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Saturated Hydraulic Conductivity Variation in Cultivated and Virgin Soils

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Abstract: Variation of saturated hydraulic conductivity (K_s) values of soils under diverse management practices may be needed to determine the required sample number, sample size, and chose suitable sample scheme for characterize the K_s values used in water flow and solute transport modelling studies. The purpose of this study was to examine the variability in K_s and try to understand some part of the determinism of this variability in virgin and adjacent cultivated field using 36 undisturbed soil samples from each location with 0.5-m grid space. K_s was measured with 100 cm^3 undisturbed soil cores in laboratory using falling or constant head methods. The results showed that variability of ln (K_s) values (variance = 10.3) at the cultivated site was 2.5 times greater than that (variance = 2.5) at the virgin site. Furthermore, significant K_s differences exist between cultivated sample locations and within the rows of each cultivated location. Greater variations occurred in two cultivated locations may be attributed to compaction by traffic and soil tillage resulting in heterogeneous bulk density over the study area.

Key Words: Saturated hydraulic conductivity, Cultivated field, Virgin field, Soil compaction, Bulk density

İşlenen ve İşlenmeyen Toprakta Doygun Hidrolik İletkenlik Değişkenliği

Özet: Su akışı ve eriyik madde taşınımının modellemeleri çalışmalarında kullanılan doymuş hidrolik iletkenliğin tanımlanması için gerekli olan örnekleme sayısı ve miktarının belirlenmesi ve uygun örnekleme planının seçiminde farklı uygulamalar altındaki toprakların doygun hidrolik iletkenlik (K_s) değerlerindeki değişime ihtiyaç duyulabilir. Bu çalışmanın amacı, 0.5 m ızgara aralıklı her bir örnekleme istasyonundan 36 adet bozulmamış toprak örneğini kullanarak, işlenen ve işlenmeyen komşu arazilerdeki K_s değişkenliğini ve değişkenliği meydana getiren bazı nedenleri anlamaya çalışmaktır. K_s ölçümleri, laboratuvarda değişken ve sabit su yükleri altında, 100 cm^3 hacimli bozulmamış toprak örnekleri kullanılarak gerçekleştirilmiştir. Sonuçlar işlenen arazideki ln (K_s) değerlerinin (varyans = 10.3) işlenmeyen arazidekilerinden (varyans = 4.2) 2.5 kat daha fazla bir değişkenlik gösterdiğini, hatta işlenen arazideki örnekleme istasyonları arasında ve bu istasyonların kendi içlerindeki sıralar arasında da büyük K_s değişkenliğin olduğu göstermiştir. İşlenen arazideki iki örnekleme istasyonuna ait daha büyük K_s değişkenliği, tarla trafiği kaynaklı toprak sıkışması ve devamlı toprak işlemesi kaynaklı heterojen hacim ağırlığından kaynaklanmış olabilir.

Anahtar Sözcükler: Hidrolik iletkenlik, Hacim ağırlığı, Tarımsal işlenen arazi, İşlenmeyen arazi, Toprak sıkışması

Introduction

Knowledge of the soil saturated hydraulic conductivity (K_s) for soils is essential for designing irrigation, drainage, and wastewater systems; modeling studies; understanding and predicting the rates of infiltration, runoff, erosion, seepage, upflux, solute transport, water flows into drains, etc., that, in turn, affect crop performance and the environment. K_s may vary over several orders of magnitude within a single soil series or formation. This variability may increase if K_s is determined in laboratory using small-sized undisturbed soil cores (Mallants et al., 1997), which is sometimes essential for the studies such as upflux, infiltration and seepage, for individual layers.

The properties of natural soils are quite variable. For example, K_s can vary significantly since the structure of pores in soils may be varied as affected by different rates of biological, physical, and chemical processes. The tillage

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is one of the physical activities affecting the K_s. However, the effects of the tillage on K_s are not consistent because of the differences in K_s measurement methods, in times after the tillage of K_s measurement, in soil texture and soil moisture, in tillage types, in intensities of the tillage operations, etc.

The total porosity, distribution of pore sizes, and tortuosity-in short, the pore geometry of the soil (Hillel, 1982) are the soil characteristics affecting K_s. Pore arrangement of a tilled soil will vary temporally because of settling and arrangement of particles. Pores in the tilled soil are unstable due to tillage, shrink-swell, and root and faunal activity (Logsdon and Jaynes, 1996). Therefore, soil population to be sampled should be subdivided into sampling strata which are as homogeneous as possible, and the several sources of variation within the population should be sampled if valid inferences are to be made about the population from the samples (Peterson and Calvin, 1986).

