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Comparisons of Infiltration Capacities in Different Parklands and Farming Systems of Semi-Arid Burkina Faso

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Abstract

The organic matter content of the soil (SOM) is a key property for soil aggregation and water infiltration in the semi-arid parklands of West Africa. This study is comparing infiltration capacities (IC) in fields, where SOM is managed in different ways, in two villages in the western part of Burkina Faso. Steady-state IC was measured with a tension disc infiltrometer. In the village of Dossi, measurements were made before tilling (in June 2005) under and in between trees in fields of *Vitellaria paradoxa* and *Faidherbia albida* and with the addition of extra leaves in the latter field. In Bondoukuy infiltration capacity was measured before and after tilling in plots with or without compost and with annual or biannual tillage. The results showed that infiltration capacity was higher under trees (104 mm/h) than in between trees (69 mm/h) and higher in the *Vitellaria*-field (117 mm/h) than in the *Faidherbia*-field (58 mm/h). The addition of compost increases IC (79 mm/h vs. 58 mm/h) and biannual tillage could also have an improving effect (75 mm/h vs. 62 mm/h). The study demonstrated the potential of improving infiltration by managing trees and soil organic matter.

Keywords: biannual tillage, compost, *Faidherbia albida*, infiltration capacity, soil organic matter, tension disc infiltrometer, *Vitellaria paradoxa*

Résumé

La teneur en matière organique du sol (MOS) joue un rôle important dans l'agrégation du sol et l'infiltration de l'eau dans les parcs en zone semi-arid de l'Afrique de l'ouest. Cette étude a été menée dans deux villages de l'ouest du Burkina Faso et compare la capacité d'infiltration dans des champs dont la gestion de la MOS est différente. La stabilité d'infiltration a été mesurée avec un infiltromètre à membrane. Dans le village de Dossi, les mesures on été faites avant labour (en juin 2005) dans deux parcs agroforestiers à *Vitellaria paradoxa* et à *Faidherbia albida* en dessous et entre les arbres. Dans le parc à *F. albida*, des feuilles de *V. Paradoxa* ont été apportées. Dans le village de Bondokuy, les mesures d'infiltration ont été faites avant et après labour dans des parcelles avec ou sans apport de compost et avec labour annuel ou bi-annuel. Les résultats ont montré que la capacité d'infiltration était plus élevée en dessous des arbres (104 mm/h) qu'entre les arbres (69 mm/h) et plus élevée dans le parc à *Vitellaria paradoxa* (117 mm/h) par rapport au parc *Faidherbia albida* (58 mm/h). Le labour bi-annuel pourrait amélioré la capacité d'infiltration (75mm/h vs. 62 mm/h). Cette étude a démontré la potentielle amélioration de l'infiltration par une gestion adéquate des arbres et de la matière organique du sol.

Mots-clés: capacité d'infiltration, compost, *Faidherbia albida,* infiltromètre à membrane, labour bi-annuel, matière organique du sol, *Vitellaria paradoxa*.

Sammanfattning

I de halvtorra jordbrukssystemen i Västafrika är jordens organiska material (SOM) viktigt för bildandet av aggregat, vilka i sin tur underlättar infiltrationen av regnvattnen. Denna studie jämför infiltrationskapaciteten (IC), i västra delen av Burkina Faso, på fält där SOM sköts på olika sätt. Den slutliga infiltrationskapaciteten (steady-state IC) mättes med en tensiondiskinfiltrometer. I byn Dossi gjordes mätningarna före plöjning (i juni 2005) på två fält, under och mellan träd. På det första växte *Vitellaria paradoxa* och på det andra *Faidherbia albida* och där fanns det även en behandling med extra löv. I Bondoukuy mättes IC före och efter plöjning på provytor med eller utan kompost samt med plöjning varje eller vartannat år. Resultaten visade att infiltrationskapaciteten var högre under träd (104 mm/h) än mellan träd (69 mm/h) och högre där *Vitellaria* växte (117 mm/h) än där *Faidherbia* växte (58mm/h). Kompost ökar IC (79 mm/h mot 58 mm/h) och plöjning vartannat år kan också ha en förbättrande effekt (75 mm/h mot 62 mm/h). Studien visar vilken potential som finns för att förbättra infiltrationen genom att sköta träden och jordens organiska material på rätt sätt.

Sökord: *Faidherbia albida*, infiltrationskapacitet, jordens organiska material, kompost, plöjning vartannat år, tensiondiskinfiltrometer, *Vitellaria paradoxa*

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1 Introduction

Infiltration capacity (IC) is a key property of semi-arid soils. When precipitation is sparse on an annual basis, the importance of getting as much water as possible deep into the ground is great. A high infiltration capacity prevents surface runoff and soil erosion, common phenomena in Burkina Faso, where rain momentarily can reach an intensity of 120mm/h (Son and Bourarach, 2001) (Fig. 1.1). The recharge of soil water reserves and ground water are also important issues in this area; the more water infiltrating, the greater are the chances of a high recharge. Soil structure is a main determinant of infiltration capacity and for its development soil organic matter is of importance (Dutartre et al, 1993).

Figure 1.1 Heavy rain causes ponded infiltration.

The hypotheses for the investigations of this study are based on the correlation of soil organic matter (SOM), soil structure and infiltration capacity. Trees increase the soil organic matter content in soils, by shedding their leaves yearly (Kessler, 1992; Oliver, 2002; Kater et al, 1992). When the leaves are incorporated in the soil, it gets a better moisture holding capacity and the infiltration is improved, by giving the soil a better aggregated structure. The same thing happens when compost is applied to the fields, another way of increasing the organic matter content of the soil. The Ana Trees, *Faidherbia albida* (Del.) A. Chev., grow traditionally in fields closer to the villages than the Shea Butter Trees, *Vitellaria paradoxa* C. F. Gaertn. The former fields gain more organic material due to household waste being thrown there and they are also enriched by faeces from grazing livestock. Biannual tillage may improve soil surface properties compared to annual tillage (Franzluebbers et al, 1999). If the surface soil structure is improved, there will be a greater infiltration capacity and improved water use efficiency in the long run.

Hypotheses:
1. Infiltration capacity is higher under trees than in between trees.
2. The addition of extra leaves increases infiltration.
3. Infiltration is higher in the parkland of *Faidherbia albida* than in the parkland of *Vitellaria paradoxa.*
4. Infiltration is higher where organic matter is applied, compared to where only mineral fertilisers are added.
5. Bi-annual tillage increases infiltration compared to annual tillage.

