Yield and Protein of Wheat and Durum in Brown Soil Zone as Affected by Long-term Tillage System and Crop Rotation

Brian G. McConkey[1], Fernando Selles[1], Perry Miller[2], and Con Campbell[3]
[1]Agriculture and Agri-Food Canada, Swift Current, SK, S9H 3X2,
[2] Montana State University, Bozeman. MT
[3] Agriculture and Agri-Food Canada, Ottawa, ON (retired)

Key words: yield, protein, wheat, durum, nitrogen, tillage, no-till, crop rotation, fallow, pea, chickpea, canola

Abstract

Three tillage-rotation experiments in the Brown soil zone showed that spring wheat and durum grain yield and protein were affected by tillage system, length of time in tillage system, crop sequence. During the initial 15 years of no-tillage (NT) monoculture wheat, grain yield and protein were equal or lower than minimum-till (MT) or conventional tillage (CT). These differences were attributed to reduced N availability with NT, likely from greater N immobilization (sequestration) in soil organic matter under NT. However, during the last several years, grain yield and protein with NT continuous wheat has been equal to higher than with MT practices. This may be due to improved management, specifically better control of foxtail barley and side banding of N at time of seeding, and/or simply a longer time in NT. When following non-cereal crop, spring wheat and durum had equal or higher yield and protein than wheat following wheat. In diversified rotations, the wheat or durum had highest yield under NT practices. Wheat on MT and NT fallow, with an extra 23 kg/ha fertilizer N applied, had higher grain protein than wheat on CT fallow but not higher grain yield. Durum grown on fallow after a pulse crop had higher yield and protein than that grown after fallow after durum.

Introduction

Although NT for a brief period has no effect on N cycling (Carter and Rennie 1984), decreased supply of nitrogen (N) is cited as a reason for failure to achieve crop yield potentials under reduced and no till (NT) systems (Larney et al., 1994). Legumes in rotation increase N availability for subsequent crops (Izaurralde et al. 1995) and greater N fixation for pulse crops has been reported under NT than tilled systems (Matas et al. 1997). McConkey et al. (2002) concluded that wheat grown under no-tillage systems in Brown and Dark Brown soil zones showed evidence of nitrogen deficiency. They attributed that nitrogen deficiency to N sequestration in increased soil organic matter. Our objective was to update our knowledge of the effect of tillage system, pulse and oilseed crops, and additional fertilizer N (latter for wheat on fallow only) on the grain yield and protein of wheat and durum.

Materials and Methods

The Loam-Tillage and Loam-Rotation experiments were located on Swinton Loam (Orthic Brown) at SPARC, Swift Current, SK. The Clay-Tillage study was located on Sceptre Clay (Rego Brown) at Stewart Valley, SK, 50 km NNW of Swift Current. The Loam-Tillage study (initiated 1981) and the Clay-Tillage (initiated 1982) were designed to investigate tillage system impacts for hard red spring wheat-fallow (W-F) and continuous wheat (Cont W) rotations. In 1996, the W-F rotations on Clay-Tillage site were converted to wheat-pulse (W-P), keeping the long-term tillage history of the plots, with pulse alternating between pea (1996, 1997, 2000, 2001), desi chickpea (1998 and 1999), and lentil (2002). In 1997, the W-F plots for the Loam-Tillage experiment, were split and one half of these plots remained in existing system while the other half were put into a wheat-pulse (W-P) rotation, retaining their long-term tillage history, with the pulse alternating between kabuli chickpea (1997, 1998, 2001, 2002) and field pea (1999 and 2000). In these studies, MT Cont W and W-P involved a single tillage operation with a heavy-duty cultivator and mounted harrows immediately before seeding with a hoe drill. NT Cont W and W-P and NT W-F in the crop year had application of glyphosate before seeding with a disc drill (up to 1995) or hoe drill (after 1995). A combination tillage treatment was started in 1995 on a previous Cont W NT system in which was MT in odd years and NT in even years (this was the only system with only one phase present each year). A combination tillage was started in 1997 for a W-P system (superimposed on a W-F MT system) in which was MT for (W)-P phase and NT for the W-(P) phase. A modest input Cont W was started in 1996 that received N rates for dry conditions and only received grassy weed herbicides as considered absolutely necessary and then only at 2/3 of label rate. CT W-F involved spraying with 2,4-D for winter annual broadleaf weed control and two to four tillages during summerfallow with a heavy duty cultivator and/or rod weeder plus a single tillage operation with a heavy-duty cultivator and mounted harrows immediately before seeding with a hoe drill. MT W-F involved initial weed control until July with mix of glyphosate with 2,4-D or dicamba with one or two tillage operations in July-August with a heavy-duty cultivator or wide-blade cultivator plus a single tillage operation with a heavy-duty cultivator and mounted harrows immediately before seeding with a hoe drill. NT W-F had fall 2,4-D followed by two to four applications as required for weed control during fallow with a mix of glyphosate with 2,4-D or dicamba. The NT systems have also received periodic post-harvest glyphosate when required for control of foxtail barley starting in 1996. One Cont W NT treatment was continued without every receiving fall glyphosate. Post-emergent and occasional pre-emergence herbicides were applied to all treatments as required for good weed control.

The Loam-Rotation experiment was initiated in 1995 and currently has 9 rotations but only three are discussed in this paper: Durum-Durum-Fallow (D-D-F) and Canola-Durum-Fallow under both NT and MT, and Durum-Pulse-Fallow (D-P-F) under NT only. Production practices were similar to those for the Loam-Tillage on experiment described above. The pulse crop was lentil in 1995, desi chickpea in 1996 and 1997 and field pea in 1998-2002.

