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Water Infiltration Characteristics into Soil Profile as Influenced by Different Tillage Practices

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Abstract: A three year (1996-1998) study was conducted at Epemakinde, a rainforest zone of Southwestern Nigeria to assess the influence of different tillage practices viz: conventional (CT), minimum (MT) traditional (TT) and zero (ZT) on soil infiltration rate, sorptivity and transmissivity. The adjoining natural forest (NF) was also incorporated as the fifth treatment (control). All the treatments were treplicated and within each plot, a series of six infiltration runs (tests) was carried out. Results obtained demonstrated that infiltration rate, sorptivity and transmissivity were generally higher in FT and ZT plots than the tilled plots. This implies that zero tilled treatment had improved infiltration characteristics with time than the tillage treatments. Moreover, surface runoff and nutrient loss would be higher in tilled soil than the zero tillage and this has implication for water management. Kostiakov's model generally had relatively higher values than the Philip's model, suggesting that the infiltration process in these soils was better described by the former model than the later.

Key words: Tillage practices · Infiltration rate · Sorptivity · Transmissivity · Rainforest zone

INTRODUCTION

Tillage, defined as the physical, chemical or biological manipulation of the soil in order to optimize conditions for enhanced crop production [1] has been used in many agro-ecologies. However, some tillage operations are reported to be capable of inducing profound changes in soil physico-chemical status. Matula [2] reported that tillage operation could have both favourable and unfavourable effects on different physical properties of topsoil. It has been observed that when tillage treatments are carried out, especially on the wet soil, stable soil aggregates are crushed or smeared, macro porosity is decreased and puddled soil is created [2]. This action exposes organic matter that was protected inside the aggregates, accelerating its loss by decomposition [3]. Some studies have shown that aggregation and the associated desirable soil physical properties (bulk density, porosity, degree of aeration, capillary water capacity and others) and hydro-physical properties related to infiltration rate decline after long periods of tilled row-crop cultivation [4].

On a loessial soil, Ehlers [5] observed that due to a continuous macro-channel system connecting the soil surface with the subsoil, infiltrability was enhanced in untilled soil, but in the tilled soil, water was held in upper soil layers where the depth of infiltration depended more on time and initial water content of the soil. Studies by Lal [6,7] revealed a better water infiltrability under no till system than ploughed system and the mean infiltration rate for no till soil was three times that of tilled soil. Some other studies [8,9] have also confirmed higher infiltration rates for no tillage than for tilled treatment and attributed this to higher population of earthworm in the no tillage plots compared to the tilled plot.

Influence of tillage on macroporosity and infiltration have been reported not only to follow a trend, but also to vary with previous weather conditions and result of cultural practices [10]. Infiltration rates under no tillage (with or without cultivation) compared with tilled treatments (e.g. mould-board, chisels or roto-tilled) for some soils may be faster [11,12], slower [13,14] or not significantly different [15]. The presence or absence of surface seals and/or surface-connected macropores appear to have the greatest influence on the ability to detect significant tillage differences infiltration [11,12]. Another factor affecting infiltration under no tillage had been noted to be consolidation of the soil

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surface due to raindrop impact before crop cover is established [16]. Traffic-induced soil compaction may also reduce infiltration rate under no tillage [16] whereas recently tilled soil has rapid infiltration under it is settled by rainfall.

Against this contrasting and seemingly location specific findings, a study was conducted to evaluate the influence of some tillage practices on infiltration rate, sorptivity and transmissivity in Epemakinde, a rainforest agro-ecology of Southwestern Nigeria.

MATERIALS AND METHODS

Description of the Study Site: The trial was conducted bring in 1996-1998 on a 2-hectare land of the IBSRAM's experimental field located at the Ondo State Afforestation Project site in Epemakinde (4°45\ E and 6°45\ N), Southwestern Nigeria. Epemakinde is a forested area underlain by a sedimentary deposit of coastal plain sands. The soils are Ultisols and Alfisols [17], slightly to fairly acidic (pH 4.9-6.7), medium textured (sandy loam to sandy clayey loam top and sandy loam to sandy clayey below and moderately well structure (granular/crumb top and sub-angular blocky below). The farming system practiced in the area is shifting cultivation and the cropping system is mainly tree crop based-kola (*Cola nitida* (Ventenat) Schott and Endicher), cocoa (*Theobroma cacao* L.) and rubber (*Hevea brasiliensis* (Mull and Aurg) with some arable crops-maize (*Zea mays* L.), cassava (*Manihot esculenta* Crantz), cocoyam (*Xanthosoma* spp. / *Colocasia* spp.) and plantain/banana (*Musa* spp.). The rainfall pattern is bimodal with long (April-August) and short (August-November) rainy seasons separated by a short dry spell of uncertain length, usually during the month of August. The mean daily temperature ranges from 25°C-37 °C and the annual temperature is 24°C-26°C [17], while relative humidity ranged between 65 and 80 %. The field plot used for the trial was under high forest (over 70 years old) until 1994 when different bush clearing techniques (Bulldozed, Bulldozed-not windrowed and Slash and burn) trials were carried out. Detailed description of the trials has been documented by Eneji *et al.* [18] and Aiyelari and Agboola [19]. In 1995, tillage experiment was initiated and imposed across the bush clearing methods.

Experimental Design: The experiment was set up as a randomized complete block design (RCBD) with four tillage treatments and three replications. The tillage treatments consisted of Minimum (MT), Conventional (CT), Traditional (TT) and Zero (ZT). Throughout the investigation period, the MT and CT plots were prepared with a tractor mounted disc plough, that is, ploughed once (at about 25 cm soil depth), but the CT plots were further harrowed (at about 25 cm soil depth) once while the MT plots were not harrowed. Plots that received ZT treatment had no mechanical manipulation of the soil, but only involved manual clearing (with machete), followed by burning of the residues after drying. Traditional tillage treatment involved manual clearing as in ZT, followed by the making of mounds prepared with traditional (native) hoe. The tillage treatments were randomly assigned to the plots at the beginning of the study and retained in the same locations throughout the duration of the study. Each replication was separated from the other by a 4 m alley way while interplot spacing was 3 m. The adjoining natural forest (NF) was also incorporated as a treatment to serve as a control (a check) and equally replicated three times.

Double ring inflitrometer (30; 50 cm inner and outer diameter) and method as described by Anderson and Ingram [20] was used. A series of six infiltration runs (tests) were conducted on plot basis at 1, 2 and 4 months after planting (MAP). At each spot, samples were collected at 0-15 and 15-30 cm soil depths for gravimetrical determination of initial soil moisture content. Infiltration data generated were fitted into (i) Kostiakov's [21] and (ii) Philip's [22] infiltration models and analyzed to estimate the sorptivity and transmissivity of the soil thus:

The Philip's Model:

$$I = St\ \tfrac{1}{2} + At \qquad (1)$$

Where I = Cumulative infiltration (cm)
S = Soil water sorptivity (cm hr^{-1})
A = Constant considered as an intercept (soil water transmissivity-cm hr^{-1})
t = Time elapsed (minutes)

To estimate S and A parameters, both sides of Equation 1 were divided by $t^{½}$ [23] giving:

$$1/t\ \tfrac{1}{2} = At^{\frac{1}{2}} + S \qquad (2)$$

A plot of $1/t^{½}$ against $t^{½}$ is a straight line with S as the intercept and A, the slope.

