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# The Challenges of Conservation Agriculture to Increase Maize Yield in Vulnerable Production Systems in Central Mozambique

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## ABSTRACT

Smallholder farming under rainfed low input crop production in central Mozambique is characterized by considerable risk of crop failure, low yields and substantial decline in soil fertility; therefore, many rural households face food insecurity. In order to revert this situation, conservation agriculture (CA) has been promoted in the region by international research and development organizations. This study presents the results of on-station four years long-term trial in CA, being conducted in Sussundenga (central Mozambique), with special focus on maize yield and soil water balance. The local climate is wet semi-arid, soil type is Haplic Lixisols (FAO soil classification system) and soil texture is sandy loam.

The on-station trial in Sussundenga is a randomized blocks design with four replications, one conventional treatment with sole maize, using the mouldboard plough (animal traction), and nine CA treatments utilizing different seeding technologies and crop rotation of sunflower, beans and maize. The different seeding technologies under CA are direct seeding, basins and jab planter. The APSIM model was satisfactorily calibrated using an additional high fertilized trial in the site and was used to simulate crop yield and water balance for the long term trial condition. The APSIM simulated yield and soil water matched well with the observed data in the long term trial, root mean standard error (RMSE) was 6.8 to 14.6 (2-4% volume of soil water) and simulated grain deviation was about 6% of the measured. High termites' activity in the trial site prevented the accumulation of crop residues in CA plots as intended; therefore, field results did not show significant differences in maize yield. The results also showed no significant differences in the studied soil fertility indicators (soil organic matter, total nitrogen, available phosphorus) and below ground soil fauna. Runoff measurements in the trial plots using the mini-rainfall method showed a tendency to be reduced in CA plots with significantly lower runoff in the CA plots were previous crop was beans. The water balance study showed that 47% and 52% of rain was lost as runoff respectively in the cropping season 2008-9 and 2009-10 with about the same total rainfall; and that, in the cropping season 2009-10, more rain water was lost through runoff and deep drainage, 5% and 7% more, respectively, resulting in comparative yield reduction over three times lower.

Simulating with the APSIM model a scenario with crop residues (supposing that termites were absent), the resulted more runoff abstraction showed to favour drainage rather than crop water uptake; in contrary, maize residues showed to result in nitrogen immobilization that implied lower crop water uptake and yield reduction in the wetter season 2008-09; therefore, yield doubled for the drier season 2009-10. Nevertheless, further local experimental results are needed to investigate the extent of the nitrogen immobilization as cropping systems that can reduce the impact of termites' activities, and improve soil organic matter to enhance soil water retention. Although the on-station results with CA seem to have failed to show immediate benefits, for a quick adoption by the smallholder farmers in the area, field observation suggest that the direct seeding technology would be very useful as a low energy option in seeding, one of the critical labour demand stage.



*Key words: Conservation agriculture, soil water balance, APSIM model, maize, Mozambique.*

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**List of Symbols and Units**

| *Symbol* | *Definition* | *Units* |
|---|---|---|
| air_dry | Soil moisture at air dry point | $cm^3.cm^{-3}$ |
| bd | Bulk density | $g.cm^{-3}$ |
| CEC | Cation exchange capacity | cmol+/Kg |
| CN | Curve Number | - |
| C/N, CNR | Carbon nitrogen ratio | - |
| CN2Bare | Runoff curve number of bare soil | - |
| CONA | Second stage soil evaporation coefficient | mm |
| DAS | Days after seeding | d |
| Dlayer | Soil Layer thickness | mm |
| Dp | Deep percolation | mm |
| ΔSW | Change in soil water storage | mm |
| DUL, dul | Volumetric water content at drained upper limit for each soil layer | $cm^3.cm^{-3}$ |
| Ec | Crop water uptake, crop transpiration | mm |
| Es | Soil evaporation | mm |
| ESP | Exchangeable sodium percentage | % |
| ETo | Reference evapotranspiration | mm |
| ETP | Potential evapotranspiration | mm |
| fbiom | Inert biomass carbon fraction | - |
| finert | Inert soil carbon fraction | - |
| kl | Soil water availability factor | - |
| LL15, ll15 | Volumetric water content for each layer corresponding to a soil potential of 15 bar | $cm^3.cm^{-3}$ |
| maxt | Maximum temperature | $^oC$ |
| mint | Minimum temperature | $^oC$ |
| Q, Runoff | Surface Runoff | mm |
| R, Rain | Rainfall | mm |
| rad | Incoming solar radiation | $MJ.m^{-2}$ |
| RMSE | root mean standard error | - |
| Salb | Soil albedo | - |
| SAT, sat | Volumetric water content at saturation for each soil layer | $cm^3.cm^{-3}$ |
| SW | Soil water | mm |
| SW90 | Total soil water (0-90 cm depth) | mm |
| T | Temperature | $^oC$ |
| U | First stage soil evaporation coefficient | mm |
| vol. | Volumetric soil water content | % |
| w | Gravimetric soil water content | $g.g^{-1}$ |

## List of Abbreviations

| | |
|---|---|
| A1M, A2M, A_M: | Direct seeding maize-sunflower rotation |
| ANE: | National Road Administration, Mozambique |
| APSIM: | Agricultural Production System siMulator |
| B1M, B2M, B3M, B_M: | Direct seeding maize-sunflower-beans rotation |
| BA: | Basins |
| BIOM: | Biomass |
| BOKU: | University of Natural Resources and Life Sciences, Vienna-Austria |
| C: | Carbon |
| CA: | Conservation agriculture |
| CIAT: | International Center for Tropical Agriculture |
| CIRAD: | Agricultural Research for Development |
| CP: | Check plot; traditional farmers practice using the mouldboard plough with animal traction. |
| CRM: | Crop residues mulch |
| CWP: | Crop water productivity - the marketable crop yield over actual evapotranspiration (Kg.m-3) |
| DAS: | Days after seeding |
| DS: | Direct seeding with animal drawn seeder |
| FAO: | Food and Agriculrure Organization of the United Nations |
| FOM: | Fresh organic matter |
| GLM: | General linear model |
| HUM: | Humus |
| IDL: | Initial drainage curve |
| IIAM: | Agrarian Research Institute, Mozambique |
| JP: | Jab planter |
| K: | Potassium |
| LLT: | Long Term Trial |
| LSD: | Least Significant Difference |
| MS: | Direct seeding maize with sunflower as a relay crop |
| N: | Nitrogen |
| NASA: | National Aeronautics and Space Administration |
| P: | Phosphorus |
| SCS: | Soil Conservation Service |
| SOC: | Soil organic carbon |
| SOM: | Soil organic matter |
| TIA: | National Agriculture Survey, Mozambique |
| UEM: | University Eduardo Mondlane, Maputo-Mozambique |
| USDA: | United States Department of Agriculture |
| WB: | World Bank |

# 1. Introduction

## 1.1 General Introduction

Smallholder farming under rainfed low input crop production, representing more than 90% of the total cultivated area, in central Mozambique, is characterized by considerable risk of crop failure, low yields and substantial decline in soil fertility; therefore, many rural households face food insecurity. In order to revert this situation, conservation agriculture (CA) has been promoted in the region by international research and development organizations such as Sasakawa-Global 2000, Howard et al. (2003), CIAT (International Centre for Tropical Agriculture) and CIMMYT (International Maize and Wheat Improvement Centre) among others, including a wide number of national and international partners. CA is a production system that is based on minimum soil disturbance, the maintenance of a cover (live or dead vegetable material) on the soil surface and crop rotation (Giller et al., 2009; FAO, 2001), especially aiming to maintain and improve yields, stimulate biological functioning of the soil and reduce the impact of droughts and other hazards. It is then assumed that CA principles can support the basis for a sustainable crop production in smallholder farming in central Mozambique. Therefore, in order to assess, in the area, the effects of CA over time, a long term on-station trial in CA was initiated in the year 2006 in the Sussundenga agrarian station (central Mozambique). The research was jointly initiated by CIAT, CIMMYT, BOKU (University of Natural Resources and Life Sciences in Vienna) and IIAM (Agrarian Research Institute, Mozambique).

The study area, Sussundenga agrarian station (Figure 1.1) is located in the province of Manica, Central Mozambique, 19° 20′ latitude south, 33° 14′ longitude east, at about 620 m of altitude. The local climate is wet semi-arid, soil type is Haplic Lixisols (FAO soil classification system) and soil texture is sandy loam. The trial is a randomized blocks design with four replications, one conventional treatment with sole maize, using the mouldboard plough (animal traction), and nine CA treatments utilizing different seeding technologies and crop rotation of sunflower, beans and maize. The common beans *Phaseolus vulgaris* L. is one of the main legumes in the diet of many rural and urban poor in Mozambique, and important source of protein. Beans, is consumed either as grain or leaves, alongside with maize *Zea mays* L.; sunflower *Helianthus annuus* L., is used basically as a cash crop and therefore offer a good opportunity of being widely adopted where the market exists. This study presents and discusses the results of the long term trial with special focus on maize yield and soil water balance.

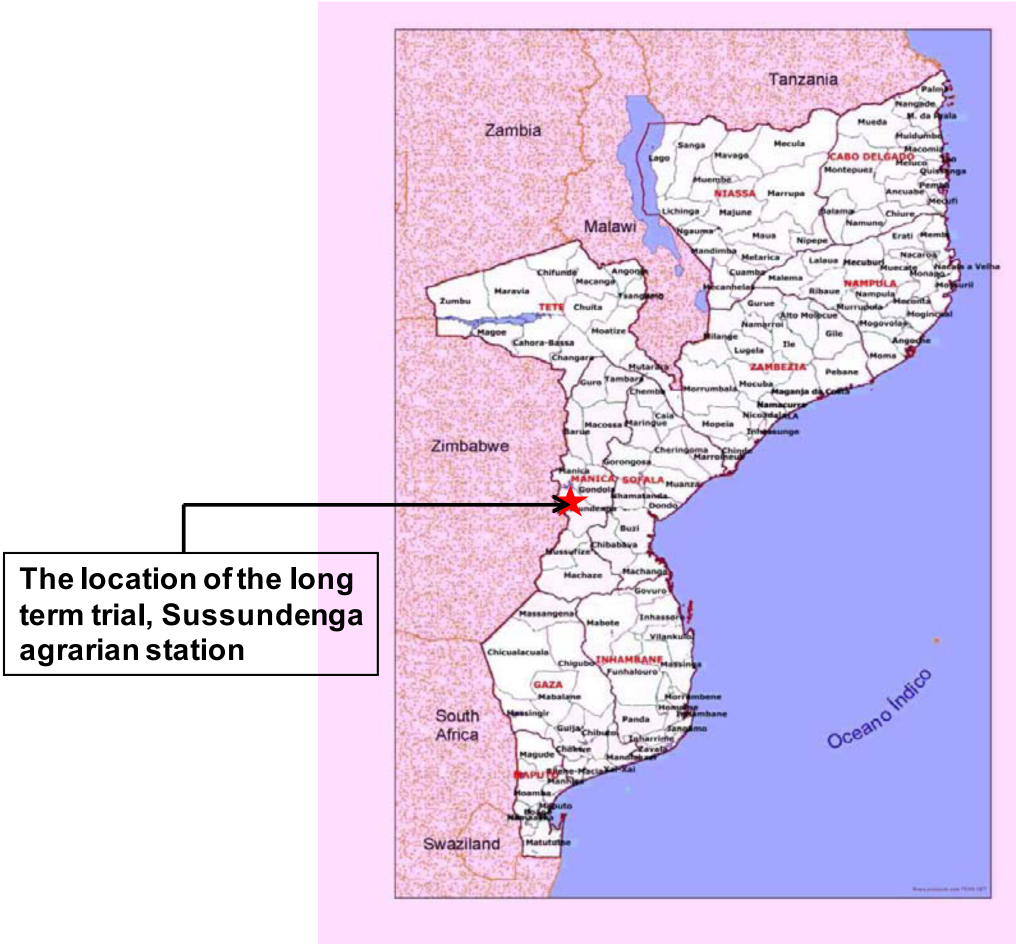



**Figure 1.1: The Study Area Location – Sussundenga Agrarian Station, Central Mozambique, map from (TIA, 2003).**

## 1.2 Study Hypothesis and Objectives

***Study Hypothesis:***

Since many of the advantages of CA have been reported elsewhere and it is being promoted in the area, this study tried progressively to assess three hypotheses based on the long term trial research in Sussundenga:

Hypothesis 1 was that CA enhances soil properties to improve maize crop production and reduce the impact of dry spells in rainfed cropping system. Data collected in continuous maize cropping treatments under different seeding technologies were analyzed;

Hypothesis 2 was that crop rotation as one of the basic components of the CA productions system increases its potential to produce short-term beneficial impacts in soil properties and increase maize production. Under this hypothesis data collected in the traditional tillage were used with that collected in the direct seeding maize in different rotation arrangements with sunflower and beans and;

Hypothesis 3 was that the practice of CA will improve soil water storage and increased maize crop yield compared to traditional tillage in Sussundenga, central Mozambique. Under this hypothesis the collected data were used to calibrate the APSIM model in order to supplement the study on the interaction processes between the local climate and soil management effects on soil water balance, crop growth and crop yield.

***Objectives:***
The main objective of this study is to assess the effect of CA on crop yield and relevant soil aspects in water balance to support its adoption by smallholder farming under rainfed low input crop production in central Mozambique. Therefore, specific objectives were:

- To compare maize crop yield under the different seeding technologies;
- To evaluate changes in soil biological activity as the result of CA practices in the area;
- To evaluate soil infiltration pattern under different seeding technologies;
- To evaluate changes in selected soil fertility (soil organic matter, total nitrogen and available phosphorus) as a result of CA practices in the area;
- To calibrate and use the APSIM model to study soil water balance and maize crop growth in the study area.

## 1.3 Thesis Outline

This thesis is divided into 5 chapters:

Chapter 1 is a brief presentation of the motivation of the study, the study hypothesis and objectives.

Chapter 2 presents a literature review with focus on "the challenges of CA for sustainable crop production of smallholder farmers in central Mozambique". It presents the main characteristics of smallholder farming in central Mozambique; then reviews the principles of CA and main characteristics, and finally discusses possible relevant aspects of CA for a sustainable smallholder farming in central Mozambique.

Chapter 3 is the methodology used in the study. It starts by presenting the established long term trial in CA and the characteristics of the study area (soil and climate); then follows an overview of the APSIM model and then; it also describes the materials and methods used in collecting the different sets of field data, respectively, meteorological data, crop data, soil moisture measurements, soil infiltration measurements and soil biological activity record.

Chapter 4 presents and discusses the main results in four sub-units; unit 4.1, presents the general data (meteorological data, soil data and the calibration of the AquaPro probes used to measure soil moisture); unit 4.2, presents and discusses the data collected in continuous maize cropping treatments under different seeding technologies; unit 4.3, presents and discusses data collected in the traditional tillage comparatively to the different crop rotation arrangements and; unit 4.4 covers the APSIM model calibration and simulation results. Each sub-unit (4.2 to 4.4) ends with a short review on the main findings.

Chapter 5 outlines the main findings of this study and the recommendations for further research both to clarify some specific aspects and to apply the presented findings.

## 2. Literature Review: The Challenges of Conservation Agriculture for Sustainable Crop Production of Smallholder Farmers in Central Mozambique.

### 2.1. Characteristics of Smallholder Farming in Central Mozambique

Rainfed crop production is extensively practiced in central Mozambique by smallholder farmers; however, due to the scarce and erratic rainfall in the vast semi-arid areas, the risk of crop failure is considerable, in some areas higher than 50% (Reddy, 1986). Smallholder farmers represent 90% of the total cultivated area in the country (TIA, 2008), contributes with a quarter of the gross domestic product (INE, 2010). The fact that smallholder agriculture employs about 80% of active population, according to the national census of 2007 (INE, 2010), shows the paramount importance of this sector in the national economy.

The agriculture production in Mozambique is also characterized by very low levels of inputs; the national agriculture surveys (TIA, 2003; TIA, 2008) show that the use of improved technologies in central Mozambique is as follow: animal traction, 11.4%; tractor, 1.3%; chemical fertilizers, 2.5%; pesticides 5.1%; Manure 1.8%. Mather (2009) shows that the use of animal traction increases total landholding by 13.8% and crop income by 33% of the smallholder farmers. Nutrient decline is also substantial in rainfed smallholder farming; for the case of maize production, Folmer et al., (1998) report a decline of nitrogen, phosphorus and potassium in the order of 47.9; 9.9; and 36.5 Kg/ha/year respectively. Average maize yield is between 0.4 to 1.3 tons/ha from the potential yield of 5 – 6.5 tons/ha (Howard et al., 2003). It seems that both irregularities of rains and low input use in smallholder farming are the most important reason for low crop production. It is however believed that some growth in agriculture production in the country since 1994 has primarily come from agricultural extensification (increasing the cultivated area) rather that from increasing productivity (Mather, 2009).

Irregularity of rainfall, even within the rainy period, has led to a strategy of minimizing seasonal risks, rather than maximizing production, whereas land availability is relatively less limiting (except in the suburban zones).Thus spreading of sowing seems a way to spread both labour demand and risks (Schouwenaars, 1988); a similar strategy is that most farmers cultivate several different plots, some plots may be near the homestead and others quite a distance away. Since most of the cropping practices rely on hand hoe, labour availability for land preparation, seeding, weeding and harvesting are limiting crop production factor. With a hand hoe, land preparation is usually cleaning crop residues that are piled together and burnt; seeding and weeding are also done using hand hoe, which poses a lot of pressure on the need for labour. Late planting and failure to weed in time result in considerable crop yield reduction; Howard et al. (2003), report average values losses of 200 Kg/ha/week in late planting and 200Kg/ha for the late weeding in Ethiopia.

Shifting agriculture is still a traditional strategy to cope with decline in soil fertility among smallholder farmers in central Mozambique, and slash and burn agriculture practice for the soil preparation using a hand hoe is predominant. As a result of high risk of crop failure and low crop productivity, many rural households face food insecurity in the region. This study intends then to assess possible contribution of CA for improving crop production in smallholder farming in central Mozambique through improved rain water use and soil fertility management.

## 2.2. Review on CA principles and comparable characteristics

### 2.2.1 Principles of CA and Crop Production

As referred in the introduction, Conservation Agriculture (CA) is a production system that is based on minimum soil disturbance, the maintenance of a cover (live or dead vegetable material) on the soil surface and crop rotation (Giller et al., 2009; FAO, 2001). The goal of this is to maintain and improve yields, stimulate biological functioning of the soil and reduce the impact of droughts and other hazards.

There is a very diverse use of terminology concerning tillage operation, therefore, in this study it is used the definitions presented by FAO (2000), to better clarify the differences between the terms conservation tillage or conservation agriculture, reduced tillage and minimum tillage (see Table 2.1). Conservation tillage is referred as that of minimum soil disturbance (or tillage that does not invert the soil) and the maintenance of at least 30 percent of soil surface covered with residues after sowing.  Reduced tillage refers to tilling the whole soil surface but eliminating the other operations on conventional tillage system such as disc harrow, chisel plough, and rotary cultivator. Conventional tillage involves inversion of the soil, normally with a mouldboard or a disc plough as the primary tillage operation, followed by secondary tillage with a disc harrow. Depending on the implements which are used, on the number of passes, and the amount of crop residue which remains after the seed has been placed, reduced tillage can then be classified as either a conservation or non-conservation tillage system (see Table 2.1).

The traditional farmer's practices that consist of using animal traction for tillage with mouldboard plough to a depth of 10-15 cm can be defined as a reduced tillage according to Table 2.1. Tillage with animal traction in central Mozambique is followed by sowing and weed control using hand hoe. Shifting agriculture still a traditional strategy to cope with decline in soil fertility among smallholder farmers in central Mozambique, and slash and burn agriculture practice for the soil preparation using a hand hoe is predominant.

**Table 2.1: Tillage systems classified according to the degree of disturbance to the soil and the surface cover of residues (FAO, 2000)**

| Conventional tillage | | Non-conservation tillage | Conservation tillage | | | | |
|---|---|---|---|---|---|---|---|
| Mouldboard plough | Disc plough | Reduced tillage | Reduced tillage | Ridge tillage | Tined tillage | Strip tillage | Zero tillage |
| *Less soil disturbance both in intensity and frequency* → | | | | | | | |
| *Increased cover with residues* → | | | | | | | |

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 believed 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; Vandermeer et al., 1998).

The effect of Crop residues mulch (CRM), as presented by Erenstein (2002), is known to bring a number of advantages to crop production: inhibits the germination of many weed seeds, minimizing weed competition with the crop; reduce soil temperature; prevents excessive soil evaporation; protection of soil surface against splash erosion, improved infiltration and reduce runoff; habitat and resources for associated biodiversity; maintenance of soil organic matter; microbial products promoting aggregate stabilization.

Scopel et al. (2004) studied in detail the runoff reduction due to crop residues mulch. Other important factor related to CA is the no-tillage. Contrary to conventional agriculture where tillage is considered to create favourable soil structure, prepare the seedbed and control weeds, tillage accelerates soil erosion and destroys the soil structure by reducing the aggregate size. Tillage is also regarded as harmful to soil micro organisms and accelerates organic matter loss in the topsoil due to resulting accelerated erosion. Then, the soil becomes susceptible to compaction reducing water infiltration and storage.

On the other hand, crop rotation and crop cover are used to maximize biological control, i.e., more plant and crop diversity (FAO, 2001). The advantages on the use of cover crops are compiled by Vandermeer et al. (1998) as: maximize biological control by diversifying the environment to cut the continuation undesired soil organisms, pests and pathogens; legume crop cover has the potential to increase soil N fertility in vulnerable farming systems through biological N-fixation; legume in general used for mulch or as a living cover it protects the soil from erosion and enriches the soil with organic matter and nitrogen through rhizobium symbiosis; capture of plant nutrient excess (e.g., in the fallow period); protection of soil surface against splash erosion, improved infiltration; habitat and resources for associated biodiversity (beneficial soil organisms, pests, pathogens and their control agents); resources for soil organisms mediating soil processes; creation of micro-climate and reduction of wind speed of boundary layer; entrapment of wind and water-borne sediment.

### 2.2.2 Conservation Agriculture and Soil Water Management

Conservation agriculture can be regarded as a water harvesting strategy since it enhances infiltration by reducing run-off, and soil water retention is increased due to the increase in soil organic matter in the top soil. In fact, various authors have shown the impact of dry spells on low yields in semi-arid areas (Barron et al., 2003; Rockstrom et al., 2002; Fox and Rockstrom 2002), as the relevance of CA as a water harvesting strategy. Ngigi et al., (2006), show that conservation tillage increases soil moisture storage by 18-50% compared to traditional tillage.

Experiences with rainwater management technologies also show that soil fertility plays a very important role and that highest yields were realized when conservation farming was combined with soil fertility management. Therefore, combining conservations farming with soil fertility management will result in a significant increase in crop water productivity (Barron et al., 2003; Rockstrom et al., 2002; Fox and Rockstrom 2002).

The potential of CA as Water Harvesting Strategy is related to the following: improves soil structure and enhances infiltration (roots and microbial activity built soil structure); Reduces surface run-off and enhances infiltration; soil water retention is increased due to the increase in top-soil organic matter; mulch intercepts radiation reducing soil evaporation; the additional soil moisture is attributed to increased infiltration and storage. It is then realized that CA has the potential to mitigate the effects of short dry spells that are often the major cause of low yields in Sub Saharan Africa rainfed agriculture (Rockstrom et al., 2009; Barron et al., 2003; Rockstrom et al., 2002; Fox and Rockstrom, 2002); and that a typical water balance on crop production in the semi-arid show that there still a big potential to reduce water losses and increase crop rain productivity.

Zwart and Bastiaanssen (2004) on studying a large set of data on crop water productivity (CWP) show that the large range of CWP offers a high opportunity for increasing agriculture production with 20-40% less water and that soil fertility plays very important role in CWP. This is supported by the above already pointed studies that combined conservation farming with soil fertility management can result in a significant increase in CWP.

In some situations CA practice may be challenged due to the lack of protective soil cover, especially in semi-arid zones; such would be the cases of low straw production or use of crop residues as fodder and grazing, or in case residues are consumed by termites. It is recommended in such cases to shape the soil surface into structures such as ridges and furrows to conserve water (FAO, 2000). Field observations in central Mozambique led to the preliminary conclusion that residue cover are endangered either by the open grazing system in the fallow period or by termites. During a fallow period, after the crop harvesting, it is a common practice to let cattle and goats to freely graze (Giller et al., 2009); on the other hand termites consumed all residues before the next cropping season started. This situation will definitely pose serious problems for the adoption of CA as a complete technological package, as observed in central Mozambique, more residues in the soil created condition for increased termites' activity. Leonard and Rajot (2001) report an increased infiltration with termites activity especially with more than 30 termites holes per square meter; and that the most important factor is the runoff interception by the termites holes comparatively to the ponded infiltration. Other studies report improved surface soil structure due to increased termites' activity on crusted soils and increase in water infiltration (Mando and Miedema, 1997; Mando, 1997). Although it can be anticipated that increased termites activity will result in increased rain water infiltration, the overall water balance and the wide range of benefits from crop residue mulch need to be assessed comparatively.

### 2.3. Relevant Aspects of Conservation Agriculture for Sustainable Smallholder Farming in Central Mozambique

Some of the important characteristics related to CA relevant for the sustainability of smallholder farming in central Mozambique include the need for a: labour saving based crop production; more intensive crop production (accounting both for increased input use and refrain in shifting cultivation); more integrated soil fertility and; more market oriented for an increased crop income. CA principles can support the basis for a sustainable crop production in smallholder farming in central Mozambique; therefore, need to be conveniently supplemented by appropriate strategy on agriculture development.

Labour savings in smallholder farming in central Mozambique is one of the important changes that can bring immediate impact in the production system; and the use of animal traction as a low energy option can definitely contribute to this. Thus, a continued and more vigorous promotion of the adoption of animal traction is an option. However, this need to be supplemented with the overall intensification of the production system changing from low input to high input crop production system for increased benefits; otherwise, the use of animal traction will benefit the increase in the cultivated area and less on productivity while the recurrence to shifting agriculture as a strategy for decreasing soil fertility will remain predominant. In the end, the cost related to production intensification need to be properly assessed. The process of adoption of new technology package is a complex one; farmers will adopt new technology when it is shown to increase income and reduce risk and where there is market access (WB, 2005). Ito et al. (2006), show the experience of enhancing crop production of smallholder farmers with CA in Ethiopia and central Mozambique with the 'Sasakawa Global 2000'. More commonly, the lack of uptake occurs because farmers are constrained in resources; the seek for short-term benefits and impacts are important; it is therefore questionable if the apparent success did not result from the promotion within a technology package, and that similar examples show that, when the project support stops farmers quickly revert to their former crop management practices (Giller et al., 2009). The problems with residues that may be grazed or consumed by termites in most of the central region of Mozambique demand a prior adaptation of CA packages such as ridges and furrows type of soil management that can be easily implemented by animal traction.

