Input Level and Crop Diversity Effects on Nitrate-N and Extractable P, Aggregation, and Organic C and N in Soil after Sixth Year in the Second Six-Year Rotation Cycle

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INTRODUCTION

Under and over fertilization is uneconomical and when applied in excess of crop needs there is potential for environmental damage through leaching and denitrification/N_2O emissions of nitrate-N and loss of P with runoff. Changes in nutrient accumulation and distribution in the soil profile vary with rates, sources and duration of fertilizer application, species, yield potential and rooting characteristics of crop, climate, type and management of soil, and residue (Seyfried et al., 1991; Guillard et al., 1995; Cowie, et al., 1996; Katupitiya et al., 1997; Vos et al., 1998). The concentration of nitrate-N in a soil profile can be elevated by inclusion of legumes, green manure and fallow in a cropping system (Guillard et al, 1995; Katupitiya et al., 1997). High rates of N fertilization and limited crop uptake of N during the growing season can result in excessive accumulation of nitrate-N in the soil. This excess N can be decreased with efficient cropping systems (Guillard et al., 1995). The magnitude of P accumulation in soil has also been found to depend on soil type, cropping intensity and diversity and fertilizer amount (Campbell et al., 1984b; McCollum, 1991). On the other hand, marked decline in available P level of surface soil has been observed from continuous cropping in the absence of P fertilization (Bailey et al., 1971).

Crops with taproots can penetrate deep into the soil where crops with fibrous roots can not reach. Compared with annual crops which extracted nitrate-N only from 0-120 cm soil, alfalfa extracted significant amounts of nitrate-N to 270 cm soil depth (Entz et al., 2001). Nutrients present in the sub-soil may thus be used by taproot plants and become available in surface soil after crop residues are returned to the soil. This can improve the economic productivity when surface soil has low fertility, and enhance retention of nutrients and minimize environmental damage under high fertility conditions. Rotation of fibrous and taproot crops in a cropping sequence can therefore improve the cycling and crop use of nutrients from a soil.

In the Prairie Provinces of Canada, research has shown that elimination of tillage, returning of crop residue or adequate fertilization can be used to increase organic matter and improve aggregation in some soils (Nuttall et al., 1986; Campbell et al., 1991; Nyborg et al., 1995b; Malhi et al., 2006; Singh and Malhi, 2006; Malhi and Kutcher, 2007). In an Alberta study, Nyborg et al. (1995a) reported effect of tillage, straw management and N fertilization on soil N balance. However, information is lacking on these parameters when different crops with different crop diversities are grown in rotations under various alternative cropping systems. The objective of this study was to determine the influence of input level and cropping diversity on accumulation and distribution of nitrate-N and extractable P in the soil profile in the second 6-year rotation cycle, aggregation, organic C and organic N in surface soil, and nutrient balance after two 6-year rotation cycles under various alternative cropping systems. The objective of this study was to determine the influence of input level and cropping diversity on accumulation and distribution of nitrate-N and extractable P in the soil profile in the second 6-year rotation cycle, aggregation, and organic C and N in surface soil after two 6-year rotation cycles under various cropping systems.

Materials and Methods

The field experiment was established in 1995 on a Dark Brown loam soil at Scott, Saskatchewan. Growing season (May to August) precipitation during the study year 2006 and long-term means are given in Table 1. The 54 treatments were combinations of three input levels (organic – ORG, reduced – RED and high – HIGH), three cropping diversities (low diversity – LOW, diversified annual grains – DAG and diversified annual grains and perennial crops - DAP) and six crop phases of the cropping sequence. The second 6-year rotation cycle started in 2001 growing season. A split-split plot design with four replications was used. Input, diversity and crop phase were the main, sub and sub-sub plots, respectively. Each sub-sub plot measured 40 m x 12.8 m.

Table 1. Monthly precipitation in growing season (GS) in 2006 and long-term average at Scott, Saskatchewan.

	Precipitation (mm)				
Year	May	June	July	August	GS Total[1]
2006	62.8	45.6	34.6	46.8	189.8
LT[a]	34.7	67.3	65.6	43.7	211.3

[a]LT = Long term, based on the 1961-1990 data for Scott, Saskatchewan (Environment Canada).

