

# CHANGES IN SOIL BIOLOGICAL AND PHYSICAL PROPERTIES UNDER REDUCED TILLAGE SYSTEMS

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## ABSTRACT

Interest in reduced tillage systems has increased in recent years, though important questions remain as to the impacts of such systems on soil quality and nutrient cycling. We examined the effects of tillage on soil biochemical (N and C mineralization, microbial biomass, and light fraction of organic matter) and physical (aggregate stability and size distribution) attributes at seven long-term sites in Saskatchewan, representing a range of soil types and crop rotations. Reduction in tillage increased mineralizable N at most sites, though the effect of tillage was usually not as strong as that of crop rotation (continuous cropping vs. wheat-fallow). Other indicators (microbial biomass N, light fraction N) also provided evidence of improved N fertility under reduced tillage. These findings are in apparent conflict with recent reports that adoption of reduced tillage can reduce N uptake and protein content of wheat. This anomaly remains to be resolved. Wet aggregate stability was improved by reduction in tillage and by elimination of summer fallow on a sandy loam and a silt loam, but treatment effects were small or absent in the heavy textured soils. Aggregate stability increased between spring and fall and decreased during winter. On a sandy loam, where wind erosion was a perennial threat, cropping intensity did not affect the wind-erodible fraction (aggregates < 0.84 mm) but reducing tillage did decrease erodibility of the fallow phase. Data collected between 1982 and 1994 showed that wind erodibility varied considerably from year to year, but there was no discernible relationship with weather or residue amounts from the previous crop.

## INTRODUCTION

There has been a significant shift in Saskatchewan from conventional tillage to reduced- and zero-tillage, but we still do not fully understand the impacts of this shift on soil and environmental quality. The existence of seven long-term field experiments in Saskatchewan (Table 1) provided a unique opportunity to evaluate the effects of conservation tillage on soil quality. In this paper, data collected in an ongoing study

at these sites will be used to illustrate some effects of tillage on biological and physical indicators of soil quality.

## MATERIALS AND METHODS

### Field Sites

A brief summary of the long-term tillage experiments is given in Table 1. Details of experimental design, management and agronomic performance have been published elsewhere (Brandt, 1992; Lafond et al., 1992; McConkey et al., 1996).

Table 1. Summary of long-term tillage experiments in Saskatchewan.

| Site           | Established | Soil type  | Tillage treatments          | Rotations                                |
|----------------|-------------|------------|-----------------------------|--|
| Swift Current  | 1981        | Silt loam  | Zero, minimum, conventional | Cont. wheat<br>Wheat-fallow              |
| Stewart Valley | 1982        | Heavy clay | Zero, minimum, conventional | Cont. wheat<br>Wheat-fallow              |
| Cantuar        | 1982        | Sandy loam | Zero, conventional          | Cont. wheat<br>Wheat-fallow              |
| Indian Head    | 1986        | Heavy clay | Zero, minimum, conventional | F-W-W-WW<br>W-W-Flax-WW<br>Pea-W-Flax-WW |
| Melfort        | 1969        | Silty clay | Zero, reduced, conventional | Wheat-fallow                             |
| Saskatoon      | 1982        | Clay       | Zero, conventional          | Wheat-fallow                             |
| Scott          | 1978        | Loam       | Zero, conventional          | F-oilseed-W<br>W-oilseed-W               |

W = spring wheat; WW = winter wheat; F = fallow.

### **Biochemical methods**

In 1994-1995, soil samples were taken from the 0-7.5 and 7.5-15 cm depths of the sites listed in Table 1 to determine biological attributes. The aerobic incubation procedure of Campbell et al. (1993) was used to measure N mineralization. Soil samples were wetted to field capacity and incubated at 35°C for 16 weeks, with periodic leaching of mineral N. Potentially mineralizable N ( $N_p$ ) and the rate constant,  $k$ , were estimated by nonlinear regression of the incubation data using the Marquardt iteration method. Carbon mineralization (soil respiration) was determined by measuring  $CO_2$  evolution from soil incubated at field capacity for 14 days at 21°C. Microbial biomass N was measured by incubating with chloroform for 10 days, followed by extraction and determination of ninhydrin N (Amato and Ladd, 1988). The light fraction of soil organic matter was separated using a concentrated sodium iodide solution (specific gravity 1.7), as described by Janzen et al. (1992). After separation, the light fraction was dried (110°C), weighed, and analyzed for C and N.

