EFFECT OF FERTILIZER, LEGUMES AND CROPPING FREQUENCY ON SOIL ORGANIC MATTER IN A LONG-TERM ROTATION - CHANGES AFTER 6 YEARS OF ZERO TILLAGE

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ABSTRACT

Society is interested in methods of increasing C storage in soil, so as to reduce CO, concentration in the atmosphere, which may contribute to Global warming. Scientists have demonstrated that the adoption of better management practices, such as proper use of fertilizers, including legumes in rotations, cropping more frequently or employing less summerfallow, may increase C storage in soils. However, the question has been raised regarding the accuracy of the amounts of C believed to be gained, because most of the past calculations were made on a volume basis rather than the more accurate equivalent mass basis. A long-term crop rotation study being conducted on a thin Black Chemozemic fine-textured soil at Indian Head was sampled in May 1987 and in September 1996 and total organic C and N determined using Carlo Erba combustion technique. The experiment was managed with conventional tillage from 1958 to 1989 and changed to no-tillage in 1990. We calculated C and N in the O-7.5 and 7.5- 15 cm depth using the volumetric and equivalent mass approaches, but our conclusions are based on the O-7.5 cm depth which was the only one showing significant effects. Both methods of calculation confirmed the efficacy of adopting BMP's for increasing C storage in soil, and showed that the latter was directly associated with the amount of crop residues returned to the soil. However, the results also showed that where bulk density is substantially different between sampling times, the volume basis of analysis can lead to erroneous conclusions. The equivalent mass analysis showed that in this experiment, 6 years of no-tillage has not increased soil organic matter; instead, systems that are not being fertilized are continuing to lose organic matter, while those being fertilized, or which have high fertility due to inclusion of legumes, are maintaining the organic matter at a constant level. We suggest that scientists who have appropriate data should consider reanalyzing them using both techniques to determine if their previous conclusions are still valid.

INTRODUCTION

It has been well established that improved plant nutrition, through proper fertilization or the inclusion of legumes in rotations, will increase soil organic matter (Campbell et al. 1996a; Janzen et al. 1997). Further, it is well known that increasing the frequency of cropping (reducing the fallow frequency) will also lead to an increase in soil organic matter (Janzen et al. 1996; Campbell et al. 1996a). There is much evidence that reducing the amount of tillage may also result in an increase in soil organic matter (Janzen et al. 1997; Campbell et al. 1995, 1996c). Most of the evidence upon

which these conclusions are based were obtained by making comparisons, either on a concentration basis (bulk density not used in calculation), or on a volume basis (bulk density used in calculation). However, recently it has been suggested by some researchers that a more accurate interpretation of such data would be derived from an analysis using the "equivalent mass" concept (Ellert and Bettany 1995). The resolution of this question is important in light of society's current interest in finding mechanisms by which we may increase C storage in soils and reduce CO, in the atmosphere, thereby mitigating against the greenhouse effect and Global warming.

In 1987 we sampled a 30-year crop rotation experiment in a thin Black Chemozem at Indian Head (Campbell et al. 1996a). The study had been conducted with conventional tillage management. In 1990 the experiment was changed to no-tillage. In 1996 we resampled this study to determine: (a) if the change to no-tillage had resulted in significant changes in soil organic matter, and (b) whether the method of calculating the organic matter (volume vs equivalent mass basis) would influence our interpretation of the results.

MATERIALS AND METHODS

The 39-year ongoing crop rotation experiment at Indian Head is situated on a fine-textured thin Black Chemozem on the Agriculture Canada Experimental Farm. The description and results from this study have been well documented (Campbell et al. 1996a), consequently, we will only present information pertinent to a discussion of this paper.