In the ORG input, the management was based on non-chemical means to mimic what an organic grower might do. Rhizobia inoculation prior to seeding of legume for N fixation and *Penicillium bilaii*[1] ([1]available under the trade names Provide or Jumpstart from Philom Bios Ltd.) to enhance P uptake were used. Tillage was the sole means of weed control. The RED input integrated long-term management of pests and nutrients, with chemical inputs used to supplement other management practices. The objective was to reduce inputs (pesticides, fertilizers, fossil fuels) such that any yield reduction was more than offset by reduced input costs. For example, N application was based on soil test N for each plot minus 11 kg N ha^{-1}. Phosphorus was added at 15 kg P ha^{-1}. In the HIGH input, management was based on pest thresholds for pesticides and soil tests for fertilizers**,** complimented by CT. Long-term management of pests and nutrients was of minimal concern as chemicals were used to respond to pest problems or nutrient deficiencies as they arose. Application of N fertilizer was based on soil test N. In practice, actual N rates for HIGH differed very little from RED because soil test N levels were higher for HIGH. Rate of applied P was at 15 P kg ha^{-1}.

In the LOW cropping diversity, the crop sequence was fallow or green manure – wheat – wheat - fallow or green manure – oilseed - wheat. With ORG the oilseed was mustard, and with RED and HIGH it was canola. Fallow was managed as green manure (GM) of lentils in both fallow phases under ORG, GM lentil in the first and chem-fallow in the second fallow phase under RED, and tillage-fallow in both fallow phases under HIGH input. The six-year crop rotations in the DAG cropping diversity, were GM (lentils – *Lens culinaris* Medicus) fallow – wheat (*Triticum aestivum* L.) – field pea – barley – GM (sweet clover – *Melilotus officinalis* (L.) fallow – mustard (*Brassica juncea* L.) under ORG; and canola (*Brassica napus* L. *and B. rapa* L.) – fall rye (*Secale cereale* L.) – field pea (*Pisum sativum* L.) – barley (*Hordeum vulgare* L.) – flax (*Linum usitatissimum* L.) – wheat under RED and HIGH inputs. The DAP diversity consisted of a rotation of annual grains and perennials in a mustard (ORG)/canola (RED and HIGH) – wheat – barley – alfalfa (*Medicago sativa* Leyss) – alfalfa hay – alfalfa hay sequence.

At the end of 2006 growing season (i.e., after 12 years or after sixth year of second 6-year rotation cycle), soil was sampled (2 cores/ plot with a 2 cm diameter coring tube) from the 0-15, 15-30, 30-60 and 60-90 cm depths in each plot in October. The samples were air dried, ground to pass a 2-mm sieve, and analyzed for nitrate-N (Technicon Industrial Systems, 1973) and extractable P (Melich, 1984). In selected treatments, soil was also sampled to the 240 cm depth in order to determine the extent of nitrate-N leaching in relation to input level and crop diversity.

For organic C and N in soil, samples were collected from the 0-7.5 and 7.5-15 cm depths at 8 locations per plot using a 2.4 cm diameter coring tube. Bulk density of soil was determined by the core method (Culley, 1993). The samples were air dried at room temperature after removing coarse roots and easily detectable crop residues, and ground to pass through a 2-mm sieve. Sub-samples were pulverized in a vibrating-ball mill (Retsch, Type MM2, Brinkman Instruments Co., Toronto, Ontario). The method of Technicon Industrial Systems (1977) was used to determine TON in the soil. Light fraction organic matter (LFOM) was separated using a NaI solution of 1.7 Mg m^{-3} specific gravity, following the method described by Janzen et al. (1992) and modified by Izaurralde et al. (1998). The C and N in LFOM (LFOC, LFON) were measured by Dumas combustion using a Carlo Erba instrument (Model NA 1500, Carlo Erba Strumentazione, Italy).

Soil samples for aggregation were collected from the 0-5 cm depth at two inter-row locations in each plot using a rectangular trough (15 cm x 17.5 cm) with minimal disturbance. The soil was air dried to about 5 g water 100 g^{-1} soil. The samples were shaken, using an automatic rotary sieve shaker, at 12 cycles per minute, through a nest of sieves with equivalent diameter of 38, 12.7, 6.4, 2.0, 1.3, and 0.5 mm, and a pan underneath (Chepil, 1962). Aggregate fraction retained on each sieve and the pan was expressed as a percentage of total dry soil mass. The results were expressed as percent aggregate size distribution as well as mean weight diameter (Van Bavel, 1950). Any coarse roots detected in the soil after sieving were removed by hand. The data were subjected to analysis of variance (ANOVA) in SAS (SAS Institute Inc., 1989) and least significant difference ($LSD_{0.05}$) was used to determine significant differences between treatment means.