For all three experiments, fertilizer N was applied according to soil-test recommendations based on late fall nitrates in the upper 60 cm of soil (see Table 1). The exceptions were the modest-input Cont W described above and, starting in 1997, an additional 23 kg/ha of N was applied on NT W-F and MT W-F for the Loam-Tillage experiment to investigate if the extra fertilizer would improve grain yield and protein as well as to try to achieve the yield potential of the additional stored water in those reduced tillage systems. Methods of fertilizer placement changed over time: before 1990 all N was broadcast as ammonium nitrate, from 1990 to 1995 fertilizer N (ammonium nitrate) was placed with seed up to 44 kg/ha with the remainder broadcast on the surface before seeding, and after 1995, all fertilizer was side banded as urea. For all experiments, fertilizer P (mono-ammonium phosphate) was applied according to soil test-recommendations based on fall $NaHCO_3$-extractable P in the upper 15 cm of soil, typically application rate was 9.5 kg/ha of P.

The Loam-Tillage experiment had 4 replicates while the Clay-Tillage and Loam-Rotation experiments had 3 replicates. Plot sizes were 15 x 34 m, 15 x 30 m, and 14 x 26m for the Loam -Tillage, Clay-Tillage, and Loam-Rotation experiments, respectively.

Statistical analyses were done using SAS Proc Mixed, using a p=0.10 to separate means.

Results and Discussion

Precipitation

With exception of 2001, annual and growing season precipitation was been average to above-average since 1989 at Swift Current (Figure 1). At Stewart Valley, growing season precipitation has been more variable around the mean, with the exception of 1989-94 when precipitation was consistently near to above average.

Soil Water and Nitrogen

No allowance was made for any future mineralized N from preceding pulse crop so the average fertilizer N added to (W)-P (the phase in () pertains to the results) was similar to that for adequately fertilized Cont W because they had similar nitrates in the fall and the spring (Table 1). Less fertilizer N was added to (D)-P-F than (D)-D-F because the former had more soil nitrate than the latter. Canola in the rotation had an apparent effect on soil nitrate as 2 years after growing the canola as the chem fallow in the C-D-F rotation was higher than the D-D-F rotation, although only statistically significant for the C-D-F MT versus the D-D-F (MT or NT). When considering the entire 120 cm profile, this effect of canola in the rotations was still obvious under a MT system, for which in one-half of years had more soil nitrate-N in the spring than its MT monoculture durum counterpart (Figure 2a). This effect of canola on N cycling is unexplained as crude N balances (fertilizer N added less grain N removed) were about similar for C-D-F as D-D-F (data not shown). Chem fallow after a pulse crop (i.e. NT (D)-P-F) averaged 13-16 kg/ha more soil nitrate than either chem or MT fallow after durum. We attributed this to N mineralized from the pulse residues in the fallow year. For the Clay-Tillage Experiment, the effect of pulse in the rotation on any increase in soil nitrate N was only evident from 2000-2002.

Available soil water after chem fallow was greater than after tilled fallow although the difference was small and not significant in some periods. There was no significant difference in soil water for chem fallow after a pulse (i.e. (D)-P-F) durum (i.e. (D)-D-F). As expected, soil water after fallow averaged higher than that after stubble. For the continuous cropped rotations, there was no clear effect of tillage on soil water near seeding. In the loam-tillage experiment, soil water near seeding was greater for Cont W in the 1998-2002 period than the W-P rotations. However, there was no difference among these rotations in the clay tillage experiment. Soil water after canola was not statistically different than that after durum.

Wheat and Durum Grain Yield and Protein

Crop on stubble

Within the loam-tillage experiment, for Cont W over the period of 1982-1996, tillage system had no effect on average wheat grain yield or protein (Table 1, Figure 3a). Similarly, for the 1997–2002 period, there was no consistent effect of tillage system on grain yield (Figure 4a) or protein (Figure 4 b) of Cont W. After 10 years of NT Cont W, the grain yield, protein, and N fertilizer additions reached approximate equality with MT Cont W (Figure 3a). As expected, the no-fall glyphosate Cont W and modest-input Cont W had lower yield than the other Cont W having better weed control or N fertilization, although the amount was relatively small and not significant. Averaged over 1998-2002, the modest-input Cont W had lower grain protein than the other Cont W systems; this was attributed to lower N fertilizer. However, in the drought year of 2001, the modest input had the highest yield of any of the wheat on stubble (significantly higher than the (W)-P systems or the no-fall glyphosate Cont W). This lower yield in 2001 for the systems receiving more N fertilizer was attributed to “haying off” (i.e. N increased biomass that used up stored soil water faster).

For Cont W for 1983-96 period within the Clay-Tillage experiment, both average grain yield and protein were lower for NT than MT, although the difference was not statistically significant (Table 1, Figure 3b). McConkey et al. (2002) attributed this effect to N deficiency due to N immobilized (sequestered) in the increased soil organic matter in the NT system. However, for 1997-2002 period, there was a consistent trend for higher yield and grain N uptake for NT Cont W than MT Cont W (Figure 3b). Thus, N deficiency for NT was no longer a factor. Possibly the rate of organic matter increase had lessened thereby reducing problems from N sequestration and/or the elimination of broadcast N by switching to side banding in 1996 had reduced the problems. In 1997 and 1999, the (W)-P had higher yield then Cont W. In 2000 NT (W)-P had higher yield than Cont W. Despite the higher yields, in four of the six years (1998, 2000-02), the (W)-P had higher protein than Cont W. This indicates better N availability on pulse stubble. This improved N availability on pulse stubble was not readily evident from soil nitrate-N (Figure 2b), especially for the NT (W)-P.

The alternating MT-NT Cont W (combo tillage system) in the Clay-Tillage experiment had some interesting results. In two of the three years (2000 and 2002) when it was NT, it had significantly higher yields than MT Cont W although the long-term NT Cont W yields were not different from MT Cont W. There was also a trend for the NT phase of the Combo Tillage to have higher grain protein than long-term NT Cont W. We speculate that the MT phase increases N mineralization from organic matter but the effect does become important until the year following tillage. In all four years when it was MT (1995, 1997, 1999, and 2001), the Combo Tillage had performance very similar to long-term MT Cont W.

In the Loam-Rotation experiment, the durum on canola stubble (i.e. C-(D)-F), yielded more than durum on durum, the difference being significant for NT C-(D)-F vs. MT D-(D)-F.

