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Comparing Tillage Techniques by Using a New Infiltration Method

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Abstract: A one-year field trial in Italy was carried out for comparing tillage systems such as 50 cm chiselling (CH), 40 cm plow-till (PT40) and 20 cm plow-till (PT20) according to results of a new developed infiltration method. Ponded infiltration rates were measured to obtain the field saturated hydraulic conductivity (K_{fs}) using single ring infiltrometers on six dates with six replications in three sites on a sandy clayey loam soil.

In both PT20 and CH plots, K_{fs} after tillage increased temporarily to a value of about 4 and 9 times greater than that observed before tillage, respectively. However, late in the season, it tended to be not significantly different from the one before tillage for both. In PT40 plot, K_{fs} remained relatively constant during the year except May. At the end of the year, PT40 had the greatest K_{fs} and CH had the lowest.

As a result, it was found that the tillage technique used does not have appreciable effect on the K_{fs} for this type of soil. Although tillage recreates transmission pores in increasing K_{fs}, such pores were temporary, and tillage-created cracks may have collapsed within the season as a result of raindrop impact and wetting-drying cycles.

Toprak İşleme Tekniklerinin Yeni Bir İnfiltrasyon Yönteminin Kullanımı ile Karşılaştırılması

Özet: 50 cm derinliğindeki çizelin (CH), 40 cm (PT40) ve 20 cm derinliğindeki pulluk (PT20) gibi çeşitli toprak işleme tekniklerini yeni geliştirilen tek silindirli infiltrasyon testi sonuçlarına göre karşılaştırmak amacıyla İtalya'da bir yıllık bir arazi denemesi gerçekleştirilmiştir. Doygun hidrolik iletkenlik (K_{fs}) 6 ayrı tarihte 6 yinelemeli olarak 3 ayrı konuda tek silindirli infiltrometreler kullanılarak kumlu killi tınlı topraklar üzerinde belirlenmiştir.

Hem PT20 ve hem de CH konularında, toprak işlemeden sonraki K_{fs} öncekine göre zamanla geçici olarak sırasıyla 4 ve 9 kere daha büyük bir değere ulaşmıştır. Bununla birlikte, mevsim sonunda toprak işlemeden önceki değere göre her iki konu içinde önemli bir farklılık bulunamamıştır. PT40 konusundaki K_{fs}, mayıs ayı hariç yıl boyunca nisbeten sabit kalmıştır. PT40 yıl sonunda en yüksek K_{fs}'ye sahipken CH en düşük K_{fs}'yi vermiştir.

Sonuç olarak, kullanılan toprak işleme tekniklerinin bu tip topraklar için K_{fs} üzerinde önemli bir etkiye sahip olmadığı bulunmuştur. Toprak işleme K_{fs}'yi artırmada geçici iletim gözenekleri oluşturmasına rağmen bu gözenekler mevsim içinde yağmur damlası etkisi ve ıslanma-kuruma devirleri sonucunda çökmüştür.

Introduction

The ability of the soil in the unsaturated zone to retain and conduct water is a function of its hydraulic properties. These hydraulic properties depend on the pore size distribution, which is significantly affected by tillage practices, the texture and the structure of each soil. Of these, tillage is one of the most costly inputs in crop production and its primary objective is to characterize the tilled soil conditions, and determine which of the resulting conditions are most favourable for plant growth.

Any manipulation that changes soil condition may be considered as tillage. Tillage systems affect the amount of water moving both over the surface and into and through the soil and lead to variable water flux patterns due to differences in surface runoff and downward movement owing to the creation or destruction of soil structure and macropores (1).

Gish and Starr (2), Starr (3), Van Es (4) and Prieksat et al. (5) observed significant temporal variability in soil hydraulic properties under field conditions and found interactions due to tillage. However, De Franchi et al. (6) conducted a study by searching the effect of six tillage techniques on the water infiltration rate in the soil during the crop season. They showed that the tillage techniques used does not have appreciable effect on the infiltration rate.

Allmaras et al. (7) measuring the hydraulic properties of soil in situ found an increased conductivity at lower water contents in chiselled plot. They attributed this increased water movement to greater aggregation produced by chiselling. On the other hand, Baumhardt et al. (8) reported that crusts and the formation of seals due to raindrop impact decreased infiltration and eliminated the effect of chisel tillage for increasing infiltration.

In the absence of the measured data, regression equations based on basic soil properties such as soil texture, organic matter and bulk density are used to estimate soil water retention and hydraulic properties (9). Currently, these relationships, often referred to as pedo-transfer functions, remain constant in time and do not incorporate information on soil management practices.

