The Effect of Pulse Crop Rotation and Controlled-Release Urea on the N Accumulation and End-Use Quality of CWRS Wheat

D. Przednowek[1], D. Flaten[1], H. Sapirstein[1], M. Entz[1], B. Irvine[2], B. McConkey[3]

[1]Faculty of Agricultural and Food Sciences, University of Manitoba, Winnipeg, MB R3T 2N2
[2]Agriculture and Agri-Food Canada Research Centre, P. O. Box 1000A,R. R. #3, Brandon, Manitoba, R7A 5Y3
[3] Agriculture and Agri-Food Canada Semiarid Prairie Agricultural Research Centre, Swift Current, SK, S9H 3X2

Key Words: annual grain legumes, fertilizer N source, breadmaking quality, CWRS wheat

Abstract

Spring wheat was grown at Carman in 2000 and 2001, and at Brandon, MB, in 2001, on field pea and flax stubble at three rates of N (0, 30, and 90 kg N ha^{-1}) supplied as ammonium nitrate (AN) or controlled release urea (CRU), a polyurethane-coated urea. Wheat was grown in 2000 and 2001 at Swift Current, SK, on field pea and durum stubble at three rates of urea N (34, 50, and 78 kg N ha^{-1}) based on soil test recommendations. Wheat grown on field pea stubble (P-W) had higher protein content (PC) than wheat grown on flax/durum stubble (F-W) at four of the five sites evaluated. Contrary to expectations, post-anthesis apparent net mineralized N and proportion of total N uptake were higher for F-W compared to P-W at the Carman 2000 and Brandon 2001 sites. Differences between fertilizer N sources were minor. Breadmaking quality of the wheat end-use quality was also assessed. At the same flour protein content (FPC), P-W had a shorter Mixograph dough development time, work input-to-peak, dough strength index, and breakdown resistance, and also tended to be more extensible than F-W.

Introduction

Besides grade, protein concentration (PC) is widely recognized as one of the most influential factors affecting wheat breadmaking quality. Although end-users are willing to pay a premium for Canada Western Red Spring (CWRS) wheat of acceptable quality and high PC, end-users also demand consistency. As grain origination becomes more regionalized, the averaging of wheat quality may decline (Preston et al. 2002), increasing the importance of a thorough understanding of the effect of agronomic practices and environment on end-use quality.

Annual grain legumes such as field pea improve soil N status directly via the mineralization of legume residue N, indirectly through the reduction of fertilizer N immobilization, and through the conservation of soil N via biological N fixation. In the Northern Plains, the increased N availability from legume residues is attributed primarily to mineralization of residue N during the growing season (Badaruddin and Meyer 1994; Beckie et al. 1997; Flaten and Greer 1998; Miller et al. 2002), one perceived benefit of which is improved synchrony of N availability and plant N uptake. Controlled-release fertilizers may also improve the synchrony of N uptake and N availability and reduce N losses to the environment via leaching and denitrification. Haderlein et al. (2001) evaluated the effect of side-banded controlled-release urea (CRU) and conventional urea on spring wheat and found significantly higher PC and NUE for the CRU treatment as a result of higher N uptake and recovery later in the growing season.

Protein composition is also an important aspect of breadmaking quality. Gliadin is responsible for the viscous properties of dough during mixing, while glutenin confers dough strength and resistance to extension (Schofield 1986). Interestingly, the accumulation of individual protein fractions in the kernel is well defined and asynchronous (Stone and Savin 1999); gliadin is synthesized most rapidly in early kernel development, glutenin is not synthesized in appreciable quantities until mid-filling, and polymerization of glutenin occurs late in kernel development. Factors such as crop rotation and source of N fertilizer may also alter the intensity or duration of the deposition of individual protein fractions during the filling period may alter protein composition and subsequently affect composition and quality of the protein in the wheat kernel.

The main objective of this study was to evaluate the effect of pulse crop rotation and CRU on N accumulation and end-use quality of CWRS wheat. We wanted to validate the observation that annual grain legumes and CRU improve the timing of N availability and crop demand. We also wanted to determine whether at the same PC, previous crop or fertilizer N source produced wheat with different end-use quality characteristics that could be explained by differences in protein composition, possibly as a result of the alteration of N accumulation pattern.

