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# Agroforestry systems and soil surface management of a tropical alfisol:
## *V. Water infiltrability, transmissivity and soil water sorptivity*

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**Key words**: Soil structure, hydraulic conductivity, biopores, physical degradation, infiltration models

**Abstract**. Soil infiltrability was evaluated once a year for five consecutive years in a longterm agroforestry experiment established on an Alfisol in western Nigeria. There were 6 treatments involving plow-till, no-till, contour hedges of *Leucaena Leucocephala* and *Gliricidia sepium* established every 4- and 2-m intervals. Continuous cultivation based on 2 crops per year caused drastic reductions in infiltrability in all treatments. The rate of decline was, however, the most severe in no-till treatment. Following 5 years of continuous cultivation, the equilibrium infiltration rate was 8, 19, 21 and 24 cm/h for no-till, *Gliricidia*-based, plow-till and *Leucaena*-based treatments, respectively. The cumulative infiltration at 2 h was 24, 59, 70 and 76 cm for no-till, *Gliricidia*-based, *Leucaena*-based and plow-till treatments. There were also significant differences among treatments in relation to soil water sorptivity (S). The infiltration data were expressed in terms of Philip's and Kostiakov's infiltration models.

## Introduction

Water infiltration rate of a soil is an integrated response of transmission pores, their relative volume and continuity and tortuosity, and changes in structural porosity during the infiltration process. The term infiltrability, defined as infiltration flux when water is made freely available at the soil surface, is limited by soil's profile characteristics. Soil infiltrability and its variation with time depend upon the initial wetness, texture, and structural attributes of the soil [Hillel, 1980]. Infiltrability is affected both by soil's surface and subsurface conditions. The initial infiltrability is affected by the degree and stability of soil's porous and open structure.

The infiltrability of undisturbed soils supporting a tropical rainforest is generally high for both horizontal and vertical components of water flow [Lal, 1975; Wolf and Drosdoff, 1976]. With cultivation, however, the infiltration rate of most uplands declines because of the rapid deterioration in soil structure and the susceptibility of these soils to formation of surface crust and seal [Lal, 1986]. Fallowing with various legume and grass cover crops is known to improve soil's infiltrability [Pereira et al., 1958; Lal et al., 1978; 1979]. The benefits accrued during the fallowing are, however, easily lost by cultivation [Pereira et al., 1954; Lal, 1985; Wilkinson, 1975; Wilkinson and Aina, 1976].

The effects of presence of trees and perennial shrubs in a landscape on soils hydrological characteristics have not been extensively studied. In Kenya, Pereira et al. [1962] and Pereira [1973; 1979] reported favorable hydrological characteristics of a soil managed by the 'taungya' or 'shamba' system of agroforestry. The effects of contour hedges of perennial shrubs on soil's hydrological characteristics, however, have not been extensively studied. The objective of this experiment, therefore, was to evaluate infiltrability of a tropical Alfisol under different systems of management and determine improvements in water-intake rate, if any, caused by growing food crop annuals in association with woody perennials.

## Materials and methods

Infiltrability characteristics were measured on field runoff plots established in March 1982 at the research farm of the International Institute of Tropical Agriculture (IITA). IITA is situated at latitude 7° 30′ N and longitude 3° 54′ E at Ibadan, in a region underlain by metamorphic rocks belonging to the Pre-Cambrian Basement Complex. The major rock type is banded gneiss, a grey quartz-biotite plagioclase-hornblende paragneiss.

Sizeable aquifers in the Basement Complex are rare. Shallow groundwater is found in localized fractured strata or faults and in places where the impervious subsoil or bedrock forms a trough. Streams and creeks are fed by direct rainfall, interflow and runoff. IITA is situated in the ecological zone of moist lowland tropical forest. The climax vegetation is moist semi-deciduous forest. The vegetation at the experimental site was a secondary regrowth of about five years that was cleared in February–March 1982 to establish field runoff plots.

Soil of the experimental site belongs to the Ibadan series and is classified as Oxic Paleustalf. Physical properties of a typical soil profile are shown in Table 1. Six field plots, 10 × 70 m each, were established on that series with a natural slope of about 7%. Infiltration rates were monitored annually for 5 consecutive years for three agroforestry systems. Systems were: (A) non-agroforestry with plow-till and no-till treatments, (B) contour hedgerows of *Leucaena leucocephala* established at 4-m and 2-m intervals and (C) contour hedgerows of *Gliricidia sepium* established at 4-m and 2-m intervals. Details of field layout has been described in a companion report [Lal, 1989a].

*Table 1.* Physical characteristics of a typical profile of an Ibadan soil series.

| Depth (cm) | Gravel (%) | Mechanical analysis (%) | | | Moisture equivalent (%) |
|---|---|---|---|---|---|
| | | Sand | Silt | Clay | |
| 0–25 | 9 | 71.0 | 11.7 | 17.3 | 9.0 |
| 25–50 | 44 | 71.6 | 11.1 | 17.3 | 4.5 |
| 50–62 | 60 | 80.6 | 6.1 | 13.3 | 4.5 |
| 62–72 | 50 | 76.6 | 7.1 | 16.3 | 5.0 |
| 72–115 | 35 | 58.2 | 5.4 | 36.4 | 12.9 |
| 115–155 | 14 | 49.2 | 13.4 | 37.4 | 18.0 |

Infiltration rates were monitored at 2 sites per plot before initiating the experiment and during the dry season every year thereafter. Infiltration rates were measured using a double-ring or flooding type infiltrometer. These were made of two concentric rings. The inner ring was 30 cm in diameter and was pushed into the soil for about 15 cm. The outer ring was about 40 cm in diameter and was pushed into the soil for about 20 cm. A constant head of 5 cm of water was maintained in the inner ring while free water surface was always ascertained in the outer. Surface soil of the inner ring was protected by a perforated plastic sheet to avoid soil dispersion. Infiltration studies were carried out, in the middle of two adjacent hedgerows or two crop rows, for at least two-hours.

