SEASONAL CHANGES IN SOIL BIOCHEMICAL CHARACTERISTICS AS INFLUENCED BY CROP ROTATIONS AND FERTILIZERS

C.A. Campbell', Guang Wen', V.O. Biederbeck', G.P. Lafond, R.P. Zentner and J. Schoenau

Agriculture & Agri-Food Canada. Semiarid Prairie Agricultural Research Centre. Swift Current, SK. S9H 3X2, Agriculture & Agri-Food Canada. Research Farm. Indian Head. SK. SOG 2K0. and "Department of Soil Science. University of Saskatchewan. Saskatoon. SK. S7N 5A8

ABSTRACT

Preliminary results of an experiment to assess the influence of cropping frequency, fertilization, and rotation phase, on trends in selected soil biochemical attributes during a 6 month period (May to October) in a Brown and a Black chemozem, showed that organic C and total N were very stable, while light fraction-C (LF-C) was less dynamic than we previously assumed. Nonetheless, the LF-C was a major source of the C that was mineralized. Microbial biomass was the most dynamic attribute assessed and was the only attribute influenced by soil moisture, to which it was surprisingly negatively related.

INTRODUCTION

The cycling of C and N in soil is controlled by organic substrates, microorganisms that mediate the latter's decomposition, weather conditions that regulate the rates, and is modified by the character of the soil and the method of crop management (e.g., use of fertilizers, tillage, crop type). Considerable information has been collected regarding static values of some of the soil biochemical attributes that are important in the control of nutrient tie-up and release from soils, but much less information on the dynamics of these characteristics throughout the year is available in Canada (McGill et al. 1986). Such information will improve our understanding of how such characteristics respond to short-term and long-term stimuli and how they are inter-related. This would thus enhance our ability to quantify their behaviour in soils, thereby improving our ability to assess their impact on the fertility and productivity of soils.

Our objective was to monitor changes in selected soil biochemical characteristics throughout the growing season in several cropping systems in two long-term crop rotation experiments, one in a Brown and the other in a Black chemozem, and to explain the reason for observed changes.

MATERIALS AND METHODS

Starting in early May 1995, and continuing until late October, we sampled the 0- to 7.5-cm depth of one replicate of each of 3 rotation/phase treatments in the old rotation experiment (initiated in 1967) at Swift Current, and 11 rotation/phase treatments in the long-term rotation experiment (initiated in 1957) at Indian Head (Campbell et al. 1996). A bulb sampler (6 cm diam.) was used to take 8-10 random cores per plot each time. These samples were cornposited to provide one sample per treatment, They were quickly transferred to a cold room for storage at about 1-3°C until processed. Processing involved sieving through < 2 mm mesh screen, discarding residues on screen, mixing soil, and dividing the soil into two. One-half was kept field-moist in the cold room and the other half was air-dried and stored in the cold room. Soil moisture content was determined on the field-moist samples.

The air-dry samples were used to determine organic C and total N using the Carlo Erba equipment. This soil was also used for determination of potentially mineralizable N (not discussed here), and light fraction organic matter. The field-moist soil was used to determine C mineralization and microbial biomass. All methods used are described elsewhere (Biederbeck et al. 1994). In each case, samples taken at different times were stored and all like analyses done at the same time to reduce incidence of systematic analytical errors.

Means and standard deviations (over time of sampling) were calculated for each soil characteristic. As well, correlation and, where significant ($P < 0.05$), regression analysis, were performed to determine the inter-relation of the various characteristics measured for each soil and between soils of each site.

RESULTS AND DISCUSSION

To assist us in interpreting these complex results we formulated some hypotheses:

Hypotheses

Crop management effects: Soil biochemical attributes will increase with cropping frequency, fertilization, and be unaffected by phase of the rotation (Campbell et al. 1996).

Organic C and total N trends: For any treatment, organic C and N will behave similarly over the growing season. They will tend to remain constant because C and N inputs and CO_2 losses are small compared to C and N content of the soil.