The Kostiakov's model:

$$I = Kt^a \tag{3}$$

Where I = Cumulative infiltration (cm)
K = A soil-dependent parameter which is closely related to the transmission characteristics of the soil.
a = Another soil-dependent parameter whose value varies between 0 and 1.
t = Time elapsed (minutes)

To estimate these parameters Equation 3 was linearised [23] thus:

$$\log_{10} I = a \log t + \log_{10} K \tag{4}$$

A plot of $\log_{10}$ I against $\log_{10} t$ give $\log_{10} K$ as the intercept and as the slope from where the actual value of K can be obtained. The cumulative infiltration was obtained after equilibrium state by differentiating Equation 1 to obtain

$$dl/dt = i = \tfrac{1}{2} St^{-\frac{1}{2}} + A \tag{5}$$

where I = instantaneous infiltration rate at time, t. The lowest value of I is the equilibrium infiltration rate, which has practical implications for water management studies. The Duncan multiple range test was used to separate the mean and the treatments [24].

RESULTS

Figures 1 to 6 and Tables 1 and 2 indicate that soil water infiltration and transmission characteristics as influenced by different tillage practices. Tillage practices had significant effect on initial infiltration rate (at 1 minute), instantaneous infiltration rate (at 1 hour), final infiltration rate, cumulative infiltration rate (after 180 minutes) and time to attain equilibrium infiltration (Figures 1 to 3 and Table 1). Throughout the study period, the rates of infiltration and cumulative infiltration were generally higher in FR than other treatments (Figures 1 to 6) but among the cropped plots, ZT plot had higher rates of infiltration.

In 1996, the initial infiltration rate (Table 1) ranged from 80 cm hr^{-1} in both CT and TT to 320 cm hr^{-1} in FR at 1 month after planting (MAP); from 84 (MT) to 240 cm hr^{-1} (FR) at 2 MAP; and from 70 (CT) to 200 cm hr^{-1} (FR) at 1, 2 and 4 MAP, respectively. Among the cultivated plots, ZT exceeded that of CT, MT and TT by 50, 38 and 50%, respectively at 1 % probability level in FR (280 cm hr^{-1}) and lowest in both CT and TT (136 cm hr^{-1}) at 1 MAP. At 2 MAP, it ranged from 136 to 272 cm hr^{-1} in TT and FR, respectively. While it ranged from 104 to 360 cm hr^{-1} in TT and FR, respectively at 4 MAP. Comparing the cropped plots, the result indicated that ZT had higher initial infiltration rate than CT, MT and TT by about 32, 28 and 32% at 1 MAP. At 2 MAP, ZT exceeded CT, MT and TT by about 28, 33 and 37%, respectively whereas at 4 MAP, MT was higher than CT, TT and ZT by about 20, 26 and 3%, respectively. During the 1998 cropping cycle, initial infiltration rate was significantly highest in FT (320 cm hr^{-1}) and lowest in CT (140 cm hr^{-1}) at 1 MAP; at 2 MAP, CT (160 cm hr^{-1}) had the lowest infiltration rate while FR (306 cm hr^{-1}) had the highest. At 4 MAP, it ranged from 134 (MT) to 200 cm hr^{-1} (FR). Among the cultivated plots, ZT exceeded CT, MT and TT by 30, 20 and 18% at 1 MAP; 27, 18 and 11% at 2 MAP; and 26, 27 and 13% at 4 MAP. The Infiltration rate was generally highest at the onset whereas general reduction in water intake with time was observed in all the treatments. Similar trends were observed in the following years (1997 and 1998).

Instantaneous infiltration rate almost followed the pattern observed in initial infiltration rate (Table 1). In 1996, instantaneous infiltration was significantly highest in FR (160 cm hr^{-1}) and lowest one in TT (42 cm hr^{-1}) at 1 MAP. At 2 MAP, it ranged from 50 cm hr^{-1} in both CT and TT to 120 cm hr^{-1} in FR; and at 4 MAP, it ranged from 36 (TT) to 120 cm hr^{-1} (FR). Among the cultivated plots, ZT treatment superseded other tillage practices by 43 to 66 % at 1 MAP, whereas at 2 and 4 MAP, it was higher in MT than other tillage treatments by 3 to 31 % and 7 to 38 %, respectively. In 1997, the highest instantaneous infiltration rate was observed in CT (180 cm hr^{-1}) and the lowest in ZT (72 cm hr^{-1}) at 1 MAP. At 2 MAP, it ranged from 116 cm hr^{-1} in TT to 204 cm hr^{-1} in FR; at 4 MAP, it was significantly highest in FR (206 cm hr^{-1}) and lowest in TT (56 cm hr^{-1}). Among the cropped plots, CT had higher instantaneous infiltration rate than other treatments by 50 to 60 % at 1 MAP. At both 2 and 4 MAP, ZT exceeded other tillage practices by 20 to 29 % and 17 to 52 %, respectively. In 1998, the instantaneous infiltration rate ranged from 100 (CT) to 240 cm hr^{-1} (FR) at 1 MAP.