RESULTS AND DISCUSSION

Soil Nitrate-N

Input level effects on nitrate-N

Earlier research has reported increase in soil nitrate-N level with increasing N fertilizer rate in dryland agriculture (Campbell et al., 1994; Guillard et al. (1995). Kolbe et al. (1999) suggested that properly managed organic agriculture, with reduced inputs, may decrease potential risk of nitrate leaching in soil because of reduced input of N to the soil system. However, in the present study, the amount nitrate-N in the 0-90 cm depth did not differ among the three input levels (Table 2). This was most likely due to improvement in moisture conditions in the last 4 years (2003, 2004, 2005 and 2006) which resulted in better crop growth and uptake of N. The results on mass of nitrate-N in different soil layers did not suggested any significant downward movement of nitrate-N in the soil profile due to input level.

Table 2. Distribution of nitrate-N in the soil profile in relation to input levels, averaged across the three crop diversities and six crop phases, in fall 2006 at Scott, Saskatchewan.

	Nitrate-N (kg ha^{-1}) in soil layers (cm)				
Input level	0-15	15-30	30-60	60-90	0-90
ORG	13	17	16	15	62
RED	13	13	14	18	58
HIGH	12	15	15	18	60
LSD $_{(0.05)}$	ns	3	ns	ns	ns

and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$ and not significant, respectively.

Crop diversity effects on nitrate-N

The LOW and/or DAG diversity resulted in greater nitrate-N compared to DAP in the 15-30, 30-60 and 60-90 cm soil layers (Table 3). For the 0-90 cm soil, the nitrate-N level showed a trend of LOW = DAG > DAP. Input x crop diversity interaction effect on nitrate-N in 0-90 cm soil was not significant (Table 4), but the order of nitrate-N in soil was HIGH > ORG = RED in the LOW diversity and ORG > RED = HIGH in the DAG diversity. In the DAP diversity, there were no differences in nitrate-N among input levels. Other workers have also observed reduced soil nitrate-N as a result of increased cropping intensity. For example, double cropping decreased nitrate-N in soil compared to a single crop or noncropped fallow (Guillard et al., 1995). In 4-year rotations on a Black Chernozemic soil, Grant and Lafond (1994) observed significantly higher nitrate-N in the 0-15 and 60-120 cm soil layers under a crop-crop-crop-fallow system compared to the two systems with four years of cropping. They stated that the moisture conserved in the fallow period led to increased downward movement of nitrate-N, increasing the possibility of nitrate-N leaching below the root zone. Similarly, greater nitrate-N in the 90-120 soil depth was observed from a wheat-fallow rotation than under continuous annual wheat (Campbell et al., 1984a); and nitrate-N within and below the root zone (120 cm depth) was greater under fallow-wheat than under wheat monoculture rotation (Zentner et al., 2001). Cropping systems that include perennial plants have been shown to be effective in reducing subsoil nitrate-N accumulation (Olsen et al., 1970).

Table 3. Distribution of nitrate-N in the soil profile in relation to cropping diversity, averaged across three input levels and six crop phases, in fall 2006 at Scott, Saskatchewan.

	Nitrate-N (kg ha^{-1}) in soil layers (cm)				
Diversity level	0-15	15-30	30-60	60-90	0-90
LOW	13	16	16	21	67
DAG	13	16	18	19	66
DAP	13	12	11	11	47
LSD $_{(0.05)}$	ns	2**	4**	4***	8***

$^{**, ***}$ and ns refer to significant treatment effects in ANOVA at $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 4. Interaction effects of cropping diversity and input level on nitrate-N in 0-90 cm soil, averaged across six crop phases, in fall 2006 at Scott, Saskatchewan.

