1996-02-22

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Nitrogen Release, Uptake and Yield of Wheat in the Brown Soil Zone at the Landscape-Scale as Influenced by Tillage Treatments

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Abstract: Comparison of the effects of short-term mechanical and no-till fallow managements on nitrogen (N) availability was conducted in an undulating landscape in the Brown soil zone in southwestern Saskatchewan. The effects of these fallow managements were assessed by i) crop N uptake and yield and ii) ^{15}N tracer technique (A value approach) and ***in situ*** burial of anion exchange membrane (AEM) probes.

No significant differences in spring soil nitrate or mean soil temperature were observed between the treatments. However, spring moisture content of the surface soil samples was significantly higher under no-till compared to mechanical fallow. At the landform scale, shoulder positions of the respective tillage systems had significantly lower crop N uptake, yield and apparent N mineralization compared to other slope positions. The contribution of shoulders under no-till towards N uptake and grain yield were 8.25 and 445 kg/ha higher compared to shoulders in mechanical fallow. Soil N supplying capacity as determined by A value and AEM techniques along with crop N uptake and yield was not significantly different between the tillage treatments, indicating that N availability is not likely to be greatly affected in initial years by switching to no-till in these soils.

Introduction

Changes in surface soil properties associated with different fallow managements may subsequently affect nutrient release, uptake and crop yield. With the advent of new technology, for example, advancement in seeding and fertilizer equipment, some of the earlier major concerns of reduced nitrogen availability when adopting a no-till system need to re-evaluated. The appearance and extent of damage caused by lower spring soil temperatures (Wall and Stobbe 1983; Carter and Rennie 1985), increased weed and disease infestations and lower nutrient availability, especially nitrogen (Kitur et al., 1984; Huggins and Pan 1988; Hons et al., 1988; Knowles et al., 1993) have been identified as concerns and may vary with the type of tillage system and the climatic conditions. Furthermore, since most of the farmlands in Saskatchewan, exists as undulating landscapes with varying levels of soil moisture and fertility at different slope positions (Pennock et al., 1987), transforming tillage research data from the level plot-based studies to variable farm field landscapes may not be quite appropriate. Previous studies have addressed nitrogen availability differences largely through changes in spring and fall profile nitrate levels and crop yield, with few attempts to look at tillage effects on organic N turnover directly. We conducted an intensive study of the nature of N release and availability over the fallow season among the slope positions and between mechanical and no-till fallow managements in 1994 (Jowkin and Schoenau 1995). These two sites were subjected to a cropping season during 1995 to compare the availability of N to the succeeding spring wheat crop and the impact of landscape positions and tillage practices on overall crop yield.

Materials and Methods

Site Description: The soil at the study site (NW30-20-3-3) in the Brown soil zone are mainly of Echo, Haverhill and Kettlehut Association (Ayres et al., 1985). The soils under these associations are derived from glacial till parent material with varying soil textures from upper slope positions (sandy loam to sandy clay loam) to lower slope positions (loam to clay loam). An area of 150 X

150 m^2 in a variable undulating to rolling topography which was under mechanical fallow-cereal rotation since it was brought under cultivation in 1917 was selected. The entire landscape was surveyed using a 10 m2 systematic grid design and based on digital elevation model, the points of intersection of the grids were quantitatively classified into either shoulder (SH), footslope (FS), or level (LE) landform element complexes (LEC) (Pennock et al., 1987). Two fallow managements i) mechanical fallow and ii) no-till (chemfallow) fallow systems were established in 1994 season by dividing the entire landscape into two equal parts. Ten randomly selected grid points from each of the LEC within each of the tillage treatments were selected for the subsequent study. A meteorological station was set up to monitor daily precipitation over the growing season. In the early spring of 1995, surface soil samples (0- 10 cm) were collected for 2M KC1 extractable nitrate and soil' moisture content.

