The sensitivity of shoot growth of corn to the least limiting water range of soils

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Abstract

The least limiting water range (LLWR), the range in soil water content within which limitations to plant growth associated with water potential, aeration and mechanical resistance to root penetration are minimal, has been proposed as an index of the structural quality of soils for crop growth. An hypothesis that is implicit in the proposed use of LLWR as an index of soil structural quality is that crop growth is negatively related to the proportion of the total number of measurements in which the water content falls outside the LLWR ($P_{out}$) and therefore given a certain climate positively related to the magnitude of the LLWR. The objective of this investigation was to test the hypothesis that plant response, specifically shoot growth rate of corn ($Zea mays$ L.), can be functionally related to $P_{out}$ and the LLWR of soils. The study was carried out on a farm with a side-by-side comparison of no-till and conventional-till. Thirty two paired sampling sites were located along the two transects. The LLWR and $P_{out}$ were calculated for the 0-20 cm depth in each sampling site. Shoot growth rate (SGR) was measured during a 17 and 16 day period in 1992 and 1993, respectively that corresponded to the 10-11 leaf stage. Although the variation in $P_{out}$ accounted for a larger percentage of the variation in SGR than did LLWR, the correlation between SGR and LLWR was high and justifies further studies to determine if crop yield can be related to LLWR under different soil and climatic conditions.

Abbreviations: LLWR - least limiting water range, $P_{out}$ - the proportion of the total number of measurements in which the water content falls outside the LLWR, SGR - shoot growth rate of corn, NT - no-till, CT - conventional-till, CLAY - clay content, OC - organic carbon content, $D_b$ - bulk density, $\theta_{fc}$ - soil water content at field capacity, $\theta_{wp}$ - soil water content at wilting point, $\theta_{sr}$ - soil water content at critical soil resistance, $\theta_{afp}$ - soil water content with air-filled porosity at 10%, TDR - time domain reflectometry.

Introduction

Soil and crop management practices cause significant changes in the structure of soils. A multitude of parameters may be used to characterize soil structure and the need to assess the impact of new management practices has, therefore, given rise to a search for a minimum number of soil structure parameters that will provide a comprehensive basis for such assessments. Soil structure influences a range of biological and hydrologic processes and the relative importance of different aspects of soil structure varies with the process involved. Parameters that are of greatest value in assessing the impact of management on soil structure in relation to plant growth would be expected to relate to the ability of soil to provide oxygen, water and support the proliferation of roots. The manifestation of changes in soil structure on plant growth is strongly dependent on climate and therefore characterization of soil structure must be linked to climate.

The least limiting water range (LLWR) has been proposed as an index of the structural quality of soils.
for crop growth (Da Silva et al., 1994) and is based on the concept introduced by Letey (1985). The LLWR is defined as the range in soil water content within which limitations to plant growth associated with water potential, aeration and mechanical resistance to root penetration are minimal. Once limiting values of matric potential, aeration and mechanical impedance are defined, the water contents are determined experimentally for each of these limiting conditions and the LLWR computed. The concept of a least limiting water range could also be applied to soil water potential rather than water content (Boone et al., 1986, 1987).

Da Silva and Kay (1996a) have shown that the LLWR is strongly dependent on clay and organic carbon contents as well as bulk density. Of these variables, organic carbon and bulk density would be expected to be most sensitive to management practices.

An hypothesis that is implicit in the use of the LLWR is that the soil water content will fall outside of the least limiting water range more frequently as the LLWR of soils (under similar climate conditions) gets narrower (Kay, 1989). Da Silva and Kay (1996b) measured soil water contents at 64 locations within a single field in which the LLWR varied from 0 to 0.390 cm$^3$ cm$^{-3}$ and found that the proportion of the total number of measurements in which the water content falls outside the LLWR ($p_{out}$) did indeed increase as the LLWR got narrower. Values of $p_{out}$ also varied with tillage and climatic conditions.

Another hypothesis that is implicit in the proposed use of LLWR as an index of soil structural quality is that crop growth and yield are negatively related to $p_{out}$ and therefore positively related to the magnitude of the LLWR (Kay, 1989). This hypothesis does not: (a) distinguish between instances in which the water content falls outside of the upper limit and those in which the water content falls outside of the lower limit or (b) specifically account for variation in the duration of the periods in which the water content falls outside of the LLWR. There is limited information in the literature that relates to this hypothesis and none that can be used to test it rigorously.

Shoot growth can be measured non-destructively and simultaneously with water content and is an appropriate parameter to initially assess the relation between plant response and the LLWR. The sensitivity of shoot growth, specifically leaf elongation, to soil water status has been demonstrated (e.g. Acevedo et al., 1971; Dwyer and Stewart, 1986; Masle and Passioura, 1987; Passioura, 1991). Additional studies relating yield to the LLWR are merited if a strong relation between plant growth and LLWR is found.

The objective of this investigation was to test the hypothesis that plant response, specifically shoot growth rate, can be functionally related to $p_{out}$ and the LLWR of soils.

**Materials and methods**

Field studies were conducted in 1991, 1992 and 1993 on a private farm located near Clinton, Ontario, Canada. Data on plant response were collected in 1992 and 1993 only. A field scale side-by-side comparisons of no-till (NT) and conventional-till (CT) (moldboard plowing in fall followed by cultivation in spring) had been maintained on the farm for 11 years prior the initiation of the study. The comparison (in the form of a strip) transversed soils with a range in properties. Thirty-two plots (6 m long by 4.5 m wide) were established along transects about 500 m length in each of the two tillage treatment. The plots were located along the transects to give a systematic variation in soil texture and were paired between tillage treatments. Preliminary characterization of the site revealed no major textural or structural discontinuities in the soil profile. The upper part of the profile would contain the largest proportion of plant roots and experience the greatest temporal variation in soil water content (and the subsequent variation in limiting conditions). Consequently, the greatest emphasis was placed on characterizing the 0-20 cm depth. Details on the climate at the site and the range in soil properties are given in Da Silva and Kay (1996a).

Corn (hybrid ‘Pioneer Brand 3751’) was sown to a population that was double the normal density on 12 May, 1992 and 10 May, 1993. The plants were manually thinned to a density of 67000 plants ha$^{-1}$ about two weeks after emergence, thereby removing any effect of soil structure on plant density.

Starter fertilizer (15-30-10) was applied (225 kg ha$^{-1}$) through the planter in all plots. All plots were side-dressed with 28% N solution of urea and $\text{NH}_4\text{NO}_3$ at a rate of 135 kg ha$^{-1}$.

Plant tissue analyses were carried out in the 1992 growing season. The plant material was collected at the silking stage and analyzed for N, P, K, Ca and Mg. All of these nutrients were present in levels considered normal for corn.

Pedotransfer functions relating the water retention curve and soil resistance curve with clay content