Recently, new or modified methods have been developed to measure the hydraulic properties in situ (10). A single ring infiltrometer with a Mariotte bottle measures the steady state flux of water out of a ring at a constant positive head to estimate the field saturated conductivity. It relies on theoretical assumptions about the shape of the saturated bulb around the ring and employs numerically determined shape factors. Because the method contains both vertical and lateral flow components it may yield different results than methods that measure the conductivity only in one direction, especially when anisotropic conditions exist.

Because the field data altered by and following tillage are rare, the primary objective of this study is to describe changes occurring in saturated hydraulic conductivity over time due to the applied different tillage methods on a bare and flat soil.

Material and Method

Field experiments were conducted at the Agricultural Farm of the University of Bari located at Policoro in the Southern Italy. The average annual rainfall is 562.3 mm. Summer and winter average temperatures are 24.09°C and 8.77°C, respectively. The predominant soil type in the sites is sandy clayey loam classified as Vertic Xerofluvent. Mean bulk density of the field was found as 1.33 g/cm^3.

The experimental field was equally divided into 3 sites each having an area of 9000 m^2 (30 m* 300 m) where infiltration tests were conducted on the homogeneous soil. Soil management systems were 50 cm chiselling (CH), 20 and 40 cm plow-till (PT20 and PT40, respectively). CH plot was chiselled on 22 October 1994. PT plots were plowed on 25 October 1994 and 15 November 1994, respectively. All the plots were rototilled on 25 November 1995.

In each plot, 6 individual cylinders were used close enough together so that they could conveniently be run simultaneously. Ponded infiltration measurements were made of 6 dates from 17 October to 11 May (17-20 October, 19-22 December, 23-26 January, 20-23 February, 20-23 March and 8-11 May). Each set of 6 infiltrometers in one plot took 1 day to complete. While measurement of October occurred prior to tillage, the others occurred after tillage.

Infiltration measurements were made using 15 cm inside diameter steel rings inserted into the soil to a depth of 5 cm. The surface of the soil was protected by a cheesecloth. Infiltrometer runs were made after prewetting the soil using a portable rainfall simulator to avoid the effect of different soil moisture content and cracks upon infiltration Although the same sites were used for the test in both December and January, infiltration tests were conducted in different and close sites for the following measurements because the appeared cracks and soil disturbance caused by removed cylinders after completing the test formed an unusable soil surface. Ponded infiltration rates were measured using an 11 cm inside diameter Mariotte-type bottle with a hydraulic head of 0.10 m inside the ring, established through instantaneous ponding. Testing time for each infiltrometer varied from 5 to 24 hours.

In obtaining the infiltration functions of the soils, the three-parameter modified Kostiakov equation given in equation (1) was used (11):

$$I = kt^n+f_ot \tag{1}$$

where I is the cumulative infiltration (mm), k is the value of the cumulative infiltration at unit time (mm/h^n), n is the slope of the cumulative infiltration versus time data (unitless), f_o is the final infiltration rate (mm/h) and t is the time (h). From the measurements of I with time, f_o, n and k of the equation were found using Tablecurve (12) packet program for each site.

Field-saturated hydraulic conductivity (K_{fs}) was determined according to (10), assuming one-dimensional water flow in the infiltration ring and divergent three-dimensional flow below the ring:

$$K_{fs} = GQ_s/(a.H+\pi a^2G+a/\alpha) \tag{2}$$

where K_{fs} is the field-saturated hydraulic conductivity (mm/h), Q_s was calculated multiplying the f_o by the water surface area of the cylinder (mm^3/h), H is the hydraulic head of ponded water in the ring (mm), a is the radius of the infiltration ring (mm), α is a parameter related to soil hydraulic conductivity functions, assumed to be equal to 4000 mm^{-1}, as obtained by (13), G is a dimensionless shape factor determined from equation (3) as given below (10):

$$G = 0.316\ (d/a) + 0.184 \quad (3)$$

where d is the depth of ring insertion (mm).

Results and Discussion

Mean and coefficient of variation (CV) of f_o values obtained from the I function are given in Table 1 in terms of the plot and the measurement date. Means and coefficients of variation are the average of 4 to 6 measurements for each site in each month. The CV of f_o for all sites ranged from 23 to 79%. These results are consistent with the conclusions of Hamblin (14) and Ankeny et al. (15).

The missing measurements over 6 infiltrometers occurred due to deep cracks in the experimental plot and to a broken infiltrometer in January. Since the ring infiltrometer gave unreliable results due to the former problem these values were not taken into account in evaluating the tillage effect on infiltration data. Ankeny et al. (15) also reported the same sources of error in the estimation of steady-state infiltration rates.