Of the 9 cropping systems we discuss 8 in this paper. They are the fallow-wheat (F-W), F-W-W, and continuous wheat (Cont W) systems, unfertilized and fertilized with N and P; and also the unfertilized legume green manure-wheat-wheat (GM-W-W), and F-W-W-H (brome-alfalfa hay)-H-H systems. We had sampled these systems in May 1987 (Campbell et al. 1991b) and stored air-dry soil in plastic bottles. In September 1996 we again soil sampled these treatments taking soil cores (3.80 cm diam.) with a coring truck from the 0-7.5,7.5-15, 15-30, 30-45 and 45-60 cm depths. Two subsamples were taken from all 4 replicates of the wheat on fallow or GM phase and Cont W, and the samples processed and analyzed separately. On each sample we determined bulk density (Tessier and Steppuhn 1990) and total and organic C and total N using a Carlo Erba combustion analyzer. We reanalyzed the 1987 soil samples (O-7.5 and 7.5-15 cm depth) at the same time. Organic C and total N concentrations were converted to a volume basis (multiply by bulk density and depth) and to an equivalent mass basis as outlined by Ellert and Bettany (1995).

Analysis of variance was done on data for each year separately. Because subsample was not significant for any factor, we averaged over subsample (1996 only) and analyzed the combined data over years as a split plot with treatment as main plot and year as subplot for data of the O-7.5 cm depth (the only depth showing significant treatment effects). For equivalent mass analysis we used the heaviest O-7.5 cm depth increment as the standard (1027.8 Mg ha-') and used soil from the 7.5-15 cm depth increment to make all others equal to this mass. We used grain yields to estimate straw and root residues returned to the land (Campbell et al. 1991a).

RESULTS AND DISCUSSION

Effect of fertilizer and cropping freauencv

The interaction between treatment and year was not significant for any factor, consequently the results are, in most instances, presented as averages over years. When calculated on a volume basis, organic C (total N also) in the O-7.5 cm depth increased with cropping frequency and was increased by N and P fertilizer in the F-W-W and Cont W, but not in F-W rotation (Fig. 1). Although there appeared to be an increase in C (and N) between 1987 and 1996, analysis of covariance with bulk density (Fig. 2) showed that the higher bulk density in 1996 was responsible for this observation, not the conversion to no-tillage. The higher bulk density in 1996 compared to 1987 was related to the much drier conditions that existed when sampled (after harvest) in 1996 compared to spring 1987 and the swelling nature of this clay soil.

When the analyses were made on an equivalent mass basis (Fig. 3), although there was a tendency for cropping frequency to increase organic C (and N, not shown) between F-W and F-W-W, this difference was not significant ($P < 0.05$); only Cont W was greater than the fallow systems and only when fertilized with N and P. In contrast to the results calculated on a volume basis, fertilizer only increased organic C (and N, not shown) for Cont W, though there was a tendency to increase them in the F-W-W system. Further, on an equivalent mass basis the effect of year was opposite to results obtained on a volume basis with indications of a decrease in organic matter over the 1 O-year period 1987 to 1996 (Fig. 3). Although the treatment-by-year interaction was not significant for this equivalent mass analysis, we have shown the results in this manner (Fig. 4) because it appears that there is a tendency for the unfertilized treatments to show a decrease while C in the fertilized treatments have remained constant. The response in organic matter to cropping frequency and fertilizer was partly a function of input crop residues (compare Figs. 1, 3 and 5) as observed by others (Campbell et al. 1996a; Nyborg et al. 1995).

Effect of legumes

Although the treatment-by-year interaction was not significant, we show the results in this manner (Fig. 6) to support the observation we earlier made regarding the apparent effect of fertility on maintenance or continual degradation of soil organic matter based on equivalent mass calculations. Thus, the GM-W-W system which, though fixing N, is in a degrading mode (Campbell et al. 1996a) is still tending to lose organic matter (despite the conversion to no-tillage). On the other hand, the 6-year rotation that includes 3 years of brome-alfalfa hay and which, with Cont W (N + P) has the most fertile soil among these systems (Campbell et al. 1996a), is maintaining organic matter.

Generally the trend in results are similar whether calculated on a volume or equivalent mass basis. They show that the inclusion of legume green manure has tended to increase soil organic matter compared to unfertilized F-W-W, while the 6-year hay system has increased organic C and N significantly ($P < 0.05$) compared to the other two treatments. Although not shown, Campbell et al. (1996a) have demonstrated that these responses are associated with the amount of N content of the crop residues returned to the land.

