

STRAW REMOVAL AND FERTILIZATION ON GRAIN YIELDS AND SOIL ORGANIC MATTER IN A FALLOW-WHEAT-WHEAT ROTATION

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ABSTRACT

There is considerable interest being shown in the harvest and use of straw for industrial purposes in Manitoba and Alberta. In 1987 we measured soil C and N in a 30-year crop rotation experiment at Indian Head. Results at that time suggested that harvesting straw two in three years from a properly fertilized fallow-wheat-wheat system did not deleteriously influence soil organic matter. Our calculations in 1987 were based on a "volume basis". Recently, some scientists have suggested that such calculations can sometimes lead to inaccurate interpretations. They suggested that calculations based on an equivalent mass basis would be more accurate. Consequently, we resampled this experiment in 1996 and made calculations using both volume and mass basis. We concluded that the latter may indeed provide more meaningful results. In contrast to the results with the volume analysis the equivalent mass analysis suggested that the harvesting of straw has resulted in a strong tendency for soil C and N to decrease over the years. This implies that the practice of harvesting and using straw for industrial purposes will have negative consequences for soil conservation in the long run. To date, soil degradation due to straw removal has not been reflected in grain yields. This study also showed that soil organic N was increased by fertilizer, and organic C tended to be increased. There was a close association between organic C and N and estimated crop residue (straw and roots) input into soil when the calculations were made on mass basis, but not when calculated on a volume basis. Grain yields of the unfertilized system is gradually decreasing, reflecting the gradual soil quality degradation of this system.

INTRODUCTION

Soil organic C storage in soils is a function of a balance between C inputs via primary production and C losses via decomposition. If crop residues are to be removed and used for industrial purposes, such as making paper or particle board, as is currently proposed and/or being done in Manitoba and Alberta, or used for cattle feed, will this negatively influence soil organic matter and soil productivity?

The influence of fertilizers on grain yields and crop residue production is invariably positive and concomitantly increases in soil organic matter generally accompany such treatments, particularly if annual cropping is practiced (Campbell et al. 191b; Barber 1979; Gregorich and Drury 1996). An exception to this is when soil organic C is already high, in which case fertilization may not increase it further (Campbell et al. 1996; Nyborg et al. 1995).

Straw removal does not appear to have any negative influence on grain yields (Campbell et al. 1991a; Barber 1979; Karle et al. 1994; Janssen and Whitney 1995). However, its influence on soil organic matter is less certain. For example, Barber (1979) measured the influence of straw removal vs incorporation for 10 years with continuous corn on a silt loam in Indiana and observed 10% greater soil C favoring the system in which residues were incorporated. In a similar study in Wisconsin, Karle et al. (1994) also found that, under no-tillage, 10 years of straw removal from a continuous corn system resulted in lower soil organic C and N than when straw was retained. Further, doubling crop residues increased organic C and N more than the normal straw treatment. In contrast to these findings, we found no significant effect of straw removal from a fallow-wheat-wheat system on a heavy textured thin Black Chernozem after 30 years (measured in 1987) at Indian Head, Saskatchewan (Campbell et al. 1991a). In an 11-year study with continuous barley, conducted on a Gray Luvisolic soil and a Black Chernozemic soil in North Central Alberta, Nyborg et al. (1995) found no significant ($P < 0.05$) effect of straw removal on soil C (measured on a volume basis) in the Gray Luvisol though fertilizer N increased it. In contrast, on the Black Chernozem, with twice as much organic C, straw removal decreased soil C in the 0-15 cm depth, but the latter was unaffected by fertilizer. These workers showed a direct relationship between soil C increase over the 11 years versus C returned as crop residues ($r^2 = 0.76$). In a 12-year study conducted on a silt loam in East Central Kansas, Janssen and Whitney (1995) report that for soybean-wheat-grain sorghum rotation, residue removal or normal residue incorporated resulted in a decrease in organic matter when unfertilized. Doubling crop residue, especially when also fertilized, increased organic matter the most. (Values in the latter study were expressed as concentrations).