### **Soil Aggregation**

Soil samples from the top 5 cm were air dried and sieved using a rotary sieve to determine aggregate size distribution (Chepil, 1962). The proportion of erodible material (aggregates  $\leq 0.84$  mm) was estimated. Wet aggregate stability was measured using air dry aggregates (1-2 mm) by wet sieving (Kemper and Rosenau, 1986). Aggregates were wet sieved (sieve hole size was 0.26 mm) in distilled water for 3 min using an apparatus with a stroke length of 1.3 cm and a stroke frequency of 35 cycles per min. Material passing through the sieve (unstable aggregates) was dried (110°C) and weighed. Coarse sand ( $> 0.26$  mm) was separated from the material remaining on the sieve by ultrasonic vibration. Stable aggregates from which the coarse sand had been removed were collected and dried. Water stability of aggregates was calculated by expressing the mass of stable aggregates as a percentage of the total (stable plus unstable) aggregates.

## **RESULTS AND DISCUSSION**

### **Biological Properties**

Management effects on biological properties were generally significant ( $P < 0.05$ ) only in the 0-7.5 cm depth; thus, the following discussion will be restricted to top 7.5 cm. The potential of soil to mineralize N can be measured in terms of parameters such as cumulative N mineralized during an incubation period or the initial potential rate of mineralization ( $N_p k$ ). Our data consistently showed that N supplying power of the soil decreased as fallow frequency increased (Fig. 1). Cumulative N mineralization and  $N_p k$  increased as tillage intensity at Swift Current, Stewart Valley, Cantuar (Fig. 1), and Melfort but there was no effect at Saskatoon.

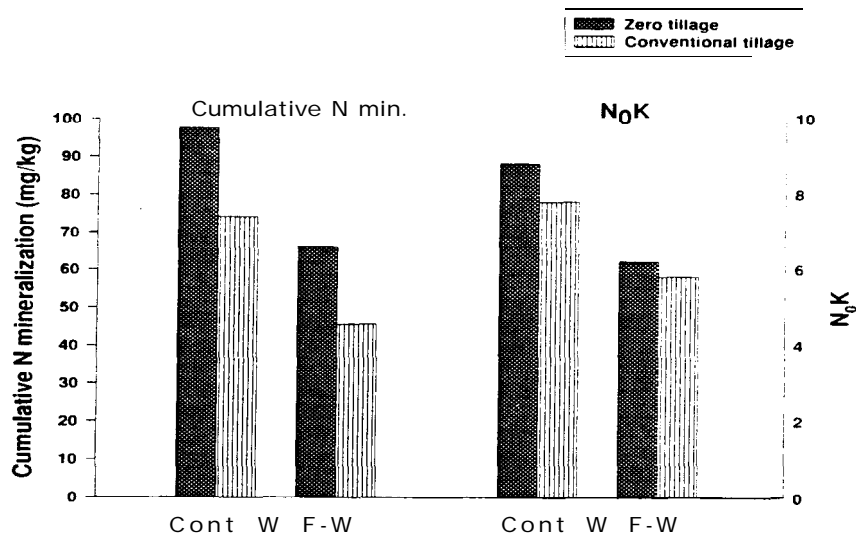


Fig. 1. Effect of rotation and tillage on cumulative amounts of N mineralized during 16 weeks and on N<sub>0</sub>k in sandy loam at Cantuar [values are averaged over the two phases of the fallow-wheat (F-W) rotation].

Carbon mineralization, a measure of organic matter decomposition by soil microorganisms, showed trends similar to N mineralization. Data for Indian Head (Fig. 2) demonstrate that summer fallowing as little as one year in four can cause a significant reduction in C mineralization. This is a reflection of decreased inputs of crop residues. Reducing tillage intensity tended to increase C mineralization (Fig. 2).

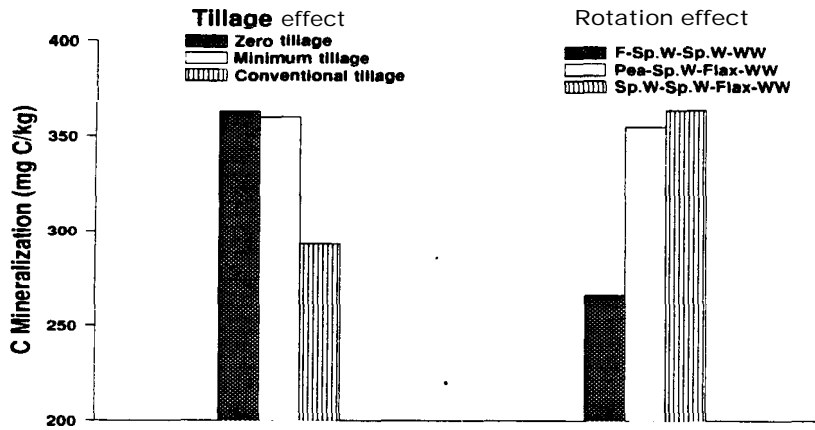


Fig. 2. Effect of rotation (values averaged over tillage treatments) and tillage (values averaged over rotations) on C mineralization in the O-7.5 cm depth at Indian Head.