	Cropping diversity			
	LOW	DAG	DAP	Mean
Input level	Nitrate-N (kg ha^{-1}) in 0-90 cm soil			
ORG	65	75	45	62
RED	62	62	51	58
HIGH	73	61	47	60
Mean	67	66	47	
LSD $_{(0.05)}$	Input x diversity = ns; Input= ns ; Diversity = 8***			

*** and ns refer to significant treatment effects in ANOVA at $P \leq 0.001$ and not significant, respectively.

Crop phase and input level effects on nitrate-N under different crop diversities

Nitrate-N in soil in different cropping diversities varied with crop species and input level. In LOW cropping diversity, the amount of nitrate-N in soil was greater at HIGH input level in many cases (Table 5). At ORG input level, GM/F1 had the greatest, followed closely by GM/F2, and wheat2, wheat3 or mustard had the lowest nitrate-N in soil. At RED input level, the nitrate-N in soil was greatest after GM/F2, lowest after canola, and intermediate after other crops. At HIGH input level, GM/F1 had the greatest, followed closely by GM/F2, and wheat1 and wheat3 had the lowest nitrate-N in soil. Averaged across the three inputs, nitrate-N was greatest after GM/F1, followed by GM/F2 and was lowest after wheat3, which was equal to mustard/canola and wheat2. Maximum soil nitrate-N was observed in 4 cases at HIGH input and in 2 cases at RED input. On the other hand, minimum amounts of nitrate-N were observed in 1 case at ORG input, in 2 cases at HIGH input, and in 3 cases at RED input. Whenever ORG input level had greater nitrate-N than RED input level, probably lack of P in soil in the ORG system retarded plant growth and N use by the crop.

Table 5. Influence of crop phase in LOW cropping diversity on nitrate-N in soil (0-90 cm) under three input levels in fall 2006 at Scott, Saskatchewan.

	Crop phase					
	GM/F1[a]	Wheat1	Wheat2	GM/F2	Mustard[b]	Wheat3
Input level	Nitrate-N (kg ha^{-1}) in 0-90 cm soil					
ORG	86	63	53	82	54	53
RED	66	66	61	75	43	60
HIGH	111	78	52	82	67	45
Mean	88	69	55	79	55	53
LSD $_{(0.05)}$	Input x crop phase = ns ; Crop phase = 20**					

[a]Chem fallow under RED and tilled fallow under HIGH input. [b]Canola under RED and HIGH inputs.

** and ns refer to significant treatment effects in ANOVA at $P \leq 0.01$ and not significant, respectively.

In the DAG cropping diversity, GM/F1, wheat and GM/F2 crop phases at ORG input showed significantly more nitrate-N compared to other crop phases at RED and HIGH inputs in most cases (Table 6). Some of these differences may be associated with the different crops grown in ORG than in the other two input systems. Between the RED and HIGH inputs, which had similar crop phases, soil nitrate-N was tended to be greater at HIGH compared to RED input only after barley and wheat, while the opposite tended to be true after flax, pea and canola, and little difference after spring rye. The sequences were GM/F1 > spring rye > GM/F2 > mustard > pea > barley at ORG input, wheat > flax > pea > barley ≥ canola ≥ spring rye at RED input, and wheat > barley > pea ≥ flax = spring rye = canola at HIGH input. Maximum soil nitrate-N was observed in 3 cases at ORG input, in I case at RED input and in 2 cases at HIGH input. Minimum amounts of nitrate-N were also observed in 3 cases at ORG input, in I case at RED input and in 2 cases at HIGH input. Whenever ORG input level had greater nitrate-N than RED or HIGH input level, this was probably due to the fact that lack of P in soil in the ORG system retarded plant growth and N use by the crop.

In the DAP cropping diversity, nitrate-N in 0-90 cm soil showed relatively diminished influence of crop phase and input level than under LOW diversity (Table 7). The amount of nitrate-N in soil in DAP was less than DAG or LOW and varied with crop, usually highest after hay2. The sequences were hay2 > mustard > wheat > barley = alfalfa = hay1 at ORG input, hay2 > canola > barley = wheat ≥ hay1 ≥ alfalfa at RED input, and hay2 > canola > wheat > hay1 ≥ barley ≥

alfalfa at HIGH input. Maximum soil nitrate-N was observed in 3 cases at RED input and in 3 cases at HIGH input. On the other hand, minimum amounts of nitrate-N were observed in 5 cases at ORG input and in I case at HIGH input.

Table 6. Influence of crop phase in DAG cropping diversity on nitrate-N in soil (0-90 cm) under three input levels in fall 2006 at Scott, Saskatchewan.

	Crop phase					
	GM1[a] Canola	Wheat Spring Rye	Pea Pea	Barley Barley	GM2 Flax	Mustard Wheat
Input level	Nitrate-N (kg ha^{-1}) in 0-90 cm soil					
ORG	123	94	43	34	83	69
RED	54	40	69	58	72	78
HIGH	42	45	54	66	47	110
Mean	73	60	56	53	68	86
LSD $_{(0.05)}$	Input x crop phase = 38*** ; Crop phase = 22*					

[a] The crop sequence was GM (lentil)-wheat-pea-barley-GM (sweet clover)-mustard under ORG, and canola-fall rye-peas-barley-flax-wheat under RED and HIGH inputs.