The most fundamental impact of CA in the semi-arid areas is the water harvesting effect (Rockstrom et al., 2009). Therefore, there is a need to assess if CA improves considerably crop production in already better years rather than stabilizing crop production. Considering the parallel need for intensification of the production system, CA becomes a more resources intensive agriculture system and turn "inappropriate for the vast majority of resource constrained smallholder farmers and farming systems (Giller et al., 2009)". So, a more market oriented package principle (in a market developed) seems to adequately address such concerns on the adoption of CA. The success with CA in central Mozambique, after Howard et al., (2003) is already a good indication. Nevertheless, if the same level of crop productivity can be attained with CA under the discussed principles it is already a success considering the gains in labour savings and lower pressure on land resources by refraining in shifting cultivation and land degradation. However, many of the gains may not be directly perceived by smallholder farmers that oversee substantial and immediate results. Referring to Giller et al., (2009), the constraints for CA adoptions are common to other strategies for improvement of productivity, the main issues to be addressed are the Institutional elements required for all successful strategies for agricultural intensification.

## 3. Methodology

### 3.1. The on-station trial in Conservation Agriculture on Sussundenga, Central Mozambique

In order to monitor and evaluate the effects over time of Conservation Agriculture (CA) practices on crop yield, soil quality, weeds, pests and diseases, a long-term on-station trial is being conducted since the year 2006 in Sussundenga (agrarian station), Central Mozambique. The research is jointly conducted by CIMMYT (International Maize and Wheat Improvement Centre), CIAT (International Centre for Tropical Agriculture) BOKU (University of Natural Resources and Life Sciences, Vienna) and IIAM (Agrarian Research Institute, Mozambique).

The on-station trial is a randomized block design with four replications, one conventional treatment with sole maize, using the mouldboard plough (animal traction), and nine CA treatments utilizing different seeding technologies and crop rotation of sunflower, beans and maize. The trial comprises 4 replication totalizing 40 plots with 24x18 square meters each plot.

**Treatments Description:**

- T1: Check plot (**CP**); traditional farmers practice using the mouldboard plough with animal traction, maize as a sole crop, no residue retention, stubbles incorporated
- 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 retained)
- T3: Basin (**BA**), maize as a **sole** crop, residue retention
- T4: Jab planter (**JP**), maize as a **sole** crop, residue retention
- T5: Direct seeding with animal drawn seeder (**MS**), maize with sunflower as a **relay** crop, residue retention
- T6: Crop rotation A1(**A1M**): direct seeding with animal drawn seeder, maize-sunflower rotation (Phase1), residue retention; *Maize(2006)-Sunflower-Maize*
- T7: Crop rotation A2 (**A2S**): direct seeding with animal drawn seeder, maize-sunflower rotation (Phase2), residue retention; *Sunflower(2006)-Maize-Sunflower*
- T8: Crop rotation B1(B1M): direct seeding with animal drawn seeder, maize-sunflower–beans rotation (Phase1), residue retention; Maize(2006)-Sunflower-Beans
- T9: Crop rotation B2 (**B2S**): direct seeding with animal drawn seeder, maize-sunflower-beans rotation (Phase 2), residue retention; *Sunflower(2006)-Beans-Maize.*
- T10: Crop rotation B3 (**B3B**): direct seeding with animal drawn seeder, maize-sunflower-beans rotation (Phase 3), residue retention; *Beans(2006)-Maize-Sunflower.*

**Description on the seeding technologies:**
Four seeding technologies were studied in the trial on CA in Sussundenga, the mouldboard plough with animal traction, the direct seeding with animal traction, the basins, and the jab planter.

Mouldboard plough with animal traction (CP): traditional tillage treatment was carried out with a mouldboard plough before planting (Figure 3.1). The tillage depth was about 10-15 cm and was followed by a hand seeding of sole maize and basal fertilizer application. The seeding depth was about 10 cm depth.

**Figure 3.1: Traditional tillage with animal traction using a mouldboard plough (left). A photo of a mouldboard plough used in the trial (right).**

Direct Seeding (DS): a technique that refers to seeding/planting without ploughing or cultivation to prepare a seedbed (Figure 3.2). Direct seeding with animal traction direct seeder allowed a simultaneous application of basal fertilizer at a depth of 10 cm. The direct seeder was prior calibrated to deliver the required seed and amount of fertilizer.

**Figure 3.2: Direct seeding with animal traction (left); fertilizer and field containers of the direct seeder (middle), and a plot after direct seeding, before crop emergence (right)**

Basins (BA): the basins were dug with the use of a hand hoe before seeding (Figure 3.3). The basin were approximately (15cm x 15cm) and 15 cm deep, with spacing of 90 cm between rows and 50 cm between basins in the row; the basin were dug before the starting of the cropping season.

Hand fertilizer application per basin was followed by hand seeding of sole maize in the basins. The basins were covered with the rest of the soil after placing the seeds what resulted in a seeding depth of about 10 cm.

**Figure 3.3: Basins being prepared with a hand hoe.**

Jab planter (JP): a manual jab planter (Figure 3.4) allowed a direct seeding of maize and simultaneous application of basal fertilizer at a depth of about 10 cm. The jab planter was prior regulated to deliver the required seed and amount of fertilizer.

**Figure 3.4: A manual jab planter being used in the trial plots (left and middle pictures) , and filling of a jab planter container with fertilizer. One container is for seeds and the other is for fertilizer (right).**

## 3.2. Site Description

### 3.2.1 Location and Climate

Sussundenga Agrarian Research Station is located in Central Mozambique (Manica province): 19 deg 20min latitude South; 33deg 14min longitude East; 620 m of altitude. The local climate in Sussundenga is wet semi-arid (Reddy, 2006), average annual rainfall 1,155 mm and potential evapotranspiration 1,386 mm; average minimum temperature is 9.5 $^{o}$C in the month of July and average maximum temperature is 29.1 $^{o}$C in the month of January. Table 3.1 present the average monthly climatic data and Figure 3.5 the monthly rainfall distribution and potential evapotranspiration (Wijnhoud, 1997).

**Table 3.1: Average Monthly Climatic Data, Sussundenga Agrarian Station**

19$^{o}$20' Latitude South; 33$^{o}$14' Longitude East; 620m Altitude.

| Month | Temperature ($^{o}$C) | | | Air Humidity | V. pressure | Sunshine | | Wind Speed | Rainfall | ETP |
|---|---|---|---|---|---|---|---|---|---|---|
| | Avg | Max. | Min. | (%) | (mbar) | (hr/dia) | (%) | (m/s) | (mm) | (mm) |
| Jan | 24.4 | 29.1 | 19.6 | 77 | 22.8 | 7.4 | 56 | 1.7 | 194 | 147 |
| Feb | 23.7 | 28.2 | 19.2 | 77 | 22.8 | 7.1 | 56 | 1.8 | 245 | 123 |
| Mar | 23.1 | 27.7 | 17.8 | 76 | 21.4 | 7.2 | 59 | 1.7 | 186 | 124 |
| Apr | 21.2 | 26.4 | 16.0 | 76 | 18.8 | 8.0 | 68 | 1.5 | 52 | 97 |
| May | 19.0 | 25.4 | 12.5 | 70 | 15.5 | 8.3 | 74 | 1.5 | 22 | 79 |
| Jun | 16.7 | 23.2 | 10.3 | 68 | 13.1 | 7.9 | 72 | 1.7 | 11 | 64 |
| Jul | 16.6 | 23.5 | 9.5 | 61 | 11.9 | 8.3 | 75 | 1.8 | 10 | 77 |
| Aug | 18.4 | 25.6 | 11.2 | 65 | 13.3 | 8.4 | 73 | 1.7 | 14 | 98 |
| Sep | 21.1 | 28.7 | 13.5 | 57 | 14.2 | 8.8 | 73 | 1.9 | 10 | 135 |
| Oct | 23.1 | 29.9 | 16.3 | 61 | 17.2 | 7.7 | 61 | 2.0 | 36 | 152 |
| Nov | 23.8 | 29.5 | 18.1 | 64 | 19.1 | 7.2 | 55 | 1.9 | 122 | 146 |
| Dec | 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).**

**ETP** = Potential evapotranspiration (Penman)

The rains show two distinct periods, the rainy season from October to March, and the dry season and the coldest from April to September; temperature and rainfall distribution show that the wet season is hot and the dry season is relatively cooler (Figure 3.6).

Recommended planting dates start at the end of November after the first rain of 25 mm in a single day or 30 mm in two consecutive days in light textured soils, or just before a good rain in heavy textured soils. The rainy season presents 89% of the total annual rains, from October to March, and the dry and cold season with 11% of the rain from April to September. High rainfall variability results in a risk of crop failure under rainfed agriculture, dry spells area likely to happen (Reddy, 1986).

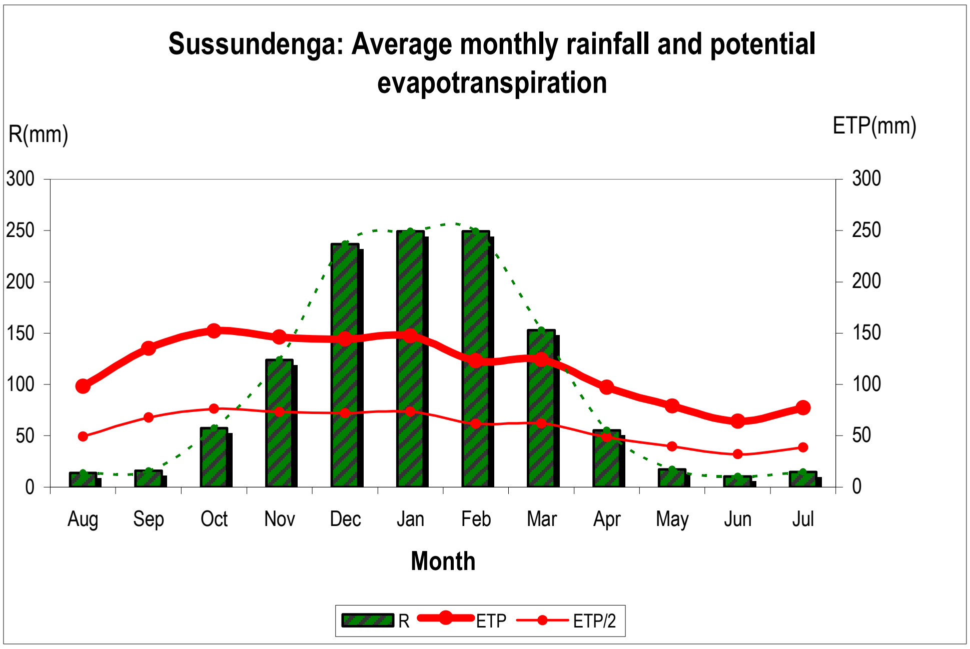



**Figure 3.5: Rainfall (R) and potential evapotranspiration (ETP). The main agriculture season under rainfed cropping starts in November.**

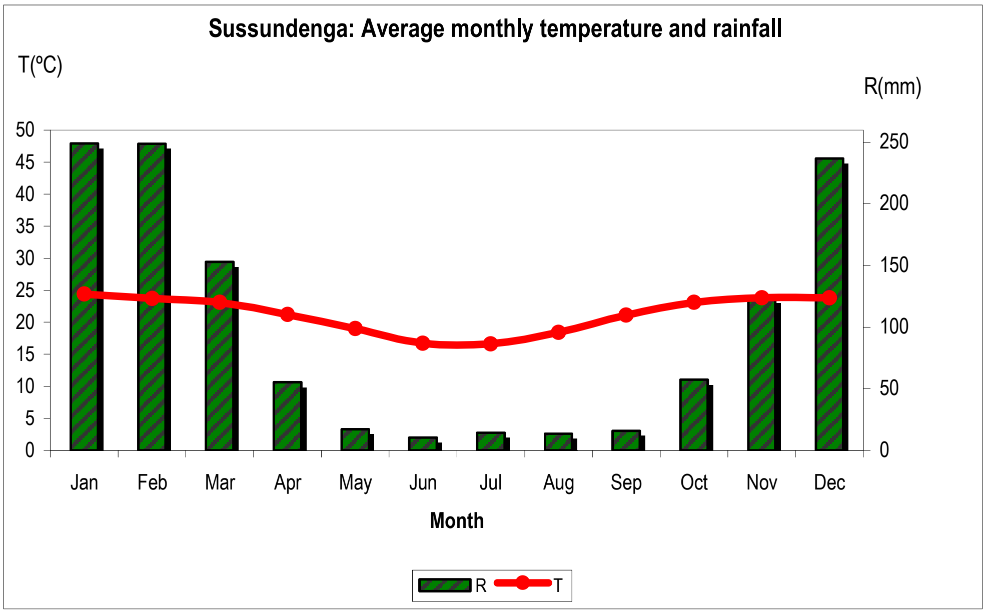



**Figure 3.6: Temperature and rainfall distribution. The wet season is hot and the dry season is relatively cooler**

### 3.2.2 Soils

The soil of the study area belong to the group of fine textured red soils, in the high plains of Chimoio (Manica Province), originated from metamorphic acid rocks (gneiss, migmatite) in situ weathered. The predominant soil types at Sussundenga agrarian station are Ferralsols (haplics and rhodics), Haplic Lixisols and Haplic Acrisols. In the experimental plots, the soil types are Haplic Lixisols, according to FAO soil classification system, and soil texture is sandy loam, the slope is generally 1-2% (Wijnhoud, 1997).

Lixisols and Ferralsols have good physical properties but they present a low natural fertility. Their low fertility and the tendency to fix phosphates and aluminium toxicity are serious limitations for crop production. Hence, farming requires recurrent inputs of fertilizers and/or lime (Driessen and Dudal, 1989).

As a base line study, profile description and soil sampling in the profile wall for laboratory analysis were conducted in the trial site as described in the methodology for data collection. The area was in a fallow period of about 10 years before the initiation of the trial in the year 2006, whereby herbaceous vegetation have been established. The mains vegetation type in the area is scrub grassland ((Wijnhoud, 1997).

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 nitrogen and phosphorus (Wijnhoud, 1997).

Wijnhoud (1997) points out some of the soil degradation types in the Sussundenga agrarian station as that related to research activities carried out in the past, especially: soil compactions as related to the use of machinery for cleaning the land and for tillage operations; reduction 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; and increased soil acidification, due to the probably use of N-fertilizers of the type $(NH_4)^2SO_4$, most known to cause acidification.

### 3.3. The APSIM Model Overview

#### 3.3.1. The APSIM Model Structure

APSIM, Agricultural Production System siMulator, has been developed by the Agricultural Production Systems Research Unit in Australia. The APSIM model can simulate climatic and soil management effects on crop growth and crop yield; simulate trends in soil productivity as influenced by management, including crop sequences and crop residues management; it is therefore integrate soil, weather, management and crop (McCown et al., 1995; McCown et al., 1996).

A key feature of APSIM is the central position of the soil rather than the crops; changes in the status of the soil state variables are simulated continuously in response to weather and management; crops come and go, finding the soil in a particular state and leaving it in an altered state (McCown et al., 1996; Probert et al., 1998). Thus, the APSIM model seems to be appropriate to simulate the impact of different soil management option in CA and traditional practices under this study.

Crop growth, crop management, soil water balance and other processes are represented as modules which relate to each other only through a central control unit, the 'Engine'. Plant growth modules are interchangeable, and more than one growth module can be connected simultaneously, Figure 3.7, (McCown et al., 1996; Keating et al., 2003).

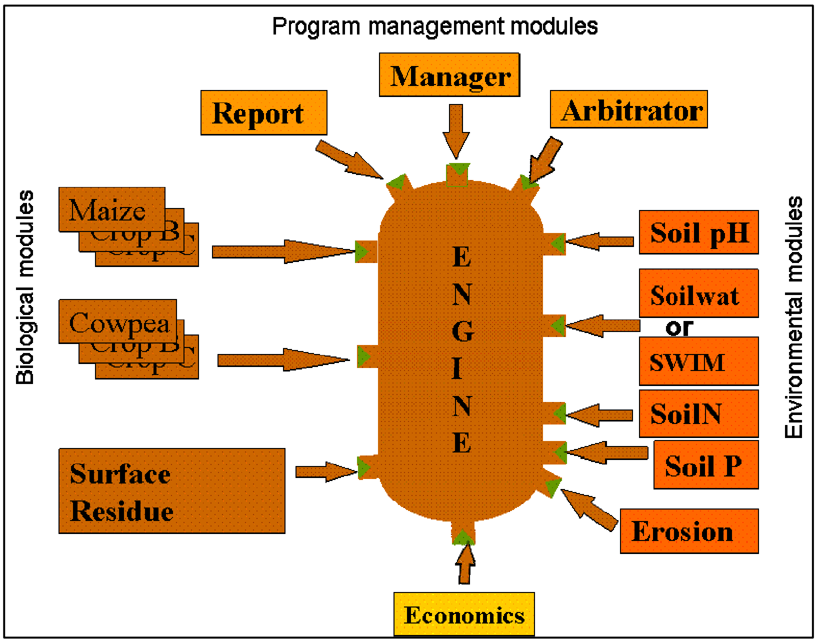


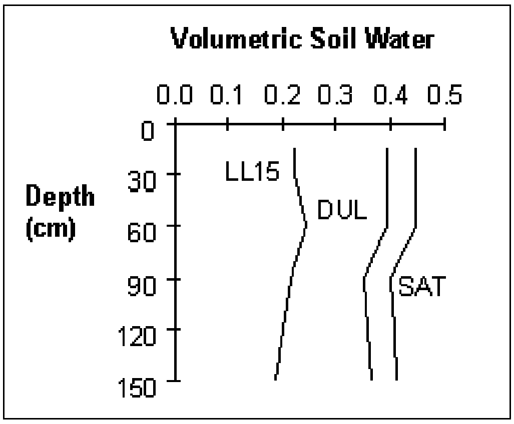

**Figure 3.7: The structure of the APSIM program. Modules are readily pulled out or plugged in (McCown et al., 1996; Keating et al., 2003).**

To simulate maize growth in the case in this study, five modules were linked within APSIM model: a crop module (APSIM-maize), a soil-water module (SoilWAT), the soil nitrogen module (SoilN), the residue module (SurfaceOM). Input data required by the APSIM model, are related to the climate (daily minimum and maximum temperatures, radiation and rainfall), crop genetic and soil characteristics such as plant and soil management (tillage, planting, fertilizer application).

### 3.3.2. The Soil Water Module

Soil-water module is a cascading layer model (Keating et al., 2003). It operates on a daily time step. The water characteristics of the soil are specified in terms of the lower limit (LL15), drained upper limit (DUL) and saturated (SAT) volumetric water contents of a sequence of soil layers. Water movement is described using separate algorithms for saturated or unsaturated flow. Redistribution of solutes, such as nitrate- and urea-N, is carried out in this module. Runoff is calculated using the USDA curve number technique and takes into account and correct for soil moisture and residue and plant cover; similarly, evaporation is described as a two-stage process (energy-limited and water limited) based on potential evaporation (Priestly-Taylor).

Infiltration or water movement into any layer that exceeds the saturation capacity of the layer automatically cascades to the next layer. Figure 3.8 shows an example of soil properties used to configure the soil water layers.




LL15 is the 15Bar lower limit of soil water content. It is approximately the driest water content achievable by plant extraction. DUL is the drained upper limit of soil water content. It is the content of water retained after gravitational flow. DUL is sometimes referred to as “Field Capacity”. SAT is the Saturated water content.

**Figure 3.8: Example of soil properties in configuration of soil-water layers (McCown et al., 1996).**

Runoff from rainfall is calculated using the USDA-Soil Conservation Service procedure known as the curve number technique. The procedure uses total precipitation from one or more storms occurring on a given day to estimate runoff (Figure 3.9). For SoilWater module, the user only needs to supply the curve number for average antecedent rainfall conditions (CN2). From this value the wet (high runoff potential) response curve and the dry (low runoff potential) response curve are calculated. SoilWater will then use the family of curves between these two extremes for calculation of runoff depending on the daily moisture status of the soil (Figure 3.9, left), as, a residue cover status (Figure 3.10).

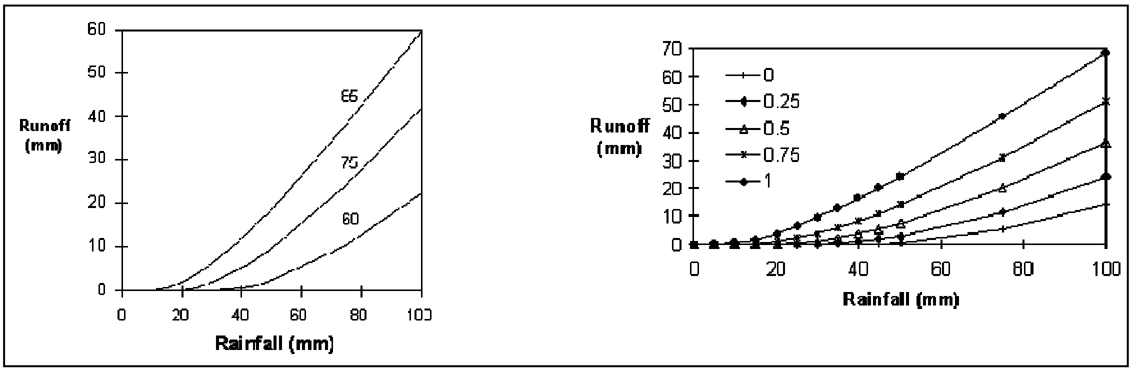



**Figure 3.9: Example of Runoff average response curves, curve numbers (CN2) 60, 75 and 85 (on the left); Runoff response curve (75) modified for a range of soil moisture conditions (0-dry, 1-wet) on the right (McCown et al., 1996).**

Surface residues inhibit the transport of water across the soil surface during runoff events and so different families of response curves are used according to the amount of crop and residue cover. The extent of the effect on runoff is specified by a threshold residue cover, above which there is no effect, and the corresponding curve number reduction.

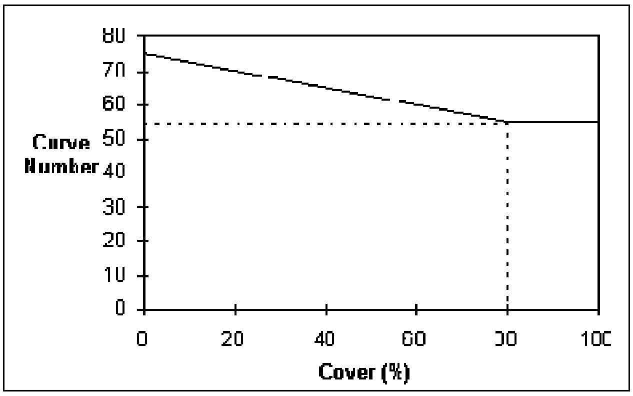



**Figure 3.10: Example of residue cover effect on CN where bare soil CN is 75 and total reduction in CN is 20 at 80% cover (McCown et al., 1996).**

Soil evaporation is assumed to take place in two stages: the constant and the falling rate stages. In the first stage the soil is sufficiently wet for water to be transported to the surface at a rate at least equal to the potential evaporation rate. Potential evapotranspiration is calculated using an equilibrium evaporation concept as modified by Priestly and Taylor (1972). Once the water content of the soil has decreased below a threshold value the rate of supply from the soil will be less than potential evaporation (second stage evaporation). These behaviours are described in SoilWater through the use of two parameters: U and CONA. The parameter U represents the amount of cumulative evaporation before soil supply decreases below atmospheric demand. The parameter CONA specifies the change in cumulative second stage evaporation against the square root of time (Figure 3.11). Thus,

For $t <= t_1$; $Es = E$

For $t > t_1$; $\Sigma Es = U.t + CONA.\ (t-t_1)^{1/2}$

Where Es is actual soil evaporation; E is potential soil evaporation; t and $t_1$ is respectively time and time to the end of the first stage evaporation; U, first stage soil evaporation coefficient and CONA, the second stage soil evaporation coefficient.

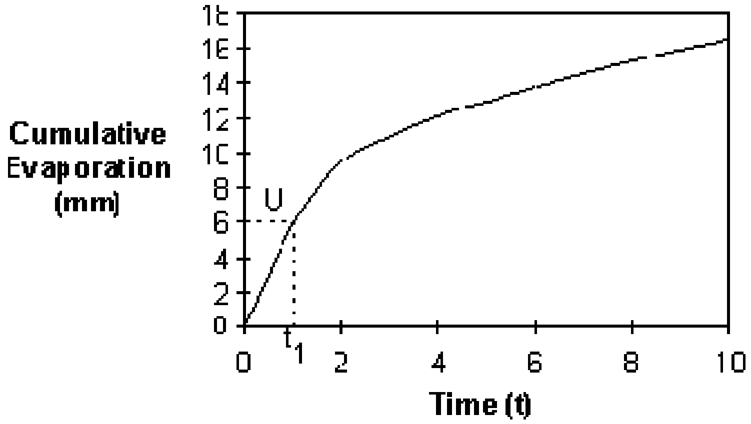



**Figure 3.11: Example for cumulative Soil Evaporation through time for U = 6 mm and CONA = 3.5. (McCown et al., 1996).**

$t_1$ is time to the end of the first stage evaporation; U, first stage soil evaporation coefficient and CONA, the second stage soil evaporation coefficient.

In unsaturated Water Flow, water contents below field capacity (DUL), movement depends upon the water content gradient between adjacent layers and the diffusivity, which is a function of the average water contents of the two layers. The diffusivity is defined by two parameters set by the user (diffus_const, diffus_slope).

