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Effects of conservation agriculture on surface termite activity in Central Mozambique

Diplomarbeit zur Erlangung des akademischen Grades Diplomingenieur

eingereicht von:

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September 2008

GERMAN ABSTRACT (ZUSAMMENFASSUNG)

Einfluss bodenschonender Landwirtschaft auf die Termitenaktivität in Zentralmosambik

Die Aufbringung von Mulch ist eine wichtige Komponente bodenschonender Landwirtschaft, die weiters auf minimale Störung des Bodens und Fruchtwechsel basiert. Auf einer landwirtschaftlichen Versuchsanlage in Sussundenga in Zentralmosambik wurden die Wechselwirkungen zwischen bodenschonender Landwirtschaft und der Termitenaktivität erforscht. Der 2006 auf lehmigen Böden angelegte Versuch besteht aus sechs bodenschonenden Anbaumethoden mit verschiedenen Sämethoden und Fruchtfolgen (z.B. Rotation von Mais mit Sonnenblumen und Bohnen) und einem konventionell gepflügten Teil mit Mais. Die Oberflächen-Termitenaktivität wurde durch Zählung der Termitenlöcher in einem vordefinierten Raster auf jedem Feld durchgeführt. Zusätzlich wurde der potentielle Effekt der Termitenaktivität auf die Wasserinfiltration mit einem Mini-Regen-Simulator abgeschätzt. Messungen erfolgten im zweiten Jahr nach der Anlegung des Versuchsfeldes (2008).

Die Ergebnise zeigen, dass die Termitenaktivitäten bei bodenschonender Landwirtschaft signifikant höher sind als auf den konventionell bearbeiteten Feldern. Nicht nur die Bearbeitungsmethode, auch die Art des Mulches der vorhergehenden Pflanze beeinflusste die Termitenaktivität: Termiten bevorzugten Mais und Bohnen mehr als Sonnenblumenreste. Zusätzlich bewirkte eine spätere Pflanzzeit und deshalb das nichtvorhandensein eines Schattens eine geringere Anzahl an Termiten auf einigen Feldern.

Die höchste Termitenlochdichte (61 Löcher/m²) wurde bei der Anbaumethode mit „Becken“ mit Mais und die geringste Dichte (7 Löcher/m²) bei konventionell gepflügten Feldern mit angebautem Mais festgestellt.

Kein signifikanter Unterschied konnte hingegen bei den Infiltrationsmessungen zwischen den bodenschonenden und den konventionell gepflügten Anbaumethoden festgestellt werden. Viele Einflussfaktoren, wie die Ausführung der Messungen selber und Wetter- sowie Bodeneinflüsse führten zu keinen direkten Zusammenhang. Dadurch konnte kein Einfluss einer höheren Termitendichte auf die Wasserinfiltration nachgewiesen werden. Diese Forschungsarbeit zeigt aber, dass bodenschonende Landwirtschaft bereits nach zwei Jahren Auswirkung auf die biologische Aktivität hat.

ABSTRACT

Crop residues are crucial for Conservation Agriculture (CA), a cropping system based on minimal soil disturbance, residue retention and crop rotations. At Sussundenga Research Station situated in Central Mozambique, investigated we the effects of CA on termite activity. The trial established in 2006 on loamy soils consisted of six CA treatments with different seeding technologies and crop rotations (i.e. rotations of maize with sunflower and beans) and one conventionally ploughed (CP) treatment with continues maize cultivation. Measurements were taken in the second cropping season after the trial establishment (in 2008). Surface termite activity was recorded by counting termite holes in a predefined raster on each plot. Furthermore, potential effects of termite activity on water infiltration were measured with a mini-rainfall-simulator. The results show that surface termite activity is significantly higher on CA than on CP plots. Apart from tillage treatment, the type of residues retained from the previous crop was important for the extent of termite activity. Termites preferred maize stalks and bean residues over sunflower residues. The time of planting and therefore the missing shade in some treatments resulted in fewer termite holes. The highest termite-hole densities (61 holes/m²) were found in manmade basins with maize, the lowest densities were found for conventional practice with continues maize cultivation (7 holes/m²). More termites are active on CA plots with residue retention.

During infiltration measurements no significant differences were found between CA and CP treatments. Many factors like measurement errors and weather events and soil behaviour influenced the results. Thus, no impact of higher amounts of termite holes on water infiltration was recorded. The study clearly shows that CA, already after two cropping seasons has an impact on biological activity.

GERMAN ACKNOWLEDGEMENTS (DANKSAGUNG)

Besonders bedanken möchte ich mich vor allem bei meiner Familie, die mich all die Jahre meiner Ausbildung und des Studiums unterstützt haben.

Dank gebührt weiters

Ao. Univ.-Prof. Dipl.-Ing. Dr. nat. techn. Willibald Loiskandl für die Betreuung der Arbeit.
MSc. Sebastião Inacio Famba , für die Hilfe und Organisation in Mosambik.
Dipl.-Ing. Alexandra Strauss-Sieberth für Ihre Unterstützung bei meiner Arbeit.
Tito Jamal und *Paulino Luis* für die Hilfe bei der Feldarbeit und deren Freundschaft in Mosambik.

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GERMAN FOREWORD (VORWORT)

Ursprünglich hätte die Wasserbilanz für den Vergleich verschiedenster bodenschonender Anbaumethoden auf den Versuchsfeldern der landwirtschaftlichen Versuchsstation Sussundenga ermittelt werden sollen. Aufgrund fehlender Ausrüstung zur Wassergehaltsbestimmung, die im Zoll in Maputo nicht freigegeben wurde, hat sich das Thema dieser Arbeit grundlegend geändert. Dadurch war von Beginn an alles ein bisschen ungewiss und die Änderung des Themas bzw. meiner ganzen Arbeit war nicht das einzige Unerwartete des Forschungsaufenthaltes in Mosambik. Angefangen von Hindernissen durch die Natur bis hin zu Komplikationen durch die Organisation spannte sich die Palette von Schwierigkeiten.

Visumprobleme (sowohl vor dem Reiseantritt – das Touristenvisum wurde mir zu spät zugesendet, als auch während meines Aufenthaltes – alle 30 Tage mußte ich aus Mosambik ausreisen um einen neuen Aufenthalststempel zu bekommen und zusätzlich mußte ich nach 90 Tagen ein neues Touristenvisum an der Grenze beantragen), verspätete Gepäcksankunft, Nichtpassierbarkeit von Straßen durch die Regenzeit, nicht vorbereitete Wohnungssituation, Verständigungsschwierigkeiten, Kommunikationsschwierigkeiten mit dem Institut bzw. den Betreuern, nichtvorhandene Ausrüstung sind nur einige der Probleme die ich zu bewältigen hatte.

Diese „negativen“ Erfahrungen sind aber nur ein Bruchteil von dem, was ich alles an Positives in Mosambik erlebt habe. Da ich sozusagen der einzige *Musungu*[1] war, der dort lebte, konnte ich in dem nicht ganz viermonatigen Aufenthalt, guten Kontakt zur einheimischen Bevölkerung aufbauen. Einige sind mir sehr ans Herz gewachsen, obwohl ich mich gerade einmal mit einer Person auf Englisch unterhalten konnte. Sein Name war Tito und ich habe ihn als fleißigen Arbeiter kennengelernt. Er hat mir auch immer über alles berichtet, wie die Leute so über mich dachten. Das brachte mir viele Erkenntnisse über die unterschiedlichen Denkweisen von „Afrikanern“ und „Europäern“:

„Wie, der Weisse Mann geht so weit zu Fuß? Normalerweise benutzt er für alles das Auto.“

„Das hab ich mir von dir abgeschaut, wie man effizienter Arbeiten kann – damit wir früher fertig werden.“

[1] *Musungu* ist die Bezeichnung für den „Weißen Mann“ in der Sprache der Einheimischen

Eine besondere Erfahrung war, wie glücklich Menschen sein können, obwohl sie sehr arm sind. Immer zu Späßen aufgelegt und freundlich – beschämend eigentlich für mich, da ich dort einen besonderen Luxus genoss (meine Kühltruhe war bei allen eine riesige Sensation). Wie verrückt und unverständlich müssen da nur unsere „Probleme", die wir in Österreich haben, in deren Ohren klingen?

„Gut Ding braucht Weile."

In Mosambik, schien Zeit eine gänzlich andere Definition zu haben, was ich teilweise in kuriosen Situationen entdeckt habe. Abends auf der Veranda im Dunkeln zu sitzen (da ich zwei Wochen keinen Strom hatte), war eines meiner schönsten Erlebnisse. Und viel Zeit für alles einzuplanen, ist in Afrika eine besondere Notwendigkeit – vieles dauert eben ein bischen länger, man muss Geduld aufbringen und sich dem einfach fügen.

Ich habe sehr viel dazugelernt, sei es von technischer oder sozialer Seite. Letztendlich kann man negative Erfahrungen auch postiv werten:

„Man lernt ja auch aus Fehlern."

Tito und Paulino

1 INTRODUCTION

The following research project was carried out from January 2008 to April 2008 in the framework of a cooperation of the University of Natural Resources and Applied Life Sciences, Vienna (BOKU, Austria) and the Tropical Soil Biology and Fertility Institute (TSBF) of the International Centre for Tropical Agriculture (CIAT) in Zimbabwe. It was designed as a MSc.-thesis in partial fulfilments of the requirements for the degree of "*Diplomingenieur*" at BOKU.

1.1 General project information

This thesis is incorporated in the project *"Increasing the productivity, stability, sustainability and profitability of smallholder agriculture in vulnerable production systems through more efficient use of water and nutrients"*.

Compared are different conservation agriculture practices and a traditional treatment in terms of soil hydraulic properties and other soil quality properties. Favorable water partitioning in rainfed agriculture to reduce the risk of crop failure and to improve crop water productivity in an on-station experiment at Sussundenga Research Station in Central Mozambique are delineated (FAMBA, 2007).

The long-term-trial in Sussundenga was established in October 2006 and is intended to continue at least for five years. The research for this thesis was done from January 2008 until April 2008, in the second year since trial start.

The project work is not only carried out at the long-term-trial in Sussundenga, but also at different farmers´ fields in three provinces of Central Mozambique, although the research for my MSc.-thesis was done in Sussundenga only.

1.2 Conservation agriculture

To highlight conservation agriculture some citations are compiled in the following.

"Conservation agriculture (CA), especially no-tillage (direct seeding), has been proved to provide sustainable farming in many agricultural environments virtually around the world" (REICOSKY and SAXTON, 2007).

"Traditional practices of shifting cultivation become less feasible with increasing population density, so that, fallow periods are shortened and farmers encroach forests. It is largely known that CA can protect soils against erosion; reduce the cost of energy required for tillage and fertilizers applications; and reduce pressure over natural resources" (FINDELING et al., 2003; ERENSTEIN, 2002).

Following REICOSKY and SAXTON (2007) CA requires the implementing of three principles:

- *minimum soil tillage disturbance*
- *diverse crop rotations and cover crops*
- *continuous plant residue cover*

The effect of crop residue mulch, as presented by ERENSTEIN (2002) in Figure 1 is known to bring a number of advantages to crop production:

- *inhibits the germination of many weed seeds, minimizing weed competition with the crop*
- *reducing the soil temperature*
- *preventing excessive soil evaporation*
- *protection of the soil surface against splash erosion, improved infiltration*
- *habitat and resources for associated biodiversity*
- *maintenance of soil organic matter*
- *microbial products promoting aggregate stabilization*

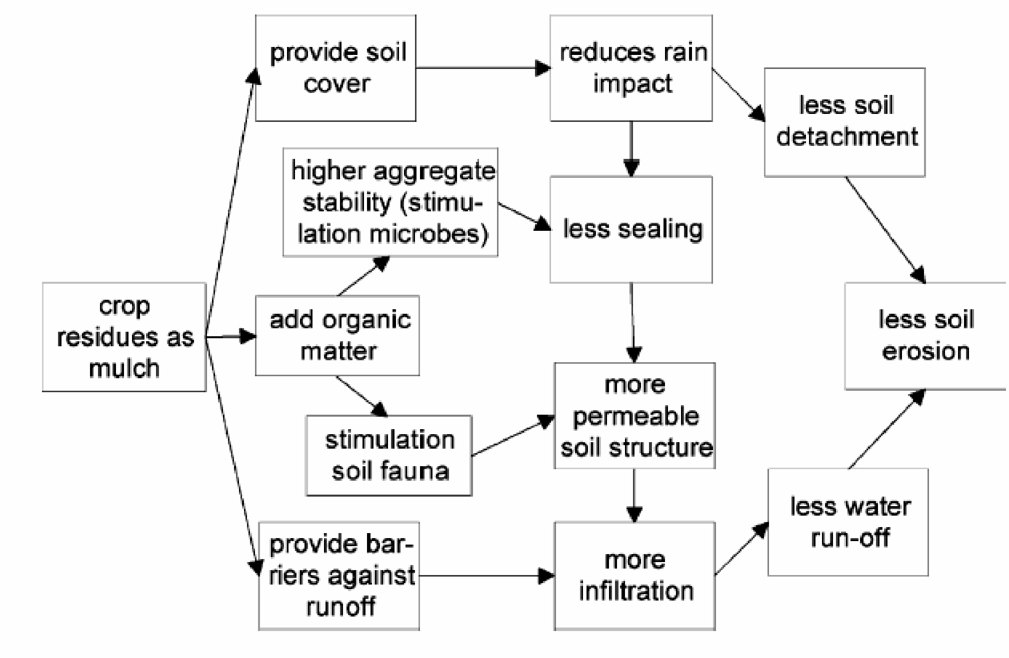


Figure 1: The effect of crop residue mulch (ERENSTEIN, 2002)

"The main direct benefit of CA and direct seeding is increased soil organic matter and its impact on the many processes that determine soil quality. The foundation underlying the three principles is their contribution and interactions with soil carbon, the primary determinant of long-term sustainable soil quality and crop production" (REICOSKY and SAXTON, 2007).

"True soil conservation is largely related to organic matter, i.e. carbon, management. By nothing more than properly managing the carbon in our agricultural ecosystems, we can have less erosion, less pollution, clean water, fresh air, healthy soil, natural fertility, higher productivity, carbon credits, beautiful landscapes and sustainability" (REICOSKY and SAXTON, 2007).

"Increased soil organic matter has a significant effect on soil water management because of increased infiltration and water-holding capacity. Enhanced soil water-holding capacity is a result of increased soil organic matter, which more readily absorbs water and releases it slowly over the season to minimize the impacts of short-term drought" (REICOSKY and SAXTON, 2007).

“Increased organic matter is known to increase soil infiltration and water-holding capacity, which significantly affect soil water management. Under these situations, crop residues slow runoff water and increase infiltration by earthworm channels, macropores and plant root holes” (EDWARDS et al., 1988).

2 OBJECTIVE

Crop residues are crucial for conservation agriculture. Since all the residues (maize, sunflower and beans) were eaten by termites I tried to find out which are the impacts of treatment (seeding method, used plants, crop rotation) on termite activity and therefore on soil properties on CA treated plots compared to a conventional ploughed plot (CP) under rainfed agriculture. Not only plant-residues were eaten by termites, also destroyed plants due to weather events (heavy rainfalls and strong wind), were attacked by them.

Four main hypothesis were formulated and investigated:

- Has CA an influence on termite activity?
- Do the termites influence the soil properties, especially the infiltration?
- If the termites influence the soil properties, in which way – negative or positive?
- Improves CA the infiltration behaviour?

Following from the hypothesis the main goal was to study the interaction of climate (precipitation), soil properties, tillage treatment, plants and termite activity.

3 STUDY AREA AND BASIC INFORMATION

The knowledge of the climatic conditions and soil resources play an important role in understanding the cross-linkage of all influencing factors.

3.1 Geographic information

The study area is situated at the Sussundenga Research Station[2] in the community of Matica, district Sussundenga which is located in the province of Manica in Central Mozambique, 19° 20´ latitude south, 33° 14´ longitude east, 620 m altitude (Figure 2, Figure 3).

Figure 2: Mozambique; study area location (AFRICAN STUDIES CENTER, 2008)

[2] *Portuguese.: Centro Zonal de Investigação Agrária da Região Centro e Estação Agrária de Sussundenga*

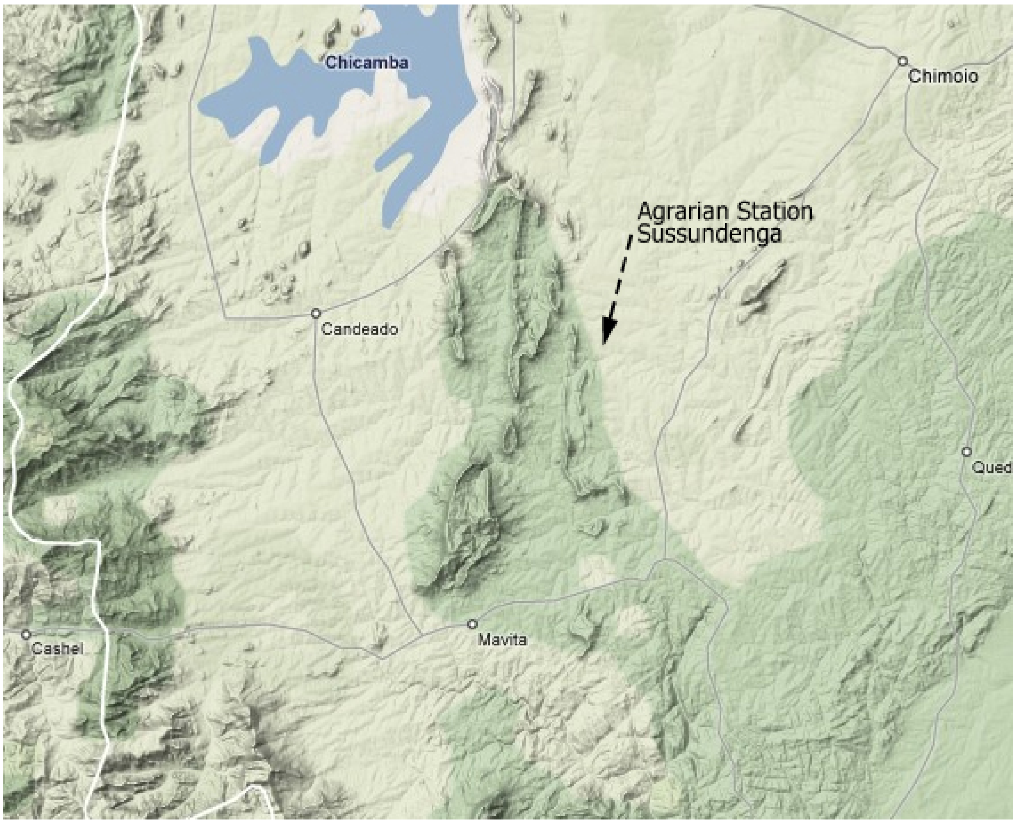


Figure 3: District of Sussundenga, province of Manica (GOOGLE MAP, 2008)

The long-term-trial is situated between the Research Station and the village Nhambamba; the distance from the Agrarian Station to the site of the long-term-trial is approximately 2 km (Figure 4).

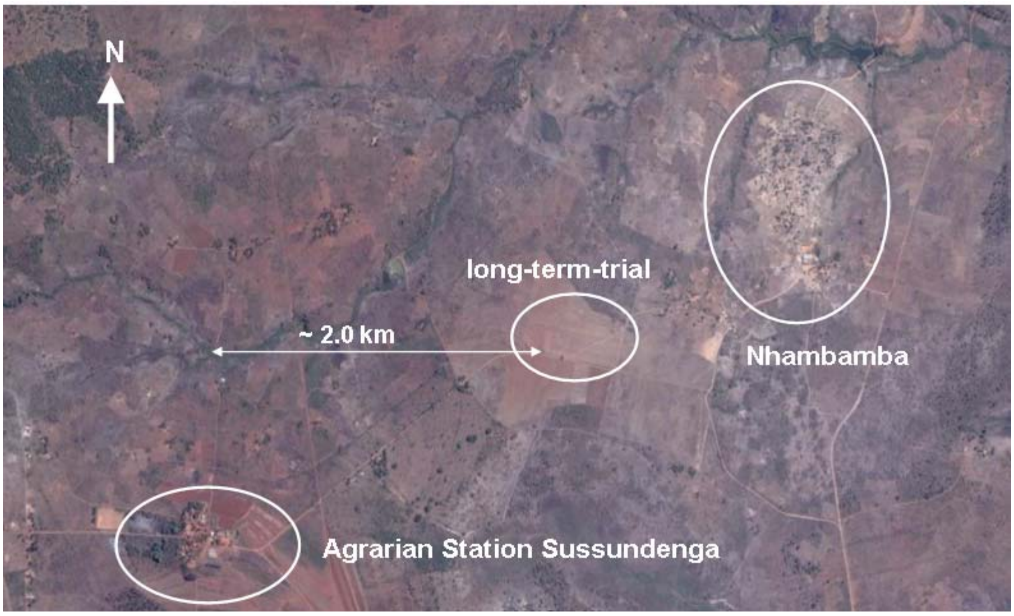


Figure 4: Area of Agrarian Station, the long-term-trial and the village Nhambamba (GOOGLE EARTH, 2008)

The area of Matica is flat to slightly hilly with an average altitude of 600 m and mountains up to 900 m west of Sussundenga Research Station (Figure 5). The slope of the long-term-trial is minimal in average 1-2%.

Figure 5: Area of Matica; view to the east

3.2 Climate information

The local climate in Sussundenga is wet semi-arid with an average annual rainfall of 1155 mm and a potential evapotranspiration of 1386 mm. The average minimum temperature is 9.5°C in July and the average maximum temperature is 29.1°C in January. Monthly data of temperature, humidity, vapour pressure, sunshine, wind speed, rainfall and potential evapotranspiration for 1997 are presented in Table 1.

Month	Temperature (oC)			Humidity	V. pressure	Sunshine		Wind Speed	Rainfall	PET'
	Avg	Max.	Min.	(%)	(mbar)	(hr/dia)	n/N, (%)	(m/s)	(mm)	(mm)
1	24,4	29,1	19,6	77	22,8	7,4	56	1,7	194	147
2	23,7	28,2	19,2	77	22,8	7,1	56	1,8	245	123
3	23,1	27,7	17,8	76	21,4	7,2	59	1,7	186	124
4	21,2	26,4	16,0	76	18,8	8,0	68	1,5	52	97
5	19,0	25,4	12,5	70	15,5	8,3	74	1,5	22	79
6	16,7	23,2	10,3	68	13,1	7,9	72	1,7	11	64
7	16,6	23,5	9,5	61	11,9	8,3	75	1,8	10	77
8	18,4	25,6	11,2	65	13,3	8,4	73	1,7	14	98
9	21,1	28,7	13,5	57	14,2	8,8	73	1,9	10	135
10	23,1	29,9	16,3	61	17,2	7,7	61	2,0	36	152
11	23,8	29,5	18,1	64	19,1	7,2	55	1,9	122	146
12	23,8	28,7	19,0	73	21,7	6,5	49	1,9	253	144
Total									1155	1386

Source: INIA-DTA database, Wijnhoud, 1997.

PET' = Potential evapotranspiration (Penman)

Table 1: Average monthly climatic data, Sussundenga Research Station (WIJNHOUD, 1997)

Figure 6 shows the average monthly rainfall in Sussundenga from 1970-2000. The highest amounts of rainfall are in the months December, January and February.

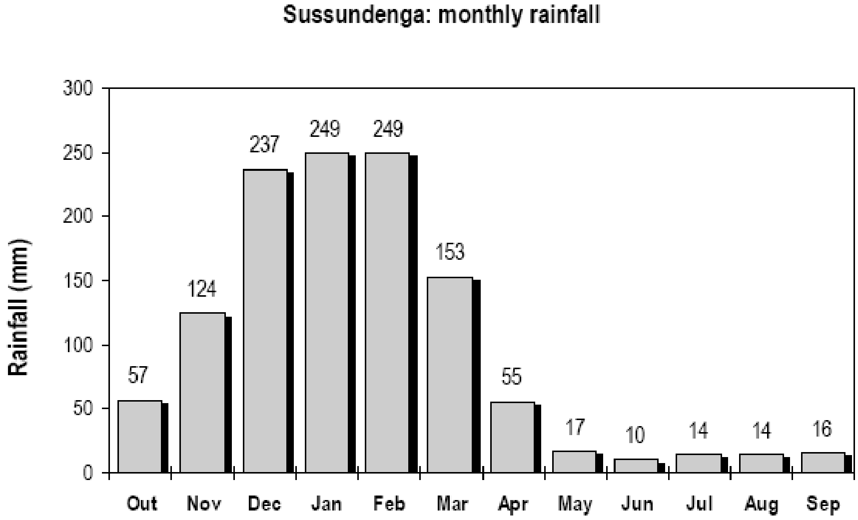


Figure 6: Average monthly rainfall, Sussundenga 1970-2000 (FAMBA, 2008a)

Two characteristic periods, the rainy season from October to March, and the dry and coldest season from April to September are distinguishable of the rainfall pattern (REDDY, 1986). For rainfed agriculture a duration of the growing season period of 180-209 days/year is given.

REDDY (1986) recommends the start of the planting at the end of November after a first rain of 25 mm in a single day or 30 mm on two consecutive days in light textured soils, or just before a good rain in heavy textured soils. *"For rainfed agriculture the expected probability of crop failure in Sussundenga is evaluated as low, ranging from 5 to 15%" (REDDY, 1986).*

89% of the total rains are in the rainy season, from October to March, 11% are in the dry and cold season from April to September.

From Figure 7 it can be seen that rainfed agriculture is possible between October and April.

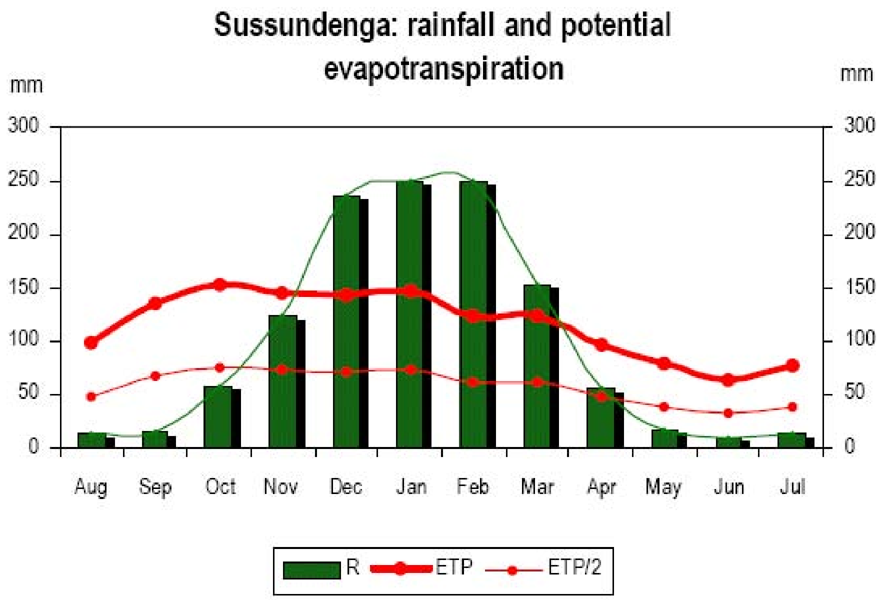


Figure 7: Rainfall (R) and potential evapotranspiration (ETP) (FAMBA, 2008a)

Rainfall data for the investigation period was available from October 2007 until January 2008 from a Meteorological Station situated at Sussundenga Research Station (approximately 2 km away from the long-term-trial) and from an on-field rain gauge (start of recording January 3rd, 2008). Data information is presented in Figure 8.

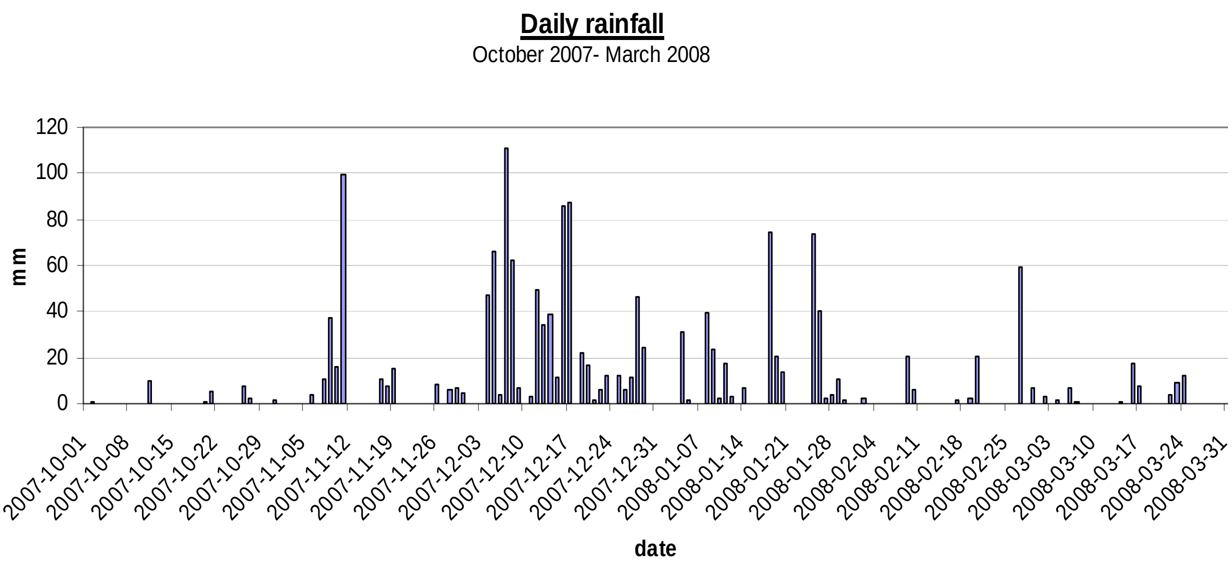


Figure 8: Daily rainfall pattern of the growing season from October 2007 until end of March 2008

First significant rain event occurred in November with precipitation up to 100 mm per day. The highest rainfalls were in December and January. In February and March the rainfalls lowered with some exceptions of heavy storms. It has to be noted that Maize (the main crop) was seeded November 27th, 2007.

In Figure 9 the monthly rainfall is presented. The amount of rainfall in December was more than twice compared to the rainfall in January and more than three times of that in November.