Although these results, calculated on an equivalent mass basis (regarded as more accurate than the more commonly used volume basis) showed no effect of 6 years of no tillage on C storage in this clay soil, this does not necessarily invalidate the numerous other previous evidence showing positive effects of reduced tillage on C storage. For example, in cases where tillage had no effect or very limited effect on bulk density (Campbell et al. 1995, 1996b, c), it is likely that calculations on a volume or mass basis would give fairly similar results. Quite likely the absolute amounts of gains would differ based on the calculation used. Perhaps it would be of interest to revisit some of these studies and compare results using the two methods of calculations to determine how this affects our current beliefs regarding the impact of various cultural treatments on soil C storage.

CONCLUSIONS

The results showed that 6 years of no-tillage management has not resulted in an increase in organic C or N in this clay soil. Though the treatment-by-year interaction was not significant, when C and N were analyzed on an equivalent mass basis there was evidence of continued loss in soil organic matter where fertilizer is not being applied (including the GM-W-W) but, where N + P are being added, or where the presence of hay crops have maintained high fertility in the soil, organic C and N have generally remained constant during the last 10 years.

The study confirmed that best management practices, such as proper fertilization combined with frequent cropping and use of legumes in rotations will increase soil C and N storage, partly through the influence of treatments on crop residues (above ground and below ground) returned to the land.

Finally, our results show a need for researchers, where possible, to revisit the calculations of their data on C storage, comparing results on volume basis to those on an equivalent mass basis. The relative treatment effects may not change but conclusions regarding storage over time may, especially if bulk density varied markedly with time.

ACKNOWLEDGEMENTS

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Fig. 1 Effect of cropping frequency and fertilizer on soil organic C in O-7.5 cm depth at Indian Head (Sampled in May 1987 and Sept 1996)

(Note: Plots were managed on conventional tillage 1958 to 1989 and no-tillage since 1990)

