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Characterizing bulk density and hydraulic conductivity changes in a potato cropped field

J. Perrone*, C.A. Madramootoo

Department of Agricultural Engineering, Macdonald Campus of McGill University, 21 111 Lakeshore Road, Ste. Anne de Bellevue, Quebec, Canada H9X-3V9

Abstract

Soil samples were taken at two depths from a potato field during the months of May and July of 1990 to determine the variation of bulk density and saturated hydraulic conductivity with time, depth and machinery traffic. Saturated hydraulic conductivity was measured with the falling head permeameter. In general, conductivity decreased with depth, whereas bulk density increased with depth. Saturated hydraulic conductivity (k_{sat}) at the surface decreased from 6.6 cm/h in May for untracked soil to 0.6 cm/h in wheel tracks in July, while bulk density increased from 1.31 to 1.51 g/cm^3. At 20–30 cm depth, k_{sat} decreased from 3.6 to 1.2 cm/h during the same time period, while bulk density increased from 1.44 to 1.71 g/cm^3. In some instances, higher values of k_{sat} were observed at lower depths. This could be due to compaction and weakening of soil structure in the upper 10 cm soil layer.

Keywords: Bulk density changes; Hydraulic conductivity changes; Potato cropped field

1. Introduction

While there have been many spatial and temporal measurements of saturated hydraulic conductivity, (Gallichand et al., 1990; Southard and Buol, 1988; Wang et al., 1985) few people have observed the combined effects of saturated hydraulic conductivity with time, depth, and compaction in intensively cropped fields. Saturated hydraulic conductivity (k_{sat}) influences runoff, drainage, infiltration, erosion and water quality. Accuracy in measuring k_{sat} is important in monitoring water movement. Compaction caused by machinery traffic has been observed to reduce k_{sat} (Voorhees, 1986), thus increasing surface runoff and soil erosion. Several hydrologic models such as DRAINMOD and CREAMS (Chemicals,

* Corresponding author.

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Runoff, and Erosion from Agricultural Management Systems) require k_{sat} as an input parameter.

Saturated hydraulic conductivity generally decreases with soil depth (Southard and Buol, 1988). Similarly, bulk density usually increases with depth. This is due to reduced pore space as a result of soil pressure. The above factors combined with increasing clay content in some soils restrict infiltration and water movement at lower soil depths, and therefore reduce saturated hydraulic conductivity. However, at greater depths in the soil profile a well-defined pore continuum can be observed, particularly in moderately well-drained and poorly drained soils (Southard and Buol, 1988). A greater pore continuity is apparent in lower soil horizons.

Soil compaction greatly influences saturated hydraulic conductivity. Compaction can significantly reduce k_{sat} since reduced pore size, continuity and weaker structure restrict water infiltration.

Saturated hydraulic conductivity varies spatially. However, many hydrologic models use single values of k_{sat} for a watershed (Brakensiek, 1977). Instead of recognizing the variability of saturated hydraulic conductivity for different situations (e.g. soil type, time of year, compacted soil layers), these models use approximate values from literature, or a few field measurements in order to estimate k_{sat}.

We conducted our study to determine the variation of saturated hydraulic conductivity and bulk density in an intensively cropped potato field using conventional tillage practices. Measurements were made in May and July of 1990 on tracked and untracked areas at depths of 0–10 and 20–30 cm.

2. Methodology

2.1. Site description

An intensively cropped potato field, located 3 km west of the town of St. Leonard d'Aston, Quebec was selected for the study. The field had a uniform slope of 0.73% and a drainage area of 4.63 ha. The soil is a Ste. Jude sandy loam with an organic matter content of 2.8%. Sand content was observed to decrease with depth. An analysis of 70 soil samples revealed a textural composition of 74% sand, 8% silt and 18% clay.

Conventional tillage operations were conducted using a 45 kw tractor (5–6 tonnes) to a depth of 20 cm. The field was ploughed in the fall, and disced and harrowed in the spring. Potatoes were planted on the site in the spring of 1990 as well as the previous year.

Monthly rainfalls for May and July of 1990 were of 48.9 mm (42% below the 10 year average) and 77.5 mm (12% below the 10 year average), respectively (Table 1). One day before the May soil sampling date, 6 mm of precipitation had accumulated. In July, approximately 40 mm of rain fell in the week prior to soil sampling. Monthly temperatures did not deviate from the long term average by more than 2°C (Table 1).