1.1 Burkina Faso

The West African country of Burkina Faso has 13,6 million inhabitants and covers an area of 274 000 km^2 (Rundquist, 2004). Burkina Faso has no coast and is surrounded by the neighbouring countries of Mali, Niger, Benin, Togo, Ghana and the Ivory Coast. The capital city is Ouagadougou and here dwell one million people. Most Burkinabes live in the countryside and in the year of 2000, 92 % were farmers, but farming only contributed with 26% of the GNP (Rundquist, 2004). The country is heavily dependent of economical support from other countries and in 2002, aid made out 15,1 % of the GNP. In the ranking made by UNDP (United Nations Development Program) 2004, Burkina Faso was classed as the 3rd poorest country in the world (Sida, 2005).

The climate of Burkina Faso is sunny, hot and dry but three different seasons are present: a dry and cool period from November to March, a hot and dry period in April and May where temperature can reach 40°C, and a wet period from June to October. In the south part of the country the yearly precipitation is around 1000 mm (Aw climate acc. to Köppen classification) but in the desert-like parts in the north (Bs/Bw climates) it is only 250 mm (Åse, 2004).

Soil degradation is a severe problem caused by a combination of sparse precipitation, immense logging of the already reduced forests and overgrazing by livestock. A rapid population growth intensifies the pressure of soil- and water resources and the need of finding a sustainable use of resources is great (Sida, 2005).

1.2 The Villages and the Parkland System

Dossi and Boudoukuy are two villages in the western part of Burkina Faso in the middle of the cotton belt. They belong to the semi-arid Sudano-Sahelian climate zone and the yearly precipitation is around 750 mm (Son and Bourarach, 2001). None of the villages has electricity.

Farming is mainly carried out in Parkland Systems, traditional Agroforestry systems suitable for the savannah-like landscapes, with scattered trees on the fields. There are many ecological benefits of having trees in the field in this part of the world. As already mentioned, they increase the organic matter content in the soils, which gives a better moisture holding capacity and improves infiltration, by giving the soil a more fine-aggregated structure (Kessler, 1992). More nutrients can generally be found under trees than in between (Oliver, 2002; CTFT, 1988). Trees also act as windbreaks, which can be important when hot winds from Sahara enter the country. The reducing of soil peak-temperature by shading can be very important, during extra hot periods, for the survival of newly planted crop (Jonsson, 1995). A negative aspect ecologically, is that trees use a lot of water and there might not be enough for the crop; they also compete for nutrients in the soil. In most cases, though, the pros may outweigh the cons.

The trees also have other, socio-economic values. The income of fruits in these Parklands is higher, per hectare, than the potential loss of yield, which shading of the planted crop could cause (Kessler 1992). By growing both trees and a crop like sorghum, farmers diversify the risks of failed yields and lowered prices. All trees could also be used as firewood, a rare and very important product in these densely populated areas.

This multiple benefits of the trees have made farmers willing to keeping them on their land, even if they reduce the grain yield. For sorghum, Kessler (1992) showed a reduction of 6%, if the normal yield is about 500kg/ha. Studies made by Jonsson (1995) with millet do not show a reduction of yield and instead an increase is suggested, due to better conditions, i.e. lower peak temperature, under trees. Today there is another problem with trees on the fields; as some farmers have started using tractors, the trees are in their way and efforts to kill trees by fire can be seen.

1.2.1 Dossi

The tiny village of Dossi is located five kilometers from Boni, another village situated along the main road running from Ouagadougou to Bobo Dioulasso, 70km southwest of Boromo. There are around 2000 inhabitants of Dossi and they are dependent on farming, many of them growing cash crops as cotton and maize. Trees as *Faidherbia albida, Vitellaria paradoxa, Parkia biglobosa* and *Adansonia digitata* are scattered in the fields and grazing livestock can be seen everywhere. Traditionally *Faidherbia albida* were the trees surrounding the family houses and the *Vitellaria paradoxa* were growing in more distant fields. INERA/SLU has run experiments in this village since 2002 in a project dealing with management of soil organic matter. In these fields, maize is sown and all work is carried out in a non-mechanized way, with oxen pulling the plough.

The soils are deep (>130cm) and classified as Cambisols, according to the FAO classification system. This could be surprising as Cambisols ("brown soils") are defined by their limited age. In the arid tropics, though, they could be found in young deposition areas or in erosion areas where more genetically mature soils have eroded away (Driessen et al, 2001). In the Faidherbia field, the surface layer has a silt-clayey texture with a high amount of stones (40 %). The deeper layers have less stones (10 %) and the material is highly weathered and friable schist. In the field of Vitellaria, the surface texture is clayey-silty and deeper down it is more clayey. The soil has a high amount of swelling clays and shows hydromorphic characters, with pseudogley in deeper horizons.

1.2.1.1 *Faidherbia albida* - The African Winterthorn

The African Winterthorn (the Ana tree) or "the miracle tree" is a nitrogen-fixing species with an unusual phenology (Fig.1.2). *Faidherbia albida* is used in Agroforestry in Parkland Systems and the tree is extra beneficial as it sheds its leaves during the rainy season, when crop is sown and remains leafless until the crop canopy is full developed. This gives that the tree does not reduce the light for the crop, as other trees can do. Higher crop yields of maize and sorghum were found under this tree, as compared to outside the canopies. That was explained by better physical conditions of the soil and better soil fertility (Jonsson, 1995). The possibility of keeping a green canopy in the dry season has to do with long taproots (30-35 m) that corresponds with the groundwater. Seedlings, which have not developed these roots, have a normal phenology with no leaves in the dry season (NFTA, 1995).

Faidherbia albida has VA-mycorrhizal associations and nodulates with *Bradyrhizobium* bacteria. In West African savannas, the tree can be a part of fire climax vegetation and optimal conditions are when annual precipitation is in the range of 500-800 mm (NFTA, 1995). Pods have a high nutritional status and fall towards the end of the dry season, when fodder is scarce (NFTA, 1995).

Figure 1.2 The African Winterthorn, *Faidherbia albida*, in the fields of Dossi in the beginning of the rainy season (June).