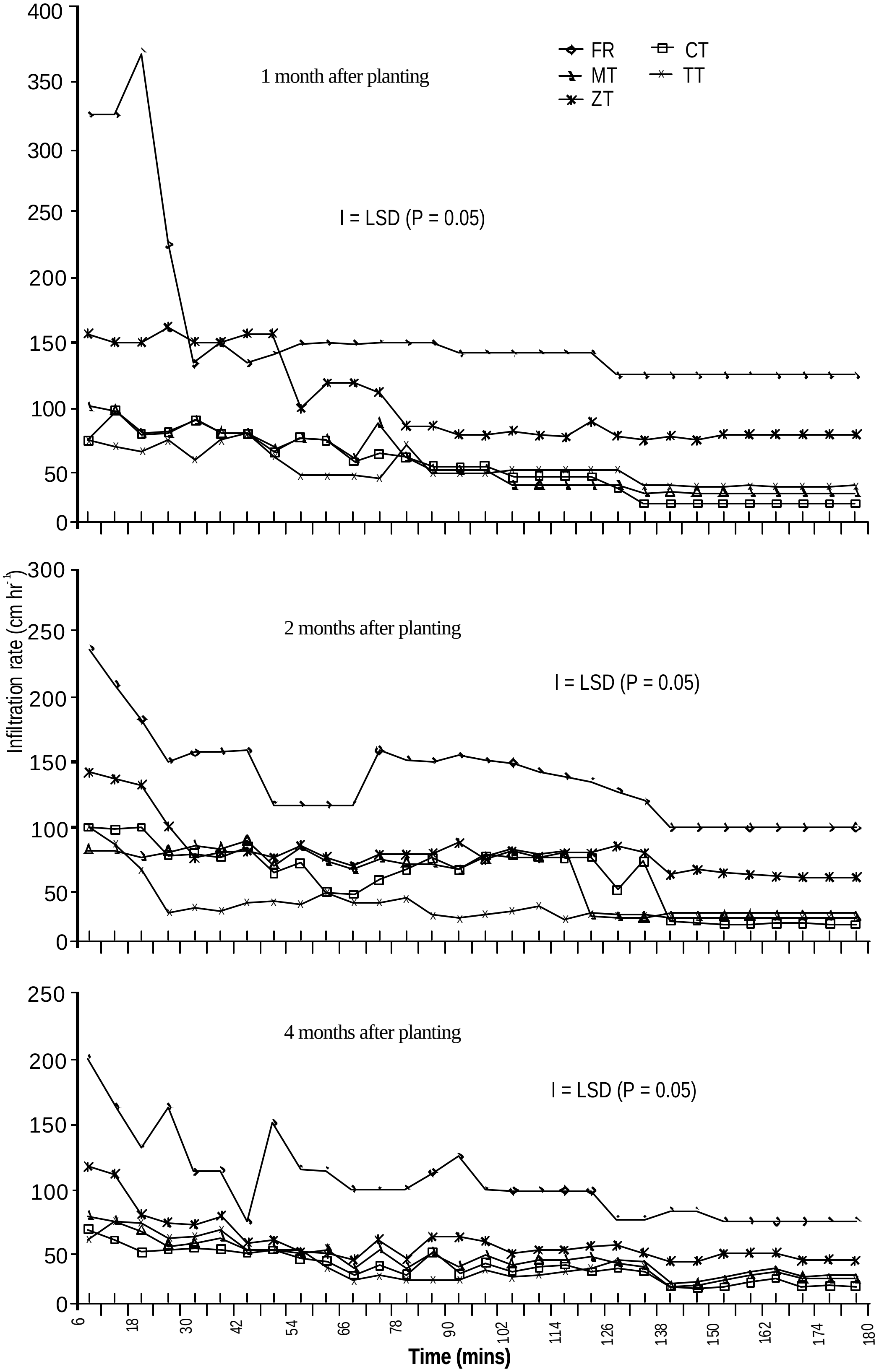

Fig. 1: Effect of tillage practices on infiltration rate in 1996

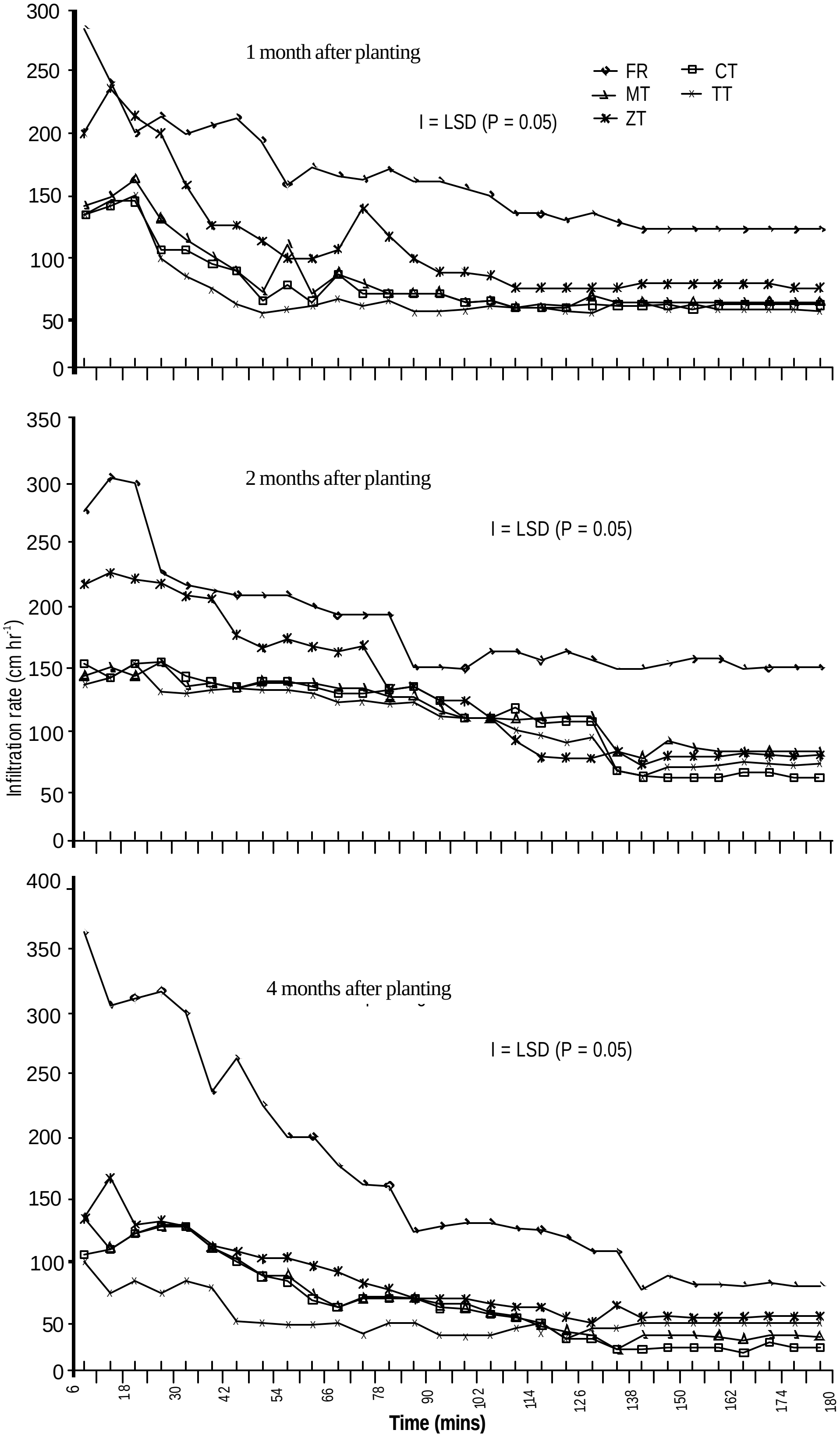

Fig. 2: Effect of tillage practices on infiltration rate in 1997

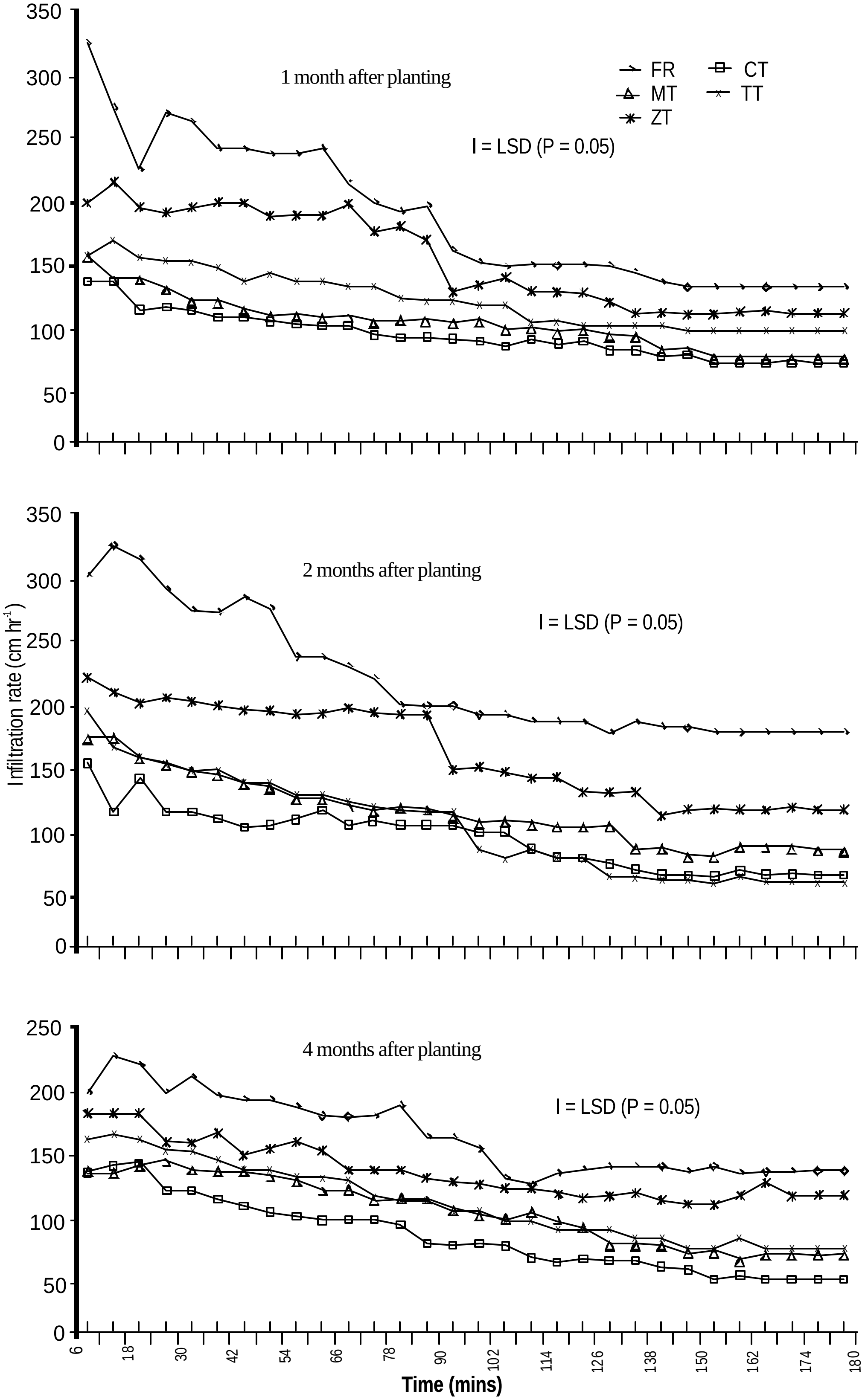

Fig. 3: Effect of tillage practices on infiltration rate in 1998

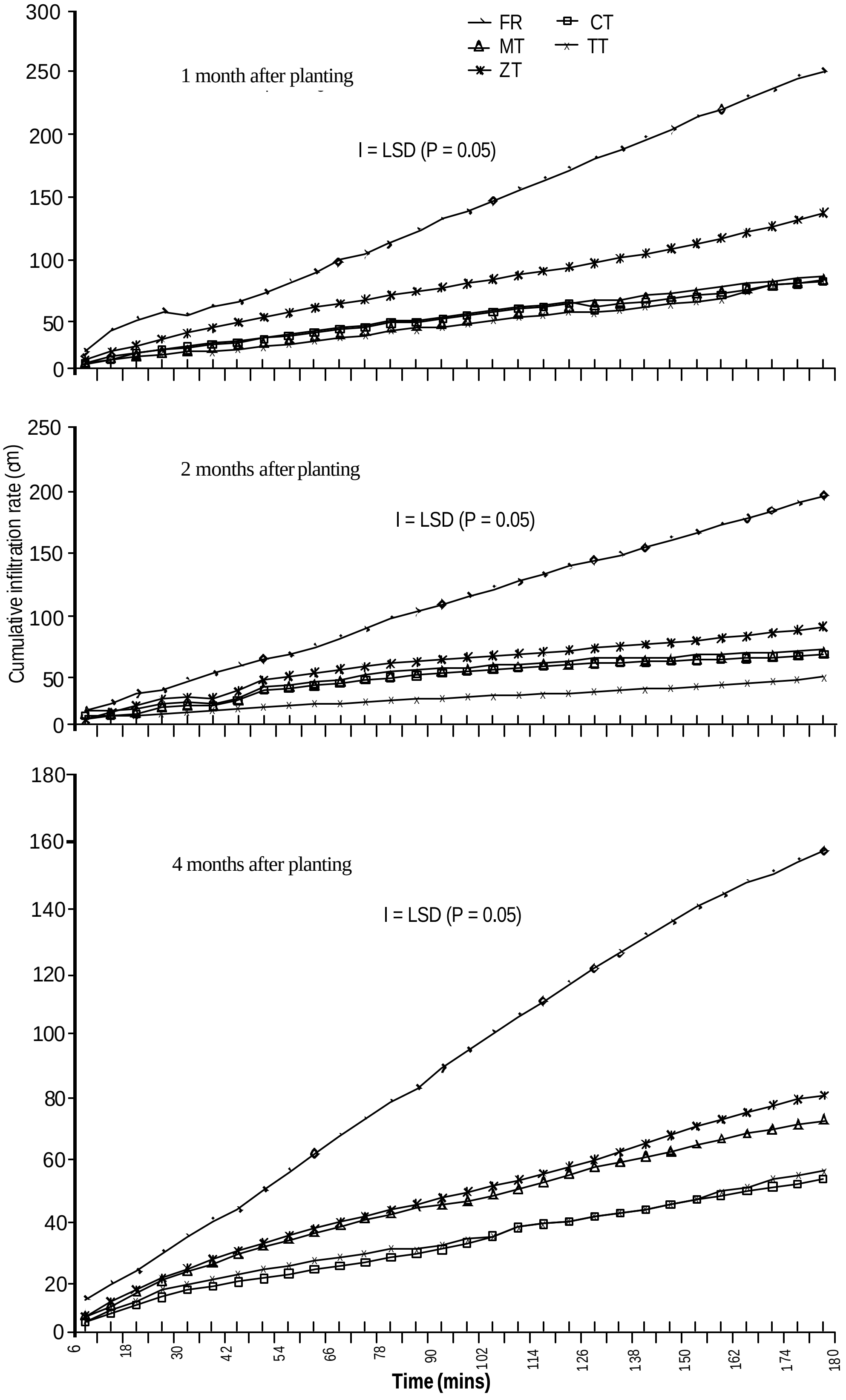

Fig. 4: Effect of tillage practices on infiltration rate in 1996

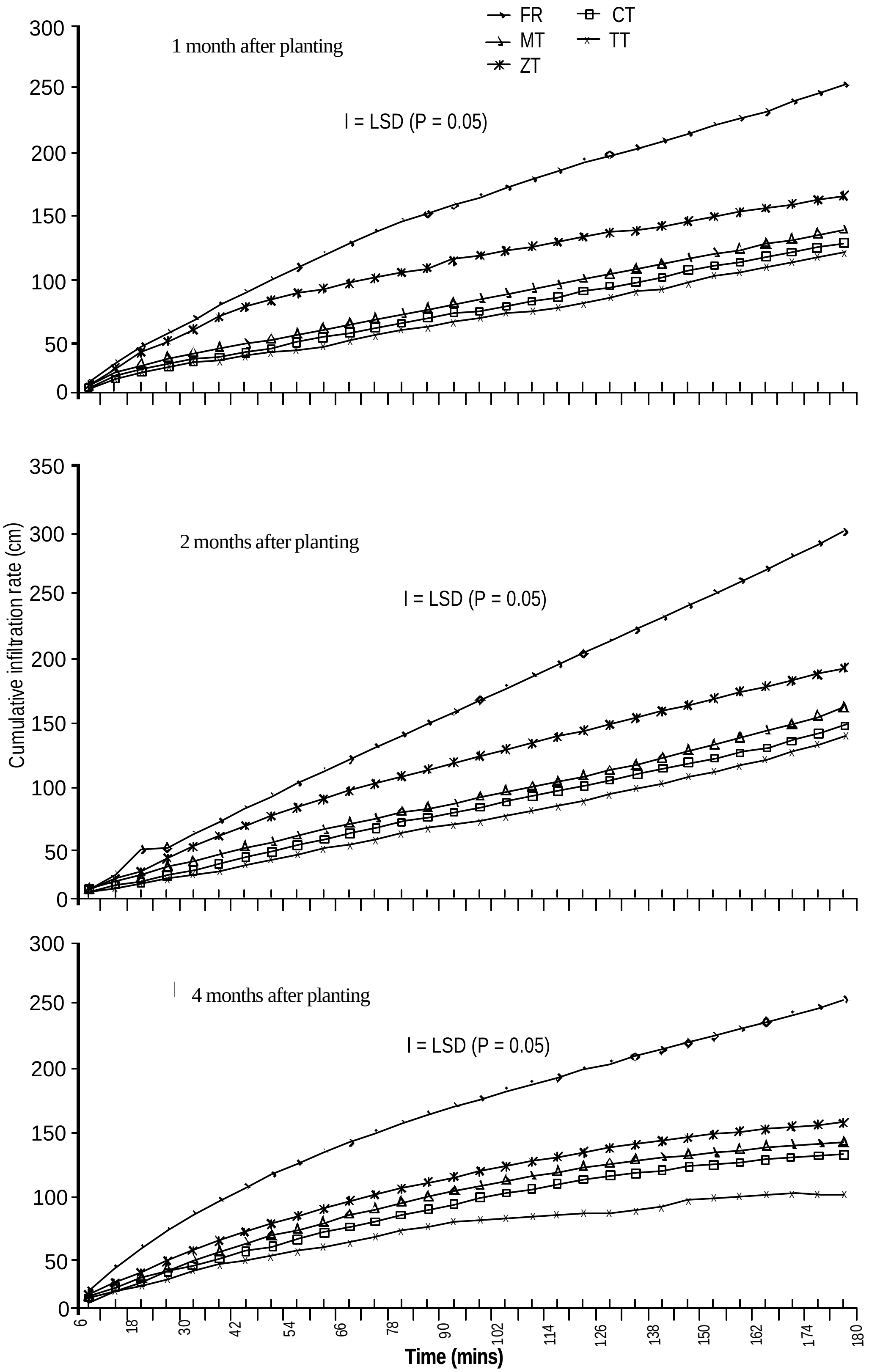

Fig. 5: Effect of tillage practices on infiltration rate in 1997

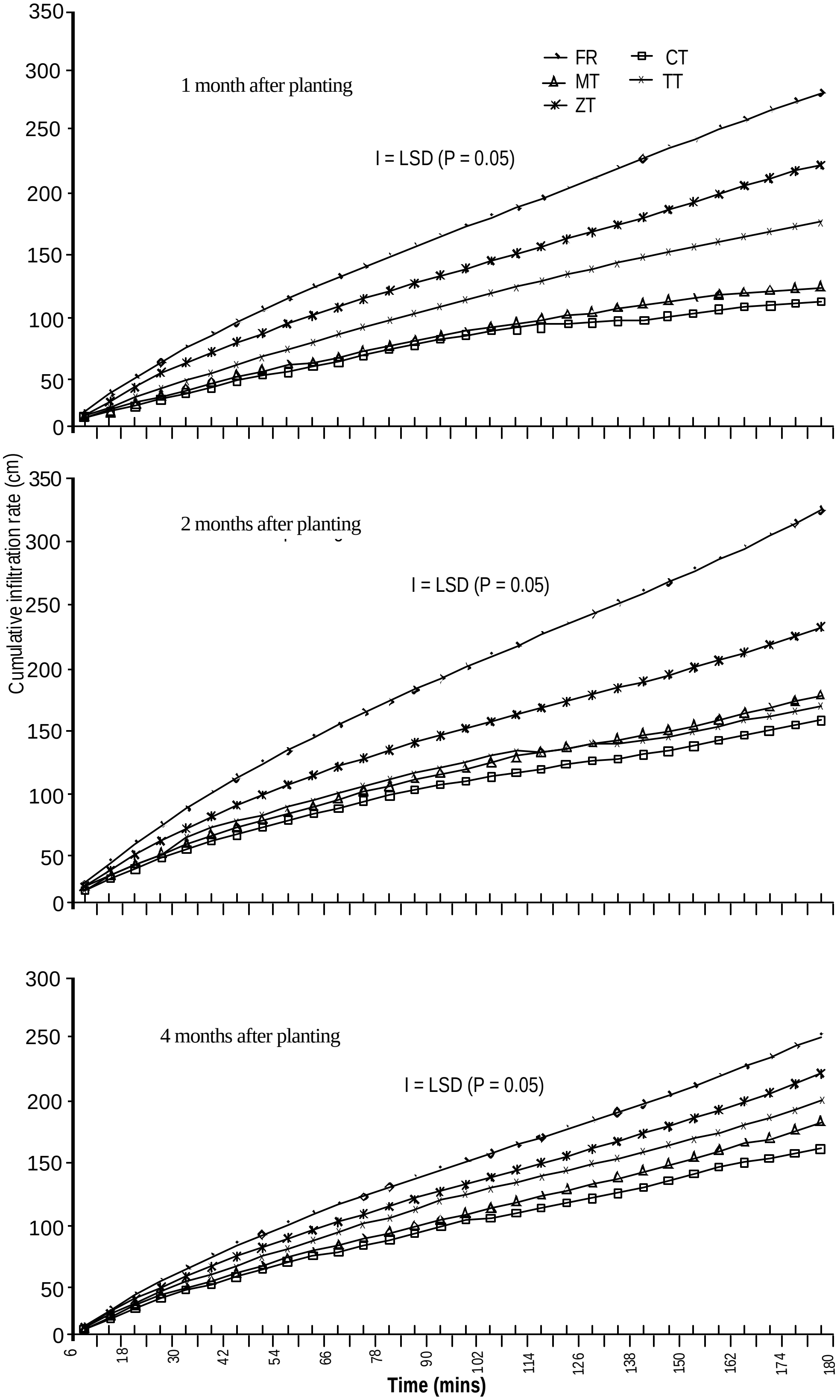

Fig. 6: Effect of tillage practices on infiltration rate in 1998

Table 1: Effect of tillage practices on water infiltration characteristics

Year	Tillage practice	Initial infiltration rate at 1 min (cmhr^{-1})			Instantaneous rate at 1 hr (cm)			Cumulative infiltration rate (cm) at 180 minutes			Equilibrium infiltration rate (cmhr^{-1})			Time to attain equilibriuminfiltration(min)		
		Months after planting														
		1	2	4	1	2	4	1	2	4	1	2	4	1	2	4
	Conventional	80c*	96bc	70c	68c	50b	42b	73.0c	72.5b	52.8c	16d	12c	16c	132b	150a	150a
	Minimum	100c	84c	82c	70c	72b	58b	82.3c	74.6b	71.6b	30c	22c	26c	156a	150a	156a