Numerous models have been proposed over the years to express infiltrability as a function of time. Among these, conceptually- or theoretically-based models are those by Green and Ampt [1911] and Philip [1957]. Commonly used empirical models include those by Kostiakov [1932], Horton [1940] and Holtan [1961]. The infiltration data were analyzed according to the Kostiakov [1932] and Philip [1957] models. The Kostiakov model is described by equations 1 and 2:

$$I = \alpha t^{\beta} \qquad \text{(Eq. 1)}$$

$$\frac{dI}{dt} = i = \alpha t^{-\beta} \qquad \text{(Eq. 2)}$$

where 'I' represent the cumulative volume of water infiltrated in time t per unit area of the soil surface, and 'i' is the volume flux density i.e. the volume of water entering a unit soil surface area per unit time. Thus $i = dI/dt$ and $I = \int_0^t i\,dt$. $\alpha$ and $\beta$ are the empirically determined constants.

Philip's model is a truncated form of a series shown by equations 3 and 4.

$$I = St^{1/2} + At \qquad \text{(Eq. 3)}$$

$$i = \frac{dI}{dt} = {}_{1/2}St^{-1/2} + A \qquad \text{(Eq. 4)}$$

where S is called the sorptivity and A is called the transmissivity. For horizontal infiltration S can be computed from equation 5.

$$S = I/t^{1/2} \qquad \text{(Eq. 5)}$$

The parameter 'S' indicates the capacity of a soil to absorb water and has the dimensions ($LT^{-1/2}$) ($cm/h^{1/2}$). The sorptivity is the dominant parameter governing the early stages of ilfiltration. As the time increases, the parameter 'A' becomes important in governing the infiltration rate.

The infiltration data from each plot for every year was analyzed to compute the characterizing parameters I, i, S, A, $\alpha$ and $\beta$.

## Results and discussion

### *Infiltration characteristics of Ibadan soil series*

Under natural conditions of an undisturbed forest, Ibadan soil series has a high infiltrability. High infiltration rate of this soil series is attributed to its gravelly and sandy texture. Furthermore, double-ring infiltrometer generally gives higher infiltration rate than those observed with the sprinkling infiltrometer or rainfall simulator. Under a secondary forest regrowth Moormann et al. [1975] measured the 2-h infiltration rate of 156 cm $h^{-1}$. For the experimental site of present study, that had previously been cultivated and had been under secondary regrowth of about five years, the infiltrability was comparatively low (Fig. 1). The infiltration rate at 2 h was about 66 cm $h^{-1}$ – about 42% of that under undisturbed secondary forest (Fig. 1).

The cumulative infiltration declined with the duration of cultivation. The mean infiltration rate (average of all treatments) at 2 h was 12 and 10 cm $h^{-1}$ following 2 and 5 years of continuous cultivation (Fig. 1). The decline in infiltration with the duration of cultivation was probably due to crusting, compaction, and drastic reduction in activity of earthworms.

### *Accumulative infiltration*

Infiltrability of this experimental site was lower than that of the undisturbed secondary forest reported by Moormann et al. [1975]. The analysis of

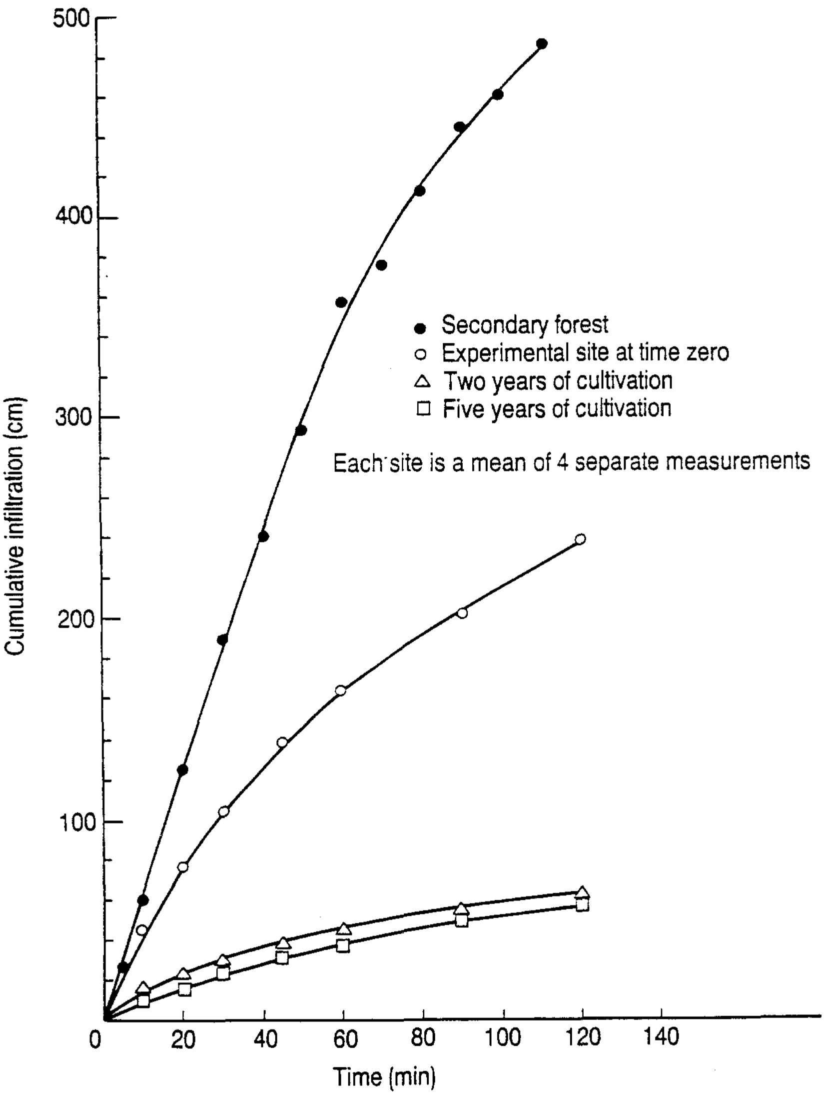


*Fig. 1.* Comparison in cumulative infiltration for an Ibadan soil series under a secondary forest with that of the experimental site under secondary regrowth, and 2 years and 4 years after cultivation.