1.2.1.2 *Vitellaria paradoxa*- The Shea Butter Tree

The Shea Butter Tree or Karité is a small to medium seized tree with a multipurpose use (Fig.1.3). The tree can be found in a 5000 km belt stretching across Africa, from Senegal in the west to the Sudan/Ethiopian border (Hall et al. 1996). *Vitellaria paradoxa* improves soil fertility, mainly due to a higher amount of soil organic matter caused by the shedding of leaves (Oliver et al, 2002, Kater et al, 1992).

The Shea Butter tree has edible fruits with a fatty stone, of which butter is made. As fruits are ripe in the beginning of the rainy season they represent a significant source of calories when other food is scarce (Boffa et al, 2000). The fruits are increasingly commercialized along the main roads and in urban centres. The fat could also be used as lamp-oil or be exported to chocolate- or make-up factories (Fries, 1991). The tree provides bark, roots and leaves, which are used in traditional medicine and the timber is hard and durable (Hall et al, 1996).

Figure 1.3 The Shea Butter Tree, *Vitellaria paradoxa*, in the fields of Dossi in the beginning of the rainy season.

1.2.2 Bondoukuy

The village of Bondoukuy is situated 100 km north of Bobo Dioulasso and, including the small settlements in the vicinity, it has around 5000 inhabitants. Cotton is the most important cash-crop in the area and especially young people are growing it, as they rather easily get out enough money for buying a moped, a very important status symbol in Burkina Faso (Ouattara, pers. com., 2005).

The experimental fields of Bondoukuy are divided into two landscapes: the "Plateau", where soils are classified as Ferric Lixisols with a sandy texture and the "Low Glacis" with loamy Ferric Luvisols. The fields of the farmers are permanent and have been under crop cover for at least fifteen years. The experiments set up by INERA/SLU have run since 2002 and the crop rotation has been cotton, maize, cotton. Due to an increasing mechanization in this area, trees are being taken away from the fields and this project studies the effects of management of soil organic matter, by using harvest residue composts and biannual tillage, in fields where there are no trees. In the surrounding areas there are still traditional Parkland systems. The farmers included in the experiment use oxen for tilling and do the planting, weeding and harvesting by hand.

2 Methology

2.1 Fieldwork

For the infiltration measurements a tension disc infiltrometer of model SW 080B (SDEC, France) was used (Fig. 2.1). The bubble-tower had three valves for air entry and they were set to correspond with the tensions of -10, -5 and 0 cm. The base plate (Soil Measurement Systems, Arizona) had a diameter of 20 cm and was separate from the reservoir but connected by a tube. The reservoir had a diameter of 4,45 cm, which gives that 1 cm of water in the reservoir equals 0,495 mm water entering the soil.

Figure 2.1 The tension disc infiltrometer in use in the cotton fields of Bondoukuy.

When preparing a place for measurement, the soil surface was made more even by gently scraping the surface roughness. A thin layer of moist sand was applied for achieving a flat surface enabling hydraulic contact under the entire disc (Fig. 2.2). Water passes were used to ensure that the surface was horizontal and also that the reservoir had a vertical position. At the start of the measurements, extra sand around the disc was taken away for avoiding water being lead out from the sides.

Figure 2.2 To enable hydraulic contact underneath the entire disc, moist sand was applied and made horizontal with a water pass.

The infiltration from a tension disc infiltrometer is tree-dimensional (Fig. 2.3) and the values for the tension of 0 cm can not be compared with the values from a double ring infiltrometer, as the latter gives one-dimensional infiltration. A comparison of pros and cons of different infiltration methods are presented in table 2.1 (Clothier, 2001) and here the tension disc infiltrometer gets the highest utility score.

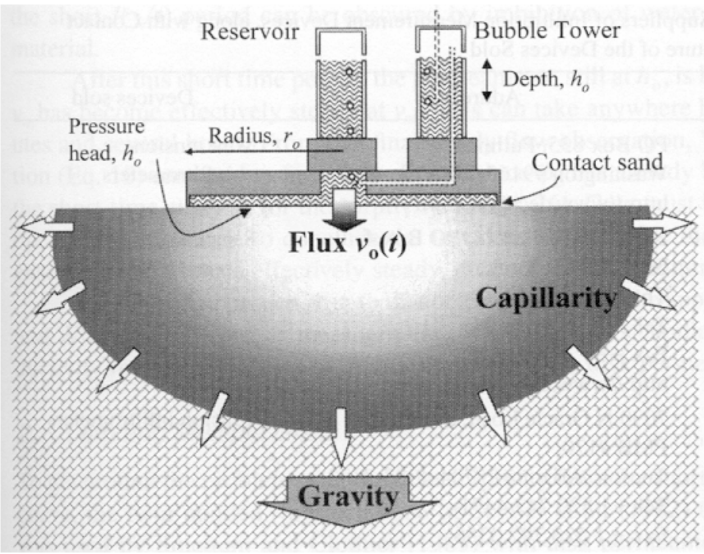

Figure 2.3 The three-dimensional flow from a tension disc infiltrometer (picture from Clothier, 2001)

Table 2.1. After Clothier, 2001.

Table 1 The relative merits of field infiltration devices against a set of criteria where the ranking of 5 implies cheap, easy, or high, and 1 suggests expensive, difficult, or low. Each attribute column contains at least one 5 (top) and at least one 1 (worst). The overall Utility of each device was found as the sum of the first six columns, multiplied by the Information content. A high Utility score indicates usefulness, with the maximum range possible being from 150 down to 6

Device	Cost 5 ≈ US$100 1 ≈ US$10,000	Physical ease of field use	Technical skills required	Site disturbance	Ease of data analysis	Ease of time–space replication	Information content	Utility score
Rings	5	5	5	1	5	4	3	75
Wells, auger hole permeameters	2	3	3	2	3	4	4	68
Pressure infiltrometers	2	2	2	1	3	4	3	42
Closed-top permeameters	2	2	1	1	1	1	2	16
Crust test	3	2	2	3	2	1	3	39
Tension and disc infiltrometers	2	3	2	4	2	4	5	85
Drippers	3	2	2	5	2	5	3	57
Rainfall simulators	1	1	1	5	3	1	1	12

2.1.1 Experimental design - Dossi

In Dossi measurements were done *before tilling* in June 2005, in six categories of field:

In between *Faidherbia albida*
Under *Faidherbia albida*
In between *Faidherbia albida* with extra leaves of *Vitellaria paradoxa**
Under *Faidherbia albida* with extra leaves of *Vitellaria paradoxa**
In between *Vittellaria paradoxa*
Under *Vittellaria paradoxa*

*The addition of extra leaves was made, after tilling, in 2004 with an amount of 12.4 kg fresh leaves, equivalent to 40kg Nitrogen per hectare.