The K_s values can be highly variable (Warrick and Nielsen, 1980) among different depths of a single soil profile as well as among different soil profiles over a landscape (spatial variability). For a silty loam soil, Coutadeur et al. (2002) used a disk infiltrometer to measure K_s in situ. They stated that tillage increased the spatial variation of the K_s of the soil. They found that soil below the wheel tracks had K_s only 40% of that of the soil between the wheel tracks in the ploughed layer. In addition, for log(K_s) values (m s^{-1}) they indicated that the variances of the K_s of the ploughed and seed bed (top 8 cm) layers were 0.48 and 0.35, respectively. Cameira et al. (2003) indicated that K_s was strongly affected by the first irrigation, and probably root development in conventional tillage. The authors also stated that the minimum tillage had produced higher K_s than conventional tillage, associated with larger coefficients of variance. Mohanty et al. (1991) set up two perpendicular transects and 66 sites with 4.6 m intervals on the transects in a cultivated no-till field with a loam soil derived from glacial till in central Iowa. The authors took three replicated undisturbed soil cores from each site at 15-cm depth. To avoid compaction due to wheel traffic, the samples were taken in the crop rows. They reported that the coefficient of variation was 90%. Later, Mohanty et al. (1994) randomly selected five sample locations roughly located at 50-m intervals and collected five core samples from each sampling site (2 by 2 m) with the distance of 10 cm in a loamy cultivated site during June and July 1990. The authors indicated that maximum variation in K_s values occurred because of the presence or absence of open-ended macropores. Byers and Stephens (1983) sampled an untilled medium-grained fluvial sand using two 14.85-m horizontal transects and taking samples every 15 cm at a constant depth of 50 cm using 100 cm^3 cores. Furthermore, they found that laboratory measured K_s (cm s^{-1}) was lognormally distributed and the variances of ln (K_s) values were between 0.411 and 0.249. They stressed that most studies showed the variance of ln (K_s) between 0.05 and 6. In the literature for vertical ln (K_s), these variances are between 0.3 and 4.8 (Bosch, 1991).

Greater variation may occur in K_s within a single soil mapping unit compared to among soil mapping units. For determining the variability of K_s of on the Emporia soil series (fine loamy, siliceous, thermic, Typic Hapludults), Albrecht et al. (1985) selected one site in each of four counties in Virginia, each site having four subsides about 30 m apart. Undisturbed cores were taken in triplicate about 30 cm apart at each subsite. For the A horizon, the authors indicated that the coefficient of variation of K_s was 112.3% and they attributed 54.4% of it to the replicates. After working on 10,000 individual core samples from about 900 sites in 7 states in the USA, Mason et al. (1957) indicated that the range of K_s values for individual soil types within a great soil group was commonly much greater than the difference between many great soil groups.

Although Mason et al. (1957) concluded that bulk density was a poor indicator of soil permeability, others found some contradicting results. Bouma and Hole (1971) studied K_s of adjacent virgin (silt loam) and cultivated (clay) Pedons at two sites during Autumn, 1969. For both sites, they reported that K_s values of surface layers in virgin sites were 1.4 and 1.3 times greater than those in cultivated soils. They reported that the reductions in K_s agreed well with increases in bulk density.

The literature indicates that data are needed to evaluate soil management effect on variation in K_s, which is an important subject in modelling and managing the soil water. Furthermore, almost all of the studies about wheel compaction are conducted on designed research and field operation plans. In most of these studies, the sampling was conducted with inadequate number of samples and only on two transects, under the center of wheel tracks and between wheel tracks. Different alteration rates on soil physical properties such as K_s and bulk density due to compaction can occur at different distances from the center of these two transects. In addition, effects of different field operations, which do not follow the same track in each pass, on K_s and bulk density may be analyzed with adequate number of undisturbed soil samples that adequately represent the soils under diverse use.

The purposes of this study were: i) to examine the variability in vertical saturated hydraulic conductivity in their surface layers of a cultivated and adjacent virgin soils, and ii) to evaluate the factors affecting the variability of K_s.

Materials and Methods

Study Site

This study was conducted in 2.1 ha cultivated and 0.36 ha virgin, level (1-2% slope), and well-drained alluvial fields (Figure 1) located 25-km northeast of downtown Tokat during 2003-2004 growing season. For the last three years, winter wheat has been grown in the cultivated area, and there was no cultivation on the virgin field in the last 15 years. The virgin field was covered by dominant plant species of ryegrass (*Lolium perenne* L.), bermudagrass (*Cynodon dactylon* L.), common lamb's quarters (*Chenopodium album* L.), saltbush (*Atriplex*), common dandelion (*Taraxacum* sp.), poison hemlock (*Conium maculatum* L.), and creeping thistle (*Cirsium arvense* L.). The topsoil in the virgin site is characterized by dark grayish brown color (dry); moderate fine to moderate medium granular structure; common fine and very fine roots; and common fine pores. The A horizon in the cultivated site is characterized by dark grayish brown color (dry); and moderate fine to moderate medium granular structure.

A two-wheeled tractor with 135-cm wheel spacing and a planter with wheel spacing of 240-cm were used for the cultivation operations in the cultivated site. Four cultivated (C1, C2, C3 and C4) and two virgin (V1 and V2) locations were sampled in the study area. Each location was 3 by 3 m in area. For selecting the sampling locations in the fields, a random soil sampling procedure was adapted except C4. The distance between the sampling locations of C1 and C4 was 1.5 m. The purpose on the taking the sample location C4 too close C1 was to test the continuity of variability observed in location C1 during initial analyses of results. The soil is clay to clay-loam in cultivated locations, and loam in virgin locations. Properties of the soil in locations are presented in Table 1.