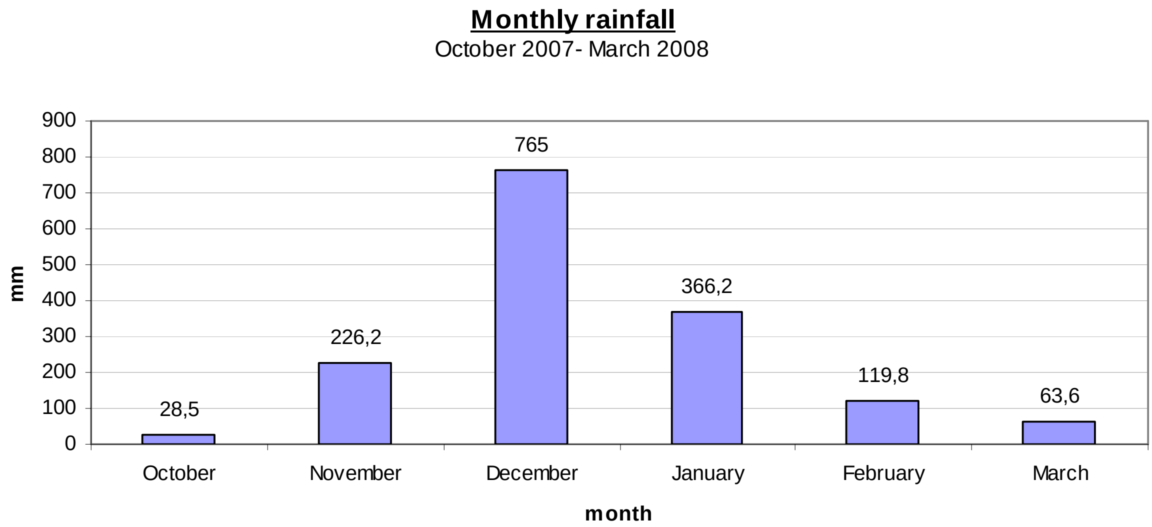


Figure 9: Monthly rainfall pattern of the growing season from October 2007 until end of March 2008

3.3 Soil information

Soil information in Sussundenga is taken from the cited researchers.

"The predominant soil types at Sussundenga Research Station are Ferralsols (haplics and rhodics), Haplic Lixisols and Haplic Acrisols. In the experimental plots, the soil map indicates that the dominant soil types are Haplic Lixisols, possibly associated with Rhodic Ferralsols, according to FAO (Food and Agricultural Organization of the United Nations) soil classification system and, with soil texture from silt to clay" (WIJNHOUD, 1997). The slope is generally 1-2%.

"Ferralsols have good physical properties but they present a low natural fertility. Their low fertility and the tendency to fix phosphates are serious limitations from crop production" (DRIESSEN and DUDAL, 1989).

"Lixisols are strongly weathered soils in which clay is washed down from the surface soil to an accumulation horizon at some depth. Lixisols present low levels of available nutrients and low nutrient reserves. However the chemical properties of Lixisols are generally better than of Ferralsols because of their relatively higher soil-pH and the absence of serious Al-toxicity. The soils of the trial site present good physical characteristics; low fertility and they are moderately acid. Good harvesting under rainfed agriculture can be granted with liming and fertilizer application, especially N, nitrogen and P, phosphorus" (WIJNHOUD, 1997).

"WIJNHOUD (1997) points out some of the soil degradation types at Sussundenga Research Station which are related to experimental activities carried out in the past, especially:

- *soil compactions as related to the use of machinery for cleaning the land and for tillage operations*
- *reductions of soil infiltration ratio directly related to the compaction process*
- *erosion, especially sheet erosion in fallow periods, directly related to the vegetation removal and reduced infiltration rates*
- *increased soil acidification, due to the probably use of N-fertilizers of the type* $(NH_4)_2SO_4$*, most known to cause acidification"*

3.4 Plants used at the long-term-trial

At the long-term-trial maize (variety *Matuba)*, sunflower and the local common bean *Phaseolus vulgaris L.* were planted.

Maize is an important food resource in Mozambique and *Phaseolus vulgaris L.* is one of the main legumes in the diet of many rural and urban poor in Mozambique and an important source of protein. Sunflower is used to produce vegetable oil.

Maize was seeded November 27th, 2007, seeding of beans and sunflower took place February 12th, 2008 and on some plots beans were seeded February 12th and March 1st, 2008.

Another legume, *Mucuna* (as cover plant) was seeded end of March or beginning of April 2008.

3.5 Treatments

Nine CA-treatments and one conventional farmers´ practise treatment (CP) were intended. CP is to be seen as a check plot for comparing the CA-treatments with traditional farmers practice. CA at the long-term-trial can be grouped into three types of practise:

- three different seeding methods (direct seeding, basins, jab-planter)
- crop rotation with two different types of crops
- crop rotation with three different types of crop

The ten treatments are:

T1: Check plot (**CP**); traditional farmers practice using the mouldboard plough, maize as a sole crop, no residue retention, stubbles incorporated (Figure 10)

T2: Direct seeding with animal drawn seeder (**DS**), maize as a **sole** crop, residue retention at a rate of 2.5-3 t ha^{-1} in the first year, thereafter all crop residues are retained (Figure 11)

T3: Basin (**BA**), maize as a **sole** crop, residue retention (Figure 12)

T4: Jab planter (**JP**), maize as a **sole** crop, residue retention (Figure 13)

T5: Direct seeding with animal drawn seeder (**MS**), maize with sunflower as a **relay** crop, residue retention (Figure 14)

T6: Crop rotation A1 (**A1M**): direct seeding with animal drawn seeder, maize-sunflower rotation (Phase 1), residue retention; *Maize (2006) - Sunflower (2007) – Maize (2008);* (Figure 15)

T7: Crop rotation A2 (**A2S**): direct seeding with animal drawn seeder, maize-sunflower rotation (Phase 2), residue retention; *Sunflower (2006) - Maize (2007) – Sunflower(2008);* (Figure 16)

T8: Crop rotation B1 (**B1M**): direct seeding with animal drawn seeder, maize-sunflower – beans rotation (Phase 1), residue retention; *Maize (2006) - Sunflower (2007)- Beans(2008);* (Figure 15)

T9: Crop rotation B2 (**B2S**): direct seeding with animal drawn seeder, maize-sunflower – beans rotation (Phase 2), residue retention; *Sunflower (2006) – Beans (2007) – Maize (2008);* (Figure 16)

T10: Crop rotation B3 (**B3B**): direct seeding with animal drawn seeder, maize-sunflower – beans rotation (Phase 3), residue retention; *Beans (2006) – Maize (2007) – Sunflower (2008);* (Figure 17)

Figure 10: Mouldboard plough (FAMBA, 2008b)

Figure 12: Basin (FAMBA, 2008b)

Figure 11: Direct seeding with animal drawn seeder

Figure 13: Jab planter

Figure 14: Maize with sunflower intercropped

Figure 15: Maize-plot

Figure 16: Sunflower-plot

Figure 17: Beans-plot

3.6 Block design

Randomised blocks with 4 replications were designed. The field consists of 4 lines with 10 plots each. The block size is 24 m times 18 m with 1 m and 2 m spacing between the plots respectively. This gives a field size of 189 m times 102 m. Plots with the same treatment have the same colour (Figure 18).

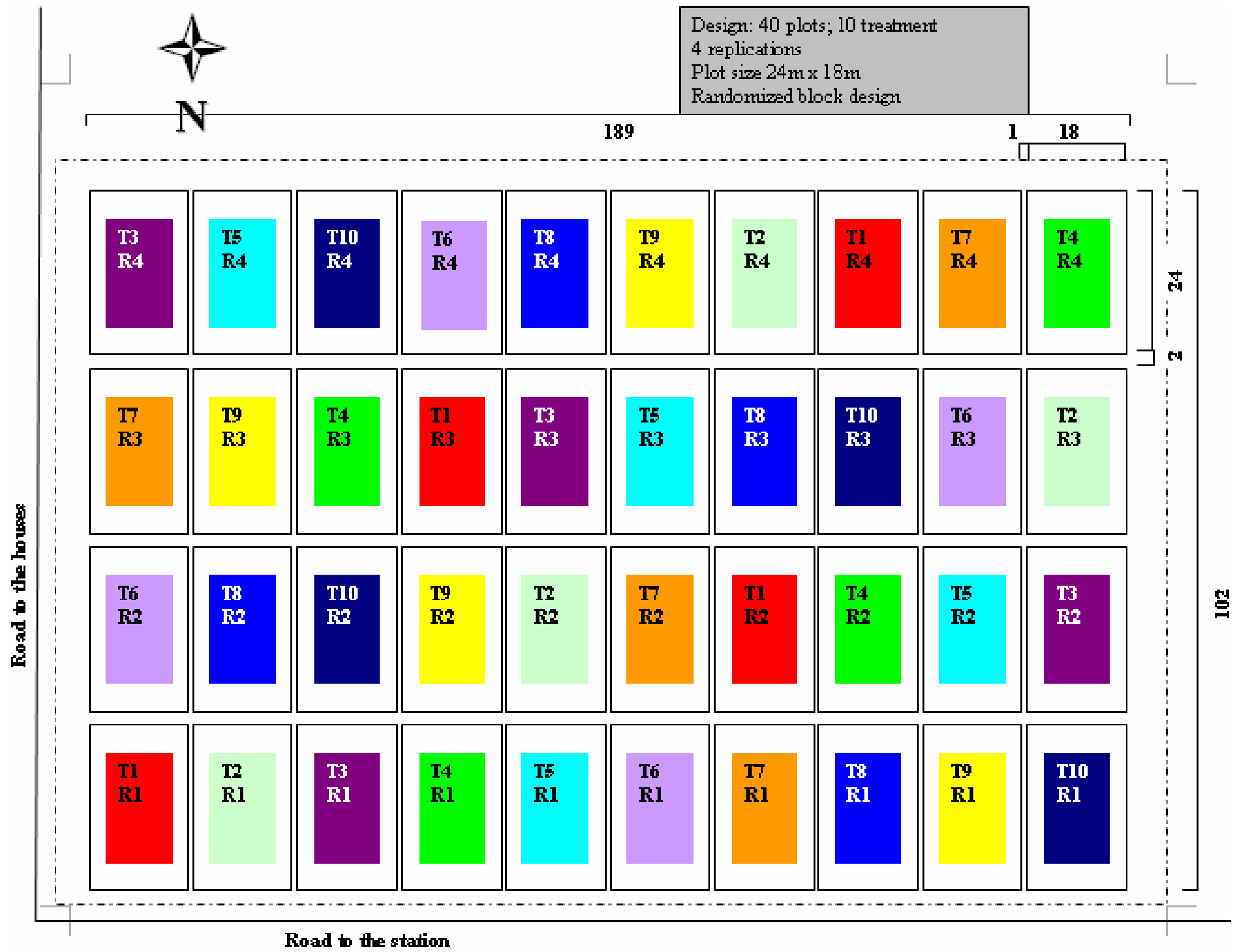


Figure 18: Long-term-trial Sussundenga – block design (FAMBA, 2007)

4 TERMITES (*ISOPTERA*) AND THEIR IMPORTANCE FOR SOILS

4.1 General information

The following text is taken from WIKIPEDIA – THE FREE ENCYCLOPEDIA (WIKIPEDIA, 2008) to provide a short description of termites.

"Termites are a group of social insects usually classified at the taxonomic rank of order Isoptera. As truly social animals, they are termed eusocial along with the ants and some bees and wasps. Termites mostly feed on dead plant material, generally in the form of wood, leaf litter, soil, or animal dung, and about 10% of the estimated 4,000 species (about 2,600 taxonomically known) are economically significant as pests that can cause serious structural damage to buildings, crops or plantation forests. Termites are major detrivores, particularly in the subtropical and tropical regions, and their recycling of wood and other plant matter is of considerable ecological importance.

Termites are generally grouped according to their feeding behaviour. Thus, the commonly used general groupings are subterranean, soil-feeding, dry wood, damp wood, and grass-eating. Of these, subterranean and dry woods are primarily responsible for damage to human-made structures.

All termites eat cellulose in its various forms as plant fibre. Cellulose is a rich energy source (as demonstrated by the amount of energy released when wood is burned), but remains difficult to digest. Termites rely primarily upon symbiotic protozoa (metamonads) such as Trichonympha, and other microbes in their gut to digest the cellulose for them and absorb the end products for their own use. Gut protozoa, such as Trichonympha, in turn rely on symbiotic bacteria embedded on their surfaces to produce some of the necessary digestive enzymes. This relationship is one of the finest examples of mutualism among animals. Most so called "higher termites", especially in the Family Termitidae, can produce their own cellulose enzymes. However, they still retain a rich gut fauna and primarily rely upon the bacteria. Due to closely related bacterial species, it is strongly presumed that the termites' gut flora is

descended from the gut flora of the ancestral wood-eating cockroaches, like those of the genus Cryptocercus.
Some species of termite practice fungiculture. They maintain a "garden" of specialized fungi of genus Termitomyces, which are nourished by the excrement of the insects. When the fungi are eaten, their spores pass undamaged through the intestines of the termites to complete the cycle by germinating in the fresh faecal pellets".

Termites at the long-term-trial can be seen in Figure 19, structure built due to termites in approximately 20 cm depth (hard material) in Figure 20 and an advanced termite mound in Figure 21.

Figure 19: Termites at the long-term-trial

Figure 21: Advanced termite mound

Figure 20: Structure built due to termites in approximately 20 cm depth (hard material)

4.2 Termites and their contribution to soil health

Soil fauna is an active part of the ecosystem and plays an important role in soil improvement.

Soil fauna (termites) perform many functions that are unnoticed. Different studies show that they modify soils, changing their properties (ARSHAD, 1981; ASAWALAM et al., 1999), improve soil aeration and water infiltration (EHLERS, 1975; WILKINSON, 1975), increase crop growth (SPAIN et al., 1992), and reduce crop root diseases (STEPHENS et al., 1993). Other reports show better crop performance on soils modified by termites and earthworms than on unmodified soil (ASAWALAM and HAUSER, 2001; OSODEKE and NZEGBULE, 1996).

The soil modifications are also acknowledged by the following citations:

"Termite communities are recognized by the mounds of soil materials, which they build and live in. Soils modified by fauna such as termites and earthworms may acquire new properties that significantly differ from the original" (ASAWALAM and JOHNSON, 2007).

"In agro-ecosystems, termites are defined as ecosystem engineers and are responsible for modifying both biotic and abiotic soil components" (JONES et al., 1994; NDIAYE et al., 2004).

"*Termite activities affect the physical status and soil formation processes making them important potential candidates for bio-tillage on crop fields. The tunnels they build in the soil facilitate both water and air exchange" (LAL et al., 2000).*

Also MANDO et al. (1997) reported increased termite activity leading to improved water infiltration rates and storage following increased termite abundance on mulched plots. Additional, MANDO et al. (1997) found out that termites also regarded as useful biological agents controlling and correcting soil crusting problems in the Sahel region.

Conservation agriculture leads to special effects on termite activity. KLADIVKO (2001) reports, that the effect of reduced tillage on water, organic matter and temperature also has a big influence on the survival and reproduction of soil fauna. The low soil disturbance does not destroy the soil fauna's nesting sites and can therefore lead to higher termite densities (NHAMO, 2007).

BENCKISER (1997), DORAN and SAFLEY (1997) conclude, that crop residues are a food resource to soil animals and hence their application influences fauna activities.

"Termites feed on cellulose plant material, and some species also have the capacity to digest lignin" (MARTIUS, 1994; UYS, 2002).

"The mechanism of digestion is either aided by symbiotic intestinal protozoa or by fungal colonies cultivated by Termitidae species" (COLLINS, 1989).

WEIBULL and OSTMAN (2003), JOUQUET et al., (2006) write in their reports that prevalence and diversity of termites have been linked to several local and catchment level factors. The generally soft-cuticled termites cannot survive desiccation and nest-building is one activity aimed at adapting conditions to their auto-ecological requirements. Temperature, humidity and soil moisture requirements play an important role in the determination of survival rates of termites.

The effects of conservation agriculture and mulching on termites and the implications of termite activities on mulched cropping fields under conservation agriculture treatments compared to conventional ploughing were studied in a project done by NHAMO (2007) in Zimbabwe. In this project the specific aim was to determine whether termites are important pests to maize, and how animal traction conventional plough, direct seeder, ripper and hand-hoe-made basins affect the extent of gallery building activities.

At the study site in Zimbabwe termites built cover runways or tunnels on the soil surface on their trails that lead to the food source. They built also similar structures on materials that they feed on, e.g., around dry maize stalks or tree branches lying on the ground. These structures, named galleries, are important for protecting the termites from desiccation during foraging activities (NHAMO, 2007). Different to this study in Zimbabwe where NHAMO (2007) recorded the gallery coverage at the long-term-trial in Mozambique no galleries were present hence only the holes in the soil surface were used as an indicator of termite activities (Figure 22).

Many research projects all over Africa report the importance of soil fauna for improving soil functions. However, I could not find contributions of termites to conservation agriculture systems in Mozambique in English. Perhaps local Portuguese literature is available.

4.3 Termites as a maize pest

NHAMO (2007) lists results of studies of termite attack on (fresh growing) maize, e.g. reports on termite attack on maize based on conventional ploughing practices, where crop residues are removed during land preparation. Observations by UYS (2002) show, where dry residues as food are available, low termite attack on the live plant, will occur. LAVELL and SPAIN (2001) explained termite preference of dry residues to living and fresh plant materials. Under food limited conditions attack of fresh plants can appear, e.g. SILESHI et al. (2005) report increased termite attack on maize on conventionally ploughed plots compared to improved fallows. However, at Sussundenga Research Station no termite attack on fresh plants was recognized. Only destroyed (due to heavy rainfall) and dead plant material were eaten by them (Figure 23, Figure 24, Figure 25).

4.4 Termites as a food resource

Termites are an important food resource for ants. Ants and termites originate not from the same family; ants are carnivorous animals, whereas termites are herbivorous (detrivores). During the studies at the long-term-trial, observations lead to the hypothesis that higher termite activity results also in visual higher numbers of ants. Ants building their nests also below the soil surface play a very important role for the soil. For nest building they undercut the soil and dig holes below soil surface with a diameter up to many centimetres (Figure 26). The holes of the ants were bigger than those of the termites and had mostly material from deeper layers around the entrance (in Sussundenga easily to see because of the red colour; Figure 27). However, in this study only termite activity was recorded.

Figure 22: Termite holes on soil surface

Figure 23: Maize field after strong wind (February 09, 2008)

Figure 24: Destroyed maize field after thunderstorm (February 28th, 2008)

Figure 25: Termite attack after thunderstorm (February 28th, 2008)

Figure 26: Hole due to ants

Figure 27: Hole due to ants

5 INFILTRATION

Chapter 5 deals with the infiltration process and its influencing factors. This theoretical knowledge is for importance to understand the outcome of the research of this thesis.

“The rate of infiltration is generally controlled by the rate of soil-water movement below the surface” (RAWLS, 2007).

SHUKLA (2006) gives a good overview of the infiltration process and its influencing factors:

“The infiltration rate of a soil depends on soil texture, structure, moisture status prior to infiltration, continuity and stability of pores, and soil suction. Soil management including tillage influences these factors. Initially, water infiltrates into the soil at a rapid rate but as time elapses, the infiltration rate attains a steady or asymptotic state, which approximates the saturated hydraulic conductivity of soil, ks. The high initial infiltration rate is observed when soil is dry. Under this situation large suction-gradient exists (suction at the soil surface is zero or atmospheric pressure and inside soil it can be 2000-15,000 cm of H_2O *depending upon dryness of soil), which forces the water rather quickly into the soil” (SHUKLA, 2006).*

“When rain falls or water is applied through sprinklers, the water supply rate may either be less than or greater than Ks of the surface soil. If the rate is less than Ks, all the water falling on soil surface enters the soil. In this case, the infiltration rate is equal to the water supply rate; the rate of supply of water determines the infiltration rate and the process of infiltration is known as “flux controlled”.

On the other hand, if water is supplied at a rate higher than the maximum infiltration rate of soil, the soil-water transmission properties determine the amount and rate of actual infiltration. Infiltration rate in this situation is called “profile controlled”.

When water infiltrates into a dry soil, the progress of water movement is observed by the darkened colour of soil, as it gets wetter. There exists a sharp downward moving boundary between the wet region and the underlying dry region, which is known as the “wetting front”.

If the water supply rate is greater than ks and the soil is dry, then for a while all the water enters the soil. In this case, the rate at which water enters the soil is greater than ks. This

occurs because water not only flows in response to gravity, but also to soil suction. Sooner or later, the supply rate begins to exceed the capability of the soil to absorb the water. At this point, water begins to build up on the soil surface and runoff begins. Runoff can also occur if the soil becomes saturated above an impermeable layer, or if the soil has a layer in which ks is less than that of the layers above it.
The time between the start of the rainfall and the initiation of runoff is known as the "time to ponding". The infiltration rate continues to decrease asymptotically and approaches ks. The steady-state infiltration rate (ic) is also termed the "steady-state infiltrability". It is approximately the same as the field saturated ks of the surface soil" (SHUKLA, 2006)"

Factors affecting the infiltration process listed from SHUKLA (2006) are:

1. Soil properties:
The ic is approximately equal to ks. Therefore, soils with higher ks tend to have more infiltration and less runoff. In addition, the pore-size distribution influences the rate of change of infiltrability. Generally speaking, the wider the range of pore sizes, the more gradual the change in the infiltration rate. The pore-size distribution is a mirror image of the particle-size distribution.

2. Initial moisture content:
If the initial moisture content of soil is high, the initial infiltration rate of soil is low. For saturated soils, the infiltration rate approaches ks almost instantaneously.

3. Rainfall:
For rainfall or water supply rates less than ks in a deep homogeneous soil, infiltration may continue indefinitely. For a given rainfall rate, the longer is the time to ponding, more gradual is the change in infiltration rate. Extremely high rainfall rates may cause slaking of aggregates at the soil surface leading to surface sealing or the formation of soil crusts.

4. Surface sealing and crusting:
Change in ks of the surface soil by slaking has a strong influence on the infiltration rate. The formation of a 5 mm thick seal can lead up to a 75% decrease in infiltration rate of soil.

5. Layered soils:

When the wetting front in the soil reaches a layer with either a coarser or a finer texture, there is a decrease in the infiltration rate for some time. If the layer has a coarser texture, the infiltration rate will recover when the large pores in that layer become saturated. For soil in which the layer is fine textured, the infiltration rate will stay low.

6. Entrapped air:

If air is trapped in the soil, ks is reduced. Water infiltration into the soil is also restricted.

5.1 Infiltration measuring methods

Many methods have been developed for measuring the rate of water intake by soils. These methods may be classified in various ways, according to the way in which the water is added (natural rainfall, irrigation, or flooding), the way in which the area for measurements is delimited (by natural slope in the case of watersheds, or by some sort of border in the case of small areas), and the way in which the measurements are made (by determining the differences between water applied and water lost by runoff or by the quantity of water needed to maintain a constant head of water on the soil). The rate of water intake is influenced by the initial water content and soil surface conditions. Therefore to interpret the results from the infiltration measurements, the knowledge of these conditions is important. The water content of the soil should always be measured before the infiltration measurement (BERTRAND, 1965).

BERTRAND (1965) points out following four characteristics of a satisfactory measurement with artificial rainfall in the field of the intake rate of water:

- *the distribution of drop sizes must be uniform over the plot area*
- *the artificial rainfall must be similar to the natural rainfall being simulated in respect of drop size, drop velocity, intensity range, and total energy value*
- *the plot area must be large enough to sample the population and give reproducible results*
- *the artificial rainfall must be applied not only to the plot but also to an adequate buffer area around the plot*

Apparatus for measuring water intake in terms of drop production can be divided into types with nozzles and simulators producing rainfall by forming drops on the tips of yarn or small-diameter glass, stainless steel, brass, or polyethylene tubes or the use of hypodermic needles. It seems that nozzles are more used than simulators with hypodermic needles; however the type using hypodermic needles was used in this study.

6 METHODOLOGY AND DATA COLLECTION

Beside literature and secondary data review two types of measurements were done: surface termite hole counting to evaluate the influence of treatments on termite activity; and infiltration measurements to get the influence of treatments on soil behaviour. Further on, both results from the measurements were compared to find a possible impact of surface termite holes on infiltration.

The main activities were:

- preparation and scheduling the fieldwork – literature study
- field work: surface termite hole counting, infiltration measurement
- analysis of the data (including statistical analysis)
- interpretation of the data

The field work was carried out from February 2nd until April 2nd, 2008.

6.1 Surface termite hole counting

Visible differences on surface termite activity were recognized at the long-term-trial in the end of January 2008. The surface termite activity can be seen from the density of holes. The diameter of the holes is approximately 0.5 to 1.5 mm. Obviously there were almost no holes at CP compared to the CA treatments. Almost no residues were left due to the termites. To record the termite holes a frame with 32 cm times 40 cm (area of 0.13 m²; Figure 28) was constructed and 15 countings were done on each plot in a raster (Figure 29). The countings took place from February 2nd until February 4th, 2008 – in the second year of establishing the trials; during growing of maize (seeding date: November 27th, 2007) and before seeding sunflower and beans.

What type of termite species was not evaluated.

Figure 28: Metal frame to record the density of termite holes

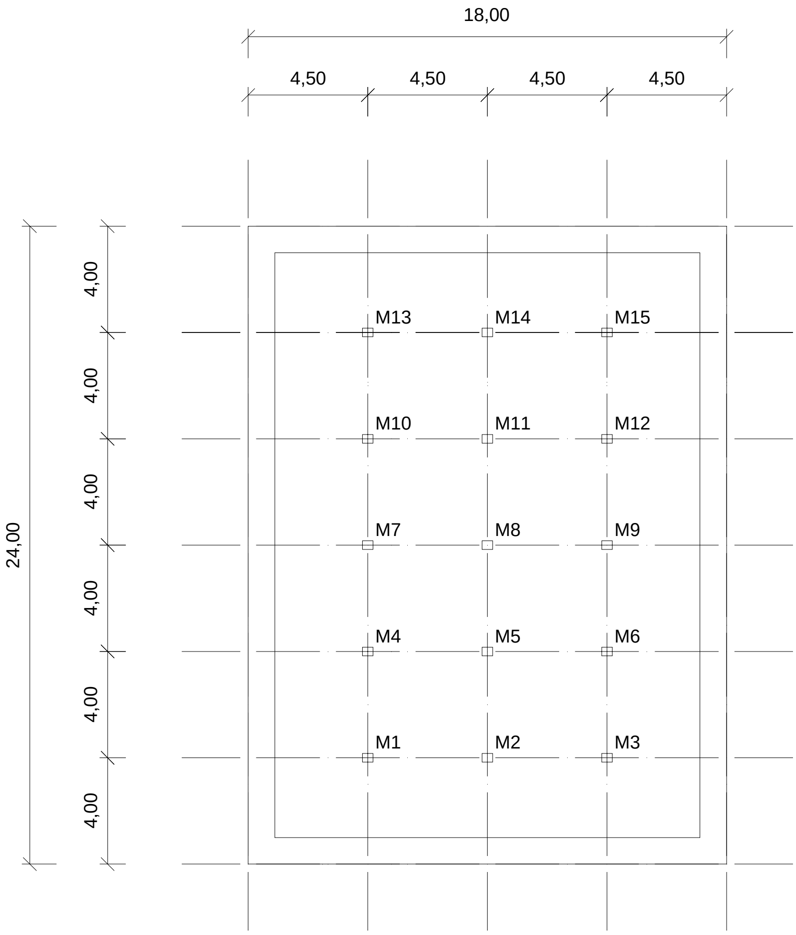


Figure 29: Sampling plan surface termite hole counting for one plot (M1 to M15 = metal frame positions)

The numbers of holes were summed up for each treatment and divided by the 15 countings and the area of the frame to get the average number of holes per m² (Equation 1).

$$termiteholes / m^2 = \frac{\sum countings}{N * A_{frame}} \qquad (1)$$

N is the number of countings per plot, *A* the area of the frame (0.13 m²).

The *Statistical Package for the Social Science SPSS* was used for statistical analysis.

6.2 Infiltration measurement

To get the potential effects of termite activity and impact of different treatments on soil behaviours infiltration measurements with a mini-rainfall-simulator were carried out.
A mini-rainfall-simulator designed by COBO and AMEZQUITA (1999) was used to measure the surface runoff of each plot. This portable mini-rainfall-simulator from CIAT uses syringes to form raindrops. It is portable to be able to make measurements where access is difficult.
AMEZQUITA et al. (1999) describe that the advantage of this mini-rainfall-simulator is that measurements can be carried out from simulated rainfalls without depending on natural precipitations. To work with constantly controlled precipitations is possible, eliminating the random and unforeseeable natural variability of rain. Further on they explained the disadvantages related to the size of the tool. Measurements of runoff and erosion from experiments with simulators carried out in small plots cannot be extrapolated to field conditions. Comparisons have to be limited between treatments. Another disadvantage is that the readings can be affected by wind (AMEZQUITA et al. 1999).

6.2.1 Assembly of the mini-rainfall-simulator of CIAT

The mini-rainfall-simulator of CIAT consists of five parts (Figure 30) (AMEZQUITA et al., 1999):

- drop distributing system with constant pressure (simulator and Mariotte´s bottle)
- adjustable tripod for supporting and levelling the drop distributing system
- recollecting tray of the water that falls outside the effective area
- recollecting tray of sediments and runoff water
- wind break curtain

Figure 30: Mini-rainfall-simulator of CIAT

Drop distributing system

The drop distributing system itself consists of a tray with 333 holes and inserted hypodermic syringes (distributors of drops), a water tank and a tube to allow air to enter, which is a tube that ensures a constant pressure for a given rain intensity (Figure 31).

Cut hypodermic syringes are used to form the drops, which can be changed to other diameter for producing different sizes of raindrops for simulating different intensities of rain. Therefore the mini-rainfall-simulator can work with drop diameter between 2.5 and 4.0 mm and corresponding rain intensities between 40 to 200 mm.

The Marriotte´s bottle enables increasing or reducing the head of pressure on the syringes and by this regulates the number of drops per time unit.