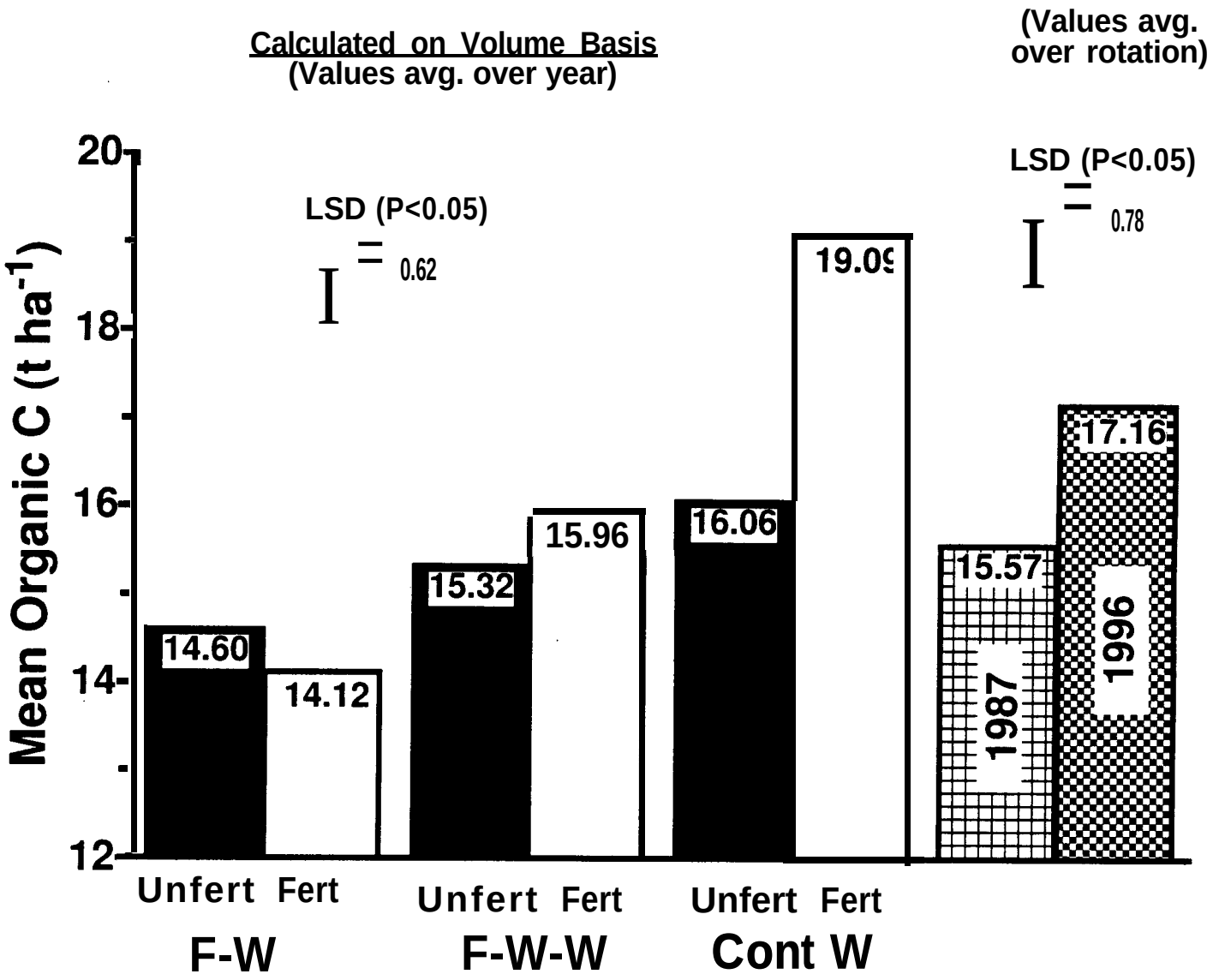

Fig. 2 Bulk densities of O-7.5 cm depth (averaged over treatment which was not significant)

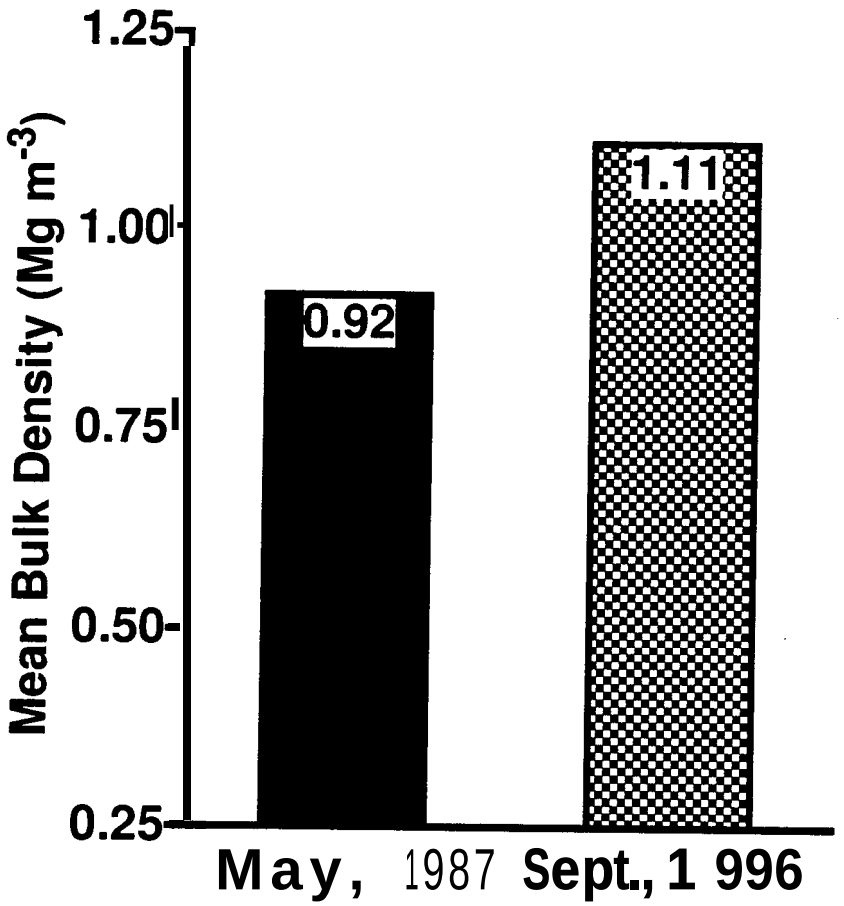

Fig. 3 Effect of cropping frequency and fertilizer on soil organic C in O-7.5 cm depth at Indian Head (Sampled in May 1987 and Sept 1996)