Seeding and Plant Sampling: Spring wheat (var. Pasqua) was direct seeded to a depth of 2.5 cm on May 10, 1995 @ 75 lb/ac using a John Deere 610 Chisellplow type Air Seeder with 12" row spacing and 16" sweeps. The seeding equipment is considered to represent high soil disturbance direct seeding without extensively incorporating crop residue into soil, especially in case of the chemfallow system. On June 8, the crop was sprayed with Dupont "Express Pack', a mixture of 2, 4 D ester 700 (@ 0.6 L/ha) and tribenuron methyl (@ 10 g/ha) using 210 Melroe Spray Coupe @ 2.9 gallons water/ac.

Tissue sampling was done at 45 days after planting (DAP). Above ground tissue samples from 15 X 15 cm2 areas at the different sampling points were sampled for dry matter yield (t/ha) and tissue N concentrations. Crop N uptake was calculated and expressed as kg N/ha.

At physiological maturity on August 16, 1995 above-ground plant samples from 1 X 1 m^2 areas at the different slope position sampling points were sampled for straw and gram yield. Both straw and grain were analyzed for percent N concentrations. Nitrogen uptake was calculated separately for grain and straw as mentioned above.

Soil N Supplying Capacity: Apart from nutrient uptake and crop yield, two different approaches: i) ^{15}N tracer technique (A value) and ii) AEM method were used to distinguish the treatments with respect to their capacity to supply mineralized N to the succeeding crop.

A Value Approach: At level landform element complexes an ^{15}N study was carried out to distinguish soil N supplying capacity of these two tillage systems to the succeeding crop by means of A value approach. Fifteen microplots (1 X 1 m^2 each) were randomly selected under each tillage treatment. Ten days after seeding these microplots were labelled with 5 kg N/ha using single labelled $(^{15}NH_4)_2SO_4$ at 10.6 atom percent ^{15}N in solution form. Fresh leaf samples from the center of each microplot were collected on June 15, June 29 and July 13. The plants were dried at 40 OC and ground in a cyclone mill (0.4-mm screen), the samples were ground further in a rotating ball-bearing mill (Knight et al., 1994)

On August 8, 1995 four to five wheat plants from the center of each microplot were harvested and separated into gram and straw manually. After drying in an oven at 40 OC, samples were ground in a Cyclone mill and further in the ball mill.

Percent N and atom percent ^{15}N were determined for all the samples on a continuous-flow isotope ratio mass spectrometer (CF-IRMS) (Europa Scientific, Crewe, England) interfaced with a Roboprep Sample converter (Europa Scientific). ^{15}N enriched pea residue (atom percent ^{15}N excess = 0.3693 and percent N = 2.24) and ^{15}N-enriched gram pea residue (atom percent ^{15}N excess = 0.5 145 and percent N= 3.63) were used as a working standard.

AEM Method: This is a simple and cost effective method of assessing nitrate supply rate over time *in situ*. *One* anion exchange membrane (AEM) probe was buried *in situ* adjacent to each of the fifteen microplots established for A value approach under each treatment. The membranes were allowed to remain in the soil for two-weeks. After two-weeks, the AEM probes were retrieved from the soil and a fresh set of AEM were buried. The AEM taken out of the soil was eluted and the eluent analyzed for nitrate, following the procedure described by Qian et al (1992). The supply rate is reported as μg NO3 sorbed/cm^2 resin surface/2 week. This method was carried out at two-week intervals from May 10 to July 25, 1995.

Soil Temperature: On April 12, 1994 soil temperature measurements were started by installing copper constantan thermocouples connected to two multiplexers (AM-ENCT) which were, in turn, connected to a Campbell Scientific CR 10 digital recorder. Daily average soil temperature at 5 cm depth was monitored until June 21, 1994. Every two-weeks soil temperature data was retrieved using a Tanon lap-top computer and transformed to an IBM computer. Average soil temperatures for the two-week period then determined using SPLIT program.

Statistics: Statistical analysis was performed in STATVIEW®. Descriptive statistics were calculated for the response variables measured in this study. Due to strong skewness and higher coefficient of variation, non-parametric Mann-Whitney U test ($p= 0.20$) was used to test the significant differences between the treatments and at landform scale within each treatment. Soil temperature data was analyzed by analysis of variance. Least significant difference (LSD) was used to compare treatments ($p= 0.05$).