Materials and Methods

Field pea (cv. Grande) and flax (cv. Norlin) were established on a Denham sandy loam at the Carman Research Station in 1999 and 2000, as well as at the Brandon Research Centre in 2000 on a Newdale loam, in four replicates arranged in a randomized complete block design. In the re-crop phase, spring wheat (cv. AC Barrie) was sown across each main plot. Five N fertilizer treatments were randomly arranged as sub-plots in each main plot, namely a control (0 kg N ha^{-1}) and 30 kg N ha^{-1} and 90 kg N ha^{-1} as commercial grade ammonium nitrate (AN) or controlled-release urea (CRU). Field pea (cv. Alfetta) and durum wheat (cv. Kyle) were established in 1999 and 2000 on a Haverhill loam at the Semiarid Prairie Agricultural Research Centre in three replicates arranged in a strip block design. In the re-crop phase, N fertilizer treatments were randomly arranged in each block, consisting of three rates of N applied as urea based on soil test recommendations for dry, average, and wet growing seasons (34, 50, and 78 kg N ha^{-1}, respectively). Blocks were subsequently sown with spring wheat (cv. AC Barrie).

Prior to planting, soil in main plots was sampled at depths of 0-15 cm, 15-60 cm, and 60-120 cm. Dry matter (DM) samples were collected at anthesis and every 7 days thereafter until 35 days after anthesis (DAA); heads were separated from the stem/leaf fraction. Plant samples were oven-dried and analyzed for total N by combustion. At anthesis, soil samples corresponding to 0-10 cm and 10-30 cm depths were collected from a trench dug perpendicular to the direction of the fertilizer bands. A single soil core was taken from the trenched area corresponding to depths of 30-50 cm, 50-70 cm, 70-90 cm, and 90-110 cm. At harvest, two soil cores were taken corresponding to anthesis sampling depths. Soil samples were ground (< 2 mm) using a rotating steel roller and sieve, extracted with 2 *M* KCl, and analyzed by autoanalyzer for NH_4-N and NO_3-N. Apparent net mineralized N (NMN) was calculated as (sampling date aboveground plant N yield + soil NO_3-N to 110 cm) – (soil NO_3-N to 120 cm prior to planting + fertilizer N rate). Plant N yield 35 DAA was used for estimating NMN at harvest.

Flour N concentration was determined by combustion analysis. Dough mixing behaviour was evaluated using a 10 g computerized Mixograph (National Manufacturing, Lincoln, NE). The following parameters were measured: mixing time to peak development (MDT), work input to MDT (WIP), bandwidth at MDT (PBW), dough resistance at MDT (PDR), breakdown resistance (BR), and strength index (SI). Dough extensibility was measured (Smewing 1995) with a TA.XT2*i* texture analyzer fitted with a Kieffer rig (Texture Technologies, Inc., Scarsdale, NY; Stable Microsystems, Surrey, UK). Parameters measured were maximum dough resistance (Rmax), dough extensibility at Rmax, extensigram area (E Area), dough extensibility at rupture (E), and Rmax/E. Flour water absorption (FAB) was determined with a Brabender Farinograph. Baking was performed using the Canadian Short Process (Preston et al. 1982). Loaf volume (LV) was determined with a rapeseed displacement apparatus.

Data were analyzed by analysis of variance (ANOVA) using procedures of the SAS Institute Inc.; effects were considered to be significant at $P < 0.05$. Pearson correlation coefficients were determined for a pooled dataset (excluding Carman-01 data due to a lack of homogeneity of variance) restricted to a common range of flour protein concentration (FPC) of the two previous crop types (field pea or flax/durum). The Proc GLM procedure was used to evaluate linear relationships between quality attributes and FPC. Previous crop and was considered to have a significant effect on a given parameter where the *P*-value of the interaction term (previous crop*FPC) of Type III sums of squares was less than 0.05.

Results and Discussion

Agronomic data in this paper are presented for only the Manitoba sites. At Carman-00 and Brandon-01, soil NO_3-N prior to planting wheat was significantly higher where field pea was grown compared to flax (Table 1). Previous crop had no effect on soil NO_3-N levels at Carman-01; overall NO_3-N levels at this site were very high, particularly at a depth of 60-120 cm. The lack of an effect of previous crop on soil NO_3-N status at Carman-01 was likely due to the initially high soil N-supplying power of the site prior to establishment of the initial phase of this rotation study. The greater N-supplying power of field pea was likely due to the sparing of soil N as well as post-harvest mineralization. A significant contribution of N from the legume residue as a result of mineralization of field pea residue during the re-crop phase of the study and prior to anthesis is unlikely, especially in light of the low growing season NMN estimate. However, post-harvest mineralization may have contributed to the N benefit of the grain legume.