variance of 'F' ratio for cumulative infiltration is shown in Table 2. The cumulative infiltration (I) for different treatments are shown for 10 and 20 min, in Table 3, 30 and 45 min in Table 4, 60 and 90 min in Table 5 and for 120 min in Table 6. There were significant differences among treatments even one year after initiating the project. One year after cultivation began, both 10- and 20-min cumulative infiltration were the highest for *Leucaena*-

*Table 2.* Analysis of variance table of 'F' ratio for cumulative infiltration at different times (min).

| Source | df | Time during the measurement (min) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 45 | 60 | 90 | 120 |
| Treatment (T) | 1 | 5.4 | 4.9 | 7.5 | 8.6 | 9.3 | 7.3 | 8.0 |
| Systems (S) | 2 | 1.8 | 2.1 | 2.2 | 2.6 | 3.8 | 4.8 | 4.9 |
| Year (Y) | 4 | 4.8 | 6.4 | 6.7 | 7.4 | 10.5 | 12.9 | 14.9 |
| S × Y | 8 | 0.2 | 0.3 | 0.4 | 0.5 | 0.7 | 1.4 | 1.6 |
| S × T | 2 | 0.9 | 1.0 | 0.7 | 0.7 | 0.8 | 1.2 | 1.3 |
| Error | 12 | | | | | | | |

based systems. The general trend was toward declining cumulative infiltration at 10- and 20-min with the cultivation duration (Table 3).

The cumulative infiltration for 30 and 45 min shown in Table 4 indicates that five years of cultivation resulted in the least cumulative infiltration in no-till and the maximum in *Leucaena*-2 m treatment. For this easily compacted sandy soil, a high level of cumulative infiltration was maintained by the plow-till treatment. Similar trends were observed in the cumulative infiltration measured for 60 and 90 min (Table 5). Five years after initiating this experiment, the cumulative infiltration at 60 min was in the order of *Leucaena*-2 m > plow-till > *Gliricidia*-4 m > *Gliricidia*-2 m > *Leucaena*-4 m > no-till (Table 5, Fig. 2).

The cumulative infiltration at 120 min after 1, 2, 3 and 5 years of cultivation is shown in Table 6. The maximum and the least infiltration were recorded for the *Leucaena*-2 m and no-till treatments, respectively. The mean cumulative infiltration in 1982 at the time of initiating the experiment was 238 cm per two hours. Five years of cultivation decreased the cumulative infiltration to merely 10.2, 23.2, 24.5, 25.3, 31.9 and 33.1 percent of the initial value for no-till, *Leucaena*-4 m, *Gliricidia*-2 m, *Gliricidia*-4 m, plow-till and *Leucaena*-2 m treatments, respectively. The cumulative infiltration declined as power function of the cultivation duration (Table 7). The rate of decline was the most severe in no-till and least in *Leucaena*-2 m treatments. For example, exponent of the cultivation duration (X) was the most negative ($-1.17$) in no-till and the least ($-0.60$) in *Leucaena*-2 m treatment.

### *Infiltration rate*

The analysis of variance for infiltration rate is shown in Table 8. Infiltration rates for different treatments are shown in Table 9 for 10 and 20 min, Table 10 for 30 and 45 min, Table 11 for 60 and 90 min, and Table 12 for 120 min.

*Table 3.* Accumulative infiltration (cm) at 10 and 20 min in different management systems and for different duration of continuous cultivation (years).

| System | Treatments | | 1 year | | 2 years | | 3 years | | 5 years | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Species | Spacing (m) | 10 | 20 | 10 | 20 | 10 | 20 | 10 | 20 |
| A | Plow-till | – | 17.5 | 30.4 | 12.5 | 19.7 | 11.0 | 16.7 | 14.7 | 24.0 |
| | No-till | – | 9.9 | 15.9 | 15.7 | 26.0 | 6.2 | 10.3 | 5.5 | 7.9 |
| B | *Leucaena* | 4 | 23.0 | 36.6 | 22.0 | 34.3 | 20.5 | 29.8 | 7.0 | 11.7 |
| | *Leucaena* | 2 | 13.8 | 24.8 | 12.9 | 19.1 | 16.7 | 26.4 | 15.5 | 25.0 |
| C | *Gliricidia* | 4 | 12.7 | 21.7 | 11.0 | 17.3 | 19.4 | 32.2 | 9.7 | 11.3 |
| | *Gliricidia* | 2 | 11.2 | 16.2 | 16.5 | 26.0 | 8.6 | 14.3 | 9.6 | 16.3 |
| | LSD (0.1) | | *10 min* | *20 min* | | | | | | |
| | Treatment (T) | | 3.7 | 6.0 | | | | | | |
| | System (S) | | 4.6 | 7.3 | | | | | | |
| | Years (Y) | | 5.9 | 9.5 | | | | | | |
| | S × T | | 10.2 | 16.4 | | | | | | |
| | S × Y | | 6.4 | 10.4 | | | | | | |

*Table 4*. Accumulative infiltration (cm) at 30 and 45 min in different management systems and for different duration of cultivation (years).