Field saturated hydraulic conductivities calculated from equation (2) and the corresponding measurement dates were plotted both before and after tillage in Figure 1.

Each point is the mean K_{fs} of the infiltrometers at each site and in each month. The dashed arrows indicate the dates of cultivation. Additionally, the numbers shown represent the rainfall values greater than 5 mm per day since it is an important factor affecting the fate of the K_{fs} on a bare soil.

K_{fs} in all tillage systems were close to each other in October before tillage was applied. In December, K_{fs} for both PT20 and CH were more than 4 and 9 times greater than the rate measured in October, respectively, and almost 2 times higher for PT40 following the tillage operations which were completed in a month period after the first measurement. These increments can probably be attributed to the ameliorating effect of tillage on soil porosity and to the well-aggregate formation in the freshly tilled topsoil. Similarly, Blevins and Frye (1) and Unger (16) reported that a recently tilled soil has higher K_{fs} than the same soil that has not been tilled yet.

Table 1. Final infiltration rate (mm/h) values for each tillage system.

Dates	Plots	Oct.	Dec.	Jan.	Feb.	March	May
	CH	3.15**	28.82*	33.45**	7.87	14.10**	8.24*
Mean	PT40	5.30*	11.67	9.68**	11.87	12.37*	16.33**
	PT20	6.17	28.40*	24.15**	11.27	21.75**	10.32*
	CH	51.75**	36.71*	53.27**	33.29	47.52**	61.29*
CV	PT40	78.87*	67.69	58.88**	32.86	64.92*	23.33**
	PT20	56.40	37.61*	47.71**	26.71	45.93**	41.67*

* Means for 5 infiltration measurements
** Means for 4 infiltration measurements

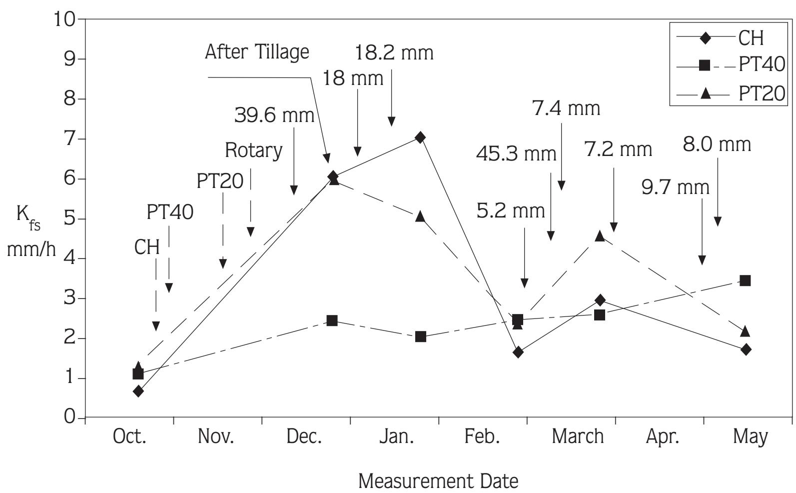

Figure 1. Mean K_{fs} values of the field for each measurement date and tillage system.

Consequently, in January, K_{fs} continued to increase only in the CH site although there was much rain. On the contrary, K_{fs} was reduced to 2.03 and 5.07 mm h^{-1} for PT40 and PT20, respectively, after 18 mm of rain that was recorded 2 times consecutively. The CH site had K_{fs} of 7.03 mm h^{-1} after the same amount of rain. These differences can be explained by the differences in aggregate distribution. Similar results were also observed by Starr (3) and Steichen et al. (17). The soil aggregates under chiselling may also be somewhat more stable due to higher organic matter content of the soil under the surface residues because the plant residues provide protection from the raindrop effect and impede movement of water as runoff allowing more time for infiltration. However, K_{fs} with plow tillage treatments was reduced in January. Tillage may have decreased K_{fs} because it buried surface residues and disrupted aggregates. Because of the problem noted above, crust caused by rainfall formed rapidly resulting in reduced K_{fs}. Similar results were also reported by Moore (18) and Freebairn et al. (19).