* and *** refer to significant treatment effects in ANOVA at $P \leq 0.05$ and $P \leq 0.001$, respectively.

Table 7. Influence of crop phase in DAP cropping diversity on nitrate-N in soil (0-90 cm) under three input levels in fall 2006 at Scott, Saskatchewan.

	Crop phase					
	Mustard/Canola[a]	Wheat	Barley	Alfalfa	Hay1	Hay2[b]
Input level	Nitrate-N (kg ha^{-1}) in 0-90 cm soil					
ORG	51	42	30	31	31	87
RED	63	39	40	31	36	92
HIGH	53	47	38	33	41	67
Mean	56	43	36	32	36	82
LSD $_{(0.05)}$	Input x crop phase = ns ; Crop phase = 13*					

[a] Mustard under ORG, and canola under RED and HIGH input levels. [b] Hay2 was oat/pea hay.

* and ns refer to significant treatment effects in ANOVA at $P \leq 0.05$ and not significant, respectively.

Deep Core Soil Samples for Nitrate-N

In selected treatments where soil samples were taken to 240 cm depth, the amount of nitrate-N (averaged across three input levels) was usually highest with LOW crop diversity and lowest with DAP crop diversity in most soil layers below 60 cm depth (Table 8). The amount of nitrate-N (averaged across three crop diversities) was higher ($P \leq 0.10$) or tended to be higher at HIGH input than the other two inputs in soil layers below 90 cm depth, but in the 60-90 cm soil layer it tended to be higher at ORG input than other two inputs. There was no consistent effect of input level or crop diversity on nitrate-N in the 0-15, 15-30 and 30-60 cm soil layers. Input level x crop diversity interaction was not significant in most cases, but the amount of nitrate-N tended to be highest in plots receiving a combination of HIGH input and LOW crop diversity in all soil layers below 90 cm depth. The amount of nitrate-N in the 30-60 and 60-90 cm layers tended to be highest in plots receiving a combination of ORG input and LOW crop diversity, but there were no consistent pattern in the 0-15 and 15-30 cm layers. The total amount of nitrate-N in the 0-240 cm soil depth tended to be highest for HIGH input-LOW diversity combination and lowest for ORG input-DAP diversity combination. The total amount of nitrate-N in the 0-240 cm soil was highest with LOW crop diversity when averaged across three input levels, and tended to be highest at HIGH input when averaged across three crop diversities. These results suggest that if N fertilizer is applied at high rates and crop frequency is low, there is a potential for accumulation and leaching of nitrate-N in the soil profile, increasing risk of ground water contamination.

Table 8. Distribution of soil nitrate-N in the 0 to 240 cm depth in selected treatments in relation to input level and crop diversity in autumn 2006 at Scott, Saskatchewan.

Treatments		Nitrate-N (kg ha^{-1}) in various soil layers (cm)									
Input level	Crop diversity	0-15	15-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	0-240
Input level x crop diversity interaction											
ORG	LOW	9	12	33	60	46	38	29	25	26	278
	DAG	9	7	17	32	51	48	31	24	26	245
	DAP	12	4	15	9	5	11	24	31	32	143
RED	LOW	20	16	13	24	65	65	60	53	46	362
	DAG	18	21	14	32	32	25	21	20	18	201
	DAP	16	8	19	9	12	15	17	28	30	154
HIGH	LOW	8	7	16	31	95	105	92	66	46	466
	DAG	11	13	15	17	52	63	47	41	35	294
	DAP	21	12	19	12	56	41	43	46	42	292
LSD$_{0.05}$		5**	9	ns	ns	ns	ns	ns	ns	ns	ns
Input level means											
ORG		10	7	22	34	34	32	28	27	28	222
RED		18	15	15	22	37	35	33	34	31	240
HIGH		13	10	17	20	68	70	58	50	40	356
	LSD$_{0.05}$	2***	ns	ns	ns	ns	37	30	ns	ns	ns
Crop diversity means											
	LOW	12	11	21	38	69	70	57	46	39	373
	DAG	13	13	15	27	45	45	33	28	26	245
	DAP	16	8	18	10	24	22	28	35	35	196
	LSD$_{0.05}$	3*	5	ns	19*	35*	22***	19**	ns	ns	104**