Light fraction-OM (LF-OM) trends: Light fraction organic matter is composed of material of intermediate resistance to decomposition from which most of the soluble sugars, celluloses and hemicelluloses have been decomposed and the remaining material, though not as resistant as humic materials, is much more resistant than fresh residues. The quantity in soil will decrease as conditions favour decomposition and will reflect historical management and agro-ecological conditions more so than recent management history (Janzen et al. 1995).

C mineralization trends: Although this characteristic will reflect recent residue inputs in situ, the preparation of soil for laboratory C-min analysis removes most of the residues by screening, therefore, C-min will primarily reflect the amount of LF-OM (Janzen et al. 1993) because this is the most labile substrate remaining in the soil.

Microbial biomass trends: Because most of the fresh residues are screened out in soil preparation, microbial biomass will be directly related to LF-OM (substrate) and to C-min (product of microbial decomposition).

Soil moisture effects: During the growing season, moisture should have no effect on organic C nor total N, and for reasons cited above, it should have no effect on LF-OM nor C-min. It may influence the very dynamic microbial population because soil drying induces spore formation while wetting will induce germination and propagation of microbes. However, Biederbeck and Campbell (1973) observed that there was a lag in the proliferation of organisms in response to wetting and drying of soil so that numbers increased during the drying phase subsequent to the wetting of the soil. Thus we may expect biomass to increase as soil dries (i.e., inversely related to soil moisture) (Campbell et al. 1973).

Observations

Crop management effects: At Swift Current, all soil biochemical attributes were, on average, greater in Cont W (N + P) than in the F-W (N + P) rotation and there was generally little difference between the fallow and wheat phases of F-W (Fig. 1).

At Indian Head, all soil biochemical attributes were, on average, greater for Cont W (N + P) than for Cont W (unfertilized), as well as for stubble wheat in the F-W-(W) (N + P) rotation, though this latter difference was much smaller than for the fertilizer effect (Fig. 2). The results at both sites, therefore support our earlier findings (Campbell et al. 1996) and our hypothesis.

Organic C and total N trends: At Swift Current, organic C (Fig. 3) and total N (not shown) trended up slightly from May to October in all 3 systems. This trend was not related to soil water (Table 1), nor to the previous year's crop residues (both phases of F-W behaved similarly), nor to sloughing of roots in cropped systems, nor to increase in C inputs due to post-harvest crop residues (fallow and cropped systems responded similarly). At Indian Head, the organic C (and N, not shown) may also be showing a slight upward trend in the two fertilized systems though not in the unfertilized Cont W (Fig. 4). There were at least two occasions when there was evidence of spatial variability: (a) on June 29 at Swift Current (Cont W, N + P) and (b) September 8 at Indian Head (Cont W, N + P) [total N behaved similar to organic C (not shown), therefore this was not an analytical error]. If we consider the size of the sampling and analytical variability relative to the small apparent trend in organic C, we can conclude that organic matter was essentially constant during the growing season. Thus, these data support our hypothesis. They also imply that we are reasonably safe in using one sampling time during a season to make comparative assessment of the long-term effects of various treatments on soil organic matter. For assessment of absolute changes however, we may need to exercise more caution in sampling.

Light fraction-C trends: At first glance there may appear to be a tendency for LF-C to increase after harvest in Cont W (N + P) at Swift Current and in the fallow phase of (F)-W (Fig. 3), but there was no similar trend in the cropped phase of F-(W) at Swift Current, nor in any of the three treatments at Indian Head (Fig. 4). Light fraction-C showed a weak negative relationship to 1995 growing season soil moisture in the fallow systems at Swift Current and Indian Head (Table 1). The latter is difficult to explain. At Indian Head there was a tendency for LF-C to increase until flag leaf stage in Cont W (N + P) (Fig. 4), but there were no similar trends in similar treatments at either site. We, therefore, conclude that the LF-C is a fairly stable soil biochemical attribute which will not reflect management or weather effects in a single season (Janzen et al. 1995). Since, as shown in Figs. 1 and 2, LF-C discriminated treatment effects, its seasonal stability implies that this is a useful index for identifying effects of cultural practices in long-term studies. The higher LF-C obtained in Cont W compared to F-W or F-W-W likely reflects not only greater inputs of residues, but shorter periods of ideal moisture conditions for decomposition in the Cont W system over the years.