Crop on fallow

For (W)-F within the loam-tillage Experiment for 1982-96, both yield and protein were ranked CT > MT > NT. The additional 23 kg/ha of fertilizer N from 1997 onwards for the MT and NT (W)-F significantly increased grain protein, although did not significantly increase grain yield, compared with CT (W)-F (Table 1, Figure 6). Interestingly, the extra N may have actually hurt yield in the drought year of 2001 due to “haying off”. Previously, when fertilizer N was more similar, NT (W)-F outyielded CT (W)-F in drought years, such as 1985 and 1988 (Figure 6b).

In the Loam-Rotation Experiment, the durum on pulse fallow (i.e. (D)-P-F) had significantly higher yield than durum on durum fallow in 1997 (vs. MT (D)-D-F only), 1998, and 1999 (vs. NT (D)-D-F only)(Figure 7a). Despite these higher yields, there was no yield dilution effect on the grain protein as the durum on pulse fallow had higher grain protein than the durum on durum fallow in 1997, 1998, and 2000 (vs. MT (D)-D-F only)(Figure 7b). Clearly, the pulse fallow was providing better N availability to the durum crop despite the fact the differences in soil nitrogen for the fallow types was made equal by applying an average of 10-14 kg/ha more N to the durum fallow (Table 1). It is hard to relate the pulse fallow N benefit to mineralization of N from pulse residue as that would presumably have already occurred during the fallow year.

To keep erosion risk acceptable with a D-P-F rotation requires that the pulse be seeded with low disturbance into abundant cereal residue, complete chem fallow after the pulse crop, and the crop seeded into the chem fallow with low disturbance direct seeding. Even high-disturbance direct seeding will greatly increase the erosion risk for this rotation without much residue after the pulse crop. Consequently, the D-P-F rotation can only be considered sustainable under NT.

Conclusions

The results from three tillage-rotation experiments in the Brown soil zone showed that spring wheat and durum grain yield and protein were affected by tillage system, length of time in tillage system, and crop sequence; many of these effects can not be easily explained. Rotations with canola or pulses provides equal to higher wheat and durum grain yield and protein than monoculture cereal systems and those benefits are more pronounced under no-tillage than minimum tillage practices. For monoculture wheat or durum rotations, minimum tillage practices provided equal to higher wheat and durum grain yield and protein than no-tillage practices for the first 15 years of no-tillage.

References

Carter, M.R., and D.A. Rennie. 1984. Nitrogen transformations under zero and shallow tillage. Soil Sci. Soc. Am. J. 48: 1077-1081.

Izaurralde, R.C., Choudhary, M., Juma, N.G., McGill, W.B., and Haberhein, L., 1995. Crop and nitrogen yield in legume-based rotations practiced with zero tillage and low-input methods. Agron. J. 87:958-964.

Larney, F.J., C.W. Lindwall, R.C. Izaurralde, and A.P. Moulin. 1994. Tillage systems for soil and water conservation on the Canadian prairies. Pages 305-328 *in* M. R. Carter (ed.) Conservation tillage in temperate agroecosystems. Lewis Publishers, Boca Raton, FL.

Matas, A., Derksen, D.A., Walley, F.L., Loeppky, H.A., van Kessel, C. 1997. The influence of tillage and crop rotation on nitrogen fixation in lentil and pea. Can. J. Plant. Sci. 77:197-200.

McConkey, B.G., Curtin, D., Campbell, C.A., Brandt, S.A., and Selles, F. 2002. Crop and soil nitrogen status of tilled and no-tillage systems in semiarid regions of Saskatchewan. Can. J. Soil Sci. 82:489-498.

Table 1. Experiments, rotation-phases, soil nitrate-N for 0-0.6 m in October and April, fertilizer N added, and available soil water before seeding, grain yield, grain protein, and grain N uptake (means between horizontal lines not followed by same letter are significantly different at p=0.10).

Experiment	Years	Rot-Phase	Tillage*	Previous Fall NO_3-N (kg ha^{-1})	Spring NO_3-N (kg ha^{-1})	Fert N (kg ha^{-1})	Soil Water (mm)	Grain Yield (kg ha^{-1})	Grain Protein (%)	Grain N (kg ha^{-1})
Loam-Tillage	82-96	(W)-F**	NT	48b	50b	26	118c	2394b	11.6a	48b
			MT	51b	60b	24	108b	2432b	12.3ab	51bc
			CT	49b	58b	24	100b	2541b	12.4b	54c
		Cont W	NT	23a	31a	51	69a	2014a	12.7b	42a
			MT	27a	30a	48	64a	2032a	12.4b	42a
	98-02	(W)-F	NT	46d	51b	53	119d	2295b	14.1b	57bc
			MT	44d	55b	53	112d	2420b	14.5b	61c
			CT	42cd	56b	33	101d	2347b	12.8a	51b
		Cont W	NT	21ab	24a	55	63c	1531a	14.8b	38a
			MT	19ab	25a	55	72c	1522a	14.4b	37a
		No-fall glyphosate Cont W	NT	24ab	30a	54	62bc	1464a	14.7b	37a
		Modest-input Cont W	MT	12a	20a	33	72c	1391a	13.3a	32a
		(W)-P	NT	24ab	20a	61	51ab	1529a	14.6b	37a
			MT	30bc	21a	58	48ab	1490a	14.8b	37a
			Combo	21ab	19a	61	48ab	1469a	14.7b	35a
	98-02	W-(P)	NT	15a	27a	5	52ab	1657a		
			MT	17a	29a	5	40a	1579a		
			Combo	14a	25a	5	45ab	1555a		
Loam-Rotation	97-02	(D)-D-F	NT	46b	47b	27	109b	2618c	11.2a	51c
			MT	45b	47b	31	107b	2633c	11.5ab	53cd
		D-(D)-F	NT	13a	15a	59	71ab	1867ab	13.0b	37ab
			MT	16a	18a	56	65ab	1783a	12.9ab	35a
		C-(D)-F	NT	16a	19a	57	60ab	2119b	12.0ab	41b
			MT	16a	21a	58	57a	1889ab	12.7ab	39ab
		(D)-P-F	NT	61d	60c	17	101b	2773c	11.9ab	57d
	97-02	(C)-D-F	NT	54cd	52bc	30	114b	1350a		
			MT	52bc	57c	29	109b	1467a		
	97-02	D-(P)-F	NT	19a	21a	5	72b	2289		
Clay-Tillage	83-96	(W)-F	NT	45b	52b	28	149b	2667b	11.4ab	56b
			MT	46b	54b	25	144b	2759b	12.0bc	61b
		Cont W	NT	25a	32a	47	77a	1908a	11.2a	40a
			MT	26a	39a	44	66a	1902a	12.2c	44a
	97-02	Cont W	NT	12a	18a	61	63a	1788ab	13.8ab	42ab
			MT	17ab	18a	57	51a	1574a	14.3bc	38a
			Combo	16ab	25a	58	76a	1749ab	14.4bc	42ab
		(W)-P	NT	18ab	23a	59	62a	1891b	14.8c	46b
			MT	23b	25a	58	67a	1808ab	14.8c	44ab
		(W)-F	CT	39c	48b	36	146b	2516c	13.0a	57c
	97-02	W-(P)	NT	14ab	25a	5	57a	1570a		
			MT	18ab	26a	5	66a	1300a		

