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Influence of Diverse Cropping Sequences on Durum Wheat Yield and Protein in the Semiarid Northern Great Plains

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The semiarid northern Great Plains is one of the major durum wheat production areas in the world. The largest proportion of Canadian durum wheat is grown in the semiarid Brown and Dark Brown soil zones of the prairies. However, there is little information available regarding the most suitable crop sequences for durum wheat production under no-till, dryland cropping systems. The objective of this study was to determine the effects of crop type and cropping sequences from the previous two years on the yield and quality of durum wheat in the semiarid northern Great Plains.

Field experiments were conducted from 1996 to 2000 at two sites in southwestern Saskatchewan. The first site was on an Orthic Brown Chernozem with loam to silt loam texture and a saturated-paste pH of 6.5 in the 0- to 15-cm depth. This site was at the Agriculture and Agri-Food Canada Semiarid Prairie Agricultural Research Centre near Swift Current. The second site was on Rego Brown Chernozem with heavy clay texture and a saturated-paste pH of 6.8 in the 0- to 15-cm depth in a farmer's field near Stewart Valley.

Three pulse crops (chickpea, lentil, and dry pea), one oilseed crop (oriental mustard), and one cereal crop (hard red spring wheat) were planted on tilled, fallow soil the first year. The next year, spring wheat, an oilseed (mustard or canola), and a pulse (lentil or dry pea) crop were no-till seeded on soil in each of the five previous crop stubbles. The third year, durum wheat was no-till planted on soil in standing stubbles of all 15 combinations of previous crop types. At each site, the three-year cropping sequences were duplicated for three cycles, staggered one year apart. The first cycle of the crop sequences began in 1996 and completed in 1998, the second began in 1997 and completed in 1999, and the third began in 1998 and completed in 2000.

Before initiation of each cycle, soil samples were collected from the sites. The soil samples were analyzed for NO_3–N and P. Soil water was determined. Values for soil bulk density were obtained. These bulk densities were used to express water content on a volumetric basis. Plant available soil water (PASW) was determined. In our study, the lower limit was 130 mm at Swift Current and 348 mm at Stewart Valley.

In the first year of the crop sequence, the five crops were grown in a randomized complete block design with three replications. Plot size was 16 by 4.5 m. All crops were grown using the recommended agronomic practices in regard to seeding date and depth, plant density, pest control, and fertilizer application. Mustard and spring wheat were fertilized using ammonium nitrate to supply 70 kg ha^{-1} total available N (i.e., residual soil N in a 120-cm depth plus fertilizer N), according to preplanting soil tests. All crops received 4.5 to 7.5 kg P ha^{-1} as monoammonium phosphate placed with the seed. The pulse crops received 5 to 8 kg ha^{-1} of an appropriate *Rhizobium* spp. inoculant. Crops were individually harvested after they reached maturity. Uncut crop stubble was left standing. Crop residues cut by the combine were chopped and spread evenly in the field with a combine-attached chopper. In mid-September, glyphosate was sprayed for weed control on all plots at a rate of 200 g a.e. ha^{-1}.

In Year 2, the recropped oilseed (canola or mustard) and spring wheat were fertilized to supply 60 to 70 kg ha^{-1} of total available N, based on previous fall soil test results. Nitrogen credits from pulse stubble were taken into account in the fertilizer calculations using equations provided by Saskatchewan Soil Testing Laboratory:

N credit (kg ha^{-1}) = 0.005 x grain yield (dry pea)
N credit (kg ha^{-1}) = 0.004 x grain yield (lentil, chickpea)

As a result, canola, mustard and spring wheat grown on pea stubble received an average of 20 kg N ha^{-1} less fertilizer than when grown on spring wheat stubble and 10 to 15 kg N ha^{-1} less than when grown on lentil and chickpea stubble. All plots received 7.5 kg P ha^{-1} as monoammonium phosphate placed with the seed. Crops were separately harvested after they reached maturity. Crop stubble was handled similar to the first year, as was post-harvest weed control. In October, soil samples were collected from each plot (to a 120-cm depth). Residual soil NO_3–N and PASW were measured from those soil samples.