Some workers have recently suggested that our method of calculating soil C contents may not always be accurate and this could be contributing to the discrepancy in results (Ellert and Bettany 1995). For example, in the literature we commonly see organic matter results expressed as concentrations (g kg^{-1}) (bulk density unaccounted for), as amounts (Mg ha^{-1}) but calculated on a volume basis; but rarely are the values calculated on an equivalent mass basis (Mg ha^{-1}). The latter is argued to be the more accurate approach (Ellert and Bettany 1995).

Because we still had stored soil samples taken in 1987 at Indian Head from the three F-W-W systems in which we examined the effect of fertilizer and straw removal, we decided to resample these treatments in 1996 and to determine C storage based on calculations made on a volume basis as we did previously (Campbell et al. 1991a) and on an equivalent mass basis.

MATERIALS AND METHODS

The 39-year crop rotation experiment at Indian Head is situated on a fine-textured thin Black Chernozem. The experiment was managed with conventional tillage from 1958 to 1989, then changed to no-tillage in 1990. Since descriptions of the study and results accruing from it have been well documented (Campbell et al. 1996) we will not elaborate further on its management in this paper.

The three F-W-W rotations (unfertilized; fertilized with N + P, straw retained; fertilized with N + P, straw removed), were soil sampled after harvest in September 1996, 39 years after commencement of the experiment. They had been previously sampled by us in May 1987 (Campbell et al. 1991a,b) and soil samples had been stored air dry in plastic bottles. In 1996 we

sampled with a Giddings corer, the wheat on fallow phase in depth increments of 0-7.5, 7.5-15, 15-30, 30-45 and 45-60 cm in all 4 replicates taking two subsamples per plot. On each of these we determined bulk density (Tessier and Steppuhn 1990) and soil C and N. Because significant differences in soil C and N were only observed in the 0-7.5 cm depth the results were based primarily on this depth. Soil C and N were determined using Carlo Erba combustion equipment. The 1987 samples were reanalyzed at the same time as the 1996 samples. Carbon and N concentrations were converted to a volume basis by multiplying by bulk density and depth increment; calculations for equivalent mass basis was done as outlined by Ellert and Bettany (1995). All calculations were done for subsamples separately, but because subsample was not significant for any factor, we averaged over subsample before conducting analysis of variance. A split plot analysis with treatment as main plot and year as subplot was conducted on bulk density, C and N in the 0-7.5 cm depth. For equivalent mass we used the heaviest 0-7.5 cm depth increment as the standard (1027.8 Mg ha⁻¹) and used soil from 7.5-15 cm depth increment to make all others equal to this mass.

When sampled in 1987, the rotations had been managed in a conventional tillage manner. In 1990 they were changed to no-tillage management. Grain yields were measured each year, as described by Campbell et al. (1991b). We estimated crop residue (straw, roots) from grain yields, as described previously by Campbell et al. (1991a).

RESULTS AND DISCUSSION

Grain yields

Grain yields for wheat grown on fallow were unaffected by fertilizer or straw removal until about 1990 (when converted to no-tillage) (Fig. 1a); thereafter, the fertilized system has out-yielded unfertilized. This could be an indication of greater N losses (denitrification, leaching) under no-till without tilling facilitating mining of the soil to compensate for lack of N addition. For wheat grown on stubble, yield response to fertilizer was apparent from 1970 when fertilizer rates were increased (Campbell et al. 1991b). Yields of unfertilized stubble are gradually decreasing with time as the soil becomes more degraded, but yields of the fertilized systems have remained fairly constant or increased slightly (Fig. 1b). These results are similar to those reported by Gregorich and Drury (1996) in a 35-year study with continuous corn in Ontario. As found for wheat on fallow, straw removal has had no effect on yields of stubble wheat. d

Soil bulk density

Soil bulk density was not influenced by treatment (data not shown) but, because soils were sampled in a much drier state (after harvest compared to early spring) in 1996, the bulk densities were much higher in the latter case than in 1987 (Fig. 2).