Each treatment was studied in two plots (4x6m) in different parts of the fields. The plots were randomly laid out (2002) in a suitable way considering the placement of the trees. In each plot, four places of measurements were randomly chosen. In total, eight measurements were made in each category of field.

2.1.2 Experimental design - Bondoukuy

The experimental design of Bondoukuy includes four farmers on the Plateau and four on the Low Glacis. Each farmer has a field with four different subplots (8x20m) (Fig. 2.4). The compost is made out of straw of sorghum and cow dung, which is left to rest in a pit for half a year. It is applied with five tonnes per hectare (dry weight) every second year (when cotton) in the same day as tilling.

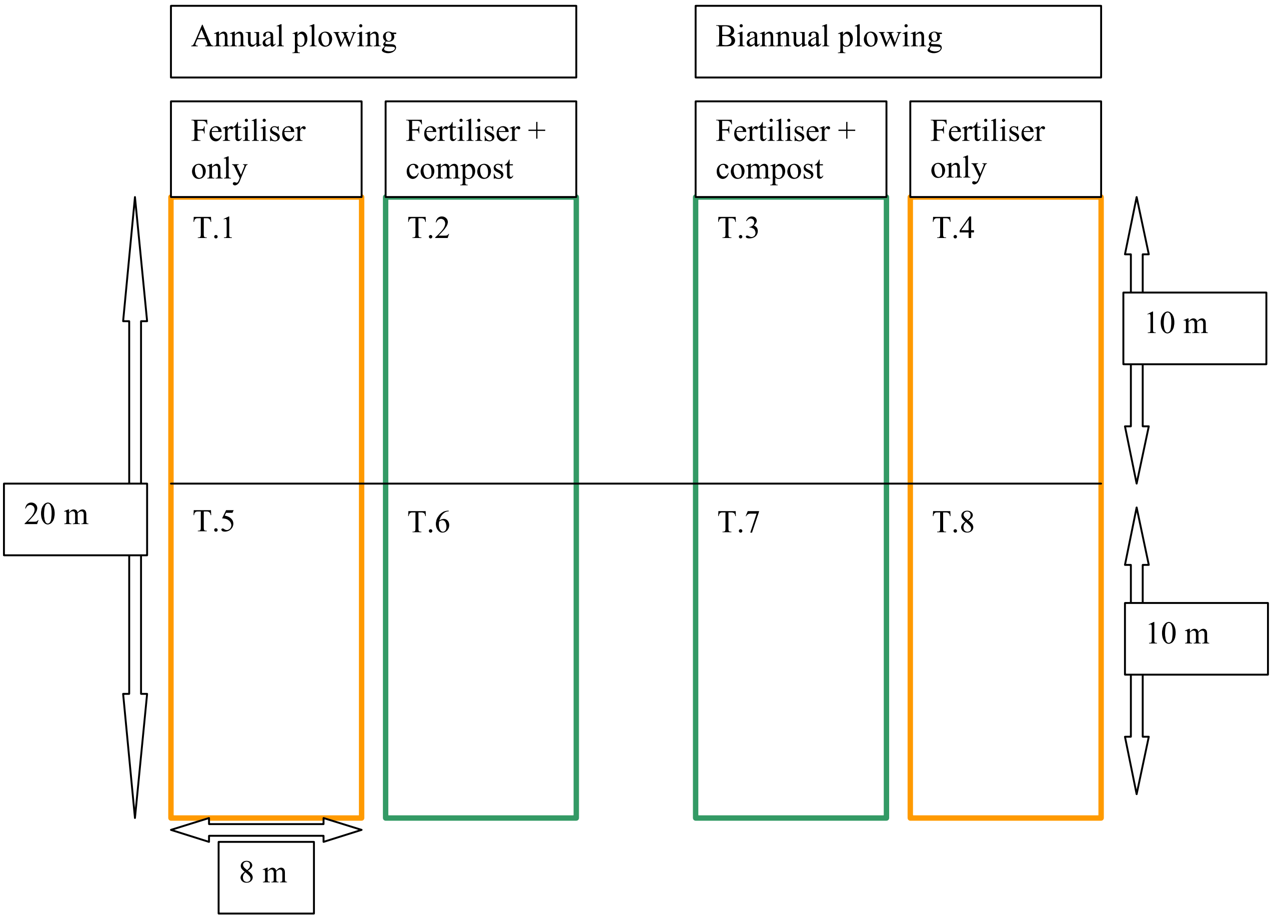

Figure 2.4 The experimental design in the fields of Bondoukuy (Ouattara, 2004).

The infiltration measurements were made in 2005, in the dry season before tilling and in the rainy season after tilling. The measurements before tilling were made in the fields of six different farmers, three on the Plateau and three on the Low Glacis. In each treatment plot two replications were made and for the zero tension a third measurement was run. This gives in total nine measurements for the zero tension in each category of field on the Plateau and eight measurements in the Low Glacis (the extra zero tension was excluded in one field) giving in total seventeen measurements.

After tilling, two replications were made in the fields of two farmers on the Plateau and two on the Low Glacis, giving a total of eight measurements in each category of field.

2.2 Statistics

2.2.1 Dossi

To determine weather the different treatments had significant impact on steady-state infiltration capacity, analysis of variance was preformed with General Linear Model in ANOVA (Minitab 14). The level of significance was set to 95% and for the treatments of Dossi following model was used:

For each field it was stated:

$$Y_{tb} = \mu + \alpha_t + \beta_b + (\alpha\beta)_{tb} + e_{tb}$$

Giving the overall formula:

$$Y_{tbf} = \mu + \alpha_t + \beta_{b(f)} + c_f + (\alpha c)_{tf} + e_{tbf}$$

Y_{tbf} = steady state infiltration capacity
μ = average
α_t = trees (t = 1 or 0)
$\beta_{b(f)}$ = block of field (b=1 or 2, f=1 or 2)
c_f = fields (Faidherbia= 1, Vitellaria =2)
$(\alpha c)_{tf}$ = the interaction between trees and field
e_{tbf} = split plot error

The interaction between trees and block of field, $(\alpha\beta)_{tb(f)}$, was excluded as the interaction showed no correlation and there were not enough degrees of freedom for the test.