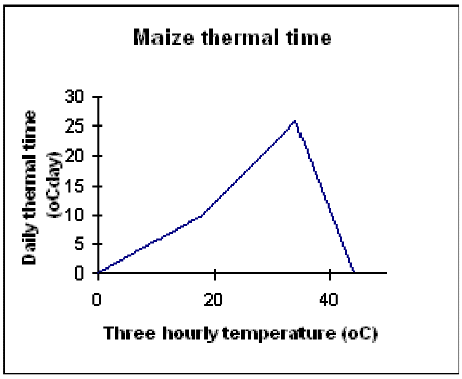
Diffusivity = diffus_const x exp (diffus_slope x thet_av)
where thet_av is the average of SW - LL15 across the two layers; SW is actual soil water content and LL15 is water content at permanent wilting point.
Flow = Diffusivity x Volumetric Soil Water Gradient

Fluxes of solutes are associated with both saturated and unsaturated water fluxes. In both cases a simple mixing algorithm is used whereby incoming water and solute is fully mixed with that already present in any layer to obtain concentrations for solutes that are applied to the water leaving the layer. Thus, solute movement can simply be calculated as the product of the water flow and the solute concentration in that water. Efficiency factors (for saturated and unsaturated flow) are specified in the SoilWater to adjust the effectiveness of mixing for either saturated or unsaturated flows.

### 3.3.3. The Maize Module

The **maize** module simulates the growth of a maize crop in a daily time-step (on an area basis not single plant). Maize growth in the model responds to climate (temperature, rainfall and radiation from the **input** module), soil water supply (from the **SoilWat** module) and soil nitrogen (from the **SoilN** module).

**Maize Phenology:** There are 11 crop stages and nine phases (time between stages) in the maize module, and commencement of each stage (except for sowing to germination which is driven by soil moisture) is determined by accumulation of thermal time. Each day the phenology routines calculate today's thermal time (degree days) from 3-hourly air temperatures interpolated from daily maximum and minimum temperatures (Figure 3.12).




Thermal time is calculated using the relationship in Figure 3.12 with the eight 3-hour estimates averaged to obtain the daily value of thermal time (in growing degree days) for the day. These daily thermal time values are cumulated into a thermal time sum which is used to determine the duration of each phase.

**Figure 3.12: Maize thermal time based on three hourly temperatures (McCown et al., 1996).**

Between the stage of emergence and flowering the calculated daily_thermal_time is reduced by water or nitrogen stresses, resulting in delayed phenology when the plant is under stress. Between the end of the juvenile phase and floral initiation the thermal development rate is sensitive to photoperiod (calculated as a function of day of year and latitude) if the cultivar is photoperiod sensitive. The model assumes that maize, as a short day plant, will have a longer phase (dependent upon cultivar) between the end of the juvenile phase and initiation if photoperiods exceed 12.5 hours.

Each day two estimates of the daily biomass production are calculated, one limited by available water for transpiration, and the other limited by radiant energy. The minimum of these two estimates is the actual biomass production for the day.
Biomass production limited by available water:

delta_drymatter_transpiration = soil_ water_ supply x transpiration_efficiency.

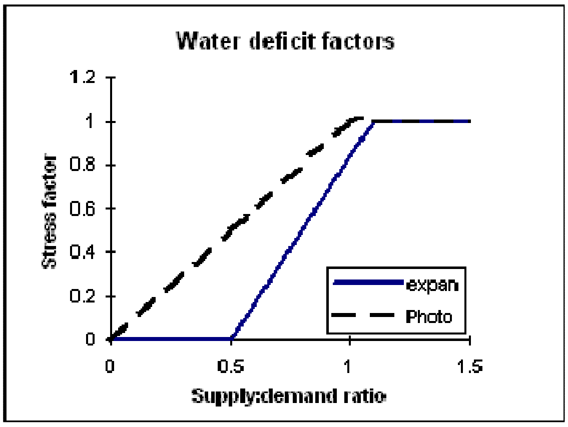
Biomass production limited by radiant energy:

dlt_drymatter_potential = rue x radiation_interception

Transpiration_efficiency is derived from the transpiration_efficiency_coefficient (=0.009) and the vapour pressure deficit (vpd) estimated from daily temperatures; rue (radiation-use efficiency) is 1.6 g MJ-1 from emergence to the start of grain-filling, and then declines to 1.06 g MJ-1 from the start of grain filling to account for the effects of leaf aging on reduced photosynthetic capacity (Muchow et al. 1990). Radiation interception is calculated from leaf area index and radiation extinction coefficient of 0.45.

**Biomass partitioning:** Daily biomass production is partitioned to different plant parts in different ratios depending on crop stage. Until the end of juvenile phase the root:shoot ratio is maintained at 1.0, and then decreases to a value of 0.087 at flowering. Between emergence and flag leaf appearance the proportion of biomass produced that is partitioned to leaf increases exponentially as leaves appear. Between the stage floral initiation and flag leaf appearance, the biomass remaining after allocation to leaf is allocated between stem and developing ear in the ration 1:0.30. After leaf growth has ceased at flag leaf appearance, biomass is partitioned between stem and ear only until the start of grain filling, where upon partitioning to grain only occurs. The maize module allows a total retranslocation of no more than 15 and 20% of leaf and stem biomass present at the start of grainfilling, respectively.

**Water deficits affecting plant growth:** Soil water deficit factors are calculated to simulate the effects of water stress on different plant growth processes (Figure 3.13).




A water availability ratio is calculated by dividing actual soil water supply (sw - ll) by the potential soil water supply (dul - ll). This ratio is used in the relationships illustrated (Figure 3.13) to derive the stress factors for photosynthesis (Photo) and leaf expansion (expan). A factor of 0 is complete stress and 1 no stress.

**Figure 3.13: Water deficit factors affecting plant growth (McCown et al., 1996).**

A fraction of plants (0.044) will be killed each day due to water stress once the cumulative water stress factor for photosynthesis exceeds 4.6.

**Nitrogen uptake:** in order to calculate **nitrogen demand** today, first potential biomass production is re-calculated unlimited by water, nitrogen or temperature i.e. as a function of rue and radiation-interception. This dry matter (biomass) is then partition into plant parts according to their current relative weights. The maize module has a defined minimum, critical and maximum N concentration for each plant part. Demand for nitrogen in each part attempts to maintain nitrogen at the critical (non stressed) level. Nitrogen demand on any day is the sum of the demands from the pre-existing biomass of each part required to reach critical N content, plus the N required to maintain critical N concentrations in today's potentially assimilated biomass.

A **nitrogen uptake maximum** is defined as the nitrogen uptake required to bring all plant part N contents to the maximum allowable concentration; **Nitrogen supply** is the sum of nitrogen available via mass flow and by diffusion:

no3_massflow (layer) = no3_conc x delta_sw (layer).

no3_diffusion (layer) = sw_avail_frac x no3_conc.

Note: these layer values are summed to root depth and sw_avail_frac is ratio of extractable soil-water over total soil-water.

If nitrogen demand cannot be satisfied by mass flow then it is supplied by diffusion. Demand can only be exceeded by supply from mass flow (up to the nitrogen uptake maximum).

**Nitrogen deficits affecting plant growth:** the N availability factor is assessed between (0-1), 1 is no stress and 0 complete stress, for the following processes: photosynthesis, expansion, phenology and grain filling. A N concentration ratio is calculated for the stover (stem + leaf), see equation below, which is used as a measure of N stress, then different constants are used to convert that ratio to a deficit factor for each of the processes. A factor of 1 is used for effecting grain N concentration, 1.25 for photosynthesis (reduces rue), 0.8 for expansion (reduces leaf area expansion) and 5.75 to slow phenological development. As a value of 1 is no stress and 0 complete stress, phenology is least sensitive to nitrogen deficiency and grain N the most.

N_conc_ratio = (N_conc_stover - N_conc_stover_min) / (N_conc_stover_crit - N_conc_stover_min).

### 3.3.4 The Soil Nitrogen Module

The SoilN module describes the dynamics of both carbon and nitrogen in soil. The transformations considered in each layer are shown in Figure 3.14. The soil organic matter is divided into two pools (**biom** and **hum**), the **biom** pool notionally representing the more labile, soil microbial biomass and microbial products, whilst **hum** comprises the rest of the soil organic matter. The flows between the different pools are calculated in terms of carbon, the corresponding nitrogen flows depending on the C:N ratio of the receiving pool. The C:N ratios of the various pools are assumed to be constant through time; C:N for **biom** is specified, and the C:N of **hum** is derived from the C:N ratio of the soil.

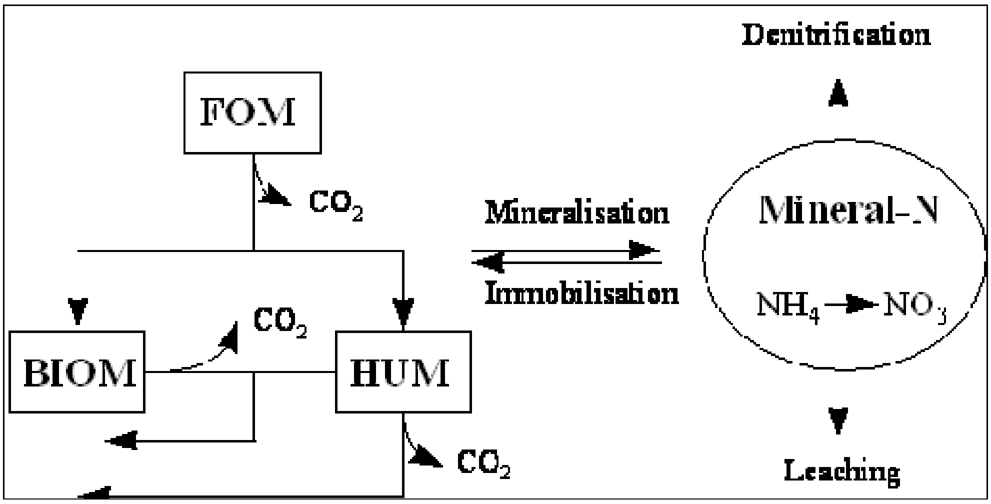



**Figure 3.14: Diagram of transformation of nitrogen and carbon occurring in each soil layer. FOM is fresh organic matter; BIOM is soil microbial biomass and Hum is humus. (McCown et al., 1996).**

Decomposition of any organic matter pool results in evolution of carbon dioxide to the atmosphere and transfers of carbon to the **biom** and **hum** pools. When **biom** decomposes there is an internal cycling of carbon (microbes feeding on microbial products).

Decomposition of **biom** and **hum** pools are calculated as first-order decay processes with the rate constants being modified by factors involving soil temperature and moisture in the layer. The fresh organic matter pool (**fom)** decomposition is additionally dependent on a C:N ratio factor. Figure 3.15 shows the impacts of different factors affecting the decomposition rates. Mineralization or immobilisation of mineral-N is determined as the balance between the release of nitrogen during decomposition and immobilisation during microbial synthesis and humification. An inadequate supply of mineral-N to satisfy the immobilisation demand results in a slowing of the decomposition.

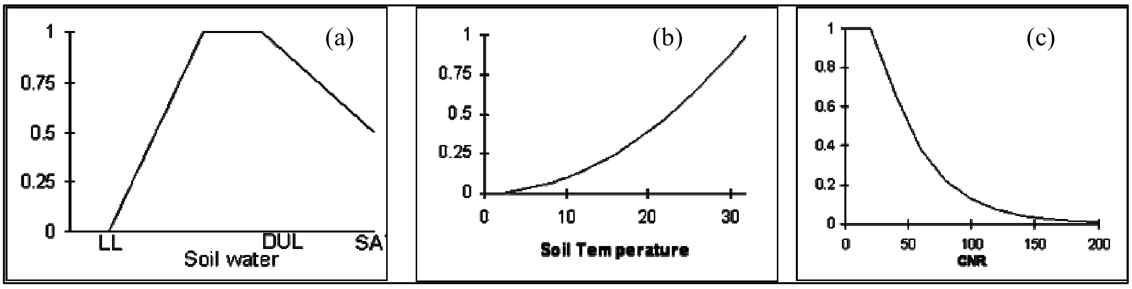



**Figure 3.15: Factors affecting the individual decay rates of the various soil organic matter pools (a) Soil water, LL is wilting point, DUL is field capacity and SAT is saturation; (b) Soil temperature and (c) C/N ratio, CNR, on fresh organic matter only (McCown et al., 1996).**

**Nitrification rate:** actual daily nitrification is reduced to allow for sub-optimal water, temperature and pH conditions (Figure 3.16).

nitrification rate = potential rate x min (water factor, temperature factor, pH factor)

potential rate = nitrification_pot x NH4 ppm / (NH4 ppm + NH4_at_half_pot)

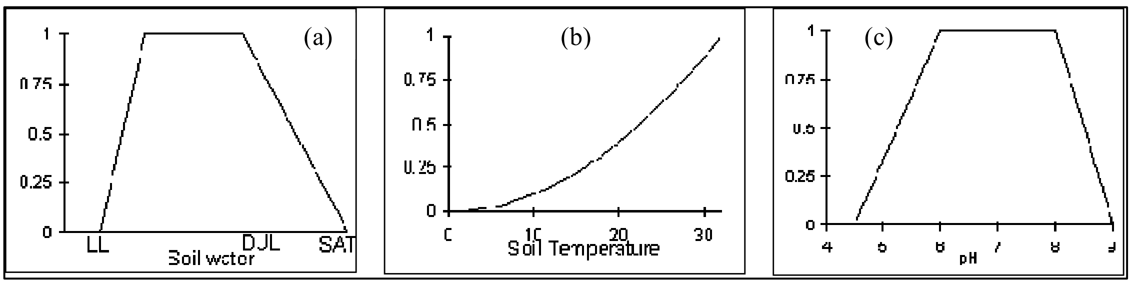



**Figure 3.16: Factors affecting the Nitrification in soils (a) Soil water, LL is wilting point, DUL is field capacity and SAT is saturation; (b) Soil temperature and (c) Soil pH (McCown et al., 1996).**

**Denitrification rate:** actual denitrification is affected by soil water, soil temperature and active carbon as follows, (see also Figure 3.17):

denitrification rate = 0.0006 x $NO_3$ x active carbon(ppm) x water factor x temperature factor.

active carbon ppm = 0.0031 x (hum_C ppm + FOM_C ppm ) + 24.5

With hum_C, the carbon in humus (ppm) and FOM_C, the carbon in fresh organic matter (ppm).

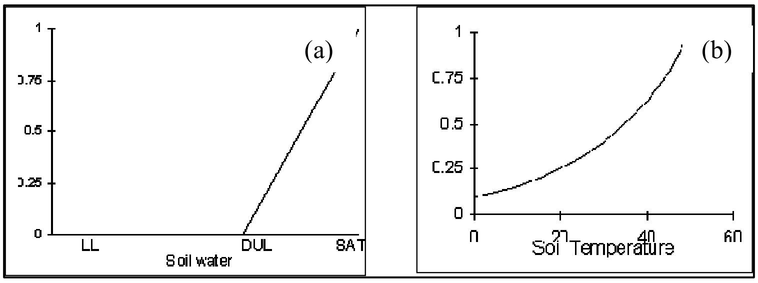



**Figure 3.17: Factors affecting the Denitrification in soils (a) Soil water, LL is wilting point, DUL is field capacity and SAT is saturation; and (b) Soil temperature (McCown et al., 1996).**

**Urea hydrolysis rate:** actual hydrolysis rate is affected by soil organic carbon (OC), soil pH, soil water, temperature (see also Figure 3.18):

potential hydrolysis fraction = -1.12 + 1.31xOC + 0.203xpH - 0.155xOCxpH

This fraction is bound between 0 and 1. For OC=1% and pH=7 the fraction=0.526

hydrolysis rate = Urea x potential hydrolysis fraction x min (temperature factor, water factor)

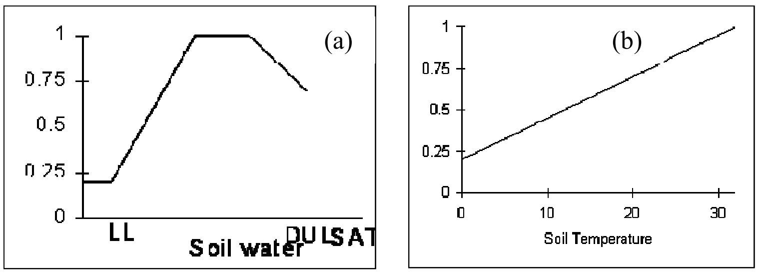



**Figure 3.18: Factors affecting the Urea hydrolysis rate in soils (a) Soil water, LL is wilting point, DUL is field capacity and SAT is saturation; and (b) Soil temperature (McCown et al., 1996).**

### 3.3.5. Surface Organic Matter Module

Surface organic matter, the above ground material can be burnt (or removed from the system), incorporated into the soil during tillage operations, or decomposed. The processes are described in Figure 3.19. Above ground residues are considered as consisting of a mixture of one or more different materials (or component parts), each of which is defined in terms of: mass (kg/ha); overall C:N ratio (); overall C:P ratio ();Standing Fraction (0-1). An overall effective cover value (0-1) is calculated using all surface organic matter components present, for the purposes of subsequently calculating surface material effect on soil evaporation and runoff.

Tillage results in a transfer of some surface OM into the soil FOM pool. Decomposition of residues results in loss of some carbon as CO2 and transfer of carbon and nitrogen to the soil. Decomposition of residues with a high C:N ratio creates an immobilisation demand, which is satisfied from mineral-N in the uppermost soil layers; in extreme situations, inadequate mineral-N in soil restricts decomposition of residues.

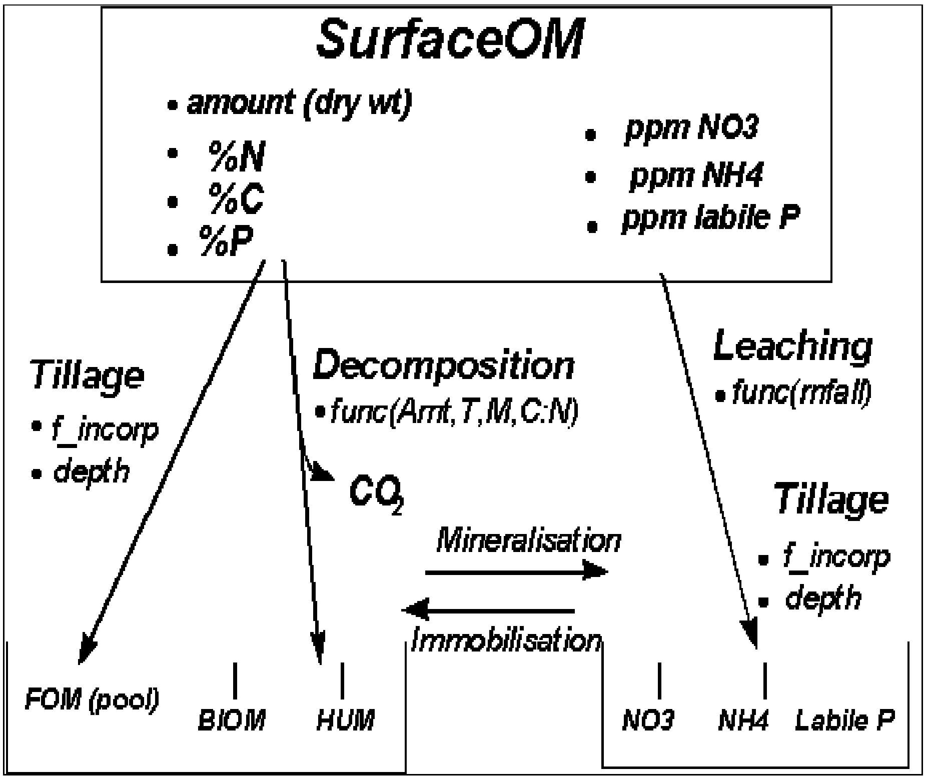



**Figure 3.19: Schematic representation of the processes in the Surface organic matter module. SurfaceOM is surface organic mater; FOM is fresh organic matter; BIOM is soil microbial biomass and Hum is humus. (McCown et al., 1996).**

Decomposition of surface OM's is calculated using a simple exponential decay algorithm where the fraction of each component decaying on daily basis in which decomposition is affected by moisture, temperature, C:N ration and contact factor with the ground as presented in Figure 3.20.

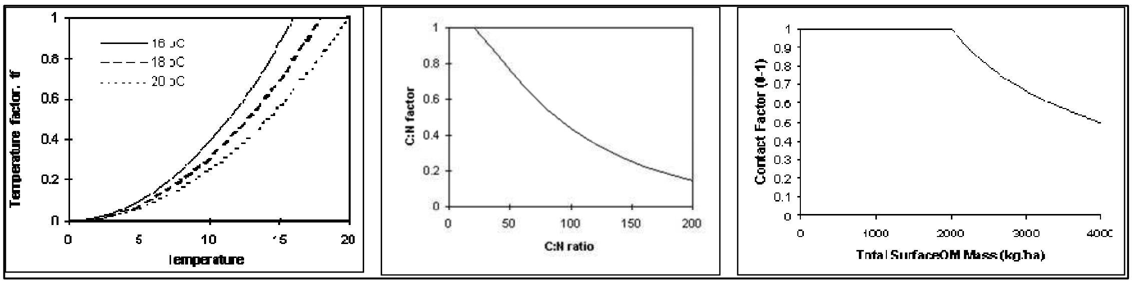



**Figure 3.20: Factors affecting Surface Organic Matter decomposition (a) air Temperature; (b) C:N ratio and; (c) Contact surface (McCown et al., 1996).**

The effect of temperature on residue decomposition is described by:

Temperature Factor = (average air temperature/opt_temp)$^2$

This factor is then constrained to values between 0 and 1. The resultant relationship is shown in Figure 15a for three values of optimum temperature. Temperature factor tf = 20 is the default. If average temperature is less than zero, the temperature factor is zero.

The effect of contact factor (Figure 3.20c), where large amounts of surface residues are present, the overall rates of decomposition will be lower. It is presumed that the material in immediate contact with the soil decomposes more rapidly than that piled on top.

### 3.4. The APSIM Model Parameterization and Calibration

Meteorological data required by APSIM model are daily minimum and maximum temperatures, radiation and rainfall. The meteorological data were measured in the trial site with a HOBO Weather Micro Station with automatic data logging. In order to simulate maize growth in the study area, the required input data for APSIM (version 7.1) was configured accordingly for the following modules: SoilWat (Soil water), SoilN (soil nitrogn), SurfaceOM (surface organic matter) , and Maize (maize crop). Soil parameters were measured from three soil profiles (up to 150 cm depth) in the trial site and supplemented by a detailed soil survey by Wijnhoud (1997). In addition, soil water measurements in the trial plots were used to assess soil water content at field capacity and air dry, especially for the top-soil (0-10 cm depth); for the purpose of water study periodic soil water measurements were conducted twice a week, during the cropping season, using AquaPro probes with access tubes installed up to 80cm depth, in the trial plots. Three access tubes were installed per plot. Table 3.2 and 3.3 show respectively the soil and crop data required in the APSIM model and the methods used for this study.

**Table 3.2: Soil parameters for the APSIM simulation and methods used. Soil samples were taken for each identified horizon at a representative depth.**

| Parameter | | Method used |
|---|---|---|
| | | |
| **Soil water parameters** | | |
| | Bulk Density ($g/cm^3$) | Oven dried (105deg. C) to constant weight, after Blake and Hartge (1986). |
| | Saturated water content ($cm^3/cm^3$) | Initial drainage Curve (IDC) as described by Klute (1986) |
| | Field capacity ($cm^3/cm^3$) | Initial drainage Curve (IDC) as described by Klute (1986) |
| | Wilting point ($cm^3/cm^3$) | - |
| | Air dry ($cm^3/cm^3$) | - |
| | | |
| **Soil N parameters** | | |
| | Organic C (g/kg) | Walkley and Black method as described by Nelson and Sommers (1982) |
| | Nitrate-N (mg/Kg) | - |
| | Total Nitrogen (N) | Kjeldahl procedure, as described by Bremner and Mulvaney (1982) |
| | | |
| **Soil P parameters** | | |
| | Labile P (mg/kg) | Olsen method as described by Olsen and Sommers (1982). |
| | P sorption (mg/kg) | Total P by the Perchloric acid ($HClO_4$) digestion (Jackson, 1958) |
| | | |
| **Other Soil profile parameters** | | |
| | pH | 1:2.5 soil:KCl (1M), by a standardized pH-meter |
| | EC | - |
| | OM | Walkley and Black method as described by Nelson and Sommers (1982) |
| | CEC | Ammonium acetate method |
| | Ca | Ammonium acetate method |
| | Mg | Ammonium acetate method |
| | Na | Ammonium acetate method |
| | K | Ammonium acetate method |
| | ESP | calculated |
| | Texture (particle size: sand, silt and clay) | Soil texture classes and size classification according to USDA system, i.e., sand (2000-50 µm), silt (50-2 µm), clay (<2 µm), Gee and Bauder (1986) |

Missing data in the soil parameters were completed using secondary source from a detailed soil survey by Wijnhoud (1997), especially that related to soil water retention and electrical conductivity (the soil is a non-saline). Initial nitrate and ammonium content was subject to calibration in the model.

**Table 3.3: Notes on the Observation of Phenology Stages. There are 11 crop stages in the APSIM maize module**

| Phenology stage | Observation Notes |
|---|---|
| Sowing | Seeding date |
| germination | - |
| emergence | Date for 50% emmergency |
| end_of_juvenile | - |
| floral_initiation | - |
| flowering | Date for 50% flowering |
| start_grain_fill | Date for 50% silking |
| end_grain_fill | - |
| maturity (*) | Date for 50% maturation: |
| harvest_ripe | - |
| end_crop | Harversting date |

(*) Physiological maturation of Maize: when the black layer is visible at the base of the grain.

Crop management data collected in the trial included: soil preparation (according to the treatments), percentage of crop residues cover in the soil at planting time, cultivar and planting density, fertilizer application (composition, amount and date of application).

Since the maize cultivar used was not previously parameterized for the APSIM model, simulations using various maize cultivars available with the model were conducted in order to select one with similar physiologic characteristics (especially phenology stages, Table 3.3). Model calibration was conducted with especial attention to yield and total soil water. For the total soil water (depth, 0-90cm), soil parameters studied were: run-off (CN, reduction factor and soil cover); and soil evaporation (parameters U and CONA). Calibration used data from a high fertilized plot trial in the adjacent area to the long term trial. To test the model, data from the 2008-09 and 2009-10 cropping seasons from the long term trial in conservation agriculture were used. Measured and simulated data on soil water and yield were compared using the root mean standard error (RMSE), base on the difference between observed and simulated values.