, *, **, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Soil Extractable P

Input level and crop diversity effects on extractable P

The effect of cropping diversity on extractable P in soil was significant at $P \leq 0.10$ (Table 9). Mean extractable P tended to be greater at HIGH input than ORG or RED input. The amount of extractable P in the 0-90 cm soil was significantly greater (but small increase) at RED and HIGH inputs than at ORG input. The amounts of extractable P in different soil layers indicate that the effect of input level was significant in the 0-15 and 15-30 cm soil layers, but there was no downward movement of extractable P in the soil profile (Table 10). Extractable P was low in the 0-30 layers and markedly low in the 30-90 cm soil layers, similar to the results odbtained by Leitch et al. (1980). This indicates that there may be little potential for taproot crops to bring P from deeper soil to the surface at this site. This also suggests that if the whole soil profile is low in available P or other nutrients, it may not be possible to sustain high crop yields under organic farming systems without using external nutrient sources (Adetunji, 1994).

Table 9. Influence of input level and cropping diversity on extractable P in soil (0-90 cm), average of six crop phases in fall 2006 at Scott, Saskatchewan.

	Cropping diversity			
Input level	LOW	DAG	DAP	Mean
	Extractable P (kg ha^{-1}) in 0-90 cm soil			
ORG	19	18	21	20
RED	28	28	30	29
HIGH	27	22	29	26
Mean	25	23	27	
LSD $_{(0.05)}$	Input x diversity = ns; Input= 6* ; Diversity = 3			

, * and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$ and not significant, respectively.

Table 10. Distribution of extractable P in soil profile in relation to input levels, averaged across three crop diversities and six crop phases, in fall 2006 at Scott, Saskatchewan.

	Extractable P (kg ha^{-1}) in soil layers (cm)				
Input level	0-15	15-30	30-60	60-90	0-90
ORG	9	7	2.2	1	20
RED	16	9	2.6	1	29
HIGH	13	9	2.2	1	26
LSD $_{(0.05)}$	3**	ns	ns	ns	6*

*,** and ns refer to significant treatment effects in ANOVA at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively.

Soil Aggregation

On average across 3 crop diversities, the proportion of fine aggregates (< 1.3 mm, erodible soil fraction) in 0-5 cm soil was lower and that of large aggregates (> 12.7 mm) was greater at RED input than other two inputs (Table 11). The proportion (averaged across 3 input levels) of fine aggregates in soil was lower and that of large aggregates was greater with DAG diversity than other two crop diversities. Mean weight diameter (MWD) of soil aggregates was largest at RED among 3 input levels, and also with DAG among 3 diversities. Input level x crop diversity interaction was significant for the proportion of fine and large aggregates, and for MWD. Proportion of fine aggregates in soil was greatest with LOW diversity and HIGH input level, and lowest with DAG diversity and RED input level, while the opposite was generally true for large aggregates. This indicated that LOW diversity and HIGH input had greater proportion of wind-erodible aggregates (Siddoway, 1963; Skidmore et al., 1986) than DAG diversity and RED input. Thus, suggesting that soil under LOW diversity and HIGH input has greater potential for erosion than that under DAG diversity and RED input. Similarly, the beneficial effect of crop diversification and reduced tillage/input was also reflected in MWD of aggregates, as MWD was largest with DAG diversity and RED input level, and smallest with LOW diversity and HIGH input level. As the quality of seedbed is closely related to aggregate size distribution (Braunack and Dexter, 1989), our data suggests better structural condition of soil when crop diversification is increased under reduced tillage/input compared to the corresponding treatments.

Soil Organic C and N

In the 0-15 cm soil, there was no significant effect of input level and crop diversity on mass of TOC and TON (Table 12). Both input level and crop diversity had significant effect on mass of LFOM, LFOC and LFON in soil. Mass of LFOM, LFOC and LFON soil was greater at RED input than that observed at ORG and HIGH inputs, and also greater under DAG and DAP diversity than LOW diversity. Input level x crop diversity interaction effect was significant for mass of LFOM, LFOC and LFON for the 7.5-15 cm soil depth. This is because that mass of LFOM, LFOC and LFON increased at ORG and RED inputs when crop diversity was changed from LOW to DAG or DAP, but at HIGH input there was little or no effect of crop diversity observed on these parameters. The results suggest that light fraction of organic matter, C and N in soil can be improved by proper input of fertilizer nutrients and by increasing cropping frequency and/or diversity. Similarly, earlier research in Alberta and Saskatchewan has shown positive effect of tillage, crop residue and fertilization on LFOM, LFOC and LFON in soil (Nyborg et al., 1995, Malhi et al., 2006). Previous research has also observed LFOC to be more sensitive to conservation or management practices than TOC (Bowman et al., 1990; Carter et al., 1994; Bolinder et al., 1999; Oyedel et al., 1999).