1996	Traditional	80c	100b	64c	42d	50b	36b	74c	53c	57.1c	40c	20c	28c	162a	138b	150a
	Zero	160b	144b	120b	122b	70b	54b	155.8b	98.9b	87.4b	70c	42b	48b	156a	150a	156a
	Forest	320a	240a	200a	160a	120a	120a	249.5a	201.1a	162.4a	120a	102a	86a	162a	156a	168a
	Conventional	136c	156d	112c	180a	132b	84c	121.3b	154.3bc	108.2b	56c	42c	32c	132b	144b	150b
	Minimum	144c	144d	140c	84c	130b	96c	132.4b	167.8b	117.7b	66c	72b	42b	144b	156a	144b
1997	Traditional	136c	136d	104c	90c	116c	56d	111.0b	149.8c	88.3c	54c	64b	46b	156b	150b	144b
	Zero	200b	216b	136b	72c	164b	116b	173.9b	195.8b	136.1b	88b	68b	58b	150b	162a	168a
	Forest	280a	272a	360a	106b	204a	206a	245.4a	295.7a	251.3a	120a	114a	88a	162a	162a	174a
	Conventional	140d	160d	136c	100c	112d	100d	130.5d	138.8d	127.6d	64d	62cd	48d	150b	144b	150c
	Minimum	160c	180c	134c	110c	124c	124c	149.6d	172.8c	162c	72d	80c	72c	156b	150b	156c
1998	Traditional	164c	196c	160b	140c	136c	136c	179.6d	156.0c	174.5c	90c	52d	84c	156b	150b	162b
	Zero	200b	220b	184b	184b	190b	156b	227.3b	237.1b	203.3b	112b	116b	108b	162ab	156b	168b
	Forest	320a	306a	200a	240a	248a	184a	293.8a	325.0a	243.0a	140a	164a	128a	174a	168a	174a