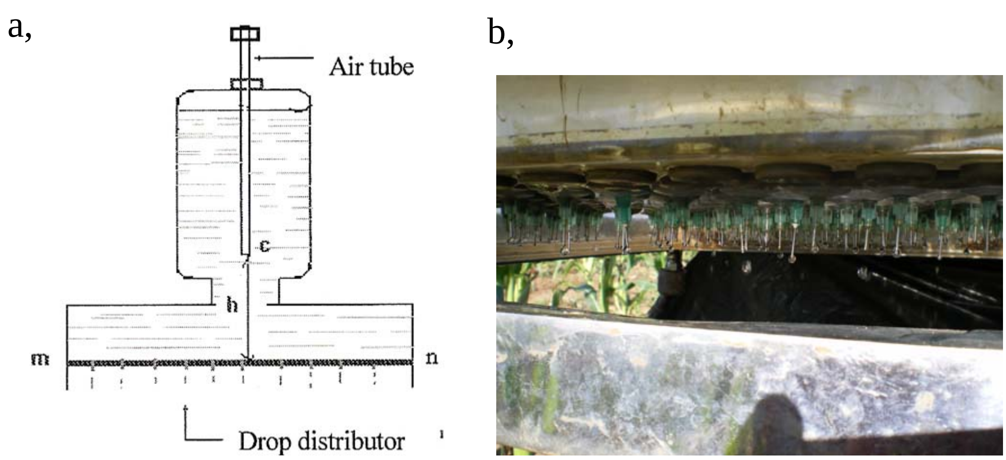


Figure 31: Drop distributor and Mariotte´s bottle

a, schematic presentation (AMEZQUITA et al., 1999) b, view from below

Adjustable tripod

An adjustable tripod is used to level the simulator at an approximately height of 1 m. This tripod consists of three legs with sharpened points at the end; two of them are expansive to facilitate the levelling of the mini-rainfall-simulator. The third leg is fixed at a height of 1 m from the ground.

Recollecting tray of water that falls outside the effective area

Water that falls outside the effective area is collected by a special tray. Regarding AMEZQUITA et al. (1999) the volume collected in this tray has great importance for the calculation the volume infiltrated and the water balance. However, this volume has not been measured at the long-term-trial in Sussundenga. For a millimeter-based calculation the amount of this water is unimportant to know for the analysis.

Recollecting tray of sediments and runoff water

The collecting area of this tray is 40 cm x 32 cm and has a frame that is 5 cm introduced into the soil to enable a vertical infiltration avoiding horizontal movements (Figure 32, Figure 33).

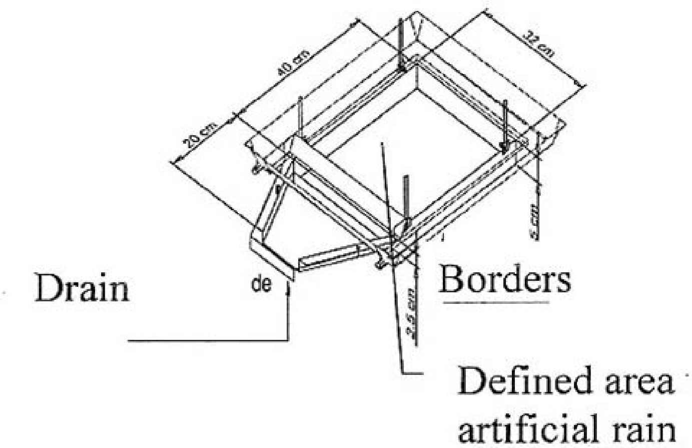


Figure 32: Recollecting tray for sediments and runoff water (AMEZQUITA et al., 1999)

Figure 33: Recollecting tray of water that falls outside the effective area and recollecting tray of sediments and runoff water

<u>Wind breaking system</u>

A wind breaking curtain protects measurements from disturbing wind.

6.2.2 Characteristics of the simulated rain

COBO (1998) investigated that the drops formed with syringes with a diameter of 2.75 mm have a mass of 0.00992 g. He calculated this using the flour-ball method proposed by BENTLEY (1994). Furthermore, he determined for different syringes diameters the terminal speed generated by the mini-rainfall-simulator. For the syringe with a diameter of 2.75 mm the terminal speed is equivalent to 4.59 m/s.

The rain energy is an important parameter in the determination of rain erosivity. Relations between energy and the intensity of natural rains cannot be used to calculate rain energy of the mini-rainfall-simulator, because its terminal drop speed is lower compared to natural raindrops and the diameter of drops is constant, which does not occur in natural rains (AMEZQUITA et al., 1999)

COBO (1998) calculated the kinetic energy of rain generated by the mini-rainfall-simulator from the Equation 2:

$$E = \frac{1}{2} * m * v^2 \qquad (2)$$

where E is the kinetic energy (J), m is the mass of the raindrops (g) and v the terminal velocity of the drops (m/s).

The obtained kinetic energy values were found to be 14.05 and 21.08 J/mm.m² for rain intensities of 80 mm/h and 120 mm/h with a drop diameter of 2.75 mm, respectively (AMEZQUITA, 1999).

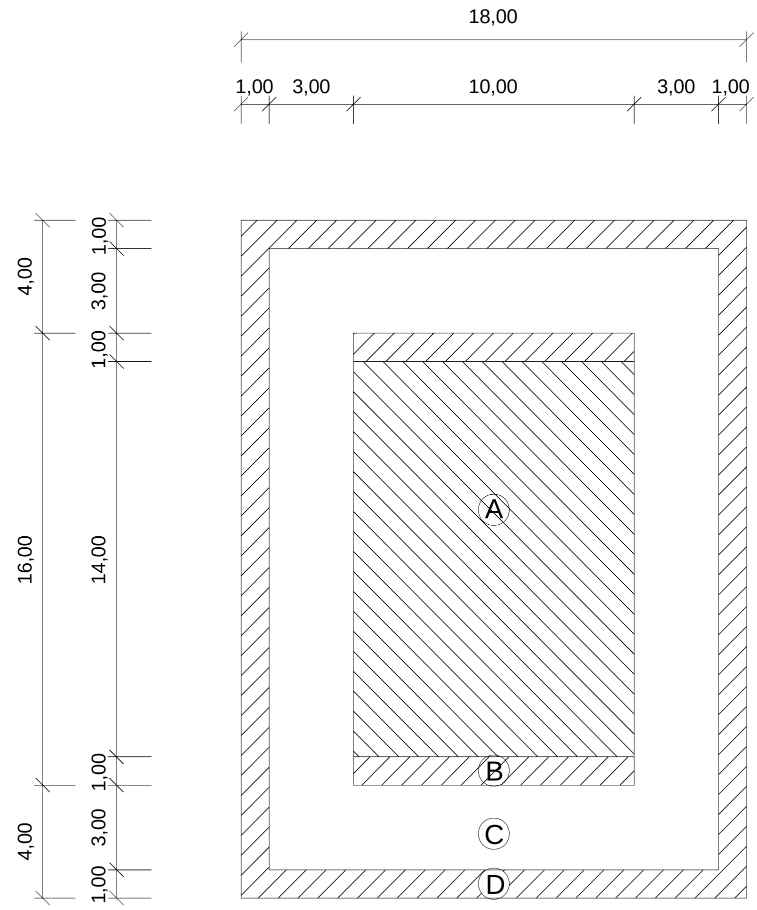
6.2.3 Intensity control

The exit of the rain drops is controlled to a constant rate and established size due the principle of the Mariotte´s bottle. The out flowing water is replaced by air that enters through the tube.

The pressure difference between the water at the simulator outlet *(m-n)* (see Figure 31) and the atmosphere determines the exit of the drops. The atmospheric pressure acts on *c* until pressure difference is equal to the pressure of the water column.

6.2.4 Field sampling concept

Each plot is separated in special areas for different measurements as it is shown in Figure 34. Area *A* is to be kept undisturbed for harvesting operations and other crop observations and non-destructive measurements. Area *B* is assigned to soil moisture measurements or other permanent devices and related sampling for check-up and area *C* is for various soil sampling procedures and other destructive field measurements. Area *D* is not for valid measurements.



(A) Area to be kept undisturbed, for harvesting operations and other crop observations and non-destrutive measurements

(B) Area to be used for moisture measurements (access tubes) or other permanet devices and related sampling for check-up

(C) Area for various soil sampling procedures and other destrutive field measurements

(D) Not for valid measurements

Figure 34: Field lay-out for measurements on experimental plots

The infiltration measurements were done in area *C* between the fourth and fifth line of maize (spacing between two lines of maize was 90 cm; see Figure 35). Beginning with plot 1 measurement 1 for each plot was carried out until plot 40. After finishing all 40 plots measurement 2 for each plot started again on plot number 1. The same order was followed for measurement 3. This gives us a number of 120 measurements, three on each plot. Some measurements failed and had to be repeated.

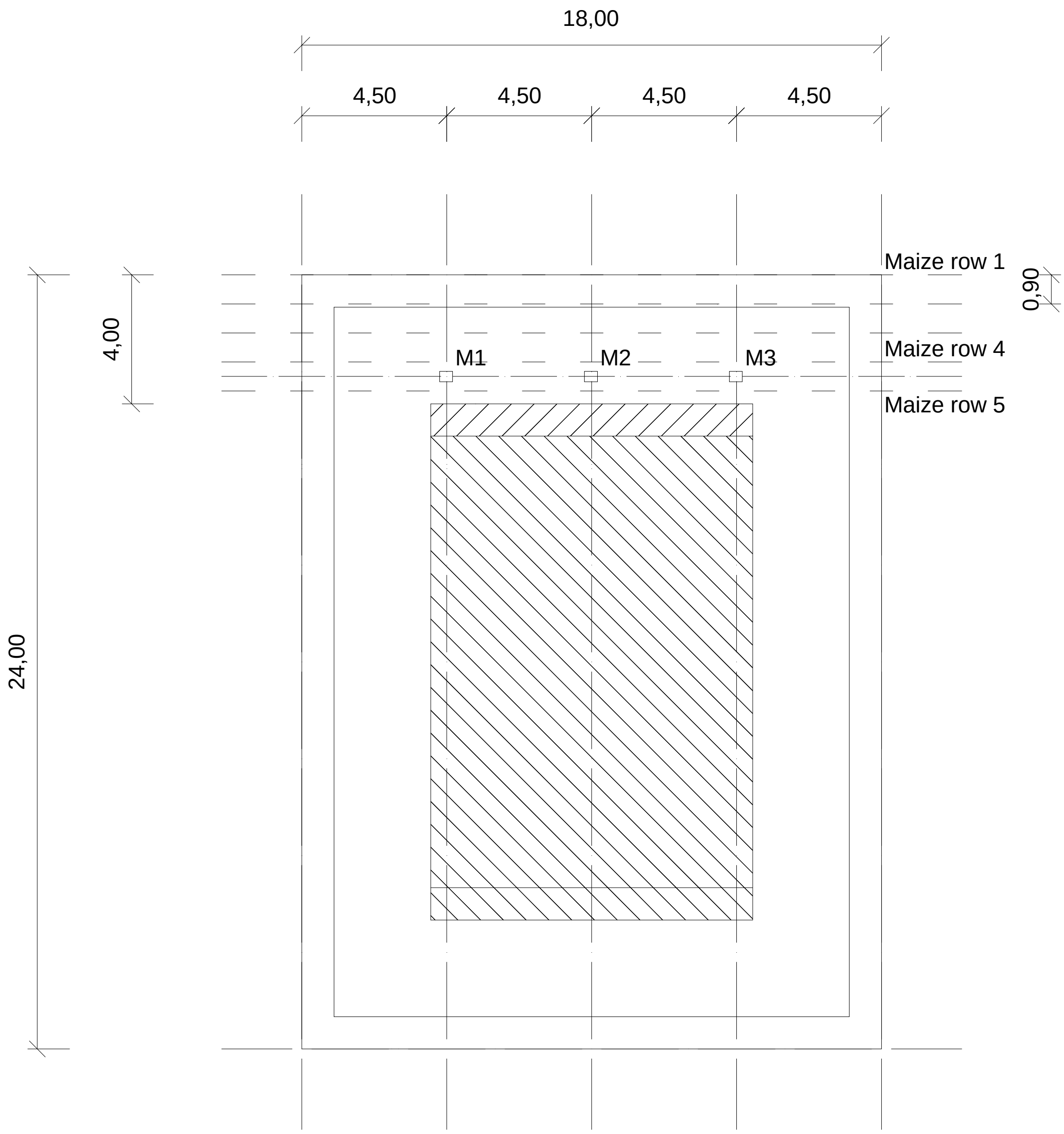


Figure 35: Sampling plan infiltration measurements for each plot

Figure 36 shows the time plan of the infiltration measurements incorporated in the graph of daily rainfall from February 2008 until beginning of April 2008.

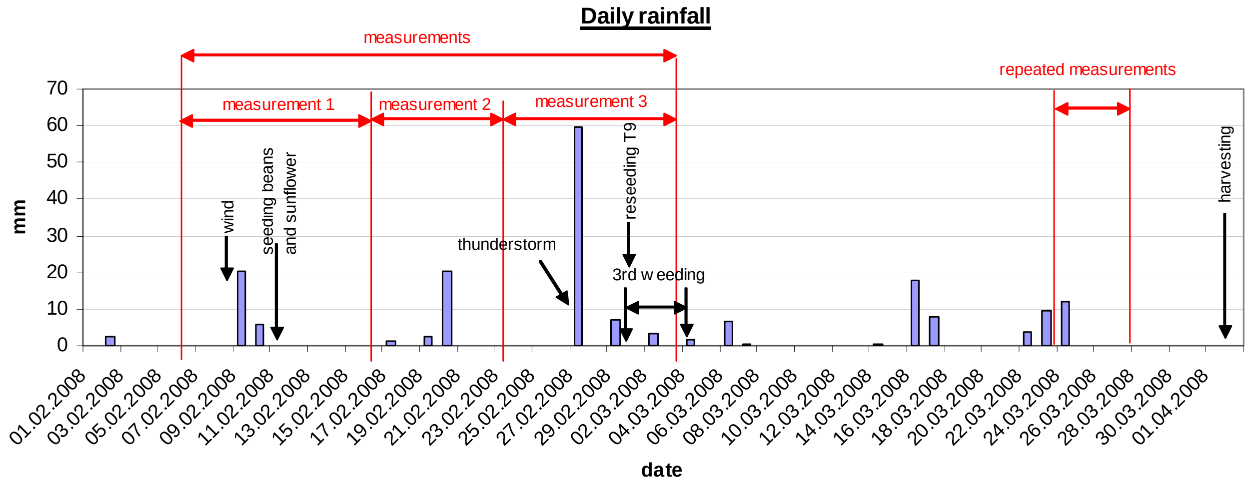


Figure 36: Time plan of infiltration measurements

In Figure 36 the big time lag during the measurements and also the different types of soil disturbances like weeding or seeding and heavy rainfalls are illustrated. Between the first set of measurement and the second set is a time lag of ten days.

6.2.5 Measurement

Measurements were carried out between the fourth and fifth row of maize. If the soil was covered with weeds the soil got cleared up with a scissor.

First, an approximately 20 cm deep hole for the runoff-collecting bucket was dug. With a rubber hammer the sediment and runoff collection tray got installed and the recollecting tray for the water that falls outside was put on it. After adjusting the tripod at an approximately height of 1 m and levelling the tripod the drop distributing system was placed on it.

Before filling the Mariotte´s bottle with water a soil sample has to be taken outside the infiltration plot area from 0-5 cm soil depth.

After filling the Mariotte´s bottle and introducing the air tube the field-set-up is done. Next step is to calibrate the simulator with a plastic funnel by collecting the total volume of the rain simulated in a time of one minute. This is necessary to determine the specific rain intensity.

The calibration has to be repeated until the right intensity is reached. At the long-term-trial the intensity was calibrated around 150 ml/min which gives us rain intensity by about 100 mm/h.

The measurement itself lasts for one hour. Every five minutes the amount of runoff water in the collecting bucket was measured and noted down in a data sheet. After one hour of measuring a final calibration has to be done to see if there was a change of the intensity during the measurement. From the initial and final intensity the mean intensity was calculated.

Erosion measurements were not necessary for this study, thus no soil water samples for erosion measurements were taken. Rain which falls outside the irrigated soil surface was not measured.

Some of the spots chosen for measurement were watered and covered with a plastic foil at the previous day to reach a sooner steady state infiltration rate at the infiltration measurements. However, the density of termites increased during night below the foil, because of that, covering the spot got dismissed. Only when the soil was too dry for a careful installation of the tray for the runoff water, plots were wetted the day before.

Additionally, a second surface termite hole counting took place before the infiltration measurement to compare it with the first and main counting.

6.2.6 Calculation

To get the infiltration rate *i* the measured surface runoff *R* was subtracted from the irrigated water. The amount of water used for irrigation (ml/min) can be calculated from the mean of the measured initial and final intensity (Equation 3).

$$Int_{mean} = \frac{Int_{initial} + Int_{final}}{2} \qquad (3)$$

The initial and final intensity were measured in millilitre per minute and the surface runoff was measured in millilitre every five minutes. In Equation 4 a conversion to mm/h takes place.

Additional, a conversion due to the different area of the drop distributing system and the effective simulator area is in Equation 4 included. The area of the drop distributing system A_s covered by all syringes is 144,500.00 mm². The effective simulator area A_e is the size of the irrigated soil surface is 130,000.00 mm².

$$i = \frac{Int_{mean}}{A_s} - \frac{R}{A_e} = Int_{mean} * \frac{1000*60}{144500} - R * \frac{1000*60}{130000*5} = Int_{mean} * 0.41522 - R * 0.09231 [mm/h] \qquad (4)$$

i………… infiltration rate (mm/h)
Int_{mean}…… mean intensity (ml/min)
R………… runoff (ml/5min)
A_s…...…… area of the drop distributing system (=144,500.00 mm²)
A_e………… effective simulator area (=130,000.00 mm²)

The simple empirical Kostiakov model was used to generate the infiltration rate. The general form of the infiltration equation given by KOSTIAKOV (1932) is

$$F = a * t^b \qquad (5)$$

where *a* and *b* are constants (0 < b > 1) and *t* stands for the time. The constants a and b are derived by curve fitting to the measured state.

The Kostiakov equation is just a simple model to generate the infiltration rate but for comparing infiltration within the same experimental area good enough and using the same equation delivers always the same calculation error.

With the Kostiakov equation the final infiltration rate after 60 minutes (i_{60}, steady state infiltration rate) for every measurement was calculated and for comparing the ten different treatments an average of i_{60} was generated.

For statistical analysis the *Statistical Package for the Social Science SPSS* was used.

Not all Kostiakov-fitted curves were used in calculating the final infiltration rate i_{60} per treatment. Curves with a lower correlation coefficient R^2 than 0.6 and curves which gave a completely different picture to all the other compared curves from the same treatment got dismissed.

6.2.7 Soil sampling

Additional to the infiltration measurements disturbed soil samples were taken to evaluate the initial water content of the soil directly before the infiltration measurement. Soil sampling took place outside the study area from 0-5 cm soil depth. This soil sample was labelled and sealed to avoid humidity losses and weighed immediately after sampling. No special equipment for soil drying was available, therefore the samples got air dried and weighed again to determine the gravimetric water content. The gravimetric water content was calculated with Equation 6

$$w = \frac{m_w}{m_s} \qquad (6)$$

where w is the gravimetric water content ($g*g^{-1}$), m_w is the mass of water (g) and m_s is the bulk solid mass (g).

6.3 Measurement problems

The time intensiveness of the infiltration measurement was the main problem (see Figure 36, page 36). One measurement requires one and a half to two hours. After some training, seven measurements per day were carried out. Some of them had to be stopped and started on a new place again during the measurement campaign. The equipment had some deficiencies at the beginning, e.g. a funnel for calibrating the intensity was missing and had to be constructed, syringes were plugged, the tray for collecting sediments and runoff water was wrong constructed etc. These deficiencies had to be solved and needed time to be repaired. Transport to Chimoio, where the equipment can be repaired, was not always available and even a transport to the fields was not every morning provided. Ten 20 litre containers filled with water from the Sussundenga Research Station were needed daily which had to be transported to the fields. Close to the long-term-trial was another well available but the water was very sandy.

Another problem was the handling of the equipment. It needed some time to find out about all the possible mistakes which can be made. Two local workers were helping with the measurements but all of us needed some training and the measurements were improving from day to day. It needed also long time to make the local workers clear not to touch or step on the soil which was selected for a measurement. During seeding or weeding many labourers were present on the long-term-trial and all needed to be controlled not to disturb the area where possible experiments can be done. A gap between the fourth and fifth line of maize was kept free for infiltration measurement on every plot, however the high number of labourers and the simultaneously work on all plots lead to soil surface disturbance, that this did not work out on every plot very well. The reason for this was the language barrier: Portuguese is the official language in Mozambique and English is not so much common in the area of Sussundenga.

All these factors led to the problem that for finishing three measurements on 40 plots long time was required. During the months when the measurements were carried out soil surface was influenced to a high disturbance. Beside these problems the measurements were made as quick and precise as possible.

7 Results and Discussion

7.1 Termite hole counting

The results of building the mean and standard deviation from the termite hole counting can be seen in Figure 37.

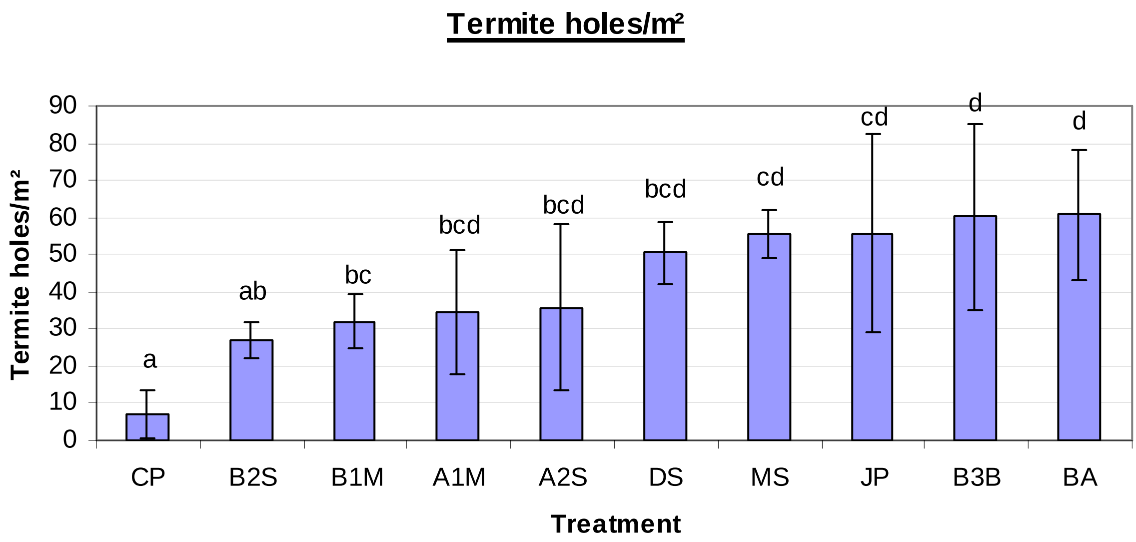


Figure 37: Termite holes per m²

The CP-plots (conventional ploughed plot, maize) have the lowest number of surface termite holes (7 holes/m²), whereas the treatments BA (basin, maize; 61 holes/m²), B3B (direct seeding, maize after beans; 60 holes/m²), JP (jab planter, maize; 56 holes/m²), MS (direct seeding, sunflower and maize intercropped; 56 holes/m²) and DS (direct seeding, maize; 51 holes/m²) show the highest density of termite holes/m². Lower numbers with a range from 27 to 36 holes/m² result from the treatments B2S (crop rotation, beans after sunflower; 27 holes/m²), B1M (crop rotation, sunflower after maize; 32 holes/m²), A1M (crop rotation, sunflower after maize; 34 holes/m²) and A2S (crop rotation, maize after sunflower; 36 holes/m²).

7.2 *Infiltration measurement*

Because of the difficult field set-up of the mini-rainfall-simulator the mean intensities vary between 93 mm/h and 110 mm/h (Figure 38).

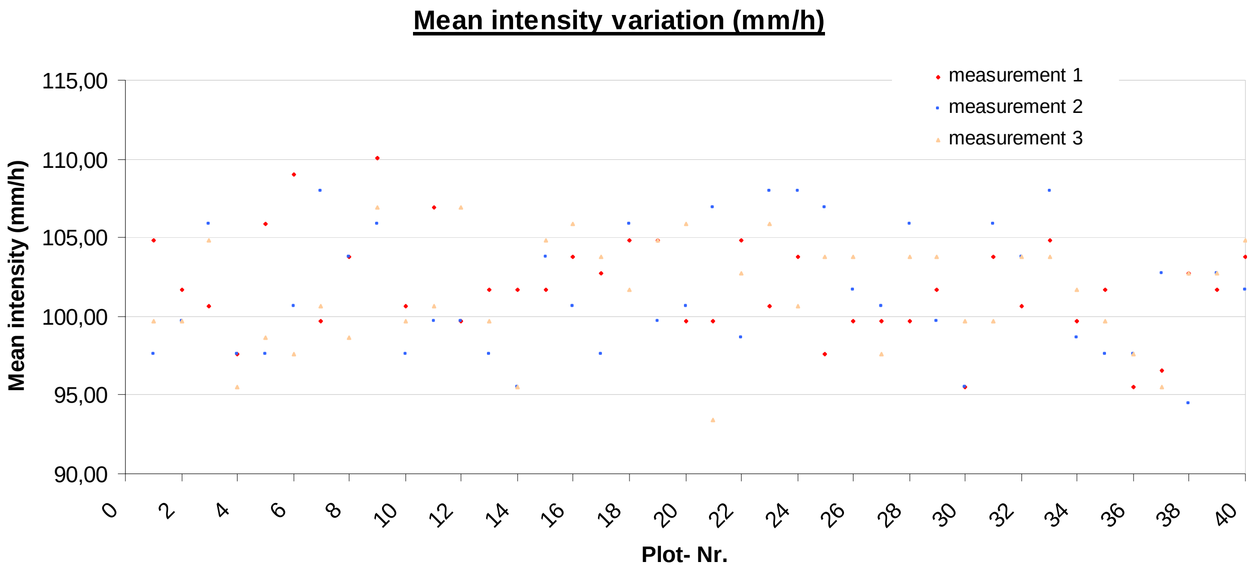


Figure 38: Mean intensity variation (mm/h)

Representative for all plots Figure 39 until Figure 48 present the results of the infiltration rate of one whole replication (replication R2). The results of all plots (1 to 40) can be found in the Annex 6. In each graph the infiltration rate from all three measurements (m1=measurement 1, m2= measurement 2, m3=measurement 3) in mm/h calculated from the surface runoff which was measured every five minutes, the fitted Kostiakov curves and corresponding equation from the three measurements and the R^2 and the date of the measurement are shown.

A dot dashed curve illustrates a measurement which was repeated in late March 2008 whereas the other measurements were made from February to beginning of March. Some of them had to be repeated because of mistakes during the process of measurement. Curves with a lower R^2 than 0.6 (statistical criteria) and curves which gave a completely different picture to all the other curves from the same treatment were not used for further interpretation. These curves are marked with a red colour in the legend of the graphs.