## 3.5. Data Collection and Analysis.

### 3.5.1 Meteorological Data.

The meteorological data were measured in the trial site with a HOBO Weather Micro Station with automatic data logging. The measured meteorological data were air temperatures, solar radiation and rainfall. The HOBO Micro station was established in October 2008, so, available data is from 14 October 2008 to 7 January 2010. Since the period under study includes 3 cropping seasons from October 2007 to June 2010, meteo data were supplemented by the existing local climatological station located about 1Km from the study trial site. In case data were missing in both sources, data from NASA Climatology Resource for Agroclimatology were used. In all case, gap filling used data derived from correlation in daily data between the HOBO Micro station and the supporting data source for minimum and maximum temperature and for daily solar radiation. For the rainfall data, correlation was established between 3-5 days data. Meteorological data were used to characterize the cropping seasons and for the water balance study with the APSIM model.

### 3.5.2 Crop Data.

Crop data were collected through direct observation and registration of crop phenology stages and crop management (Table 3.4). Crop and soil management followed the trial protocols according to the experimental design (section 3.1, describing the on-station trial); Annex A presents a detailed description of the plots management and harvesting procedures.

**Table 3.4: Registered crop phenology stages and crop management procedures in the trial**

| Parameter | | Observation/ Registration |
|---|---|---|
| | | |
| **Phenology stage** | | |
| | Seeding | Seeding date |
| | emergence | Date for 50% emmergency |
| | flowering | Date for 50% flowering |
| | start grain fill (silking) | Date for 50% silking; black layer is visble at the base of the grain |
| | maturity | Date for 50% maturation: |
| | Harversting | Harversting date |
| | | |
| **Crop Management** | | |
| | Crop | Type, variety or cultivar |
| | Seeding | Row spacing (cm) |
| | | Plant (station) spacing (cm) |
| | | Plants/station |
| | Basal Fertilizer applied (kg/ha) | Date of application and nutrient content |
| | Top-dressing applied (kg/ha) | Dates of application, amounts and nutrient content |
| | Weeding | Dates of weedings |

**Data Analysis and Statistical Method:**

To assess the impact of different treatments, crop yield was assessed using the analysis of variance (ANOVA) following the general linear model (GLM) procedure at the probability level of P<0.05; if significance is detected, then the LSD test was used to compare the means. The LSD (Least Significant Difference method) procedure uses standard error (SE) difference Student's t-statistic (T) for the degree of freedom associated with mean standard error (MSE); this method is also called the T method. LSD controls the comparisonwise error rate at alpha (significance level) but allows the experimentwise error rate to increase as the number of comparisons increases (Statistix, 2008). Given that in field trials, in particular, with large plot size (in this study plot size was 24x18 $m^2$) spatial variability might be reasonable high, the LSD test was chosen in order to account for possible spatial variability. Large plots sizes were necessary for practical purpose with the different seeding technologies. Therefore, statistical analysis was conducted for a limited number of comparisons (four treatments in total) either in continuous maize cropping treatments or for the crop rotation treatments.

In addition, crop data were used in the APSIM simulation model for better understanding of the impact of CA practices in soil water and soil fertility management.

### 3.5.3 Soil Data.

**Baseline soil data**

Soil profile description was conducted in the trial site in three profiles opened, one in the middle and two in the adjacent area. Profile description followed FAO guidelines for soil description FAO (2006) and supplemented by a previous specialized study in the area (Wijnhoud, 1997). Soil profile description was conducted in July 2009; therefore, selected sites for profile description were not previously disturbed by the on-going trial. Soil samples were taken at representative depth in the identified soil horizons and laboratory analysis conducted for selected parameters (Table 3.5).

**Table 3.5: Soil parameters analyzed in the laboratory to supplement soil profile description and methods used for the baseline soil study.**

| Parameter | | Method used |
|---|---|---|
| | | |
| **Soil water parameters** | | |
| | Bulk Density (g/cm$^3$) | Oven dried (105$^o$C) to constant weight, after Blake and Hartge (1986). |
| | Saturated water content (cm$^3$/cm$^3$) | Initial drainage Curve (IDC) as described by Klute (1986) |
| | Field capacity (cm$^3$/cm$^3$) | Initial drainage Curve (IDC) as described by Klute (1986) |
| | Wilting point (cm$^3$/cm$^3$) | - |
| | | |
| **Texture (particle size: sand, silt and clay)** | | Soil texture classes and size classification according to USDA system, i.e., sand (2000-50 μm), silt (50-2 μm), clay (<2 μm), Gee and Bauder (1986) |
| | | |
| **Soil fertility parameters** | | |
| | Organic C (g/kg) | Walkley and Black method as described by Nelson and Sommers (1982) |
| | Available P (mg/kg) | Olsen method as described by Olsen and Sommers (1982). |
| | Total P (mg/kg) | Total P by the Molybdenum blue method |
| | Total N (%) | Kjeldahl procedure, as described by Bremner and Mulvaney (1982) |
| | pH | 1:2.5 soil:KCl (1M), by a standardized pH-meter |
| | Soil organic matter (OM) | Walkley and Black method as described by Nelson and Sommers (1982) |
| | Cation exchange capacity (CEC) | Ammonium acetate method |
| | Ca | Ammonium acetate method |
| | Mg | Ammonium acetate method |
| | Na | Ammonium acetate method |
| | K | Ammonium acetate method |

Soil baseline study was intended to support the understanding of the soil potential and limitation in crop production; the data were used in the crop simulation APSIM model to study the impact of different treatments in the trial for crop production.

### Soil sampling in the trial

Soil samples were collected during the trial implementation in October 2007, just before the start of the 2007/8 season and in July 2009 (at the end of the 2008/9 season). In October 2007, Soil samples were taken on six measuring points in each plot in 5 layers (0-10cm, 10-20cm, 20-30cm, 30-60cm, 60-90cm). In July 2009, soil sampling followed the same methodology but, samples were taken only on 0-10cm depth. For the collected soil samples three soil parameters were analysed, total N, available P and soil organic matter. The methods of analysis used were Walkley and Black for soil organic matter; Kjeldahk for total-N; and Bray-1 method for P (2007 samples), Olsen method for P (2009 samples). Soil results were used to assess the impacts of different treatments in soil quality change with time. Differences in soil specific parameter was assessed using the analysis of variance following the general linear model (GLM) procedure at the probability level of $P<0.05$; if significance is detected the LSD test was used to compare the means (as explained 3.5.2 for the statistical method on crop data).

### 3.5.4 Soil Moisture Data with AquaPro probes

To monitor soil water AquaPro probes (sensors) access tubes were installed up to 82 cm depth in September 2009. The readings were started on the 30th of October 2009, once a week before the season. During the cropping season the readings were taken two times a week. The measurements of soil moisture were intended to assess the impact of different soil management technologies on soil water management and availability for crop production. Three access tubes were installed in each plot; AquaPro readings were taken in 12 different soil depths (2.5; 7.5; 15; 22.5; 30; 37.5; 45; 52.5; 60; 67.5; 75 and 80 cm depth); Figure 3.21 shows the use of the AquaPro device.

AquaPro's sensors use radio frequency technology to measure the dielectric coefficient of soil with varying moisture content. The Moisture sensor transmits a very low powered radio frequency through the soil to measure moisture. There are two copper bands on the end of the sensor that are radio antennas, one antenna transmits a low powered radio frequency signal that is received by the other antenna. The microprocessor can determine the moisture content by the change in frequency of the signal it receives. The more moisture in the soil, the more the frequency of the signal is changed. To take soil moisture readings, the AquaPro moisture sensor is inserted into the PolyPro access tubes at the desirable depth. The access tubes are installed in locations intended to monitor soil moisture levels. The access tubes are constructed of specially extruded polycarbonate plastic, and their wall dimensions have been factored into the calibration and moisture reading functions of the sensor (AquaPro Sensors, 2011).

**Figure 3.21: Photos showing the installed access tubes in the trial plots (left, up and down) and readings details with AquaPro probes (right).**

AquaPro sensors readings are related to a 'pre-calibration' in a plastic bucket of water, it is, 100% in water. This same procedure can be used to calibrate the probe to field capacity or saturation of a specific sample. In the case of a specific sample, calibration will be set to 100% for the field capacity or saturation accordingly. Therefore, media-specific sensor calibrations have been recommended over the general calibrations (Stangl et al., 2009). In order to get the real volumetric soil water content there is a need for a calibration to get a relationship between the readings and water content. AquaPro probes were calibrated in situ in the trial site following the methodology presented by Sentek (2009). AquaPro access tubes were installed in three adjacent sites, two access tubes each (Figure 3.22). AquaPro readings and samples for gravimetric soil measurements were taken. Samples were taken as close as possible to the access tubes at the corresponding depth using a auger. There after, three trenches were open closed to the sites to facilitate sampling for bulk density at the corresponding depth of the moisture measurements. Bulk density (bd) was used to convert gravimetric soil moisture (W) to volumetric soil water (vol.):

vol = w.bd.100;   with: vol. (% volume); w (g/g); bd ($g.cm^{-3}$).

Thus, a relationship was derived for a wide range of soil water between volumetric soil water (as independent variable) and AquaPro readings (as dependent variable). A linear regression analysis was conducted to assess the significance of the relationship and to derive a respective regression equation.

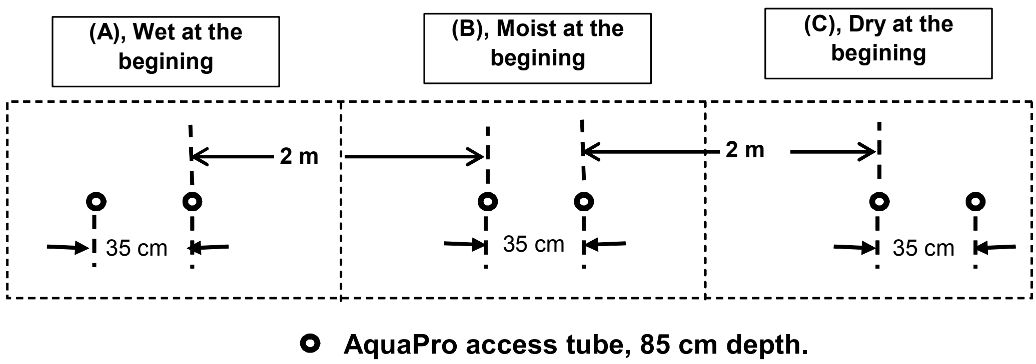



**Figure 3.22: Access tubes installed in three adjacent plots (dry, moist and wet conditions) for the calibration of AquaPro probes.**

Soil water data were used to calibrate the APSIM model and to assess soil water balance with the APSIM model in order to understand the impact of different treatments in soil water management and crop productivity in the study area.

### 3.5.5 Infiltration Measurements

Infiltration measured with a mini-rainfall simulator described by (Thierfelder et al., 2005; Amezquita et al., 1999) was used to assess soil infiltration rate in the trial plots. Measurements were conducted during three consecutive years: Feb.-Mar. 2008 (Putz, 2008); Mar.-Apr. 2009; and Jan.-Feb. 2010. The mini-rainfall generates raindrops enabled by syringes. The mini-rainfall simulator is equipped with a Mariotte flask where rain intensity can be calibrated (Figure 3.23). The simulations were conducted during 60 minutes, with collection of run-off each 5 minutes and the final run-off; a defined soil surface area (32cm x 40cm) was irrigated, see recollecting tray (Figure 3.24), and rain intensity during the measurements were allowed to be between 95-105 mm/hr. Syringes of 2.75 mm were used which lead to a mass of raindrop of 0.00992 g and a final velocity of raindrop of 4.04 $m.s^{-1}$ (Thierfelder et al., 2005). Three measurements were conducted per plot; the mini-rainfall simulator was installed at a height of about 1 m inside the plot boundary. Crop residues and weeds were carefully removed from the soil surface before measurement. The simulator was calibrated at the beginning and at the end of each measurement by collecting and measuring a defined rain period of 1 min.

**Figure 3.23: Mini-rainfall simulator used in the study, evidencing the Mariotte flask (left), and syringes arrangement (right).**

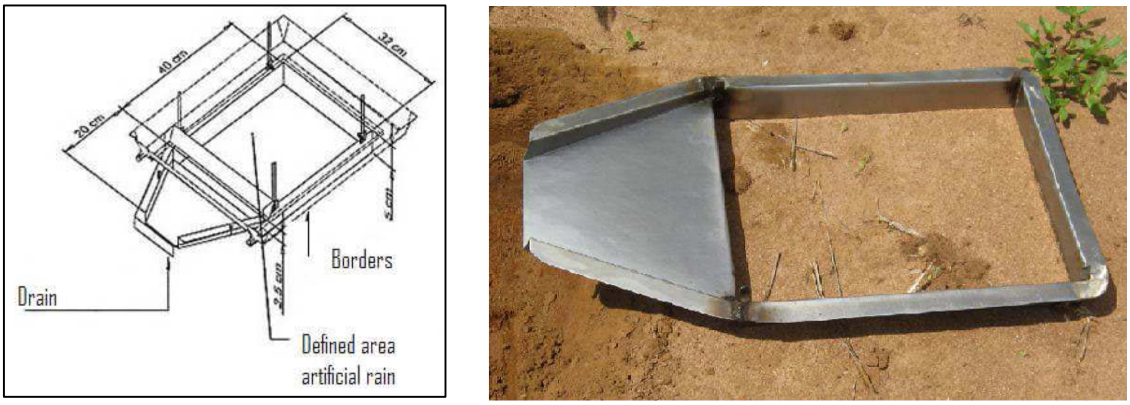



**Figure 3.24: Recollecting tray, Amesquita et al., (1999) on the left, photo of the one used in this study (right).**

To facilitate the insertion of the recollecting tray, the soil was wetted the day before for drier conditions.

The resulted total run-off after 60 minutes was used to assess the impacts of different treatments in soil infiltration capacity. Differences in run-off were assessed using the analysis of variance following the general linear model (GLM) procedure at the probability level of $P<0.05$; if significance is detected the LSD test was used to compare the means. The measured accumulated rainfall and run-off relationship were used to supplement the assessment of the APSIM model results (as explained 3.5.2 for the statistical method on crop data).

### 3.5.6 Soil Fauna and Activity

Soil fauna activity in the trial plots was assessed by counting the (i) below ground soil fauna and (ii) termites holes on the soil surface. Below ground soil fauna was assessed by collecting and counting below ground organisms (namely termites, earthworms, beetle larvae, centipedes and other visible insects) on conservation agriculture and conventionally ploughed treatments. Soil samples were collected from the field when moist, in a monolith 25x25 cm each 10 cm up to 30 cm depth. Measurements were conducted during two consecutive years, in March 2009 and February 2010.

Intense termite's activities in the study area resulted that termites consumed all crop residues before the next cropping season started. Therefore, it was initiated termite's activity assessment through termite's holes counting; it was used a metal frame with (32cm x 40cm) of surface area (Figure 3.25). The diameters of the termites' holes were approximately 0.5 to 1.5 mm (Putz, 2008). Termite's holes counting were conducted during three consecutive years, in February 2008 (Putz, 2008), March - April 2009, and May 2010 during this study; in total 15 samples were taken per plot.

**Figure 3.25: Metal frame to record the density of termites holes (Putz, 2008)**

Soil fauna activity data were assessed using the analysis of variance following the general linear model (GLM) procedure at the probability level of $P<0.05$; if significance is detected the LSD test was used to compare the means (as explained 3.5.2 for the statistical method on crop data). Soil fauna activity results were used, in this way, to supplement the assessment on soil fauna activity interactions as results of different seeding technologies being studied.

# 4. Results and Discussion

## 4.1 General Data

### 4.1.1 Meteorological Data

The meteorological data in reference is from June 2007 to June 2010. Although the trial on CA in Sussundenga was initiated in the year 2006, the crop data analysed in this study is relative to three years, namely: seasons 2007/8, 2008/9 and 2009/10; the cropping season in the study area starts in November. Available data with the HOBO micro station in the trial site are from 14 October 2008 to 7 January 2010. The Correlations between meteorological data measured in the trial site with the neighbouring Sussundenga Climatic Station as with NASA data (NASA, 2010) are presented in Annex B; the resulting equations used for the gap fillings in daily data are presented in Table 4.1. A complete set of daily data on rainfall, minimum temperature, maximum temperature and incoming solar radiation (2007-2010) was gathered for the simulations with the APSIM model used in this study.

**Table 4.1: Regression coefficients (A) and (B) from the fitted linear regression equation analysis: LLT(Y) are measured data in the trial site; Sus(X) are the measured data in the local climatic station and NASA(X) are data from (NASA, 2010).**

| Meteorological Parameter (X) | Acronym | (A) | (B) | R-squared | Probability level (Alpha=) | Observation, data used. |
|---|---|---|---|---|---|---|
| **LTT(Y) = Sus_(X) x A + B** | | | | | | |
| Maximum temperature (oC) | maxt | 0.8071 | 6.0591 | 0.9971 | 0.000 | Daily data |
| Minimum temperature (oC) | mint | 0.9504 | 1.0021 | 0.8664 | 0.000 | Daily data |
| Incoming solar radiation (MJ/m2) | rad | - | - | - | - | Daily data |
| Rainfall (mm) | rain | 0.439 | 0 | 0.9178 | - | 5-days total rain |
| **LTT(Y) = NASA(X) x A + B** | | | | | | |
| Maximum temperature (oC) | maxt | 1.0086 | 0 | 0.9886 | 0.000 | Daily data |
| Minimum temperature (oC) | mint | 1.3127 | -5.9352 | 0.8598 | 0.000 | Daily data |
| Incoming solar radiation (MJ/m2) | rad | 0.975 | 0 | 0.9862 | 0.000 | Daily data |
| Rainfall (mm) | rain | - | - | - | - | - |

Figure 4.1 presents rainfall data for the period June 2007 to June 2010 as long-term average rain and reference evapotranspiration for a comparative view; maize crop was grown during the three seasons as indicated in the Figure. Early maturing local cultivar (Matuba) was grown in the season 2007/08 while in the two following season's hybrid maize PAN67 cultivar was produced.

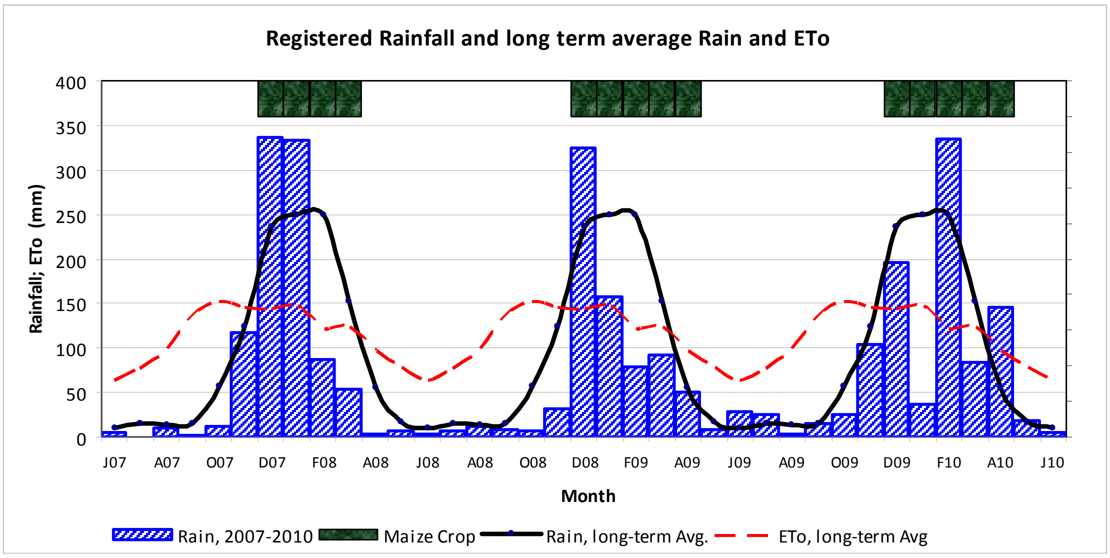



**Figure 4.1: Observed Rainfall (June 2007 – June 2010) and long-term average Rainfall and Reference Evapotranspiration (ETo) in Sussundenga. Maize cropping period in the trial is shown for the cultivar Matuba used in 2007/8 and a hybrid cultivar PAN67 used in 2008/09 and in 2009/10.**

Rainfall variability comparatively to the long-term average is evident in all three years, some months with more and others with less. In all three seasons a tendency to water stress is expected during the maize growing period. Therefore, the impact on maize production will depend on the exact amount of stress and the affected growing stage (phenology stage).

Rainfall variability is regarded as the reason for a high risk of crop failure in rainfed agriculture in Mozambique (Schouwenaars, 1988; Reddy, 1986); other studies realize that water related problems in rainfed agriculture in water scarcity prone tropics are often related to high intensity and large variability of rainfall, rather than low cumulative volumes of rainfall (Barron et al., 2003; Rokstrom et al., 1998), so that crops suffer from dry spells leading to crop lost or reduced yield.

A close view to rainfall distribution and dry spells occurrence (Figures 4.2) lead to the conclusion that, although high monthly rainfall amount were registered (from December to February) most of it occurred in few consecutive days and long dry spells were registered (7 days dry spell are shown in Figure 4.2), especially in the cropping seasons 2008/09 and 2009/10. The cropping season 2007/08 was reasonable good. A ‘dry spell’ was defined after Barron et al., (2003), as any consecutive number of days defined as ‘dry’ , and a ‘dry’ day defined as a day with less than 0.85 mm rain. Figure 4.3 presents monthly data on minimum temperature, maximum temperature and incoming solar radiation; this shows a tendency to high water demand in the same months of high rainfall, evaporative demands is high as a results of high temperatures and high solar radiation observed in the same period (reference evapotranspiration, ETo, is presented in Figure 4.2 together with rainfall).

For a better understanding and assessment of different climatic parameters including the interactions with soil properties and crop physiology, a more integrated analysis can be conducted with the help of a crop modelling. APSIM model will later be used to supplement this analysis.

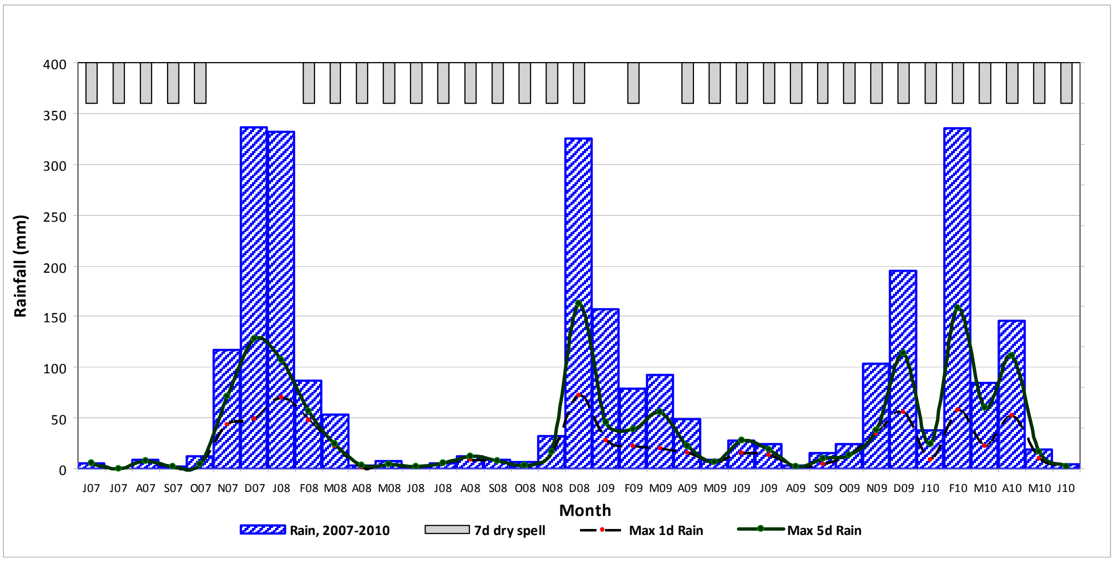



**Figure 4.2: Monthly rainfall, maximum 1 and 5-days rainfall and occurrence of a 7-days dry spell (June 2007 – June 2010) in Sussundenga.**

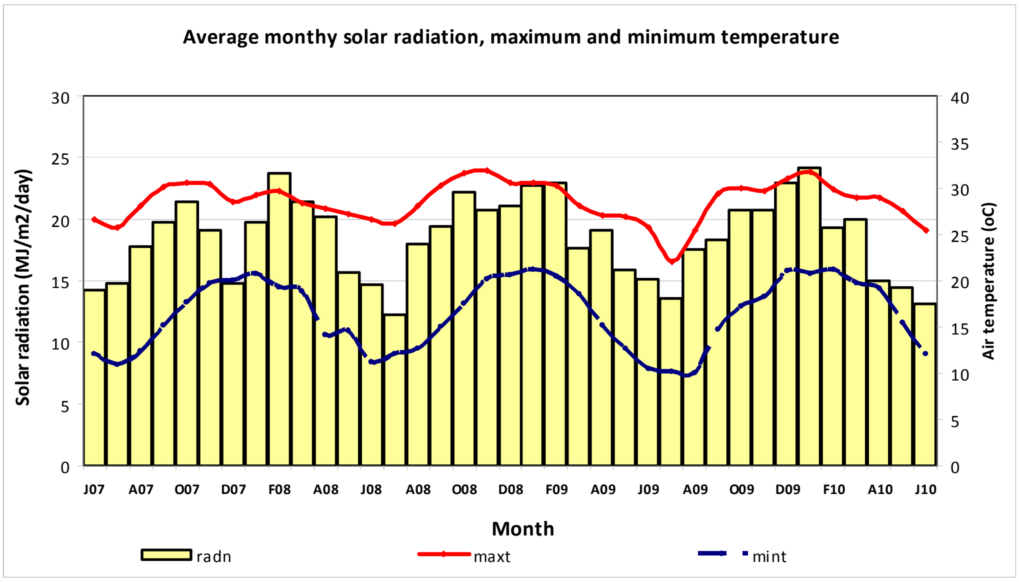



**Figure 4.3: Monthly incoming solar radiation, minimum and maximum air temperaturera (June 2007 – June 2010) in Sussundenga.**

### 4.1.2 Soil Data

Measured soil parameters, taken from the average of the three soil profile analyzed, are presented in Table 4.2; the studied soil profiles did not show great differences and were in accordance with the previous study conducted in the area (Wijnhoud, 1997). Soil laboratory analyses were conducted in the laboratory of the Agrarian Research Institute of Mozambique (IIAM) in Maputo. Soil type was described as Haplic Lixisol, according to FAO soil classification system.