2.2. Field sampling and laboratory analysis

Measurements of saturated hydraulic conductivity and bulk density were made on core samples collected from the field. Twenty-eight soil samples were collected in May, and 42

Table 1
Observed monthly rainfall and temperature in 1990

	May	June	July
Rainfall (mm)	48.9	126.2	77.5
Average rainfall (10 yr.)	84.3	92.2	87.9
Temperature (°C)	9.9	16.0	18.6
Average temp. (10 yr.)	11.7	16.2	19.4

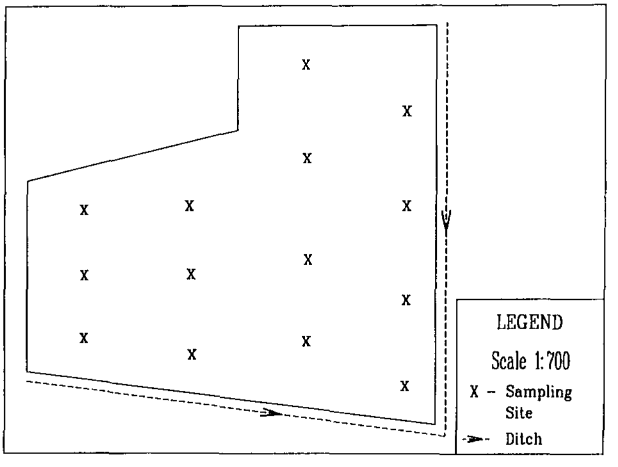

Fig. 1. Location of soil sampling sites.

in July of 1990. Samples were taken 25 m apart, on diagonal transects across the field, on both sample dates (Fig. 1).

A cylindrical core approximately 10 cm in height and 10 cm in diameter was used to extract samples from the soil. After hammering the core into the soil, it was removed and excess soil cut away from the top and bottom ends of the core. A piece of geotextile material was placed at the bottom of the core, which was then inserted in a plastic bag (Black, 1965). Two depths were sampled: 0–10 cm, and 20–30 cm. This procedure was followed in May of 1990.

In July, however, the sampling method was altered to take into account the formation of potato beds. Part of the field was compacted by machinery and formed into wheel tracks, and the remainder consisted of loose soil which formed potato beds. A typical cross-section of the plant beds and wheel tracks is shown in Fig. 2. Three sets of samples were taken to determine the effects of tracked versus untracked surfaces on k_{sat} at the soil depths. Soil samples were taken from the wheel tracks at 0–10, and 20–30 cm depth, and from the plant beds (untracked) at 0–10 cm.

The falling head permeameter method (Klute, 1986) was used to measure saturated hydraulic conductivity. After completing the conductivity measurements, samples were reweighed and placed in an oven for at least 48 h at 105°C to ensure complete drying. The samples were then reweighed to determine the bulk density.

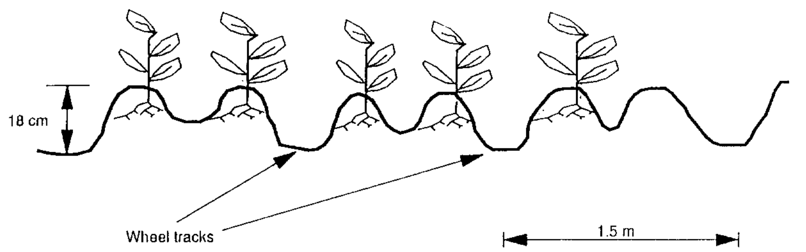

Fig. 2. A field cross-section of potato plant beds.

Table 2
Average saturated hydraulic conductivity (cm/h)

	May (0–10 cm)	May (20–30 cm)	July (Plant bed) (0–10 cm)	July tracked (0–10 cm)	July tracked (20–30 cm)
Mean (Std.)	6.60 (3.83)	3.60 (4.65)	20.40 (12.97)	0.60 (1.04)	1.20 (3.04)
Mode	5.64	2.14	18.08	0.41	0.09
Range	1.54–15.25	0.04–18.48	1.64–38.57	0.001-3.02	0.006–11.53
CV	0.58	1.29	0.64	1.73	2.53
Log mean (Std.)	5.47[a] (0.29)	1.58 (0.59)	14.06[b] (0.53)	0.32 (0.61)	0.14 (0.66)

[a] Significantly greater than at 20–30 cm depth.
[b] Significantly greater than tracked samples at 0–10 cm depth.
Std, standard deviation; CV, coefficient of variability.

3. Results and discussion

Soil samples were taken to represent two different sampling dates, wheel-tracked and untracked surfaces, and two depths. Log and arithmetic mean values of saturated hydraulic conductivity are presented in Table 2.