Fig. 1 Effect of cropping frequency and rotation phase on selected soil biochemical attributes in the 0-7.5 cm depth at Swift Current. (Values averaged over 11 sampling times, 2 May to 17 Oct. 1995)

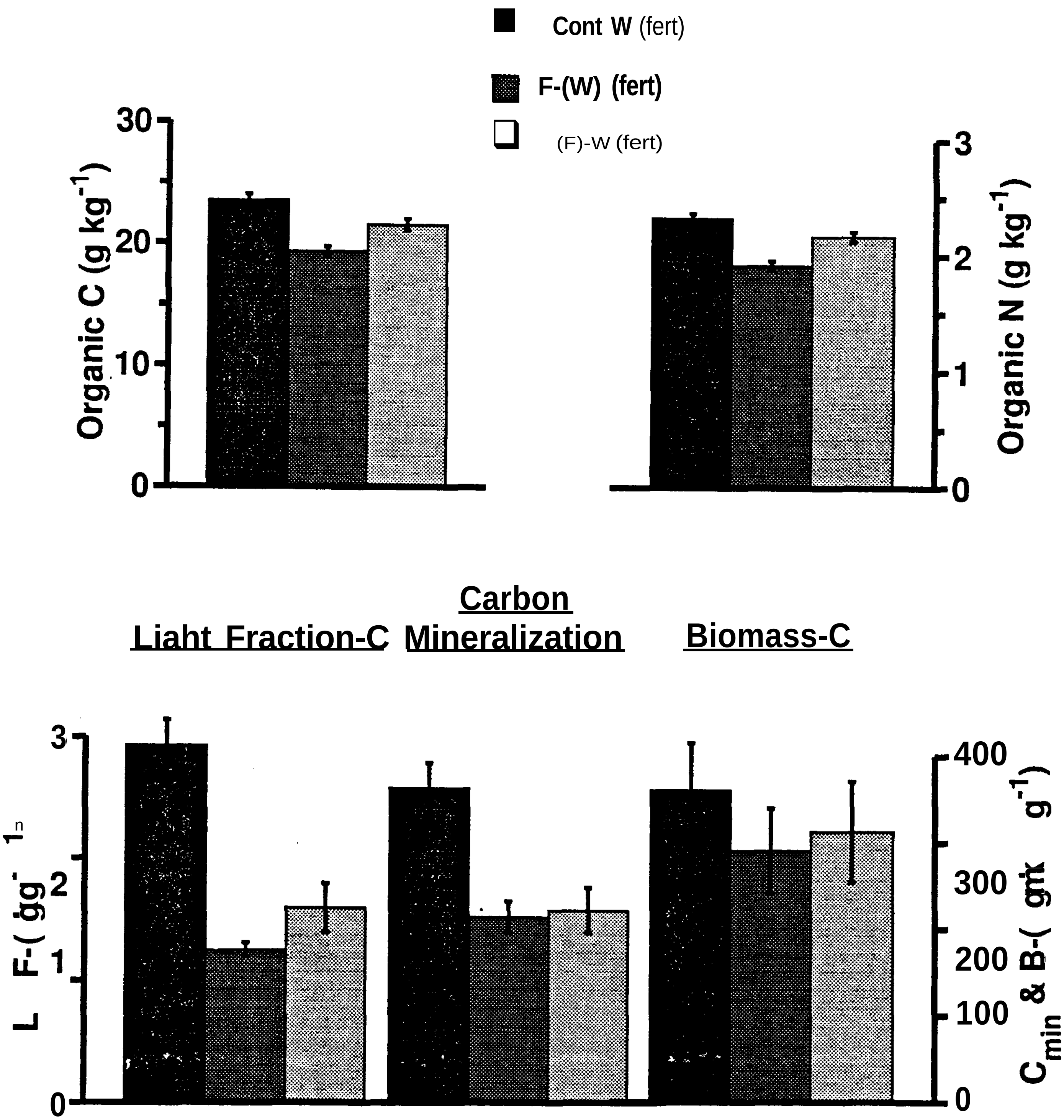

Fig. 2 Effect of cropping frequency and fertilization on selected soil biochemical attributes in the O-7.5 cm depth at Indian Head. (Values averaged over 10 sampling times, 18 May to 23 Oct.)