Results and Discussion

Soil Moisture: The most important criteria of all for cereal grain yields in southwestern Saskatchewan is the effect of amount and distribution of growing season precipitation along with spring soil water reserve (Nicholaichuk 1984; Campbell et al., 1988). In a very dry year a good spring soil moisture reserve is a prerequisite to economic yield. As well, as the soil water potential is reduced, germination and seedling emergence may also be progressively delayed (Helmerick and Pfeifer 1954; McGinnies 1960, Ashraf and Abu-Shakra 1978).

The differences in soil moisture content between the two tillage systems reflects the importance of presence and absence of crop residue on the soil surface in moisture accumulation and retention. Table 1, which depicts the gravimetric soil moisture content of surface soil samples, revealed similar trends as found in the fallow season 1994 (Jowkin and Schoenau 1995). At the landscape scale surface spring soil moisture content under chemfallow was 20.65% which is about 5% greater than mechanical fallow. A similar trend was documented by Aase and Tanaka (1987). The standing crop residue in the chemfallow treatment would trap extra snow over winter and reduce surface losses by evaporation especially on windy days (Kirkland and Keys 198 1; Tanaka and Aase 1987)

At the landform scale (Table 1) surface soil moisture content was found to be in the following order: footslope (21.98 and 20.24%) >level (21.10 and 16.86%) >shoulder (19.37 and 13.09%) in chemfallow and mechanical fallow, respectively. In the case of the chemfallow system, significant differences were observed between shoulder and footslopes, and shoulder and level positions. In contrast, all three slope positions were significantly different from each other under conventional fallow, with a greater range in water contents. In the chemfallow system the presence of greater crop residue helps to conserve soil moisture and minimize moisture redistribution (runoff) compared to mechanical fallow system in this undulating landscape.

The differences in soil moisture content at respective footslope, level and shoulder slope positions in the two tillage systems were 1.74, 4.24 and 6.28% respectively. Considering the difference of 6.28% at shoulders, the statement made by Campbell et al. (1988) that the effect of amount and distribution of growing season precipitation for cereal grain production in southwestern Saskatchewan, could be modified for the variable landscapes by considering moisture redistribution and storage capacities within the landscape as factors controlling productivity in an undulating topography.

Spring Soil NO_3-N: Surface soil samples collected in early spring for NO_3-N indicated no significant difference between chemfallow (9.80 µg/g) and mechanical fallow (9.40 µg/g) at the landscape scale (Table 1). It is significant that over the previous year fallow season, chemfallow system had significantly greater soil nitrate as determined by both AEM and 2M KC1 extraction methods. The lack of significant difference in spring nitrate levels may be related to greater downward movement of NO_3-N from the surface over the fall and in early spring under chemfallow system (data not shown).

Similar to spring soil moisture, 2M KC1 extractable nitrate at the landform scale showed significant difference between footslope (18.05 µg/g) and shoulder (6.40 µg/g), and level (11.20 µg/g) and shoulder (6.40 µg/g) positions under chemfallow. All three slope positions were significantly different from each other under mechanical fallow (Table 1). This is may be because of reduction in runoff losses from the convex to the concave portions of the landscape under chemfallow system thereby minimizing the difference in moisture among the slope positions and associated losses and gains of mineral N.