(Note: Plots were managed on conventional tillage 1958 to 1989 and no-tillage since 1990)

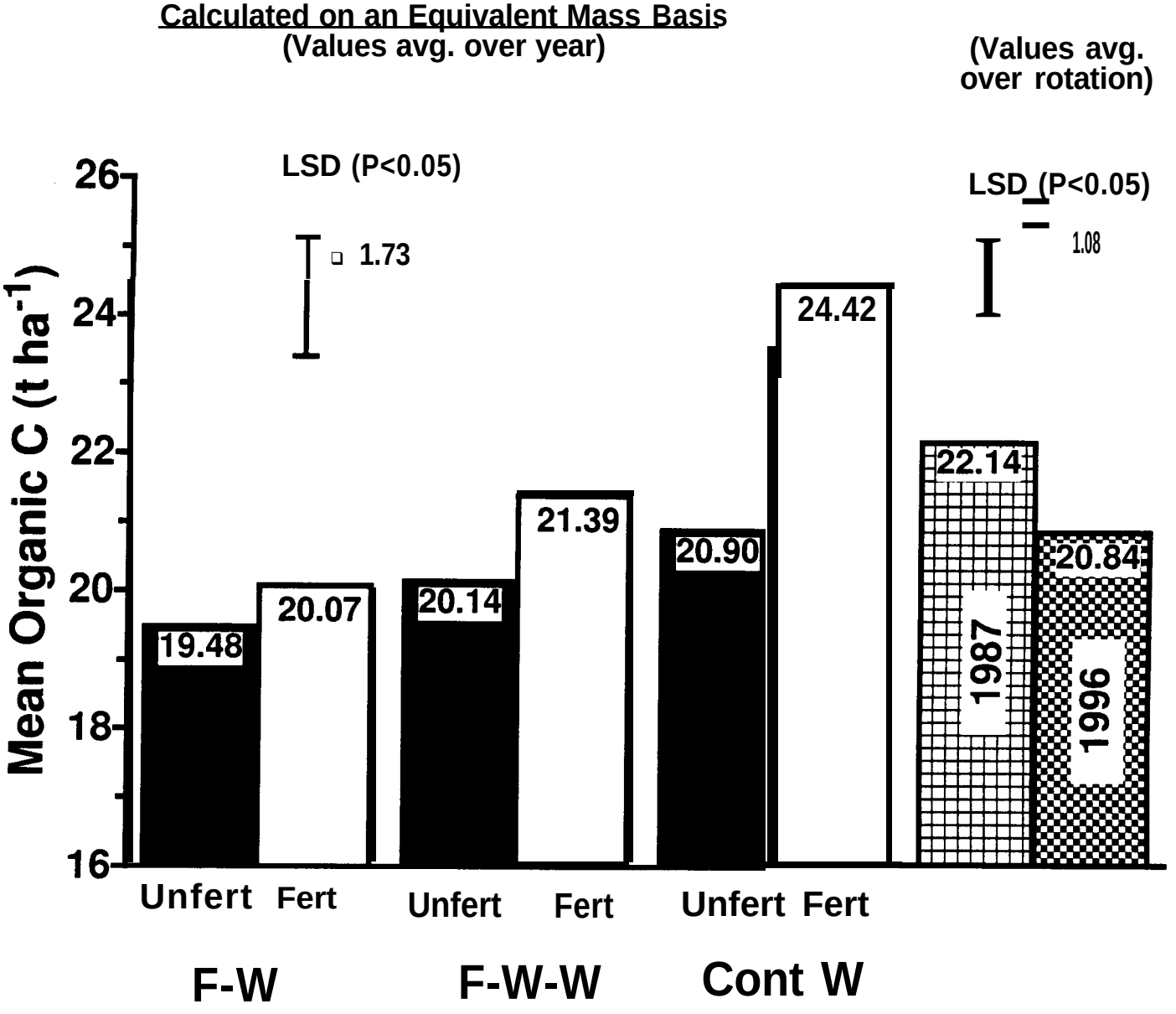

Fig. 4 Effect of cropping frequency and fertilizer on soil organic carbon in O-7.5 cm after 30 and 39 yr at Indian Head, assessed on an equivalent mass basis (all 1028.7 Mg ha")

