The Use of Large Undisturbed Cores to Assess Soil Quality - Yield Relationships in the Greenhouse

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ABSTRACT

Large undisturbed cores were taken from different landscape positions (divergent shoulders, DSH, and convergent footslopes, CFS) at two sites in the Black soil zone. The soils are classified as belonging to the Oxbow association and have been cultivated for 15 and 82 years. The cores were used in a greenhouse experiment to study the effect of soil quality on yield of spring wheat (var. Katepwa) at three levels of simulated growing season precipitation: low (123 mm season^{-1}), mid (189 mm season^{-1}), and high (332 mm season^{-1}). Grain yields in the DSH cores increased with increasing precipitation for both the 15- and 82-year soils. Moreover, the 15-year DSH cores outyielded their 82-year counterparts by 50, 76, and 85% at the low, mid, and high water levels, respectively. Cores from the CFS positions were watered only at the mid-water level. Grain yields in the 15- and 82-year CFS cores and the 15-year DSH cores were not significantly different ($P \leq 0.05$). The results of this study indicate that soil quality is a relatively minor factor when water is limiting but assumes a much greater role in years of normal or above normal growing season precipitation. These initial results also suggest that large cores are a feasible and cost-effective means of studying soil-plant relationships in the greenhouse or growth chamber.

INTRODUCTION

Perhaps the most significant impact of declining soil quality on the prairies is a reduction in grain yield - as this represents a direct loss of revenue to the farmer. A number of researchers have explored soil quality-yield relationships by adding topsoil (i.e. A horizon material) to eroded soils (Mielke and Schepers, 1986; Verity and Anderson, 1990) or stripping topsoil from non-eroded soils (Sadler, 1984; Tanaka and Aase, 1989). Although these studies clearly demonstrated the importance of topsoil to crop productivity, relatively little work has been conducted on soil quality-yield relationships in real landscapes. To assess the impact of declining soil quality on spring wheat yields on a landscape-scale basis, Pennock and Anderson (1992) established field trials on two Oxbow soils - a severely eroded soil cultivated since 1910 (T10) and a slightly eroded soil cultivated since 1977 (T77). The fields were situated within 2 km of one another and were sampled intensively with respect to soil quality characteristics (e.g., depth of A horizon, organic C content, total N, etc...). Contrary to popular wisdom, the severely eroded T10 soil out-yielded the T77 soil in 1991. Pennock and Anderson (1992) suggested that climatic factors, such as the amount and distribution of growing season precipitation, could override differences in soil quality in a given year. Under controlled environmental conditions, however, soil quality should be the dominant factor affecting crop growth and yield. Thus, in addition to repeating the field trials in 1992, a greenhouse study using cores taken from the same soils was undertaken. Here we report the results of this study.

MATERIALS AND METHODS

Large undisturbed cores from two closely situated Oxbow soils in the Black soil zone near Lanigan, Saskatchewan were collected on April 29 and May 1, 1992. One soil has been cultivated since 1910 (hereafter referred to as the 82-year cultivated site) and is severely eroded; the other has been cultivated since 1977 (15-year cultivated site) and is only slightly eroded. Both soils developed on glacial till parent materials and are characterized by hummocky terrain with 2 - 3% slopes. Soil quality and susceptibility to erosion were found to be influenced strongly by landscape position (Pennock and Anderson, 1992) as shown in Table 1. Cores were collected from divergent shoulder (DSH) and convergent footslope (CFS) positions at each site by pressing 33 cm lengths of aluminum irrigation pipe (25 cm diameter) into the soil using a truck-mounted hydraulic probe. Both landform elements were sampled at five locations within each site: three cores were collected from each DSH location and one from each CFS location. Soil depth in the cores ranged from 21 to 31 cm ($\bar{x}$ = 27.5 cm) and core weights ranged from 15 to 28 kg ($\bar{x}$ = 23 kg). The moisture status of the soil at the time the cores were collected was approximately equal to field capacity, and this condition was maintained in the greenhouse until the cores were seeded on May 16, 1992.