Table 1. Median values for spring soil moisture and spring 2M KCl-NO_3 at landscape- and landform-scale

Variables	At Landscape Scale* Chemfallow			Mechanical Fallow		
Soil Moisture (%)	20.65 a			16.86 b		
Soil Nitrate (µg/g)	9.80 a			9.40 a		
	At Landform-Scale**					
	Chemfallow			Mechanical Fallow		
	SH	FS	LE	SH	FS	LE
Soil Moisture (%)	19.37 a	21.98 b	21.10 b	13.09 a	20.24 b	16.86 c
Soil Nitrate (µg/g)	6.40 a	18.05 b	11.20 b	4.90 a	17.95 b	11.70 c

* Median values with different letter in each row are significantly different (p=0.20)

** Median values with different letter in each row under each fallow system are significantly different (p=0.20)

Soil Temperature: Lower soil temperature is one of the prime concerns in no tillage management systems. Apart from its role in nutrient cycling and numerous other physical and chemical soil processes, soil temperature will affect the germination rate and rate of crop development. For example, in controlled conditions increasing the temperature from 5 to 10 OC reduced the time of emergence of winter wheat from 24 to 10 days (Lafond and Fowler 1989). Similar results were also reported for spring wheat by de Jong and Best (1979).

As shown in Figure 1, irrespective of tillage system and slope positions, soil temperature gradually increased over the season in response to air temperature. At 5 cm depth (Table 2), under chemfallow and mechanical fallow the mean average soil temperatures were 12.28 and 13.59 OC, respectively over the season at the landscape scale. However no significant differences were observed either between or among the slope positions within the tillage treatments. The trend towards slightly lower soil temperature in chemfallow system is due to the presence of crop residue which acts as an insulating layer and may also because of significantly higher soil moisture which has greater specific heat requirement.