| System | Treatments | | 1 year | | 2 years | | 3 years | | 5 years | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Species | Spacing (m) | 30 | 45 | 30 | 45 | 30 | 45 | 30 | 45 |
| A | Plow-till | – | 41.8 | 56.5 | 26.1 | 36.0 | 22.1 | 28.8 | 33.0 | 42.8 |
| | No-till | – | 21.5 | 27.6 | 31.6 | 38.1 | 14.3 | 20.4 | 10.6 | 13.5 |
| B | *Leucaena* | 4 | 49.6 | 66.9 | 42.8 | 54.2 | 37.5 | 46.9 | 16.6 | 23.7 |
| | *Leucaena* | 2 | 33.2 | 45.3 | 24.1 | 31.3 | 34.2 | 46.0 | 32.9 | 43.3 |
| C | *Gliricidia* | 4 | 29.4 | 40.7 | 23.4 | 31.2 | 42.2 | 55.5 | 24.4 | 33.0 |
| | *Gliricidia* | 2 | 19.7 | 24.3 | 31.9 | 38.0 | 19.4 | 26.4 | 21.9 | 29.5 |
| | LSD (0.1) | | *30 min* | *45 min* | | | | | | |
| | Treatment (T) | | 7.4 | 9.5 | | | | | | |
| | System (S) | | 9.1 | 11.6 | | | | | | |
| | Years (Y) | | 11.7 | 15.0 | | | | | | |
| | S × T | | 20.3 | 25.9 | | | | | | |
| | S × Y | | 12.8 | 16.4 | | | | | | |

*Table 5*. Accumulative infiltration (cm) at 60 and 90 min in different management systems and for different duration of continuous cultivation.

| System | Treatments | | 1 year | | 2 years | | 3 years | | 5 years | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Species | Spacing (m) | 60 | 90 | 60 | 90 | 60 | 90 | 60 | 90 |
| A | Plow-till | – | 67.7 | 81.7 | 42.7 | 54.9 | 34.5 | 43.4 | 51.2 | 65.4 |
| | No-till | – | 33.2 | 42.0 | 42.8 | 49.9 | 26.3 | 33.9 | 16.1 | 21.7 |
| B | *Leucaena* | 4 | 80.0 | 101.2 | 61.8 | 76.8 | 54.3 | 63.0 | 31.2 | 44.0 |
| | *Leucaena* | 2 | 56.1 | 72.5 | 36.4 | 44.8 | 55.7 | 70.2 | 52.1 | 67.4 |
| C | *Gliricidia* | 4 | 50.7 | 36.4 | 37.9 | 49.1 | 64.0 | 75.3 | 40.6 | 51.7 |
| | *Gliricidia* | 2 | 27.8 | 33.8 | 43.3 | 52.6 | 32.4 | 43.3 | 36.3 | 48.4 |
| | LSD (0.1) | | *60 min* | *90 min* | | | | | | |
| | Treatment (T) | | 10.4 | 8.0 | | | | | | |
| | System (S) | | 12.8 | 9.7 | | | | | | |
| | Years (Y) | | 16.5 | 12.6 | | | | | | |
| | S × T | | 28.6 | 21.8 | | | | | | |
| | S × Y | | 18.1 | 13.8 | | | | | | |

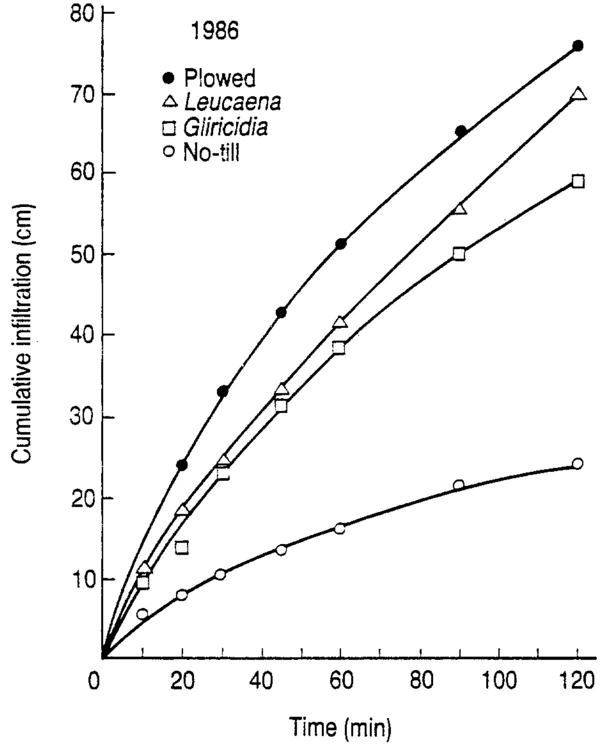


*Fig. 2.* Cumulative infiltration measured in the dry season of February 1986 as influenced by agroforestry and tillage systems.

*Table 6.* Accumulative infiltration (cm) at 120 min in different management systems and for different duration of cultivation (years).

| System | Treatment | | Duration of cultivation (years) | | | |
|---|---|---|---|---|---|---|
| | Species | Spacing (m) | 1 | 2 | 3 | 5 |
| A | Plow-till | – | 93.8 | 65.4 | 55.0 | 76.1 |
| | No-till | – | 51.0 | 55.2 | 40.1 | 24.2 |
| B | *Leucaena* | 4 | 121.1 | 89.8 | 69.5 | 55.1 |
| | *Leucaena* | 2 | 79.3 | 51.8 | 81.4 | 78.8 |
| C | *Gliricidia* | 4 | 45.8 | 57.3 | 84.7 | 60.1 |
| | *Gliricidia* | 2 | 40.7 | 61.2 | 53.8 | 58.2 |
| | LSD (0.1) | | | | | |
| | Treatment (T) | 15.2 | | | | |
| | Systems (S) | 18.7 | | | | |
| | Years (Y) | 24.1 | | | | |
| | S × T | 26.4 | | | | |
| | S × Y | 41.7 | | | | |

*Table 7*. Regression equations relating cumulative infiltration (y, cm) with cultivation duration (X) in years.