In the third year, durum wheat was planted on the 15 combinations of previous crop stubbles. Seed was treated with

Vitaflo at 2.6 g kg^{-1} seed and planted 5 cm deep at a rate of 250 viable seeds m^{-2}. Row spacing was 20 cm. Fertilizer N as ammonium nitrate was placed between the rows at the rate of 45 to 62 kg N ha^{-1}, along with 7.5 kg P ha^{-1} and 6 to 7 kg S ha^{-1}. The same rates of N, P and S were applied to all 15 combinations of previous crop stubble to determine residual soil N contributions from the different crop sequences. Weeds were controlled with a 200 g a.e. ha^{-1} application of glyphosate before seeding. When needed, weeds in the standing crop were controlled with appropriately labeled herbicides. Plant height at maturity was measured in each plot, and the center eight rows were harvested with a plot combine. The grain samples were air-dried, cleaned and weighed. Test weight and kernel weight were determined and grain yield was reported on a dry weight basis. Grain N concentration was measured and was multiplied by 5.7 to convert to grain crude protein concentration (GCPC). Crude protein yield was calculated by multiplying the grain yield by GCPC.

RESULTS AND DISCUSSION

The three-year crop sequence study was duplicated for three cycles, with the first from 1996 to 1998, the second from 1997 to 1999, and the third from 1998 to 2000. In each of the cycles, durum wheat was grown as a Year-3 crop. Growing season precipitation in the durum-grown years was generally average to above average. In 1998, total soil water (to a 120-cm depth) at spring seeding time was 20% lower than long-term averages, though growing season precipitation was near the 40-year average. In contrast, in 1999 and 2000, the growing season rainfall was 50 mm (26%) more than the 40-year average due to greater-than-average precipitation in May and July, with total soil water at spring seeding time being close to or slightly above long-term averages. The patterns and amounts of growing season precipitation were similar between the two sites.

GRAIN YIELD AND YIELD COMPONENTS

Grain yields of durum wheat ranged from 1,430 kg ha^{-1} at Swift Current in 1998 to 4,700 kg ha^{-1} at Stewart Valley in 1999. Limited preseeding soil water and the low rainfall in the early period of the growing season in 1998 reduced durum vegetative growth at Swift Current. Crop height at anthesis was 98 cm in 1998, 15% lower than canopy measured in 1999 and 2000. Higher-than-normal temperatures in the late part of the 1998 growing season caused durum wheat to have significantly lower (29%–35%) kernel weight and lower (7%–9%) test weight than those measured in the other study years. A similar soil water deficit at Stewart Valley in 1998 was the likely cause of the reduced yield at that site.

Crops grown two years before durum wheat influenced grain yields of durum wheat in three of five site-years, with the yield of durum wheat grown on mustard and pulse stubble averaging 6% to 8% higher than when grown on spring wheat stubble ($P < 0.01$). A similar response was observed for durum wheat grown on the previous year's stubble, with durum wheat grown on oilseed and pulse stubble yielding 4% to 5% higher than on spring wheat stubble ($P < 0.01$). The Year-1 x Year-2 crop sequence effects were significant ($P < 0.01$) in four of six site-years. On average, the durum wheat grain yield was 13% lower when the crop was preceded by two years of continuous spring wheat compared with broadleaf crops. No significant yield differences were observed among the various pulse–oilseed, oilseed–pulse, or pulse–cereal alternated crop sequences. Durum wheat protein yields responded to crop sequences similarly to the way grain yield responded. Examination of yield components revealed that crops grown two years before durum wheat did not influence spike density, kernel weight or test weight of durum wheat. Crops grown the year immediately before durum wheat influenced kernel weight ($P < 0.01$), with durum wheat grown on pulse stubble having the highest kernel weight. The two-year crop combinations (i.e., Year-1 x Year-2 crop types) did not influence yield components in general, but durum wheat following two years of continuous spring wheat had the lowest kernel weight.

Studies conducted in other regions of the world produced similar rotational benefits of pulses in cereal-based dryland cropping systems. Two studies in 1997 found that enhanced residual soil NO_3–N was one of the primary contributors to increased grain yields of cereals following a pulse crop. A study in 2000 reported that PASW measured at spring seeding time was 10% greater in dry pea and lentil stubble than in wheat stubble. Residual soil water in a 60-cm depth did not differ among crops, whereas large differences in residual soil water in the 60- to 120-cm depth existed among crop species. These authors believed that conserved soil water, primarily below 60-cm soil depth, contributed to the increased grain yields of cereals following a shallower-rooted crop such as lentil or dry pea in semiarid dryland regions. In the present study, we measured residual soil NO_3–N and PASW in the previous fall. Covariance analyses revealed that soil residual NO_3–N and PASW combinations accounted for up to 28% of the durum wheat yield variation in two of five site-years and none for the rest of the site-years. The remainder of the yield variation could not be explained with the soil-related measurements. The poor relationship between durum wheat grain yield and the soil-related variables in this study was probably due to soil sampling that was conducted the previous fall. Changes in PASW from fall through winter to spring are expected along with a weak response of spring crops to available soil water measured the previous fall. Additionally, the majority of soil water, particularly in Vertic soils, moves through macropores and is not uniformly distributed throughout the soil profile. Inadequate soil sampling could generate inaccurate estimates of soil water conserved in the profile. We did not assess diseases in this study, but a 1998 study observed in an adjacent field trial at Swift Current showed that the severity of leaf-spotting diseases was higher in wheat after wheat than in wheat after lentil.