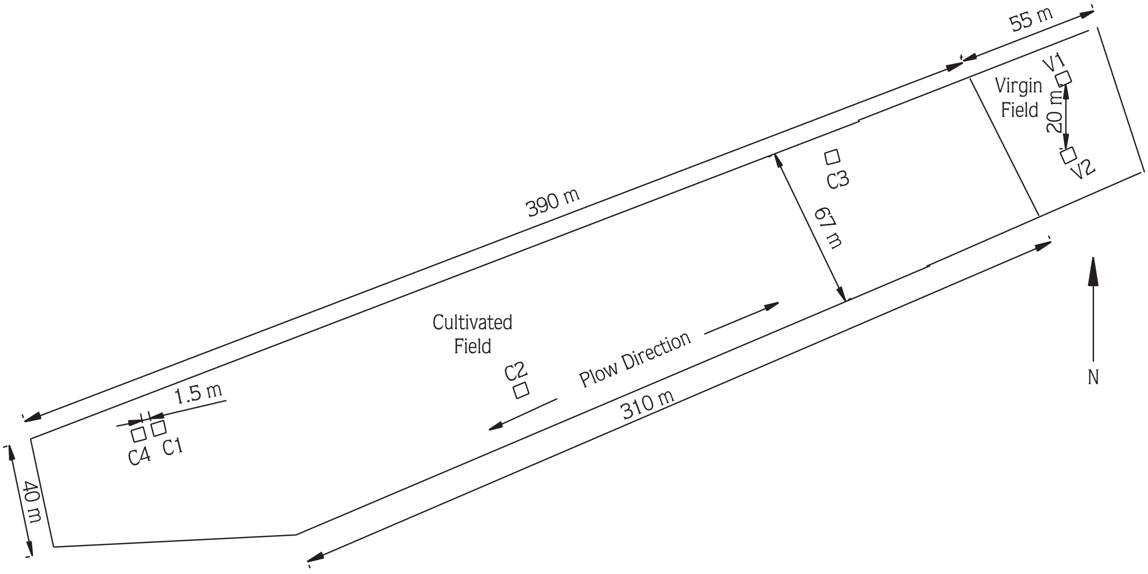


Figure 1. The plan view of fields with sampling locations indicated by squares.

Table 1. Sampling dates and some selected physical and chemical properties of topsoil (0-20 cm) in the virgin and cultivated fields.

Location	Sampling Date*	pH	$CaCO_3$ (%)	$\theta_{0.033}$[†] (%)	$\theta_{1.0}$[†] (%)	OM (%)	Sand (%)	Silt (%)	Clay (%)
C1	22/11/2003	8.07	12.31	34.46	22.62	2.40	27.7	30.0	42.3
C2	15/12/2003	8.03	18.10	36.11	23.01	2.19	22.7	27.5	49.8
C3	06/01/2004	8.12	14.18	32.76	21.29	2.49	27.7	32.5	39.8
C4	24/03/2004	8.14	14.74	34.59	20.64	2.68	27.7	37.3	35.0
V1	08/12/2003	8.07	12.13	27.04	14.23	3.67	37.5	40.0	22.5
V2	02/06/2004	8.13	11.19	26.15	14.60	4.80	37.5	42.5	20.0

*: The field was plowed on the 4th of August and planted on the 22nd of October, 2003.

[†]: water content at 0.033 and 1.0 MPa soil water tensions.

OM: organic matter.

Soil Sampling and Analysis

Prior to taking samples, the first 5-10 cm depth of surface soil was removed. Sampling was conducted using 5 cm wide and 5.1 cm long (100 cm^3 soil volume) stainless steel core samplers. The samples were taken after rainfall. For the cultivated site, the core sampler was gently driven into and pulled from the soil by pressing without using any hammer. Compared with hydraulically pressing, hammering causes more disturbance within cored soil, which increases variability (Stone, 1991) and decrease K_s (Rogers and Carter, 1987). For this operation, a hydraulically powered soil core sampler attached at the three-point hitch frame of tractor was used for the virgin field. After discarding few improper samples, total 140 samples for the cultivated field, and 69 samples for the virgin field were analyzed for the hydraulic conductivity measurements. Prior to K_s measurements vertically positioned soil samples were left to saturate from the bottom end. For samples with high K_s were determined with the constant head method, and those with low K_s were determined with the falling head method (Klute and Dirksen, 1986). Dry bulk density was determined following the procedures by Blake and Hartge (1986).