**Table 4.2: Soil profile information from the trial site in Sussundenga.**

| Soil Horizon (Depth) | 0-30 cm | 30-70 cm | 70-120 cm |
|---|---|---|---|
| **Soil water parameters** | | | |
| Bulk Density (g/cm$^3$) | 1.493 | 1.430 | 1.413 |
| Saturated water content (% vol.) | 44.0 | 45.0 | 47.0 |
| Field capacity (% vol.) | 33.0 | 36.0 | 38.0 |
| Permanent wilting point (% vol.)* | 13.5 | 28.0 | 33.0 |
| **Particle size** | | | |
| Sand (%) | 70.8 | 52 | 41 |
| Silt (%) | 11.8 | 10.4 | 8.3 |
| Clay (%) | 17.4 | 37.6 | 50.7 |
| Texture | Sandy loam | Sandy clay loam | Clay |
| **Soil fertility parameters** | | | |
| Soil Organic Matter (%) | 1.55 | 0.82 | 0.37 |
| Total P (ppm) | 32.74 | 20.13 | 21.05 |
| Total N (%) | 0.07 | 0.02 | 0.04 |
| pH (in KCl) | 4.10 | 4.65 | 5.18 |
| CEC (cmol+/Kg) | 6.48 | 4.43 | 5.89 |
| Ca (cmol/Kg) | 2.32 | 2.50 | 2.80 |
| Mg (cmol/Kg) | 0.63 | 0.71 | 0.81 |
| K (cmol/Kg) | 0.34 | 0.31 | 0.38 |
| Na (cmol/Kg) | 0.10 | 0.07 | 0.05 |

* after Wijnhoud (1997)

In the table 4.2, measured total nitrogen depth (30-70cm) seems underestimated, expected carbon/ nitrogen ratio is 9-14, Wijnhoud (1997), the presented result seem to have been strongly affected by spatial variability; therefore, carbon/ nitrogen ration was carefully assessed in the simulation with the APSIM model and final value was subject to calibration.

The soil of the study area belong to the group of fine textured red soils originated from metamorphic acid rocks (gneiss, migmatite) in situ weathered (Wijnhoud, 1997). Under natural conditions, they can be evaluated as having good physical properties, especially, water retention and infiltration capacity; therefore, the values of bulk density are high (Table 4.2, all values higher than 1.3 g.cm$^{-3}$) for a good root development; it will result in reduced infiltration capacity and reduced aeration, (FAO, 2006). The high bulk density in this soil is referred as a result of machinery use in the agrarian station (Wijnhoud, 1997). The soil fertility of this soil is poor as evaluated by its low CEC, low base saturation, low soil organic matter and low soil nitrogen; due to its high acidity, a low nutrient availability for crop growth is expected with especial reference to phosphorus that may be retained in aluminium or iron complexes. Thus, general recommendation to improve crop productivity of this soil should focus on the reduction of the bulk density, through addition of organic matter and to the use of fertilizers and lime for improved nutrient availability to crops.

### 4.1.3 Calibration of AquaPro Probes for the Measurement of Soil Water in Sussundenga Trial Site

**Results on Soil Bulk Density:**
Figure 4.4 shows the results on the measurement of bulk density for calibration of AquaPro probes.

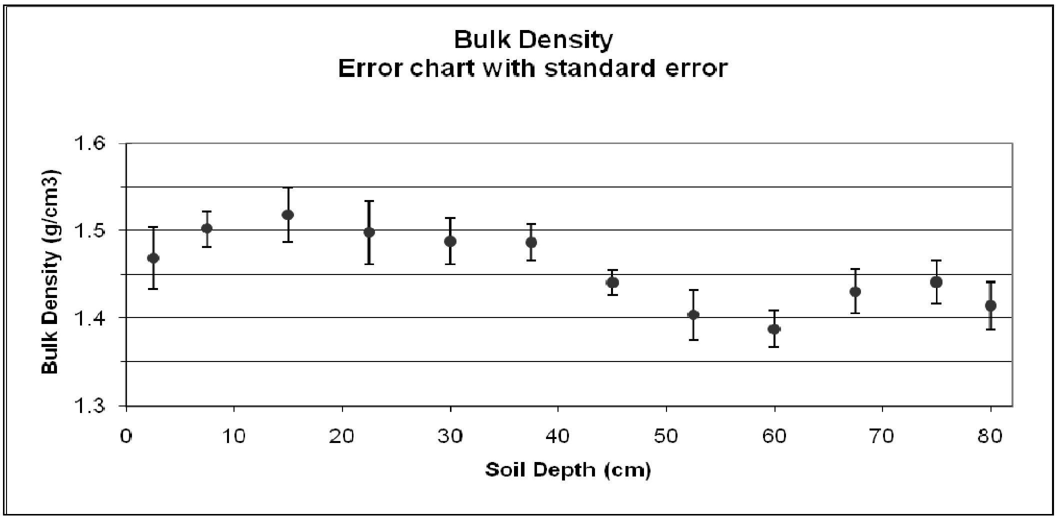



**Figure 4.4: Measured soil bulk density for the calibration of AquaPro probes.**

From the bulk density results (Figure 4.4), in the top soil, soil organic matter may contribute to relatively low bulk density (the top 10cm). There is a tendency then of reducing bulk density from the top to about 60 cm depth; this may be a result of the high compaction on the top soil due to use of machinery (tractor for ploughing) and the fact that texture tend to be finer with depth resulting in a natural lowering of bulk density.

**Relationship Between Volumetric Soil Water Content and AquaPro Readings:**
The fitted values of volumetric water content and AquaPro readings was good (Figure 4.5) with regression coefficient R-squared = 0.82; at statistical significance probability level of less than 0.001%. The statistical analysis was conducted using the software Statistix 9.0.

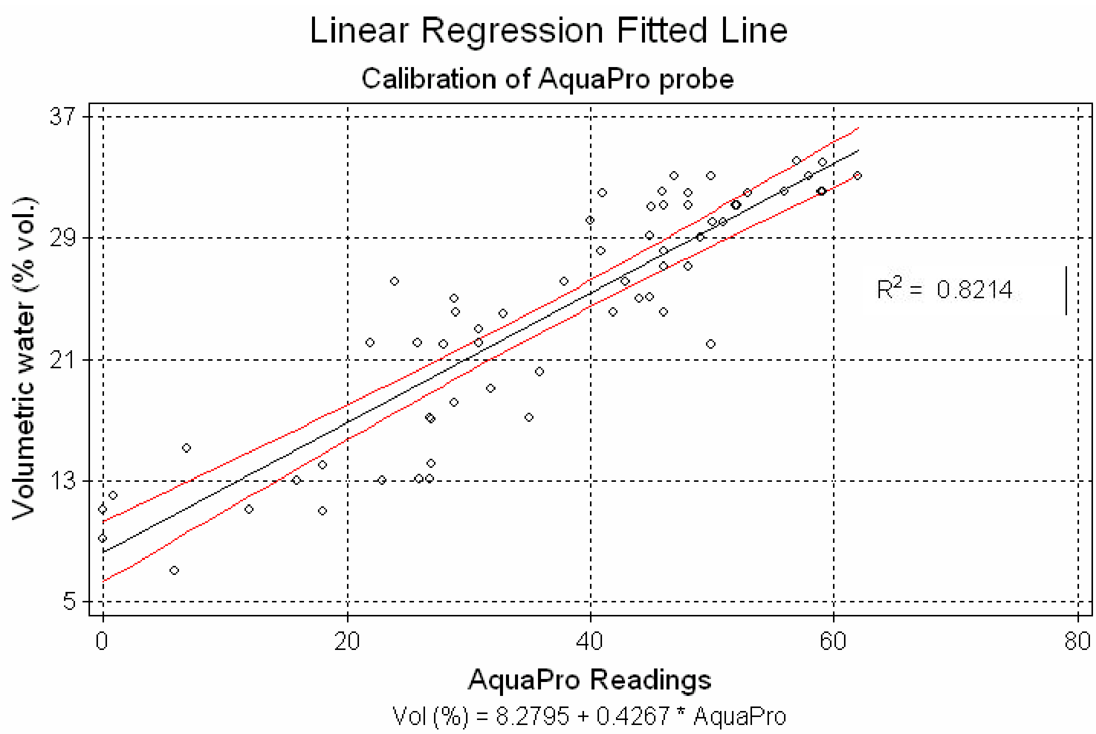



**Figure 4.5: Calibration curve of AquaPro probes readings to volumetric water content, lateral lines indicate the 95% confidence interval.**

The resulting regression equation was used to convert the AquaPro readings (AquaPro) to volumetric water content (vol.): vol. = 8.2795 + 0.4267*AquaPro.

## 4.2 Assessment of the Impact of Conservation Agriculture in Soil Properties and Maize Yield under Rainfed Continuous Maize Production in Sussundenga

### 4.2.1 Maize Yield

Maize (*Zea mays* L.) yield under continuous maize cropping in the four seeding technologies studied, direct seeding (DS), basins (BA), jab planter (JP) and traditional tillage with animal traction using a mouldboard plough (CP) were evaluated. Crop management data and observed phenology stages are presented in table 4.3 for three cropping seasons 2007/08, 2008/09 and 2009/10.

**Table 4.3: General crop management data and observed phenology stages for three cropping seasons in Sussundenga. The cultivar used in the year 2007/08 is different from the following two years as planting density.**

| Cropping Year | 2007/08 | 2008/09 | 2009/10 |
|---|---|---|---|
| | | | |
| **Crop Management (General)** | | | |
| Maize variety | Matuba | PAN67 | PAN67 |
| Basal fertizer application date | 27/11/2007 | 10/12/2008 | 25/11/2009 |
| Formula of basal fertilizer | 7:14:7 | 12:12:12 | 12:12:12 |
| Quantity of Basal fertlizer (Kg/ha) | 165 | 165 | 165 |
| Top-dressing applied (kg/ha) | 200 | 200 | 200 |
| Top-dressing fertilizer used | urea | urea | urea |
| N content in top dressing fertilizer (%) | 46 | 46 | 46 |
| Date of 1st top dressing | 05/01/2008 | 15/01/2009 | 06/01/2010 |
| Date of 2nd top dressing | 31/01/2008 | 09/02/2009 | 28/01/2010 |
| Date of 1st weeding | 20/12/2007 | 29/12/2008 | 05/12/2009 |
| Date of 2nd weeding | 15/01/2008 | 11/01/2009 | 24/12/2009 |
| Date of 3rd weeding | 01/03/2008 | 07/02/2009 | 04/02/2010 |
| Row spacing (cm) | 90 | 90 | 90 |
| Plant (station) spacing (cm) | 50 | 50 | 50 |
| Plants/station | 1 | 2 | 2 |
| | | | |
| **Phenology stage** | | | |
| Seeding | 27/11/2007 | 10/12/2008 | 25/11/2009 |
| emergence | 05/12/2007 | 20/12/2008 | 02/12/2009 |
| flowering | 04/02/2008 | 12/02/2009 | 27/01/2010 |
| start grain fill (silking) | 15/02/2008 | 18/02/2009 | 25/02/2010 |
| maturity | 02/03/2008 | 04/04/2009 | 15/03/2010 |
| Harversting | 02/04/2008 | 05/05/2009 | 07/04/2010 |

Top dressing (Table 4.3) with urea was applied in two split applications of 100 Kg/ha each; notice also that plant density in 2007/08 was half of the remaining year.

In Table 4.4, more information is provided concerning the management of a cover crop and crop residues. As initially planned, crop residues were expected to build up in the CA plots, therefore, due to high termites' activity in the area crop residues were completely removed by the termites. In the first two years of the trial, residues were brought from outside the trial area (especially grass residues) up to 30% ground cover at seeding. However, the residues remained not more than two weeks. In order to increase dry matter production for ground cover, in the third and forth year (years 2008 and 2009) *Mucuna pruriens* was seeded when maize crop started wilting. Nevertheless, ground cover did not increase much, only 10% of ground cover was reached at the beginning of the 2009/10 season (table 4.3).

**Table 4.4: Crop residues management in different treatments and observed data on crop residues at seeding. Crop residues cover did no build up as expected in the CA plots due to high termites' activity.**

| Treatment | CP | DS | BA | JP |
|---|---|---|---|---|
| **Treatment short description** | mouldboard plough with animal traction | CA: Direct seeding with animal traction | CA: Basin | CA: Jab Planter |
| **Year 2006/07** | | | | |
| Residue cover at maize seeding (%) | 0 | 30 | 30 | 30 |
| Seeding data for Mucuna pruriens | - | - | - | - |
| Date, residues removal | 27/11/2007 | No | No | No |
| **Year 2007/08** | | | | |
| Residue cover at maize seeding (%) | 0 | 30 | 30 | 30 |
| Seeding data for Mucuna pruriens | 02/03/2008 | 02/03/2008 | 02/03/2008 | 02/03/2008 |
| Date, residues removal | 02/04/2008 | - | - | - |
| **Year 2008/09** | | | | |
| Residue cover at maize seeding (%) | 0 | 0 | 0 | 0 |
| Seeding data for Mucuna pruriens | 12/02/2009 | 12/02/2009 | 12/02/2009 | 12/02/2009 |
| Date, residues removal | 05/05/2009 | No | No | No |
| **Year 2009/10** | | | | |
| Residue cover at maize seeding (%) | 0 | 10 | 10 | 10 |
| Seeding data for Mucuna pruriens | 25/02/2010 | 25/02/2010 | 25/02/2010 | 25/02/2010 |
| Date, residues removal | 07/04/2010 | No | No | No |

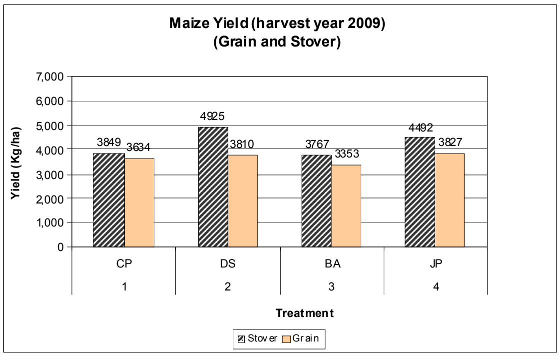
From the table 4.4 it can be seen that residue cover were not satisfactory for the fully conservation agriculture practice; crop residues cover is one of the basic principles of conservation agriculture practice.

The table 4.5 shows that maize crop yield under continuous maize cropping did not significantly differ among the three CA treatments and the traditional tillage studied, during the three consecutive years presented. The assessment was done for the grain yield as for the total above ground biomass except grain (the stover) from the second year after the starting of the trial. Figures 4.6 presents the maize yield for the last two years (seasons 2008/09 and 2009/10) with emphasis to yield variability between years as a result mainly of rainfall variability; rain distribution were very different in the two years and dry spells of different durations occurred and impacted severely the 2009/10 season.

**Table 4.5: Average maize yield* (grain and stover) for three consecutive harvesting years.**

| Treatment | Description | Grain yield (Kg/ha) | | | | | | Stover yield (Kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2008** | | 2009 | | 2010 | | 2008** | | 2009 | | 2010 | |
| CP | Check Plot, traditional farmers practice | 777.8 | a | 3634.0 | b | 1266.6 | c | 1117.0 | a | 3849.3 | b | 1941.1 | c |
| DS | Direct seeding, continuous maize | 924.0 | a | 3810.0 | b | 1067.8 | c | 1363.3 | a | 4924.8 | b | 1703.2 | c |
| BA | Basins, continuous maize | 1058.0 | a | 3353.3 | b | 1163.5 | c | 1472.8 | a | 3767.3 | b | 1842.1 | c |
| JP | Jab Planter, continuous maize | 1032.5 | a | 3827.3 | b | 939.6 | c | 1478.0 | a | 4492.3 | b | 1863.8 | c |

* Treatments means within the same column followed by the same letter are not significantly different at probability leve of 0.05.
** Data from Christian Thierfelder, CIMMYT, Harare



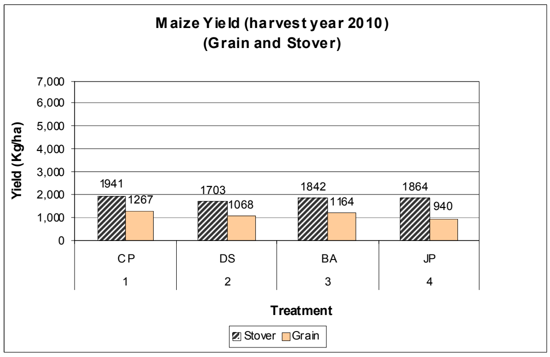




**Figure 4.6: Maize yield in harvesting years 2009 and 2010, no significant differences were found between the treatments in the same year; yield differences between the two years were perceived as a result of differences in rainfall patterns.**

Nevertheless, differences in yield due to different treatments were not evident, a number of soil parameters were assessed in order to understand possible tendency on cumulative impacts in soil properties. A special attention was oriented to soil water, water infiltration dynamics, soil fertility parameters (especially organic matter, soil nitrogen and available phosphorus), and soil fauna activity. The intense termite's activity in the area that consumed all crop residues before the starting of the next season demanded special attention in the fauna activity assessment.

### 4.2.2 Soil Water Measurements

Soil water was measured from November 2008 covering two consecutive seasons. Soil water reflected directly the rainfall distribution within the season and dry spells of long duration impacted negatively crop water uptake; Figures 4.7 and 4.8 show the measured total soil water in the 0-90 cm depth and rainfall during the maize growing seasons 2008/09 and 2009/10.

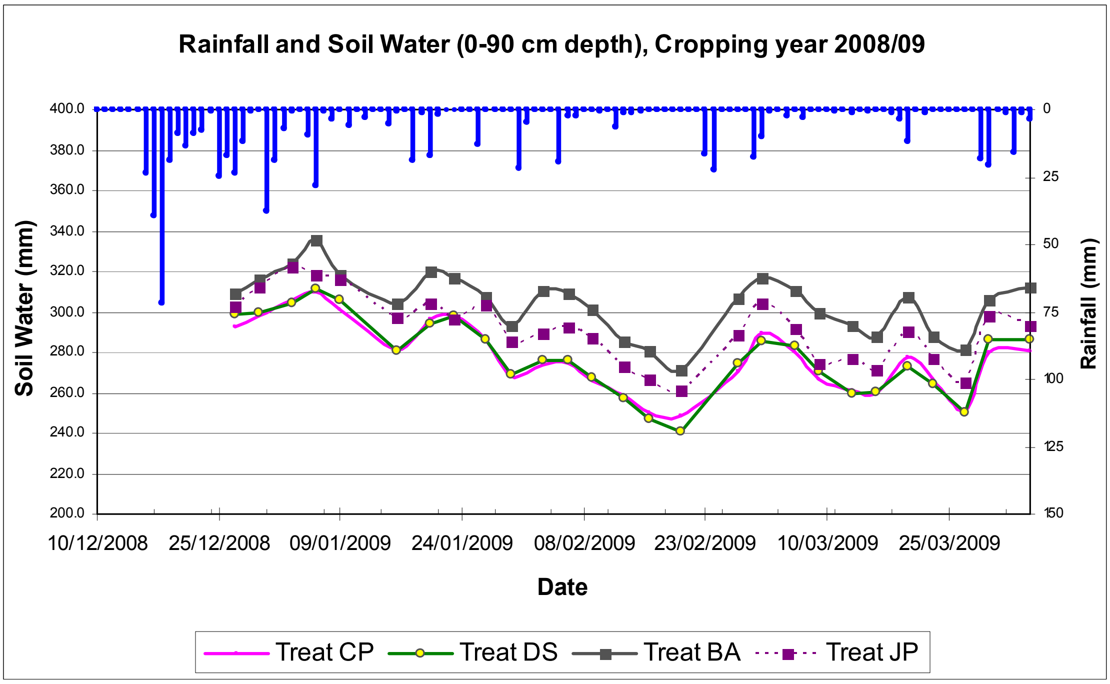



**Figure 4.7: Rainfall and measured average total soil water (0-90 cm depth), 2008-09 season in maize crop, treatments CP, DS, BA and JP.**

In Figure 4.7 cropping year 2008/09, a short dry spell affected the maize crop in the flowering (mid-February). In general, to the two extremes, tillage treatment shows less total soil water than basin treatment. In the cropping season 2009/10 (Figure 4.8), a long dry spell separated by small showers affected the crop in its majority of growing season, from crop emergence and to all flowering stage (flowering 27 January). Excessive rains were registered at maturation. Similarly to the previous cropping season, tillage treatment shows less total soil water than basin treatment; differently, JP treatment follows the CP treatment. In both cases different treatments did not show significant differences in maize yield within the same year, as shown in Table 4.5. Therefore, water shortage affected strongly the 2009/10 maize crop in its most sensitive stage (the flowering and grain filling) with direct impact in total yield. Minimum total soil water was about 250 mm in the 2008/09 cropping season and about 220 mm in the 2009/10 cropping season (Figures 4.7 and 4.8).

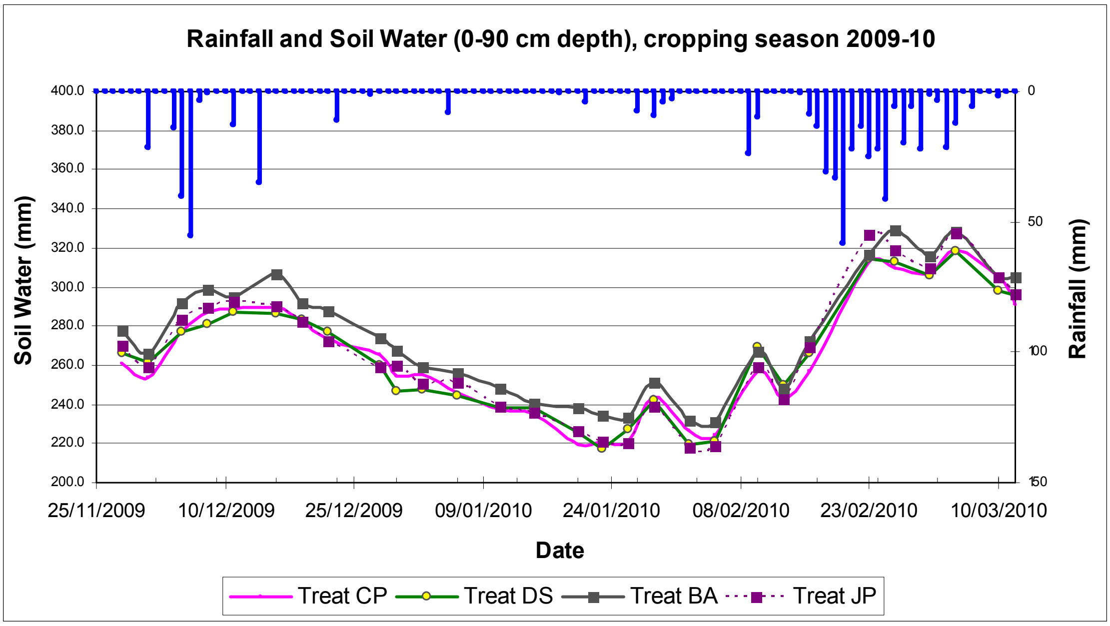



**Figure 4.8: Rainfall and average total soil water (0-90 cm depth), 2009-10 season in maize crop, treatments CP, DS, BA and JP.**

### 4.2.3 Water Infiltration Study

Infiltration measurements in the trial plots were conducted in three consecutive years using a mini-rainfall simulator (2008 – 2010). Results, Table 4.6, show changes through the years, while in 2008 (the second year with the trial) no significant differences were detected between treatments, in 2009 and 2010 some differences appeared. In 2008, traditional tillage treatment (CP) produced more run-off than direct seeded treatment (DS) and cumulatively compared to basins (BA) in the year 2010. As expected, tillage will result in soil compaction reducing its capacity to infiltrate water; it is therefore not completely clear why JP treatment was not different from CP. The impact of the differences on the infiltration patterns are slightly visible in the soil moisture measurements (Figures 4.7 and 4.8), showing the CP treatment with less total soil water than BA treatment and slightly with BA, and JP treatment following the CP treatment pattern; therefore, the difference did not produce important effect in crop yield, crop yield was not significantly different.

**Table 4.6: Average results on accumulated run-off in 60 minutes from the mini-rainfall simulator measured in three consecutive years (2008-2010). Simulated rain intensity was 100±5 mm.h$^{-1}$.**

| Treatment* | Description | Total run-off in 60 minutes (mm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2008** | | 2009 | | 2010 | |
| CP | Check Plot, traditional farmers practice | 43.6 | a | 57.3 | a | 59.6 | a |
| DS | Direct seeding, continuous maize | 43.8 | a | 41.1 | b | 45.2 | c |
| BA | Basins, continuous maize | 60.1 | a | 55.9 | ab | 47.7 | bc |
| JP | Jab Planter, continuous maize | 53.6 | a | 54.7 | ab | 56.0 | ab |

* Treatments means within the same column followed by the same letter are not significantly different at probability leve of 0.05.
** Data from (Putz, 2008)

### 4.2.4 Soil Organic Matter, Nitrogen and Phosphorus

On the assessment of soil fertility parameter, especially soil organic matter, total nitrogen and available phosphorus, Table 4.7 shows that only in the top 10cm soil organic matter were significantly low in traditional tillage (CP) compared to Basins (BA). Direct seeding (DS) and Jab planter (JP) were not different either from CP or from JP. The other parameters (nitrogen and phosphorus) did not show any significant difference. These results lead to the preliminary conclusion, for the study area, that CA without crop residues mulch will not produce, at least in the short-term, the intended favourable change in soil properties in continuous maize cropping.

**Table 4.7: Average soil organic matter (SOM), total nitrogen and available phosphorus P-Olsen measured in July 2009, at the end of the third crop season from beginning of the long-term trial.**

| Treatment* | Description | Soil depth 0-10 cm | | | | | | Soil depth 10-20 cm | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SOM (%) | | Total N (%) | | P-Olsen (ppm) | | SOM (%) | | Total N (%) | | P-Olsen (ppm) | |
| CP | Check Plot, traditional farmers practice | 1.48 | b | 0.04 | a | 23.2 | a | 1.44 | a | 0.04 | a | 14.92 | a |
| DS | Direct seeding, continuous maize | 1.53 | b | 0.04 | a | 10.8 | a | 1.39 | a | 0.04 | a | 10.87 | a |
| BA | Basins, continuous maize | 1.77 | a | 0.05 | a | 12.7 | a | 1.62 | a | 0.04 | a | 17.22 | a |
| JP | Jab Planter, continuous maize | 1.68 | ab | 0.04 | a | 14.9 | a | 1.63 | a | 0.04 | a | 15.66 | a |

* Treatments means within the same column followed by the same letter are not significantly different at probability leve of (Alpha=0.05).