* NT=no-till (low disturbance one-pass direct seeding), MT=minimum tillage, combo=annually alternating MT and NT

**W-F = wheat-fallow rotation, W-P = wheat-pulse rotation, D-D-F =durum-durum-fallow rotation, C-D-F=canola-durum-fallow rotation, Cont W=continuous wheat, (crop) signifies the phase of the rotation.

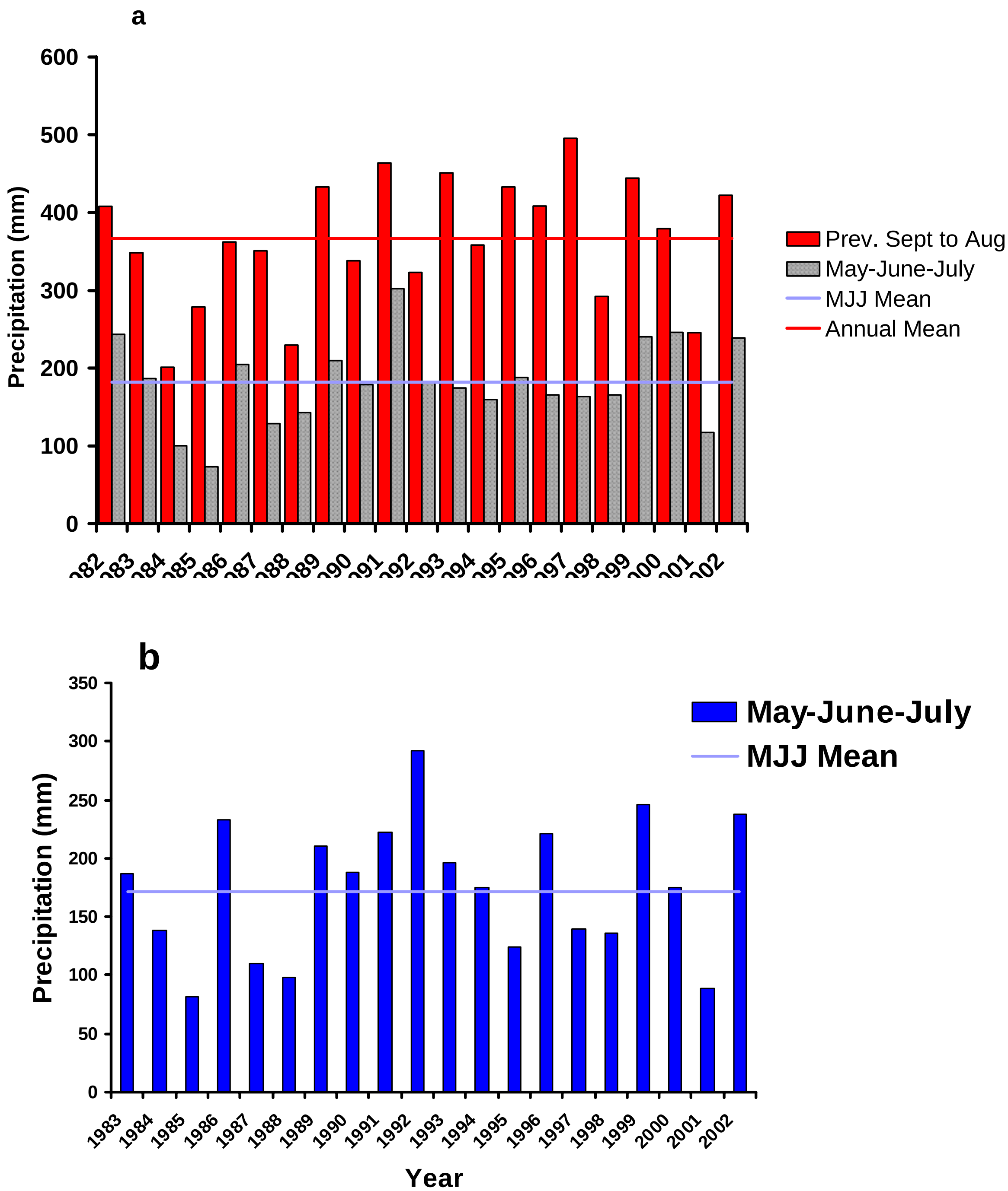
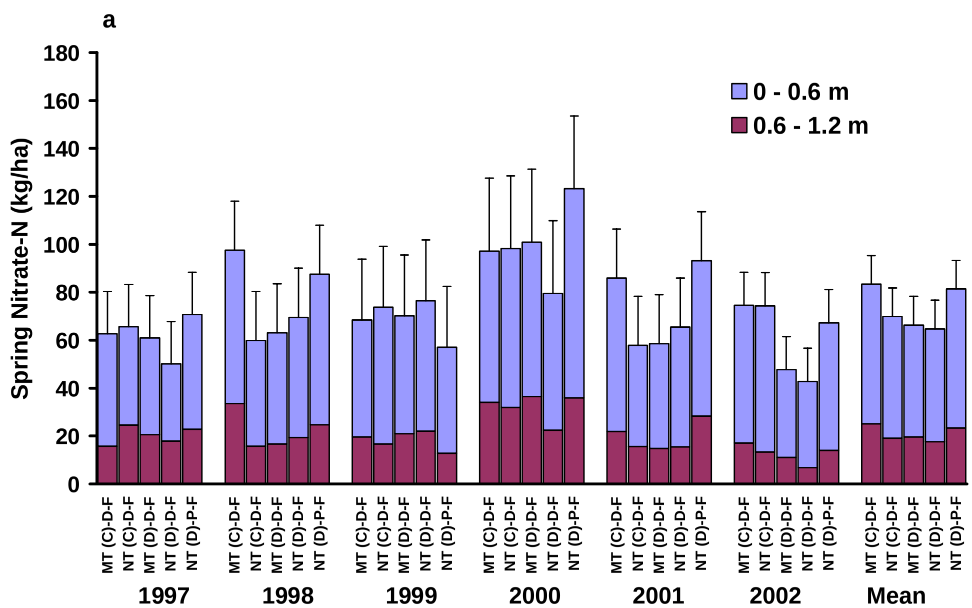