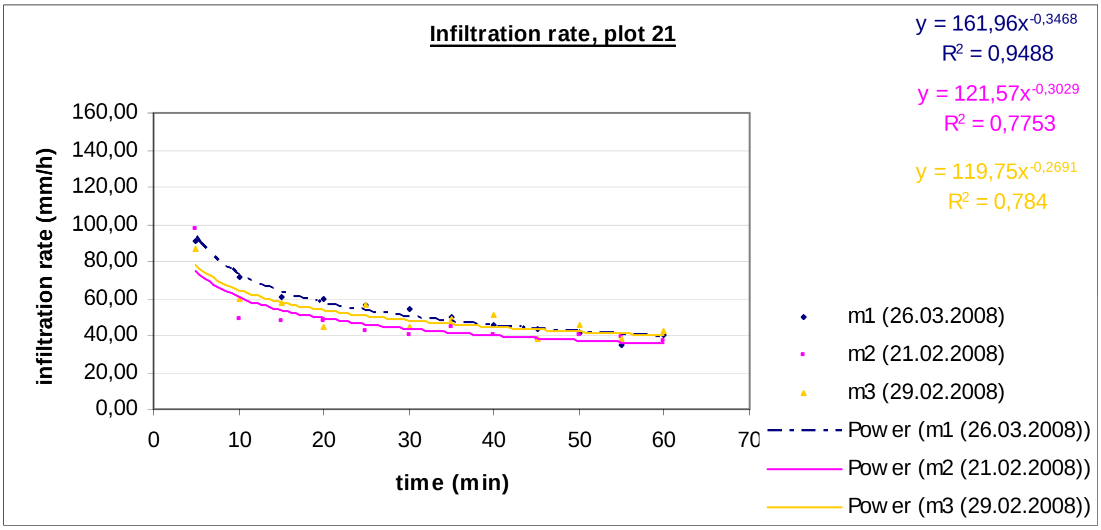


Figure 39: Infiltration rate, plot 21 (crop rotation, maize after sunflower)

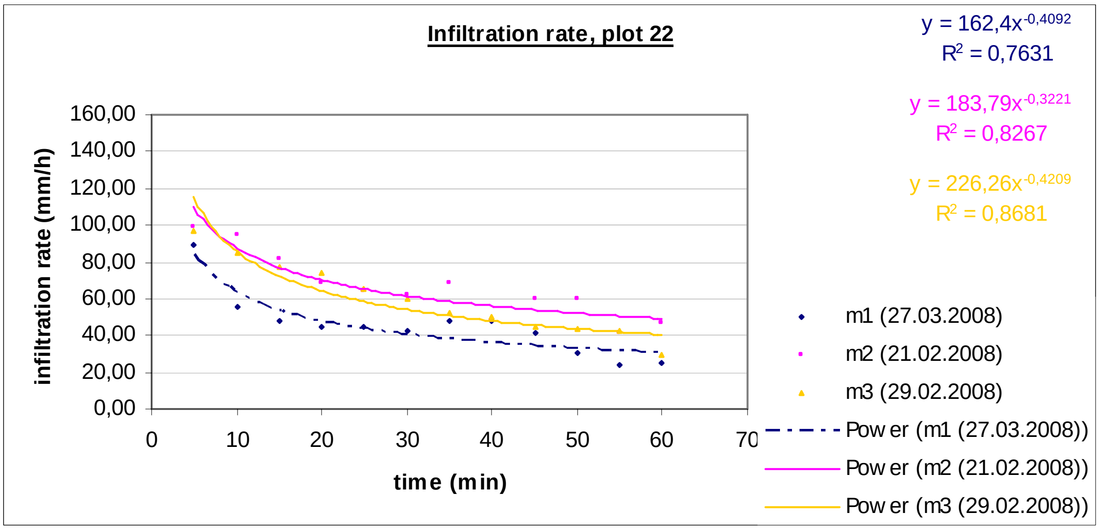


Figure 40: Infiltration rate, plot 22 (crop rotation, beans after sunflower)

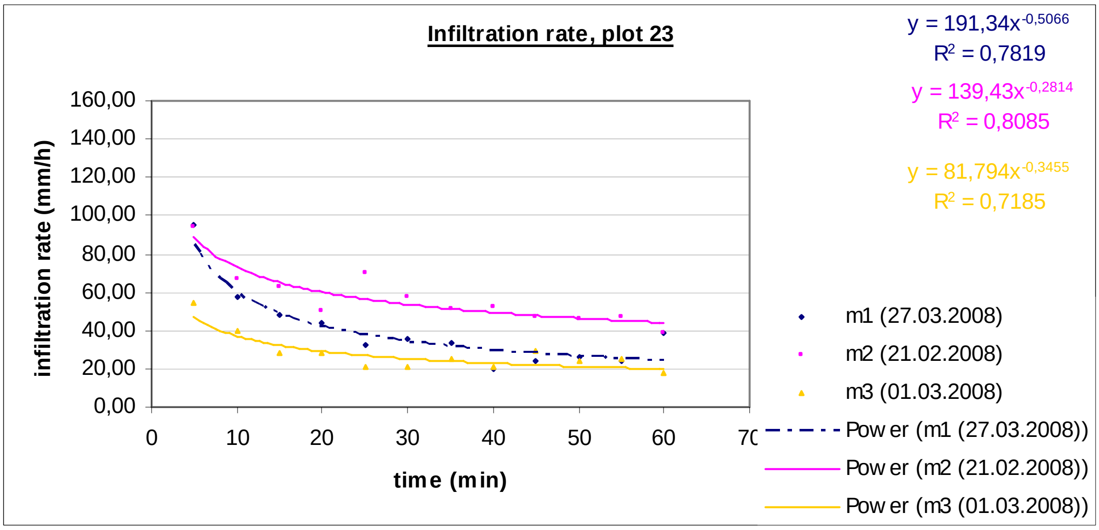


Figure 41: Infiltration rate, plot 23 (jab planter, maize)

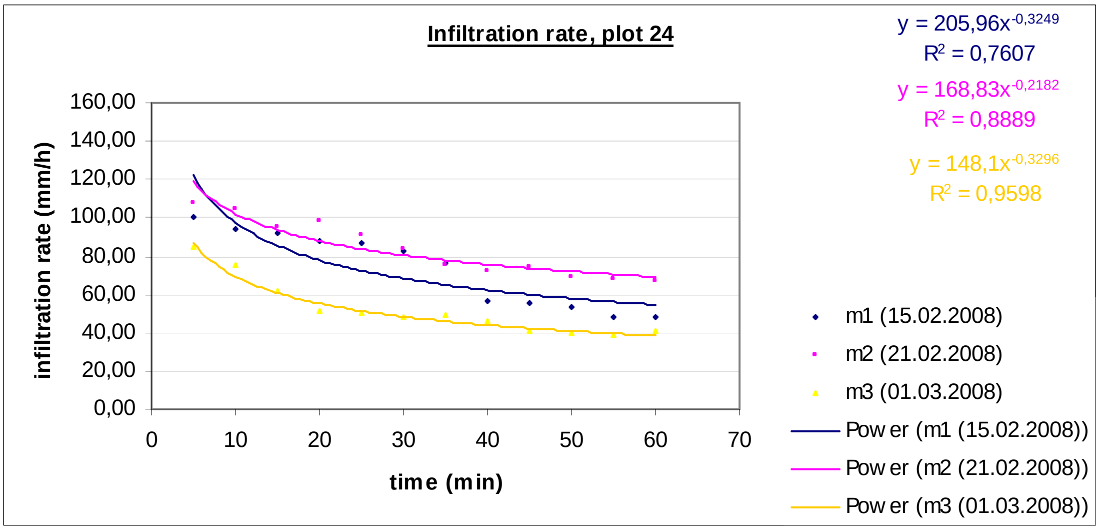


Figure 42: Infiltration rate, plot 24 (conventional ploughed plot, maize)

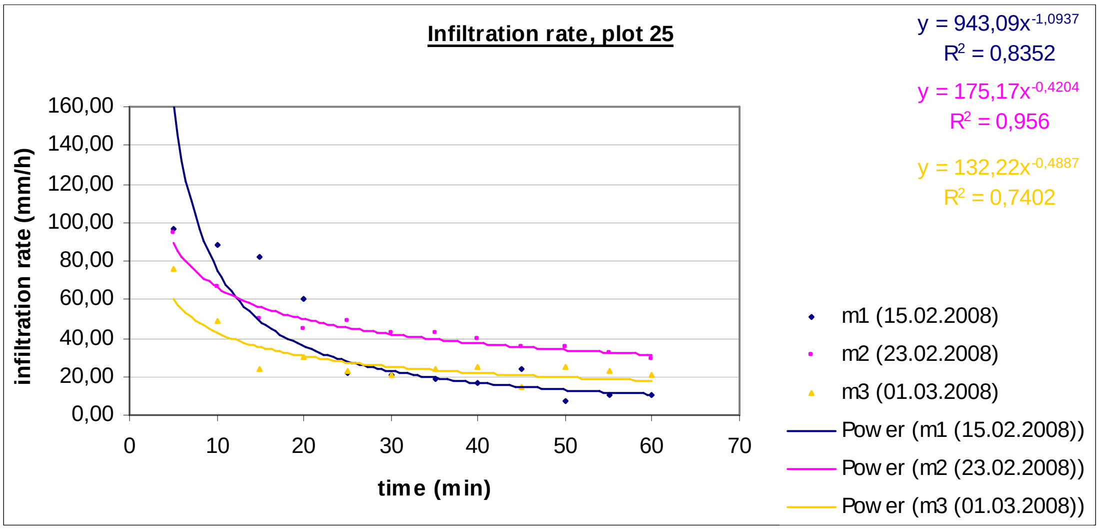


Figure 43: Infiltration rate, plot 25 (basin, maize)

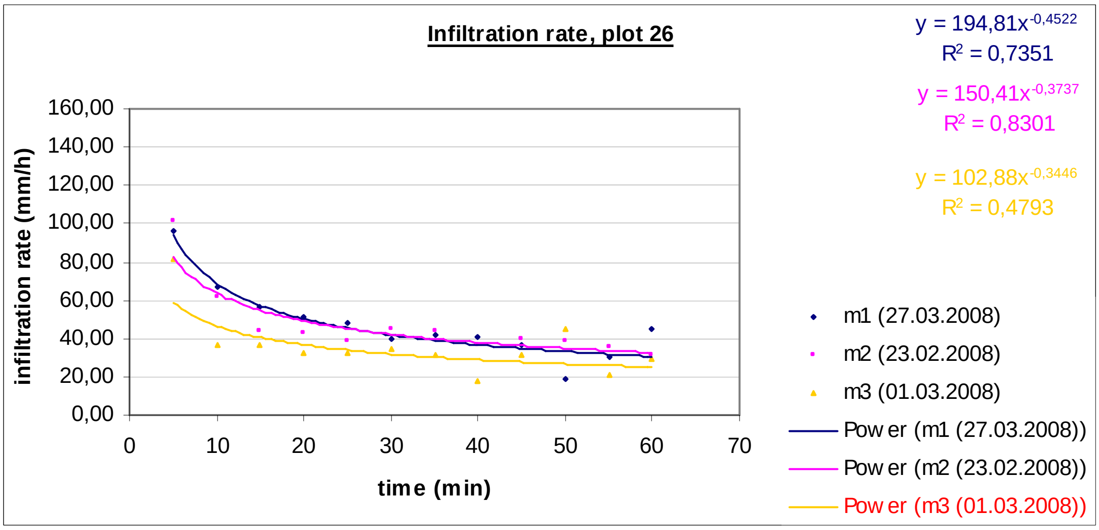


Figure 44: Infiltration rate, plot 26 (direct seeding, maize with sunflower intercropped)

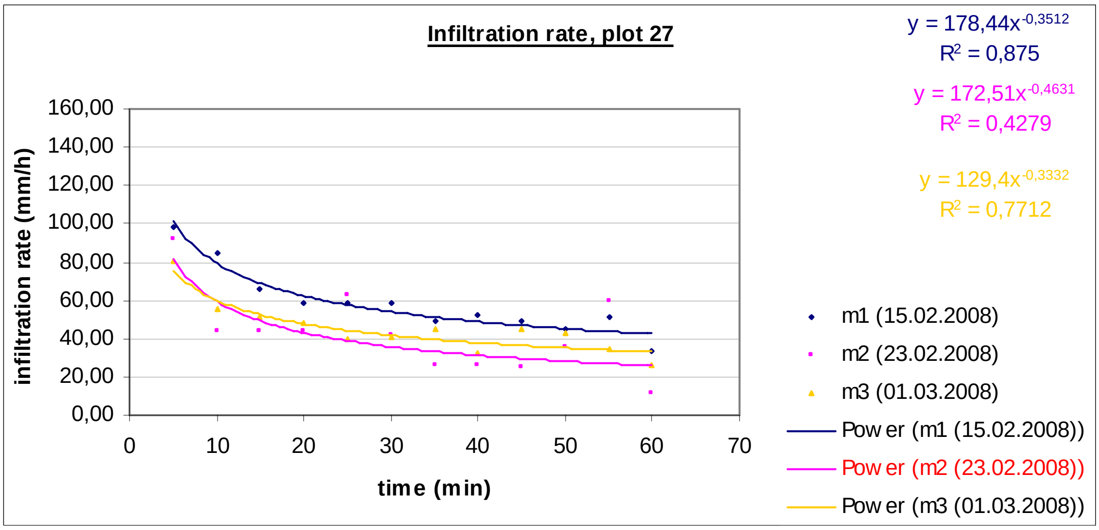


Figure 45: Infiltration rate, plot 27 (crop rotation, sunflower after maize)

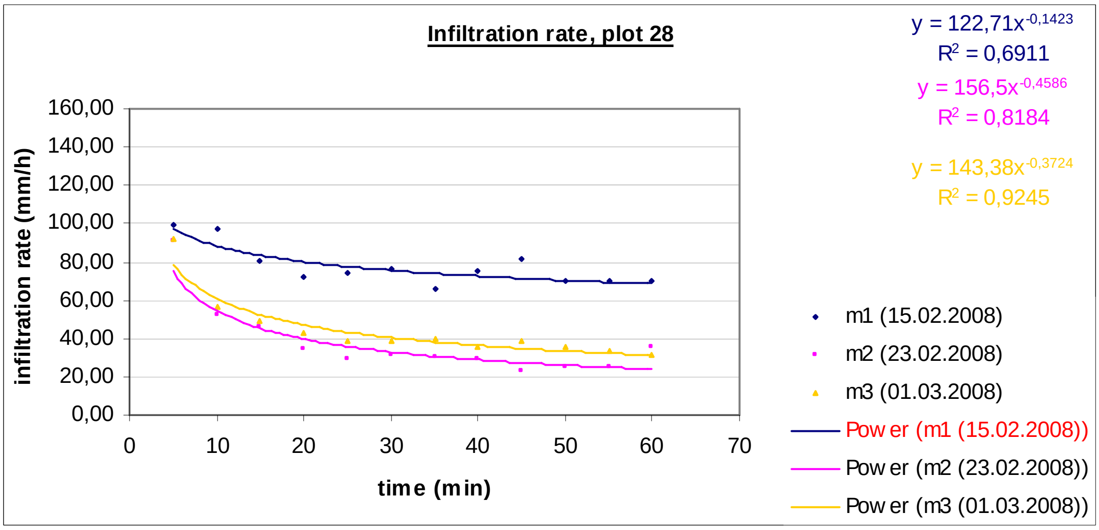


Figure 46: Infiltration rate, plot 28 (crop rotation, maize after beans)

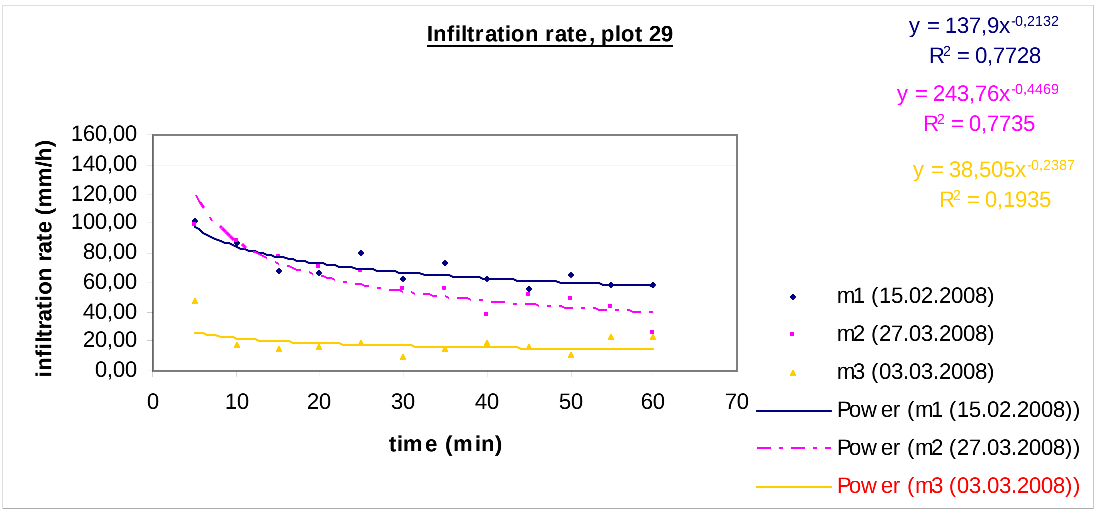


Figure 47: Infiltration rate, plot 29 (crop rotation, sunflower after maize)

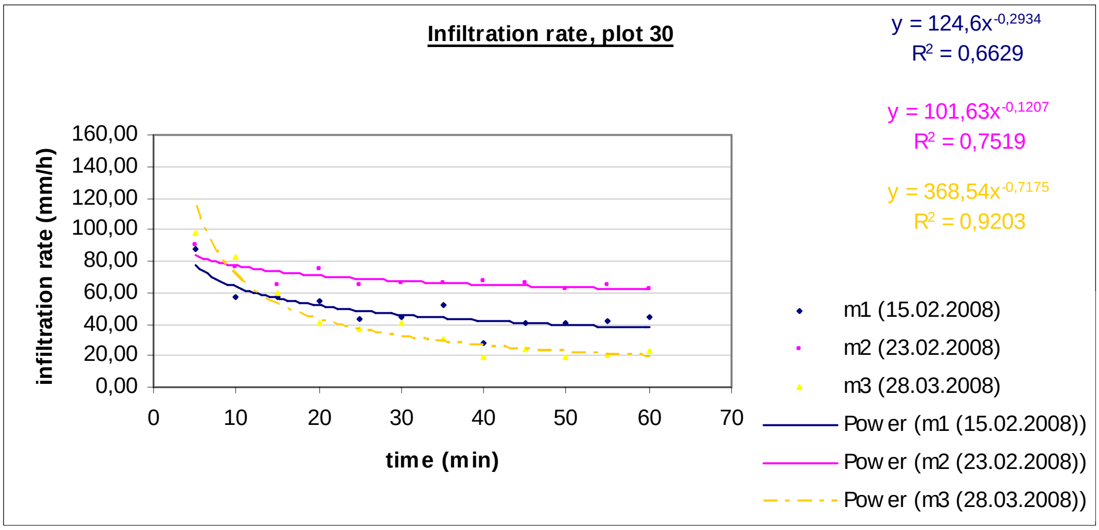


Figure 48: Infiltration rate, plot 30 (direct seeding, maize)

These obtained results make it difficult to compare the different treatments; every plot and measurement shows a different behaviour of the infiltration rate. Not all fitted curves match like in Figure 39. Many factors influence the shape of the curves, especially the big time lag between the measurements and therefore other conditions, e.g. initial soil moisture are responsible that the three measurements differ from each other.

The steady state infiltration at saturation should reach the same value therefore, for comparing the ten different treatments the final infiltration rate at 60 minutes (i_{60}) for each treatment was calculated with the Kostiakov equation (Figure 49; values see Annex 3):

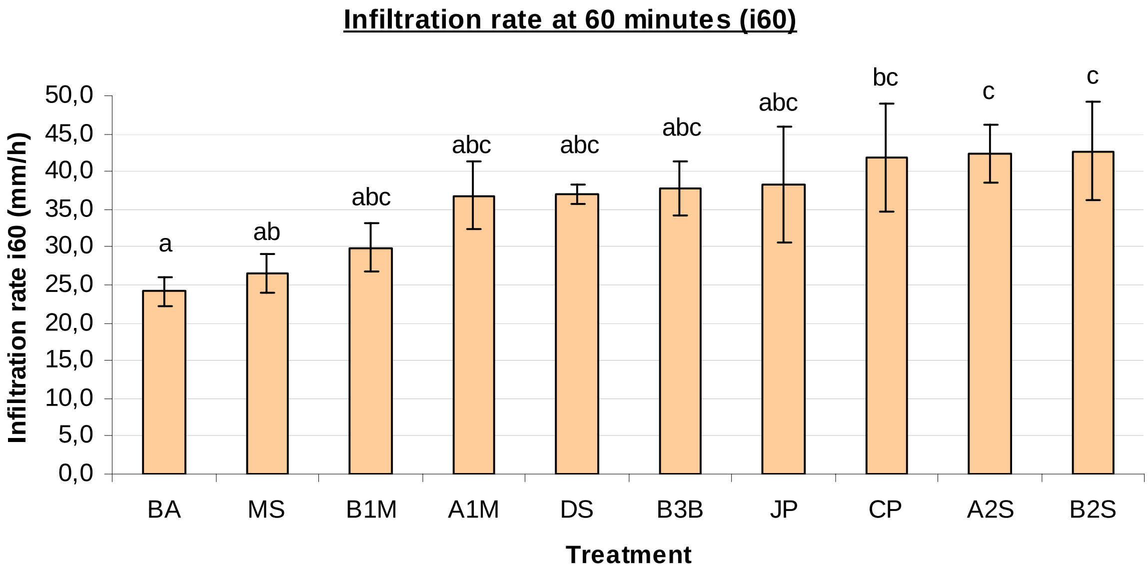
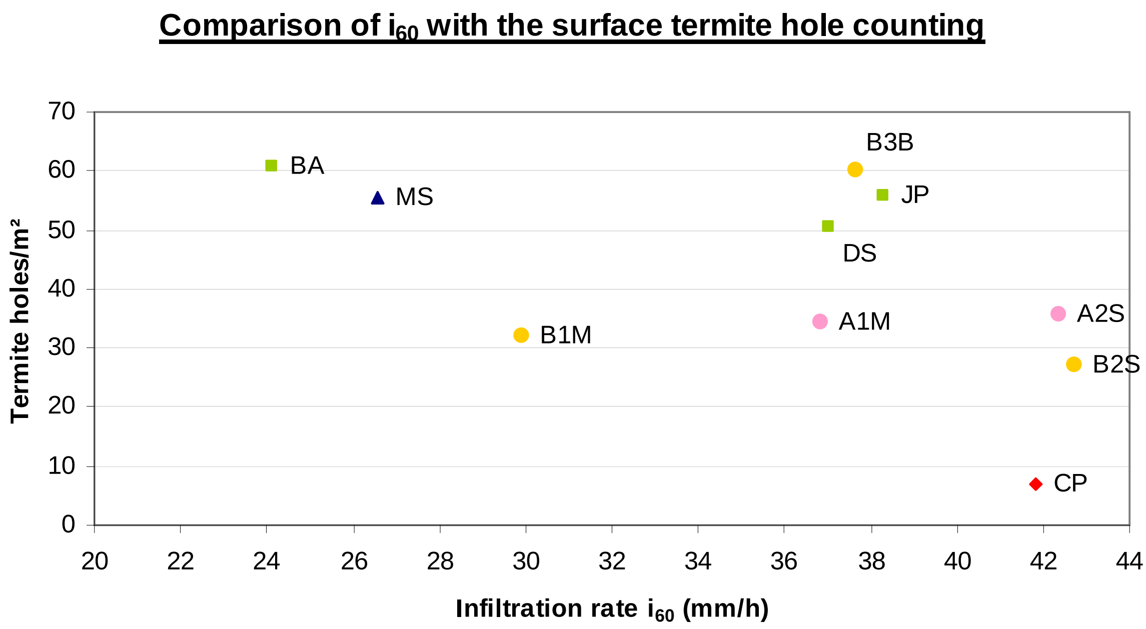


Figure 49: Infiltration rate at 60 minutes (i_{60})

However, the infiltration rates after 60 minutes (i_{60}) do not show a clear tendency. The values of infiltration rate range from 24.1 mm/h (BA) to 42.7 mm/h (B2S). The i_{60} of CP gives not a significant difference compared to the i_{60} of the most conservation agriculture treatments except basin (BA) and direct seeding with animal drawn seeder, where maize is intercropped with sunflower (MS).

7.3 Comparison of termite activity and infiltration measurement

Despite the influencing factors at infiltration measurement a comparison with the surface termite hole counting was attempted (Figure 50). This comparison should be considered with caution.



CP: Check plot (CP)
DS: Direct seeding with animal drawn seeder
BA: Basin
JP: Jab planter
MS: Direct seeding with animal drawn seeder, intercropping

A1M: Crop rotation A1
A2S: Crop rotation A2
B1M: Crop rotation B1
B2S: Crop rotation B2
B3B: Crop rotation B3

Figure 50: Comparison of i_{60} with the surface termite hole counting

From the aspect of surface termite holes compared to the infiltration rate at 60 minutes i_{60} the plots with lower numbers of holes have a higher infiltration rate. Especially the conventional ploughed plots (CP) have the lowest density of surface termite holes but with an i_{60} of 41.8 mm/h a high infiltration rate.

The highest number of surface termite holes has BA (61 holes/m²), but the lowest i_{60} (24.1 mm/h). On plots with crop rotation (B1M, B2S, A1M, A2S) numbers of surface termite holes vary between 27 holes/m² and 36 holes/m², whereas the i_{60} shows a high variation between 29.9 mm/h and 42.7 mm/h. An exception gives the treatment B3B which has a high i_{60} (37.7 mm/h) and a high number of surface termite holes (60 holes/m²).
Comparing types of tillage treatments (direct seeding, basin and jab planter) direct seeding (73.0 mm/h, 51 holes/m²) and jab planter (38.3 mm/h, 56 holes/m²) point out a similar result, the treatment basin (24.1 mm/h, 61 holes/m²) is completely different from them. DS, A1M and B1M are the same direct seeded treated plots with maize in the first year. In growing season 2008 on DS plots maize was planted, whereas on A1M and B1M plots sunflower. A1M and B1M can be grouped as same treatments, they have almost the same densities of surface termite holes (A1M 34 holes/m², B1M 32 holes/m²) however, i_{60} has a big difference (A1M 36.8 mm/h, B1M 29.9 mm/h).

Further on all the recorded data, the initial gravimetric water content, the mean intensity, the date of the infiltration measurement, precipitation of the previous seven days, the maximal precipitation of one day in previous seven days, if there was rain the day before the measurement and if the spot got watered the day before were considered to find a tendency of the results (see Annex 3). However, not a simple conclusive result could be drawn from all this data. The influencing factors are manifold and termite activity is only one of them.

8 CONCLUSION AND RECOMMENDATION

8.1 Termites

The results at the long-term-trial in Sussundenga show the same manner as in similar studies about termites in Zimbabwe (see chapter 4.2). NHAMO (2007) concludes: *"The lower densities in the CP-plots were mainly a result that no residues were applied as mulch. Mulching attracts termites in conservation agriculture treatments and provide them a suitable foraging site. Removal of residue limited energy sources. Application of surface mulches, crop or grass residues, that contain cellulose and crude protein attracted more termites and this led to increased foraging activities at these sites on plots with conservation agriculture. Further on ploughing disturbs the upper layer of the soil and thus the habitats and nests of the termites"*.

Apart from tillage treatment the type of residues retained from the previous crop was important for the extent of termite activity: termites preferred maize stalks and bean residues over sunflower residues. Except for CP, where no residues retained on the plots, the maize- or bean-planted treatments show the highest termite densities (DS, MS, JP, B3B, BA).

Missing shade in some treatments resulted in fewer termite holes. During counting in February 2008 the plots with the treatments A1M, B1M and B2S were bare because sunflower and beans have not been seeded at that time. As mentioned in chapter 4.2 termites cannot survive desiccation, thus shade is an important factor for their habitat. The missing shade was also the reason that the only maize-planted treatment A2S results in lower termite hole densities than the other maize-planted treatments.

The surface termite holes counting were during three days. Notice that this recording was during a very short time, after some weeks or months the habitat-behaviour of the termites can be different. Many factors influence the habitat. The most influencing factor in the growing season 2008 was the weather: heavy rain with wind on the February 9^{th} and more important the thunderstorm on the February 27^{th} with a precipitation of 59.6 mm in one and a half hour destroyed a large part of the maize plants. The destroyed and fallen maize plants were again a food resource for the termites and eaten up immediately. Thus had the effect that little was left for harvest beginning of May.

Due to missing residues and therefore missing mulch on the CA-plots the soil is more exposed to the impact of splash erosion. Maintaining crop residues as mulch to provide soil cover is one main principle in conservation agriculture. Therefore *Mucuna*, a legume was planted to protect the soil against splash erosion on all plots – on maize plots as well on sunflower and bean plots.

8.2 Infiltration measurement

The infiltration measurements do not deliver unique results, the influencing factors are from the equipment and methodology itself and as well as from the soil behaviour or weather conditions.

Precariousness of the methodology

The results from the mini-rainfall-simulator from CIAT should be used carefully. Some points of the methodology and the operation of the mini-rainfall-simulator should be improved for future measurements.

- The drop distributing system is a static and not a rotating system, the raindrops fall constant on the same place whereas other spots of the surface get not impacted by raindrops. Other simulator types have a rotating system, where the irrigation covers the whole area.
- Plugged syringes due to the water quality can lead to unequal application of rainfall. The water at Sussundenga Research Station was sandy and after a long and hot day doing measurements (up to 11 hours) the temperature of the water in the transport buckets increased which led to increased algal formation and biological activity and therefore plugged syringes. Also viscosity changed and by that the outflow rate.
- The calculation of the infiltration rate takes in account the area of the drop distributing system and not the number of the syringes itself. At the measurement it is not clear how many syringes irrigate the effective area and how many drop outside.
- A not well centred mini-rainfall-simulator over the effective area leads to the fact that more drops fall outside.

- Not detected is how much water splashes back from the second tray (recollecting tray of the water that falls outside the effective area) into the effective area.
- The infiltration measurement takes place on a small area. 0.09% of the whole plot area (24 m * 18 m = 432 m^2) was used for infiltration measurements (3 * 0.13 m^2).
- The wide variance of the intensities (see Figure 38, page 42) results from the difficult handling of the valve. This valve to adjust the amount of air entering the Mariotte´s bottle for the desired rain intensity reacts very sensible on opening or closing.
- The high rainfall intensity of approximately 100 mm/h can cause slaking of aggregates at the soil surface which leads to sealing and crusting. However, the chosen rain intensity is similar to the natural rain intensities in this area.
- Time lag: 120 measurements are intensive and require a long time. Future measurements should be focused on the first four treatments (CP, DS, BA, JP) to get better results for comparing conservation agriculture and conventional ploughing. The procedure can be tightened when every day an experiment will be carried out on the same four treatment plots (all four replications). The conditions will be the same within one treatment but still difficult for comparing with others. Another way to tighten the procedure is that all three measurements of one plot can be done at one day. To finish one replication one week will be needed. To find the perfect way is not easy – there will be always some influences and field work means always that unexpected things can happen.
- Installing the recollecting tray for the sediments and runoff water into dry soil was difficult and hammering transferred the upper soil to vibrate. Therefore dry plots had to be watered a day before which led to a higher water content.
- The wind break curtain was not always efficient enough because of changing direction of the wind.

Soil influence

Infiltration is a behaviour of the soil and not only a soil property; thus infiltration is a sum of many parameters (storage and conductivity properties). Compare also with chapter 5.

- The pore-size distribution influences the rate of change of infiltrability (SHUKLA, 2006).

- Unclear is if less surface runoff results either from micro storage of water on the soil surface, higher infiltration due to more holes (macro pore infiltration), or matrix infiltration. Variation of the surface leads to micro storage. Irrigated water can be retained on the soil surface up to some millimeter and prevents from immediate run off. Important for further research will be what is the dominating effect of infiltration (matrix infiltration or macro pores). One possibility is an experiment with a tension infiltrometer.
- Impermeable layers can lead to surface runoff when the layer above is saturated. Layered soils (coarser or finer texture) influence the infiltrabilty.
- Infiltration is also a matter of storage. The ploughed layer of the ploughed plots has a higher storage capacity. The ploughed layer will be filled up and the infiltration downwards can take place after some time, e.g. after the 60 minutes of the performed experiment. Because of this a comparison of the CA-plots with the CP-plots is not possible. In further research the ploughed layer has to be removed and an experiment over a very long time can result in better and clearer results.
- Pores (termite holes) can be blocked or air bubbles which can not escape can lead to a filling up of the first centimeters of the pores with water and therefore no further infiltration is possible.
- The long-term-trial was exposed to disturbance by people working on the fields, pigs which came to the fields during night and heavy rainfalls. Soil compaction, crusting and sealing of surface soil pores was pronounced.
- Former soil compaction due to the use of machinery for cleaning the land and for tillage operations can still have influence on the soil.

Termite activity influence

- Not clear is if the termite holes contribute to infiltration behaviour. Termites bring up finer material to the soil surface, whereas they construct hard material further down the soil (see Figure 20). Unclear is also how termites protect themselves during rainfalls. Whereas earthworms come to the surface during rain events no termites have been recognized. Further studies have to be done to evaluate the length and distribution of the termite holes.

- No mulch cover due to the termites makes the soil more exposed to splash erosion. Remedy has been done with planting *Mucuna* to provide better soil covering.
- When plots were watered and covered with a plastic foil a day before the measurements the termite activity increased during the night.
- More research is needed, e.g. experiments on a long-term-basis (completely saturating of the soil – a 5 cm layer of the soil has to be removed after wetting – performing the infiltration measurement – removing again a soil layer – infiltration measurement…) can show the influence of the distribution of termite holes over depth.