Statistical Analysis

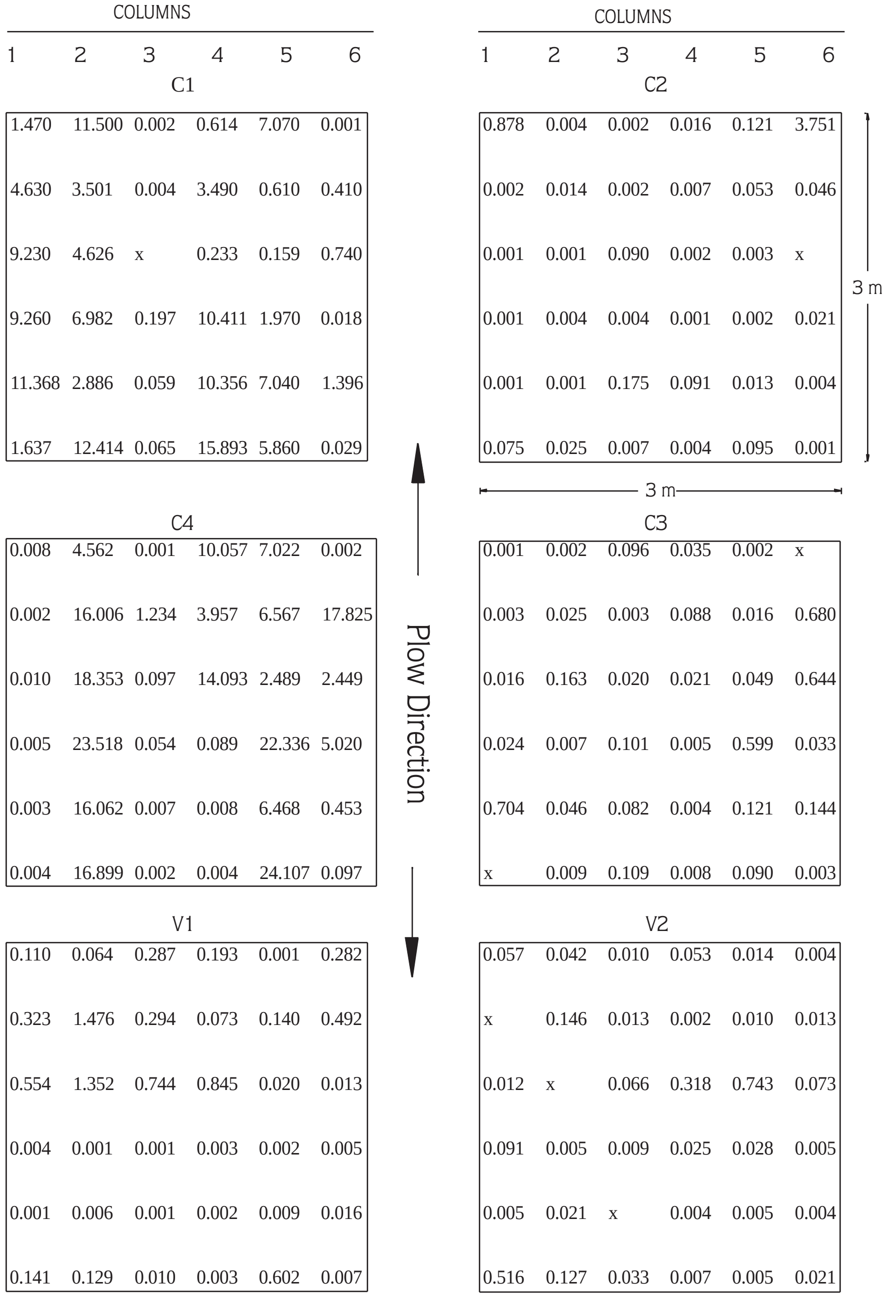
To ensure that number of samples was adequate for 0.05 level of probability, 36 undisturbed core samples were collected from each location with a grid space of 0.5 m. For testing adequacy of this number and presenting useful information for future studies to estimate the number of samples required to estimate the mean value for each normally distributed variable, the following equation (Petersen and Calvin, 1986; Zar, 1996) was used:

$$rn = \frac{s^2\, t_a^2}{d^2} \qquad (1)$$

where s^2 is the sample variance estimated with n-1 degrees of freedom, t_α is the Student's t with rn-1 degrees of freedom at the α probability level, and d is the half-width of the desired confidence interval. The solution was achieved by iteration. Descriptive statistics including minimum, maximum, mean, standard deviation, and variance were calculated for variables K_s and bulk density (ρ_b). The Ryan-Joiner test (Ryan and Joiner, 1976; D'Agostino and Stephen, 1986) (similar to the Shapiro-Wilk test) for the cumulative probability values approximated with (i-0.5)/n was used to check normality and lognormality of K_s and ρ_b data sets. This test is based on judging the near linearity of normal probability plots by computing their correlation coefficient. To determine whether there were significant differences between K_s and ρ_b data sets from cultivated and virgin fields, a one-way analysis of variance (ANOVA) was conducted. Comparative analyses were performed between fields, locations, and columns within each cultivated location. Fisher's pairwise comparison test at $P < 0.05$ was used to distinguish fields, locations, and columns. All the statistical tests were implemented with MINITAB package program (1994).