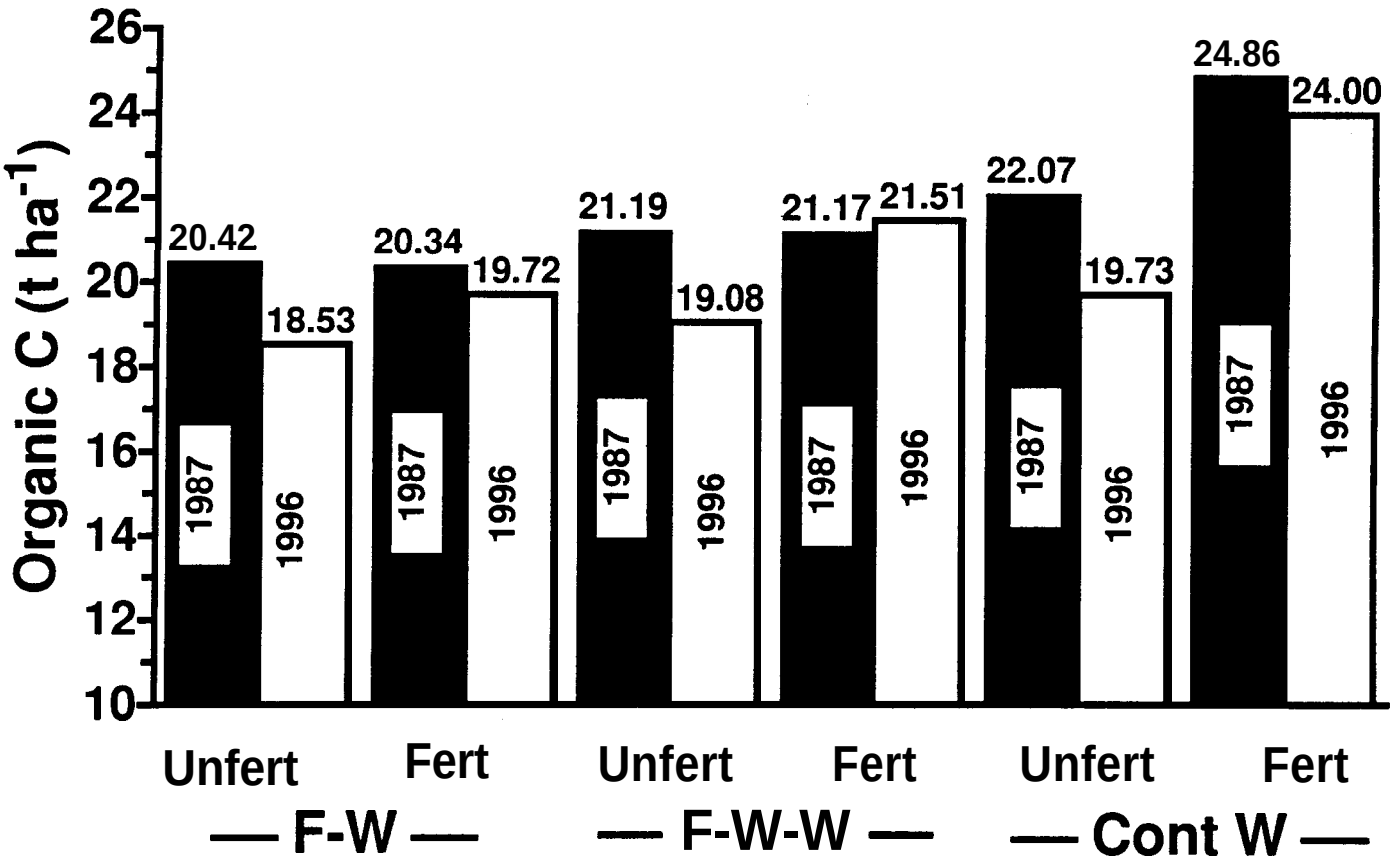

Fig. 5 Estimated total residue input (19594996) straw + roots Effect of cropping frequency and fertilizer