<u>Soil moisture influence</u>

- The initial water content influences the infiltration behaviour at the beginning of measurements. In drier soils firstly a higher infiltration rate is recorded and after some times the infiltration rate decreases and reaches an asymptotic behaviour. Depending how dry the soil is the asymptotic behaviour can be reached earlier or later (the worst case is after 60 minutes). In wetter soils the initial infiltration is much smaller.
- Soil moisture measurements should be done before and after the infiltration measurements for comparing the infiltration behaviour of the soil
- Measurements should be done at least three days after a rainfall event. Then the infiltration front went further down.

It is difficult to say which of all these factors lead to the present infiltration behaviour. More or less it is a cross-correlation of influences and splitting it up is very difficult. The study clearly shows that CA, already after two cropping seasons has an impact on biological activity. More termites are active on CA plots with residue retention. However, a clear correlation between higher amounts of surface termite holes and increased infiltration could not yet be found.

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10 ANNEXES

ANNEX 1: Data sheet for the termite hole counting

Treat	Label	Crop	Rep	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	Sum	Average
1	CP	Maize	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0,1
2	DS	Maize	1	10	11	11	5	0	0	10	2	1	4	6	10	7	2	9	88	5,9
3	BA	Maize	1	1	1	4	0	0	0	3	11	17	4	2	20	0	4	10	77	5,1
4	JP	Maize	1				5	2	18	0	2	11	7	11	12	0	11	5	84	7,0
5	MS	Maize +SF	1	2	4	10	8	0	0	0	10	1	2	3	12	18	23	5	98	6,5
6	A1M	Sunflower	1	0	1	0	0	0	0	5	0	5	1	3	0	4	0	0	19	1,3
7	A2S	Maize	1	0	0	1	0	1	0	0	0	0	0	0	0	3	0	4	9	0,6
8	B1M	Sunflower	1	0	0	0	0	0	4	20	6	4	4	6	3	3	2	8	60	4,0
9	B2S	Beans	1	0	3	0	0	2	0	4	1	5	10	12	0	2	14	7	60	4,0
10	B3B	Maize	1	3	4	7	0	0	4	2	0	7	18	6	5	7	2	11	76	5,1
6	A1M	Sunflower	2	3	8	5	1	19	8	0	12	1	5	5	0	8	4	8	87	5,8
8	B1M	Sunflower	2	0	1	0	10	1	2	0	4	0	0	3	8	7	0	7	43	2,9
10	B3B	Maize	2	16	1	17	3	12	9	15	2	1	17	15	22	15	12	16	173	11,5
9	B2S	Beans	2	17	1	0	7	0	0	4	0	1	8	0	8	0	7	9	62	4,1
2	DS	Maize	2	0	17	8	22	6	10	6	3	4	0	8	2	7	8	3	104	6,9
7	A2S	Maize	2	8	9	9	15	3	5	15	3	10	0	2	3	7	14	10	113	7,5
1	CP	Maize	2	2	0	1	0	0	0	2	2	0	0	0	0	2	9	0	18	1,2
4	JP	Maize	2	1	10	1	1	10	13	13	22	22	23	15	25	12	10	2	180	12,0
5	MS	Maize +SF	2	0	2	1	9	8	3	16	10	18	12	2	17	0	9	4	111	7,4
3	BA	Maize	2	14	6	9	9	9	12	20	4	8	9	6	12	13	13	13	157	10,5
7	A2S	Maize	3	7	1	3	6	3	10	4	1	1	2	0	16	0	12	8	74	4,9
9	B2S	Beans	3	5	0	0	0	12	10	4	0	0	0	7	5	0	0	0	43	2,9
4	JP	Maize	3	16	12	6	0	0	7	7	0	0	0	0	0	1	6	2	57	3,8
1	CP	Maize	3	0	2	0	0	0	0	0	0	4	0	0	0	1	0	0	7	0,5
3	BA	Maize	3	10	8	5	8	6	3	14	3	11	10	17	11	11	7	9	133	8,9
5	MS	Maize +SF	3	5	14	0	3	10	8	4	13	7	11	1	2	6	10	5	99	6,6
8	B1M	Sunflower	3	11	5	7	4	5	2	5	10	6	0	2	4	6	0	5	72	4,8
10	B3B	Maize	3	6	8	1	3	18	8	1	4	7	4	5	4	1	6	1	77	5,1
6	A1M	Sunflower	3	8	7	5	3	9	6	2	7	9	1	8	9	5	7	2	88	5,9
2	DS	Maize	3	10	0	0	5	5	9	0	1	2	14	12	10	5	6	4	83	5,5
3	BA	Maize	4	11	13	0	12	13	2	11	1	0	6	3	6	0	15	14	107	7,1
5	MS	Maize +SF	4	2	5	23	10	12	4	8	5	4	1	12	22	17	0	0	125	8,3
10	B3B	Maize	4	14	11	18	10	12	15	8	0	7	16	10	5	7	0	10	143	9,5
6	A1M	Sunflower	4	9	4	0	2	5	2	5	10	0	10	9	7	0	6	5	74	4,9
8	B1M	Sunflower	4	12	10	10	4	3	3	7	4	6	1	2	4	0	0	9	75	5,0
9	B2S	Beans	4	0	8	10	9	3	1	0	2	0	0	4	0	4	1	5	47	3,1
2	DS	Maize	4	3	10	16	7	3	5	5	5	9	10	10	10	4	13	9	119	7,9
1	CP	Maize	4	0	0	1	0	0	0	7	0	0	0	6	0	1	2	12	29	1,9
7	A2S	Maize	4	3	17	13	4	1	3	8	1	7	1	5	0	1	9	9	82	5,5
4	JP	Maize	4	8	7	8	9	6	4	10	1	2	4	6	4	12	0	12	93	6,2

Table 2: Termite hole counting

ANNEX 2: Data sheet for infiltration (surface runoff) measurement

Measurement 1														
Plot Nr.	Initial Intensity	5min	10min	15min	20min	25min	30min	35min	40min	45min	50min	55min	60min	Final intensity
	(ml/min)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml)	(ml/min)
1	250	542	860	885	890	885	930	875	1020	1026	1058	1025	1050	255
2	245	320	655	685	665	665	755	760	775	755	810	690	860	245
3	250	0	90	480	572	500	564	490	635	688	742	910	790	235
4	240	305	636	638	690	715	735	500	910	614	672	720	694	230
5	255	280	675	795	805	800	945	595	1040	1040	925	900	810	255
6	260	25	122	172	162	392	394	605	625	625	660	530	475	265
7	245	500	935	920	980	980	950	1000	955	955	1020	980	980	235
8	255	460	900	900	940	935	935	920	980	950	975	945	945	245
9	265	700	960	855	855	840	880	605	1115	800	895	810	900	265
10	245	240	644	740	925	710	713	815	820	790	915	835	885	240
11	260	82	365	400	340	470	510	455	670	520	590	632	635	255
12	245	260	310	420	415	490	430	490	430	235	510	410	550	235
13	245	145	240	275	330	395	440	450	390	415	410	440	450	245
14	245	120	240	328	310	315	360	290	415	415	400	500	470	245
15	245	92	200	252	355	455	510	400	650	565	565	550	550	245
16	250	114	210	255	280	295	285	410	465	530	500	540	565	250
17	250	52	95	135	168	246	292	250	430	340	405	340	315	245
18	255	215	696	815	810	825	850	895	855	915	860	880	935	250
19	255	0	75	305	395	530	620	705	880	775	925	925	925	250
20	240	10	235	355	420	440	445	445	560	570	550	570	530	240
21	255	100	310	425	430	470	495	535	590	615	640	700	645	225
22	255	172	535	615	650	650	680	618	620	685	805	875	865	250
23	245	64	465	575	615	735	700	725	880	825	805	825	675	240
24	250	32	100	128	170	185	230	300	515	520	545	600	600	250
25	235	15	104	170	400	820	835	850	875	800	975	950	950	235
26	250	34	360	470	520	560	650	630	640	685	870	750	595	230
27	240	15	160	365	445	450	450	550	515	542	590	525	720	240
28	240	0	30	210	300	275	250	370	265	200	315	325	325	240
29	245	0	155	370	375	235	425	315	430	505	400	475	475	245
30	230	90	420	420	440	560	550	465	730	600	590	574	558	230
31	250	290	365	665	674	732	790	800	830	815	900	830	975	250
32	235	230	552	570	552	300	560	460	760	625	630	670	545	250
33	250	15	240	485	515	582	620	675	672	745	815	715	780	255
34	240	80	510	570	620	655	405	665	815	700	685	720	720	240
35	250	72	320	400	440	440	375	490	520	530	475	695	590	240
36	230	24	230	400	365	480	450	545	480	590	595	620	620	230
37	230	0	24	315	485	360	445	435	465	445	460	420	320	235
38	250	405	715	740	740	765	720	745	750	755	735	735	765	245
39	250	365	640	645	675	465	675	570	720	800	720	730	740	240
40	245	0	135	410	440	575	580	540	540	565	595	650	565	255

Table 3: Data sheet, infiltration (surface runoff) measurement, measurement 1

Measurement 2														
Plot Nr.	Initial Intensity (ml/min)	5min (ml)	10min (ml)	15min (ml)	20min (ml)	25min (ml)	30min (ml)	35min (ml)	40min (ml)	45min (ml)	50min (ml)	55min (ml)	60min (ml)	Final intensity (ml/min)
1	240	0	110	145	220	420	580	618	598	565	625	610	640	230
2	240	134	370	470	510	530	540	634	635	640	580	720	700	240
3	260	375	765	870	835	825	865	870	925	880	840	915	915	250
4	240	150	435	460	500	505	505	530	540	566	575	565	560	230
5	240	480	875	905	905	930	890	925	940	940	885	1000	990	230
6	250	395	765	815	820	905	875	930	855	985	935	1034	875	235
7	260	115	555	620	565	586	662	634	775	728	728	750	760	260
8	260	305	635	716	710	710	840	740	900	910	735	810	945	240
9	255	245	700	800	795	740	825	825	855	890	890	915	890	255
10	240	80	400	485	530	556	580	597	592	656	624	640	640	230
11	240	375	710	745	740	770	780	875	855	870	880	875	875	240
12	240	250	540	570	530	605	645	690	718	730	650	730	825	240
13	235	104	450	530	645	325	552	600	682	715	690	580	780	235
14	230	35	100	117	117	150	242	104	405	310	355	480	290	230
15	250	106	260	435	450	505	578	565	565	575	618	706	640	250
16	240	42	270	200	280	425	460	395	565	460	530	632	400	245
17	240	28	214	270	275	405	390	405	560	550	555	560	630	230
18	255	190	655	750	800	850	800	860	890	765	945	950	955	255
19	240	115	430	480	604	664	684	662	600	740	780	875	705	240
20	245	280	565	632	705	650	745	840	820	815	915	890	895	240
21	260	100	630	646	648	698	725	675	725	745	725	740	755	255
22	240	0	40	185	325	370	395	330	550	420	425	615	565	235
23	260	155	445	490	625	410	550	610	600	660	670	660	750	260
24	260	0	40	140	110	185	260	350	390	365	420	435	445	260
25	255	134	440	620	675	630	700	695	736	770	780	815	840	260
26	245	0	435	625	642	682	615	630	710	666	680	715	765	245
27	245	94	610	620	620	415	638	805	805	820	704	445	965	240
28	255	160	585	654	775	825	810	820	830	900	870	870	760	255
29	240	0	120	240	320	350	470	470	675	525	550	615	805	240
30	240	62	212	330	225	335	315	320	300	320	355	335	360	220
31	255	200	546	696	745	785	820	860	850	915	875	920	915	255
32	240	26	300	555	592	654	715	742	792	750	925	925	950	260
33	255	28	275	360	460	400	540	600	574	652	660	700	610	265
34	240	0	15	40	68	36	92	130	165	190	250	265	265	235
35	235	0	350	485	665	485	610	625	636	684	706	722	650	235
36	235	88	310	455	460	395	586	564	605	650	644	680	630	235
37	245	0	210	320	430	510	616	654	662	690	744	710	730	250
38	230	44	385	465	550	565	572	642	652	630	634	678	722	225
39	245	134	475	365	570	415	550	542	635	642	624	655	645	250
40	250	68	290	340	390	265	330	345	350	360	355	355	375	240

Table 4: Data sheet, infiltration (surface runoff) measurement, measurement 2

Measurement 3														
Plot Nr.	Initial intensity (ml/min)	5min (ml)	10min (ml)	15min (ml)	20min (ml)	25min (ml)	30min (ml)	35min (ml)	40min (ml)	45min (ml)	50min (ml)	55min (ml)	60min (ml)	Final intensity (ml/min)
1	240	140	380	410	480	540	586	664	724	785	770	755	760	240
2	245	170	455	520	550	550	595	584	638	665	660	686	690	235
3	255	140	340	485	570	575	610	624	650	670	688	670	745	250
4	250	0	105	155	280	260	360	350	534	425	490	465	525	210
5	235	52	315	380	385	430	465	460	475	495	450	465	475	240
6	235	305	650	686	686	718	740	760	748	810	780	800	805	235
7	240	34	130	224	415	485	528	590	656	678	626	696	670	245
8	240	190	465	485	490	526	610	600	610	670	640	672	770	235
9	255	15	58	196	400	550	465	688	694	775	704	490	945	260
10	240	15	146	205	290	415	305	240	540	415	425	664	465	240
11	235	38	110	170	300	350	355	450	475	550	565	465	560	250
12	255	280	670	735	780	820	825	880	845	890	870	845	900	260
13	240	72	315	500	517	538	572	720	695	670	775	698	840	240
14	230	150	520	594	585	524	415	385	550	646	715	775	746	230
15	250	150	460	650	730	775	790	795	905	685	990	950	795	255
16	260	420	732	900	930	915	965	1028	925	1005	1050	925	925	250
17	250	105	155	245	255	330	485	510	512	595	604	572	595	250
18	240	225	430	510	574	605	628	665	705	695	730	780	960	250
19	255	48	280	500	650	625	750	805	800	900	815	965	780	250
20	255	265	654	775	750	830	820	900	865	852	780	840	845	255
21	230	80	365	395	530	400	530	485	460	608	526	598	550	220
22	245	60	194	275	315	410	470	544	566	635	642	650	790	250
23	255	560	722	842	842	915	925	880	925	830	890	880	955	255
24	245	175	275	425	540	550	574	560	596	652	665	675	650	240
25	250	305	600	865	795	875	900	865	850	965	860	875	905	250
26	250	245	733	733	770	775	750	785	935	780	640	900	805	250
27	245	180	455	500	536	624	616	575	710	566	595	680	775	225
28	255	130	510	596	656	702	705	695	744	704	744	765	780	245
29	250	610	935	970	950	925	1026	965	915	950	1000	880	870	250
30	240	22	180	435	640	676	645	750	875	820	875	855	835	240
31	245	152	550	630	690	725	715	715	785	810	780	875	825	235
32	250	475	840	795	890	920	855	755	855	940	900	765	815	250
33	250	265	395	470	495	480	590	660	650	560	860	810	620	250
34	250	250	665	710	695	715	735	765	795	790	805	760	925	240
35	240	150	565	570	665	465	540	510	735	845	900	975	975	240
36	240	58	184	270	365	395	425	440	460	460	475	510	510	230
37	240	64	410	580	572	616	715	675	690	720	612	780	765	220
38	245	140	405	568	610	550	624	620	708	520	785	670	610	250
39	235	275	568	568	604	660	554	635	558	652	614	725	624	260
40	255	400	1028	960	1000	895	930	975	990	970	880	885	990	250

Table 5: Data sheet, infiltration (surface runoff) measurement, measurement 3

ANNEX 3: Data summary

Plot-Nr.	Treatment	Label	Replication	Measurement	Initial gravimetric water content	Termite holes per m²	Mean intensity(mm/h)	i_{60} (mm/h)	R^2 (fitting curve)	Date of infiltration measurement	Precipitation previous 7 days (mm)	max Precipitation (1 day) in previous 7 days (mm)	watered previous day	rain day before (mm)
1	T1	CP	1	1	0,169	0,51	104,84	9,30	0,81	24.03.2008	20,8	9,4		9,4
1	T1	CP	1	2	0,099		97,58	38,05	0,87	17.02.2008	6,2	6,0	x	0,0
1	T1	CP	1	3	0,106		99,65	28,70	0,93	25.02.2008	22,8	20,4	x	0,0
2	T2	DS	1	1	0,173	45,13	101,73	27,14	0,75	24.03.2008	20,8	9,4		9,4
2	T2	DS	1	2	0,085		99,65	36,35	0,92	17.02.2008	6,2	6,0	x	0,0
2	T2	DS	1	3	0,094		99,65	35,91	0,96	25.02.2008	22,8	20,4	x	0,0
3	T3	BA	1	1	0,086	39,49	100,69	28,70	0,77	08.02.2008	2,6	2,6	x	0,0
3	T3	BA	1	2	0,175		105,88	20,59	0,75	24.03.2008	20,8	9,4		9,4
3	T3	BA	1	3	0,103		104,84	38,55	0,97	25.02.2008	22,8	20,4	x	0,0
4	T4	JP	1	1	0,166	53,85	97,58	28,44	0,26	24.03.2008	20,8	9,4		9,4
4	T4	JP	1	2	0,103		97,58	43,16	0,88	17.02.2008	6,2	6,0	x	0,0
4	T4	JP	1	3	0,097		95,50	49,63	0,88	25.02.2008	22,8	20,4	x	0,0
5	T5	MS	1	1	0,177	50,26	105,88	17,30	0,45	24.03.2008	20,8	9,4		9,4
5	T5	MS	1	2	0,143		97,58	7,76	0,70	18.02.2008	1,4	1,2	x	1,2
5	T5	MS	1	3	0,138		98,61	51,61	0,86	27.02.2008	20,4	20,4	x	0,0
6	T6	A1M	1	1	0,120	9,74	109,00	53,21	0,74	08.02.2008	2,6	2,6	x	0,0
6	T6	A1M	1	2	0,142		100,69	10,96	0,67	25.03.2008	25,0	12,0		12,0
6	T6	A1M	1	3	0,119		97,58	22,44	0,91	27.02.2008	20,4	20,4	x	0,0
7	T7	A2S	1	1	0,151	4,62	99,65	7,03	0,65	25.03.2008	25,0	12,0		12,0
7	T7	A2S	1	2	0,115		107,96	37,07	0,86	18.02.2008	1,4	1,2	x	1,2
7	T7	A2S	1	3	0,138		100,69	35,65	0,94	27.02.2008	20,4	20,4	x	0,0
8	T8	B1M	1	1	0,161	30,77	103,81	13,29	0,69	25.03.2008	25,0	12,0		12,0
8	T8	B1M	1	2	0,105		103,81	22,11	0,71	18.02.2008	1,4	1,2	x	1,2
8	T8	B1M	1	3	0,111		98,61	34,27	0,89	27.02.2008	20,4	20,4	x	0,0
9	T9	B2S	1	1	0,164	30,77	110,03	26,05	0,03	10.02.2008	20,4	20,2		20,2
9	T9	B2S	1	2	0,126		105,88	21,67	0,87	25.03.2008	25,0	12,0		12,0
9	T9	B2S	1	3	0,093		105,88	35,74	0,69	27.02.2008	20,4	20,4	x	0,0
10	T10	B3B	1	1	0,111	38,97	100,69	19,42	0,59	25.03.2008	25,0	12,0		12,0
10	T10	B3B	1	2	0,108		97,58	36,06	0,94	26.03.2008	25,0	12,0		0,0
10	T10	B3B	1	3	0,084		99,65	52,60	0,66	27.02.2008	20,4	20,4	x	0,0

Table 6: Data summary, replication 1

Plot-Nr.	Treatment	Label	Replication	Measurement	Initial gravimetric water content	Termite holes per m^2	Mean intensity(mm/h)	i_{60} (mm/h)	R^2 (fitting curve)	Date of infiltration measurement	Precipitation previous 7 days (mm)	max Precipitation (1 day) in previous 7 days (mm)	watered previous day	rain day before (mm)
11	T6	A1M	2	1	0,135		106,92	49,44	0,83	10.02.2008	20,4	20,2		20,2
11	T6	A1M	2	2	0,136	44,62	99,65	17,41	0,92	19.02.2008	1,4	1,2	x	0,0
11	T6	A1M	2	3	0,115		100,69	50,85	0,90	29.02.2008	59,6	59,6		0,0
12	T8	B1M	2	1	0,173		99,65	55,83	0,32	11.02.2008	26,4	20,2		6,0
12	T8	B1M	2	2	0,114	22,05	99,65	29,99	0,84	19.02.2008	1,4	1,2	x	0,0
12	T8	B1M	2	3	0,142		106,92	23,16	0,91	29.02.2008	59,6	59,6		0,0
13	T10	B3B	2	1	0,157		101,73	59,41	0,89	11.02.2008	26,4	20,2		6,0
13	T10	B3B	2	2	0,148	88,72	97,58	32,41	0,66	19.02.2008	1,4	1,2	x	0,0
13	T10	B3B	2	3	0,146		99,65	28,71	0,89	29.02.2008	59,6	59,6		0,0
14	T9	B2S	2	1	0,131		101,73	60,46	0,83	11.02.2008	26,4	20,2		6,0
14	T9	B2S	2	2	0,137	31,79	95,50	63,04	0,59	19.02.2008	1,4	1,2	x	0,0
14	T9	B2S	2	3	0,145		95,50	31,94	0,53	29.02.2008	59,6	59,6		0,0
15	T2	DS	2	1	0,136		101,73	47,40	0,83	11.02.2008	26,4	20,2		6,0
15	T2	DS	2	2	0,082	53,33	103,81	43,08	0,94	19.02.2008	1,4	1,2	x	0,0
15	T2	DS	2	3	0,109		104,84	22,36	0,71	26.03.2008	25,0	12,0		0,0
16	T7	A2S	2	1	0,104		103,81	56,00	0,85	11.02.2008	26,4	20,2		6,0
16	T7	A2S	2	2	0,070	57,95	100,69	50,98	0,73	19.02.2008	1,4	1,2	x	0,0
16	T7	A2S	2	3	0,153		105,88	12,64	0,66	28.02.2008	59,6	59,6		59,6
17	T1	CP	2	1	0,129		102,77	68,58	0,78	11.02.2008	26,4	20,2		6,0
17	T1	CP	2	2	0,077	9,23	97,58	44,25	0,91	19.02.2008	1,4	1,2	x	0,0
17	T1	CP	2	3	0,168		103,81	49,20	0,89	28.02.2008	59,6	59,6		59,6
18	T4	JP	2	1	0,119		104,84	19,21	0,85	13.02.2008	26,6	20,2		0,2
18	T4	JP	2	2	0,105	92,31	105,88	19,15	0,85	26.03.2008	25,0	12,0		0,0
18	T4	JP	2	3	0,167		101,73	27,00	0,70	26.03.2008	25,0	12,0		0,0
19	T5	MS	2	1	0,089		104,84	22,39	0,86	13.02.2008	26,6	20,2		0,2
19	T5	MS	2	2	0,118	56,92	99,65	27,34	0,80	21.02.2008	24,0	20,4		20,4
19	T5	MS	2	3	0,178		104,84	22,92	0,85	28.02.2008	59,6	59,6		59,6
20	T3	BA	2	1	0,088		99,65	46,26	0,94	13.02.2008	26,6	20,2		0,2
20	T3	BA	2	2	0,136	80,51	100,69	18,78	0,91	21.02.2008	24,0	20,4		20,4
20	T3	BA	2	3	0,181		105,88	24,23	0,75	28.02.2008	59,6	59,6		59,6

Table 7: Data summary, replication 2

Plot-Nr.	Treatment	Label	Replication	Measurement	Initial gravimetric water content	Termite holes per m²	Mean intensity(mm/h)	i_{60} (mm/h)	R^2 (fitting curve)	Date of infiltration measurement	Precipitation previous 7 days (mm)	max Precipitation (1 day) in previous 7 days (mm)	watered previous day	rain day before (mm)
21	T7	A2S	3	1	0,082		99,65	39,15	0,95	26.03.2008	25,0	12,0		0,0
21	T7	A2S	3	2	0,109	37,95	106,92	35,17	0,78	21.02.2008	24,0	20,4		20,4
21	T7	A2S	3	3	0,140		93,42	39,79	0,78	29.02.2008	59,6	59,6		0,0
22	T9	B2S	3	1	0,084		104,84	30,41	0,76	27.03.2008	25,0	12,0		0,0
22	T9	B2S	3	2	0,117	22,05	98,61	49,16	0,83	21.02.2008	24,0	20,4		20,4
22	T9	B2S	3	3	0,140		102,77	40,38	0,87	29.02.2008	59,6	59,6		0,0
23	T4	JP	3	1	0,078		100,69	24,04	0,78	27.03.2008	25,0	12,0		0,0
23	T4	JP	3	2	0,119	29,23	107,96	44,05	0,81	21.02.2008	24,0	20,4		20,4
23	T4	JP	3	3	0,174		105,88	19,87	0,72	01.03.2008	66,6	59,6		7,0
24	T1	CP	3	1			103,81	54,46	0,76	15.02.2008	26,6	20,2		0,0
24	T1	CP	3	2	0,108	3,59	107,96	69,10	0,89	21.02.2008	24,0	20,4		20,4
24	T1	CP	3	3	0,186		100,69	38,41	0,96	01.03.2008	66,6	59,6		7,0
25	T3	BA	3	1	0,071		97,58	10,71	0,84	15.02.2008	26,6	20,2		0,0
25	T3	BA	3	2	0,091	68,21	106,92	31,33	0,96	23.02.2008	24,0	20,4		0,0
25	T3	BA	3	3	0,168		103,81	17,88	0,74	01.03.2008	66,6	59,6		7,0
26	T5	MS	3	1	0,105		99,65	30,59	0,74	27.03.2008	25,0	12,0		0,0
26	T5	MS	3	2	0,097	50,77	101,73	32,57	0,83	23.02.2008	24,0	20,4		0,0
26	T5	MS	3	3	0,165		103,81	25,09	0,48	01.03.2008	66,6	59,6		7,0
27	T8	B1M	3	1	0,061		99,65	42,36	0,88	15.02.2008	26,6	20,2		0,0
27	T8	B1M	3	2	0,075	36,92	100,69	25,90	0,43	23.02.2008	24,0	20,4		0,0
27	T8	B1M	3	3	0,155		97,58	33,07	0,77	01.03.2008	66,6	59,6		7,0
28	T10	B3B	3	1	0,089		99,65	68,52	0,69	15.02.2008	26,6	20,2		0,0
28	T10	B3B	3	2	0,083	39,49	105,88	23,94	0,82	23.02.2008	24,0	20,4		0,0
28	T10	B3B	3	3	0,150		103,81	31,21	0,92	01.03.2008	66,6	59,6		7,0
29	T6	A1M	3	1	0,047		101,73	57,61	0,77	15.02.2008	26,6	20,2		0,0
29	T6	A1M	3	2	0,084	45,13	99,65	39,11	0,77	27.03.2008	25,0	12,0		0,0
29	T6	A1M	3	3	0,163		103,81	14,49	0,19	03.03.2008	70,2	59,6		3,4
30	T2	DS	3	1	0,047		95,50	37,48	0,66	15.02.2008	26,6	20,2		0,0
30	T2	DS	3	2	0,067	42,56	95,50	62,00	0,75	23.02.2008	24,0	20,4		0,0
30	T2	DS	3	3	0,161		99,65	19,53	0,92	28.03.2008	25,0	12,0		0,0

Table 8: Data summary, replication 3

Plot-Nr.	Treatment	Label	Replication	Measurement	Initial gravimetric water content	Termite holes per m²	Mean intensity(mm/h)	i_{60} (mm/h)	R^2 (fitting curve)	Date of infiltration measurement	Precipitation previous 7 days (mm)	max Precipitation (1 day) in previous 7 days (mm)	watered previous day	rain day before (mm)
31	T3	BA	4	1	0,190	54,87	103,81	20,62	0,87	16.02.2008	26,4	20,2	x	0,0
31	T3	BA	4	2	0,148		105,88	20,43	0,98	25.02.2008	22,8	20,4	x	0,0
31	T3	BA	4	3	0,149		99,65	22,16	0,93	04.03.2008	70,2	59,6		0,0
32	T5	MS	4	1	0,165	64,10	100,69	41,82	0,36	16.02.2008	26,4	20,2	x	0,0
32	T5	MS	4	2	0,140		103,81	20,81	0,90	25.02.2008	22,8	20,4	x	0,0
32	T5	MS	4	3	0,166		103,81	22,10	0,29	04.03.2008	70,2	59,6		0,0
33	T10	B3B	4	1	0,095	73,33	104,84	32,96	0,95	28.03.2008	25,0	12,0		0,0
33	T10	B3B	4	2	0,056		107,96	46,11	0,93	24.03.2008	20,8	9,4		9,4
33	T10	B3B	4	3			103,81	36,53	0,63	04.03.2008	70,2	59,6		0,0
34	T6	A1M	4	1	0,097	37,95	99,65	31,02	0,67	16.02.2008	26,4	20,2	x	0,0
34	T6	A1M	4	2	0,053		98,61	78,15	0,76	24.02.2008	24,0	20,4		0,0
34	T6	A1M	4	3	0,151		101,73	23,72	0,77	04.03.2008	70,2	59,6		0,0
35	T8	B1M	4	1	0,070	38,46	101,73	47,55	0,78	16.02.2008	26,4	20,2	x	0,0
35	T8	B1M	4	2	0,066		97,58	31,52	0,86	24.02.2008	24,0	20,4		0,0
35	T8	B1M	4	3	0,161		99,65	17,52	0,61	04.03.2008	70,2	59,6		0,0
36	T9	B2S	4	1	0,038	24,10	95,50	38,85	0,95	16.02.2008	26,4	20,2		0,0
36	T9	B2S	4	2	0,052		97,58	36,32	0,92	24.02.2008	24,0	20,4		0,0
36	T9	B2S	4	3	0,112		97,58	50,13	0,99	04.03.2008	70,2	59,6		0,0
37	T2	DS	4	1	0,057	61,03	96,54	52,65	0,61	16.02.2008	26,4	20,2		0,0
37	T2	DS	4	2	0,066		102,77	34,57	0,97	24.02.2008	24,0	20,4		0,0
37	T2	DS	4	3	0,134		95,50	25,62	0,87	03.03.2008	70,2	59,6		3,4
38	T1	CP	4	1	0,089	14,87	102,77	30,91	0,56	17.02.2008	6,2	6,0		0,0
38	T1	CP	4	2	0,060		94,46	29,93	0,96	24.02.2008	24,0	20,4		0,0
38	T1	CP	4	3	0,131		102,77	38,14	0,67	03.03.2008	70,2	59,6		3,4
39	T7	A2S	4	1	0,137	42,05	101,73	33,54	0,53	17.02.2008	6,2	6,0	x	0,0
39	T7	A2S	4	2	0,066		102,77	42,33	0,82	24.02.2008	24,0	20,4		0,0
39	T7	A2S	4	3	0,122		102,77	40,93	0,61	03.03.2008	70,2	59,6		3,4
40	T4	JP	4	1		47,69	103,81	45,00	0,88	17.02.2008	6,2	6,0		0,0
40	T4	JP	4	2	0,052		101,73	66,18	0,61	23.02.2008	24,0	20,4		0,0
40	T4	JP	4	3	0,141		104,84	14,71	0,16	03.03.2008	70,2	59,6		3,4