* Values followed by the same letters are not significantly different according to Duncan Multiple Range Test at 5% level of probability

Table 2: Effect of tillage practices on water transmission characteristics

Year	Tillage practice	Sorptivity (S)[1] (cm min^{-1})			Transmissivity[1] (A) (cm min^{-1})			Kostiakov's (A)			Constants (B)			Correlation coefficient (R^2) Philip's model			Correlation coefficient (R^2) Kostiakov's model		
		Months after planting																	
		1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4
	Conventional	3.14c*	3.43c	2.09c	0.60b	0.56b	0.44b	0.81a	0.77b	0.80a	2.20c	2.57c	1.63d	0.77c	0.81c	0.85b	0.96a	0.97a	0.98a
	Minimum	3.07c	3.04c	2.91c	0.68b	0.63b	0.58b	0.81a	0.83a	0.81a	2.42c	2.12c	2.10c	0.88b	0.76c	0.81b	0.96a	0.96a	0.97a
1996	Traditional	2.13d	3.16c	2.92c	0.62b	0.29c	0.37c	0.82a	0.67c	0.77ab	1.84d	2.67c	1.99d	0.96a	0.90b	0.69c	0.98a	0.98a	0.94b
	Zero	5.17b	4.74b	3.57b	1.33a	0.66b	0.62b	0.84a	0,73b	0.75b	3.87b	3.85b	3.01b	0.86b	0.90b	0.96a	0.97a	0.98a	0.96a
	Forest	10.83a	5.49a	4.45a	1.74a	1.74a	1.41a	0.76a	0.82a	0.82a	8.64a	5.20a	4.18a	0.92ab	0.98a	0.98a	0.98a	0.98a	0.98a
	Conventional	4.14b	4.02c	3.91b	0.99c	2.44a	0,96b	0.81a	0.81b	0.84a	3.38b	3.38b	2.83c	0.94ab	0.90a	0.83c	0.97a	0.97a	0.96a