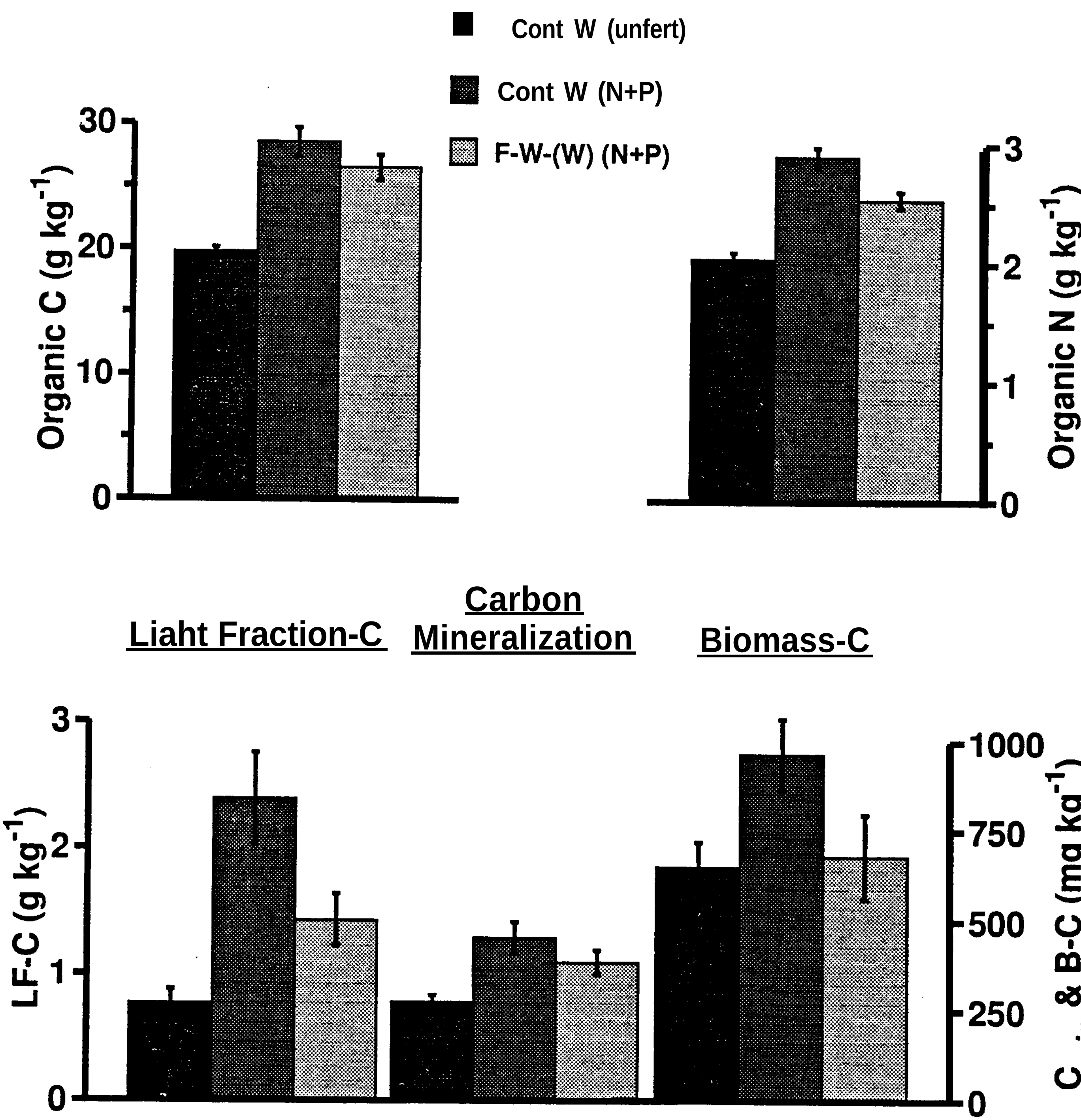

Fig.3 Changes in Soil Biochemical Characteristics (0-7.5cm) depth) ot Swift Current During 1995