Figure 1. Precipitation a) at Swift Current a) (Loam-Tillage and Loam-Rotation Experiments) and b) at Steward Valley (Clay-Tillage Experiment)



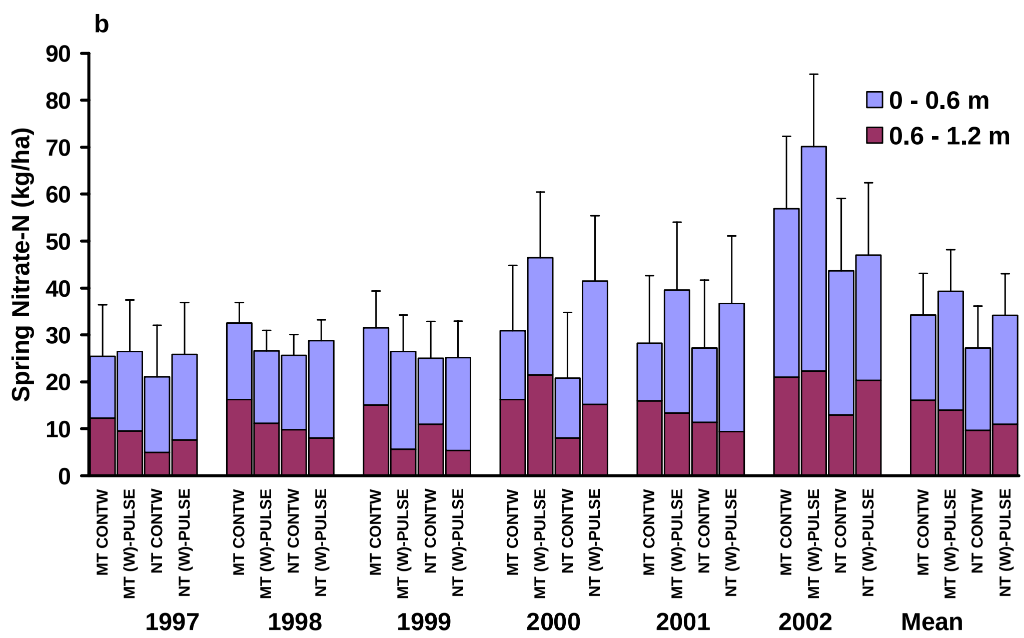


Figure 2. a) Soil nitrate-N after fallow phase for Loam-Rotation Experiment and b) for wheat phase of continuous cropping rotations for Clay-Tillage Experiment (bars are LSD at P=0.10)