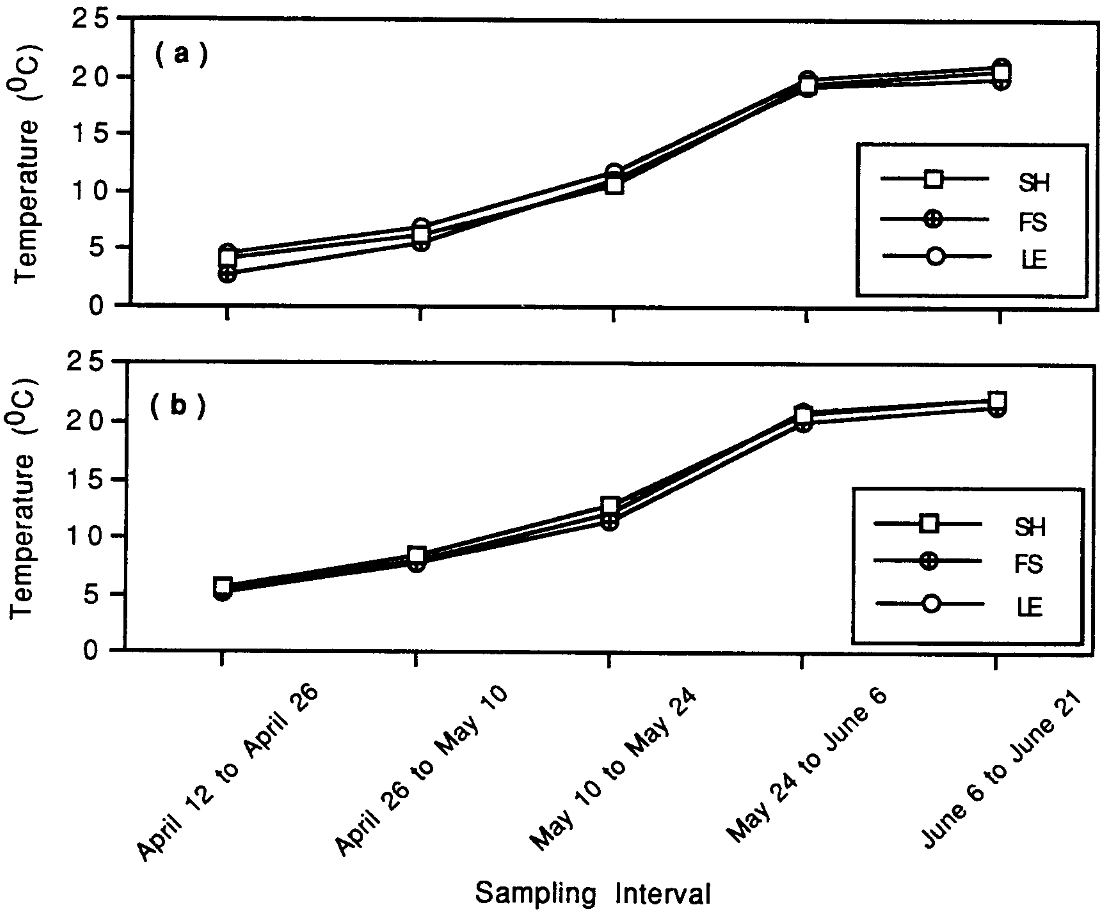

Figure 1. Average soil temperature at 5 cm depth over the season under (a) Chemfallow and (b) Mechanical fallow

Table 2. Mean average soil temperatures (5 cm depth) from April 12 to June 21, 1995 at landscape- and landform-scale

Fallow System	At Landscape-Scale*	At Landform-Scale**		
		SH	FS	LE
Chemfallow	12.28 a	12.5 a	12.0 a	13.0 a
Mechanical	13.59 a	14.0 a	13.0 a	14.0 a

* Mean values with same letters in each column indicate no significant difference exists (LSD, p=0.05)
** Mean values with same letters in each row indicate no significant difference exists (LSD, p=0.05)

Similarly, at the landform scale no significant differences in average temperature at 5 cm depth were observed (Table 2). Due to differences in amount of crop residue left on the surface, soil moisture content and orientation of slope positions to the incoming radiation might have caused a trend towards lower soil temperature at footslope positions compared to other landform element complexes under chemfallow and mechanical fallow, respectively.

Overall visual observation made in early stages of crop growth i.e., during the establishment phase, showed that seedling stage was not affected by the small differences in soil temperatures caused by the treatments. Results from recent work conducted in different environments with different crops has indicated little difference in plant population established provided the seed is placed shallow on a moist and firm seed-bed (Wilkins et al., 1988; Hall and Cholick 1989; Lanfond et al., 1992) as was the case in the present study.

Dry Matter Yield: A major objective of any agronomic research is to study the effect of treatments on crop yield. Crop yields are highly variable and depend on several soil management and environmental conditions&y matter yield at 45 DAP was not statistically significant between the tillage treatments, however, slightly greater dry matter yield. was observed under chemfallow compared mechanical fallow (Table 3). This might be related to significantly higher spring soil moisture content of chemfallow tillage system because there was no differences in spring soil nitrate levels.

At the landform scale dry matter yield levels followed similar trends as that of soil moisture and soil nitrate levels. Generally, shoulder positions showed significantly lower dry matter yield compared to footslope and level landform element complexes in each treatment (Table 3). Absence of significance difference between footslope and level positions of the respective treatments may be because of leaching and denittification losses of nitrate at footslopes owing to greater soil moisture content.

Table 3. Median values at landscape- and landform-scale for tissue samples collected at 45 days after planting (DAP) and at physiological maturity

At Landscape-Scale*

	45 DAP			At Physiological Maturity				
	Dry matter Yield (t/ha)	N (%)	N Uptake (kg/ha)	Tot. Yield (kg/ha)	Grain Yield (kg/ha)	N (%)	Grain N Uptake (kg/ha)	Total N Uptake (kg/ha)
Chemfallo w	0.80 a	4.17 a	31.90 a	5420 a	2145 a	1.90 a	42.97 a	51.84 a
Mechanical fallow	0.72 a	3.96 a	27.87 a	4600 a	1970 a	1.93 a	37.07 a	42.73 a