Three months after the last tillage practice, in the measurement of February, K_{fs} appeared to be nearly the same as before tillage for the CH and the PT20. It decreased sharply, probably as a result of soil settling showing that the significant soil structural changes can occur within a few weeks in a tilled topsoil. Prieksat et al. (5) and Cucci et al. (20) had also observed similar results. Reduced K_{fs}, however, can also be due to shrinkage. This may have occurred because significant rainfall had not been recorded for a long time period before the measurement. Additionaly, this year had below average precipitation and above-average temperature. Nevertheless, in Vertisols continuous vertical fissures can be created easily by shrinkage on drying, and volume of pores between cracks decreases as a result of shrinkage causing reduced K_{fs}. On the contrary, K_{fs} increased slightly in PT40 plot may be due to less compaction or more stable aggregates.

An important amount of rainfall caused the soil to be wet before March experiment was done. On wetting, this soils greatly expand and the attendant swelling closes the cracks increasing porosity. Increases in K_{fs} of the CH and the PT20 plots in March may be attributed to the increased porosity accompanying soil swelling. Trout and Kemper (21) had also observed similar results. On the contrary, an important K_{fs} change was not observed in the PT40 site.

Not only a decrease of K_{fs} in May was observed in the CH plot but also in the PT20 plot. This decrease in the CH plot may be attributed to the decomposition of the crop residue on the soil surface. Thus, rain decreased K_{fs} and eliminated the effect of chisel tillage for increasing infiltration, then illustrating the importance of crop residue in reducing crusting and maintaining a higher K_{fs}. Similar results were observed by Baumhardt et al. (8). Rain in the PT20 instead of crop residue effect in the CH site, however, played an important role in decreasing the K_{fs} with time.

Mean K_{fs} values with their standard deviation were given separately in Figure 2 for each tillage treatment and measurement date. The K_{fs} values after tillage for all tillage systems were not significantly different from one another except the measuremet of February and May for the CH and the PT20 sites.

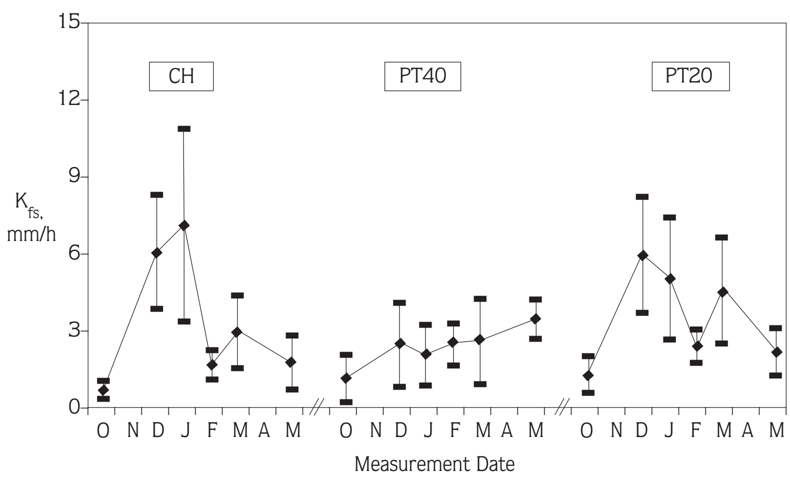

Figure 2. Mean K_{fs} values of the plots with their standard deviations for each measurement date and tillage system.

Measurements conducted after tillage did not show a significant difference among themselves in the PT40 plot. However, a significant difference in the CH was observed between the measurements before and after tillage except the experiment of May. In the PT40 site, increase in the K_{fs} after tillage appeared significantly only for the test of May. In other words, K_{fs} except May remained nearly in the same range. K_{fs} in the PT20 plot only increased significantly immediately after tillage showing that the PT20 created transitory pores in increasing infiltration. K_{fs} values are about the same for both the CH and the PT20. Ankeny et al. (15) also reported no significant differences between tillage systems. Although Unger (16) has reported that the soil inverting tillage such as moldboard plowing results in lower K_{fs} than chiselling, in our experiment it was observed that the K_{fs} were increased much higher in both PT20 and PT40 than in the CH. Initially, PT20 and CH produced a more porous soil than did PT40. This difference gradually changed with time and PT40 produced a higher porosity than did the other two. As a result, both ploughing system produced slightly higher porosity than chiselling. Shear and Moschler (22) and Soane and Pidgeon (23) reported similar results in a long-term tillage study. On the contrary, the results are in contradiction those by Bauder et al. (24) and Voorhees and Lindstrom (25).

Conclusion

At the end of this study, it was found that the tillage technique used does not have appreciable effect on the K_{fs} for this type of soil. Although tillage recreates trasmission pores in increasing K_{fs}, such pores were temporary, and tillage-created cracks may have collapsed within the season as a result of raindrop impact and wetting-drying cycles.

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