Mineralization is strongly dependent on soil moisture and temperature regime. Thiessen Martens and Entz (2001) found southern Manitoba was well-suited to relay and double cropping with winter wheat due to the potential for significant late summer and early fall precipitation and thermal energy accumulation. These conditions are conducive for rapid mineralization of N on field pea stubble immediately following harvest. Given the higher soil NO_3-N of field pea stubble at Carman-00 and Brandon-01, the potential for leaching and denitrification was elevated, both of which are of considerable concern in southern Manitoba.

Table 1. Distribution of Estimated NO_3-N in the Soil Profile Prior to Planting as Affected by Previous Crop at the Manitoba Sites.

Site Year	Field Pea	Flax	Pr > F
Carman-00	120	65	0.0015*
Carman-01	134	150	0.82
Brandon-01	81	50	0.022*

*Effects are considered significant at $P < 0.05$

At anthesis, field pea stubble had 25 kg more NO_3-N ha^{-1} than flax stubble to a depth of 110 cm at Carman-01. At Brandon-01, treatment differences observed at planting were no longer evident at anthesis. No significant differences were observed at harvest. Apparent NMN for wheat grown on flax stubble (F-W) was substantially higher than for wheat grown on field pea stubble (P-W) between anthesis and harvest at Carman-00 and Brandon-01 (Table 2). The lower apparent NMN of P-W relative to F-W may be due to the combination of N sparing and post-harvest mineralization of field pea residue. The slow, steady N release pattern of legume residues suggested by many researchers (Badaruddin and Meyer 1994; Beckie et al. 1997; Flaten and Greer 1998; Miller et al. 2002) was not observed under the conditions of this study.

Table 2. Apparent Net Mineralized N (kg N ha^{-1}) during the Growing Season at the Manitoba Sites as Affected by Previous Crop.

	Planting to Anthesis	Planting to Harvest	Anthesis to Harvest
Carman-00			
Field Pea	33 (6)	59 (11)	26 (8)
Flax	27 (5)	82 (8)	55 (8)
Pr > F	0.63	0.36	0.054
Carman-01			
Field Pea	11 (9)	66 (6)	55 (10)
Flax	16 (11)	62 (10)	46 (14)
Pr > F	0.23	0.72	0.096
Brandon-01			
Field Pea	13 (5)	14 (5)	1 (6)
Flax	18 (5)	26 (6)	8 (6)
Pr > F	0.45	0.0726	0.0355

*Standard errors are presented in parentheses.

Total N accumulation at anthesis for P-W was significantly higher than for F-W at Carman-00 and Brandon-01 (Table 3). Differences in N accumulation between P-W and F-W were maintained throughout the sampling period. While the quantity of post-anthesis N uptake was similar for P-W and F-W at all sites, the proportion of N accumulated post-anthesis was higher for F-W versus P-W, contrary to expectations. The NMN calculations also support the idea of greater post-anthesis N uptake for F-W compared to P-W as a proportion of total N uptake.

Table 3. Effect of Previous Crop on N Accumulation Pattern at the Manitoba Sites.

	Pre-Anthesis (kg N ha^{-1})		Total (kg N ha^{-1})		% Post-Anthesis	
Site Year	Pea	Flax	Pea	Flax	Pea	Flax
Carman-00	149 a	115 b	183 a	159 a	17.0 a	26.8 b
Carman-01	145 a	150 a	195 a	198 a	25.8 a	23.8 a
Brandon-01	102 a	80 b	125 a	105 b	17.6 a	24.2 b

Means followed by different letters at each site indicate significant differences at $P < 0.05$ based on Fisher's protected LSD test.