At Landform-Scale**

Variables	Chemfallow SH	Chemfallow FS	Chemfallow LE	Mechanical Fallow SH	Mechanical Fallow FS	Mechanical Fallow FS
45 DAF'						
Dry Matter Yield (t/ha)	0.60 a	0.90 b	0.88 b	0.56 a	0.90 b	0.83 b
Nitrogen (%)	3.54 a	4.50 b	4.22 c	3.52 a	4.40 b	4.02 c
Nitrogen Uptake (kg/ha)	21.38 a	38.26 b	38.06 b	19.77 a	38.42 b	30.64 b
At Physiological Maturity						
Total Yield (kg/ha)	4290 a	6810 b	6095 c	3755 a	6340 b	5060 b
Grain Yield (kg/ha)	1855 a	2445 b	2470 b	1410 a	2550 b	2060 b
Nitrogen (%)	1.86 a	1.93 a	1.93 a	1.90 a	1.95 a	1.95 a
Grain N Uptake (kg/ha)	34.14 a	47.28 b	44.98 b	25.89 a	56.61 b	37.96 b
Total N Uptake (kg/ha)	40.28 a	59.61 b	54.89 b	31.05 a	70.12 b	45.46 b

* Median values with different letters in each column are statistically significant (p-0.20)

** Median values with different letters in each row under each fallow system are statistically significant (p=0.20)

Concentration and Uptake of N: No significant difference for percent N (4.17 and 3.96) concentration in wheat at 45 DAP was observed between tillage systems (Table 3). However, significant differences were observed among the slope positions within each treatment (Table 3). For nitrogen, footslope samples had significantly greater (4.50 and 4.40%) N concentration compared to level (4.22 and 4.02%) and shoulder (3.54 and 3.52%) positions under chemfallow and mechanical fallow, respectively, reflecting greater N availability.

According to Clarke et al. (1990) the main contributor to N uptake is the dry matter production component. Over 12-yr research it was found that plant N content varied considerably with precipitation, spring soil moisture and soil nitrate content. In general, available moisture was the main factor controlling N uptake, although in some years distribution of precipitation was critical to production and thus to N uptake (Campbell et al., 1992).

Although spring soil moisture content was slightly but significantly greater under chemfallow system, absence of significant differences with respect to N indicate that little difference exists in nutrient availability and demand in the two tillage systems. Moving to a no-till fallow system then does not necessarily infer application of greater amounts of fertilizer to compensate for reduced availability as has been suggested before. Significantly lower N uptake was observed at shoulder (21.38 and 19.77 kg/ha) compared to footslope and level landform element complexes under chemfallow and mechanical fallow, respectively (Table 3). This is due to differences in mineral N concentration and moisture accumulation at different landscape positions. Clearly, landscape position has a more pronounced impact on N availability and yield than the tillage treatments under comparison in this study.

Total and Grain Yield: Final yield data generally reflected the same treatment differences as observed for the dry matter yield at 45 DAP. Total yield (grain plus straw) and grain yield were slightly higher in chemfallow (5420 and 2145 kg/ha) compared to mechanical fallow system (4600 and 1970 kg/ha), respectively (Table 3). This is consistent with the observation of slightly higher yield on the chemfallow treatment when the entire plot was harvested. Slightly greater yield levels with chemfallow system could be the result of slightly higher spring soil nitrate and significantly greater soil moisture content. Similar yield differences were reported by Brun et.al. (1986) and Aase and Tanaka (1987). Quite often lower grain yields observed for mechanical fallow can be attributed to differences in soil water conservation rather than reduced mineral N supply (Carefoot et al. 1990).

Among the slope positions, total yield was significantly lower at shoulder (4290 kg/ha) compared to level (6095 kg/ha) which was in turn significantly lower than footslope (6810 kg/ha) under chemfallow. In mechanical fallow no significant difference was observed between footslope and level positions (Table 3), although shoulders were significantly lower.

Although chemfallow had 2145 kg/ha mean grain yield, which is slightly higher than 1970 kg/ha found under mechanical fallow, the difference was not significant (Table 3). Irrespective of tillage system no significant differences were observed between footslope and level complexes. Only shoulders (1855 and 1410 kg/ha) were significantly lower than that of footslope and level complexes under chemfallow and mechanical fallow, respectively (Table 3). Greater N mineralization and moisture availability in low-lying areas of the landscape generally lead to increased yield levels of most crops (Goovaerts and Chiang 1993; Hanna et al., 1982; Sawyer 1994).