To determine weather the addition of extra leaves had an impact on steady-state infiltration capacity in the Faidherbia field, following model was used:

$$Y_{tl} = \mu + \alpha_t + \gamma_l + (\alpha\gamma)_{tl} + e_{tl}$$

Y_{tl} = steady state infiltration capacity
μ = average
α_t = trees (t = 1 or 0)
γ_l = leaves (l = 1 or 0)
$(\alpha\gamma)_{tl}$ = the interaction between trees an leaves
e_{tbf} = split plot error

To get a better picure of the entire data-set for steady-state infiltration capacity, data from each treatment were sorted in ascending order and plotted together. *Plotting position* is a way to plot ordered data, which avoid the impossible probability of 0 or 1 (Yevjevich, 1971). It also gives an estimate of the probability of infiltration capacities being less than or equal to a selected infiltration capacity. In this study, $P(x)=m/(N+1)$ was used for calcutating plotting positions, where m is the ordered sequence of x-values and N is the sample size of ungrouped data.

2.2.2 Bondoukuy

In Bondoukuy following model was used in ANOVA (General Linear Model):

For each landscape type (Low Glacis and Plateau) it was stated:

$$Y_{ikj} = \mu + \alpha_i + \beta_k + (\alpha\beta)_{ik} + c_j + (\alpha c)_{ij} + (\beta c)_{kj} + e_{ikj}$$

This gives the overall formula:

$$Y_{iklj} = \mu + \alpha_i + \beta_k + c_{j(l)} + \gamma_l + (\alpha\beta)_{ik} + (\alpha c)_{ij(l)} + (\beta c)_{kj(l)} + (\alpha\gamma)_{il} + (\beta\gamma)_{kl} + (\alpha\beta\gamma)_{ikl} + e_{ikjl}$$

Y_{iklj} = steady state infiltration capacity
μ = average
α_i = tillage (annual tillage = 1, biannual tillage = 0)
β_k = compost (k = 1 or 0)
$c_{j(l)}$ = farmer (j = 1, 2, 3)
γ_l = landscape (Plateau = 1, Low Glacis = 2)
$(\alpha\beta)_{ik}$ = interaction between tillage and compost
$(\alpha c)_{ij(l)}$ = interaction between tillage and farmer

$(\beta c)_{kj(l)}$ = interaction between compost and farmer
$(\alpha\gamma)_{il}$ = interaction between tillage and landscape
$(\beta\gamma)_{kl}$ = interaction between compost and landscape
$(\alpha\beta\gamma)_{ikl}$ = interaction between tillage, compost and landscape
e_{ikjl} = split plot error

3 Results

3.1 Dossi

Due to problems with the equipment (see Chapter 4.3), 16 measurements (tension zero) out of 48 were excluded before calculating a mean for each plot (Appendix 1). Following results are for three-dimensional infiltration at tension zero.

When using General Linear Model (Turkey-test) in ANOVA, statistical significance (P=0.014) was found for the hypothesis *IC is higher under trees than in between trees* combining both tree species investigated (Tab. 3.1, Fig. 3.1). The average value for IC *under trees* was 104 mm/h and for *in between trees* it was 69 mm/h. For the two fields, no statistical difference could be proven, but there was an obvious dissimilarity between the different blocks within the fields (P=0.006). When plotting the infiltration capacity of the two fields in ascending order, in a figure with plotting positions, there seem to be a higher infiltration capacity in the Vitellaria parkland, but it cannot be proved statistically (Fig. 3.2). This difference is also shown by the mean values, which were 117 mm/h versus 58 mm/h.

Table 3.1 The analysis in ANOVA proved significance for: *IC is higher under trees than in between trees*.

General Linear Model: IC versus Tree; Field; Block

Factor	Type	Levels	Values
Tree	fixed	2	0; 1
Field	fixed	2	1; 2
Block(Field)	random	4	1; 2; 1; 2

Analysis of Variance for IC, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Tree	1	1845,7	1845,7	1845,7	68,78	**0,014**
Field	1	7119,6	7119,6	7119,6	1,66	0,326
Block(Field)	2	8555,4	8555,4	4277,7	159,41	0,006
Tree*Field	1	6,2	6,2	6,2	0,23	0,679
Error	2	53,7	53,7	26,8		
Total	7	17580,5				

S = 5,18017   R-Sq = 99,69%   R-Sq(adj) = 98,93%

When running the General Linear Model for *extra leaves* it showed no significance (Tab. 3.2), but when plotting IC for extra leaves contra no addition of leaves, a vague difference can be seen (Fig. 3.3).

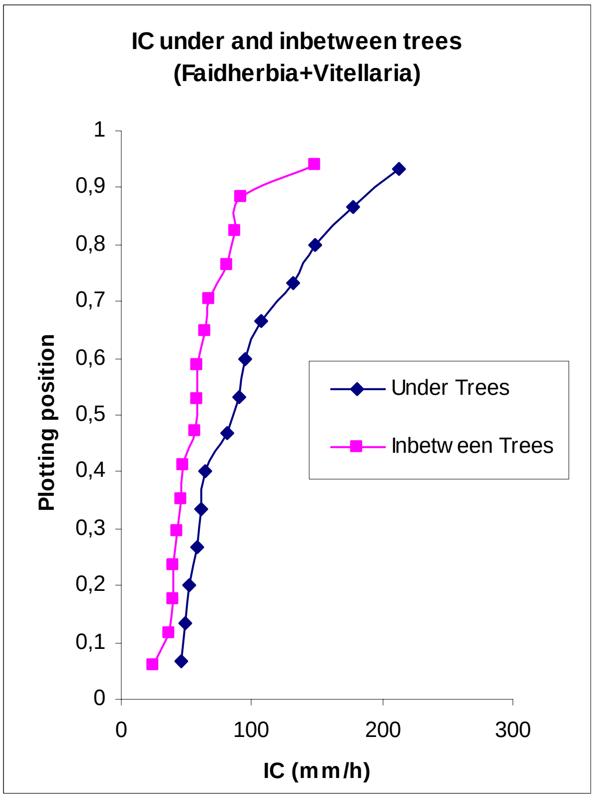

Figure 3.1 Steady-state infiltration capacities, plotted in ascending order with plotting positions, for under and in between trees.