### 4.2.5 Soil Fauna Activity

Since the observed most visible challenge to the maintenance of crop residue mulch was the intense termite activity, a study was then initiated to assess the extent and trend of termite activity in relation to CA in the trial; to supplement the study on soil fauna activity, also a below ground soil fauna activity study was conducted. The results on termites' activities 2008 - 2010 and below ground soil fauna activity 2009 – 2010 are presented in Tables 4.8 and 4.9 respectively.

**Table 4.8: Average termites' holes per square meter as an indicator of termites' activities Measurements were conducted in February 2008, March-April 2009 and May 2010.**

| Treatment | Description | Termites' holes per square meter * | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2008** | | 2009 | | 2010 | |
| CP | Check Plot, traditional farmers practice | 8.2 | b | 56.3 | b | 7.8 | a |
| DS | Direct seeding, continuous maize | 53.2 | a | 81.5 | a | 9.3 | a |
| BA | Basins, continuous maize | 58.3 | a | 70.0 | ab | 12.0 | a |
| JP | Jab Planter, continuous maize | 64.6 | a | 78.8 | a | 10.0 | a |

* Treatments means within the same column followed by the same letter are not significantly different at probability leve of 0.05.

** Data from (Putz, 2008)

The results on termites' activities (Table 4.8) show clear differences between the traditional tillage treatment (CP) and the CA treatments; in the year 2009, the differences were observed only between CP and two CA treatments, direct seeding (DS) and jab planter (JP) treatments but not with basin treatment (BA). Surprisingly, in the year 2010, differences did not occur between all treatments. It is possible that the prevailing soil and weather conditions during different measurements have influenced the final results. Field observation suggest that low presence of crop residues, drier soil conditions  hot or relatively cold weather do not favour surface termites' activity; wet soil conditions and relatively cooler weather if crop residues are present were the observed conditions for intense termites' activities. Nevertheless, the termites in the study area preferred dry crop residues (Figure 4.9, left), in case of food shortage (no crop residues) termites' started eating the standing plants at the first signal of mulching (example in Figure 4.9, right). So that, dry conditions with dry spells alternated with small amounts of rain showers could create condition for short outbreak o termites' attacking the weak living plants. During this study, termites attack on living plants did not seem alarming. However, it was evident that plots under CA had comparatively more termites' activity, since crop residues were left in the plots after harvesting, while in CP plots crop residues were removed. Nevertheless, the conducted study does not allow a clear separation of the impact of termites' activity from other parameters in soil properties. (Leonard and Rajot, 2001) reported that termites' holes influences the infiltration rate through interception of surface run-off; during this study, run-off interception by the termites' boles was visible in the rainfall simulations for infiltration measurements.

**Figure 4.9: Termites' activities in the study area, crop residues under termites' attack (left); plants attacked by termites when crop residues lacked (right).**

Below ground soil fauna results (Table 4.9) show no significant differences in the soil top 10 cm; however, differences were found for the depth 0-30cm in termites between basin (BA) and direct seeded treatments in the year 2010, with higher termites' number in BA, in the same way to a total number of soil organisms. Surprisingly, differences in total number of earthworms were observed between BA and jap planter (JP) treatments with lower number of earthworms in BA. High spatial variability was evident, as reflected by standard error, as presented in Table 4.9 for the example of earthworms recorded in February 2010 (standard error not shown). It seems that no clear impact was evident in below ground fauna due to the practice of CA in fields severely affected by termites under continuous maize production compared to the studied traditional tillage.

**Table 4.9: Below ground soil fauna, average number of organisms per square meter and type, record conducted in March 2009 and February 2010.**

| Year | Treatment* | Description | Soil depth 0-10 cm | | | | | | Soil depth 0-30 cm | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Termites | | Earthworms | | Total** | | Termites | | Earthworms | | Total** | |
| 2009 | CP | Check Plot, traditional farmers practice | 57.5 | a | 2.5 | a | 158.8 | a | 237.3 | a | 5.5 | ab | 380.3 | a |
| | DS | Direct seeding, continuous maize | 36.3 | a | 3.8 | a | 169.5 | a | 89.5 | a | 8.0 | ab | 428.0 | a |
| | BA | Basins, continuous maize | 42.5 | a | 1.3 | a | 180.0 | a | 150.8 | a | 1.3 | b | 352.3 | a |
| | JP | Jab Planter, continuous maize | 45.5 | a | 5.3 | a | 152.0 | a | 132.0 | a | 18.5 | a | 365.3 | a |
| 2010 | CP | Direct seeding, maize with sunflower as relay crop | 78.7 | a | 9.3 | a | 149.3 | a | 273.4 | ab | 12.0 | a | 369.3 | ab |
| | DS | Direct seeding maize in rotation with sunflower | 76.0 | a | 4.0 | a | 149.3 | a | 192.0 | b | 18.7 | a | 324.0 | b |
| | BA | Direct seeded maize after beans in the rotation maize-sunflower-beans | 62.7 | a | 14.7 | a | 170.7 | a | 338.7 | a | 20.0 | a | 474.7 | a |
| | JP | High Fertilized Plot trial | 125.4 | a | 10.7 | a | 221.3 | a | 290.7 | ab | 20.0 | a | 428.0 | ab |

* Treatments means within the same column and year followed by the same letter are not significantly different at probability level (Alpha=0.05).
** Total refers to all soil fauna found in the indicated soil depth

### 4.2.6 The Main Results on Impact of CA and Traditional Tillage under Rainfed Continuous Maize Production in the Study Area.

In this section, continuous maize cropping in three seeding technologies under CA, direct seeding (DS), basins (BA), jab planter (JP), were assessed comparatively to traditional tillage with animal traction using a mouldboard plough (CP). The study hypothesis was that CA enhances soil properties to improve crop production and reduce the impact of dry spells in rainfed maize production in smallholder resources poor farming systems in central Mozambique. Local conditions in Sussundenga, central Mozambique, were characterized by intense termite activity that consumed all crop residues before the start of the following season. Thus, the studied CA systems missed one of its basic components, that is, the maintenance of crop residues on the soil surface.

It needs to be noted that the present study compares the traditional tillage with a CA that are separated by a narrow difference. The tested CA techniques, due to high termites' activities, lacked one of its basic components, the crop residues cover; the studied traditional tillage, very different from conventional tillage, is regarded as a reduced tillage (Table 2.1) derived from the low tillage frequency (only once, before seeding) not followed by a secondary tillage, the tillage depth (10-15 cm), and the use of animal traction instead of heavy tractors.

The results of the last three years, out of four from the beginning of a long-term trial, showed no statistical differences in crop yields between the treatments. There were no important improvements in soil fertility indicators, nor enough evidences in improved soil water management to overcome dry spells. Study on soil fauna activity did not show consistent improvements during the study period (four years); although, it was evident that higher surface termites activity in CA plots improved water infiltration compared to traditional tillage. Therefore, it can be concluded that CA practices under the study conditions will not favour short term benefits; and adoption process among smallholder farmers may face challenges as they oversee substantial and immediate results. The most evident reason for the slow positive impact of CA in the study area was the intense termites' activities. Nevertheless, cropping systems that can reduce the impact of termites' activities and enhance crop residues cover as appropriate crop rotation systems need to be further investigated.

## 4.3 Assessment of the Impact of CA on Soil Properties and Maize Yield under Rotation with Beans and Sunflower in Sussundenga, Central Mozambique

### 4.3.1 Maize Crop Yield

Maize (*Zea mays* L.) yield was assessed on a traditional tillage using the mouldboard plough (animal traction), and three CA treatments utilizing a direct seeding technology with maize under crop rotation with sunflower (*Helianthus annuus* L.) and beans (*Phaseolus vulgaris* L.), in a long-term trial in Sussuendenga, central Mozambique. The three crop rotation settings were maize-sunflower intercropping with sunflower as a relay crop (MS), maize following sunflower in a maize-sunflower rotation (A_M), and maize following beans crop in a maize-sunflower-beans rotation (B_M); in the traditional tillage treatment (CP) a continuous maize cropping over different years was practiced. Crop management data and observed maize phenology stages are presented in Table 4.2 (previous), for three cropping seasons, 2007/08, 2008/09 and 2009/10, the long-term trial was initiated in the cropping year 2006/07, from November 2006.

Table 4.10 presents data on cover crops and crop residues at seeding time, crop residues were expected to build up in the CA plots, therefore, due to high termites' activity in the area crop residues were completely removed by the termites. In the first two years of the long-term trial, residues were brought from outside the trial area (especially grass residues) up to 30% ground cover at seeding. However, the residues remained not more than two weeks. In order to increase dry matter production for ground cover, in the third and forth year (years 2008 and 2009) *Mucuna pruriens* was seeded when maize crop started wilting; sunnhemp crop (*Crotalaria juncea*) preceded sunflower crop and the fodder radish crop (*Raphanus sativus*) preceded beans crop. Nevertheless, ground cover registered during maize seeding was still low, only 10% of ground cover was reached at the beginning of the 2009/10 season (Table 4.10).

From the Table 4.10 it can be seen that residue cover did not build as expected in the CA plots, in the third year after initiating the trial; for the fourth year, residue cover was about 25% in MS plots and 30% in A_M plots, in these plots previous crop was sunflower. Field observation showed that termites preferred beans and maize crop residues, sunflower residues were the last. So that, some sunflower residues remained up to maize seeding in the season 2009/10. Although, sunflower residues were less in MS plots than A_M plots since in the latter sunflower was a relay crop in maize crop.

**Table 4.10: Crop residues management in different treatments and observed crop residues cover at seeding. Crop residues cover did no build up as expected in the CA plots due to high termites' activity.**

| Treatment | CP | MS | A_M | B_M |
|---|---|---|---|---|
| **Treatment short description** | mouldboard plough with animal traction | Direct seeding maize, sunflower as a relay crop. | Direct seeding maize in a maize-sunflower rotation. | Direct seeding maize; maize follows beans in a maize-sunflower-beans rotation |
| **Year 2006/07** | | | | |
| Residue cover at maize seeding (%) | 0 | 30 | 30 | 30 |
| Seeding date for the cover crop | - | - | - | - |
| Seeding date for maize | | | | |
| Date, residues removal | 27/11/2007 | No | No | No |
| **Year 2007/08** | | | | |
| Residue cover at maize seeding (%) | 0 | 30 | 30 | 30 |
| Seeding date for the cover crop | 02/03/2008 | 02/03/2008 | 02/03/2008 | 02/03/2008 |
| Seeding date for maize | 27/11/2007 | 27/11/2007 | 27/11/2007 | 27/11/2007 |
| Date, residues removal | 02/04/2008 | - | - | - |
| **Year 2008/09** | | | | |
| Residue cover at maize seeding (%) | 0 | 0 | 0 | 0 |
| Seeding date for the cover crop | 12/02/2009 | 12/02/2009 | 12/02/2009 | 12/02/2009 |
| Seeding date for maize | 10/12/2008 | 10/12/2008 | 10/12/2008 | 10/12/2008 |
| Date, residues removal | 05/05/2009 | No | No | No |
| **Year 2009/10** | | | | |
| Residue cover at maize seeding (%) | 0 | 25 | 30 | 0 |
| Seeding date for the cover crop | 25/02/2010 | 25/02/2010 | 25/02/2010 | 25/02/2010 |
| Seeding date for maize | 25/11/2009 | 25/11/2009 | 25/11/2009 | 25/11/2009 |
| Date, residues removal | 07/04/2010 | No | No | No |

The Table 4.11 shows the maize crop yield data analysis for the grain yield as for the total above ground biomass except grain (stover) yield. Yield variability between years was a result mainly of rainfall variability; the cropping season 2009/10 was severely impacted by dry spells during the vegetative, flowering and grain filling stages, Figure 4.1 shows the monthly rainfall distribution during the growing seasons and Figure 4.2 the occurrence of a 7-days dry spells and that most of the rainfall was registered in few days.

Maize (grain) yield (table 4.11) was not different between the treatments in the harvest years 2008 and 2009, in the harvest year 2010 maize yield in the maize-sunflower rotation (A_M) was significantly higher than that of maize-sunflower intercropping (MS). Competition between maize and sunflower is a probable reason in this case, since water stress may have retarded maize development in this year.

**Table 4.11: Average maize yield* (grain and stover) for three consecutive harvesting years.**

| Treatment* | Description | Grain yield (Kg/ha) | | | | | | Stover yield (Kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2008** | | 2009 | | 2010 | | 2008** | | 2009 | | 2010 | |
| CP | Check Plot, traditional farmers practice | 777.8 | a | 3634.0 | a | 1266.6 | ab | 1117.0 | b | 3849.3 | b | 1941.1 | b |
| MS | Direct seeding, maize with sunflower as relay crop | 1074.5 | a | 3624.3 | a | 985.0 | b | 1413.8 | ab | 4332.8 | ab | 1534.0 | b |
| A_M | Direct seeding maize in rotation with sunflower | 1226.0 | a | 4131.8 | a | 1708.8 | a | 1674.5 | ab | 5585.8 | a | 3070.4 | a |
| B_M | Direct seeded maize after beans in the rotation maize-sunflower-beans | 1196.8 | a | 3648.8 | a | 1413.0 | ab | 2133.5 | a | 4605.0 | ab | 2348.7 | ab |

* Treatments means within the same column followed by the same letter are not significantly different at probability leve of 0.05.
** Data from Christian Thierfelder, CIMMYT, Harare

In stover yield (harvest years 2009 and 2010) maize crop after sunflower had more yield comparatively to CP treatment and additionally to MS treatment in the year 2010. It seems that with time the A_M treatment (maize after sunflower) has more advantage comparatively to the traditional tillage CP treatment; the advantage in stover yield, later with time, may be translated in higher grain maize as the total above ground biomass production is an indication of grain productivity. The higher stover yield in A_M comparatively to MS has shown higher grain yield in the same period between these treatments. The advantage on yield of the maize-sunflower rotation in this condition seems to derive from the crop residues cover as from the season 2009/10 about 30% residues cover was registered at seeding; in the previous year 2008/09, as already referred, crop residues last fist in the beans and maize plots. Comparatively to the year 2007/08 crop residues were equally set to 30% at seeding and there B_M treatment (maize after beans) had more yield comparatively to CP treatment. This is an indication that a rotation with beans could bring good results if crop residues cover is present.

### 4.3.2 Soil Water Storage

Soil water record was conducted from November 2008 covering two consecutive seasons. In general, soil water reflected directly the rainfall distribution within the season and dry spells of long duration impacted negatively crop development; Figures 4.10 and 4.11 show the total soil water in the 0-90 cm depth and rainfall during the maize growing seasons 2008/09 and 2009/10. In the 2008/09 seasons (Figure 4.10), clear difference in soil water is visible between CP (traditional tillage) treatment and MS (direct seeded maize with sunflower as a relay crop) with advantages in water storage for the MS treatment.

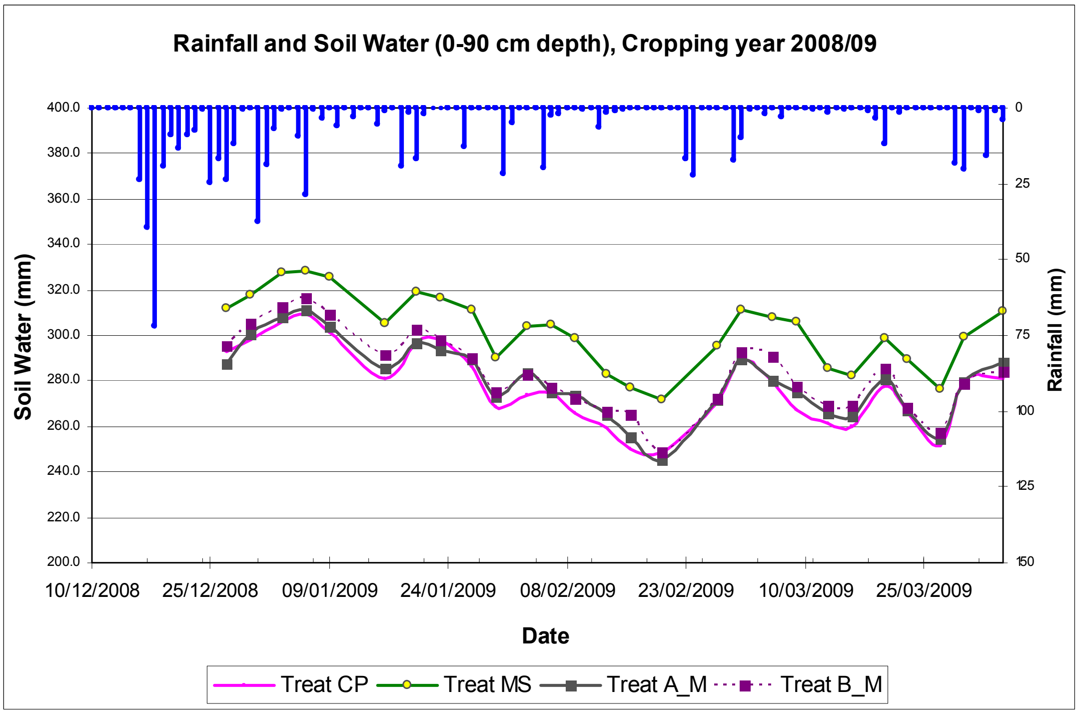



**Figure 4.10: Rainfall and average total soil water (0-90 cm depth), 2008/09 season in maize crop, treatments CP, MS, A_M and B_M.**

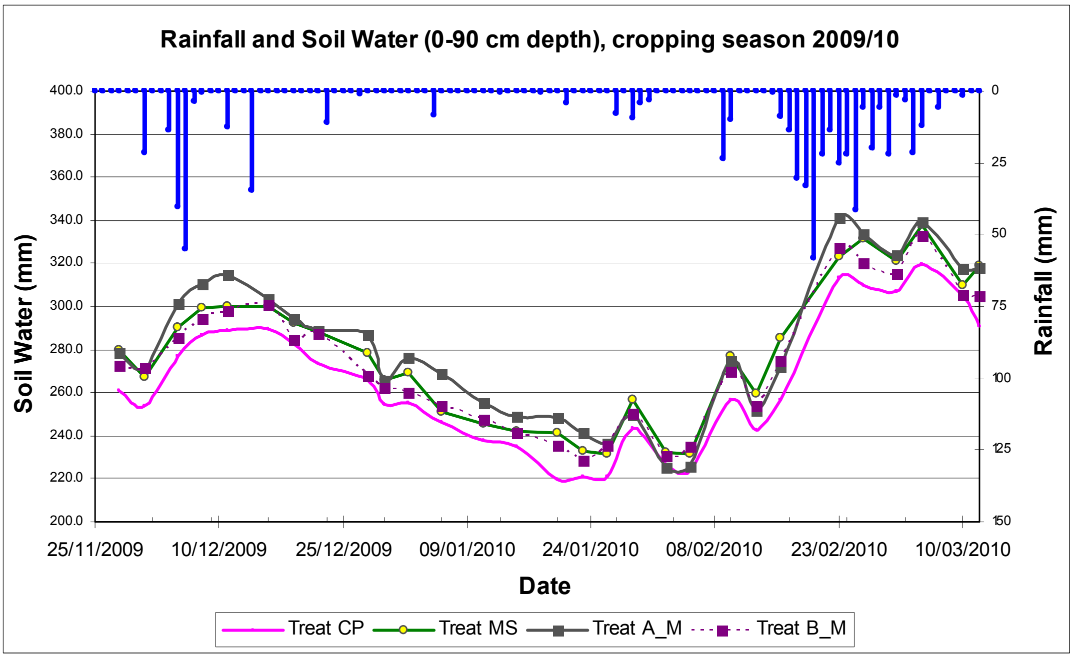



**Figure 4.11: Rainfall and average total soil water (0-90 cm depth), 2009/10 season in maize crop, treatments CP, MS, A_M and B_M.**

Though, in the following cropping season 2009/10 (Figure 4.11), A_M (maize-sunflower rotation) treatment presented more stored water compared to CP treatment. In the harvest year 2010, maize stover yield followed the advantageous tendency on water storage with higher yield in A_M treatment compared to CP treatment; therefore, in a relatively wet previous season, harvesting year 2009, the advantages on water storage of MS over CP did not reflect in yield, still, A_M treatment had higher stover yield compared to CP treatment. These results show that improved water management brings more advantages in a relatively drier year and that for a wet year other factors are more important; the results show that there have been competition over resources on MS treatment, so that, if sunflower relay crop were planted a bit later would be more convenient. The records in soil water support the results on maize yield (as previous discussed) that the advantage of the maize-sunflower rotation derives from the crop residues cover.

### 4.3.3 Water Infiltration Study

Results on the run-off measurements using the mini-rainfall simulator are presented in Table 4.12, for three consecutive years (2008 – 2010) in the four treatments, CP, MS, A_M and B_M; simulated rain intensity was 100±5 $mm.h^{-1}$. The results, show changes through the years, while in 2008 (the second year with the trial) no significant differences were detected between all treatments, in 2009 and 2010, B_M treatment (direct seeding maize after beans in sunflower-beans-maize rotation) had less total 60-minutes run-off than CP treatment (traditional tillage). Also in the year 2009, B_M treatment registered less total run-off than in A_M treatment (maize in a sunflower-maize rotation), the reason of this is not clear; nevertheless, this was not repeated in the following year. In general, the results show that water infiltration was improved under CA were previous crop was beans. Although, the improved infiltration in B_M treatments was not reflected in better soil water storage comparatively to CP treatment as would be expected; the reason for this maybe that residues cover were most important in reducing run-off than the infiltration capacity. Though, the results show the potential of this crop rotation type to improve water infiltration.

**Table 4.12: Average results on accumulated run-off in 60 minutes from the mini-rainfall simulator measured in three consecutive years (2008-2010).**

| Treatment* | Description | Total run-off in 60 minutes (mm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2008** | | 2009 | | 2010 | |
| CP | Check Plot, traditional farmers practice | 43.6 | a | 57.3 | a | 59.6 | a |
| MS | Direct seeding, maize with sunflower as relay crop | 59.2 | a | 47.9 | ab | 51.0 | ab |
| A_M | Direct seeding maize in rotation with sunflower | 52.2 | a | 53.9 | a | 51.7 | ab |
| B_M | Direct seeded maize after beans in the rotation maize-sunflower-beans | 48.4 | a | 39.2 | b | 49.6 | b |

* Treatments means within the same column followed by the same letter are not significantly different at probability leve of 0.05.
** Data from (Putz, 2008)

### 4.3.4 Soil Organic Matter, Nitrogen and Phosphorus

Measured soil fertility parameters, soil organic matter, total nitrogen and available phosphorus in July 2009, after three cropping seasons form the beginning of the long-term trial in CA agriculture are shown in Table 4.13. The results show that only in the top 10cm soil organic matter were significantly higher in MS treatment (maize-sunflower intercropping) comparatively to CP treatment (traditional tillage). It seem that the maize-sunflower intercropping produced more total organic matter and that in general, high termites' activities hinder soil organic matter accumulation and do not contribute to an increase in soil fertility.

**Table 4.13: Average soil organic matter (SOM), total nitrogen and available phosphorus P-Olsen measured in July 2009, at the end of the third crop season from beginning of the long-term trial *.**

| Treatment* | Description | Soil depth 0-10 cm | | | | | | Soil depth 10-20 cm | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SOM (%) | | Total N (% | | -Olsen (ppn | | SOM (%) | | Total N (%) | | -Olsen (ppn | |
| CP | Check Plot, traditional farmers practice | 1.48 | b | 0.04 | a | 23.2 | a | 1.44 | a | 0.04 | a | 14.9 | a |
| MS | Direct seeding, maize with sunflower as relay crop | 1.76 | a | 0.05 | a | 12.1 | a | 1.61 | a | 0.04 | a | 11.5 | a |
| A_M | Direct seeding maize in rotation with sunflower | 1.63 | ab | 0.05 | a | 11.1 | a | 1.54 | a | 0.05 | a | 10.6 | a |
| B_M | Direct seeded maize after beans in the rotation maize-sunflower-beans | 1.57 | ab | 0.05 | a | 11.6 | a | 1.39 | a | 0.06 | a | 14.3 | a |

* Treatments means within the same column followed by the same letter are not significantly different at probability leve of (Alpha=0.05).

### 4.3.5 Soil Fauna Activity

In order to assess the impact of termites' attack on crop residues in maize cropping under CA and crop rotation comparatively to the traditional tillage, surface termites' activity was recorded in the long-term trial during three consecutive years, 2008-2010. The study was supplemented by the overall assessment of below ground fauna activity recording the number of soil organisms up to 30cm depth during two years 2009-2010. Below ground fauna activity, especially earthworms' activities enhances the mineralization of carbon in soil and increases the amount of extractable nitrogen (Wessells et al., 1997) as improves soil structure (Bohlen and Edwards, 1995). Table 4.14 and 4.15 show respectively the results on termites' and below ground fauna activities.

**Table 4.14: Average termites' holes per square meter. Measurements were conducted in February 2008, March-April 2009 and May 2010.**

| Treatment* | Description | Termites' holes per square meter * | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2008** | | 2009 | | 2010 | |
| CP | Check Plot, traditional farmers practice | 8.2 | b | 56.3 | b | 7.8 | ab |
| MS | Direct seeding, maize with sunflower as relay crop | 57.1 | a | 73.8 | ab | 10.8 | a |
| A_M | Direct seeding maize in rotation with sunflower | 34.9 | ab | 77.3 | a | 9.8 | ab |
| B_M | Direct seeded maize after beans in the rotation maize-sunflower-beans | 67.0 | a | 81.8 | a | 6.0 | b |

* Treatments means within the same column followed by the same letter are not significantly different at probability leve of 0.05.
** Data from (Putz, 2008)

Surface termites' activities in 2008 were higher in the MS treatments (maize-sunflower intercropping) and B_M treatments (maize following beans in maize-sunflower-bens rotation) comparatively to CP treatment (traditional tillage). Differences were not significant with A_M treatment (maize-sunflower rotation). In the following year 2009, similar results were recorded in relation to B_M comparatively to CP. Though, since at the time maize was start mulching, the overall termites' activities seems to have increased so that differences could not be consistent. The results in the year 2010 are much inconsistent to the previous showing that termites' activities might be strongly limited by environmental conditions (water and temperature), the season was get drier with temperatures decreasing.