Data for Swift Current, Stewart Valley (Fig. 3) and Cantuar showed that microbial biomass in the 0-7.5 cm depth was significantly greater under continuous cropping than in the wheat-fallow rotation. As observed with other biological attributes, the effect of tillage on microbial biomass was not as strong as that of crop rotation, but there was a tendency for biomass N to increase when tillage intensity was decreased.

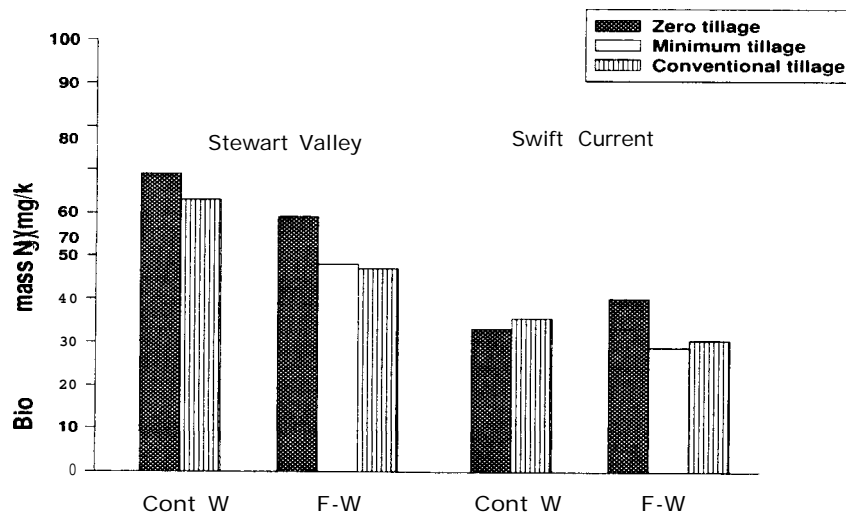


Fig. 3. Effect of rotation and tillage on microbial biomass N in 0-7.5 cm depth at Swift Current and Stewart Valley (values are averaged over the two phases of the fallow-wheat (F-W) rotation).

The light fraction of organic matter is considered an important repository for stored C in soil (Gregorich and Janzen, 1996). As shown by Indian Head data (Fig. 4), light fraction C increased when tillage intensity was reduced and summer fallow eliminated. Consistent with the findings of Janzen et al. (1992), there was a strong correlation ( $r = 0.91^{***}$ ;  $n = 9$ ) between light fraction C and C mineralization. This indicates that the light fraction is an important substrate for soil microorganisms. Carbon mineralized in 14 days, as a percentage of light fraction C, ranged from 1521%. While it would be incorrect to assume that the light fraction was the sole source of the C mineralized during incubation, the results nevertheless imply that the light fraction has a fast turnover in soil. Carbon stored in the light fraction under reduced tillage could be rapidly lost if the soil is returned to a conventional tillage regime. Data for light fraction N mirrored those described for C.

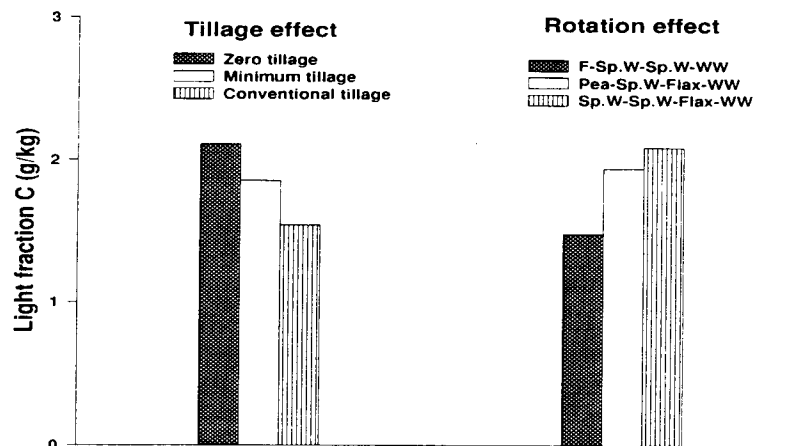


Fig. 4. Effect of rotation (values averaged over tillage treatments) and tillage (values averaged over rotations) on light fraction C in the 0-7.5 cm depth at Indian Head.

Taken together, the biological indicators used in this study suggest that the N supplying power of soil is generally enhanced by reduction or elimination of tillage. However, this improvement in N fertility often does not translate into improved agronomic performance. Lower N uptake and grain protein have been observed in wheat under reduced tillage compared with conventionally-grown wheat (McConkey et al., 1996). The explanation for this anomaly is not clear, but it may be related to factors such as differences in rooting patterns (Unger and McCalla, 1980) or loss of available N from zero till soil by denitrification (McConkey et al., 1996). This is a subject that warrants further investigation.

### Soil Aggregation

Water-stable aggregates that do not disperse are crucial for high water infiltration, good soil structure, and crop growth. Large stable aggregates at the soil surface are important in controlling erosion by wind.