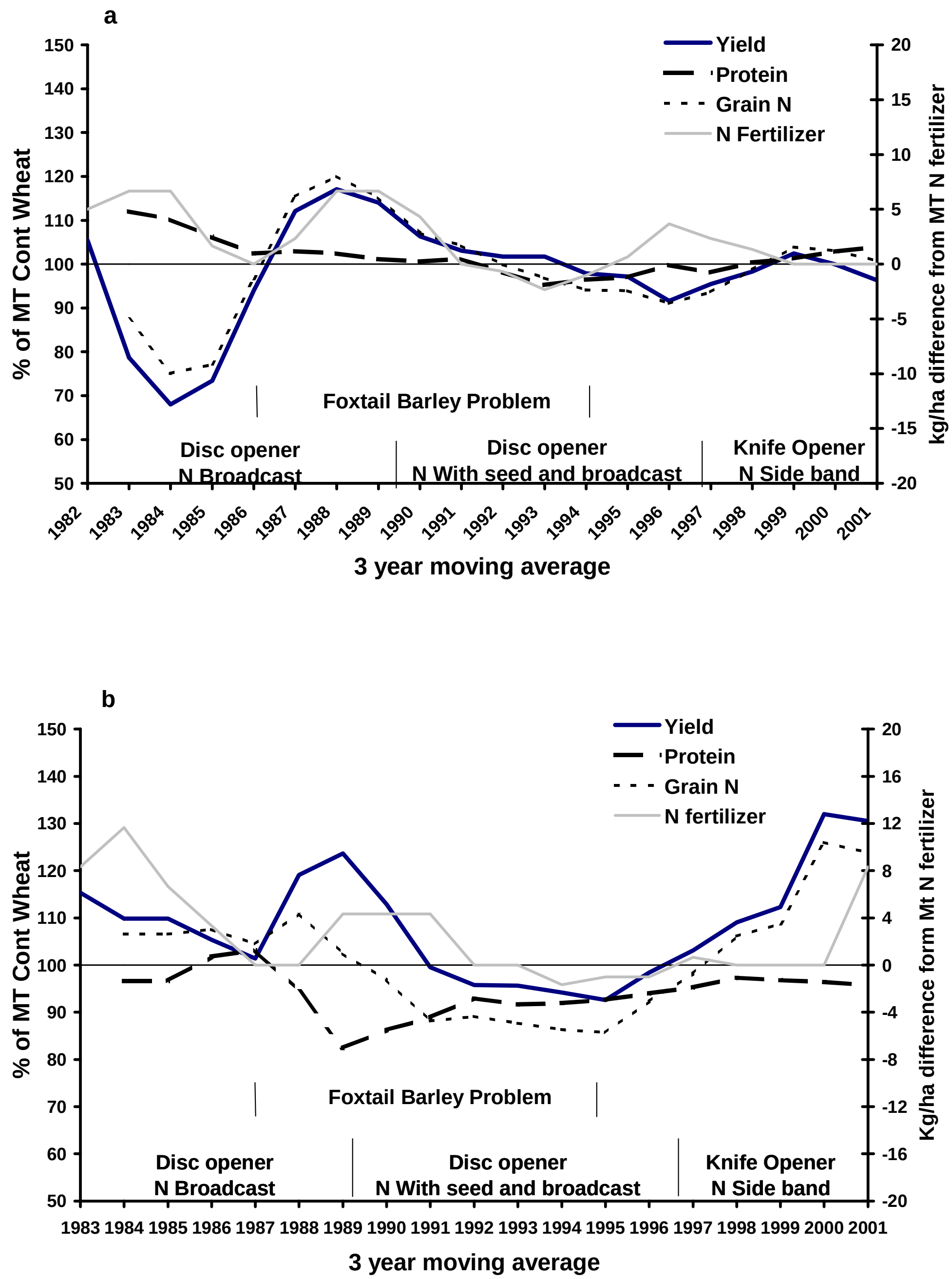
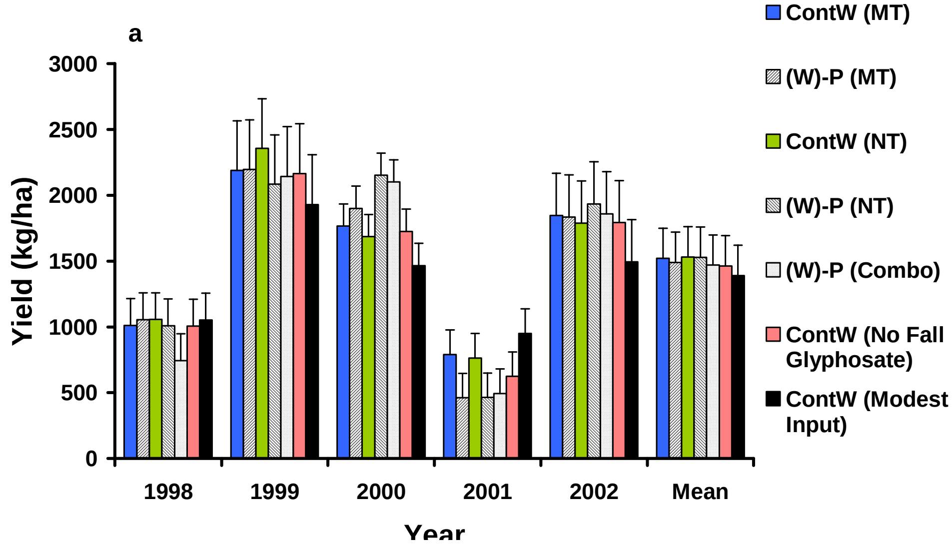


Figure 3. Moving 3-yr average relative grain yield, protein, grain N uptake, and N fertilizer additions for NT Cont W to MT Cont W for a) Loam-Tillage Experiment and b) Clay-Tillage Experiment.



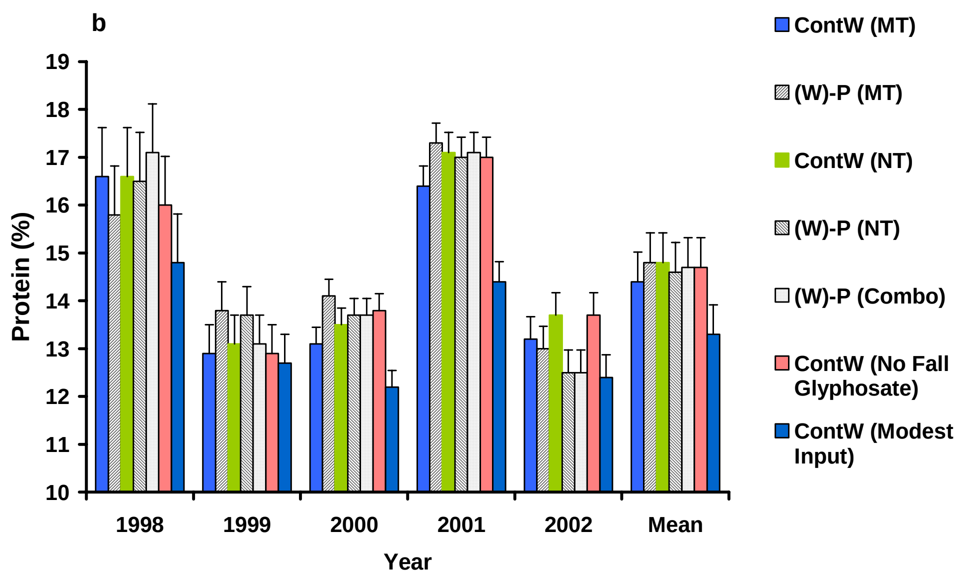


Figure 4. Wheat a) yield and b) protein for wheat in continuous cropped rotations within the Loam-Tillage experiment for 1998-2002 (bars are LSD at P=0.10)