**Table 4.15: Below ground soil fauna, average number of organisms per square meter and type conducted in March 2009 and February 2010.**

| Year | Treatment* | Description | Soil depth 0-10 cm | | | Soil depth 0-30 cm | | |
|---|---|---|---|---|---|---|---|---|
| | | | Termites | Earthworms | Total** | Termites | Earthworms | Total** |
| 2009 | CP | Check Plot, traditional farmers practice | 57.5 a | 2.5 a | 200.3 a | 237.3 a | 5.5 a | 380.3 a |
| | MS | Direct seeding, maize with sunflower as relay crop | 108.0 a | 0.0 a | 186.5 a | 200.0 a | 3.8 a | 349.3 a |
| | A_M | Direct seeding maize in rotation with sunflower | 38.5 a | 2.5 a | 165.3 a | 182.8 a | 5.3 a | 426.5 a |
| | B_M | Direct seeded maize after beans in the rotation maize-sunflower-beans | 52.0 a | 4.0 a | 158.8 a | 125.3 a | 5.3 a | 335.8 a |
| 2010 | CP | Check Plot, traditional farmers practice | 78.7 a | 9.3 a | 149.3 a | 273.4 a | 12.0 a | 369.3 a |
| | MS | Direct seeding, maize with sunflower as relay crop | 64.0 a | 2.7 a | 234.7 a | 285.4 a | 9.4 a | 540.0 a |
| | A_M | Direct seeding maize in rotation with sunflower | 116.0 a | 2.7 a | 189.3 a | 350.7 a | 20.0 a | 500.0 a |
| | B_M | Direct seeded maize after beans in the rotation maize-sunflower-beans | 101.3 a | 1.3 a | 184.0 a | 329.4 a | 2.7 a | 456.0 a |

* Treatments means within the same column and year followed by the same letter are not significantly different at probability level (Alpha=0.05).
** Total refers to all soil fauna found in the indicated soil depth

Table 4.15 shows no difference between treatments in below ground fauna activity, though it was expected that differences in food availability (organic matter) accessible to soil fauna would lead to a more biological activity (Rilay et al., 2008). Therefore, the results suggest that termites' activities were intense enough to suppress the accumulation of crop residues as soil organic matter; these results are supported by the general tendency on soil organic matter (Table 4.13).

### 4.3.6 The Main Results on the Impact of a Crop rotation component in CA on maize crop yield in Sussundenga, central Mozambique.

In this study maize yield was assessed in CA, direct seeding with animal traction and crop rotation with beans and sunflower, comparatively to traditional tillage with continuous maize cropping. The crop rotations were maize-sunflower with sunflower as a relay crop, a maize-sunflower two years rotation, and maize following beans crop in a maize-sunflower-beans three years rotation. The study hypothesis was that crop rotation as one of the basic components of the CA productions system increases its potential to produce short-term beneficial impacts in soil properties and increase maize production. Local conditions in Sussundenga, central Mozambique, were characterized by intense termite activity that consumed all crop residues before the start of the following seasons.

The trial results in the last three years, out of four from the beginning of a long-term trial, showed no differences in maize grain yield between the treatments. Therefore, a consistent higher maize stover yield in direct seeded maize under the maize-sunflower rotation, during the last two years of the study (harvest year 2009 and 2010) indicates this cropping system as promising one; soil water stored in the root zone was enhanced in the drier cropping season 2009/10 and seems that impacted positively to maize stover yield in maize sun-flower rotation. Both, harvest years 2009 and 2010, the higher maize stover yield seemed to be the result of sunflower crop residues cover that remained longer in respective plots than the bens and maize residues, due to preferential termites' attack. In the rotation maize-sunflower-beans soil infiltration was improved in maize production following beans cropping though, it was not clearly translated in improved water storage; it is therefore a good indication on the potential to of this cropping system. Although, the intense termites' activity was regarded as the limiting factor for the improvement in the soil fertility parameters (soil organic matter, total soil nitrogen and extractable phosphorus) that did not show relative improvements; high termites' activities was regarded as the limiting factor on below ground soil fauna activity in CA treatments, since that prevent the increase in crop residues and soil organic matter.

The productions systems integrating CA and crop rotation with beans and sunflower offer good opportunity for the smallholder farmers to diversify crop production with large advantages to the market. The common bean is one of the main legumes in the diet of many rural and urban poor in Mozambique , and important source of protein. Beans, is consumed either as grain or leaves, along side with maize. Both sunflower and beans are cash crops, marketable crops, and may contribute to the increased income and food security among smallholder farmers in central Mozambique.

Therefore, it can be concluded that CA practices under the study conditions will not favour short term benefits; and adoption process among smallholder farmers may face challenges as they oversee substantial and immediate results. The most evident reason for the slow positive impact of CA in the study area was the intense termites' activities. Nevertheless, cropping systems that can reduce the impact of termites' activities, and enhance crop residues cover, as suggested by the crop rotation maize-sunflower, may result in the required short-term benefits, and need to be further investigated.

## 4.4 Study of Rainfed Maize Crop Yield under CA and Traditional Tillage using the APSIM Simulation Model in Central Mozambique

### 4.4.1 APSIM Model Parameterization and Calibration

The APSIM model (version 7.1) was configured with the Maize module, the soil water module SoilWat, the soil nitrogen module SoilN and the residue module SurfaceOM to simulate total soil water 0-90 cm depth (SW90) and maize crop yield (grain and stover). Input daily meteorological data, rainfall, maximum and minimum temperature and solar radiation were measured in the trial site for the study period 2008-2010. The study intended to assess different seeding strategies and crop rotation in conservation agriculture compared to traditional practices; the emphasis was the soil water management and maize productivity under rainfed conditions in the previously described long term trial in conservation agriculture in Sussundenga, central Mozambique.

The APSIM model was calibrated using soil water and crop data from a separated trial on a High Fertilized Plot, conducted in the cropping season 2009/10, in an adjacent area of the long term trial in conservation agriculture in Sussundenga. The high fertilized plot had 9 m of length and 6 m width; the plot was not tilled and followed a previous high fertilized maize crop; the fertilizer level was 400 Kg/ha of N:P:K (12:24:12) at basal application and top dressing of 300 Kg/ha of urea. The top dressing was applied as split application of 100 Kg/ha each, respectively, at 3, 6 and 9 weeks after seeding. Seeding was manual using a hand hoe, on 90x50 cm spacing, aiming at 4.4 plants per square meter.

Soil profile description data (presented in table 4.2) were used as input for the APSIM profile data, parameterized accordingly to the adopted five soil layer thickness (Table 4.16). APSIM model calibration was performed seeking to minimize the root mean standard error (RMSE), equation below, between the measured and simulated total soil water 0-90 cm depth (SW90).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2}$$

Where $S_i$ and $O_i$ are the simulated and the observed values, respectively and n is the number of observations.

**Table 4.16: Soil profile data in the trial site, Sussundenga, Mozambique**

| Soil Layer | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| | | | | | | |
| Layer thickness (mm) | dlayer | 100 | 100 | 100 | 300 | 300 |
| **Soil Profile parameters** | | | | | | |
| OC (%) | | 0.78 | 0.78 | 0.60 | 0.41 | 0.18 |
| EC* (mS/cm) | | 0.20 | 0.20 | 0.20 | 0.10 | 0.10 |
| pH (KCl) | | 4.10 | 4.10 | 4.10 | 4.65 | 5.18 |
| CEC (cmol+/Kg) | | 6.48 | 6.48 | 6.48 | 4.43 | 5.89 |
| Ca (cmol/Kg) | | 2.32 | 2.32 | 2.32 | 2.50 | 2.80 |
| Mg (cmol/Kg) | | 0.63 | 0.63 | 0.63 | 0.71 | 0.81 |
| Na (cmol/Kg) | | 0.10 | 0.10 | 0.10 | 0.07 | 0.05 |
| K (cmol/Kg) | | 0.34 | 0.34 | 0.34 | 0.31 | 0.38 |
| ESP (%) | | 0.72 | 0.72 | 0.72 | 0.62 | 0.34 |
| Al* (meq/100g) | | 0.6 | 0.6 | 0.6 | 0.2 | 0 |
| Particle size, sand (%) | | 70.8 | 70.8 | 70.8 | 52.0 | 41.0 |
| Particle size, silt (%) | | 11.8 | 11.8 | 11.8 | 10.4 | 8.3 |
| Particle size, clay (%) | | 17.4 | 17.4 | 17.4 | 37.6 | 50.7 |
| * after Wijnhoud (1997) | | | | | | |

*CEC is Cation exchange capacity and ESP is the exchangeable sodium percentage.*

Crop data used for calibration and testing of the APSIM model are presented in Table 4.17, relatively to the measured plant density and maize yield in the trial plots. The used maize cultivar was a hybrid, PAN67.

**Table 4.17: Average plant density and maize yield (grain and stover) from the long term trial in CA and a high fertilized plot trial in Sussundenga.**

| Treatment | Description | Plant density* (pl/m2) | | Grain yield (Kg/ha) | | Stover yield (Kg/ha) | |
|---|---|---|---|---|---|---|---|
| | | 2009 | 2010 | 2009 | 2010 | 2009 | 2010 |
| CP | Check Plot, traditional farmers practice | 3.9 | 3.7 | 3,634 | 1,267 | 3,849 | 1,941 |
| DS | Direct seeding, continuous maize | 4.8 | 4.2 | 3,810 | 1,068 | 4,925 | 1,703 |
| BA | Basins, continuous maize | 4.2 | 3.6 | 3,353 | 1,164 | 3,767 | 1,842 |
| JP | Jab Planter, continuous maize | 4.0 | 3.8 | 3,827 | 940 | 4,492 | 1,864 |
| MS | Direct seeding, maize with sunflower as relay crop | 4.2 | 4.2 | 3,624 | 985 | 4,333 | 1,534 |
| A_M | Direct seeding maize in rotation with sunflower | 4.4 | 5.1 | 4,132 | 1,709 | 5,586 | 3,070 |
| B_M | Direct seeded maize after beans in the rotation maize-sunflower-beans | 4.8 | 4.8 | 3,649 | 1,413 | 4,605 | 2,349 |
| HFP | High Fertilized Plot trial | - | 4.1 | - | 1,410 | - | 3,396 |

* Plant density calculated as average from countings after crop establishment and at harvest

### 4.4.2 Model Calibration Results

The maize cultivar used in the trial was PAN67, since this cultivar was not previously parameterized for the APSIM model, preliminary simulations using various maize cultivars available with the model were conducted in order to select one with similar physiologic characteristics registered in the trial (phenology stages, previously presented Table 4.3. So, the maize cultivar SC625 was selected and used in the APSIM maize module.

Measured soil water parameters from soil profile samples were water content at saturation (sat), at field capacity (dul) and air dry (from the AquaPro probes calibration curve); from previous study in the trial area (Wijnhoud, J.D., 1997), water content at wilting point (ll15) were derived. Therefore, all these soil water retention parameters were used as initial values and further evaluated and calibrated in the model. Table 4.18 and 4.19 present the calibrated soil properties for the APSIM model in the trial site, respectively in soil layers and in the case of one value parameter. Initial soil water at the beginning of the simulation was set to '0' of the plant available water (PAW), simulation started in the driest period, and it was fixed at 1 October; initial soil nitrogen was set as a total $NO_3$-N and $NH_4$-N at 75 and 40 Kg/ha at the beginning of the simulation in 1 October. The values of $NO_3$-N and $NH_4$-N were calibrated assuming no water deficit maize production in the high fertilized plots, what resulted in a maxim maize yield (grain) of 5,827 Kg/ha. Reported experimental maize potential yield in central Mozambique is evaluated in 5 – 6.5 ton/ha (Howard et al., 2003).

**Table 4.18: Calibrated soil properties per layer used for specifying APSIM simulation in a Lixisol in Sussundenga, central Mozambique.**

| Soil Layer | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| **Soil water parameters** | | | | | | |
| Layer thickness (mm) | dlayer | 100 | 100 | 100 | 300 | 300 |
| Bulk Density (g/cc) | bd | 1.486 | 1.493 | 1.493 | 1.43 | 1.414 |
| Saturated water content (mm/mm) | sat | 0.44 | 0.44 | 0.44 | 0.45 | 0.47 |
| Field capacity (mm/mm) | dul | 0.33 | 0.33 | 0.33 | 0.36 | 0.38 |
| Wilting point (mm/mm) | ll15 | 0.135 | 0.135 | 0.135 | 0.28 | 0.33 |
| Air dry (mm/mm) | air_dry | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 |
| Drainage coeficient[a] | SWCon | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| **Soil Nitrogen parameters** | | | | | | |
| Inert soil C fraction[b] | finert | 0.7 | 0.7 | 0.7 | 0.8 | 1.0 |
| Iniciat biomass pool[c] | fbiom | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| **Maize module** | | | | | | |
| soil water availability factor | KL | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |

[a] SWCON is the proportion of water in excess of water content at field capacity that drains in one day.
[b] finert specifies the inert soil C as a fraction of the initial soil organic C
[c] fbiom specifies the initial BIOM C pool as a fraction of non-inert soil organic C

**Table 4.19: Calibrated soil constants for specifying APSIM simulation in a Lixisol in Sussundenga, central Mozambique.**

| APSIM Soil parameter | Acronym | Value |
|---|---|---|
| | | |
| **Unsaturated flow** | | |
| Diffusivity constant | DiffusConst | 50 |
| Diffusivity slope | DiffusSlope | 26.5 |
| | | |
| **Runoff** | | |
| Runoff curve number of bare soil | CN2Bare | 94 |
| | | |
| **Soil Evaporation** | | |
| First stage soil evaporation coeficient | U | 3 |
| Second stage soil evaporation coeficient | CONA | 2 |
| Soil albedo | Salb | 0.13 |
| | | |
| **Soil organic matter** | | |
| Soil C/N ration | SoilCN | 14.5 |
| | | |

Calibration for measured and observed SW90 resulted in RMSE of 9.9 representing about 2.4% volume during the entire cropping period. The simulated maize yield was 1.3% higher (grain yield) and simulated stover yield was 10% higher than the measured. Measured stover yield may be underestimated considering the high incidence of termites. Figures 4.12 and 4.13 present the calibration results of observed and APSIM simulated SW90 in maize cropping, from seeding to maturation; Calibration results were satisfactory.

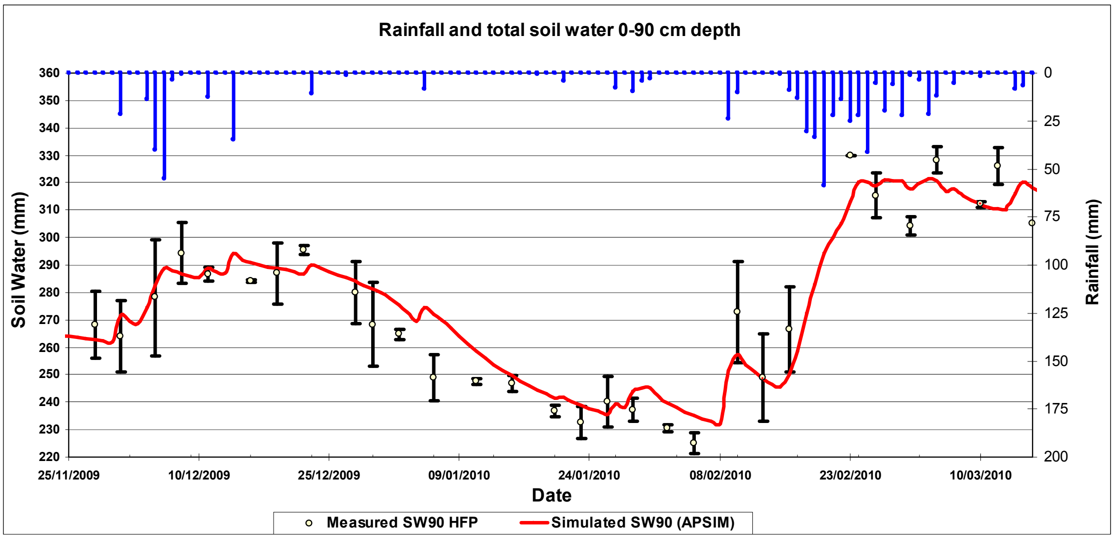



**Figure 4.12: Rainfall, observed and APSIM simulated total soil water 0-90 cm depth (SW90) in the high fertilized plots (calibration results). Bars represent standard error of observed soil water.**

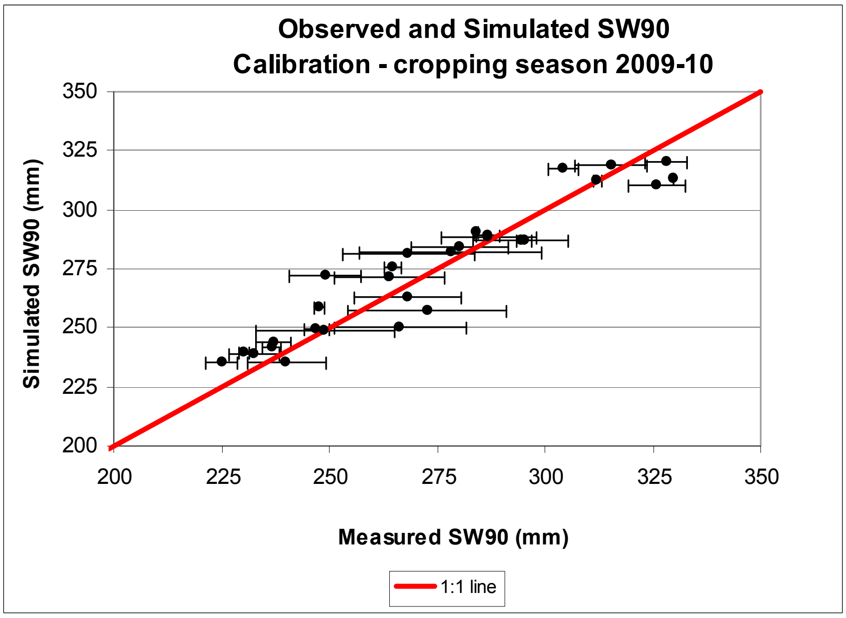



**Figure 4.13: Comparison between observed and APSIM simulated SW90 in the high fertilized plots (calibration results). Bars represent standard error of measured soil water.**

### 4.4.3 APSIM Model Testing and Evaluation

The calibrated APSIM model was used to simulate soil water and maize yield in seven different treatments in the long term trial on conservation agriculture (CA) in Sussundenga over a period of two years, the cropping seasons of 2008-09 and 2009-10. The different treatments included continuous maize cropping with four seeding technologies, the traditional tillage with animal traction using a mouldboard plough (CP), direct seeding (DS), basins (BA), jab planter (JP) and; other three crop rotation settings, maize-sunflower intercropping with sunflower as a relay crop (MS), maize following sunflower in a maize-sunflower rotation (A_M), and maize following beans crop in a maize-sunflower-beans rotation (B_M). With the exception of the CP treatment all the treatments were under CA; as described previously, crop residues were absent in most of the cropping period due to high termites' activity.

The simulation period was the third and forth year on implementation the CA trial in Sussundenga, and simulation intended to help to understand the impact of different seeding technologies in the rain water infiltration pattern. Therefore, the run-off parameter in the APSIM model was adjusted per treatment for the best fitting of the measured and observed soil water and crop yield, seeking to minimize the RMSE.

The APSIM simulation results on SW90 matched well with the measured soil water, with RMSE from 6.8 to 14.6 (Table 4.20), representing about 2-4% volume of soil water (RMSE/total porosity) for the entire growing period. Figures 4.14(a) and (b) show an example of the simulation results on SW90 for the basin treatment (BA), respectively for the period from maize seeding to maturation  as the comparison of simulated and observed SW90 with error bars; a complete set of the results per treatment are shown in Annex C. Therefore, simulated stover yield were in general higher, the ratio between simulated and measured stover varied from 1 to 2; termites' activities may have reduced the measured stover. Simulated grain yield performance, Figure 4.15, was satisfactory, deviation was about 6% of the average measured yield (RMSE/average yield).

**Table 4.20: Performance simulations of soil water with APSIM model assessed with root mean standard error (RMSE). CN2Bare parameters (CN-value for average antecedent moisture conditions) were changed for best fitting.**

| Treatment | Description | Season 2008-09 | | Season 2009-10 | |
|---|---|---|---|---|---|
| | | CN2Bare | RMSE | CN2Bare | RMSE |
| CP | Check Plot, traditional farmers practice | 95.0 | 13.5 | 95.0 | 10.9 |
| DS | Direct seeding, continuous maize | 95.0 | 13.9 | 95.0 | 11.8 |
| BA | Basins, continuous maize | 82.0 | 8.6 | 94.0 | 9.7 |
| JP | Jab Planter, continuous maize | 86.0 | 8.1 | 95.0 | 11.8 |
| MS | Direct seeding, maize with sunflower as relay crop | 82.0 | 6.8 | 95.0 | 12.2 |
| A_M | Direct seeding maize in rotation with sunflower | 94.0 | 14.6 | 94.0 | 12.4 |
| B_M | Direct seeded maize after beans in the rotation maize-sunflower-beans | 94.0 | 14.1 | 94.0 | 9.7 |

In general (Table 4.20) the treatments show a consistent response to rainfall-runoff relations, CN-values of 95 and 94; it is not so clear the fact that JP and MS treatments presented low CN-values in the 2008-09 season, while in the basins (BA treatment) more run-off abstraction may have occurred around the basins in this wetter year. This shows that basin treatment will store more water in an already wetter year than in a drier one. The APSIM model calibration with the no-tilled high fertilized plots (HFP) resulted in CN-value of 94. In all cases, the CN values used reveal a high run-off (low infiltration rate); this seems to be a consequence of the higher bulk density measured, and as referred by (Wijnhoud, 1997), soil compaction is related to the use of machinery for cleaning the land and for tillage operations in Sussundenga agrarian research station. These results show that conservation agriculture in the trial site did not improve significantly soil water storage supported by the previously results that yield response differences were not evident among treatments in both studied years (Table 4.11).

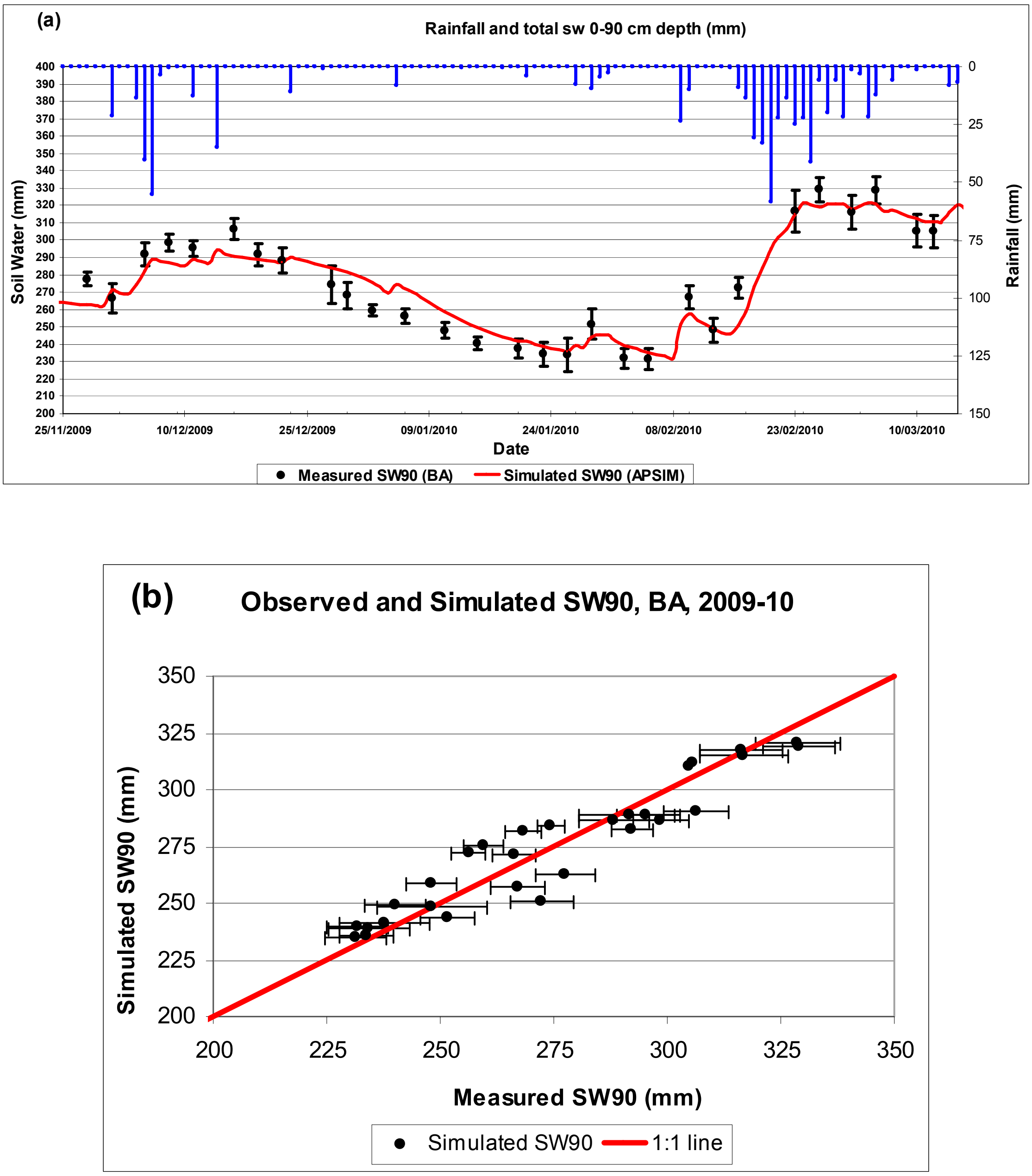



**Figure 4.14: Observed and APSIM simulated total soil water 0-90 cm depth (SW90) for the basin treatment (BA), cropping season 2009-10; (a) SW90 from maize seeding to maturation and (b) comparison of simulated and measured SW90, bars represent the standard error of the measured soil water.**

