Chapter 49

Predicting Winter Wheat Yield Loss from Soil Compaction in the Central Great Plains of the United States

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Abstract Adoption of methods to minimize the effects of soil compaction on crop production by farmers has been slow. Often farmers do not equate degradation of soil physical properties with reduction in crop yield. The objective of this study was to determine the potential yield loss caused by degradation of soil physical quality due to compaction. Soil conditions and winter wheat (*Triticum aestivum* L.) yields were observed on the Alternative Crops Rotation study at Akron, Colorado in 1996 and 1997. Changes in soil physical properties were determined by observing changes in the soil Least Limiting Water Range (LLWR), which includes limitations of water holding capacity, soil strength and soil aeration, on crop production. Grain yield decreased approximately 1,000 kg ha^{-1} per 0.1 unit decrease in LLWR, showing that soil compaction can cause serious yield reductions if not managed properly. Soil compression curves were developed to help predict the amount of soil compaction, and subsequent yield loss, to be expected with wheel traffic at various tire pressures and soil moisture conditions. Methods such as controlled wheel traffic or the use of low-pressure tires should be used to reduce soil compaction and maintain soil productivity.

Keywords Winter wheat · Yield loss · Soil compaction · Central Great Plains · USA

49.1 Introduction

The use of no-till cropping systems and better residue management in the Central Great Plains has led to water savings that allow increased cropping intensity and more diversity of crop species (Anderson et al., 1999). However, because no tillage is done to loosen the soil, concerns arise that the long-term effects of no tillage could

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P. Zdruli et al. (eds.), *Land Degradation and Desertification: Assessment, Mitigation and Remediation*, DOI 10.1007/978-90-481-8657-0_49,

49.2 Materials and Methods

This study was conducted at the Central Great Plains Research Station near Akron, Colorado on a Weld loam (fine, smectitic, mesic, Aridic Argiustolls). All data presented in this paper were collected from the ongoing Alternative Crops Research (ACR) study. The experiment consists of three replications of several rotations of crops suited for dryland crop production in the central Great Plains. Each phase of each rotation occurs each year. Crops included in the rotations are wheat, abbreviated W, corn (*Zea mays* L.), abbreviated C, and proso millet (*Panicum miliaceum* L.), abbreviated M, with or without various intensities of fallow (F). More detail about the experimental design and crop management techniques can be found in Anderson et al. (1999) and Bowman et al. (1999). We selected the wheat plots from the WF, WCF, WCM rotations in the experiment.

To construct the LLWR for a particular soil, knowledge of field capacity, wilting point, air-filled porosity and soil strength are needed for the range of bulk densities likely to occur in the field. In this paper we have defined field capacity as the water content at –33 kPa water potential, the wilting point as the water content at –1,500 kPa water potential, the aeration limitation as 10% air-filled porosity, and the strength limitation as 2 MPa cone penetrometer resistance. These criteria have also been used by da Silva et al. (1994) and Betz et al. (1998).

Soil cores (75 mm diam. by 75 mm tall) were collected with a Giddings[1] hydraulic soil probe. Cores were taken immediately after wheat harvest in July. The cores were placed in individual moisture desorption cells and the 33 kPa (field capacity) water content was determined. Bulk density was determined on the same cores. Disturbed soil samples were used to determine 1,500 kPa (wilting point) water content. Measurements of cone penetrometer resistance and corresponding water content and bulk density were taken in the field. More detail in sampling procedures can be found in Benjamin et al. (2003).

Winter wheat yields from 1996 and 1997 were plotted against the corresponding LLWR. The yield data were separated into wheat yields following a fallow period under no-till management and wheat yields either directly following millet or wheat yields under sweep tillage management.

A series of compaction tests were run on disturbed soil samples to determine the response of the Weld soil to compactive pressure. An automatic soil compactor (ELE International) was used to compact the soil. The amount of energy was varied by changing the number of blows each sample received or by changing the weight of the tamper and drop height of the tamper. The machine turns the sample such that the entire surface of the soil in the mold is covered by overlapping tamper blows. Triplicate samples were prepared at each compaction energy level. The standard

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[1]Mention of trade names in for reference only. It does not imply a recommendation of this equipment over similar makes or models.

49.3 Results

The Least Limiting Water Range (LLWR) has been used as a method to combine limitations of the soil physical environment for crop production. The LLWR can be thought of as the range of water contents, at a given bulk density, where none of these soil physical properties are limiting to crop production. Plots of −33 kPa water content vs. bulk density, −1,500 kPa water content vs. bulk density, water content and bulk density which gives 2 MPa cone penetrometer resistance, and water content and bulk density which gives 10% air-filled pore space were made and the LLWR was determined (Fig. 49.1). The range of water contents where none of these properties are limiting is shown in the cross-hatched zone. For instance, the LLWR at a bulk density of 1.2 Mg m^{-3} would be between 0.23 and 0.38 volumetric water content, resulting in a LLWR of 0.15. The LLWR is smaller as bulk density increases. The LLWR at a bulk density of 1.6 Mg m^{-3} would be between 0.25 and 0.29 water content, resulting in a LLWR of 0.04.