Table 1. Median values of soil quality indices for the Oxbow soils as influenced by cultivation intensity (from Pennock and Anderson, 1992)

Cultivation Intensity (yr)	Landform Element					
	Shoulders[a]			Footslopes[a]		
	BD ($Mg\ m^{-3}$)	OC ($Mg\ ha^{-1}$)	TN ($Mg\ ha^{-1}$)	BD ($Mg\ m^{-3}$)	OC ($Mg\ ha^{-1}$)	TN ($Mg\ ha^{-1}$)
15	1.25 (0.19)[b]	95.7 (27.5)	8.2 (3.0)	1.26 (0.19)	94.2 (32.7)	8.4 (3.7)
82	1.42 (0.06)	52.8 (18.2)	6.2 (1.8)	1.35 (0.19)	88.7 (41.1)	8.1 (1.9)

[a]Abbreviations: BD, bulk density (0 - 15 cm); OC, organic carbon (0 - 45 cm); TN, total nitrogen (0 - 45 cm).
[b]Numbers in parentheses are the interquartile ranges.

The experiment was set-up in a greenhouse using a completely randomized design with four treatments (soils), three sub-treatments (water) and five reps. Plastic pot saucers (30 cm dia.) were placed under all cores. Prior to seeding, cores were fertilized at a rate equivalent to 40 kg N ha^{-1} and 20 kg P_2O_5 ha^{-1}. A concentrated fertilizer solution was prepared using laboratory grade chemicals (52.3 g NH_4NO_3 L^{-1} and 16.4 g $NH_4H_2PO_4$ L^{-1}), diluted 1:10 (v/v) with deionized water, added at a rate of 100 mL $core^{-1}$ to the surface of each soil, and incorporated to a depth of approximately 8 cm. Spring wheat (*Triticum aestivum* L. Katepwa) seeds were soaked in deionized water for about 10 minutes immediately prior to seeding and planted at a density of 13 seeds $core^{-1}$ (equivalent to the field rate of 90 kg seed ha^{-1}).

Water treatments were based on the probability of precipitation during the growing season. These probabilities were derived from an analysis of the long term (30 year) weather data for the Environment Canada meteorological station at Watrous, Saskatchewan (approximately 40 km southwest of Lanigan). The precipitation data were analyzed statistically and grouped into quartiles using Proc Univariate of SAS (SAS, 1990). The first quartile (Q1; low water treatment) marks the minimum amount of precipitation that can be expected in 75 years out of 100 and is representative of drought conditions; the second quartile (Q2; mid water treatment) indicates the median rainfall, i.e. the minimum amount of precipitation that can be expected in 50 years out of 100 and is representative of an average year; and the third quartile (Q3; high water treatment) marks the minimum amount of precipitation that can be expected in 25 years out of 100 and is representative of wet conditions. The monthly precipitation quartiles (and corresponding water treatments) are listed in Table 2.

Table 2. Precipitation quartiles and weekly water treatments

Month	Q1 (low-water)		Q2 (mid-water)		Q3 (high water)	
	---- mm rain month^{-1} (mL water core^{-1} week^{-1}) ----					
May	26.1	(331)	38.8	(492)	56.6	(717)
June	44.8	(568)	62.8	(796)	119.0	(1445)
July	32.1	(407)	52.5	(665)	94.0	(1191)
August	20.4	(259)	34.7	(440)	62.0	(786)

Field crops have access to sub-surface water as well as precipitation. Thus, field estimates of the available soil water (to a depth of 110 cm) were made from *in situ* neutron probe measurements. Access tubes were installed in DSH and CFS positions at each site and measurements were obtained at two week intervals throughout the growing season. The sub-surface (30 - 110 cm) soil water content at the start of the season was used as a reference against which measurements obtained later in the season were compared. Decreases in sub-surface soil water content were assumed to be due to crop utilization. Thus, we treated this available sub-surface moisture as a reserve supply which could be added to the cores in the event water stress became severe during the growing season. The addition of this water became necessary only once, in late June, and was supplied to all cores as 5 mm of additional "precipitation". Although not normally considered growing season precipitation, two weeks of August precipitation were applied - in mid-July, to compensate for the compressed growing season in the greenhouse, and the final watering on August 1st.