	Minimum	4.61b	2.91d	4.36b	1.06b	1.52b	0,98b	0.81a	0.91a	0.81a	3.67b	3.01b	3.36b	0.92ab	0.96a	0.86c	0.96a	0.98a	0.97a
1997	Traditional	4.43b	3.35c	2.97d	0.81c	1.70b	0.71b	0.77a	0.89a	0.81a	3.60b	3.02b	2.41c	0.94ab	0.94a	0.92a	0.97a	0.98a	0.96a
	Zero	7.06a	7.45b	4.38b	1.27b	1.45b	1.18a	0.78a	0.82b	0.84a	5.51a	5.51a	3.43b	0.90b	0.85b	0.90a	0.96a	0,96a	0.94a
	Forest	6.45a	9.55a	13.59a	2.19a	1.64b	1.64a	0.84a	0.91a	0.74b	5.90a	4.36a	9.99a	0.96a	0.92a	0.74d	0.98a	0.90b	0.98a
	Conventional	3.56b	3.60d	4.1b	1.16b	1.27b	1.11c	0.84a	0.87bc	0.83b	3.15c	3.30c	3.31bc	0.96a	0.96a	0.90b	0.98a	0.98a	0.97a
	Minimum	3.64b	3.5d	2.52c	1.37b	1.68b	1.67b	0.85a	0.85bc	0.93a	3.38c	4.00b	2.72c	0.96a	0.90b	0.96a	0.97a	0.95a	0.98a
1998	Traditional	3.70b	6.09b	3.76b	1.72b	1.29b	1.67b	0.90a	0.85bc	0.89a	3.44c	4.68b	3.48b	0.96a	0.85c	0.96a	0.98a	0.96a	0.98a
	Zero	4.01b	4.73c	3.70b	2.29a	2.32a	1.99b	0.90a	0.81c	0.90a	4.27b	4.55b	3.82b	0.94a	0.96a	0.98a	0.98a	0.97a	0.98a
	Forest	7.50a	8.16a	4.58a	2.68a	2.95a	2.37a	0.85a	0.90a	0.91a	6.76a	7.03a	4.30a	0.96a	0.94ab	0.94b	0.98a	0.98a	0.98a

[1] Obtained by analysis of Philip's (1957) infiltration model.