Results and Discussion

The measured K_s values (cm h^{-1}) in both the cultivated and virgin fields are given in Figure 2. The columns of data in Figure 2 are parallel to the plow direction. The results of Ryan-Joiner normality and lognormality test are given in Table 2. The results showed that K_s fit better with the lognormal distribution while bulk density (ρ_b) could be assumed as either normally or lognormally distributed. The better agreement with the ln transformed data for location C3 is further exemplified in Figure 3 by the fractile diagram. When values of ln (K_s) were used, almost a straight line resulted, indicating that



C1

1	2	3	4	5	6
1.470	11.500	0.002	0.614	7.070	0.001
4.630	3.501	0.004	3.490	0.610	0.410
9.230	4.626	x	0.233	0.159	0.740
9.260	6.982	0.197	10.411	1.970	0.018
11.368	2.886	0.059	10.356	7.040	1.396
1.637	12.414	0.065	15.893	5.860	0.029

C2

1	2	3	4	5	6
0.878	0.004	0.002	0.016	0.121	3.751
0.002	0.014	0.002	0.007	0.053	0.046
0.001	0.001	0.090	0.002	0.003	x
0.001	0.004	0.004	0.001	0.002	0.021
0.001	0.001	0.175	0.091	0.013	0.004
0.075	0.025	0.007	0.004	0.095	0.001

C4

1	2	3	4	5	6
0.008	4.562	0.001	10.057	7.022	0.002
0.002	16.006	1.234	3.957	6.567	17.825
0.010	18.353	0.097	14.093	2.489	2.449
0.005	23.518	0.054	0.089	22.336	5.020
0.003	16.062	0.007	0.008	6.468	0.453
0.004	16.899	0.002	0.004	24.107	0.097

C3

1	2	3	4	5	6
0.001	0.002	0.096	0.035	0.002	x
0.003	0.025	0.003	0.088	0.016	0.680
0.016	0.163	0.020	0.021	0.049	0.644
0.024	0.007	0.101	0.005	0.599	0.033
0.704	0.046	0.082	0.004	0.121	0.144
x	0.009	0.109	0.008	0.090	0.003

V1

1	2	3	4	5	6
0.110	0.064	0.287	0.193	0.001	0.282
0.323	1.476	0.294	0.073	0.140	0.492
0.554	1.352	0.744	0.845	0.020	0.013
0.004	0.001	0.001	0.003	0.002	0.005
0.001	0.006	0.001	0.002	0.009	0.016
0.141	0.129	0.010	0.003	0.602	0.007

V2

1	2	3	4	5	6
0.057	0.042	0.010	0.053	0.014	0.004
x	0.146	0.013	0.002	0.010	0.013
0.012	x	0.066	0.318	0.743	0.073
0.091	0.005	0.009	0.025	0.028	0.005
0.005	0.021	x	0.004	0.005	0.004
0.516	0.127	0.033	0.007	0.005	0.021

x : missing data

Figure 2. Results of vertical saturated hydraulic conductivity (K_s) (cm h^{-1}) measurements in surface layer of sampling locations.

Table 2. Results of Ryan-Joiner distributional tests for saturated vertical hydraulic conductivity (Ks) and bulk density (ρ_b) values.

Property	Distribution	Locations					
		C1	C2	C3	C4	V1	V2
Ks	Normal	0.92*	0.50*	0.75*	0.88*	0.83*	0.70*
	Lognormal	0.94*	0.97	0.99	0.93*	0.98	0.98
ρ_b	Normal	0.96	0.97	0.95*	0.97	0.96*	0.99
	Lognormal	0.97	0.98	0.94*	0.97	0.95*	0.99

* : Rejection of distribution at the 0.05 probability level.