Summary

The amount of nitrate-N in the 0-90 cm soil was greatest at ORG input under DAG diversity or at HIGH input under LOW diversity, with the lowest nitrate-N at all inputs under DAP diversity. In few instances, ORG input had greater nitrate-N than RED or HIGH input, most likely due to lack of P in soil for crop growth. The nitrate-N in various soil depths suggested some downward movement of nitrate-N when LOW or DAG cropping diversity was compared to DAP diversity at HIGH input. Nitrate-N in soil in different cropping diversities varied with crop species and input level. In LOW cropping diversity, nitrate-N in soil was greatest after GM/F1 at ORG input, GM/F2 at RED input and GM/F1 at HIGH input, and was lowest after wheat2 or wheat3 at ORG input, after canola at RED input, and wheat3 at HIGH input level. In DAG cropping diversity, nitrate-N in soil was greatest after GM/F1 at ORG input, and after wheat at RED and HIGH inputs, and was lowest after barley at ORG input, after spring rye at RED input, and after canola at HIGH input. In DAP cropping diversity, nitrate-N in soil was greatest after hay2 and was usually lowest after alfalfa at all input levels.

Extractable P in soil was higher (but small increase) under HIGH or RED inputs than ORG input in the 0-15 cm (also 15-30 cm) layer. There was no effect of cropping diversity on extractable P in soil. Low inherent P levels in soil were considered responsible for lack of differences between the diversities. Extractable P in soil was low in the surface and extremely low in the subsoil layers, indicating that at this site there may have little potential for bringing P from sub-soil to the surface by using taproot crops. This also suggests that if surface and sub-soil are low in available P or other nutrients, it may not be possible to sustain high crop yields under organic farming systems without using external nutrient sources. Proportion of fine aggregates (< 1.3 mm – erodible soil fraction) in 0-5 cm soil was greater with LOW diversity and HIGH input, and lowest with DAG diversity and RED input. The opposite was generally true for large aggregates (> 12.7 mm). Mass of LFOM, LFOC and LFON in 0-15 cm soil was greater at RED input than ORG and HIGH inputs and also greater under DAG and DAP diversity than LOW diversity. In conclusion, the findings suggest that soil quality can be improved and nutrient accumulation in the soil profile can be minimized by using reducing or elimination of tillage and proper fertilizer input under diversified cropping systems.

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Table 11. The effect of input level, crop diversity and input level x crop diversity on dry soil aggregate distribution percentage for each size and mean weight diameter (MWD) in autumn 2006 at Scott, Saskatchewan.

Treatments			Percentage for each soil aggregate size (mm)						
Input level	Crop diversity	MWD (mm)	A < 0.42	B 0.42 to 0.83	C 0.83 to 2.0	D 2.0 to 6.4	E 6.4 to 12.7	F 12.7 to 38.0	G > 38.0
Input level x crop diversity interaction									
ORG	LOW	16.78	20.21	7.14	4.36	16.65	10.12	25.74	15.77
	DAG	13.72	26.86	8.94	5.02	17.06	9.09	20.33	12.69
	DAP	14.46	23.63	7.83	4.63	17.76	10.80	22.73	12.62
RED	LOW	18.39	19.45	5.99	3.57	13.64	9.47	31.40	16.48
	DAG	19.31	19.09	5.89	3.46	13.96	8.85	29.58	19.17
	DAP	14.55	24.61	8.58	4.58	15.63	9.44	25.10	12.07
HIGH	LOW	10.67	34.03	8.74	4.31	15.64	9.42	21.27	6.58
	DAG	16.00	21.15	6.25	3.81	16.11	10.80	29.33	12.55
	DAP	15.21	23.38	8.86	4.10	16.29	10.38	26.56	12.43
LSD$_{0.05}$		4.28*	7.39**	2.11*	0.90	ns	1.11*	5.17**	7.06