The wheat was harvested on August 13, 1992 (89 days after planting). The above ground biomass (stems, leaves and heads) was placed in paper bags, dried at 49 °C for four days, and weighed. The heads were then separated from the stems, threshed and cleaned using a single head thresher (Precision Machines, Lincoln, NE), and the seeds collected in plastic vials. Dry matter production (g core^{-1}), total seed yield (g core^{-1}) and seed number were determined. Seed weight (mg seed^{-1}), harvest index (grain yield ÷ dry matter yield), and extrapolated grain yield (kg ha^{-1}) were calculated from the harvest data.

Data were analyzed in SAS using Duncans' Multiple Range test for assessing differences between water treatments within landform elements and the Least Significant Difference (LSD) technique for assessing differences between landform elements within each water treatment.

RESULTS AND DISCUSSION

The effects of soil quality on seedling emergence, averaged over all water treatments, are shown in Fig. 1. Whereas emergence was similar in the 15- and 82-year CFS and 15-year DSH cores, it was delayed in the 82-year DSH cores. This effect was likely a result of the severe surface crusting that was characteristic of the 82-year DSH cores. Nevertheless, plant emergence in the 82-year DSH cores was similar to that in the other cores after 8 days. Other studies have reported an inhibition of corn emergence on exposed subsoils due to crusting or lower soil temperature (Olson, 1977; Mielke and Schepers, 1986).

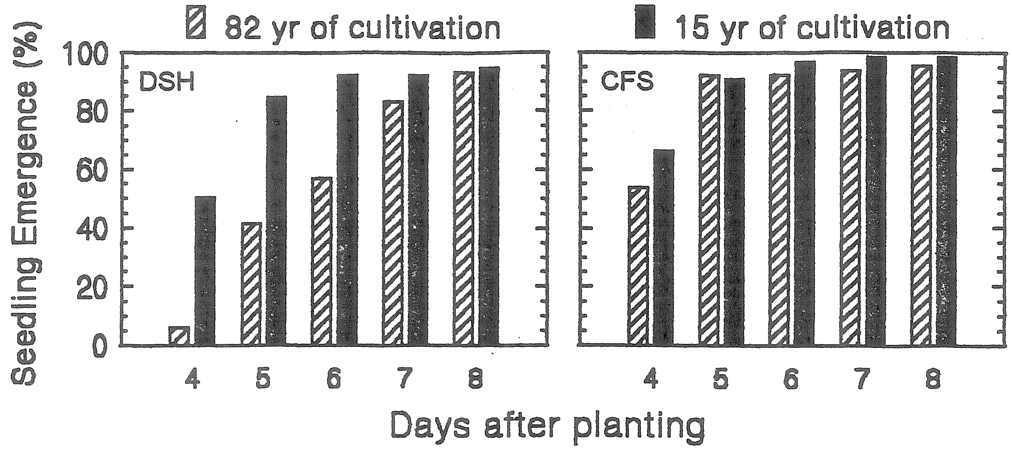

Fig. 1. Seedling emergence in cores collected from different landscape positions in the 15- and 82-yr cultivated soils.