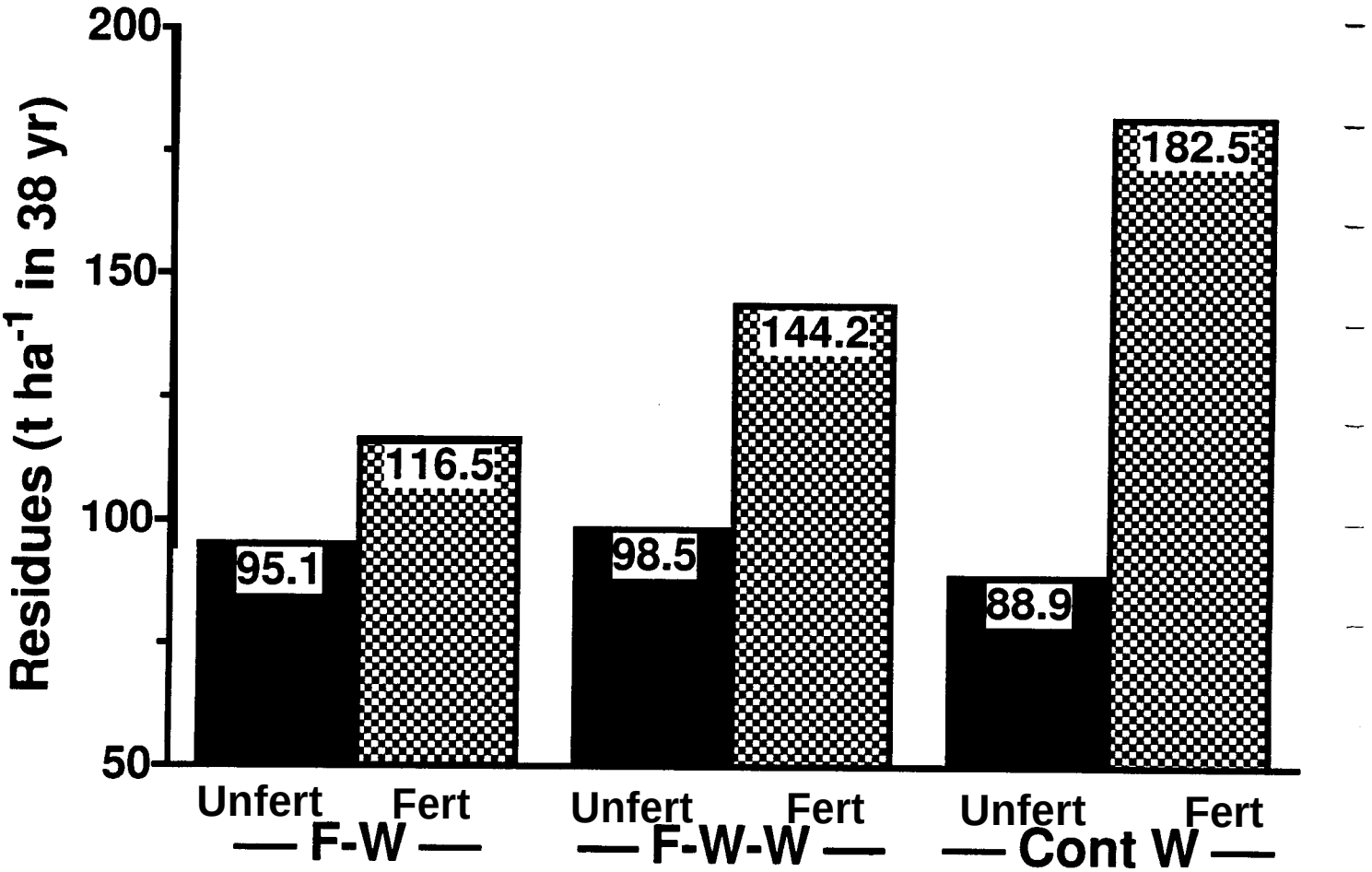

Fig. 6 Effect of legume green manure (GM) and hay crops (H) on soil organic C in O-7.5 cm depth after 30 and 39 yr at Indian Head (Conventional tillage 1958-l 989, no-tillage since 1990)