N Concentration and Uptake in Grain: Soil and environmental factors influence grain N concentration which is an essential and important economic quality factor for wheat (Henry et al., 1986). There was no effect of tillage treatments on grain N concentration at the landscape or at the landform scale (Table 3). In contrast to biomass N concentrations observed at 45 DAP, absence of significant differences in grain at harvest indicates that in early stages of crop growth wheat N concentration differences are more closely related to N availability. The similarity in %N in grain among tillage treatments and landform elements indicates that N availability relation to water supply was similar in tillage treatments and relative to landscape position.

Grain N uptake and total N uptake (grain plus straw) of wheat in chemfallow (42.97 and 51.84 kg/ha) were similar to that of mechanical fallow (37.07 and 42.73 kg/ha). At the landform scale no difference between footslope and level complexes within each tillage treatment was observed (Table 3).

Soil N Supplying Capacity

A Value Approach: Of the several methods available to distinguish any variation in N supplying power between treatments, ^{15}N tracer technique is considered to be one of the most powerful tools to differentiate soil and fertilizer N source to the growing crop over the season.

The main reason for sampling fresh leaf samples three times over the season is because although the wheat crop meets majority of its N requirement in the early growth stages, under certain conditions the stability or the temporal variability of A value depends on initial soil N and also subsequent N mineralization potentials of different treatments under consideration (Matus et al., 1995). A values calculated for samples collected at physiological maturity may indicate an integrated effect of different sources of N to crop uptake.

The A values determined for fresh leaf samples, representing the most recent plant growth varied from 422.3 to 340.6 kg/ha and 623.9 to 350.1 kg/ha under chemfallow and mechanical fallow, respectively (Table 4). Except for the first time sampling where mechanical fallow had significantly greater A value compared to chemfallow system, no significant differences between the tillage treatments were observed for the second, third and for final yield components. Absence of significantly different A values of straw (489.8 and 460.7 kg/ha) and grain (478.6 and 438.1 kg/ha) for both tillage treatments confirm that soil N availability did not differ with treatments. A similar observation was made by Dowdell and Crees (1980). They found no difference in apparent N immobilization in direct-drilled and plowed soils; nor was there a tillage effect on plant recovery of ^{15}N.

Table 4. Median A values for plant samples collected from the ^{15}N microplots at different intervals at level landform element complexes

Fallow System	Sampling Interval				
	June 15	June 29	July 13	August 8 Straw	August 8 Grain
Chemical	422 a	341 a	352 a	490 a	479 a
Mechanical	624 b	350 a	363 a	461 a	438 a

Median values with different letters in each column are significantly different (p=0.20)

Nitrate Supply Rate (AEM Method): Anion exchange membrane sorbed nitrate was also used to study supply rate of mineralized N to the subsequent crop. This may be considered an alternate method compared to A value approach. Continuous *in situ* burial of the membranes includes a measurement of supply rate capability from initial soil N and that which is mineralized over the two-week period.

Figure 2 shows a gradual decrease in anion exchange sorbed nitrate ($AEM-NO_3$) over the season under both tillage systems. Unlike in the fallow season, the presence of crop during the cropping season competes with the buried resin for nitrate, depleting soil and fertilizer N to meet its nutrient requirement. The trend also indicates that wheat crop accumulates most of its required N for growth and reproduction early in the growing season, and later remobilizes N stored in the vegetative plant parts to the reproductive parts. Bioavailability of $AEM-NO_3$ declined from 28.75 to 0.33 $\mu g/cm^2/2$ week and 22.36 to 0.57 $\mu g/cm^2/2$ week, respectively under chemfallow and mechanical fallow. However although chemfallow had slightly higher nitrate supply rate overall median $AEM-NO_3$ was not statistically significant between the two tillage treatments.

This study clearly supports the results obtained both by A value approach and by the yield data for the treatments under consideration. The foregoing results leave no doubt that both A value approach and AEM method constitute a useful standard for characterizing relative soil N availability from different crop residue managements and that shifting to no-till fallow practices does not appear to have a large impact on N availability.