Table 9: Data summary, replication 4

ANNEX 4: Pictures of the surface termite holes

Figure 51: Treatment 1 (CP), replication 1

Figure 52: Treatment 2 (DS), replication 1

Figure 53: Treatment 3 (BA), replication1

Figure 54: Treatment 4 (JP), replication 1

Figure 55: Treatment 5 (MS), replication 1

Figure 56: Treatment 6 (A1M), replication 1

Figure 57: Treatment 7 (A2S), replication 1

Figure 58: Treatment 8 (B1M), replication 1

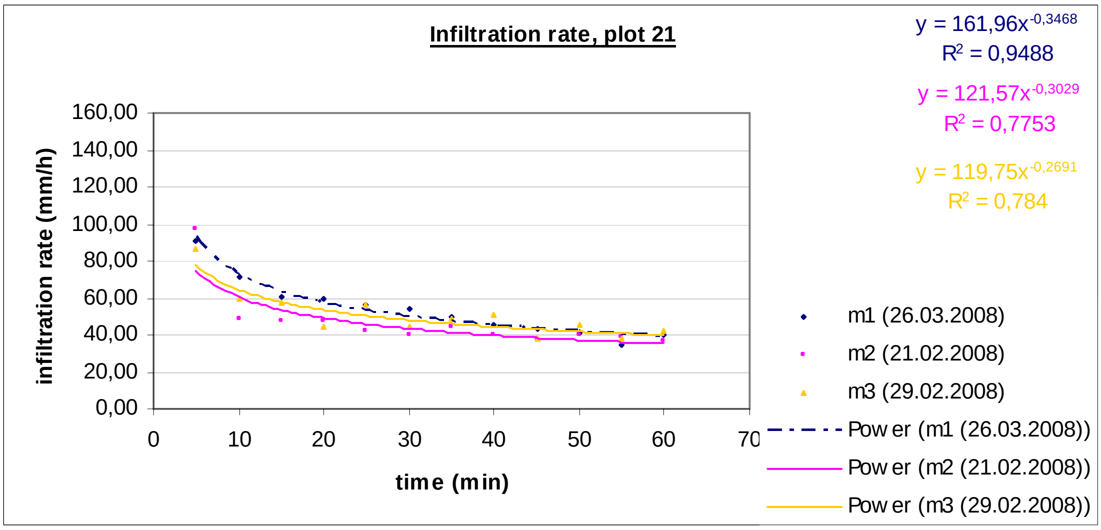
Figure 59: Treatment 9 (B2S), replication 1

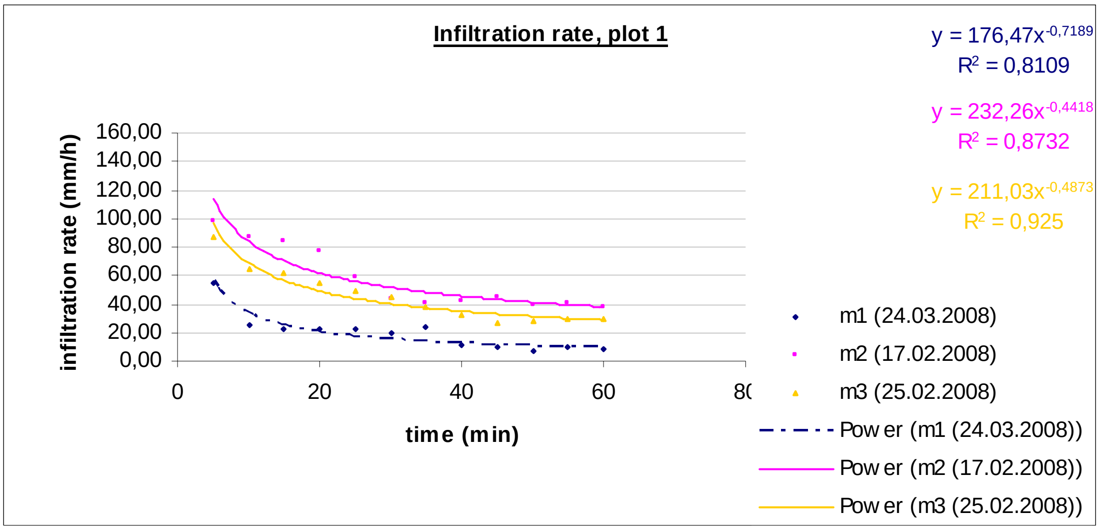
Figure 60: Treatment 10 (B3B), replication 1

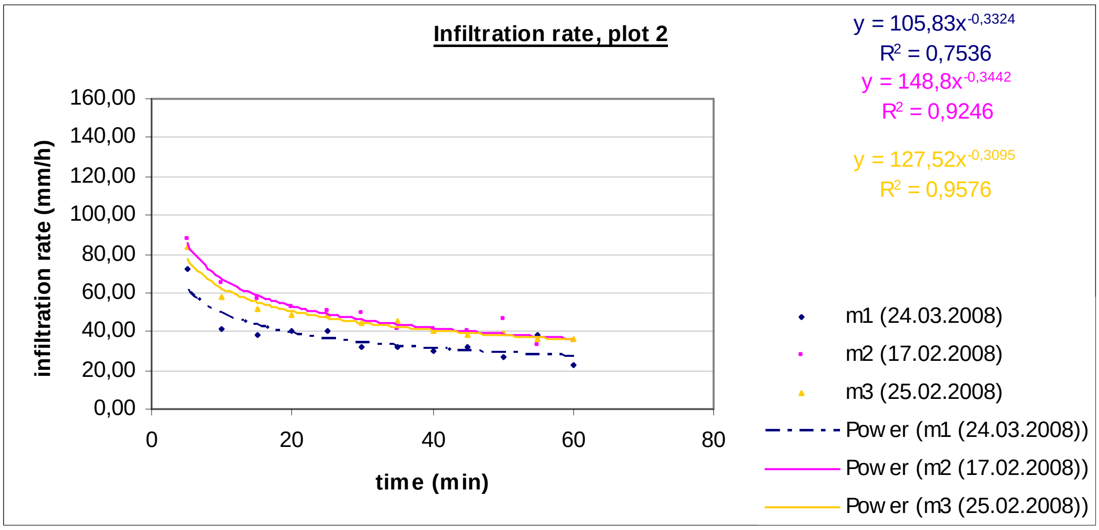
ANNEX 6: Infiltration rate

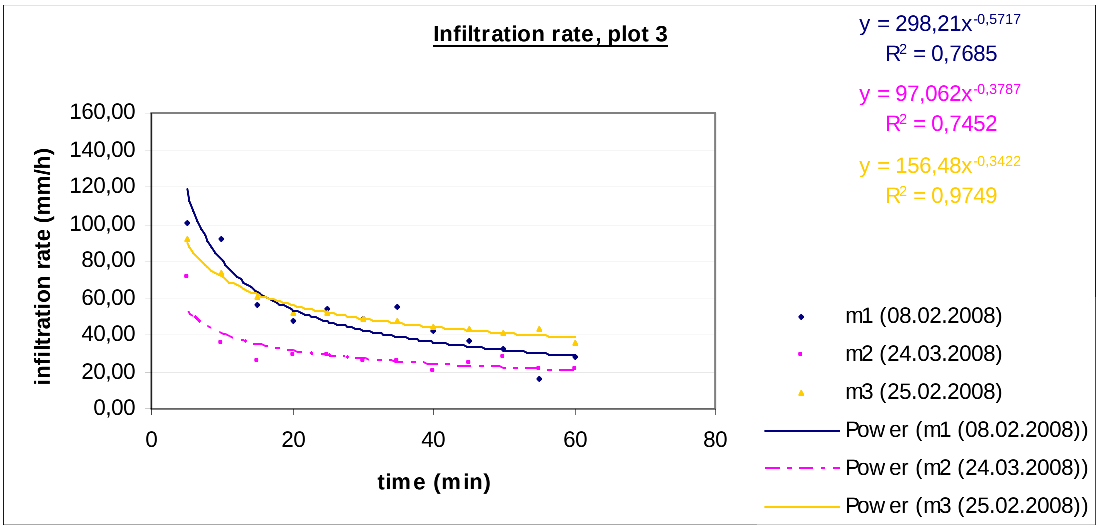
In each graph the infiltration rate from all three measurements (m1=measurement 1, m2= measurement 2, m3=measurement 3) in mm/h calculated from the surface runoff which was measured every five minutes, the fitted Kostiakov curves and corresponding equation from the three measurements and the R^2 and the date of the measurement are shown.

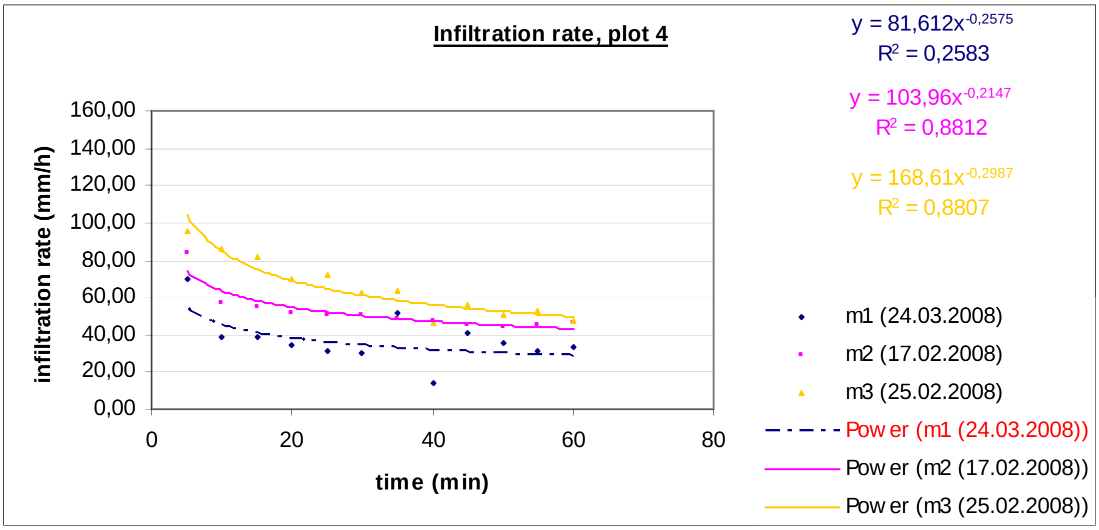
A dot dashed curve illustrates a measurement which was repeated in late March 2008 whereas the other measurements were made from February to beginning of March. Some of them had to be repeated because of mistakes during the process of measurement. Curves with a lower R^2 than 0.6 (statistical criteria) and curves which gave a completely different picture to all the other curves from the same treatment were not used for further interpretation. These curves are marked with a red colour in the legend of the graphs.

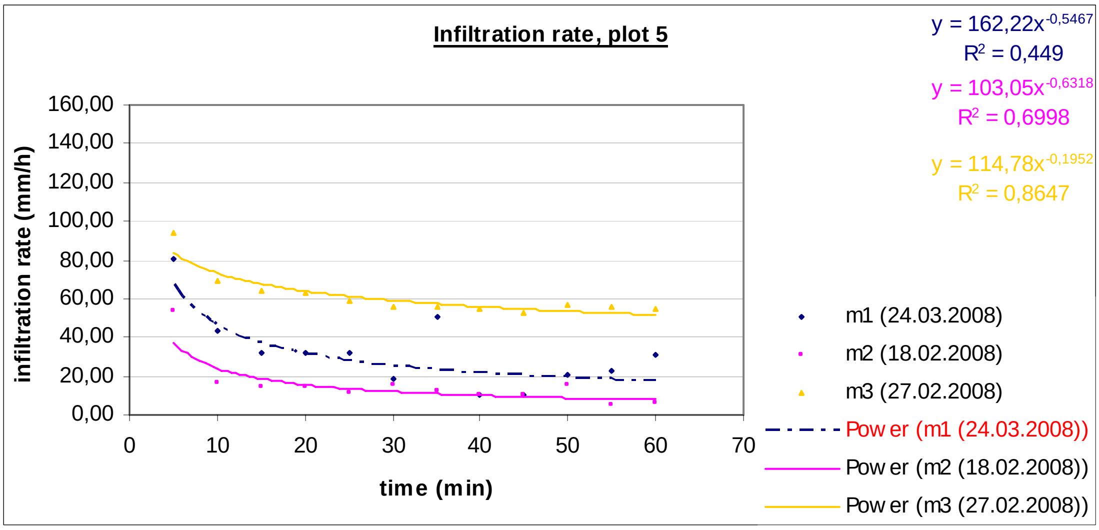


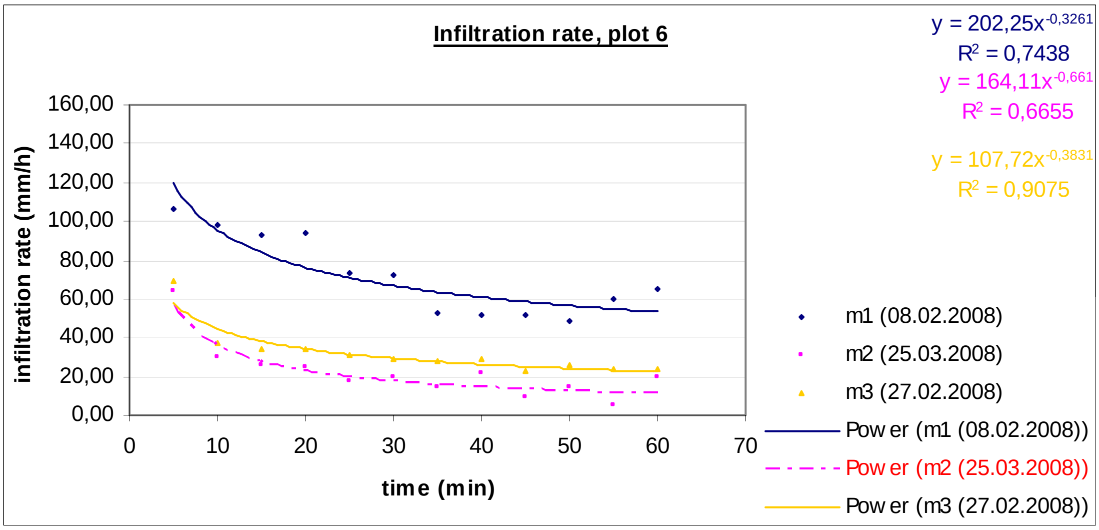

Infiltration rate, plot 1
y = 176,47x-0,7189
R2 = 0,8109
y = 232,26x-0,4418
R2 = 0,8732
y = 211,03x-0,4873
R2 = 0,925
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
20
40
60
80
time (min)
m1 (24.03.2008)
m2 (17.02.2008)
m3 (25.02.2008)
Power (m1 (24.03.2008))
Power (m2 (17.02.2008))
Power (m3 (25.02.2008))

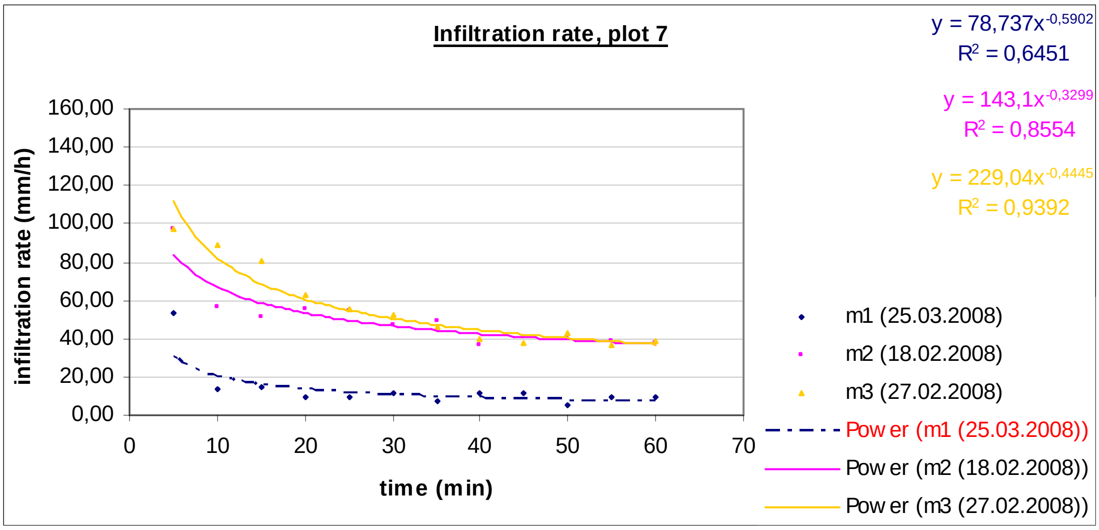

Infiltration rate, plot 2
y = 105,83x-0,3324
R2 = 0,7536
y = 148,8x-0,3442
R2 = 0,9246
y = 127,52x-0,3095
R2 = 0,9576
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
20
40
60
80
time (min)
m1 (24.03.2008)
m2 (17.02.2008)
m3 (25.02.2008)
Power (m1 (24.03.2008))
Power (m2 (17.02.2008))
Power (m3 (25.02.2008))

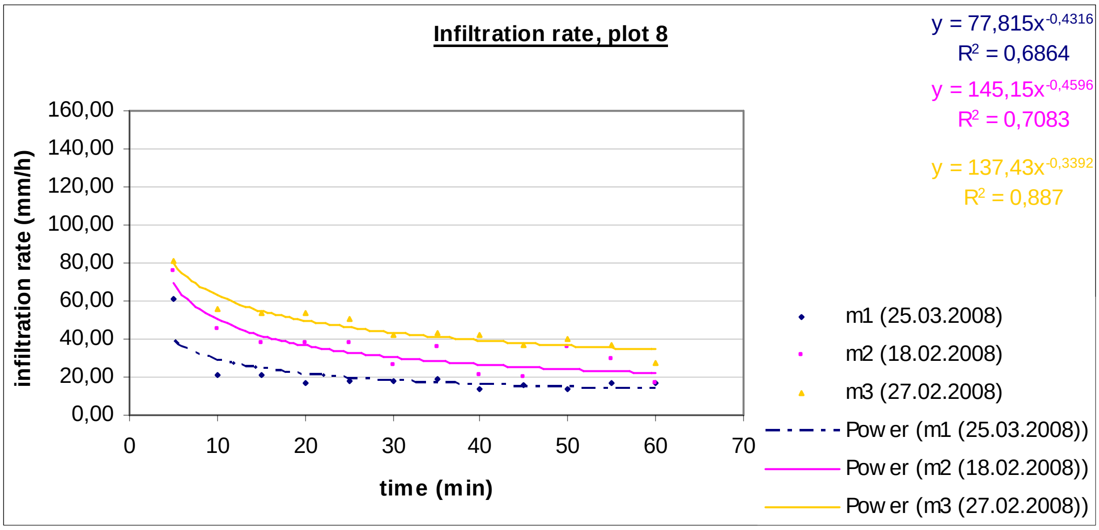

Infiltration rate, plot 3
y = 298,21x-0,5717
R2 = 0,7685
y = 97,062x-0,3787
R2 = 0,7452
y = 156,48x-0,3422
R2 = 0,9749
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
20
40
60
80
time (min)
m1 (08.02.2008)
m2 (24.03.2008)
m3 (25.02.2008)
Power (m1 (08.02.2008))
Power (m2 (24.03.2008))
Power (m3 (25.02.2008))

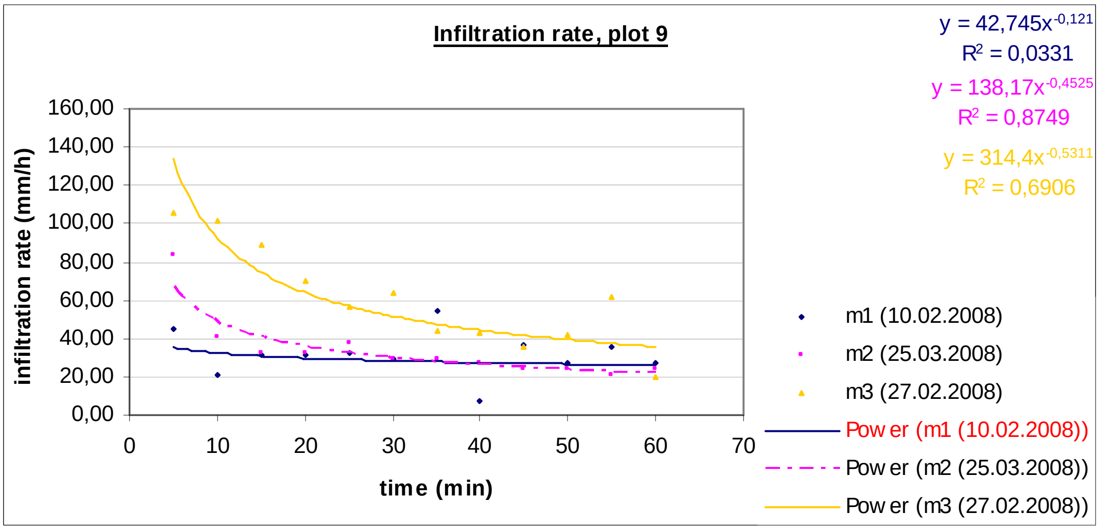

Infiltration rate, plot 4
y = 81,612x-0,2575
R2 = 0,2583
y = 103,96x-0,2147
R2 = 0,8812
y = 168,61x-0,2987
R2 = 0,8807
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
20
40
60
80
time (min)
m1 (24.03.2008)
m2 (17.02.2008)
m3 (25.02.2008)
Pow er (m1 (24.03.2008))
Pow er (m2 (17.02.2008))
Pow er (m3 (25.02.2008))


Infiltration rate, plot 5
y = 162,22x-0,5467
R2 = 0,449
y = 103,05x-0,6318
R2 = 0,6998
y = 114,78x-0,1952
R2 = 0,8647
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (24.03.2008)
m2 (18.02.2008)
m3 (27.02.2008)
Pow er (m1 (24.03.2008))
Pow er (m2 (18.02.2008))
Pow er (m3 (27.02.2008))


Infiltration rate, plot 6
y = 202,25x-0,3261
R2 = 0,7438
y = 164,11x-0,661
R2 = 0,6655
y = 107,72x-0,3831
R2 = 0,9075
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (08.02.2008)
m2 (25.03.2008)
m3 (27.02.2008)
Pow er (m1 (08.02.2008))
Pow er (m2 (25.03.2008))
Pow er (m3 (27.02.2008))


Infiltration rate, plot 7
y = 78,737x-0,5902
R2 = 0,6451
y = 143,1x-0,3299
R2 = 0,8554
y = 229,04x-0,4445
R2 = 0,9392
infiltration rate (mm/h)
time (min)
m1 (25.03.2008)
m2 (18.02.2008)
m3 (27.02.2008)
Power (m1 (25.03.2008))
Power (m2 (18.02.2008))
Power (m3 (27.02.2008))


Infiltration rate, plot 8
y = 77,815x-0,4316
R2 = 0,6864
y = 145,15x-0,4596
R2 = 0,7083
y = 137,43x-0,3392
R2 = 0,887
infiltration rate (mm/h)
time (min)
m1 (25.03.2008)
m2 (18.02.2008)
m3 (27.02.2008)
Power (m1 (25.03.2008))
Power (m2 (18.02.2008))
Power (m3 (27.02.2008))


Infiltration rate, plot 9
y = 42,745x-0,121
R2 = 0,0331
y = 138,17x-0,4525
R2 = 0,8749
y = 314,4x-0,5311
R2 = 0,6906
infiltration rate (mm/h)
time (min)
m1 (10.02.2008)
m2 (25.03.2008)
m3 (27.02.2008)
Power (m1 (10.02.2008))
Power (m2 (25.03.2008))
Power (m3 (27.02.2008))

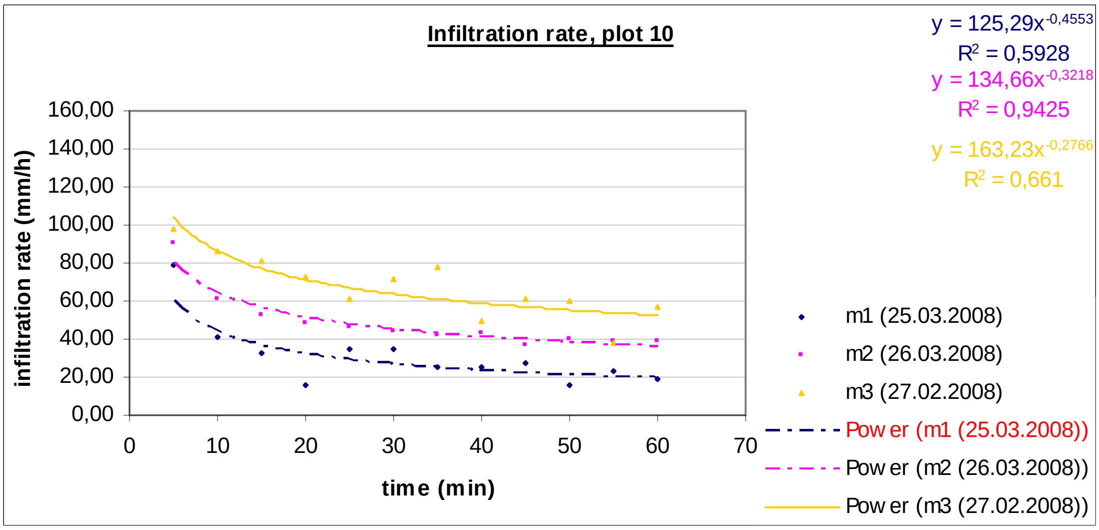
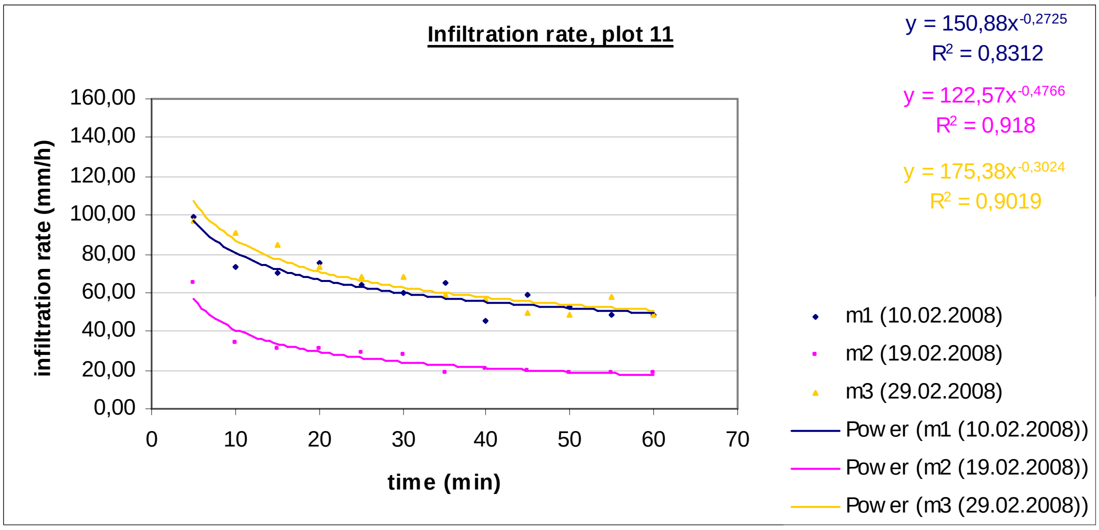
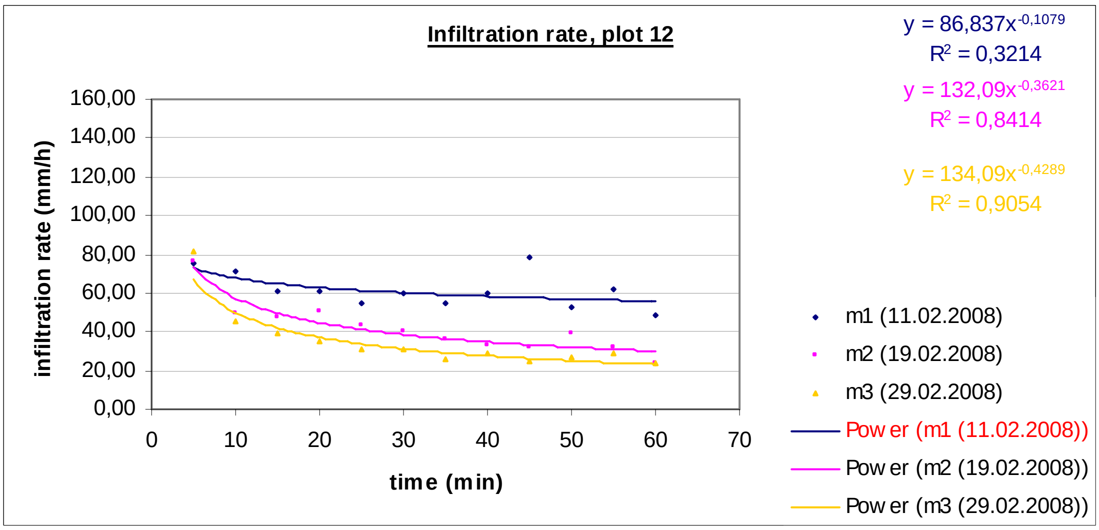
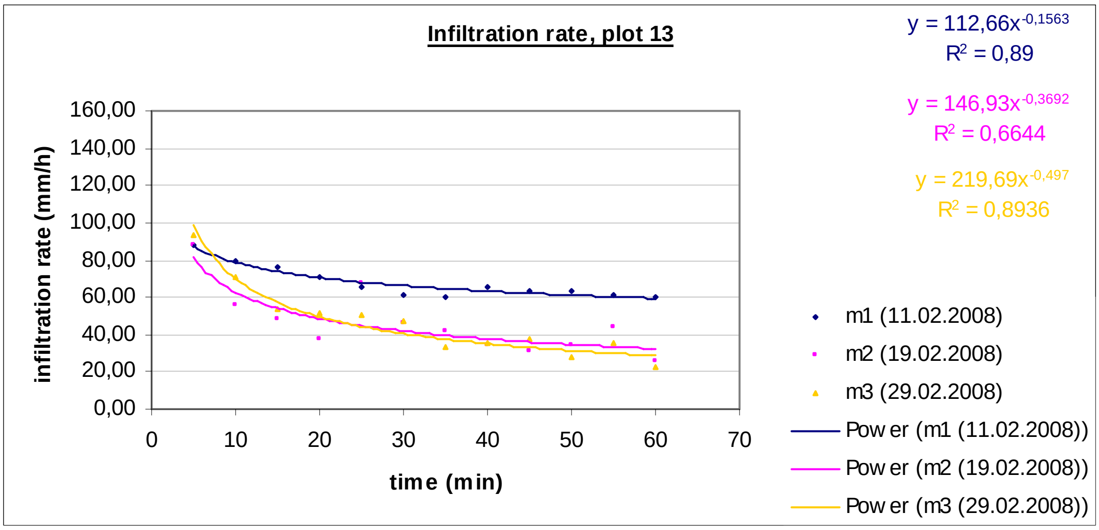
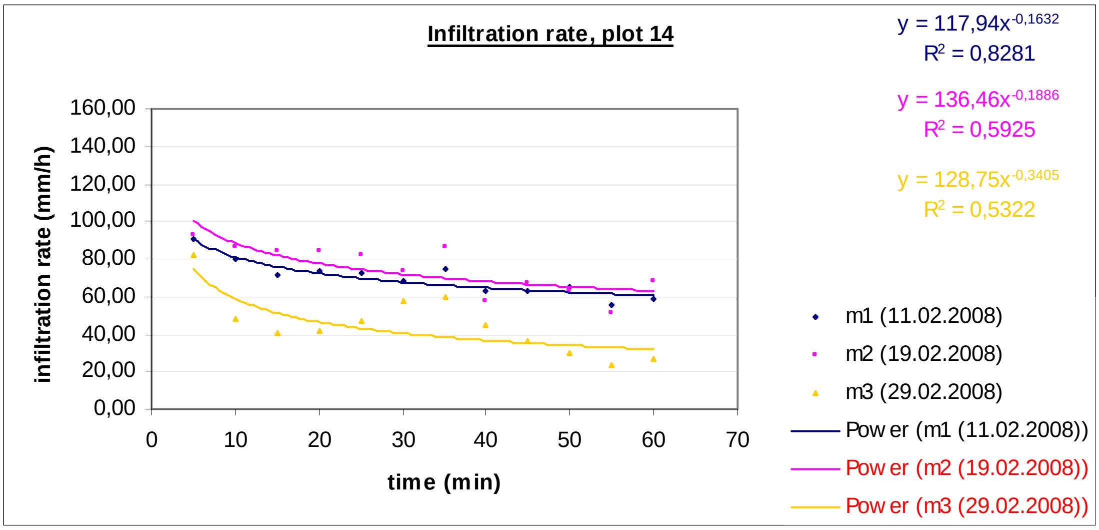