Total N accumulation at anthesis for the AN treatment was significantly higher than for the CRU treatment at Carman-00 and Brandon-01 (Table 4). These results conform to expectations based on the N release pattern of the two N sources. Based on its N release pattern, the quantity of post-anthesis N uptake of the CRU treatment was expected to exceed that of AN. However, only the results from Brandon-01 are in agreement with these expectations (Table 4). A direct comparison of these results with those of Haderlein et al. (2001) is not valid since Haderlein et al. compared CRU to conventional urea, not AN. The Brandon site was the best suited to evaluate the effect of fertilizer N source on wheat N accumulation, since treatment effects were less likely to be masked by high concentrations of soil N, as encountered at the Carman sites.

Table 4. Effect of Fertilizer N Source on N Accumulation Pattern at the Manitoba Sites.

	Pre-Anthesis (kg N ha^{-1})		Total (kg N ha^{-1})		% Post-Anthesis	
Site Year	AN	CRU	AN	CRU	AN	CRU
Carman-00	146 a	134 b	185 a	167 a	20.8 a	17.6 a
Carman-01	149 a	155 a	195 a	208 a	24.2 a	25.0 a
Brandon-01	105 a	93 a	120 a	125 a	10.7 a	26.1 b

Means followed by different letters at each site indicate significant differences at $P < 0.05$ based on Fisher's protected LSD test.

P-W had significantly higher FPC than wheat grown on flax/durum stubble at three of five site years (Table 5). Fertilizer N source had no effect on FPC at any of the Manitoba sites. Overall, there was no significant effect of previous crop on FPC observed at the Brandon-01 site. FPC was significantly higher for P-W than for F-W at the 30 kg N ha^{-1} and 90 kg N ha^{-1} N rates. Higher PC was observed for F-W compared to P-W in the control treatment as due to the dilution effect of yield on PC. P-W had significantly higher FPC than wheat grown on durum stubble in 2000 and 2001 at the Swift Current sites. A combination of low soil N supply relative to the Manitoba sites, as well as above average soil moisture conditions, resulted in low FPC at Swift Current in 2000, while dry conditions produced high FPC in 2001.

Table 5. Effect of Previous Crop on Flour Protein Content.

Site Year	Pea	Flax	Pr > F
Carman-00	15.4	13.8	0.0369*
Swift Current-00	12.5	10.8	0.0006*
Carman-01	16.5	16.4	0.55
Brandon-01	14.8	13.9	0.13
Swift Current-01	15.6	14.5	0.0182*

*Effects are considered significant at $P < 0.05$

Besides its effect on protein concentration, previous crop had an effect on end-use quality (Table 6). Below a FPC of 14%, wheat grown on flax/durum stubble had higher Mixograph MDT compared to P-W; regression lines converged at FPC greater than 15% (Fig. 1). Wheat grown on flax/durum stubble also had significantly higher WIP than P-W (Fig. 1), as well as considerably higher SI, though not statistically significant. No interaction was observed between previous crop and FPC for micro-extension test parameters, although P-W produced dough that was more extensible than wheat grown on flax/durum stubble at FPC less than 14%. No previous crop*FPC interaction was observed for either FAB or LV.

Table 6. Coefficients of determination (r^2) of the pooled dataset for flour protein content (FPC) and selected quality attributes, as well as degree of significance for the interaction between previous crop and FPC.

Parameter	FPC (r^2)	Prev. Crop*FPC (Pr > F)
Mixograph		
MDT	0.53****	0.0009***
PDR	0.82****	0.34^{ns}
WIP	0.13***	0.0145*
PBW	0.03^{ns}	0.94^{ns}
BR	0.43****	0.48^{ns}
SI	0.14****	0.0889^{ns}
Micro-Extension Test		
Rmax	0.00^{ns}	0.68^{ns}
E at Rmax	0.40****	0.12^{ns}
E Area	0.17****	0.86^{ns}
E	0.35****	0.16^{ns}
Rmax/E	0.08**	0.29^{ns}
Breadmaking		
FAB	0.57****	0.72^{ns}
LV	0.68****	0.62^{ns}

ns, *, **, ***, **** = not significant, significant at P<0.05, 0.01, 0.001, and 0.0001, respectively.

One possible explanation for the contrasting effects of previous crop on dough strength may be attributable to the pattern of protein accumulation in the kernel as influenced by N accumulation pattern. In theory, under the conditions of this study, P-W would be expected to yield weaker, more extensible dough. The N uptake pattern of P-W can be described as “front-loaded.” A lower proportion of total N uptake occured after anthesis for P-W than for F-W, meaning in theory there is a lower proportion of N available for glutenin synthesis and a higher proportion of N available during synthesis of gliadin. This study suggests that this theory has merit. However, differences in N accumulation pattern attributable to previous crop were insufficient to yield definitive answers.