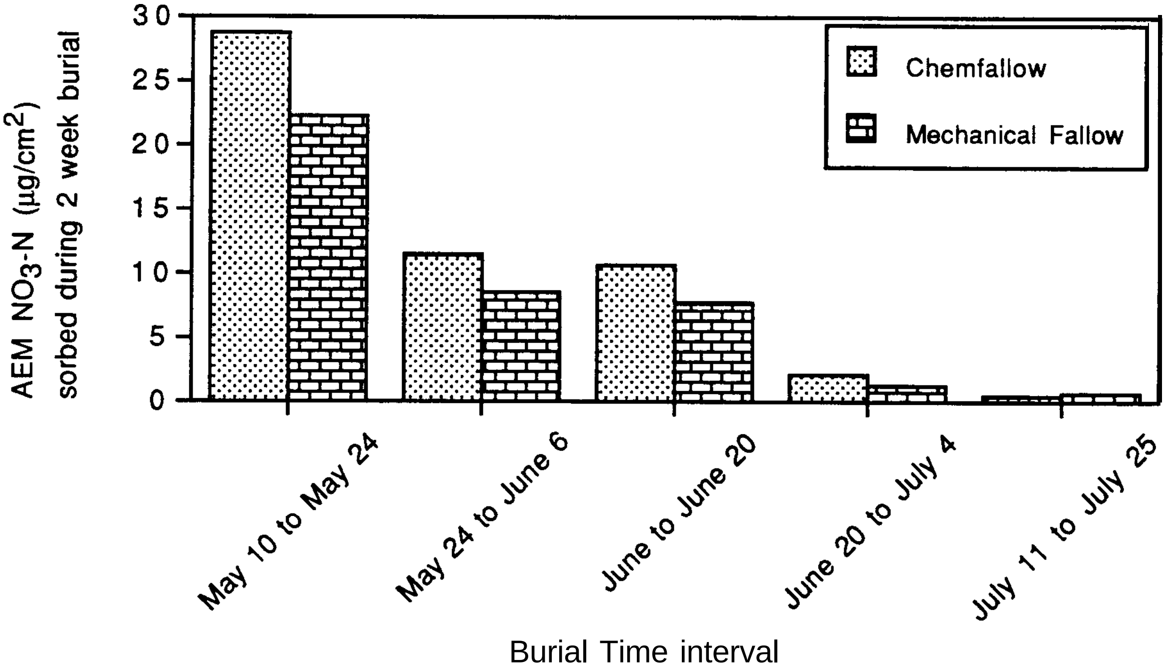

Figure 2. Nitrate supply rate determined by AEM in situ burial at two-week intervals over the growing season at level landform element complexes under chemical and mechanical fallow

Summary and Conclusion

Overall, switching to chemfallow system in initial years of establishment appears to be associated with some small changes in soil temperature and moisture regime. The presence and maintainance of crop residue on the soil surface especially in an undulating landscape helps to reduce surface runoff and evaporation leading to slightly higher grain yield compared to mechanical fallow where soil is left exposed to the external environment. Slightly higher crop yield at shoulder positions under chemfallow system means higher crop residue return and may therefore improve and/or maintain soil productivity over the long-run compared to shoulders under mechanical fallow system. The overall effect of tillage on N mineralization-immobilization over the fallow season and N availability to the subsequent crop seems to be minor. It is also evident from the present study conducted that previous concepts about reduced soil disturbance by tillage reducing soil organic matter turnover and release of nitrogen to the plant available inorganic form may not be universally applicable. Soils which have been cultivated for several decades and low in organic matter content might have small proportions of macroaggregates, so the impact of exposure and breakdown by tillage would be relatively minor. Instead, it appears that landscape position has a much greater impact on nitrogen availability and crop yield than tillage practices in variable to undulating glacial till landscapes of the Brown soil zone.

Acknowledgement: The authors gratefully acknowledge the support of the Canada-Saskatchewan Agriculture Green Plan Project.

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