| System | Treatment | | Regression equation | Correlation coefficient ($R^2$) |
|---|---|---|---|---|
| | Species | Spacing (m) | | |
| A | Plow-till | – | $Y = 182\ X^{-0.71}$ | 0.72 |
| | No-till | – | $Y = 186\ X^{-1.17}$ | 0.89 |
| B | *Leucaena* | 4 | $Y = 224\ X^{-0.82}$ | 0.99 |
| | *Leucaena* | 2 | $Y = 166\ X^{-0.60}$ | 0.53 |
| C | *Gliricidia* | 4 | $Y = 145\ X^{-0.61}$ | 0.42 |
| | *Gliricidia* | 2 | $Y = 145\ X^{-0.70}$ | 0.48 |

*Table 8*. Analysis of variance table of 'F' ratio for infiltration late at different times.

| Source | df | Time during the measurement (min) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 45 | 60 | 90 | 120 |
| Treatment (T) | 1 | 5.4 | 3.4 | 7.9 | 9.4 | 8.9 | 0.7 | 7.8 |
| Systems (S) | 2 | 1.8 | 2.2 | 1.2 | 3.2 | 15.2 | 4.1 | 3.9 |
| Year (Y) | 4 | 4.8 | 8.2 | 2.8 | 7.5 | 39.5 | 10.8 | 18.8 |
| S × Y | 8 | 0.2 | 0.5 | 0.6 | 0.8 | 4.6 | 2.2 | 1.7 |
| S × T | 2 | 0.9 | 1.0 | 0.1 | 0.4 | 2.1 | 3.1 | 2.2 |
| Error | 12 | | | | | | | |

Similar to the cumulative infiltration, the infiltration rate also declined with the duration of cultivation. Effects of agroforestry and soil management treatments on infiltration rates were apparent at the end of the first cropping year in January 1983. The *Leucaena*-4 m treatments had the highest initial infiltration rate. The lowest initial infiltration rate was recorded for the no-till treatment. At intermediate (30 to 90 min) and long time (120 min) trends in infiltration rates among treatments were similar to those of the observations made for the end of the first cropping cycle.

At the end of the fifth cropping cycle in January 1987, the equilibrium infiltration rate were in the order of *Leucaena* > plow-till > *Gliricidia* > no-till (Fig. 3). The relative equilibrium infiltration rates in 1987 were 1.00, 3.36, 3.92, 4.28, 4.44 and 4.56 for no-till, *Gliricidia*-4 m, *Gliricidia*-2 m, plow-till, *Leucaena*-4 m and *Leucaena*-2 m, respectively.

Comparison of the infiltration rates before starting the experiment in March 1982 and at the end of the 5th year in January 1986 indicate a severe decline in the equilibrium infiltration rate in all treatments. The rate of decline, however, differed among treatments. The decline was less drastic in *Leucaena*-based and plow-till compared with the no-till treatment. Table 13 depicts regression equations relating infiltration rate with the cultivation

*Table 9*. Infiltration rate (cm $hr^{-1}$) at 10 and 20 min in different management systems and for different duration of continuous cultivation (years).

| System | Treatments | | 1 year | | 2 years | | 3 years | | 5 years | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Species | Spacing (m) | 10 | 20 | 10 | 20 | 10 | 20 | 10 | 20 |
| A | Plow-till | – | 105 | 77.4 | 75.0 | 43.2 | 66.0 | 34.2 | 88.2 | 55.8 |
| | No-till | – | 59.4 | 36.0 | 94.2 | 61.8 | 37.2 | 24.6 | 33.0 | 14.4 |
| B | *Leucaena* | 4 | 138 | 81.6 | 132 | 73.8 | 123 | 55.8 | 42.0 | 28.2 |
| | *Leucaena* | 2 | 82.8 | 66.0 | 77.4 | 37.2 | 100 | 58.2 | 93.0 | 57.0 |
| C | *Gliricidia* | 4 | 76.2 | 54.0 | 66.0 | 37.8 | 116 | 76.8 | 58.2 | 9.6 |
| | *Gliricidia* | 2 | 67.2 | 30.0 | 99.0 | 57.0 | 51.6 | 34.2 | 57.6 | 40.2 |
| | LSD (0.1) | | *10 min* | *20 min* | | | | | | |
| | Treatment (T) | | 22.3 | 14.9 | | | | | | |
| | System (S) | | 27.3 | 18.2 | | | | | | |
| | Years (Y) | | 35.3 | 23.5 | | | | | | |
| | S × T | | 38.6 | 25.8 | | | | | | |
| | S × Y | | 61.1 | 40.8 | | | | | | |

*Table 10*. Infiltration rate at 30 and 45 min in different management systems and for different duration of continuous cultivation (years).

| System | Treatments | | 1 year | | 2 years | | 3 years | | 5 years | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Species | Spacing (m) | 30 | 45 | 30 | 45 | 30 | 45 | 30 | 45 |
| A | Plow-till | – | 68.4 | 58.8 | 38.4 | 39.6 | 32.4 | 26.8 | 54.0 | 39.2 |
| | No-till | – | 33.6 | 24.4 | 33.6 | 26.0 | 24.0 | 24.4 | 16.2 | 11.6 |
| B | *Leucaena* | 4 | 78.0 | 69.2 | 51.0 | 45.6 | 46.2 | 37.6 | 29.4 | 28.4 |
| | *Leucaena* | 2 | 50.4 | 48.4 | 30.0 | 28.8 | 46.8 | 47.2 | 47.4 | 41.6 |
| C | *Gliricidia* | 4 | 46.2 | 45.2 | 36.6 | 31.2 | 60.0 | 53.2 | 78.6 | 34.4 |
| | *Gliricidia* | 2 | 21.0 | 18.4 | 35.4 | 24.4 | 30.6 | 28.0 | 33.6 | 30.4 |
| | LSD (0.1) | | *30 min* | *45 min* | | | | | | |
| | Treatment (T) | | 15.1 | 9.8 | | | | | | |
| | System (S) | | 18.5 | 12.1 | | | | | | |
| | Years (Y) | | 23.9 | 15.6 | | | | | | |
| | S × T | | 26.2 | 17.1 | | | | | | |
| | S × Y | | 41.4 | 27.0 | | | | | | |