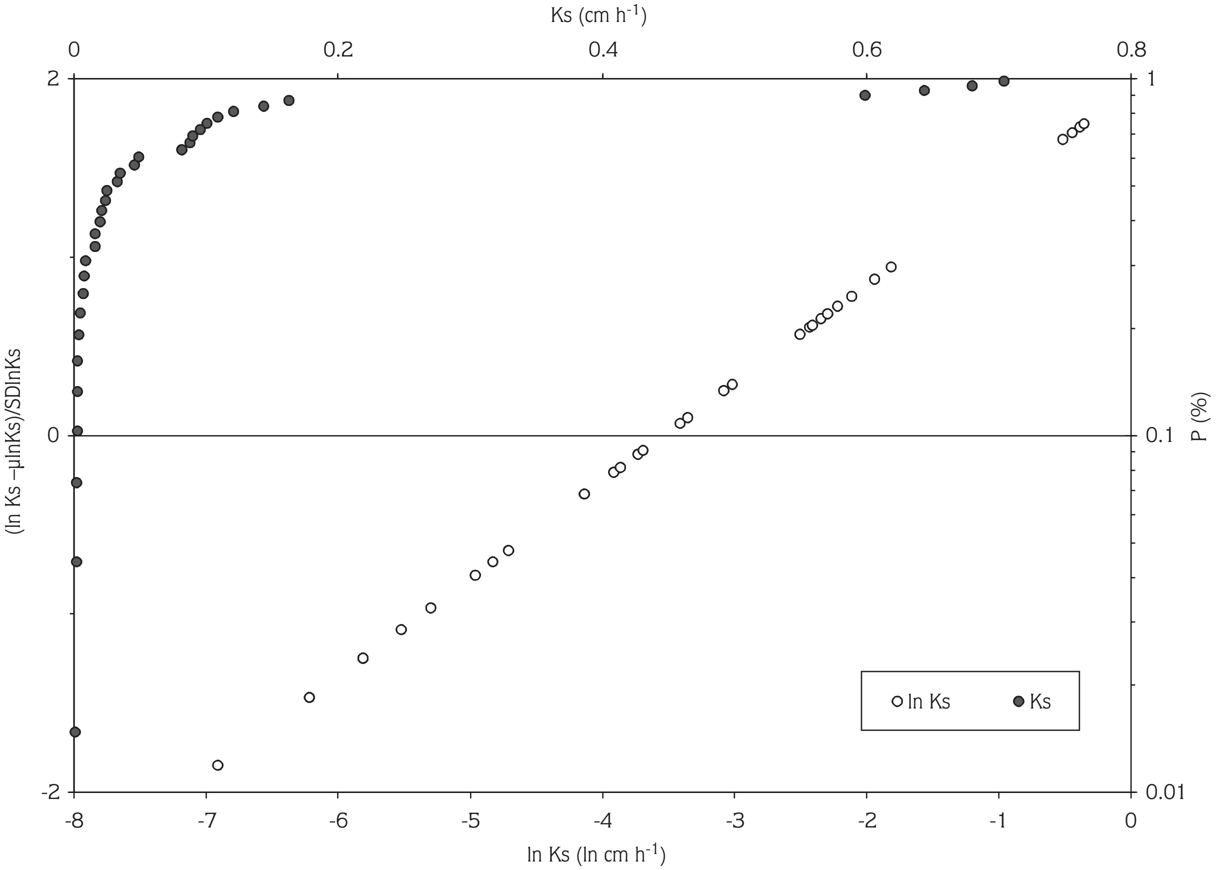


Figure 3. Fractile diagram of saturated hydraulic conductivity (K_s) values measured in the cultivated location C3.

logarithmic values were normally distributed. Similar results were stated by others (Baker and Bouma, 1976; Byers and Stephens, 1983; Istok et al., 1994; Logsdon and Jaynes, 1996; Coutadeur et al., 2002). In this study, considering the results by Lascano and Hatfield (1992) and Istok et al. (1994) ρ_b was assumed as normally distributed for further analyses.

When all K_s and ρ_b values from cultivated and virgin locations were combined and separated into two different field groups, one cultivated and other virgin, the variance values of all ln (K_s) from cultivated and virgin fields were 10.3 and 4.2, respectively, and the variance values of ρ_b were 7.3 x 10^{-3} and 7.6 x 10^{-3}, respectively. The ANOVA test for ln (K_s) and ρ_b data sets from cultivated and virgin fields showed that these fields were significantly different at $P < 0.002$ and $P < 0.001$, respectively.

The number of samples required to estimate K_s and ρ_b within 10% of the true mean for 95% probability level in each location were determined and are given in Table 3. The results proved that numbers of samples (36) used for estimates of K_s and ρ_b were adequate for each location, except the locations of C1 and C4 for K_s. Couple of descriptive statistics for the measured K_s and bulk density values for locations were also summarized in Table 3. The average K_s values were 32 times greater in C1 and 42 times in C4 compared to the average in other locations. The standard deviation values for both C1 and C4 were also 13 and 23 times, respectively, larger than the overall average standard deviation value for the other locations. For the ln transformed K_s values, results of one-way ANOVA with multiple mean comparison indicated that C1 and C4 were significantly different from the other locations. The test also indicated no significant differences among the mean of ln (K_s) for virgin and the other two cultivated locations (C2 and C3). Furthermore, no significant difference occurred between the K_s values from C2 and C3 and virgin locations, while the least mean and standard deviation were observed in one of the virgin locations (V2). One of the physical reasons obtaining this kind of K_s similarities from adjacent cultivated and virgin locations can be spatial variability of K_s for cultivated alluvial fields in large scale. Therefore, some locations of cultivated fields may produce similar K_s values to those of

Table 3. Descriptive statistics for the vertical saturated hydraulic conductivity (K_s) (cm h^{-1}) and the bulk density (ρ_b) (g cm^{-3}) values for locations in cultivated and virgin fields.

K_s	Location					
	C1	C2	C3	C4	V1	V2
Number of samples (n)	35	35	34	36	36	33
Maximum, cm h^{-1}	15.893	3.751	0.704	24.107	1.476	0.743
Minimum, cm h^{-1}	0.001	0.001	0.001	0.002	0.001	0.002
Mean, cm h^{-1}	4.175	0.158	0.116	6.110	0.228	0.075
Standard deviation, cm h^{-1}	4.586	0.643	0.206	8.030	0.370	0.158
Geometric mean*, cm h^{-1}	$0.907^{a\#}$	0.010^{b}	0.029^{bc}	0.358^{a}	0.033^{c}	0.021^{bc}
Standard deviation, ln (K_s)*,cm s^{-1}	2.664	2.109	1.822	3.658	2.447	1.511
Variance, ln (K_s)	7.097	4.448	3.320	13.381	5.988	2.283
Coefficient of variation+, %	32.15	16.47	15.54	39.70	21.09	12.56
Required sample size (rn)	43	13	12	63	20	9
ρ_b						
Number of samples (n)	24	32	35	31	26	26
Maximum, gcm^{-3}	1.445	1.251	1.418	1.315	1.583	1.650
Minimum, gcm^{-3}	1.084	1.045	1.174	0.939	1.260	1.449
Mean, gcm^{-3}	$1.209^{a\#}$	1.153^{b}	1.300^{c}	1.214^{a}	1.450^{d}	1.561^{e}
Standard deviation, gcm^{-3}	0.083	0.045	0.043	0.088	0.077	0.056
Variance	0.007	0.002	0.002	0.008	0.006	0.003
Coefficient of variation, %	6.86	3.90	3.31	7.25	5.31	3.59
Required sample size (rn)	5	4	3	4	4	3

: Values followed by the same letter are not significantly different at 0.05 probability level.

