row.
[z] SFB = Sweep/froc.
*, ** Significant at the 0.05 and 0.01 probability level, respectively.

Table 5. Means, analysis of variance, and contrasts for grain yield, grain protein, and nitrogen use efficiency of barley grown at Wakaw in 1995.

Treatments	Footslope	Shoulder	Footslope	Shoulder	Footslope	Shoulder
	Grain yield (t ha^{-1})		Grain protein (%)		N[t] use efficiency (kg ha^{-1})	
Control	1.77	1.01	8.8	8.9		
U70PR	2.73	2.77	10.4	8.8	60.3	62.3
AN70PR	2.72	2.34	9.7	9.3	28.6	54.2
AA35PR	1.55	1.52	8.6	8.4	17.0	46.9
AA70PR	2.80	2.18	8.9	9.1	31.0	41.0
AA105PR	2.66	2.67	9.2	9.7	37.9	78.8
AA35SFB	2.46	2.00	8.9	8.2	19.9	67.9
AA70SFB	**2.46**	**2.56**	10.0	**8.0**	**37.1**	**44.4**
AA105SFB	2.62	2.74	10.7	10.6	33.8	45.5
Mean	2.42	2.20	9.5	9.0	33.2	55.2
SE”	0.21	0.21	0.6	0.6	11.5	13.0
LSD $_{(0.05)}$	0.60	0.60	1.2	1.2	NS”	NS
Source	***Probability level***					
Treatments (T)	**	**	*	*	NS	NS
Control vs. N	**	**	NS	NS		
Granular vs. AA[x]	NS	NS	NS	NS	NS	NS
PR[y] vs. SFB[z]	NS	NS	NS	NS	NS	NS
PR35 vs. 105	**	**	NS	NS	NS	NS
sFB35 vs. 105	NS	NS	*	**	NS	NS

[t] N = Nitrogen.
[u] SE = Standard error..
[w] LSD = Least significant difference at the 0.05 probability level.
NS = Not simificant.
[x] AA = Anhydrous ammonia.
[y] PR = Paired row.
[z] SFB = Sweep/froc.
*, ** Significant at the 0.05 and 0.01 probability level, respectively.