*Table 11*. Infiltration rate at 60 and 90 min in different management systems and for different duration of continuous cultivation.

| System | Treatments | | 1 year | | 2 years | | 3 years | | 5 years | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Species | Spacing (m) | 60 | 90 | 60 | 90 | 60 | 90 | 60 | 90 |
| A | Plow-till | – | 44.8 | 28.0 | 26.8 | 24.4 | 22.8 | 17.8 | 33.6 | 28.4 |
| | No-till | – | 22.4 | 17.6 | 18.8 | 14.2 | 23.6 | 15.2 | 10.4 | 11.2 |
| B | *Leucaena* | 4 | 52.4 | 42.4 | 30.4 | 30.0 | 29.6 | 17.4 | 30.0 | 25.6 |
| | *Leucaena* | 2 | 43.2 | 32.8 | 20.4 | 16.8 | 38.8 | 29.0 | 35.2 | 30.6 |
| C | *Gliricidia* | 4 | 40.0 | – | 26.8 | 22.4 | 34.0 | 22.6 | 30.4 | 22.2 |
| | *Gliricidia* | 2 | 14.0 | 12.0 | 21.2 | 18.6 | 24.0 | 21.8 | 27.2 | 24.2 |
| | LSD (0.1) | | *60 min* | *90 min* | | | | | | |
| | Treatment (T) | | 5.2 | 8.0 | | | | | | |
| | System (S) | | 6.4 | 9.7 | | | | | | |
| | Years (Y) | | 8.3 | 12.6 | | | | | | |
| | S × T | | 9.1 | 13.8 | | | | | | |
| | S × Y | | 14.3 | 21.8 | | | | | | |

*Table 12.* Infiltration rate ($cm\,hr^{-1}$) at 120 min in different management systems and for different duration of continuous cultivation.

| System | Treatment | | Duration of cultivation (years) | | | |
|---|---|---|---|---|---|---|
| | Species | Spacing (m) | 1 | 2 | 3 | 5 |
| A | Plow-till | – | 24.2 | 21.0 | 23.2 | 21.4 |
| | No-till | – | 18.0 | 10.6 | 12.4 | 5.0 |
| B | *Leucaena* | 4 | 39.8 | 26.0 | 13.0 | 22.2 |
| | *Leucaena* | 2 | 13.6 | 14.0 | 22.4 | 22.8 |
| C | *Gliricidia* | 4 | 18.8 | 16.4 | 18.8 | 16.8 |
| | *Gliricidia* | 2 | 13.8 | 17.2 | 21.0 | 19.6 |
| | LSD (0.1) | *120 min* | | | | |
| | Treatment (T) | 5.8 | | | | |
| | Systems (S) | 7.1 | | | | |
| | Years (Y) | 9.1 | | | | |
| | S × T | 10.0 | | | | |
| | S × Y | 15.8 | | | | |

duration. Regression equations indicate that equilibrium infiltration rate decreased as a power function of cultivation duration. The time exponent was most negative (– 1.29) in no-till and least negative (– 0.46) in *Leucaena*-2 m treatment. The infiltration rate declined most rapidly in the no-till system of seedbed preparation. The severe decline in infiltration rate of no-till treatment is also in accord with high soil bulk density and penetrometer resistance for the no-till treatment [Lal, 1989b].

*Infiltration model*

Sorptivity and transmissivity characteristics computed on the basis of Philip's [1957] model are shown in Table 14. The analysis of variance table for these coefficients is shown in Table 15. By the end of first cropping cycle, soil-water sorptivity (S) was in the order of *Leucaena*-4 m > plow-till > - *Gliricidia*-4 m > *Leucaena*-2 m > *Gliricidia*-2 m > no-till. Over the period of 5 years of cropping, however, soil-water sorptivity changed in all treatments. Computations made on the data for the 5th year of cultivation revealed S to be in the order of *Leucaena*-2 m > plow-till > *Gliricidia*-2 m > *Gliricidia*-4 m > no-till > *Leucaena*-4 m. Although *Leucaena*-4 m and *Gliricidia*-4 m treatments had relatively low sorptivity, transmissivity values were high for these agroforestry systems. High values of transmissivity coefficients were reflected in the high equilibrium infiltration rates measured for these treatments.

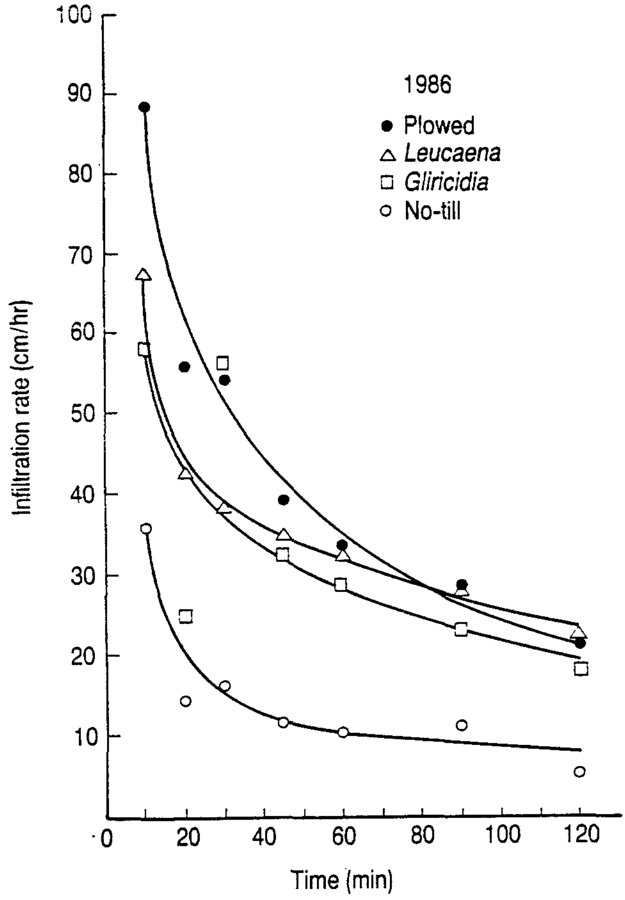


*Fig. 3.* Effects of tillage methods and agroforestry systems on infiltration rate measured during the dry season of February 1986.