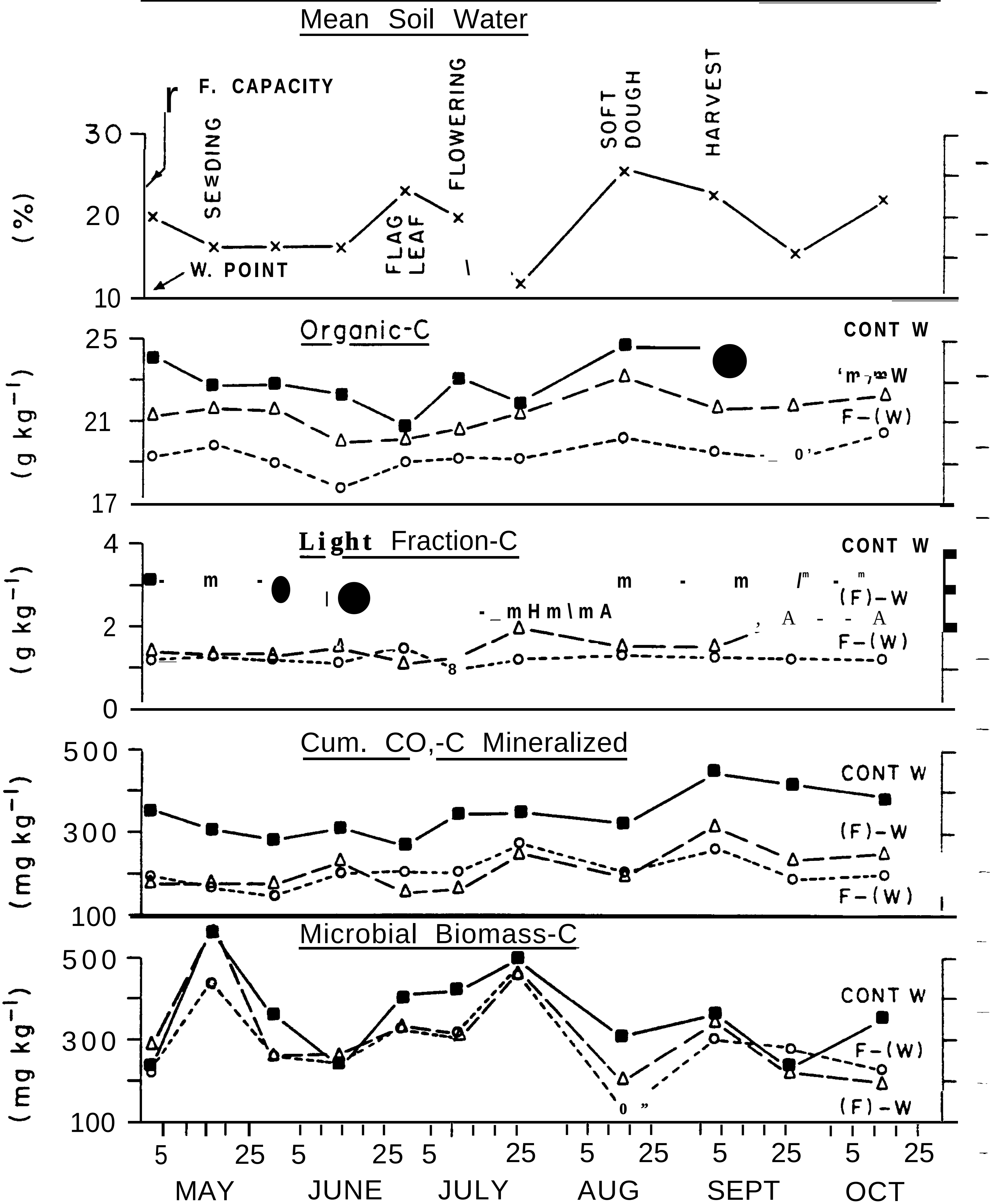

Fig. 4 Changes in Soil Biochemical Characteristics (0 – 7.5 cm depth) at Indion Head During 1995