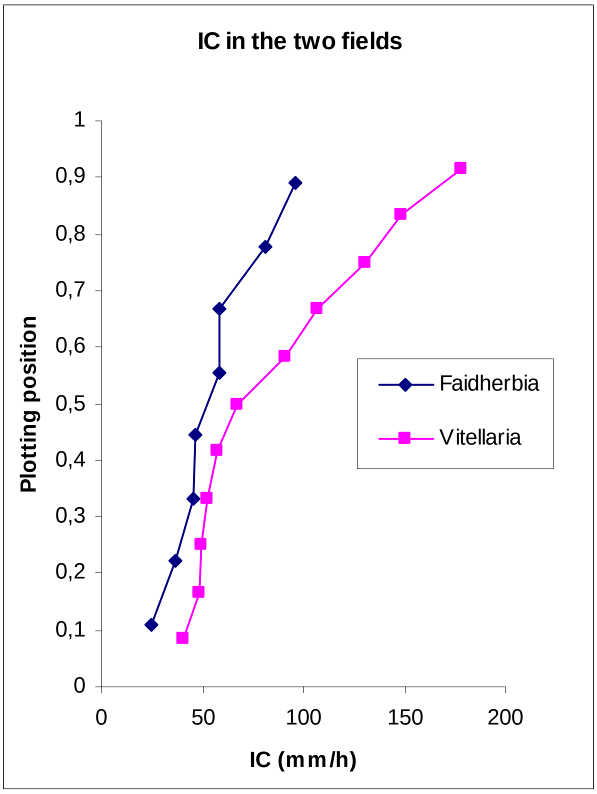

Figure 3.2 Steady state infiltration capacities, plotted in ascending order with plotting positions, in the fields of Faidherbia and Vitellaria.

Table 3.2 The analysis in ANOVA showed no statistical difference for steady-state infiltration capacity for extra leaves compared to the control.

General Linear Model: LogIC versus Tree; Leaves

Factor	Type	Levels	Values
Tree	fixed	2	0; 1
Leaves	fixed	2	0; 1

Analysis of Variance for LogI, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Tree	1	0,07905	0,07905	0,07905	6,38	0,065
Leaves	1	0,02941	0,02941	0,02941	2,37	**0,198**
Tree*Leaves	1	0,00459	0,00459	0,00459	0,37	0,576
Error	4	0,04958	0,04958	0,01240		
Total	7	0,16263				

S = 0,111336   R-Sq = 69,51%   R-Sq(adj) = 46,65%

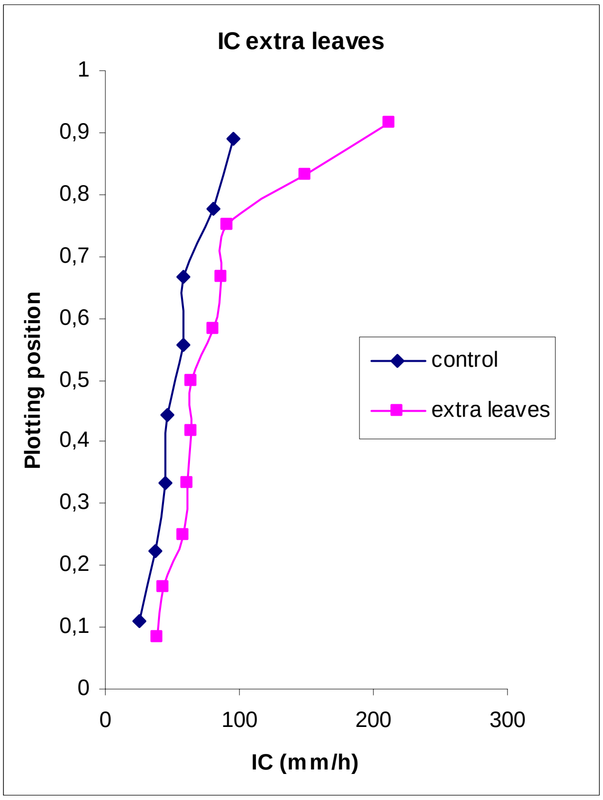

Figure 3.3 Steady-state infiltration capacities, plotted in ascending order with plotting positions, for the plots with extra leaves and the control.

3.2 Bondoukuy

In Bondoukuy 60 values out of 64, before tilling at tension zero, could be used. All values for the Plateau after tilling seemed reliable, but due to heavy rains and lack of time, this part of the study was not completed and the results from the Low Glacis after tilling were excluded.

The statistical analysis for the results, before tilling, in Bondoukuy, showed a positive relationship between compost and steady state infiltration capacity at the 95% level (P=0.009, Tab. 3.3). The mean values were 79 mm/h for *compost* and 58 mm/h for *no compost*. The difference in infiltration capacity in the two landscapes, Plateau and Low Glacis, was also statistical significant (P=0.018, Tab. 3.3). The difference between annual and biannual tillage could not be shown with ANOVA. The mean value for *biannual* tillage was 75 mm/h compared to 62 mm/h for *annual* tillage and the distribution is shown in Figure 3.4.

The results after tilling were also used in different models but they did not show any statistical differences.

Table 3.3 ANOVA, General Linear Model, Log IC (mm/h) versus **C**ompost, **T**illage, **L**andscape and **F**armer showed significance for Compost and Landscape.

General Linear Model: LogIC versus C; T; L; F

Factor	Type	Levels	Values
C	fixed	2	0; 1
T	fixed	2	0; 1
L	fixed	2	0; 1
F(L)	random	6	1; 2; 3; 1; 2; 3