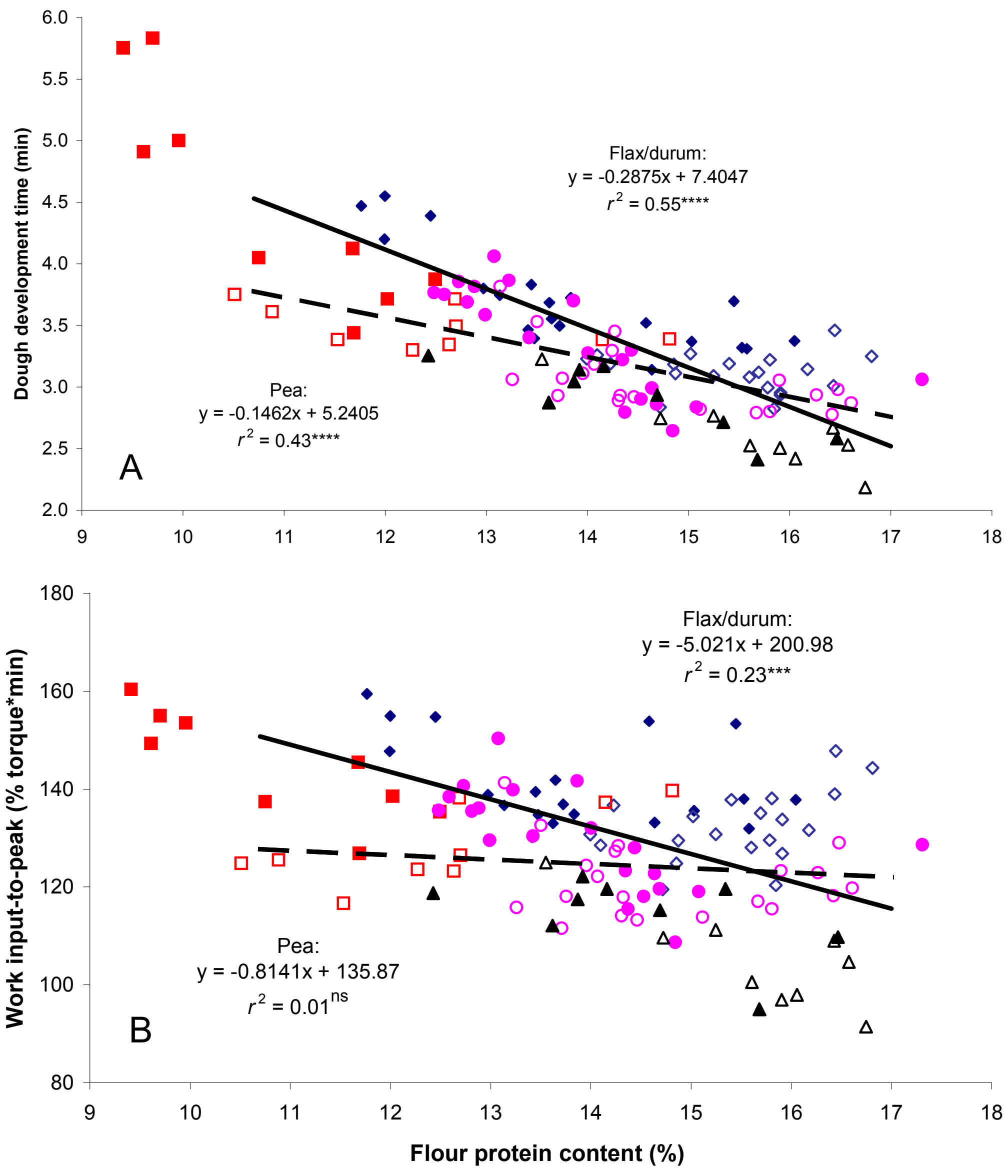

Figure 1. Effect of previous crop on Mixograph dough development time (A) and work input-to-peak (B). Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift Current-00 (■), Brandon-01 (•), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]

In a number of instances, there was a poor relationship between FPC and quality attributes, indicating the strong effect of growing season conditions on wheat end-use quality. In most instances, the strength of the relationship between quality attributes and FPC was strengthened when Swift Current-01 data was excluded from the pooled dataset (data not presented). Interestingly, compared to flour samples from the Carman-00 and Brandon-01 sites, the dough strength and resistance to extension of Swift Current-01 samples was much lower. As mentioned previously, a lack of soil moisture during the growing season reduced yields substantially. Clearly, growing season conditions had a strong effect on end-use quality, be it in terms of an effect on protein composition or some other aspect of end-use quality.