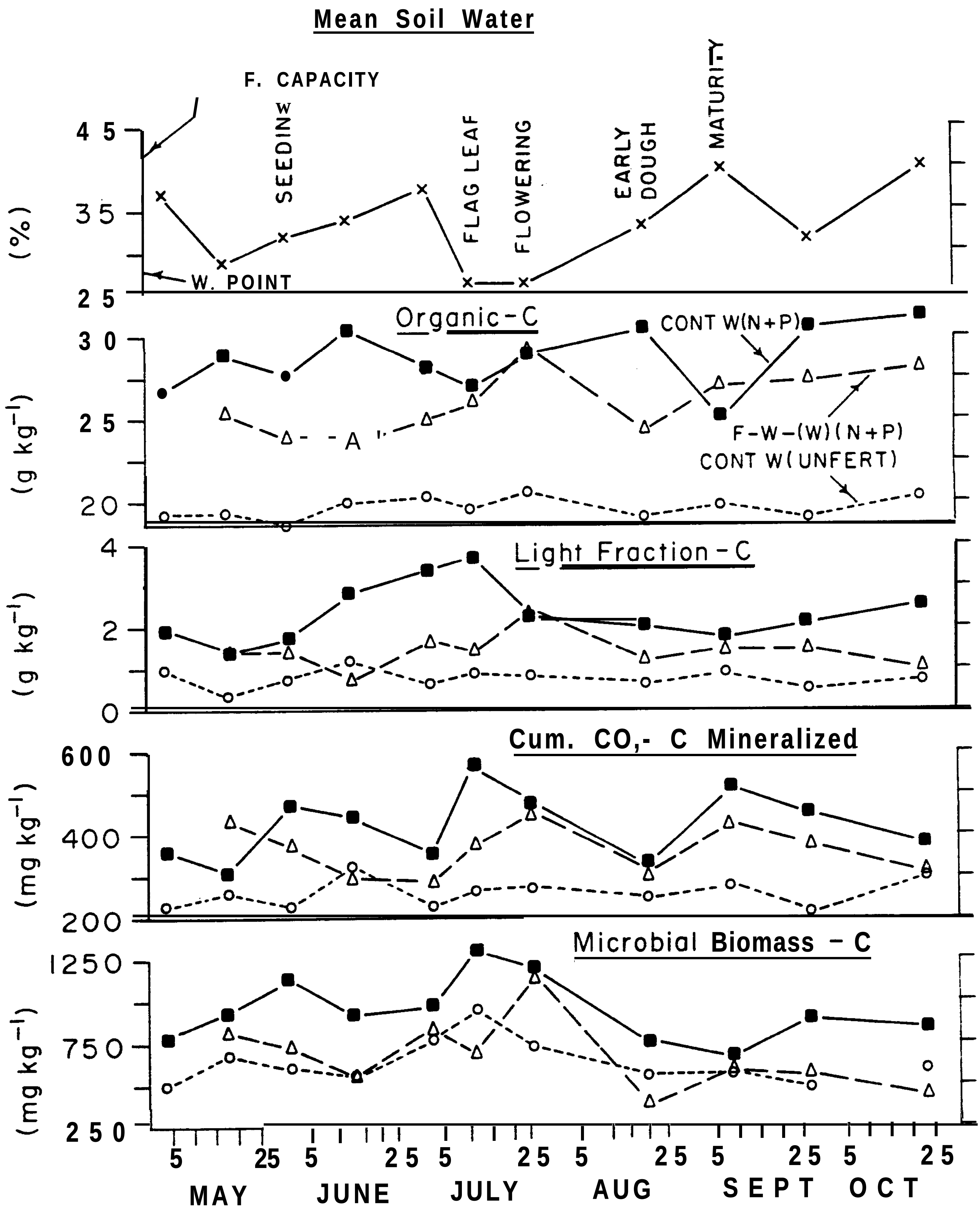

Table I. Correlations(r)* between soil attributes in rotations at Swift Current and Indian Head for soil samples taken (0-7.5 depth) bctwcc" May and October IYY5

	Soil attributes					
Soil attributes	Moisture	Org C	Org N	LF-C	CO,-C	Biomass-C
Swift Current				Cont W (N + P)		
Moisture	1.0	ns	0.53'	ns	ns	ns
Org C		1.0	0.50'	0.78"	0.65'	ns
Org N			1.0	ns	ns	ns
LF-C				1.0	0.54'	ns
co,-c					1.0	ns
				F-(W) (N + P)		
Moisture	1.0	0.54'	ns	ns	ns	-0.61'
Org c		1.0	ns	ns	ns	ns
Org N			1.0	ns	-0.5'	ns
LF-C				1.0	ns	ns
co,-c					1.0	ns
				(F)-W (N + P)		
Moisture	1.0	ns	ns	-0.49'	ns	ns
Org C		1.0	ns	0.46'	ns	ns
Org N			1.0	ns	ns	ns
LF-C				1.0	0.58'	ns
co,-c					1.0	"s
Indian Head				Cont W (N + P)		
Moisture	1.0	ns	ns	ns	ns	-0.70"
Org C		1.0	ns	ns	-0.50'	ns
Org N			1.0	ns	ns	0.49'
LF-C				1.0	ns	0.46'
co,-c					1.0	0.48'
				Cont W (unfert)		
Moisture	1.0	ns	ns	ns	ns	-0.50'
Org C		1.0	ns	0.49'	0.58'	ns
Org N			1.0	0.46'	0.58'	ns
LF-C				1.0	0.71'	ns
CO_2-C					1.0	ns
				F-W-(W) (N + P)		
Moisture	1.0	ns	ns	-0.47'	ns	-0.64'
Org C		1.0	0.75"	0.53'	ns	ns
Org N			1.0	0.82"	0.46'	0.68'
LF-C				1.0	0.64'	0.84"
co,-c					1.0	0.63'

* ns, ‡, †, *, **, denote not significant and significant at P < 0.20, P < 0.10, P < 0.05 and P < 0.01, respectively.

, F = fallow. W = spring wheat, Cant = continuous, N = nitrogen, P = phosphorus and ( ) denote rotation phase sampled.

C mineralization trends: At Swift Current (Fig. 3) and Indian Head (Fig. 4) there appeared (at first glance) to be an increase in C mineralized between dough and harvest stages, which could have been credited to senescing roots (Franzluebbers et al. 1995). However, note that the (F)-W responded in the same manner as the cropped systems, indicating that neither roots nor recent residues were responsible for this apparent increase in C-min. There was no relationship of C-min to soil moisture (Table 1). There may have been a relationship to temperature, but we have not examined this factor yet. It appears that a source of this C was the LF-C (Table 1) which corroborates the findings of Janzen et al. (1993) and Biederbeck et al. (1994). This also supports our hypothesis suggesting that by removing the fresh crop residues during soil preparation we have forced the soil microorganisms to use the most available source of C remaining in soil as substrate, i.e., the LF-C. In situ they would likely have used the fresh crop residues preferentially. In contrast to the other attributes discussed so far, the C-min appeared to show more dynamic responses, especially in systems that had built up more labile substrates (well-fertilized stubble wheat) and in the more humid environment (Indian Head).