*Table 13.* Regression equations relating the equilibrium infiltration rate (y, cm/hr) with the cultivation duration (X) in years.

| System | Treatment | | Regression equation | Correlation coefficient ($R^2$) |
|---|---|---|---|---|
| | Species | Spacing (m) | | |
| A | Plow-till | – | $Y = 47\ X^{-0.55}$ | 0.72 |
| | No-till | – | $Y = 54\ X^{-1.29}$ | 0.94 |
| B | *Leucaena* | 4 | $Y = 58\ X^{-0.72}$ | 0.73 |
| | *Leucaena* | 2 | $Y = 36\ X^{-0.46}$ | 0.28 |
| C | *Gliricidia* | 4 | $Y = 44\ X^{-0.67}$ | 0.69 |
| | *Gliricidia* | 2 | $Y = 38\ X^{-0.53}$ | 0.41 |

*Table 14*. Sorptivity, transmissivity and correlation coefficients ($R^2$) of the Philip's model of infiltration ($I = St^{1/2} + At$).

| System | Treatments | | 1 year | | | 2 years | | | 3 years | | | 5 years | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Species | Spacing (m) | S | A | $R^2$ | S | A | $R^2$ | S | A | $R^2$ | S | A | $R^2$ |
| A | Plow-till | – | 92.2 | −3.0 | 0.96 | 58.4 | −0.3 | 0.94 | 50.4 | −1.5 | 0.90 | 73.6 | −3.0 | 0.98 |
| | No-till | – | 47.8 | −1.5 | 0.98 | 99.2 | −28.7 | 0.98 | 24.2 | 7.0 | 0.85 | 27.4 | −3.6 | 0.88 |
| B | *Leucaena* | 4 | 108.8 | −0.5 | 0.97 | 121.2 | −24.7 | 0.96 | 119.8 | −33.1 | 0.96 | 18.1 | 17.4 | 0.80 |
| | *Leucaena* | 2 | 69.8 | 2.0 | 0.90 | 68.8 | −13.5 | 0.94 | 82.6 | −5.7 | 0.96 | 75.8 | −3.4 | 0.98 |
| C | *Gliricidia* | 4 | 85.0 | −20.3 | 0.60 | 51.8 | −0.45 | 0.96 | 112.4 | −19.9 | 0.99 | 35.2 | 12.4 | 0.19 |
| | *Gliricidia* | 2 | 60.8 | −15.1 | 0.90 | 96.4 | −24.8 | 0.96 | 34.2 | 7.4 | 0.97 | 41.4 | 5.9 | 0.99 |
| | LSD | | *0.05* | | *0.01* | | | | | | | | | |
| | | | S | A | S | A | | | | | | | | |
| | Treatments (T) | | 30.4 | 15.0 | 24.8 | 12.3 | | | | | | | | |
| | Systems (S) | | 37.2 | 18.4 | 30.4 | 15.0 | | | | | | | | |
| | Years (Y) | | 48.0 | 23.7 | 39.3 | 19.4 | | | | | | | | |
| | S × T | | 52.6 | 26.0 | 43.0 | 21.2 | | | | | | | | |
| | S × Y | | 83.1 | 41.1 | 68.0 | 33.6 | | | | | | | | |

S = Sorptivity
T = Transmissivity
t = time (minutes)

*Table 15*. Analysis of variance table of 'F' ratio for sorptivity and transmissivity coefficients of Philip's model, and coefficient (α) and exponent (β) of Kostiakov's model.

| Source | df | Philip's model | | Kostiakov's model | | | |
|---|---|---|---|---|---|---|---|
| | | Sorptivity | Transmissivity | Coefficient | | Exponent | |
| | | | | Cumulative | Rate | Cumulative | Rate |
| Treatment (T) | 1 | 3.3 | 0.04 | 0.06 | 0.2 | 9.0 | 11.7 |
| Systems (S) | 2 | 0.6 | 0.6 | 0.4 | 0.8 | 4.6 | 5.3 |
| Year (Y) | 4 | 1.8 | 2.5 | 2.5 | 2.8 | 8.3 | 11.3 |
| S × T | 2 | 0.5 | 0.3 | 0.3 | 0.4 | 2.1 | 2.3 |
| S × Y | 8 | 0.4 | 1.6 | 1.3 | 1.0 | 0.8 | 0.9 |
| Error | 12 | | | | | | |

Coefficients and exponent values computed on the basis of Kostiakov's model are shown in Tables 16 and 17 for cumulative infiltration and the infiltration rate, respectively. From the very high values of correlation coefficients, it seems that the infiltration process is better described by Kostiakov than Philip's model.

There were slight changes in the values of coefficients and exponents for cumulative infiltration with the duration of cultivation. The exponent β was negative for the cumulative infiltration rate (Table 17). At the end of the fifth year of cultivation cycle, the coefficient for the infiltration rate was the least for the no-till treatment. Similarly, the exponent was the lowest (most negative) for the no-till and the highest (least negative) for the *Leucaena*-4 m treatment. Magnitude of the negative exponent is indicative of the magnitude of decline of infiltrate rate from a high initial value to the steady state infiltration capacity.