* Within the same column, values followed by the same letters are not significantly different $p < 0.05$ using Duncan's Multiple Range Test.

At 2 MAP, it ranged from 112 (CT) to 248 cm hr^{-1} (FR) while at 4 MAP, the range was from 100 (CT) to 240 cm hr^{-1} (FR) at 1 MAP. At 2 MAP, the range was from 112 cm hr^{-1} in CT to 248 cm hr^{-1} in FR while at 4 MAP, it ranged from 100 cm hr^{-1} in CT to 184 cm hr^{-1} in FR. This indicates that among the cropped plots, ZT was higher than others by 24 to 464% at 1 MAP, 28 to 41 at 2 MAP and 13 to 36 % at 4 MAP.

The cumulative infiltration rate (Figures 4 to 6) showed that in 1996, FR had the highest values at 1 (249.5 cm), 2 (201.1 cm) and 4 (162.4 cm) MAP while the lowest values were observed in CT (73 cm) at 1 MAP, TT (53 cm) at 2 MAP and CT (52.8 cm) at 4 MAP. Comparing all the cropped plots, the results revealed that ZT exceeded others by 53% at 1 MAP, 25 to 46 % at 2 MAP; and 18 % at 4 MAP. In 1997, cumulative infiltration rate ranged from 111 cm hr^{-1} in TT to 245.4 cm hr^{-1} in FR at 1 MAP; 154.3 cm hr^{-1} in CT to 295.7 cm hr^{-1} at 2 MAP; and 88.3 cm hr^{-1} in TT to 251.3 cm hr^{-1} in FR at 4 MAP (Figure 5). This indicated that among the cropped plots, ZT accumulated more water than other treatments by 24 to 36% at 1 MAP; 14 to 23% at 2 MAP; and 14 to 35% at 4 MAP. In 1998, FR had the highest cumulative infiltration rate at 1, 2 and 4 MAP with values 293.8, 325.0 and 243.0 cm hr^{-1}, respectively, while the lowest values were all observed in CT (130.5, 138.8 and 127.6 cm hr^{-1}) during the corresponding months (Figure 6). This means that among all the cropped plots, ZT was higher than others by 21 to 43 %, 37 to 41 % at and 20 to 37 % at 1, 2 and 4 MAP.

In 1996, the lowest equilibrium infiltration rates (Table 1) at 1 (16 cm hr^{-1}), 2 (12 cm hr^{-1}) and 4 (16 cm hr^{-1}) MAP were obtained in CT while the highest ones were observed in FR (120, 102 and 86 cm hr^{-1} for the corresponding months). Among the cultivated plots, ZT had the highest equilibrium rate, exceeding others by 43 to 77%, 48 to 71 at and 42 to 67% at 1, 2 and 4 MAP, respectively. In 1997, the equilibrium infiltration rate ranged from 54 (TT) to 120 cm hr^{-1} (FR) at 1 MAP. At both 2 and 4 MAP, it ranged from 42 and 144 cm hr^{-1} in CT to 32 and 88 cm hr^{-1} in FR. Within cropped plots, ZT superseded others by 25 to 39 % (1 MAP) and 21 to 45 % (4 MAP). At 2 MAP, MT was higher than others by 6 to 42 %. In 1998, the equilibrium infiltration rate ranged form 64 in CT to 140 cm hr^{-1} in FR at 1 MAP; 52 in TT to 164 cm hr^{-1} in FR at 2 MAP; and 48 in Ct to 128 cm hr^{-1} in FR at 4 MAP. Among the cropped plots, ZT, which had the highest equilibrium infiltration rate at the three sampling intervals, exceeded the others by about 20-43 % at, 31-55% and 22-56% at 1, 2 and 4 MAP, respectively.

The time taken to attain steady-state (equilibrium) only differed significantly at 1 and 2 MAP in 1996 (Table 1). At 1 MAP, it ranged from 138 in TT to 156 minutes in FR. In 1997, the time taken attain equilibrium infiltration differed significantly throughout the sampling intervals. It ranges from 132 (CT) to 162 minutes (FR) at 1 MAP, 144 (CT) to 162 minutes in both FR and ZT; and 144 in both MT and TT to 174 minutes in FR at 4 MAP. The time taken to attain steady-state infiltration also differed significantly in 1998. It was significantly lowest in CT (150, 144 and 150 minutes) and highest in FR (174, 168 and 174 minutes at the three sampling intervals. The results also revealed that ZT took more time to attain equilibrium infiltration among the cropped plots, during most of the intervals.

Results of infiltration data fitted to Philip [22] and Kostiakov [21] models indicated that there were significant differences (Table 2) among the studied tillage practices. Sorptivity of soil water (S) was highly significant in FR with values 10.83, 5.49 and 4.45 cm min^{-1} at 1, 2 and 4 MAP, respectively in 1996. The lowest values were observed in TT (2.13 cm min^{-1}) at 1 MAP; MT (3.04 cm min^{-1}) at 2 MAP and in CT (2.09 cm min^{-1}) at 4 MAP. Among the cultivated plots, ZT exceeded other tillage practices by 39-59%, at 1 MAP, 28-36 % and 18-41% at 1, 2 and 4 MAP, respectively. In 1997, sorptivity also differed significantly. It ranged from 4.14 in CT to 6.45 cm min^{-1} in FR at 1 MAP; 3.35 in TT to 9.55 cm min^{-1} in FR at 2 MAP; and 2.97 in TT to 13.59 cm min^{-1} at 4 MAP. These indicated that among the cropped plot, ZT was higher than the others by 35-41% at 1 MAP; 46-61% at 2 MAP; and 0.5-32 % at 4 MAP. During the 1998 cropping cycle, sorptivity ranged from 3.56 in CT to 7.50 cm min^{-1} in FR; 3.55 in MT to 8.16 cm min^{-1} in FR and 2.52 in MT to 4.58 cm min^{-1} at 1, 2 and 4 MAP, respectively. This revealed that ZT superseded other cropped plots by 8-11% at 1 MAP. Contrastingly, TT was higher than other cropped plots by 22-41% at 2 MAP whereas at 4 MAP, CT treatment exceeded the others by 10-39%.