* : Geometric mean ($\exp(1/n*\Sigma \ln K_s)$), standard deviation ln (K_s), and variance ln (K_s) were calculated since the distribution of K_s was lognormal.

+ : Calculated using ln (K_s) in units of cm s^{-1} to prevent values in both negative and positive sign.

virgin fields. The other reason can be textural variability between the locations C2-C3 and V1-V2. While the tillage decreases K_s of the soil under cultivated fields, no tillage in virgin fields may increase K_s of the soils in these fields.

The variances calculated for ln (K_s) for the locations are high, while they, except those for C1 and C4, were in the range (0.05-6.0) stated by Byers and Stephens (1983). The overall coefficient of variation (CV) values were also high. Using small sized cores and determining K_s values in laboratory may results in greater variance and CV values. When the whole K_s values for the cultivated and virgin sites were compared, overall mean and standard deviation values for the cultivated site were 17 times larger than those for the virgin site. The tillage increased variation of K_s as stated by Bouma and Hole (1971), and Coutadeur et al. (2002).

The greatest mean bulk density values were in the virgin locations, while the highest CV values occurred in the cultivated locations of C1 and C4. Overall mean of ρ_b for the virgin locations was 24% greater than that for the cultivated locations. One of the reasons of such low ρ_b values in cultivated locations may be attributed loosening effect of tillage combined with the finer texture (Table 1) and incompleted soil consolidation. Furthermore, significant differences for ρ_b existed between the locations, except locations of C1 and C4. These differences are due to small standard deviations and CV values for ρ_b (Table 3) compared to those for K_s.

To detect any field traffic or manipulation effect on the variability of K_s measured in the cultivated field, one-way ANOVA test with multiple mean comparison between K_s and ρ_b values of columns of each cultivated location was employed. The columns were selected since the plow direction was parallel with the columns (Figure 2). The test results were given in Table 4. Considering the raw K_s values of each columns for cultivated locations (Figure 2) and geometric means for these columns (Table 4), the reasons for observed K_s variability in locations C1 and C4 became understandable. Almost all K_s values in columns 1, 2, 4, and 5 for location C1 and all K_s values in columns of 2 and 5, and mostly K_s values in columns of 4 and 6 for location C4 were highly greater than those K_s values in other columns of cultivated field. The columns having low ρ_b values possessed high K_s values (Table 4). One of the reasons of such high K_s values from undisturbed soil samples of which ρ_b values are low may be loose, unconsolidated or unsettled soil structure formed during seedbed preparation or planting in these columns.

Consideration of the high mean ρ_b and low geometric mean K_s values in columns 3 and 6 for location C1 with the distance of these two columns (150 cm) covered by the tractor wheel space with width of tire (135 +32 = 167 cm) may support the wheel traffic effect on these columns, too. Results of regression analyses, given in Figure 4, between ln (K_s) and ρ_b for the cultivated locations with the medium coefficient of determination values (0.48 and 0.59) for locations of C1 and C4 may support the effects

Table 4. Comparison of geometric mean and arithmetic mean values of saturated hydraulic conductivity (K_s) and bulk density (ρ_b), respectively, for columns of cultivated locations.

Property	Location	Column					
		1	2	3	4	5	6
K_s (ln cm h^{-1})	C1	$4.702^{a\#}$	6.001^{a}	0.023^{b}	3.080^{a}	1.954^{a}	0.078^{b}
	C2	0.007^{a}	0.004^{a}	0.011^{a}	0.007^{a}	0.019^{a}	0.027^{a}
	C3	0.015^{a}	0.017^{a}	0.042^{a}	0.015^{a}	0.047^{a}	0.091^{a}
	C4	0.005^{a}	14.296^{b}	0.021^{a}	0.342c	8.585^{b}	0.518c
ρ_b (g cm^{-3})	C1	1.176^{ab}	1.107^{a}	1.250^{bc}	1.167^{abc}	1.192^{abc}	1.280^{c}
	C2	1.177^{a}	1.153^{ab}	1.154^{ab}	1.186^{a}	1.141^{ab}	1.106^{b}
	C3	1.273^{ac}	1.319^{bc}	1.306^{cd}	1.320^{bc}	1.312^{c}	1.260^{ad}
	C4	1.284^{a}	1.120^{b}	1.237^{a}	1.231^{a}	1.057^{b}	1.236^{a}

[#]: Values followed by the same letter are not significantly different at 0.05 probability level.

of traffic and seedbed manipulation on K_s variability in these cultivated locations. Similar effects might happened at the some columns of location C4. Furthermore, temporal effects on the variability of K_s and ρ_b among cultivated locations might have occurred because of varying sampling intervals after planting. Ersahin (2003) studied the spatial relationship between infiltration rate and some soil properties in the study area. The author reported a strong negative relationship between infiltration rate and bulk density of subsoil (30-60 cm). The soils in cultivated locations possessed higher clay and lower sand content than the soils in virgin locations (Table 1). This would result in low K_s and ρ_b in cultivated field. This kind of texture variability between the adjacent sites can be expected in an alluvial area. Further research is needed to confirm these reasons by controlling traffic, operations of seedbed preparation, soil moisture distribution, rainfall, and applying spatial analysis techniques.