Wheel traffic effects on soil bulk density, and the corresponding effect on LLWR, are dependent on compaction pressure and the water content of the soil when trafficked. The effects of compaction pressure and soil water content for a Weld loam are shown in Fig. 49.2. For a compaction pressure of 172 kPa, the range of bulk density would be 1.4–1.54 Mg m^{-3} depending on the water content of the soil at compaction. For higher compaction pressures, the bulk density increases. For a compaction pressure of 614 kPa, the range of bulk density would be 1.5–1.7 Mg m^{-3}. The optimum water content for compaction decreases with increasing compaction pressure. The optimum water content for compaction at 172 kPa is about 0.20 g g^{-1}. The optimum water content for compaction at 614 kPa is 0.15 g g^{-1}.

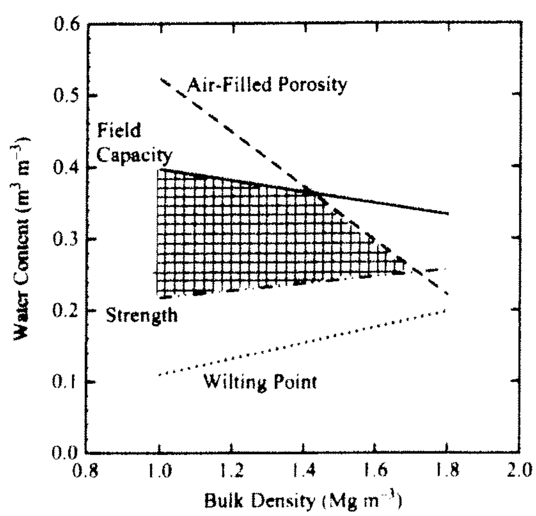

Fig. 49.1 Determination of the Least Limiting Water Range (LLWR) for a Weld loam at Akron, Colorado

49.4 Discussion

Uncontrolled traffic patterns are common in many commercial agricultural fields. Some fields may be covered many times by implements in the course of a crop year (Kuipers and van de Zande, 1994). Farmers can use information on the compaction characteristics of the soil and the response of the crop to soil physical conditions to make better decisions on management of their fields. Compaction information may help them determine the effects of machinery operations on soil compaction and subsequent effects on potential wheat yield.

For instance, farmers must often decide when the water content of the soil in a field is suitable for field operations. If a farmer were to traffic this soil with a water content of 0.10 g g^{-1} water content with an implement that provides 172 kPa pressure, the farmer could expect the soil to compact to a bulk density of about 1.4 Mg m^{-3} (Fig. 49.2). If rainfall or irrigation was to occur such that the water content increased to 0.2 g g^{-1} and the field was trafficked with the same implement, the farmer could expect the soil to compact to a bulk density of about 1.54 Mg m^{-3}, increasing the amount of compaction. If the entire surface of the soil were covered with wheel tracks the difference in LLWR would be the change of LLWR from 0.13 to 0.08 (from Fig. 49.1), a decrease of 0.05. A decrease in LLWR of 0.05 would result in a winter wheat yield loss of about 500 kg ha^{-1} (from Fig. 49.3). Information such as this can point out to the farmer the risk involved when trafficking the soil when it is too wet.

Farmers often have decisions to make on the size of machinery used and the compactive pressure the selected implement will have on the soil. An implement that provides 172 kPa compaction pressure on a soil with a water content of 0.15 g g^{-1} will compact the soil to a bulk density of about 1.5 Mg m^{-3}, whereas an implement that provides 344 kPa compaction pressure on the same soil under the same conditions will compact the soil to a bulk density of about 1.6 Mg m^{-3} (Fig. 49.2). The change in LLWR would be from 0.09 to 0.04 (Fig. 49.1) and a winter wheat yield loss of about 500 kg ha^{-1} (Fig. 49.3). Farmers can use this information to make decisions on the size and weights of machines for field operations.

Sometimes field operations on soil that is too wet or using relatively large machines for farming is unavoidable. Devising a controlled wheel traffic pattern on the field helps limit the damage caused by compaction to the entire field. The goal of a controlled wheel traffic system is to create poorer conditions, as noted in the above examples, on part of the field but preserve more optimal conditions on the area between the wheel tracks. Showing the direct influence of wheel traffic on the soil physical condition and the subsequent affects on productivity may provide incentive for farmers to devise such controlled wheel traffic systems for their operations.

49.5 Conclusions

Soil compaction has the potential to severely limit crop production. The primary method to avoid compaction is to not traffic the soil when the soil is wet, as that is