Analysis of Variance for LogIC, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	
K	1	0,09355	0,09355	0,09355	22,70	**0,009**	
P	1	0,04344	0,04344	0,04344	0,93	0,390	
L	1	0,41704	0,41704	0,41704	15,01	**0,018**	
C*T	1	0,02281	0,02281	0,02281	1,19	0,337	
C*L	1	0,00124	0,00124	0,00124	0,30	0,613	
T*L	1	0,00614	0,00614	0,00614	0,13	0,735	
C*T*L	1	0,02825	0,02825	0,02825	1,47	0,292	
F(L)	4	0,11114	0,11114	0,02778	0,88	0,614	x
C*F(L)	4	0,01649	0,01649	0,00412	0,21	0,918	
T*F(L)	4	0,18704	0,18704	0,04676	2,43	0,205	
Error	4	0,07690	0,07690	0,01923			
Total	23	1,00404					

x Not an exact F-test.
S = 0,138657   R-Sq = 92,34%   R-Sq(adj) = 55,96%

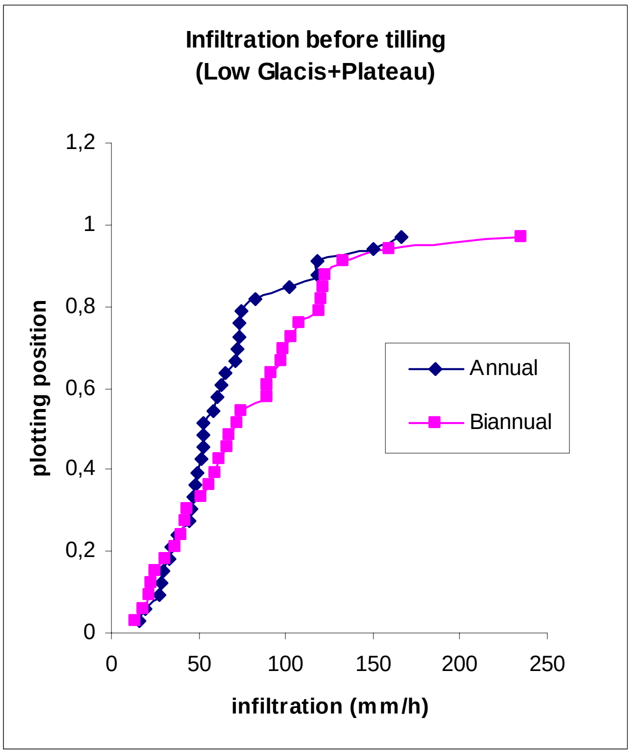

Figure 3.4 Steady state infiltration capacities plotted in ascending order with plotting positions, for both annual and biannual tillage.

4 Discussion

4.1 Dossi

The results showed that infiltration under trees is higher than in between trees. This could be explained by that the soil under trees obtains more organic material, not just from the shedding of leaves, but also from dead branches and roots. The soil also gets another structure when roots die and are decomposed, leaving channels where water can flow more easily. Other explanations could be that grazing livestock prefer the shadow under the trees and this leads to a higher amount of faeces, with compost-effect, under trees. Birds, sitting in the three crown, could also contribute to the same effect. The "under tree" plots had a tree-trunk standing immediately outside the border and this makes one think that there could be a difference in infiltration capacity depending on in which part of the plot the measurements were made. However, when plotting distance to tree versus infiltration capacity, it is not possible reading out a trend where infiltration is higher closer to the tree (Fig. 4.1). This shows that one plot can be said to be a homogenous unit, when considering the impact of a certain tree on steady-state infiltration capacity.

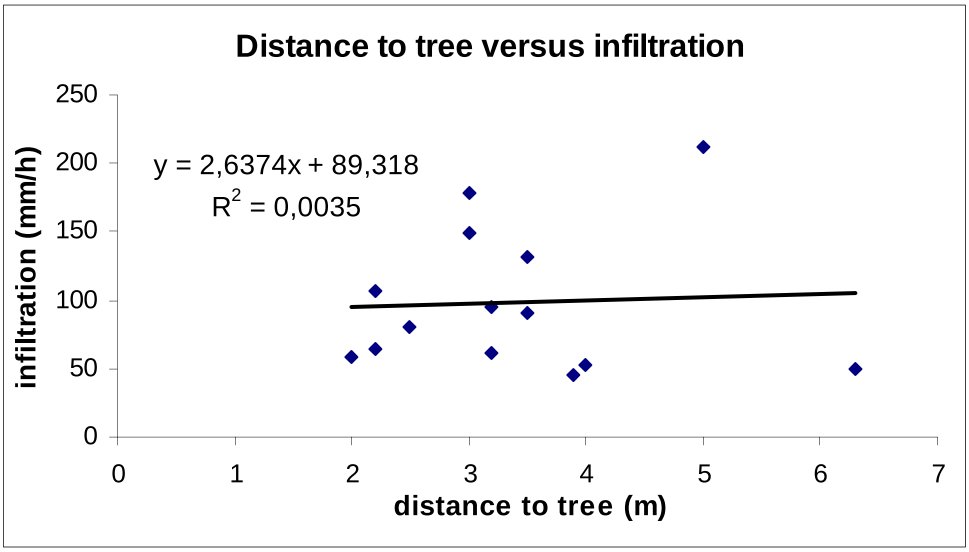

Figure 4.1 Steady-state infiltration shows no increase within the plot, when measuring closer to the tree.

When it comes to the addition of extra leaves, no statistically proved impact on steady-state infiltration capacity was shown. The lack of significance could be due to too few replications, as measurements only where made in the Faidherbia field, but there could also be other reasons. The application of extra leaves in the plots has only been made once (in 2004). When comparing with the difference caused by trees standing there for twenty years or more, it is not surprising that the addition of extra leaves did not cause much of alternation. A problem with the addition of extra leaves is that they are spread by the wind around the plots. This is also interesting when considering the impact of leaves in general, compared to the influence of roots and braches. Leaves are important for the soil organic matter content of the whole field, but the concentration of leaves will always be higher in places protected by the wind. When studying the pattern of leaf-spreading, I noticed that there were higher amount of leaves in small depressions in the landscape and not necessarily all around the trees. Leaves cannot entirely explain the higher infiltration capacity under trees but, as mentioned before, the alternation of soil structure by roots and the addition of soil organic matter from dead branches and roots could also be the cause.

The higher infiltration capacity in the field of Vitellaria compared to the field of Faidherbia could be explained by the difference in soil types. The dry soil of the Vitellaria field had cracks due to swelling clays and these are causing a higher infiltration. If running the experiment for a very long time or if the soil is almost saturated by heavy rains, there is probably a possibility of a lower IC in the Vitellaria field. Another reason for the lower IC in the Faidherbia field could be that the leaves there are more easily decomposed as they contain more nitrogen and other nutrients. In this climate, with an extremely high decomposition speed, when soil is moist, a slower rate could be of importance for conserving some soil organic matter, giving structure to the soil. Slower decomposition in the Vitellaria field could also be due to a lower pH: 5,74 compared to 6,11 in the Faidherbia field in the upper horizon (Gnankambary, unpubl.). The hypothesis stating that infiltration capacity should be higher in the Faidherbia field is based on the fact that these fields traditionally have more soil organic matter due to their closer position to the settlements. In this case, though, the Vitellaria field also had some newer houses near by, and livestock were grazing (and fertilizing) in this field as well. When comparing the Carbon and Nitrogen content of the soils, the fields showed no difference (Gnankambary, unpubl.).