Input level means								
ORG	14.98	23.57	7.97	4.67	17.16	10.01	22.94	13.69
RED	17.42	21.05	6.82	3.87	14.41	9.25	28.69	15.91
HIGH	13.96	26.19	7.28	4.07	16.01	10.20	25.72	10.52
LSD$_{0.05}$	3.36	4.99	ns	0.84	2.34	ns	3.22*	5.93
Crop diversity means								
LOW	15.28	24.57	7.29	4.08	15.31	9.67	26.14	12.95
DAG	16.34	22.37	7.03	4.10	15.71	9.58	26.42	14.80
DAP	14.74	23.87	7.76	4.44	16.56	10.21	24.80	12.37
LSD$_{0.05}$	ns	ns	ns	ns	ns	ns	ns	ns

, *, **, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 12. Effect of input level and crop diversity on the mass of total organic C (TOC), N (TON), and light fraction organic matter (LFOM), C (LFOC and N(LFON) in 0-15 cm soil in autumn 2006 at Scott, Saskatchewan.

Treatments		Mass of TOC (Mg C ha^{-1})			Mass of TON (Mg N ha^{-1})			Mass of LFOM (Mg ha^{-1})			Mass of LFOC (Mg C ha^{-1})			Mass of LFON (Mg N ha^{-1})		
Input level	Crop diversity	0-7.5	7.5-15	0-15	0-7.5	7.5-15	0-15	0-7.5	7.5-15	0-15	0-7.5	7.5-15	0-15	0-7.5	7.5-15	0-15
Input level x crop diversity interaction																
ORG	LOW	21.17	21.24	42.40	2.003	2.141	4.143	9.59	5.021	14.61	1.988	1.061	3.049	0.131	0.064	0.195
	DAG	19.93	22.50	42.42	1.976	2.307	4.284	8.68	5.268	13.95	1.837	1.128	2.965	0.122	0.067	0.189
	DAP	21.08	20.99	42.07	2.075	2.045	4.120	8.11	6.448	14.56	1.763	1.494	3.257	0.116	0.091	0.207
RED	LOW	22.94	19.33	42.26	2.099	1.853	3.952	13.25	3.526	16.77	2.898	0.679	3.577	0.196	0.041	0.236
	DAG	23.93	20.53	44.46	2.274	2.102	4.376	13.17	4.709	17.88	2.725	1.009	3.733	0.187	0.062	0.249
	DAP	22.65	20.52	43.17	2.204	1.941	4.145	13.59	8.207	21.79	3.180	1.834	5.015	0.219	0.119	0.338
HIGH	LOW	20.87	22.20	43.07	2.004	2.127	4.131	8.73	4.335	13.07	1.718	0.869	2.587	0.116	0.054	0.170
	DAG	21.16	21.70	42.86	2.024	2.055	4.079	12.36	4.820	17.18	2.685	0.975	3.660	0.178	0.061	0.239
	DAP	19.73	21.32	41.04	2.022	2.088	4.111	12.36	4.496	16.86	2.509	0.878	3.387	0.178	0.054	0.232
LSD$_{0.05}$		ns	ns	ns	ns	ns	ns	ns	1.70**	ns	ns	0.418**	ns	ns	0.023**	ns
Input level means																
ORG		20.73	21.57	42.30	2.018	2.164	4.182	8.79	5.579	14.37	1.863	1.228	3.090	0.123	0.074	0.197
RED		23.17	20.13	43.30	2.193	1.965	4.157	13.33	5.481	18.81	2.934	1.174	4.108	0.200	0.074	0.274
HIGH		20.58	21.74	42.32	2.017	2.090	4.107	11.15	4.550	15.70	2.304	0.907	3.211	0.158	0.056	0.214
	LSD$_{0.05}$	ns	ns	ns	ns	ns	ns	1.37***	ns	2.67*	0.218***	ns	0.521**	0.015***	ns	0.029**
Crop diversity means																
	LOW	21.66	20.92	42.58	2.035	2.040	4.075	10.52	4.294	14.82	2.201	0.870	3.071	0.148	0.053	0.200
	DAG	21.67	21.57	43.25	2.091	2.155	4.246	11.40	4.932	16.34	2.415	1.037	3.453	0.163	0.063	0.226
	DAP	21.15	20.94	42.09	2.100	2.025	4.125	11.35	6.384	17.74	2.484	1.402	3.886	0.171	0.088	0.259
	LSD$_{0.05}$	ns	ns	ns	ns	ns	ns	ns	0.979***	2.53	ns	0.241***	0.624*	ns	0.013***	0.039*

, *, **, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

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