The trends in emergence persisted for the duration of the study. That is, at all growth stages and for all water treatments, crop vigour was greater in the 15-year DSH cores than the 82-year DSH cores but was comparable in the 15- and 82-year CFS cores. Harvest results are presented in Table 3. Total dry matter and grain yield increased significantly with increasing "precipitation" for both the 15- and 82-year DSH cores. Furthermore, total dry matter production in the 15-year DSH cores exceeded that in the 82-year DSH cores by 67, 85 and 85% for the low, mid, and high water treatments, respectively. Likewise, grain yield in the 15-year DSH cores was 50, 76 and 86% higher than that in the 82-year DSH cores at the low, medium and high water treatments, respectively. Yield increases in the 15-year DSH cores, with the exception of grain yield at the low water treatment, were significant at the $P \leq 0.05$ level. These results coroborate the commonly held belief that soil quality has less influence on crop yield in years with below normal precipitation than in years with normal or above normal precipitation (Dormaar et al, 1986; Tanaka and Aase, 1989). In the mid water treatment, dry matter and grain yield for the 15- and 82-year CFS and 15-year DSH cores were not significantly different ($P \leq 0.05$), suggesting that these landform elements differ little in terms of soil quality. Grain yield differences between the various soil quality-water treatment combinations reflected both the total number of seeds produced and seed weight. Both of these yield components increased with increasing precipitation and were generally greater for the 15-year DSH cores than the 82-year DSH cores. Tanaka and Aase (1989) observed the same relationship between seed weight of spring wheat and growing season precipitation, however they found that seed weight increased as depth of topsoil removed (i.e., "erosion") increased. Harvest indices were fairly consistent across all soil-landform-water treatment combinations (Table 3).

In general, extrapolated grain yields obtained on the cores (Table 3) would be considered modest field yields for the Oxbow association given the same amounts and distribution of growing season precipitation. This may reflect the absence of available subsurface moisture in the cores and illustrates the difficulty of relating greenhouse and growth chamber experiments to the field.

Nevertheless, the initial results are encouraging and suggest that large cores are a viable and

Table 3. Grain and dry matter yields for the Oxbow soils as influenced by water treatment[a]

Cultivation Intensity	LFE[b]	Precipitation Quartile	—— Seed —— Number	Weight (mg)	— Yield (g core^{-1}) — Grain	Dry Matter	HI[c]	Extrapolated GrainYield (kg ha^{-1})
15 yr	DSH	Q1	126 c	25.3 b	3.12 c	8.14 c	0.38 b	615 c
		Q2	280 b	26.5 ab	7.38 b	17.04 b	0.43 ab	1455 b
		Q3	427 a	30.5 a	12.89 a	30.25 a	0.43 ab	2543 a
	CFS	Q2	277 b	28.1 ab	7.78 b	17.46 b	0.45 a	1534 b
82 yr	DSH	Q1	96 C	21.7 B	2.08 C	4.86 C	0.43 AB	410 C
		Q2	158 B	26.7 A	4.20 B	9.23 B	0.46 A	828 B
		Q3	258 A	26.9 A	6.96 A	16.37 A	0.42 B	1372 A
	CFS	Q2	253 A	29.1 A	7.33 A	16.84 A	0.44 A	1446 A

[a]Within sites, mean values (n = 5) followed by the same letter are not significantly different (LSD; P ≤ 0.05).
[b]Landform element (DSH = divergent shoulder; CFS = convergent footslope).
[c]Harvest Index (HI) = grain yield ÷ total dry matter yield.

cost-effective (approximately $10 per core for materials) means of studying soil quality-yield as well as other soil-plant relationships. Indeed, large cores may represent a more realistic alternative to conventional plastic pots. Space allocation and the ability of personnel to handle the heavy cores must be considered prior to initiating such an experiment.

CONCLUSIONS

Difference in grain yield between the 15- and 82-year DSH cores increased with increasing "precipitation", indicating that soil quality is a relatively minor factor when water is limiting but assumes a much greater role in years of normal or above normal growing season precipitation. Grain yield on the 15- and 82-year CFS cores were similar, suggesting that soil quality in this landscape position was relatively unaffected by cultivation intensity.

Large soil cores were found to be a practical and effective means of studying soil quality-yield relationships in the greenhouse. The size of the cores as well as the table space required are factors which may make them impractical in certain cases. Because of the large volume of undisturbed soil, cores offer obvious advantages over standard pots.

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