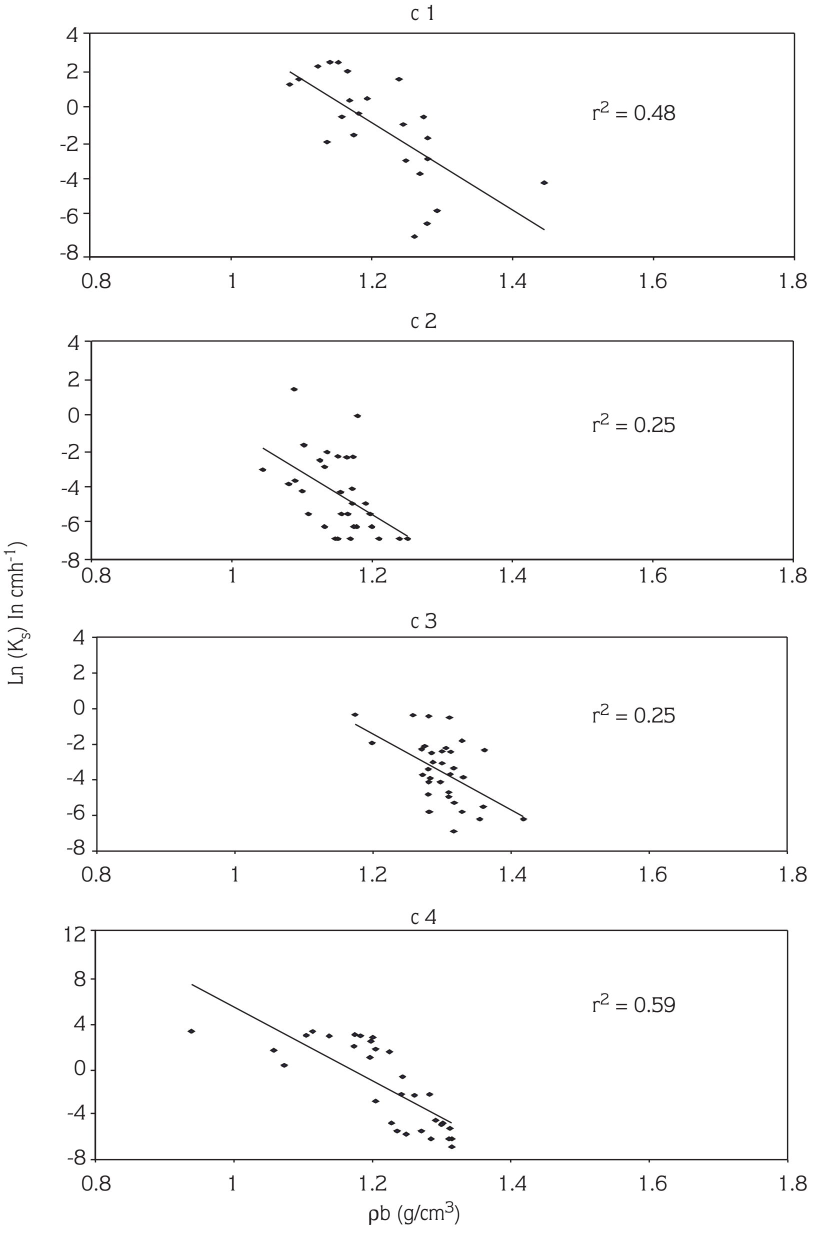


Figure 4. Dependence of ln (K_s) on ρ_b for cultivated locations.

Conclusions

The variance values of ln (K_s) for the cultivated (clay to clay loam) and virgin (loam) sites were 10.3 and 4.2 $cm^2 h^{-2}$, respectively, and the variance values of ρ_b were 7.3 x 10^{-3} and 7.6 x $10^{-3} g^2 cm^{-6}$, respectively. The variability in K_s in the surface layers of both virgin and cultivated field soils was high. The use of small core samples and measuring K_s in laboratory may further increase this variability. The variability in cultivated fields may be increased by agricultural traffic and field operations. Use of larger undisturbed soil samples or measuring K_s in field may result in small variability in K_s.

The measured mean bulk density values in the cultivated and virgin fields were 1.22 and 1.51 g cm^{-3}, respectively. The greater bulk density values occurred in the locations of virgin field than in cultivated locations. Although overall variability in ρ_b was small, the variability was large in two cultivated locations due to compaction caused by tillage.

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