Soil organic C and N

The treatment-by-year interaction was not significant, therefore we have shown these results averaged over year (Fig. 3). The results, when expressed on a volume basis [as we did previously (Campbell et al. 1991a)], show a significant ($P < 0.05$) increase in N (and almost in organic C) in

response to fertilizer; however, there is no effect of straw removal. Thus, on a volume basis, the results obtained in 1996 were as obtained in 1987 and were interpreted to mean that roots play a much more significant role in influencing soil organic matter than does above-ground residues (compare Figs. 3 and 4).

When the calculations were made on an equivalent mass basis (Fig. 3, right side), statistically ($P < 0.05$) the results did not tell a different story from the volume basis analysis, but there was a stronger tendency for straw removal to result in a negative influence on soil organic C and N. Further, now the organic matter response to the treatments did not mimic root residues as much as it did the total crop residues (compare Figs. 3 and 4). These results seem more plausible than those based on the volume calculations. It seems that if a treatment causes the production of more crop residues (e.g., fertilizer) and it tends to increase soil organic matter then the converse should hold true (removal of straw should result in lowering organic matter).

CONCLUSIONS

These results, although they do not imply that all results obtained that were not based on an equivalent mass calculation are inaccurate or invalid, do suggest that where treatments or time of sampling has greatly influenced bulk density, a recalculation of results on an equal mass basis may be warranted. This could result in marked changes in our interpretations.

Although these results show no significant effect of straw removal on soil organic C and N, the strong negative trend suggests that our earlier conclusions, suggesting that straw can be harvested in the Black soil zone without seriously impairing the soil, was premature. Instead, we now suggest that caution should be exhibited if straw is to be harvested on a regular basis.

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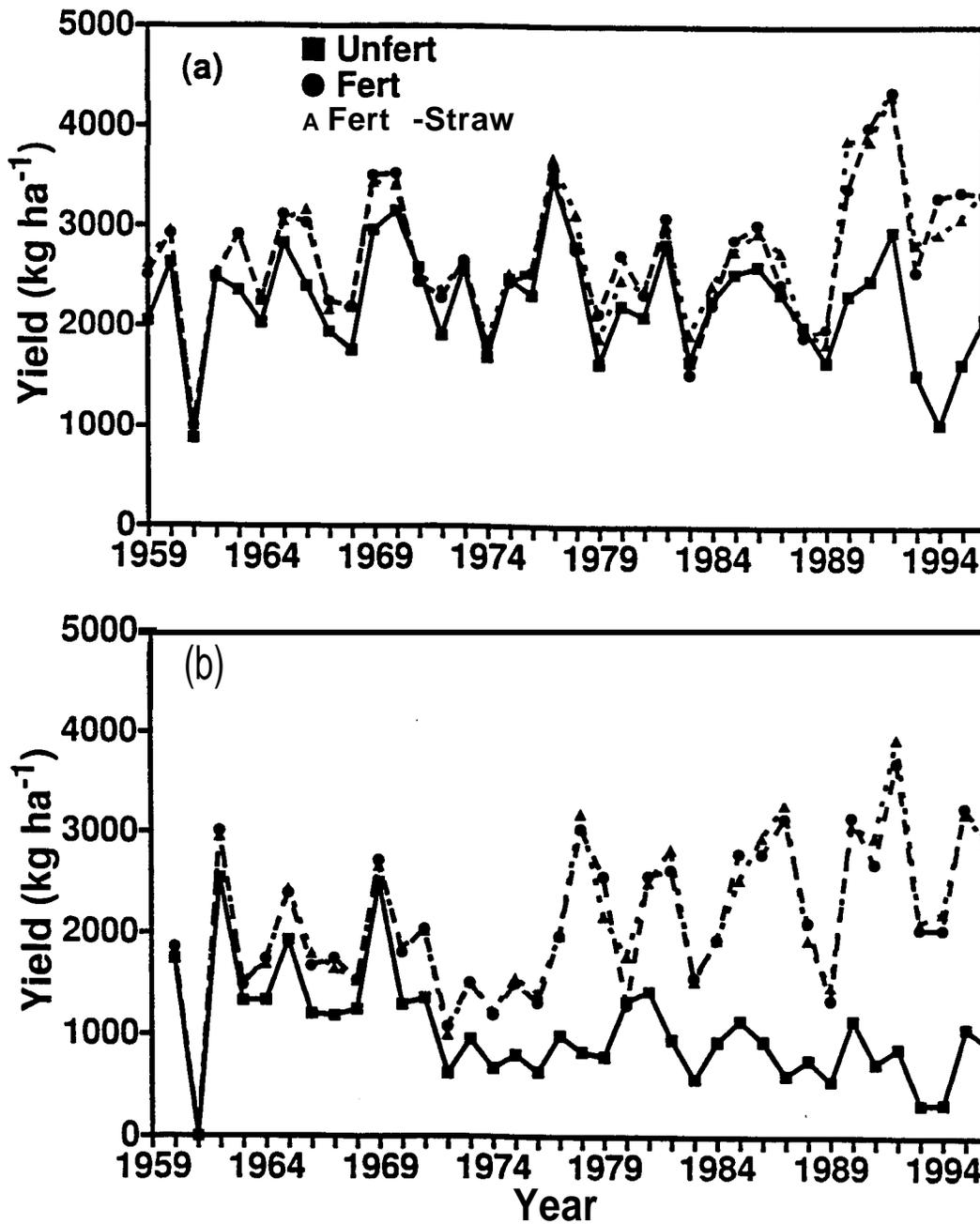
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Fig. 1 Influence of fertilization and straw removed on grain yields of wheat (a) grown on fallow, (b) grown on stubble, in a fallow-wheat-wheat rotation at Indian Head over 39 years