Similarly, transmissivity of soil water (A) also differed significantly among tillage practices (Table 2). In 1996, it ranged from 0.60 (CT) to 1.74 cm min^{-1} in FR; 0.29 (TT) to 1.74 cm min^{-1} (FR) and 0.37 (TT) to 1.44 cm min^{-1} in FR at 1, 2 and 4 MAP, respectively. In 1997, it ranged from 0.81 (TT) to 2.19 (FR); 1.45 (ZT) to 2.44 cm min^{-1} (CT) and p.71 (TT) to 1.64 cm min^{-1} (FR) at the same sequences. In 1998, the maximimum values of transmissivity were 2.68 and 2.95 cm min^{-1} in FR at 1 and 2 MAP while the minimum ones were 1.16 and 1.27 in CT at 1 and 2 MAP, respectively. At 4 MAP, the treatments were statistically similar but ranged from 0.84 in CT to 0.90 cm min^{-1} in both TT and ZT. These demonstrated that among the cropped plots, ZT had higher soil transmissivity than other treatments by 49-55%; 5-56% and 6-40 % at 1, 2 and 4 MAP, respectively (1996). In 1997, ZT plots exceeded other cropped plots by 17-36% at 1 MAP and 17-14% at 4 MAP, whereas at 2 MAP, CT exceeded the others by 30-41%. In 1998, ZT exceeded others by 25-49 %; 28-45% and 16-44% at 1, 2 and 4 MAP, respectively. Kostiakov's constant B was statistically similar at 1 MAP but at 2 MAP, it was highest in MT (0.83) and lowest in TT (0.67) while at 4 MAP, it ranged from 0.75 in ZT to 0.82 in FR. This shows that ZT was higher than other cropped plots by 1 to 10% at 1 MAP whereas at both 2 (1 to 19%) and 4 (1 to 7%) MAP, MT indicated higher values than other cropped plots. In 1997, it ranged from 0.77 in TT and ZT to 0.74 in FT at 4 MAP. Among the cropped plots, both CT and MT exceeded others by 4 to 5% at 1 MAP. At 2 MAP, MT was higher than other cropped plots by 2 to 11% while at 4 MAP, both CT and ZT were higher than MT and TT by 4%. In 1998, there was no significant difference among the treatments at 1 MAP. At 2 MAP, it ranged from 0.81 in ZT to 0.90 in FR while at 4 MAP, it ranged from 0.83 in CT to 0.93 in MT. This revealed that at 1 MAP, both TT and ZT were higher than TT and CT by 6 to 7% while CT and MT exceeded other cropped plots by 2 to 7% at 2 MAP and 3 to 11% at 4 MAP, respectively.

Kostiakov's constant K also differed significantly among tillage treatments (Table 2). In 1996, the range was from 1.84 in TT to 8.64 in FR at 1 MAP; 2.12 in MT to 5.20 in FR at 2 MAP; and 1.63 in CT to 4.18 in FR at 4 MAP. This indicates that among cropped plots, ZT treatment was higher than others by 37-52 %; 31-45 % and 30-46 % at the same sequence. In 1997, Kostiakov's constant K was significantly highest in FR (5.90) and lowest in CT (3.38) at 1 MAP. At 2 MAP, it ranged from 3.01 in MT to 5.51 in ZT whereas at 4 MAP, it ranged from 2.41 in TT to 9.99 in FR. This reflects increases ranging from 33 to 39, 39 to 45 and 2 to 32% by ZT at 1, 2 and 4 MAP, respectively over other cropped plots. In 1998, it ranged from 3.15 in CT to 7.03 in FR at 2 MAP and 2.72 in MT to 4.30 in FR at 4 MAP. This indicates that among the cropped plots, ZT superseded others by 19 to 26% at 1 MAP; 3 to 29% at 2 MAP; and 9 to 29% at 4 MAP. There were significant differences in the coefficient of dependability (R^2) for both Philip's and Kostiakov's models (Table 2). However, it was observed that Kostiakov's model generally had relatively higher values than Philip's model, suggesting that the infiltration process is better described by Kostiakov's model than the Philip's model.

DISCUSSION

Infiltration and cumulative infiltration rates were generally higher in FR than other treatments. Among the cropped plots, ZT had higher rates of infiltration. The rates however reduced with years of cultivation in the cropped plots. Zero tillage also had the highest equilibrium infiltration among the plots during most of the sampling intervals. This could be attributed to many factors such as initial moisture content, higher soil organic matter and biological activities (which were higher in FR and ZT than the tilled treatments), better pore size distribution and continuity and compaction or crust formation of the subsurface layer in the ploughed-based treatments. Differences in soil surface infiltration due to tillage treatments had been reported to vary with time due to surface seal formation after heavy rains and soil cracking under drying conditions [10]. The initial and instantaneous infiltration rates in FR and ZT plots at all sampling intervals were observed to be faster than in tilled treatments. Ehlers [25] found that water infiltration through macro-channel created by earthworms indicated free water in zero till soil down to 180 cm depth while in tilled soil, no channel was able to accept and conduct free water. A better infiltrability in ZT system than tilled one had also been reported by Lal [6,7] where the mean infiltration rate for no till soil was three times that of tilled ones. Similarly, findings from studies conducted elsewhere [8] indicated that ZT and infiltration rates than the tilled systems. This was due to higher population of earthworms in ZT compared to the tilled systems. Earthworm channels have been found to be more continuous, less tortuous and more stable than macro-pores created during tillage [26] and hence more effective in providing pathways for water and air movement through the profile. Similar conclusions were also drawn from studies [27,28] conducted in different locations in Nigeria. Findings from this study indicate that continuous use of tractor may in a long run impede soil water infiltration characteristics to the detriment of crops grown.

Result of infiltration data fitted to Philip [22] and Kostiakov [21] models showed significant differences. Sorptivity (S) and transmissivity (A) were generally higher in FT and ZT than the tilled treatments. Correlation coefficient of dependability values obtained for S and A of both Philip's and Kostiokov's models varied among tillage treatments. However, Kostiakov's model generally had relatively higher values than Philip's one, suggesting that the infiltration process in these soils is better described by Kostiakov's than the Philip's model. Ajayi [29] observed that sorptivity and transmissivity in zero tillage showed improved infiltration characteristics with time than the tilled treatments.

CONCLUSIONS

Realistic planning of water management and conservation practices for efficient and stable agriculture requires accurate information on the water intake rate under different soil conditions. The result from this study has demonstrated that infiltration rate, sorptivity and transmissivity were generally higher in FT and ZT than the tillage treatments. This implies that zero tillage treatment had improved infiltration characteristics with time than the tillage treatment. Moreover, surface runoff and nutrient loss would be higher in tilled soil than the zero tillage. Kostiakov's model generally had relatively higher values than the Philip's model, suggesting that the infiltration process in these soils is better described by the former model than the later.

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