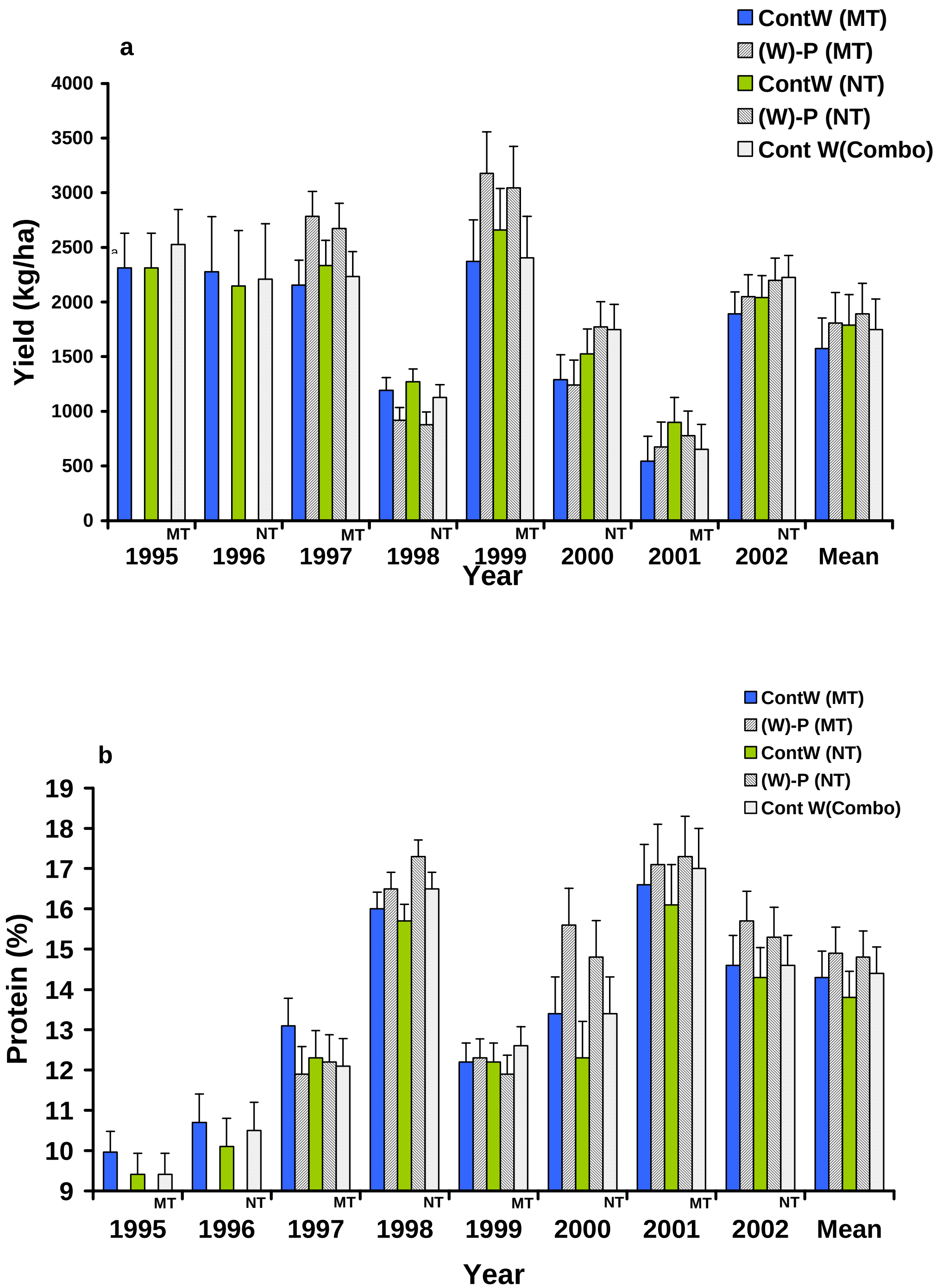
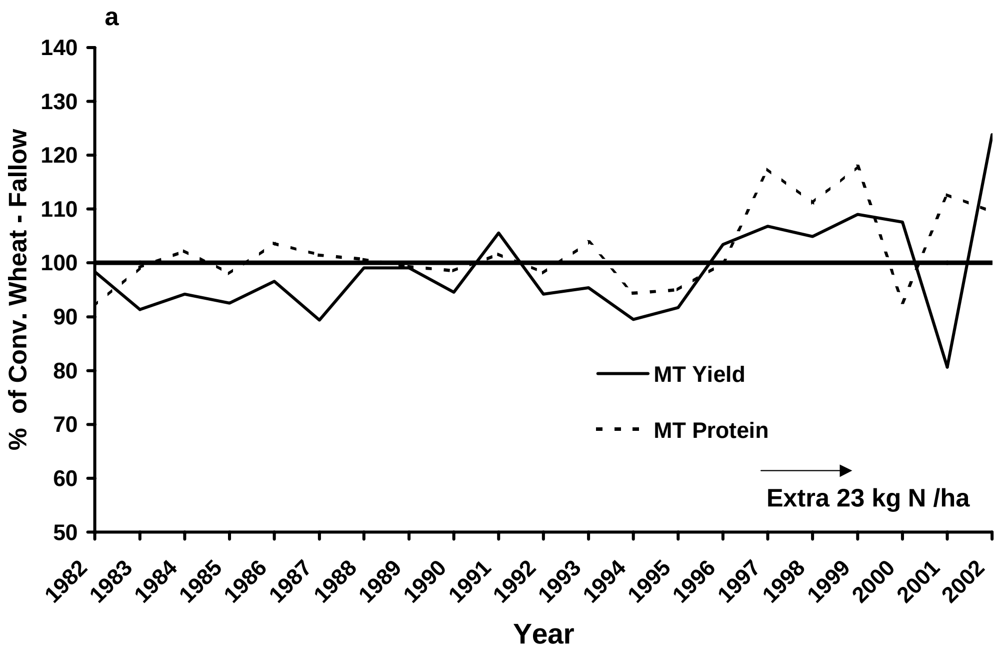