Conclusions

Contrary to expectations, post-anthesis apparent net mineralized N and proportion of total N uptake were higher for F-W compared to P-W at the Carman 2000 and Brandon 2001 sites. The greater N-supplying power of field pea was likely due to the sparing of soil N as well as post-harvest mineralization. Unlike other similar studies conducted in the Northern Plains, the potential for post-harvest mineralization was much greater than expected, likely due to favorable soil temperature and moisture conditions. Fertilizer N source had minor effects on N accumulation pattern, although the high N fertility of the Carman sites may have masked treatment differences that might have otherwise been observed under more typical soil N fertility conditions. Previous crop had a strong effect on Mixograph MDT and WIP; P-W produced weaker dough than wheat grown on flax/durum stubble, possibly as a result of altered protein composition due to N accumulation pattern. Pronounced differences were observed among site years.

References

Badaruddin, M., and Meyer, D. W. 1994. Grain legume effects on soil nitrogen, grain yield, and nitrogen nutrition of wheat. Crop Sci. 34: 1304-1309.

Beckie, H. J., Brandt, S. A., Schoenau, J. J., Campbell, C. A., Henry, J. L, and Janzen, H. H. 1997. Nitrogen contribution of field pea in annual cropping systems. 2. Total nitrogen benefit. Can. J. Plant Sci. 77: 323-331.

Flaten, B., and Greer, K. 1998. Nitrogen supplying power of canola versus pea stubble under zero and conventional tillage systems. p. 327-330. In: Wheat Protein Production and Marketing. Proceedings of the Wheat Protein Symposium. Fowler, D. B. et al. eds. University Extension Press, University of Saskatchewan, Saskatoon, SK.

Haderlein, L., Jensen, T. L., Dowbenko, R. E., and Blaylock, A. D. 2001. Controlled release urea as a nitrogen source for spring wheat in western Canada: yield, grain N content, and N use efficiency. In: Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International itrogen Conference on Science and Policy. TheScientificWorld 1.

Miller, P. R., Waddington, J., McDonald, C. L., and Derksen, D. A. 2002. Cropping sequence affects wheat productivity on the semiarid northern Great Plains. Can. J. Plant Sci. 82: 307-318.

Preston, K. R., Hucl, P., Townley-Smith, T. F., Dexter, J. E., Williams, P. C., and Stevenson, S. G. 2002. Effects of cultivar and environment on farinograph and Canadian short process mixing properties of Canada western red spring wheat. Can. J. Plant Sci. 81: 391-398.

Preston, K. R., Kilborn R. H., and Black, H. C. 1982. The GRL pilot mill. II. Physical dough and baking properties of flour streams milled from Canadian red spring wheats. Can. Inst. of Food Sci. Technol. J. 15 (1).

Schofield, J. D. 1986. Flour proteins: structure and functionality in baked products. p. 14-29. In: Chemistry and Physics of Baking: Materials, Processes, and Products. Blanshard, J. M. V., Frazier, P. J., and Galliard, T. eds. Royal Society of Chemistry.

Smewing, J. 1995. The Measurement of Dough and Gluten Extensibility using the SMS/Kieffer Rig and the *TA.XT2* Texture Analyzer. Stable Micro Systems, Ltd., Surrey, England.

Stone, P. J., and Savin, R. 1999. Grain quality and its physiological determinants. p. 85-120. In: Wheat: Ecology and Physiology of Yield Determination. Satorre, E. H. and Slafer, G. A. eds. Food Products Press. New York.

Thiessen Martens, J. R., and Entz, M. H. 2001. Availability of late-season heat and water resources for relay and double-cropping with winter wheat in prairie Canada. Can. J. Plant Sci. 81: 273-276.