4.2 Bondoukuy

The results of Bondoukuy, *before tilling,* showed significance for the hypotesis: *Infiltration is higher where organic matter is applied, compared to where only mineral fertilisers are added*. These are nice results when considering the short duration of the treatments! It shows the importance and the potential of managing the soil organic matter content of tropical soils.

The infiltration capacity was also statistically differentiable for the different landscape types. This is explained by the different soil types and especially by the fact that the soils of the Plateau is of a coarser texture with around 75 % of sand, 20 % silt and 5 % clay in the upper layer (Ouattara, 2004). This could be compared with the Low Glacis where the particle size distribution is: 40 % sand, 45 % silt and 15 % clay in the upper two decimetres.

Biannual tillage could not be proven to have positive effect of steady-state infiltration capacity in this study. This is not at all surprising, considering the short time of the experiment. As these measurements were made in the third year of the experiment, the plots that are tilled every second year have just been tilled one time less than the plots being tilled every year. This is too little for improving the soil structure for steady-state infiltration capacity.

The results *after tilling* were not statistically significant but there was a tendency (P=0,065) towards that compost increased steady-state IC. The reasons why no significance could be proven are many. First of all there were few measurements, as the data from the Low Glacis had to be excluded due to heavy rains and an all-saturated soil profile. The infiltration capacity after tilling also varies with the amount and intensity of the precipitation that has come since the day of tilling (Ndiaye et al, 2005). Immediately after tilling the infiltration capacity is very high but when the rain comes, a lot of particles are flushed away, the soil surface becomes sealed by particles and a crust is formed. The plough-rows are of importance anyway, as the whole field quickly gets ponded during a heavy rain, and the plants, which are planted on the ridge, are not completely drowned in water.

4.3 The tension disc infiltrometer

The tension disc infiltrometer may have a high utility score in the comparison made by Clothier (Table 2.1) but *in situ* in Burkina Faso, I would have preferred a more robust method, like the double-ring infiltrometer. The tension disc infiltrometer was chosen as it consumes less water, runs quicker and gives more data, but it is very difficult to get reserve parts if something breaks down! As it is a complex instrument, there are many things that can cause problems. In our case the closing tap on the tube broke down half way through the measurements in Dossi.

When I had started to analyse the data and wanted to check the calibration of the infiltrometer, I found out that the calibration instrument broke four years ago… This is not a problem for the comparisons, giving the result in my study, but for the exact values, an accurate calibration is of importance. A not precise calibration could explain why water leached out from the sides at tension zero in several measurements. This happened especially in the clayey and compact soils, before tilling, in Dossi. Tension zero might have been a vague positive pressure and these values had to be excluded from the data set. This explains why most of the 16 measurements out of 48 in Dossi were left out. Other reasons for extremely high values of the steady-state infiltration capacity are holes in the ground caused by ants or termites and tree-roots.

Other problems with the measurements were: finding the right type of sand for enabling hydraulic contact and applying just the right amount for getting the surface flat and horizontal, but not too much, giving the water an easier way of escaping than infiltrating into the ground (just a problem at tension zero). Another problem, when having a too thick sand-layer, is keeping the bubble-tower and the disc at the same level.

When determining the duration of the measurements at each tension, steady-state is reach relatively quick for the sandy soils. When measuring steady-state infiltration capacity on clayey soils, the time for reaching steady-state is multiplied. As reaching steady-state is a slow process, especially in dry swelling clays, the flow seems to be steady long before the final speed is reached. This is the case for some of the measurements in this study and they where excluded, but they were mainly at tension -10cm, so they were not included in these results, anyway.

Much more results are possible to extract from my data, i.e. saturated conductivity and the sorbtivity at present soil moisture. In Bondoukuy, before tilling, the soil-moisture before and after each measurement was determined. This also gives the possibility of calculating the sorptivity for a dry soil, the near saturated conductivity and the mean pore-size distribution. All data in my study are values for three-dimensional infiltration. They can be transfigured into one-dimensional infiltration data by a set of calculations described by Messing and Jarvis (1993).

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Appendix 1

Mean values of steady-state infiltration capacities for the plots of **Bondoukuy** *before tilling*:

Plateau before tilling				Low Glacis before tilling			
Farmer	Compost	Tillage	µ IC (mm/h)	Farmer	Compost	Tillage	µ IC (mm/h)
1	no	annual	63,99	1	no	annual	30,276
2	no	annual	61,164	2	no	annual	26,748
3	no	annual	69,516	3	no	annual	38,232
1	yes	annual	127,176	1	yes	annual	39,948
2	yes	annual	45,048	2	yes	annual	73,8
3	yes	annual	97,104	3	yes	annual	67,572
1	no	biannual	81,288	1	no	biannual	65,424
2	no	biannual	81,618	2	no	biannual	29,076
3	no	biannual	87,744	3	no	biannual	57,762
1	yes	biannual	90,492	1	yes	biannual	65,124
2	yes	biannual	143,884	2	yes	biannual	24,78
3	yes	biannual	100,656	3	yes	biannual	72,432

Mean values of steady-state infiltration capacities for the plots of **Bondoukuy** *after tilling*:

Plateau after tilling			
Farmer	Compost	Tillage	µ IC (mm/h)
1	no	annual	242,838
2	no	annual	124,416
1	yes	annual	160,056
2	yes	annual	216,918
1	no	biannual	176,22
2	no	biannual	352,89
1	yes	biannual	498,744
2	yes	biannual	432,396

Mean values of steady-state infiltration capacities for the plots of **Dossi** *before tilling*:

Dossi before tilling			
Field	Tree	extra leaves	µ IC (mm/h)
Faidherbia	in between	no	41,58
Faidherbia	in between	no	41,508
Faidherbia	under	no	80,964
Faidherbia	under	no	66,396
Faidherbia	in between	yes	53,472
Faidherbia	in between	yes	70,344
Faidherbia	under	yes	63
Faidherbia	under	yes	150,516
Vitellaria	in between	no	148,536
Vitellaria	in between	no	57,396
Vitellaria	under	no	178,222
Vitellaria	under	no	84,951