**Fig. 2 Bulk densities of 0-7.5 cm depth
(averaged over treatment which was not significant)**

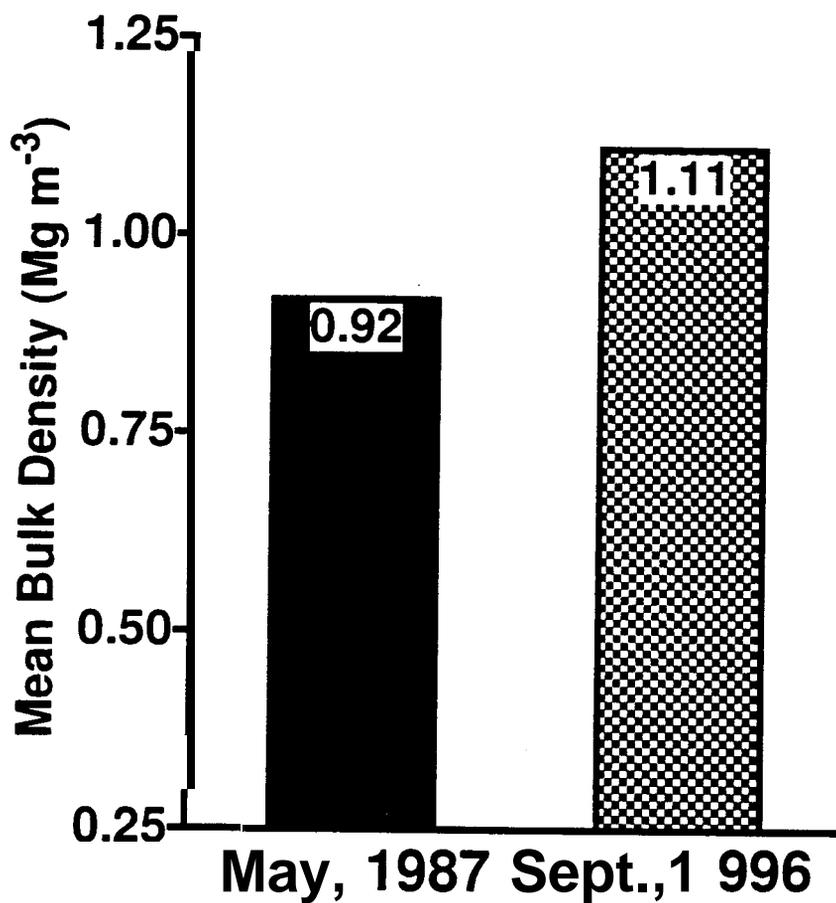


Fig. 3 Effect of fertilizer and straw removal on soil organic C and N in 0-7.5 cm depth of F-W-W, measured in May 1987 (after 30 years) and Sept 1996 (after 39 years) (values averaged over time)