Microbial biomass trends: Microbial biomass showed the greatest fluctuations throughout the growing season at both sites (Figs, 3 and 4). At Swift Current, it was apparent that the perturbations were not a function of the treatments since they all cycled together, was not related to the other biochemical attributes, but was inversely related to soil moisture in all cases (not shown), but only significant in one case (Table 1). At Indian Head, biomass-C was inversely related to soil moisture in all cases (Table 1) and in two treatments was positively related to both LF-C (substrate for organisms) and C-min (product of decomposition). The results obtained at Indian Head support our earlier stated hypothesis suggesting that the microbes used the LF-C. The inverse relationship to soil moisture at both sites suggest this was no coincidence. A close look at Figures 3 and 4 show that the inverse relationship primarily occurs after late June. We are unable to explain this other than our suggestion regarding a lag in growth of microbes in response to available water. Note also that at both sites 1995 was relatively wet and soil moisture was usually in the available range and frequently the soil was wet to saturation. The latter would tend to decrease fungal populations, then as the soil dried population would increase again, providing the soil did not completely dry out (Campbell et al. 1973).

CONCLUSIONS

Our results show that organic C and total N are independent of sampling time within a period of 1 year. Light fraction, though more dynamic than these two characteristics, is also less labile than is commonly believed. This is because much of the easily decomposable materials have been mineralized before the remaining material enters the LF. Because we have removed the most labile materials (fresh residues) in sample preparation the C-min in these systems mainly reflect the most labile substrate remaining (i.e., the LF). Microbial biomass showed the most dynamic behaviour of those constituents measured and was the only attribute that consistently responded to soil moisture, albeit in a surprising manner.

ACKNOWLEDGEMENTS

This project was funded in part by Canada/Saskatchewan Agriculture Green Plan Initiative.

REFERENCES

Biederbeck, V.O., Janzen, H.H., Campbell, C.A. and Zentner, R.P. 1994. Labile soil organic matter as influenced by cropping practices in an arid environment. Soil Biol. and Biochem. 26(2): 1647- 1656.

Campbell, C.A., Biederbeck, V.O., Warder, F.G. and Robertson, G.W. 1973. Effect of rainfall and subsequent drying on nitrogen and phosphorus changes in a dryland fallow loam. Soil Sci. Soc. Amer. Proc. 37: 909-915.

Campbell, C.A., Janzen, H.H. and Juma, N.G. 1996. Case studies of soil quality in the Canadian Prairies: Long-term field experiments. In E.G. Gregorich and M.R. Carter (eds.) Soil Quality for Crop Production. Elsevier Science Publishers, Amsterdam. (In press).

Franzluebbers, A.J., Hons, F.M. and Zuberer, D.A. 1995. Tillage and crop effects on seasonal soil carbon and nitrogen dynamics. Soil Sci. Soc. Amer. J. 59: 1618-1624.

Janzen, H.H., Campbell, C.A., Brandt, S.A., Lafond, G.P. and Townley-Smith, L. 1993. Light fraction organic matter in soils from long-term crop rotations. Soil Sci. Soc. Amer. J. 56: 1799- 1806.

Janzen, H.H., Olson, B.M. and Larney, F.J. 1995. Quality criteria for prairie soils in Alberta. CAESA Report - Project No. RES-005-93.

McGill, W.B., Cannon, K.R., Robertson, J.A. and Cook, F.O. 1986. Dynamics of soil microbial biomass and water-soluble organic C in Breton L after 50 years of cropping to two rotations. Can. J. Soil Sci. 66: 1-l 9.