3.1. Variation of hydraulic conductivity and bulk density with depth

In general, samples at 0–10 cm had higher saturated hydraulic conductivities and lower bulk densities than those at 20–30 cm depth (Tables 2, 3). For example, in May the log mean saturated hydraulic conductivity at 0–10 cm (5.47 cm/h) was greater than at 20–30 cm depth (1.58 cm/h). Similarly, the average bulk density was lower for 0–10 cm deep samples (1.31 g/cm^3) than at 20–30 cm (1.44 g/cm^3), (Tables 2, 3). A statistical analysis showed the difference in k_{sat} at the two depths to be significant at the 0.01 level. This general trend was expected since deeper soil layers tend to be more compacted than those above, thereby yielding a higher bulk density and lower hydraulic conductivity. Furthermore, the field site had been chiselled before sampling in May. This resulted in fairly uniform field conditions.

3.2. Variation of hydraulic conductivity and bulk density with wheel traffic

In July, the log mean saturated hydraulic conductivity of 0–10 cm compacted (wheel track) samples was slightly less than that of 20–30 cm deep samples (0.14 cm/h as opposed to 0.32 cm/h); the average bulk density was again lower for 0–10 cm samples (1.51 g/cm^3) than at 20–30 cm depth (1.71 g/cm^3), (Tables 2, 3). A statistical analysis performed at the 0.01 level of significance showed that k_{sat} was not significantly greater at 0–10 cm depth when compared to samples at 20–30 cm in July. The decrease in k_{sat} is believed to be due to compaction. Furthermore, although compaction increased bulk density at both depths (Table 3), pore continuity was probably more greatly reduced in the shallower layer resulting in a lower k_{sat} at 0–10 cm depth.

Log mean k_{sat} was much greater at 0–10 cm depth in the plant bed (14.06 cm/h) and bulk density was much lower (1.16 g/cm^3) than in tracked areas (Tables 2, 3). Loosening of soil for hilling, or ridging, therefore greatly increased saturated hydraulic conductivity. This hypothesis was not rejected at the 0.01 level of significance.

3.3. Relationship between hydraulic conductivity and bulk density

Much of the changes in saturated hydraulic conductivity can be explained by a corresponding change in bulk density. Generally, as bulk density increased, k_{sat} decreased (Fig. 3). However, this does not hold true for all samples. Logarithmic saturated hydraulic conductivity versus logarithmic bulk density for individual samples is shown in Figure 3. The plot of log mean k_{sat} versus log mean bulk density for the two sample dates and depths is shown in Fig. 4. Both demonstrate a general trend of decreasing saturated hydraulic conductivity with increasing bulk density.

These results are in agreement with previous literature. Much research has observed bulk density to increase and k_{sat} to decrease with increasing soil depth (e.g., Bathke and Cassel, 1991; Jabro, 1992). As mentioned earlier, other studies have witnessed similar effects on bulk density and k_{sat} due to compaction by wheel traffic (Jorge et al., 1992; Aust et al., 1993). Associated with wheel traffic are the effects of tillage practices and their duration through successive growing seasons, another well-documented subject (Scott and Wood, 1989; Johnson et al., 1989). However, little research has monitored the combined effects

Table 3
Average bulk density (g/cm^3)

	May (0–10 cm)	May (20–30 cm)	July (Plant bed) (0–10 cm)	July tracked (0–10 cm)	July tracked (20–30 cm)
Mean (Std.)	1.31 (0.10)	1.44 (0.09)	1.16 (0.10)	1.51 (0.18)	1.71 (0.20)
Mode	1.31	1.48	1.14	1.52	1.77
Range	1.18–1.54	1.23–1.53	0.98–1.37	1.27–1.94	1.21–1.99
CV	0.08	0.12	0.09	0.12	0.12

Std, standard deviation; CV, coefficient of variability.

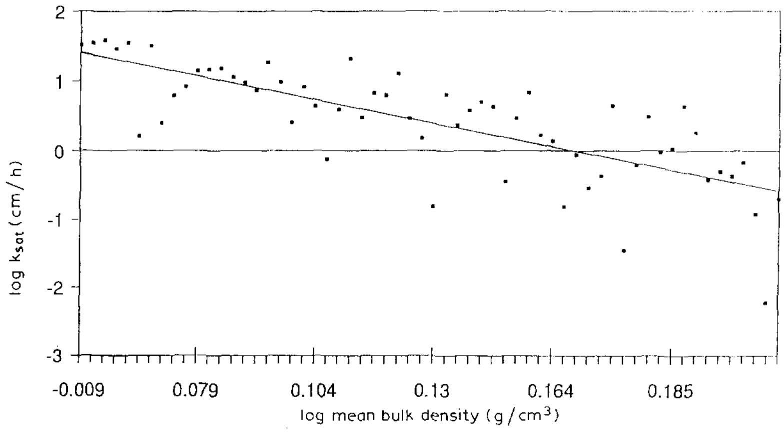

Fig. 3. Log k_{sat} vs. log bulk density.