GRAIN CRUDE PROTEIN CONCENTRATION

Growing conditions strongly influenced durum wheat GCPC, with the GCPC being highest in 1998 when grain yield was the lowest. The crop grown two years before durum wheat affected durum wheat GCPC in two of five site-years. The GCPC of durum wheat grown on spring wheat stubble (two years prior) averaged 6% lower than when grown on pulse stubble. The three pulses (pea, lentil and chickpea) had similar rotational effects on durum wheat GCPC, and with a few exceptions, they did not differ from that of mustard or canola. Crops grown the year immediately before durum wheat affected durum wheat GCPC at all sites except Stewart Valley in 1999. Averaged over the five site-years, the GCPC of durum wheat grown on mustard or canola and pulse stubbles from the previous year was 10% and 15% higher, respectively, than when grown on spring wheat stubble ($P < 0.01$). Year-1 x Year-2 crop combinations significantly affected durum wheat GCPC in four of five site-years, and the GCPC values at Swift Current in 1998 were not statistically different among treatments. The durum wheat GCPC averaged 16% to 19% higher when the crop was grown in two years of continuous pulses or pulse–oilseed alternated crop sequences than when grown in two years of continuous spring wheat. Other researchers observed similar rotational effects of pulse crops on cereal GCPC.

The increased protein concentration in durum wheat following pulse–pulse, oilseed–pulse or pulse–oilseed cropping sequences was partially due to increases in the symbiotically fixed N contained in the pulse crop residues and the gradual release of mineralizable N as crop residues decomposed during the growing season. Researchers in 1992, in a long-term wheat–lentil rotation study at Swift Current, observed that there was a cumulative enhancement of the N-supplying power of the soil after lentil due to the pulse residual contribution. The lentil–wheat rotation resulted in a gradual reduction in fertilizer N requirements of the mixed cropping system compared with a wheat-based monoculture. A study in 1993 also found that there was less deep-leached NO_3–N associated with the wheat–lentil rotation due to better synchrony of N uptake from the lentil residue decomposition compared with well-fertilized continuous wheat. A 1994 study demonstrated that addition of N fertilizer increases cereal protein yields in a continuous cereal rotation, but the protein yield could not be elevated to the same levels as those obtained in pulse–cereal rotations. In the present study, covariance analyses revealed that post-harvest residual soil N plus PASW accounted for 12% to 24% of the GCPC variation in three of five site-years and none in the two remaining site-years. The poor correlation between durum wheat GCPC and the soil-related variables was probably due to our soil sampling, which was conducted the previous fall. We did not measure potential changes of soil NO_3–N levels during the winter months and the following spring and summer. Durum wheat grown on the no-tilled soil that had mineralizable, high-N crop stubble might benefit from potentially mineralized N over a longer growing period.

YIELD–PROTEIN RELATIONSHIP

There was a negative relationship between grain yield and GCPC in durum wheat. As grain yield increased from 1,500 to 3,200 kg ha^{-1}, the GCPC decreased from 190 to 130 g kg^{-1}, equivalent to protein content on a dry matter basis from 18% to 10%. In 1998, durum wheat produced half as much as the grain yields produced in 1999 and 2000 due to lower-than-normal moisture in the earlier growing season and greater-than-normal temperatures in the latter part of the growing season. In the same year, the durum wheat GCPC was the greatest. Cropping sequences strongly influenced the relationship between durum wheat grain yield and GCPC. At the yield level of 1,700 kg ha^{-1}, durum grown after a pulse or an oilseed crop produced 15% higher GCPC than durum following spring wheat. As yields increased beyond 1,700 kg ha^{-1}, there was a tendency for durum wheat GCPC to decline more sharply when the crop was preceded by an oilseed crop rather than a pulse crop. Coefficients of the regression equations were statistically significant between preceding pulses and oilseed. Preceding spring wheat had the lowest intercept value, whereas its slope did not differ from that of the pulses, indicating that at any given yield level, the GCPC of durum wheat grown after a cereal will be 15% lower than when grown after a pulse. In cases where the overall grain yields exceeded 3,200 kg ha^{-1}, crop sequences had little effect on the association between GCPC and grain yields. This implies that the effects of previous crops on durum wheat GCPC diminish under environmental conditions conductive to higher grain yields.