## Conclusions

Decline in infiltration rate with continuous cultivation with motorized farm operations on these soils has already been established [Lal, 1985]. For sandy soils, soil compaction in no-till treatments can drastically decrease soil infiltrability. A major difference between this and the previous study lies in the fact that the rate of decline in infiltration rate is less with agro-forestry than food-crop systems. Tree-based systems maintain favorable infiltration rate due to biochannels and better soil structure than in food-crop systems.

The data presented support the following conclusions:

1. Infiltration rate declined with the duration of cultivation. The magnitude of decline, however, differed among treatments.

*Table 16.* Coefficients and exponents of the Kostiakov's model for accumulative infiltration ($I = \theta t^{\beta}$).

| System | Treatments | | 1 year | | | 2 years | | | 3 years | | | 5 years | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Species | Spacing (m) | α | β | $R^2$ | α | β | $R^2$ | α | β | $R^2$ | α | β | $R^2$ |
| A | Plow-till | – | 1.80 | 0.68 | 0.99 | 1.62 | 0.67 | 0.99 | 1.54 | 0.64 | 0.99 | 1.70 | 0.67 | 0.99 |
| | No-till | – | 1.52 | 0.66 | 0.99 | 1.62 | 0.49 | 0.98 | 1.39 | 0.77 | 0.99 | 1.21 | 0.62 | 0.99 |
| B | *Leucaena* | 4 | 1.89 | 0.67 | 0.99 | 1.79 | 0.56 | 0.99 | 1.72 | 0.50 | 0.99 | 1.49 | 0.85 | 0.99 |
| | *Leucaena* | 2 | 1.73 | 0.72 | 0.99 | 1.55 | 0.57 | 0.99 | 1.73 | 0.65 | 0.99 | 1.71 | 0.66 | 0.99 |
| C | *Gliricidia* | 4 | 1.58 | 0.51 | 0.82 | 1.57 | 0.68 | 0.99 | 1.78 | 0.59 | 0.99 | 1.57 | 0.81 | 0.95 |
| | *Gliricidia* | 2 | 1.45 | 0.51 | 0.99 | 1.64 | 0.51 | 0.99 | 1.51 | 0.74 | 1.00 | 1.56 | 0.73 | 1.00 |
| | LSD | | *0.05* | | *0.10* | | | | | | | | | |
| | | | α | β | α | β | | | | | | | | |
| | Treatments (T) | | 0.09 | 0.83 | 0.08 | 0.68 | | | | | | | | |
| | Systems (S) | | 0.12 | 1.02 | 0.09 | 0.83 | | | | | | | | |
| | Years (Y) | | 0.15 | 1.32 | 0.12 | 1.08 | | | | | | | | |
| | S × T | | 0.17 | 1.45 | 0.14 | 1.18 | | | | | | | | |
| | S × Y | | 0.27 | 2.29 | 0.22 | 1.87 | | | | | | | | |

*Table 17*. Coefficient and exponents of the Kostiakov's model for infiltration rate ($i = \alpha t^{-\beta}$).

| System | Treatments | | 1 year | | | 2 years | | | 3 years | | | 5 years | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Species | Spacing (m) | α | β | $R^2$ | α | β | $R^2$ | α | β | $R^2$ | α | β | $R^2$ |
| A | Plow-till | – | 1.6 | −0.60 | 0.94 | 1.5 | −0.48 | 0.94 | 1.4 | −0.45 | 0.86 | 1.5 | −0.54 | 0.98 |
| | No-till | – | 1.4 | −0.49 | 0.97 | 1.3 | −0.90 | 0.99 | 1.3 | −0.38 | 0.84 | 1.0 | −0.60 | 0.84 |
| B | *Leucaena* | 4 | 1.7 | −0.49 | 0.97 | 1.6 | −0.66 | 0.96 | 1.4 | −0.85 | 0.98 | 1.4 | −0.20 | 0.76 |
| | *Leucaena* | 2 | 1.5 | −0.60 | 0.80 | 1.3 | −0.65 | 0.97 | 1.6 | −0.55 | 0.96 | 1.5 | −0.52 | 0.98 |
| C | *Gliricidia* | 4 | 1.5 | −0.50 | 0.89 | 1.4 | −0.50 | 0.96 | 1.5 | −0.75 | 0.97 | 1.4 | −0.28 | 0.11 |
| | *Gliricidia* | 2 | 1.2 | −0.65 | 0.90 | 1.8 | −0.73 | 0.96 | 1.4 | −0.35 | 0.96 | 1.4 | −0.40 | 0.99 |
| | LSD | | *0.05* | | *0.10* | | | | | | | | | |
| | | | α | β | α | β | | | | | | | | |
| | Treatments (T) | | 0.09 | 0.09 | 0.07 | 0.07 | | | | | | | | |
| | Systems (S) | | 0.11 | 0.11 | 0.09 | 0.09 | | | | | | | | |
| | Year (Y) | | 0.15 | 0.14 | 0.12 | 0.11 | | | | | | | | |
| | S × T | | 0.16 | 0.15 | 0.13 | 0.13 | | | | | | | | |
| | S × Y | | 0.26 | 0.25 | 0.21 | 0.20 | | | | | | | | |

i = infiltration rate
t = time (min)

2. By the end of the 5th year of cultivation cycle, the equilibrium infiltration rate was the highest in *Leucaena*-based and plow-till compared with the no-till treatments.
3. The decline in equilibrium infiltration rate was due to structural degradation, decrease in soil organic matter content, and reduction in activity of earthworms and other soil fauna. The relative decline in infiltration rate among treatments was generally in accord with alterations in other properties e.g. soil organic carbon content.
4. Differences in infiltration characteristics among treatments are reflected in soil water sorptivity (S) computed on the basis of Philip's model.
5. With some exception, Kostiakov's model described the infiltration process better than Philip's model.

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