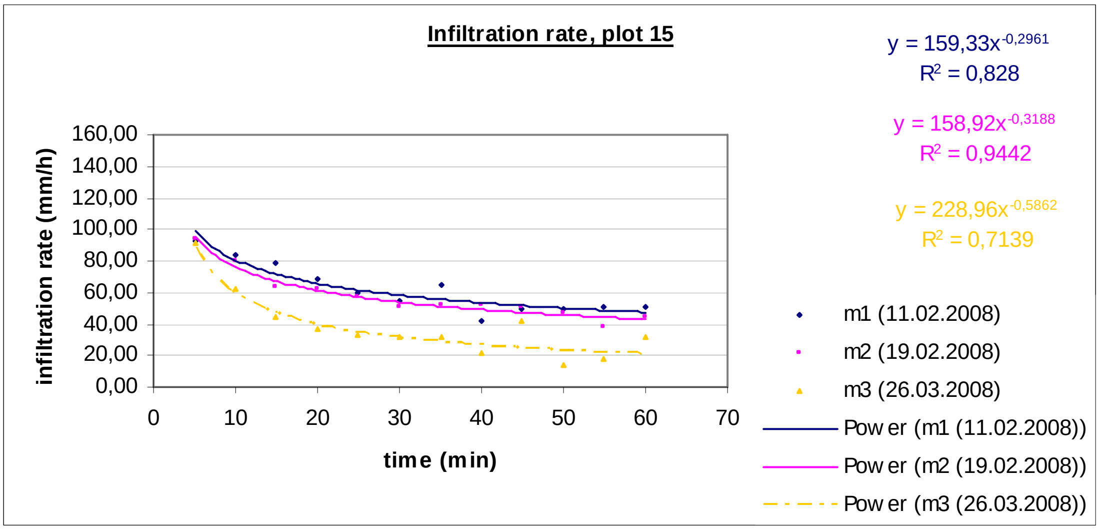
Figure 61: Infiltration rate, replication 1, plot 1 – plot 10

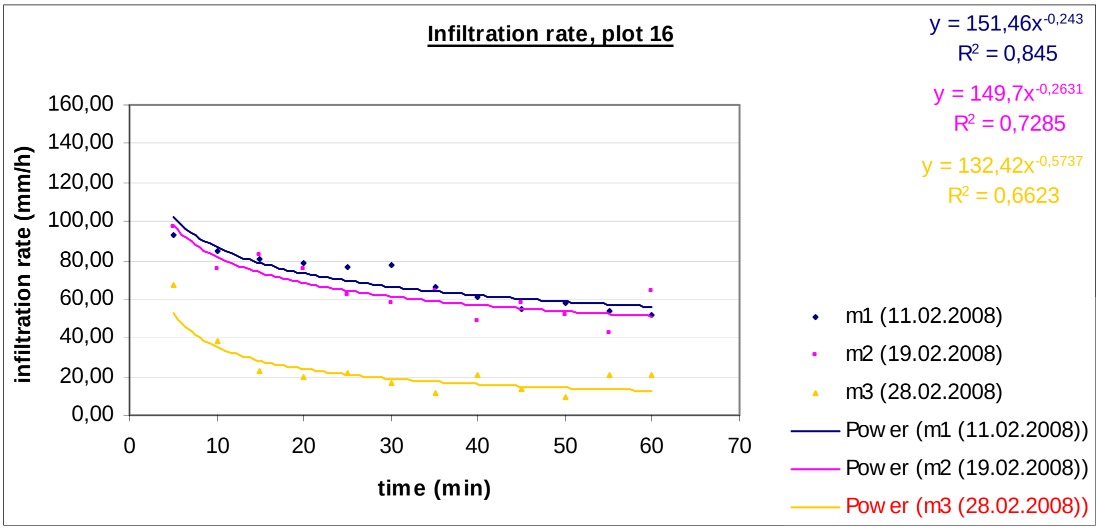


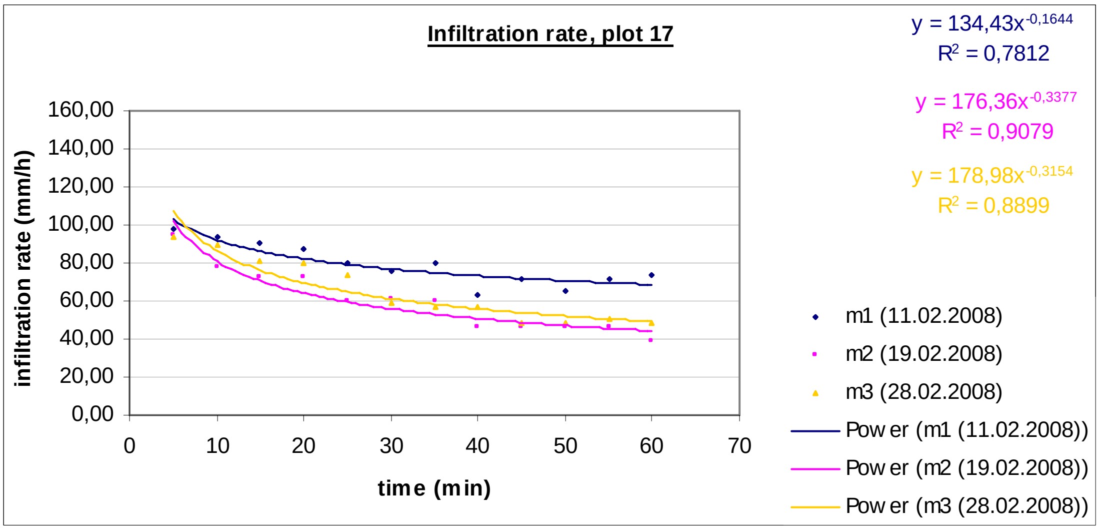


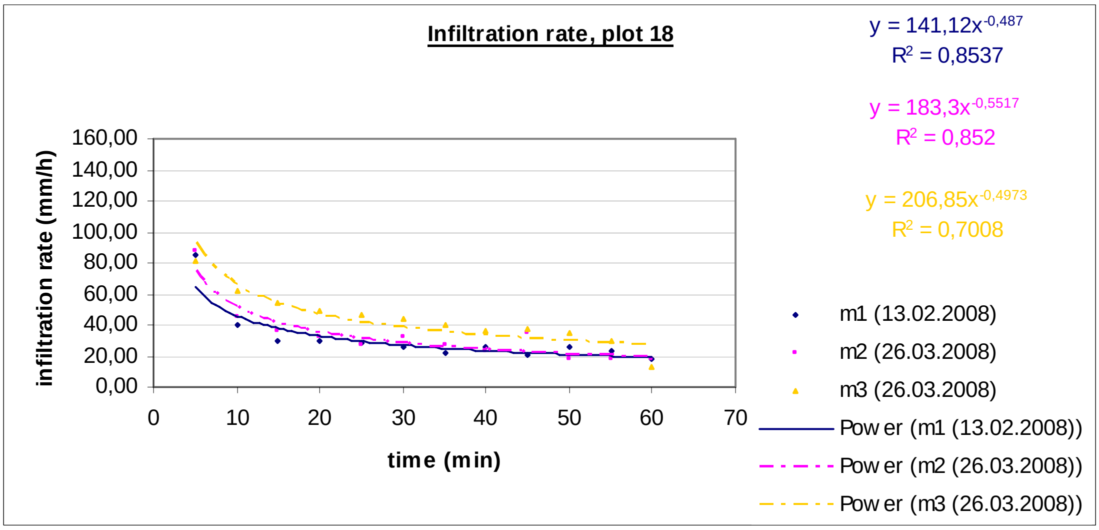

Infiltration rate, plot 13
y = 112,66x-0,1563
R2 = 0,89
y = 146,93x-0,3692
R2 = 0,6644
y = 219,69x-0,497
R2 = 0,8936
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (11.02.2008)
m2 (19.02.2008)
m3 (29.02.2008)
Power (m1 (11.02.2008))
Power (m2 (19.02.2008))
Power (m3 (29.02.2008))

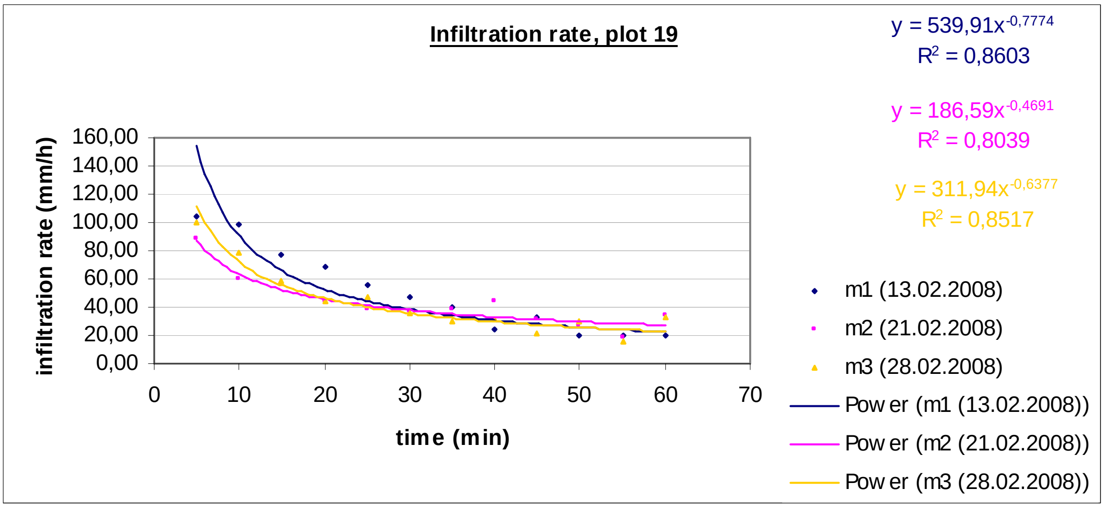

Infiltration rate, plot 14
y = 117,94x-0,1632
R2 = 0,8281
y = 136,46x-0,1886
R2 = 0,5925
y = 128,75x-0,3405
R2 = 0,5322
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (11.02.2008)
m2 (19.02.2008)
m3 (29.02.2008)
Power (m1 (11.02.2008))
Power (m2 (19.02.2008))
Power (m3 (29.02.2008))


Infiltration rate, plot 15
y = 159,33x-0,2961
R2 = 0,828
y = 158,92x-0,3188
R2 = 0,9442
y = 228,96x-0,5862
R2 = 0,7139
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (11.02.2008)
m2 (19.02.2008)
m3 (26.03.2008)
Power (m1 (11.02.2008))
Power (m2 (19.02.2008))
Power (m3 (26.03.2008))


Infiltration rate, plot 16
y = 151,46x^-0,243
R² = 0,845
y = 149,7x^-0,2631
R² = 0,7285
y = 132,42x^-0,5737
R² = 0,6623
infiltration rate (mm/h)
time (min)
m1 (11.02.2008)
m2 (19.02.2008)
m3 (28.02.2008)
Power (m1 (11.02.2008))
Power (m2 (19.02.2008))
Power (m3 (28.02.2008))


Infiltration rate, plot 17
y = 134,43x^-0,1644
R² = 0,7812
y = 176,36x^-0,3377
R² = 0,9079
y = 178,98x^-0,3154
R² = 0,8899
infiltration rate (mm/h)
time (min)
m1 (11.02.2008)
m2 (19.02.2008)
m3 (28.02.2008)
Power (m1 (11.02.2008))
Power (m2 (19.02.2008))
Power (m3 (28.02.2008))


Infiltration rate, plot 18
y = 141,12x^-0,487
R² = 0,8537
y = 183,3x^-0,5517
R² = 0,852
y = 206,85x^-0,4973
R² = 0,7008
infiltration rate (mm/h)
time (min)
m1 (13.02.2008)
m2 (26.03.2008)
m3 (26.03.2008)
Power (m1 (13.02.2008))
Power (m2 (26.03.2008))
Power (m3 (26.03.2008))



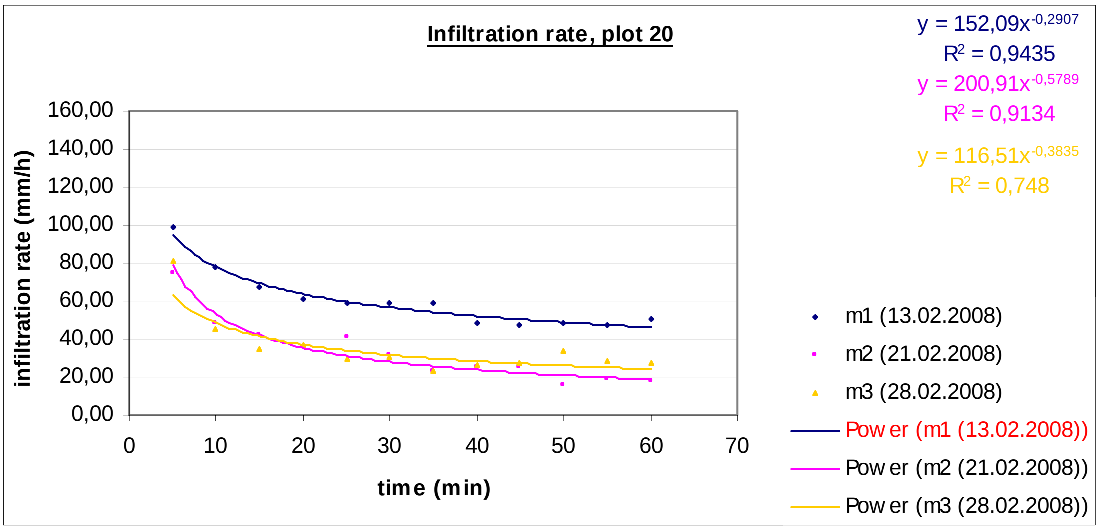
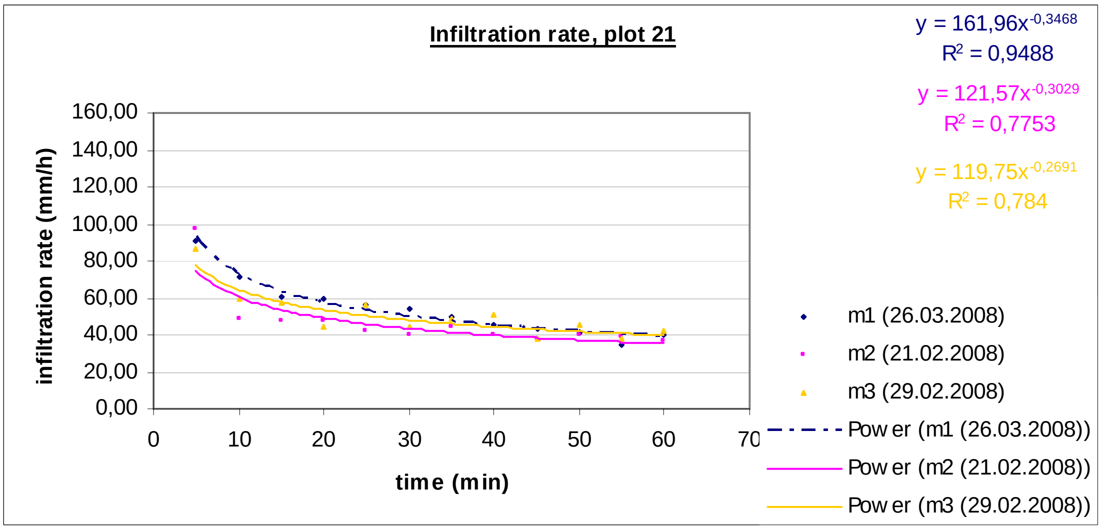
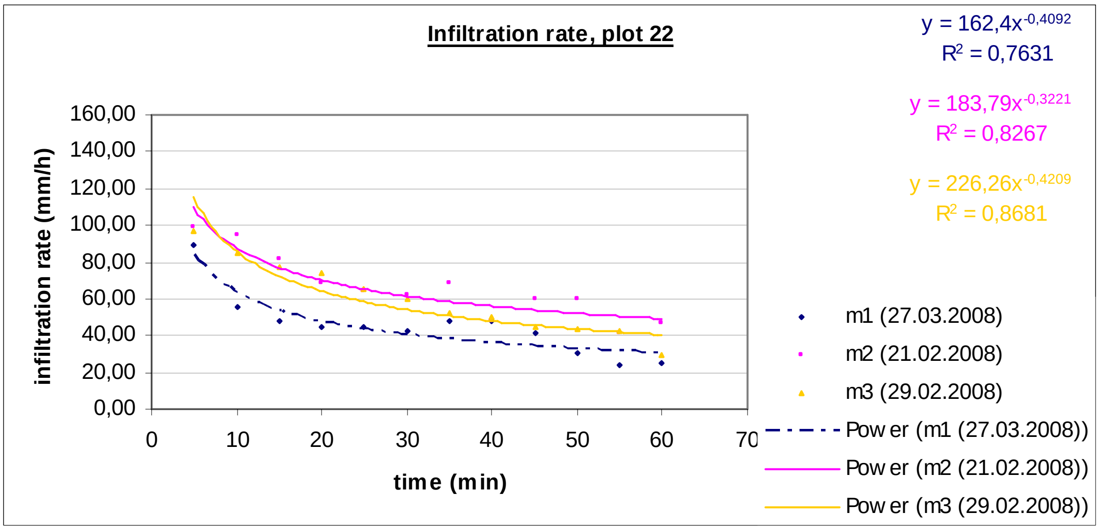
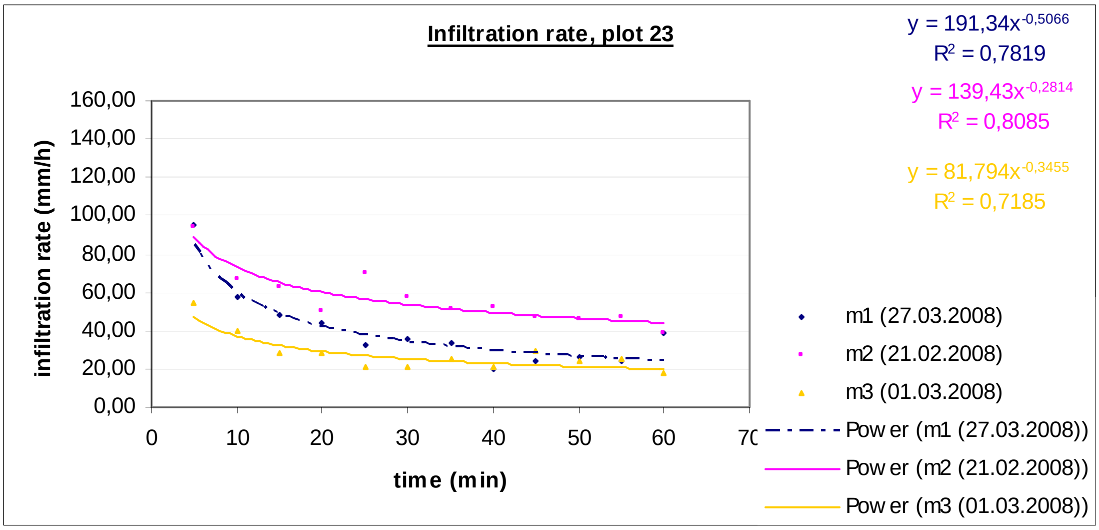
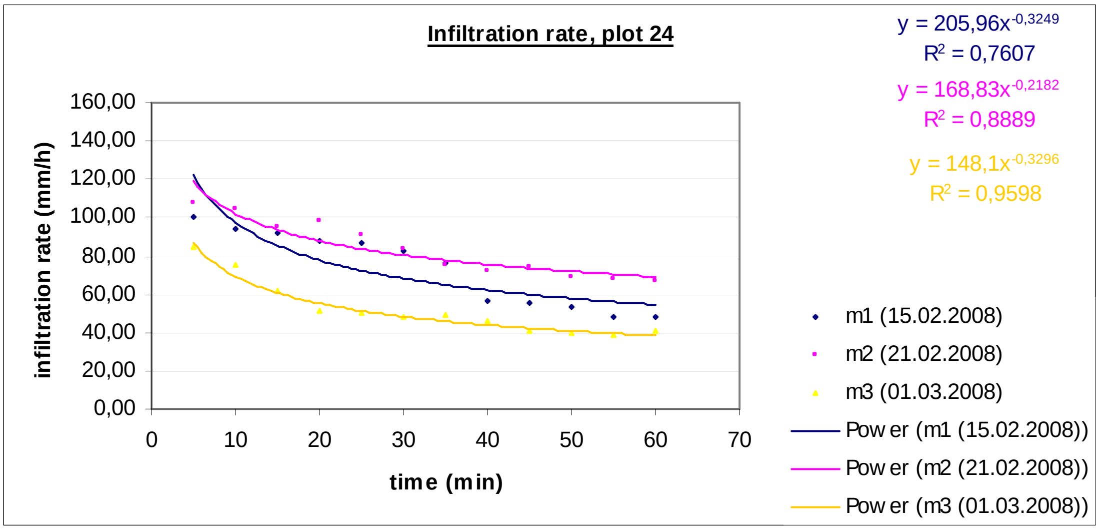


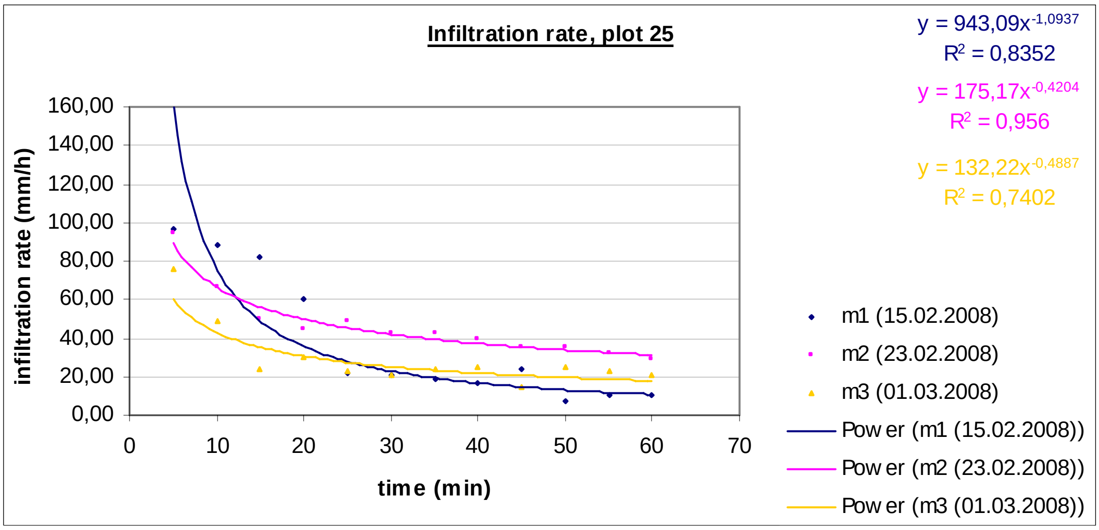
Figure 62: Infiltration rate, replication 2, plot 11 – plot 20

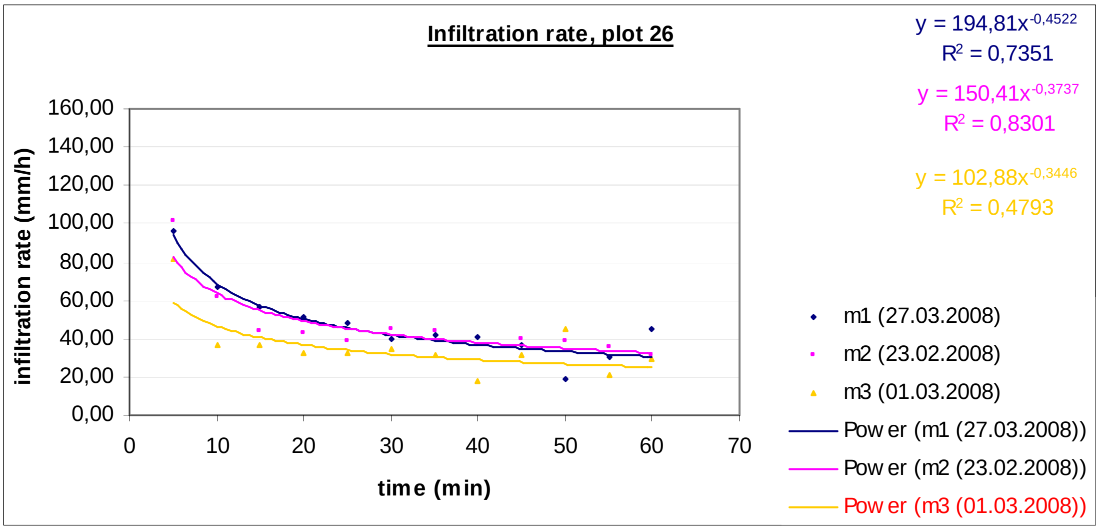


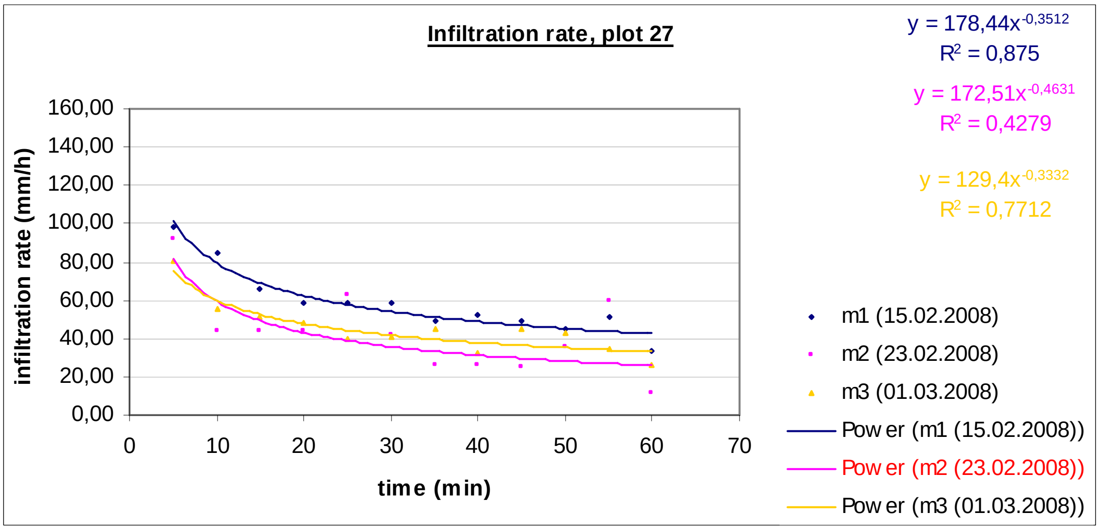

Infiltration rate, plot 22
y = 162,4x^-0,4092
R² = 0,7631
y = 183,79x^-0,3221
R² = 0,8267
y = 226,26x^-0,4209
R² = 0,8681
infiltration rate (mm/h)
time (min)
m1 (27.03.2008)
m2 (21.02.2008)
m3 (29.02.2008)
Power (m1 (27.03.2008))
Power (m2 (21.02.2008))
Power (m3 (29.02.2008))