In summary, crops grown immediately before durum wheat influenced the grain yield and GCPC of durum wheat more than crops grown two years before the durum wheat. Continuous cereal systems reduced durum wheat grain yields by 4% to 8% and GCPC by 8% to 16% compared with cropping systems that included an oilseed or a pulse crop one or two years before durum wheat. The increased yield of durum wheat preceded by an oilseed or a pulse crop was related to residual soil NO_3–N and PASW, but these two factors only accounted for up to 28% of the observed yield variation. In years when growing season precipitation was above long-term averages, the crop sequence effects on durum wheat were more evident than those observed in a dry year. Durum wheat GCPC increased with greater residual soil NO_3–N and PASW in three of five site-years; in these cases, 12% to 24% of the GCPC variation was explained by these two factor combinations. In the present study, potential contribution of residual soil NO_3–N to the increased durum wheat grain yield and GCPC may have been underestimated. Sampling soils in the previous fall did not consider potentially mineralizable N from crop residue decomposition during the winter months and the following spring and summer. Nevertheless, significant crop sequence effects existed, even for studies wherein the residual soil N and PASW were not attributable to the increased grain yield and GCPC in durum wheat.

These observations lead us to speculate that, besides residual soil N and PASW measured in the previous fall, other factors such as microbial activity and potential N releases during the post-harvest period and the following spring and summer play important roles in boosting grain yields and quality of subsequent cereal crops. Further studies are needed to elucidate these great rotational benefits in the semiarid northern Great Plains.

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Influence of Diverse Cropping Sequences on Durum Wheat Yield and Protein in the Semiarid Northern Great Plains

October Self-Study Examination

DETACH HERE

1. The semiarid northern Great Plains is one of the major:

[ ] a. lentil production areas in the world.
[ ] b. chickpea production areas in the world.
[ ] c. oriental mustard production areas in the world.
[ ] d. durum wheat production areas in the world.

2. The experiments were conducted in soils with textures of:

[ ] a. silt, sand and clay.
[ ] b. loam, silt loam and clay.
[ ] c. sandy loam, clay and silty clay loam.
[ ] d. clay, loamy sand and silt.

3. Before initiation of each cycle, soil samples were collected from the sites and analyzed for the following nutrients:

[ ] a. nitrate nitrogen and phosphorus.
[ ] b. phosphorus and heavy metals.
[ ] c. heavy metals and potassium.
[ ] d. potassium and sulfur.

4. The three-year crop sequence study was duplicated for:

[ ] a. 2 cycles.
[ ] b. 3 cycles.
[ ] c. 4 cycles.
[ ] d. 5 cycles.

5. Grain yields of durum wheat over the course of this study ranged from:

[ ] a. 1,142 kg ha^{-1} to 5,000 kg ha^{-1}.
[ ] b. 1,233 kg ha^{-1} to 4,950 kg ha^{-1}.
[ ] c. 1,395 kg ha^{-1} to 4,800 kg ha^{-1}.
[ ] d. 1,430 kg ha^{-1} to 4,700 kg ha^{-1}.

6. When durum wheat was preceded by two years of continuous spring wheat:

[ ] a. yield was 20% lower than when the crop was preceded by broadleaf crops.
[ ] b. yield was 13% lower than when the crop was preceded by broadleaf crops.
[ ] c. yield was 20% higher than when the crop was preceded by broadleaf crops.
[ ] d. yield was 13% higher than when the crop was preceded by broadleaf crops.

7. Examining yield differences between the various pulse-oilseed sequences found:

[ ] a. the oilseed-pulse rotation to yield higher durum wheat crops.
[ ] b. the pulse-oilseed rotation to yield higher durum wheat crops.
[ ] c. the pulse-cereal rotation to yield higher durum wheat crops.
[ ] d. no significant yield differences.

8. The grain crude protein concentration of durum wheat grown on spring wheat stubble (two years prior) averaged:

[ ] a. 6% lower than when grown on pulse stubble.
[ ] b. 10% lower than when grown on pulse stubble.
[ ] c. 3% higher than when grown on pulse stubble.
[ ] d. 6% higher than when grown on pulse stubble.

Over

9. Comparing the effects of the three pulses (pea, lentil and chickpea) on grain crude protein concentration (GCPC), this study found:

[ ] a. greater GCPC from peas.
[ ] b. greater GCPC from lentils.
[ ] c. greater GCPC from chickpeas.
[ ] d. they all had similar rotational effects.

10. As grain yield increased from 1,500 to 3,200 kg ha^{-1} the GCPC:

[ ] a. decreased from 190 to 130 g kg^{-1}.
[ ] b. increased from 190 to 230 g kg^{-1}.
[ ] c. stayed the same.
[ ] d. could not be measured.

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