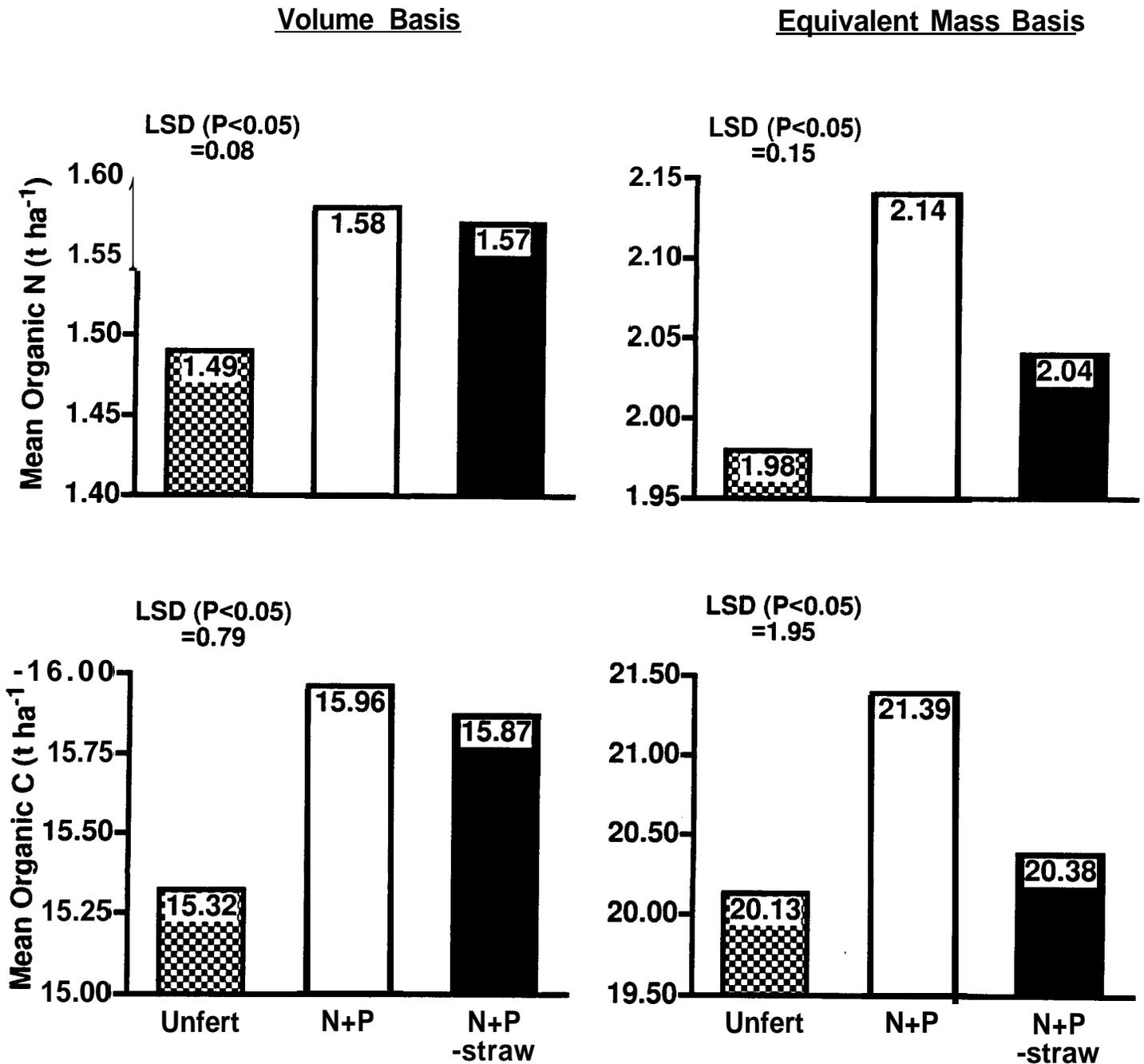


Fig. 4 Crop residue input in F-W-W rotations-effect of fertilizer and straw removal (1959-1996)