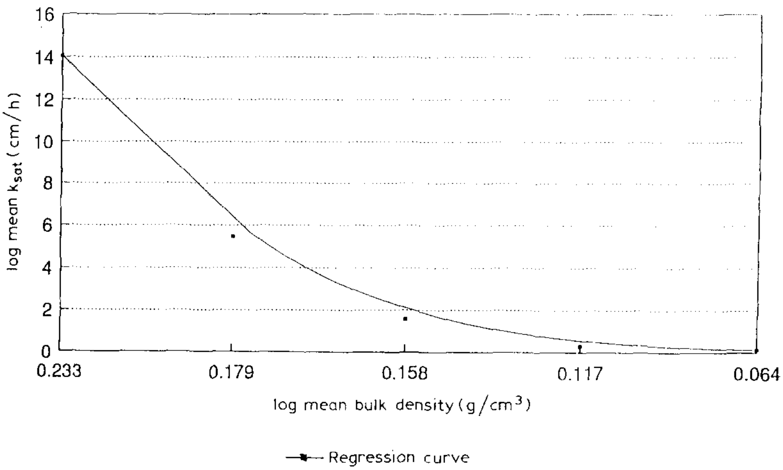

Fig. 4. k_{sat} vs. bulk density.

of compaction and increasing soil depth on bulk density and saturated hydraulic conductivity.

When observing the specific case of 0–10 cm versus 20–30 cm tracked samples taken in July, shallower samples with a lower bulk density (1.51 g/cm^3 compared to 1.71 g/cm^3) did not have a significantly greater saturated hydraulic conductivity at the 0.01 level. Furthermore, the arithmetic mean k_{sat} was actually lower for 0–10 cm samples (0.6 cm/h) than for 20–30 cm samples (1.20 cm/h).

These results are not in accordance with previous literature. Though k_{sat} was seen to decrease, and bulk density to increase considerably after compaction in July when compared to samples taken in May, a significant difference in k_{sat} was not observed with increasing depth. The general trend of decreasing saturated hydraulic conductivity with increasing depth and bulk density was altered when compaction was present.

4. Conclusion

Soil samples were taken from a potato field in St. Leonard d'Aston, Quebec twice during the 1990 growing season, at depths of 0–10 and 20–30 cm. Saturated hydraulic conductivity, bulk density, and soil texture analyses were performed to determine their variation with time, depth, and compaction.

Generally, conductivity decreased with depth, except in wheel tracked areas. The decrease in k_{sat} at the soil surface was due to compaction.

When comparing samples taken in May to those in July, two variations were observed. The loosening of soil to form the plant bed greatly increased saturated hydraulic conductivity and decreased bulk density. However, compacted samples from wheel track areas at 0–10 cm and 20–30 cm taken in July experienced a substantial decrease in k_{sat} and increase in bulk density. Log mean hydraulic conductivity for 0–10 cm and 20–30 cm samples decreased from 5.47 to 0.32 cm/h, and 1.58 to 0.14 cm/h from May to July; while bulk density for 0–10 cm and 20–30 cm samples increased from 1.31 to 1.51 g/cm^3, and from 1.44 to 1.71 g/cm^3 during the same time period.

Samples taken in July showed greater variation than those taken in May. This was probably due to the variations in machinery movements and loads. Higher coefficients of variability were found in the wheel tracks compared to the plant beds. Although the coefficient of variability of k_{sat} for bedded samples was 64%, wheel-tracked samples at 0–10 cm and 20–30 cm depth yielded a CV of 173% and 253%, respectively.

In summary, the field was more uniform in May, and therefore did not exhibit significant variability in saturated hydraulic conductivity at 0–10 cm depth than at 20–30 cm. When planting was completed, k_{sat} decreased considerably in wheel tracks at 0–10 cm depth, but not significantly at 20–30 cm depth in the tracked areas.

These results have implications on hydrologic modelling and field management. Most hydrologic models use an average single value of hydraulic conductivity to predict infiltration, runoff, erosion and chemical movement. Our field observations showed that more runoff and erosion were generated in tracked areas compared to untracked areas. There was more infiltration of rainfall in the untracked areas. A k_{sat} value based on an arithmetic average for the entire field may predict steady infiltration into the soil and no considerable runoff and erosion. However, this is contrary to our field observations. It is therefore proposed that a weighted average of k_{sat} with respect to wheel tracked and untracked areas be calculated and input to hydrologic models, or the value of k_{sat} should be made to vary with time of year. Furthermore, machinery used in field management (e.g. crop sprayers) should have tines installed at their rear in order to loosen the wheel tracked soil zones.

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