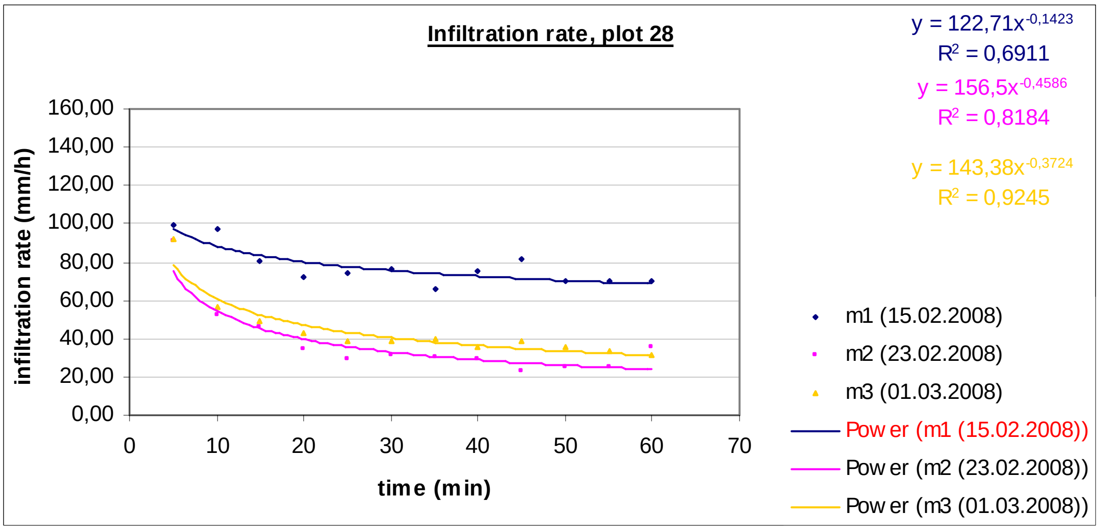

Infiltration rate, plot 23
y = 191,34x^-0,5066
R² = 0,7819
y = 139,43x^-0,2814
R² = 0,8085
y = 81,794x^-0,3455
R² = 0,7185
infiltration rate (mm/h)
time (min)
m1 (27.03.2008)
m2 (21.02.2008)
m3 (01.03.2008)
Power (m1 (27.03.2008))
Power (m2 (21.02.2008))
Power (m3 (01.03.2008))

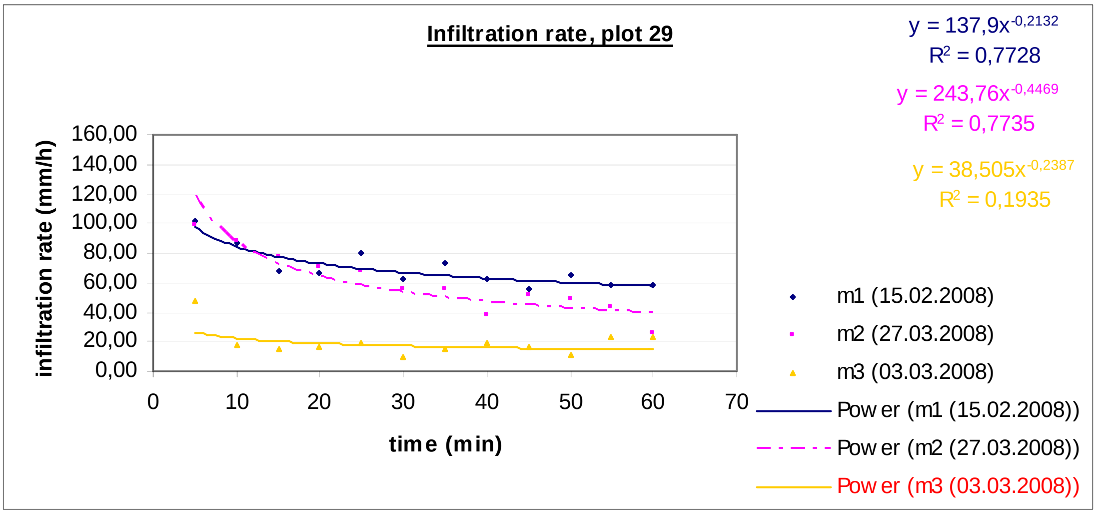

Infiltration rate, plot 24
y = 205,96x^-0,3249
R² = 0,7607
y = 168,83x^-0,2182
R² = 0,8889
y = 148,1x^-0,3296
R² = 0,9598
infiltration rate (mm/h)
time (min)
m1 (15.02.2008)
m2 (21.02.2008)
m3 (01.03.2008)
Power (m1 (15.02.2008))
Power (m2 (21.02.2008))
Power (m3 (01.03.2008))


Infiltration rate, plot 25
y = 943,09x-1,0937
R² = 0,8352
y = 175,17x-0,4204
R² = 0,956
y = 132,22x-0,4887
R² = 0,7402
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (15.02.2008)
m2 (23.02.2008)
m3 (01.03.2008)
Power (m1 (15.02.2008))
Power (m2 (23.02.2008))
Power (m3 (01.03.2008))


Infiltration rate, plot 26
y = 194,81x-0,4522
R² = 0,7351
y = 150,41x-0,3737
R² = 0,8301
y = 102,88x-0,3446
R² = 0,4793
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (27.03.2008)
m2 (23.02.2008)
m3 (01.03.2008)
Power (m1 (27.03.2008))
Power (m2 (23.02.2008))
Power (m3 (01.03.2008))


Infiltration rate, plot 27
y = 178,44x-0,3512
R² = 0,875
y = 172,51x-0,4631
R² = 0,4279
y = 129,4x-0,3332
R² = 0,7712
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (15.02.2008)
m2 (23.02.2008)
m3 (01.03.2008)
Power (m1 (15.02.2008))
Power (m2 (23.02.2008))
Power (m3 (01.03.2008))





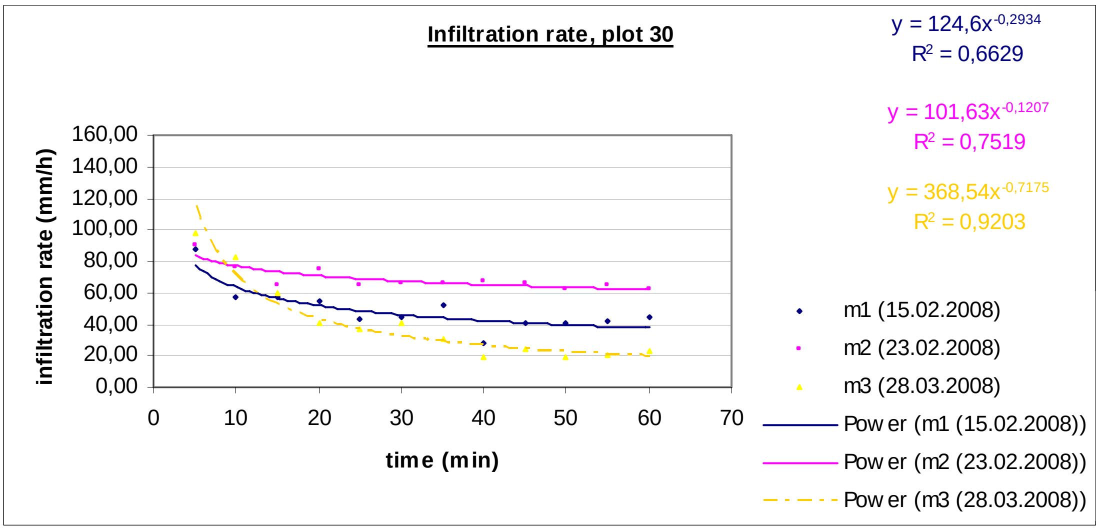
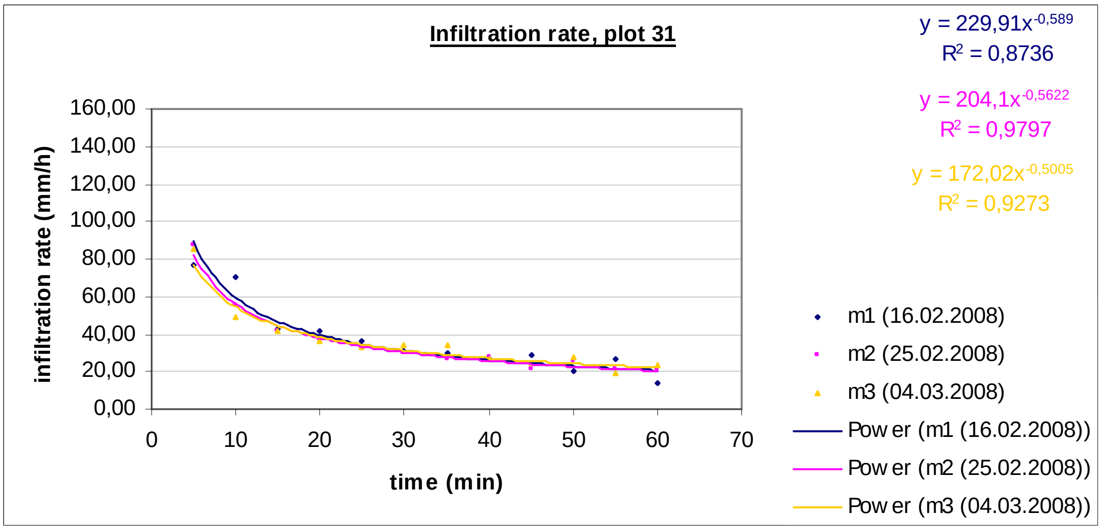
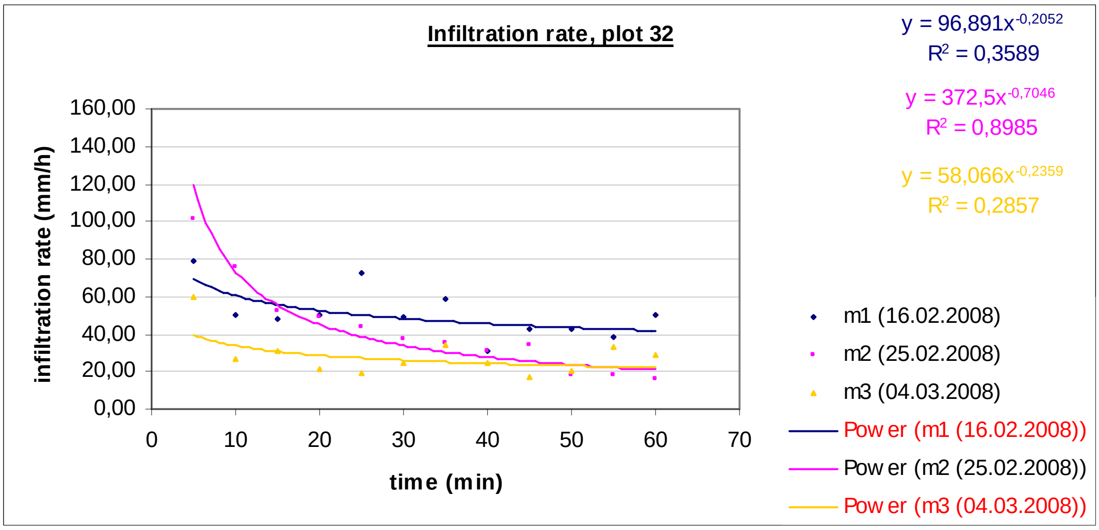
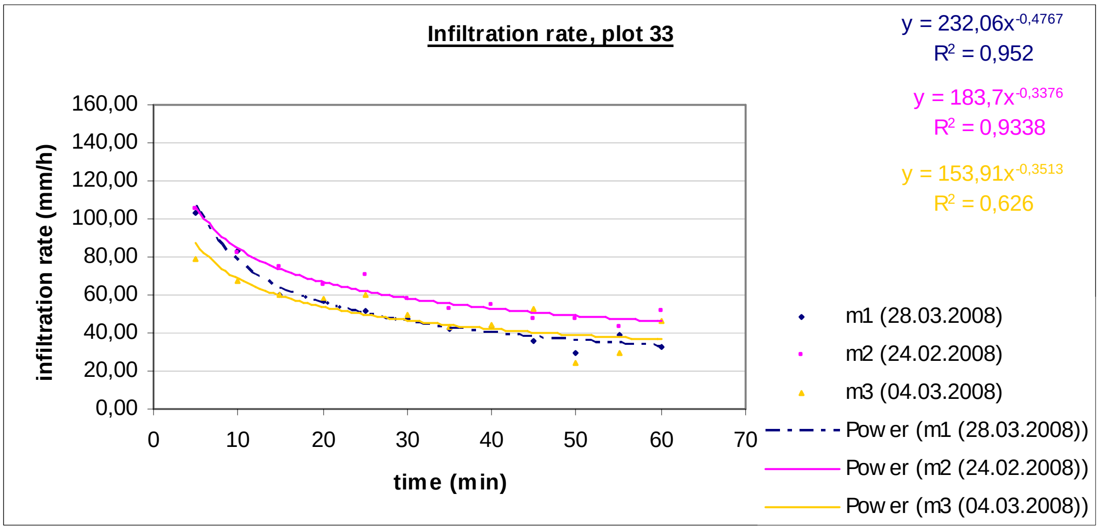
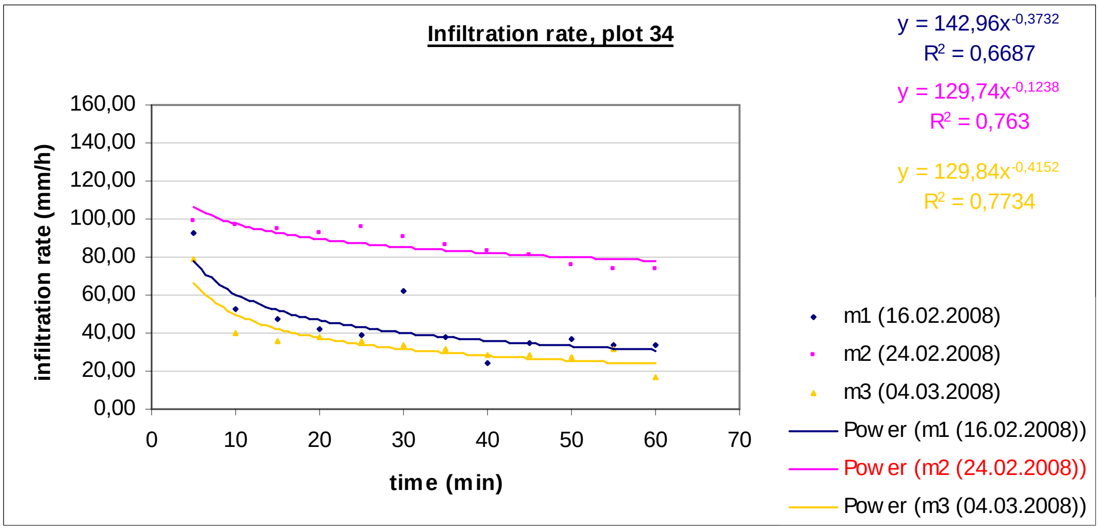


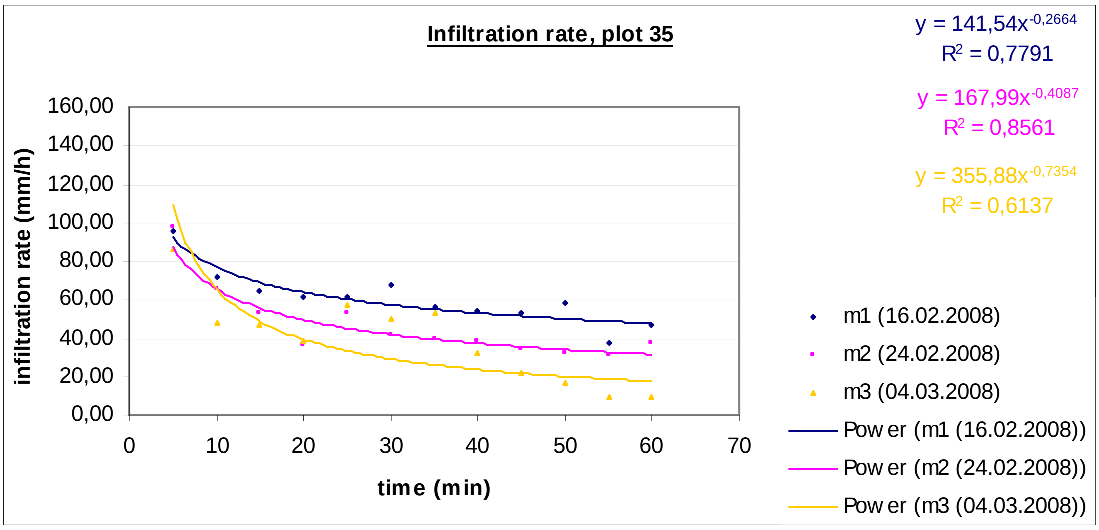
Figure 63: Infiltration rate, replication 3, plot 21 – plot 30

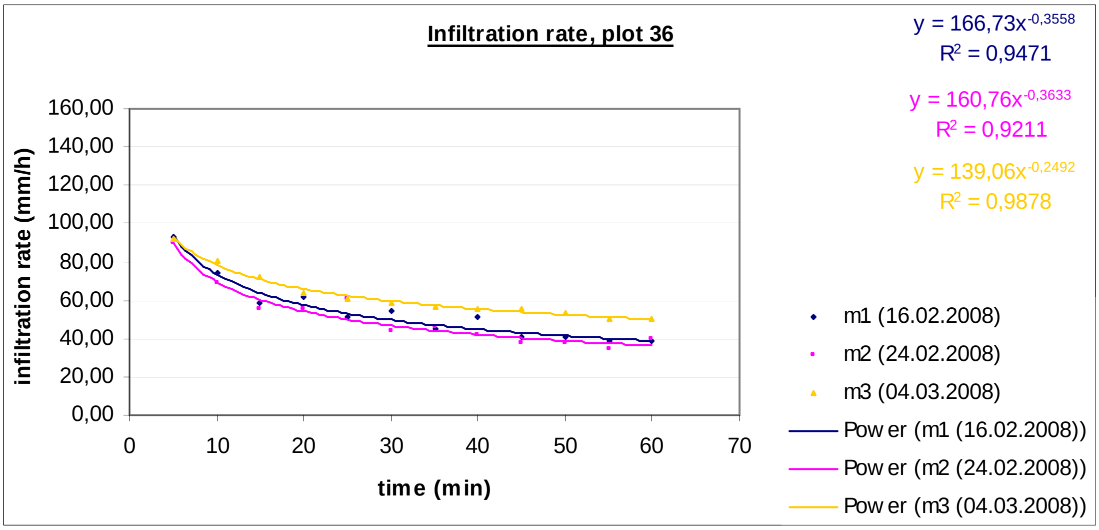

Infiltration rate, plot 31
y = 229,91x-0,589
R2 = 0,8736
y = 204,1x-0,5622
R2 = 0,9797
y = 172,02x-0,5005
R2 = 0,9273
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0 10 20 30 40 50 60 70
time (min)
m1 (16.02.2008)
m2 (25.02.2008)
m3 (04.03.2008)
Power (m1 (16.02.2008))
Power (m2 (25.02.2008))
Power (m3 (04.03.2008))

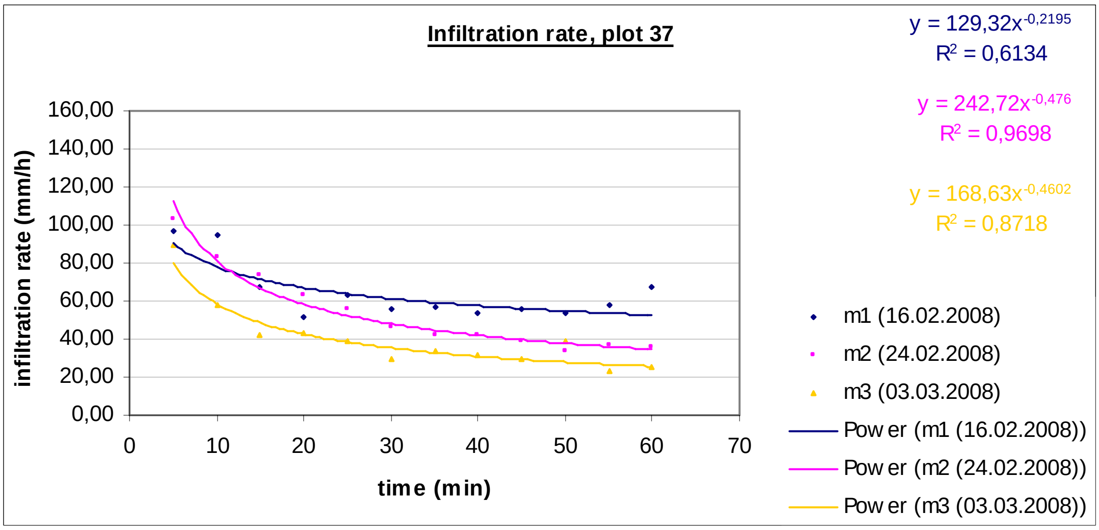

Infiltration rate, plot 32
y = 96,891x-0,2052
R2 = 0,3589
y = 372,5x-0,7046
R2 = 0,8985
y = 58,066x-0,2359
R2 = 0,2857
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0 10 20 30 40 50 60 70
time (min)
m1 (16.02.2008)
m2 (25.02.2008)
m3 (04.03.2008)
Power (m1 (16.02.2008))
Power (m2 (25.02.2008))
Power (m3 (04.03.2008))

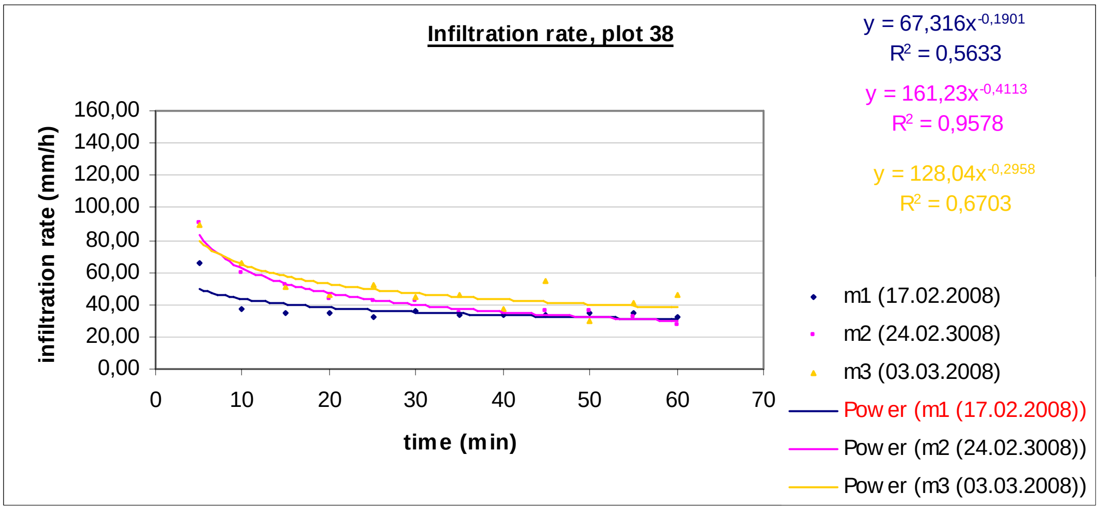

Infiltration rate, plot 33
y = 232,06x-0,4767
R2 = 0,952
y = 183,7x-0,3376
R2 = 0,9338
y = 153,91x-0,3513
R2 = 0,626
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0 10 20 30 40 50 60 70
time (min)
m1 (28.03.2008)
m2 (24.02.2008)
m3 (04.03.2008)
Power (m1 (28.03.2008))
Power (m2 (24.02.2008))
Power (m3 (04.03.2008))

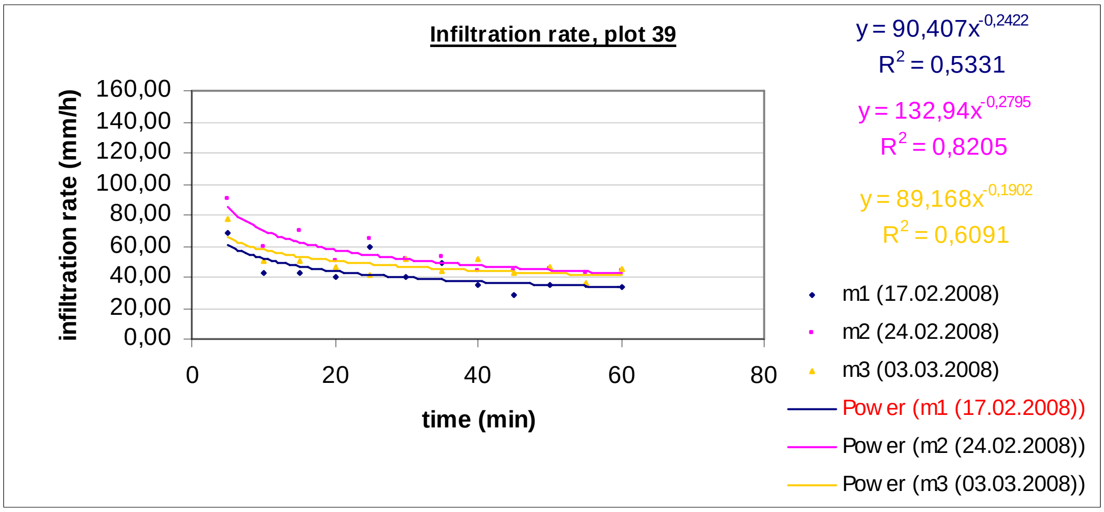

Infiltration rate, plot 34
y = 142,96x-0,3732
R2 = 0,6687
y = 129,74x-0,1238
R2 = 0,763
y = 129,84x-0,4152
R2 = 0,7734
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (16.02.2008)
m2 (24.02.2008)
m3 (04.03.2008)
Power (m1 (16.02.2008))
Power (m2 (24.02.2008))
Power (m3 (04.03.2008))


Infiltration rate, plot 35
y = 141,54x-0,2664
R2 = 0,7791
y = 167,99x-0,4087
R2 = 0,8561
y = 355,88x-0,7354
R2 = 0,6137
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (16.02.2008)
m2 (24.02.2008)
m3 (04.03.2008)
Power (m1 (16.02.2008))
Power (m2 (24.02.2008))
Power (m3 (04.03.2008))


Infiltration rate, plot 36
y = 166,73x-0,3558
R2 = 0,9471
y = 160,76x-0,3633
R2 = 0,9211
y = 139,06x-0,2492
R2 = 0,9878
infiltration rate (mm/h)
160,00
140,00
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0
10
20
30
40
50
60
70
time (min)
m1 (16.02.2008)
m2 (24.02.2008)
m3 (04.03.2008)
Power (m1 (16.02.2008))
Power (m2 (24.02.2008))
Power (m3 (04.03.2008))


Infiltration rate, plot 37
y = 129,32x-0,2195
R2 = 0,6134
y = 242,72x-0,476
R2 = 0,9698
y = 168,63x-0,4602
R2 = 0,8718
infiltration rate (mm/h)
time (min)
m1 (16.02.2008)
m2 (24.02.2008)
m3 (03.03.2008)
Pow er (m1 (16.02.2008))
Pow er (m2 (24.02.2008))
Pow er (m3 (03.03.2008))


Infiltration rate, plot 38
y = 67,316x-0,1901
R2 = 0,5633
y = 161,23x-0,4113
R2 = 0,9578
y = 128,04x-0,2958
R2 = 0,6703
infiltration rate (mm/h)
time (min)
m1 (17.02.2008)
m2 (24.02.3008)
m3 (03.03.2008)
Pow er (m1 (17.02.2008))
Pow er (m2 (24.02.3008))
Pow er (m3 (03.03.2008))


Infiltration rate, plot 39
y = 90,407x-0,2422
R2 = 0,5331
y = 132,94x-0,2795
R2 = 0,8205
y = 89,168x-0,1902
R2 = 0,6091
infiltration rate (mm/h)
time (min)
m1 (17.02.2008)
m2 (24.02.2008)
m3 (03.03.2008)
Pow er (m1 (17.02.2008))
Pow er (m2 (24.02.2008))
Pow er (m3 (03.03.2008))

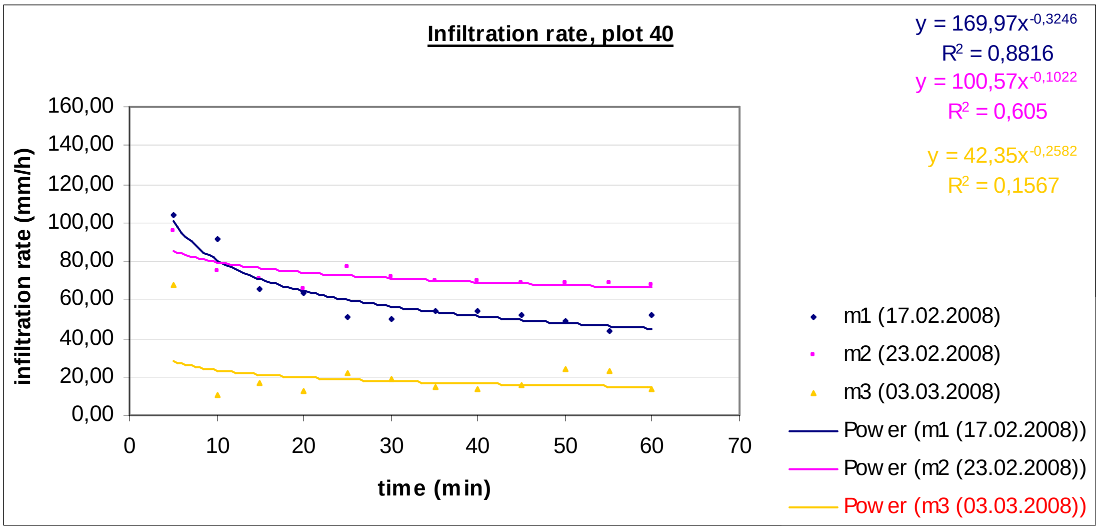


Figure 64: Infiltration rate, replication 4, plot 31 – plot 40