In the silt loam at Swift Current (Fig. 5) and the sandy loam at Cantuar, water stability of soil aggregates was higher under continuous cropping than under wheat-fallow and under zero tillage vs. conventional tillage. At both sites, aggregate stability was related to biochemical properties such as mineralizable N and microbial biomass. Management effects on aggregate stability in the heavy textured soils were small or absent. This suggests that clay soils with strong shrink-swell properties may be more difficult to stabilize than light textured soils.

Monitoring carried out at Swift Current, Stewart Valley, and Cantuar revealed large temporal changes in aggregate stability. Values increased between spring and fall, 1994 but, by spring 1995, values were similar to those obtained in the previous spring.

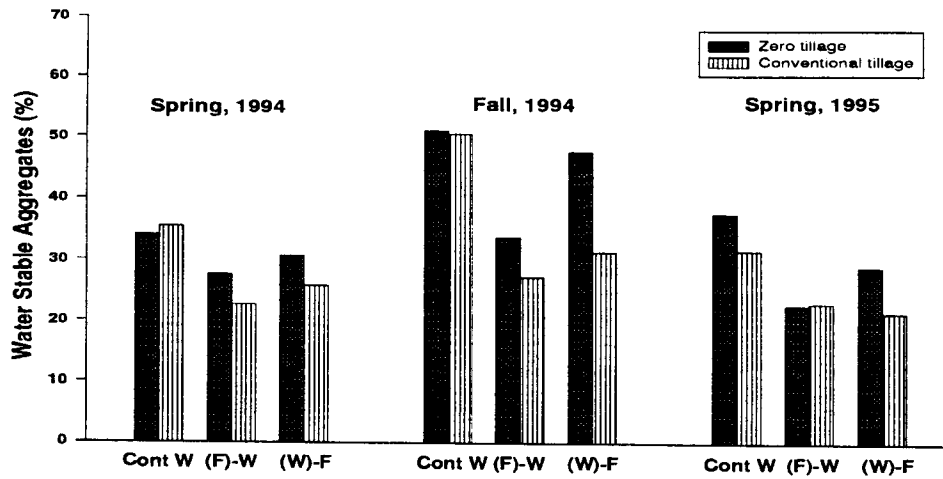


Fig. 5. Effect of rotation and tillage on wet aggregate stability at Swift Current between spring 1994 and spring 1995. Results refer to phase in parentheses.

On the sandy loam at Cantuar, where wind erosion is a perennial problem, cropping frequency did not influence soil erodibility but reducing tillage brought about a small, but important, decrease in erodibility in the fallow phase (Fig. 6). Historical data (1982-1994) showed considerable annual variability in wind erodibility, but there was no discernible relationship between inherent soil erodibility and either weather conditions or residue amounts left from the previous crop.

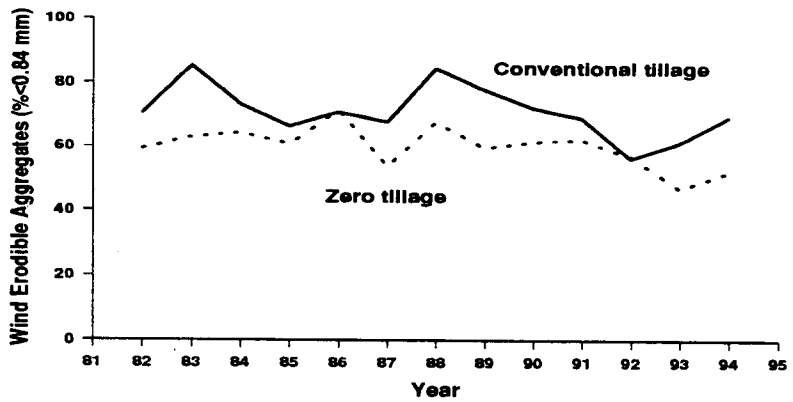


Fig. 6. Proportion of wind-erodible aggregates in fallow phase of fallow-wheat rotation as influenced by tillage at Cantuar from 1982 to 1994.

## CONCLUSIONS

Reduction in tillage generally improved indicators of soil fertility such as mineralizable C and N, microbial biomass and light fraction of soil organic matter. Evidence that reduction in tillage enhances soil N fertility appears to be inconsistent with recent findings in Saskatchewan that adoption of zero tillage can reduce N uptake and protein content of wheat. This apparent anomaly needs to be resolved. Water stability of aggregates in light and medium textured soil can be improved by reduction of tillage, but heavy textured soils may be more difficult to stabilize. Aggregate stability is a sensitive indicator of soil quality. It should be included in the suite of indices used to characterize the effects of management on soil quality. Further work is needed to understand the causes of temporal variation in aggregate stability and wind erodibility.

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