Figure 5. Wheat a)yield and b) protein for wheat in continuously cropped rotations within the Clay-Tillage experiment for 1995-2002 (bars are LSD at P=0.10)



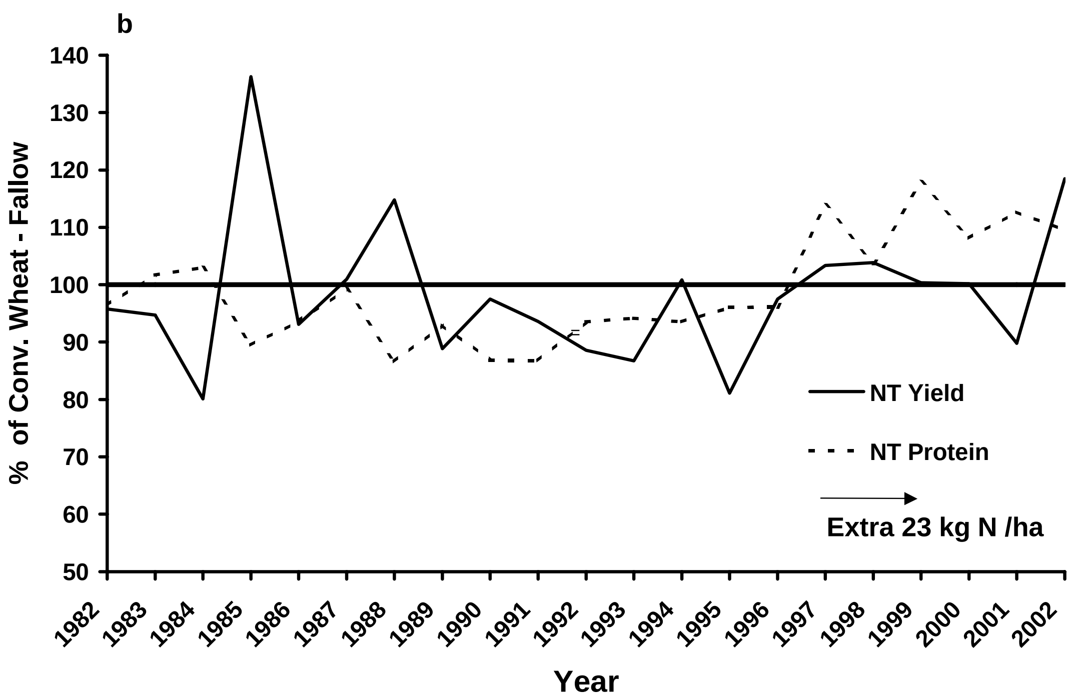
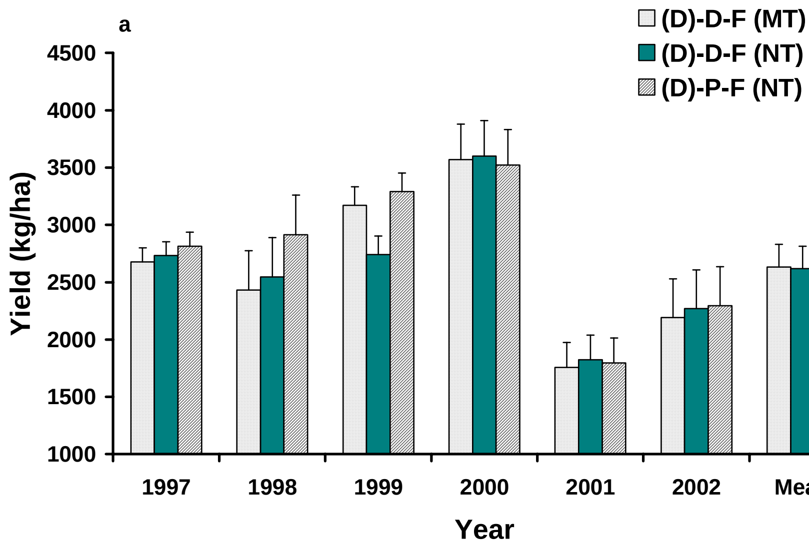


Figure 6. Relative grain yield and protein to CT (W)-F for a) MT (W)-F and b) NT (W)-F.



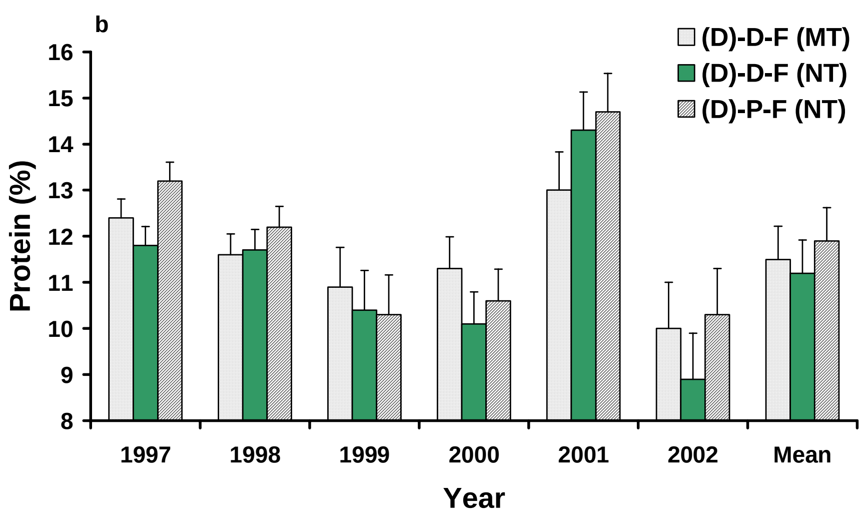


Figure 7. Wheat a) yield and b) protein for durum on fallow for Loam-Rotation Experiment (bars are LSD at P=0.10)