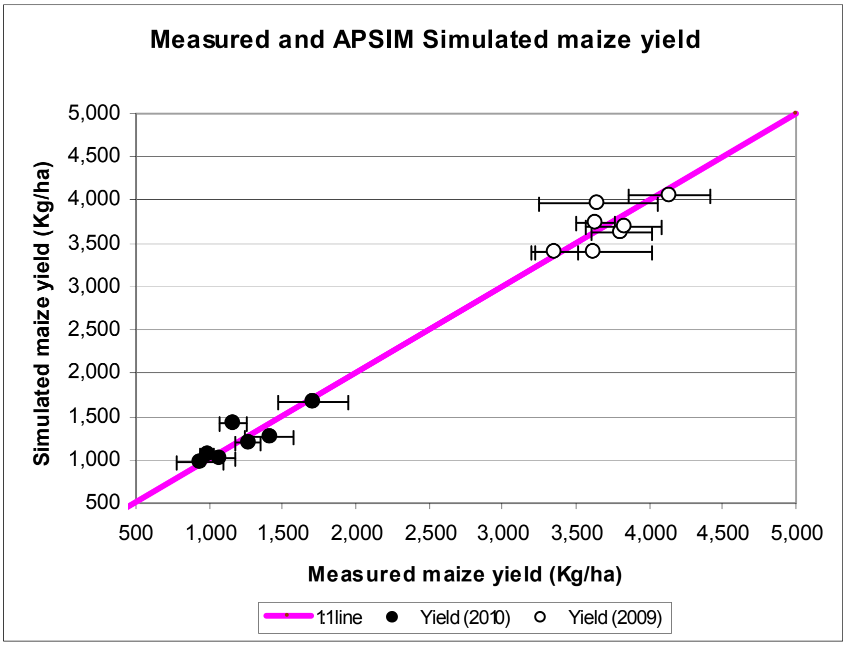
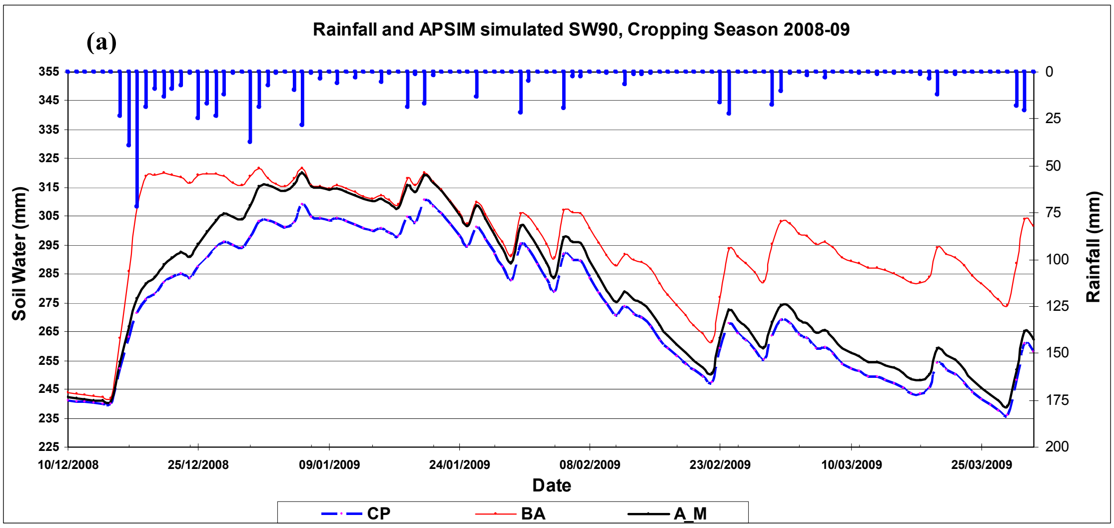



**Figure 4.15: APSIM simulated maize yield in the long term trial in CA in Sussuendenga. Bars represent standard error of measured yield (n=4).**

In relation to soil water storage, traditional tillage treatment (CP) and direct seeding treatment (DS) followed a more consistent response, CN=95 in both seasons, in the lower water storage group. Basins treatment (BA) showed good performance (more soil water stored) in the wetter season (2008-09), Figure 4.16(a,b), and an average performance in the drier cropping season 2009-10. Maize-sunflower intercropping (MS) treatment (not shown in the figures) followed the BA treatment in the wetter season but in the drier season MS treatment followed that of CP e DS treatments. The maize-sunflower rotation treatment (A_M) performed better in the drier cropping season 2009-10 and had an average performance in the wetter cropping season. Thus, the resulting simulations on soil water show differences in the run-off patterns (Figure 4.16a,b), but the differences were not significant, and yield response differences were not evident, only a slight tendency to higher stover yield in the maize-sunflower rotation, A_M treatment, in both years (Table 4.11).



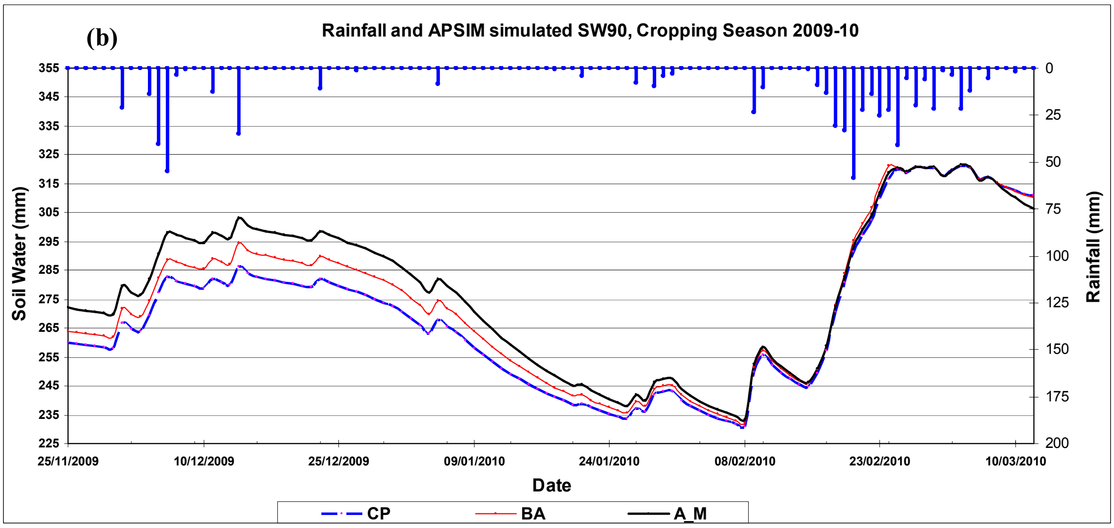




**Figure 4.16: APSIM simulated soil water 0-90 cm depth SW90 for selected treatments (a) cropping season 2008-09 and (b) cropping season 2009-10.**

### 4.4.4 Runoff Study with the Mini-rainfall Method

In order to assess the infiltration pattern and run-off processes, results on the run-off measurements using the mini-rainfall simulator for two consecutive years 2009 and 2010 are presented together with the CN-curves, Figure 4.17(A),(B). The mini-rainfall method was previously described in section 3.5.5. The CN-method for calculating run-off uses the following empirical relation:

$$Q = \frac{(P - I_a)^2}{P - I_a + S}$$

Where P is the rainfall (mm), Q is the direct runoff (mm), S is the potential maximum recharge capacity after beginning of the runoff (mm) and $I_a$ the initial abstraction (mm).

$I_a = 0.2\ S$

The relation between Q and P is valid for P > Ia, otherwise, Q=0. The potential maximum retention parameter S has been converted to the curve number (CN) as follows:

$$S = \frac{25400}{CN} - 254 \qquad \text{and} \qquad CN = \frac{25400}{254 + S}$$

In the CN-method the soil moisture conditions, antecedent moisture conditions (AMC), is another important factor influencing the final CN value, as previously described in section 3.3.2.

The measured runoff, CN-values as shown in the Figure 4.18, compared to the simulation results (CN2Bare) in the Table 4.20, suggests that the measured values were in the drier side of antecedent moisture conditions (AMC); nevertheless, field measurements were conducted in a medium wet soil in order to facilitate the insertion of the measuring frame, what involved wetting the soil a day before for the drier periods. The field measurement results on runoff suggest that the initial abstraction parameter (Ia) in the study site is small than the traditional (Ia=0.2S), from the results (Figure 4.18 and Annex D), with accumulated rainfall less than 30-40 mm, the measured runoff deviate from the fitting runoff curve above this value threshold and runoff is much higher than that tendency. Thus, a lower initial abstraction parameter in the model may improve simulation results for the study area, especially because this deviation occurs in the range of most probable daily rainfall amounts.

Therefore, the field measurement results allow a comparative study between the treatments. The field measurements support the tendency on the fitted CN-values (CNBare-values on Table 4.20) showing a tendency to a slight higher run-off on CP treatments and lower in the crop rotation CA treatments (MS, A_M and B_M treatments).

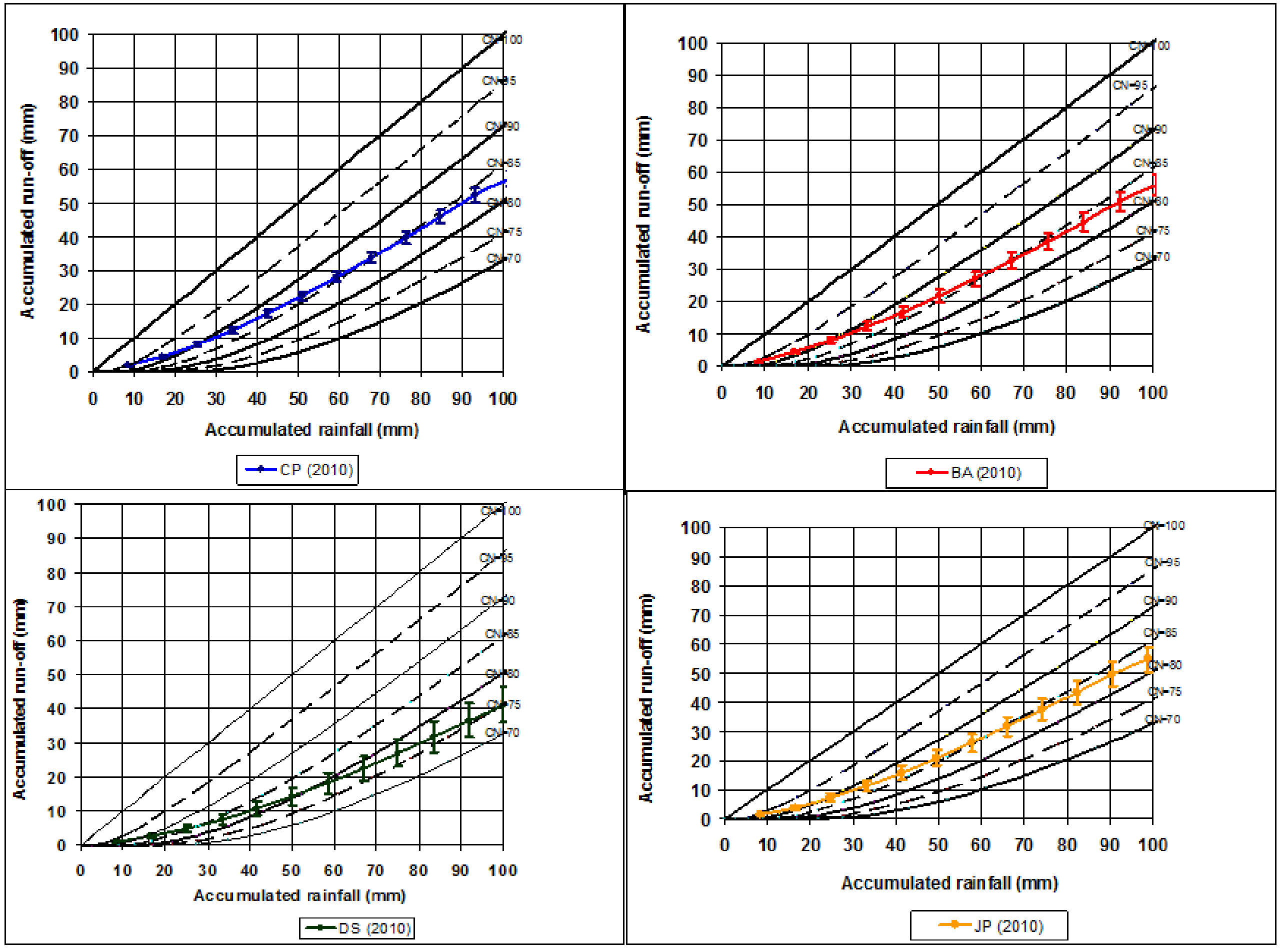



**Figure 4.17 (A): Runoff Measurement Results with the Mini-rainfall in the Year 2010 in the Long Term Trial Plots in Sussundenga, CP, DS, BA and JP treatments**

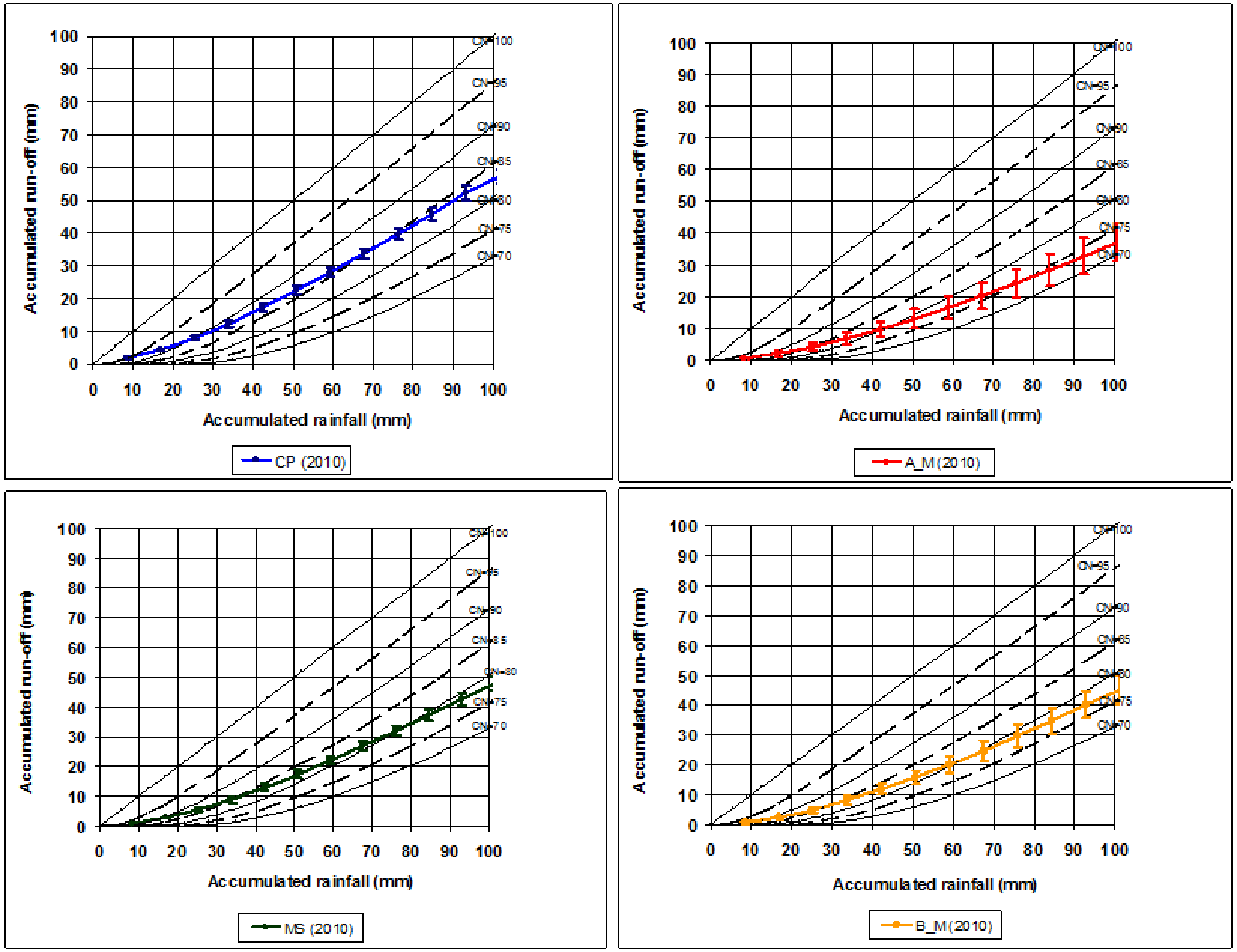



**Figure 4.17 (B): Runoff Measurement Results with the Mini-rainfall in the Year 2010 in the Long Term Trial Plots in Sussundenga, CP, MS, A_M and B_M treatments.**

### 4.4.5 APSIM Model Application to Study Soil Water Balance

The calibrated APSIM model was used to simulate soil water balance and crop growth in the study area supposing that crop residues could be maintained for the two studied years, cropping seasons of 2008-09 and 2009-10. Three scenarios were selected, the traditional practice (CP); the direct seeding maize (DS) and the direct seeding maize following sunflower crop (A_M). Crop residues level was fixed at 3,500 Kg/ha of maize and sunflower respectively in DS and A_M scenarios at the beginning of the simulation (1 October). The following water balance equation was used:

$$\Delta SW = Rain - Ec - Es - Ro - Dp$$

Where

- ΔSW: Change in water storage in the 0-90 cm depth soil profile (mm)
- Rain: Rainfall (mm)
- Ec: Crop water uptake, crop transpiration (mm)
- Es: Soil evaporation (mm)
- Runoff: Surface Runoff (mm)
- Dp: Deep percolation (mm)

The CNBare values used with the APSIM simulation model where 95 for CP and DS treatments and 94 for the A_M treatment, as previously shown in the model calibration. The results on water balance in Table 4.21 show that the two cropping seasons 2008-09 and 2009-10 had about the same total rainfall (637 and 636 mm) from the seeding to crop maturation. Therefore, rain distribution was very diverse, reasonable well distributed in the 2008-09 seasons and with long dry spells in the 2009-10 cropping season. So that, this cropping season was perceived as dry comparatively to the previous. Consequently maize yield was different, with good yields in the 2008-09 cropping season. Crop yield presented in Table 4.21 for CP and DS (without mulch) treatments were verified in the trial.

**Table 4.21: APSIM Simulated soil water balance and crop yield for maize crop in Sussundenga, Mozambique.**

| Cropping Season | Treatment | Description | Water Balance (mm) | | | | | | Yield (Kg/ha) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Rain | Ec | Es | Runoff | Dp | ΔSW | |
| 2008-09 | CP | Check Plot, traditional farmers practice | 637 | 145 | 180 | 297 | 0 | 15 | 3,692 |
| | DS (without mulch) | Direct seeding, continuous maize | 637 | 145 | 180 | 297 | 0 | 15 | 3,692 |
| | DS (+ Mulch) | Direct seeding, continuous maize | 637 | 123 | 173 | 205 | 101 | 36 | 2,959 |
| | A_M (+ Mulch) | Direct seeding maize in rotation with sunflower | 637 | 130 | 175 | 211 | 85 | 37 | 3,171 |
| 2009-10 | CP | Check Plot, traditional farmers practice | 636 | 75 | 136 | 328 | 45 | 52 | 1,118 |
| | DS (without mulch) | Direct seeding, continuous maize | 636 | 75 | 136 | 328 | 45 | 52 | 1,118 |
| | DS (+ Mulch) | Direct seeding, continuous maize | 636 | 117 | 122 | 329 | 55 | 14 | 2,269 |
| | A_M (+ Mulch) | Direct seeding maize in rotation with sunflower | 636 | 118 | 124 | 328 | 49 | 19 | 2,282 |

The water balance APSIM simulation results (Table 4.21, Figure 4.18 and Figure 4.19) show that in a year with good rainfall distribution, runoff can account to about 47% of the total rainfall. Though, CA may improve runoff abstraction to favour deep percolation (drainage). Crop water uptake was not enhanced, in contrary was reduced and consequently yield was as reduce. The reason for this seems to be the nitrogen dynamics, due to the presence of crop residues mulch, nitrogen have been immobilized in the process of resides decomposition, as shown in Figure 4.20, the simulation results of nitrogen mineralization and immobilization showing that most of the nitrogen immobilization occurred at the beginning of the 2008-09 season in conservation agriculture.

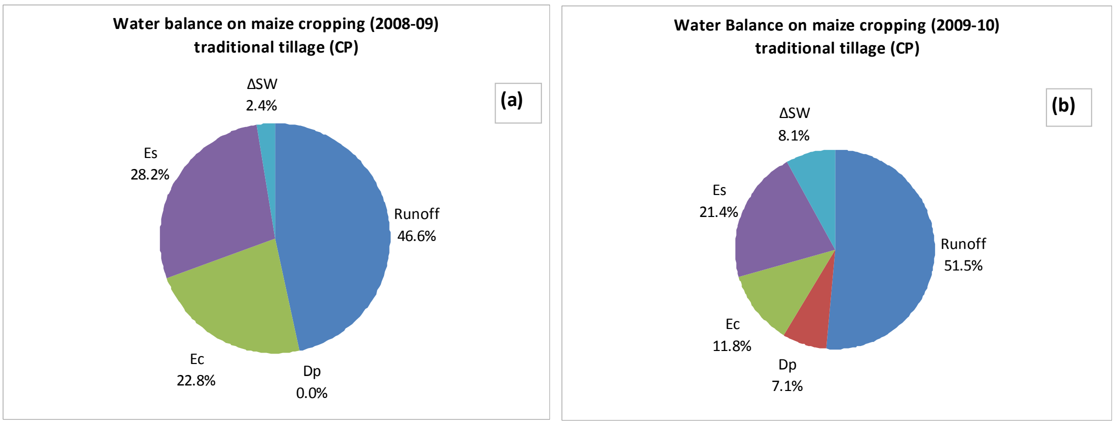



**Figure 4.18: APSIM simulation results on water balance on maize cropping under traditional tillage for the season (a) 2008-09 and (b) 2009-10.**

Nevertheless, during the 2008-09 cropping season, the A_M plots show less yield reduction than that of DS plots, probably due to a different fresh organic matter decomposition rate (sunflower with relatively less surface contact area).

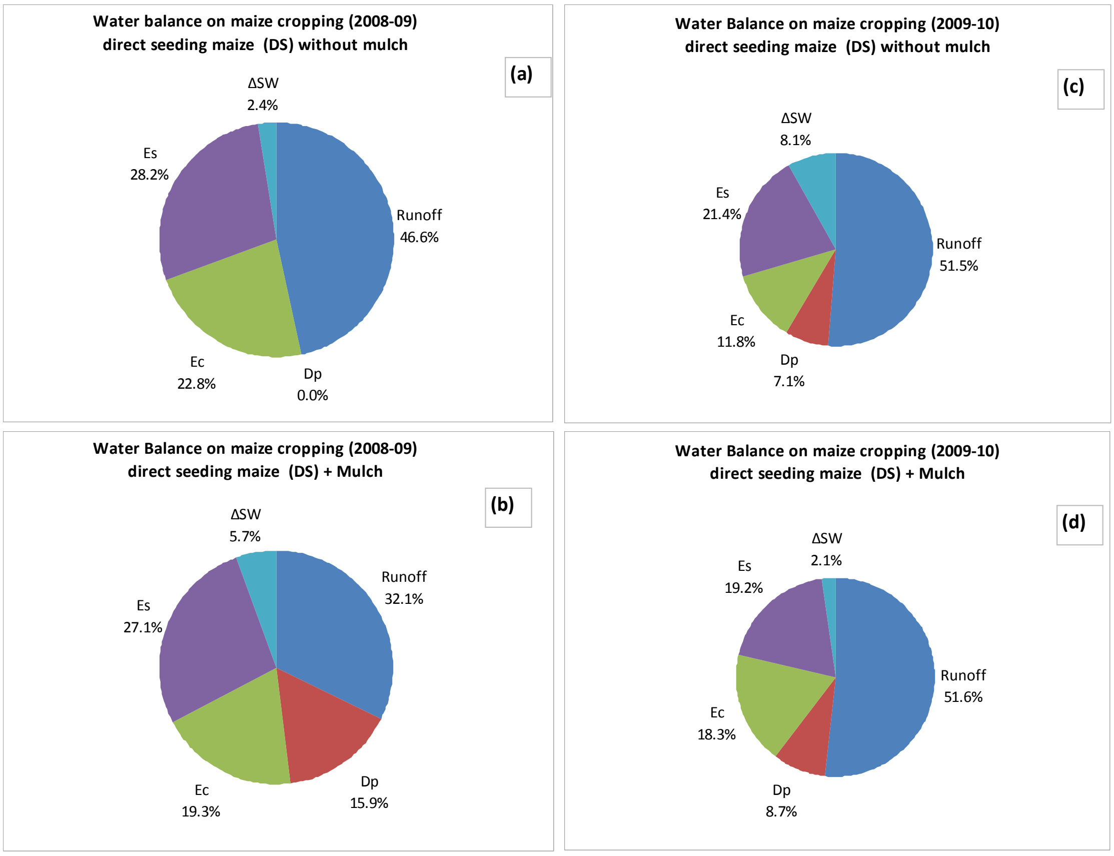



**Figure 4.19: APSIM water balance simulation results on maize under direct seeding in the presence of crop residues mulch or without mulch, respectively (a) and (b) in the 2008-09 season; (c) and (d) in the 2009-10 season.**

ΔSW: Change in water storage in the 0-90 cm depth soil profile (mm)
Rain: Rainfall (mm)
Ec: Crop water uptake (mm)
Es: Soil evaporation (mm)
Runoff: Surface Runoff (mm)
Dp: Deep percolation (mm)

In the 2009-10 cropping season, the APSIM simulation results on the direct seeding treatment (DS) show that crop residues mulch did not reduce total run-off therefore, crop water uptake was increase at the cost of reduced soil evaporation and that crop was able to uptake more water from the soil (Table 4.21 and Figure 4.19 c,d). A more close analysis on the soil water balance processes, especially runoff and soil water storege (Figures 4.21 and 4.22), it is possible to see that at the beginning of the season the mulch resulted in more water abstraction and therefore the crop may have developed better since had relatively more available soil water during the following long dry period. Such that, in the next wet period, with less residues in the soil due to the on-going decomposition and in addition crop was comparatively better developed and continued to uptake more water, created conditions for more water infiltration; in the plot without mulch the top soil quickly reached the saturation point allowing more runoff.

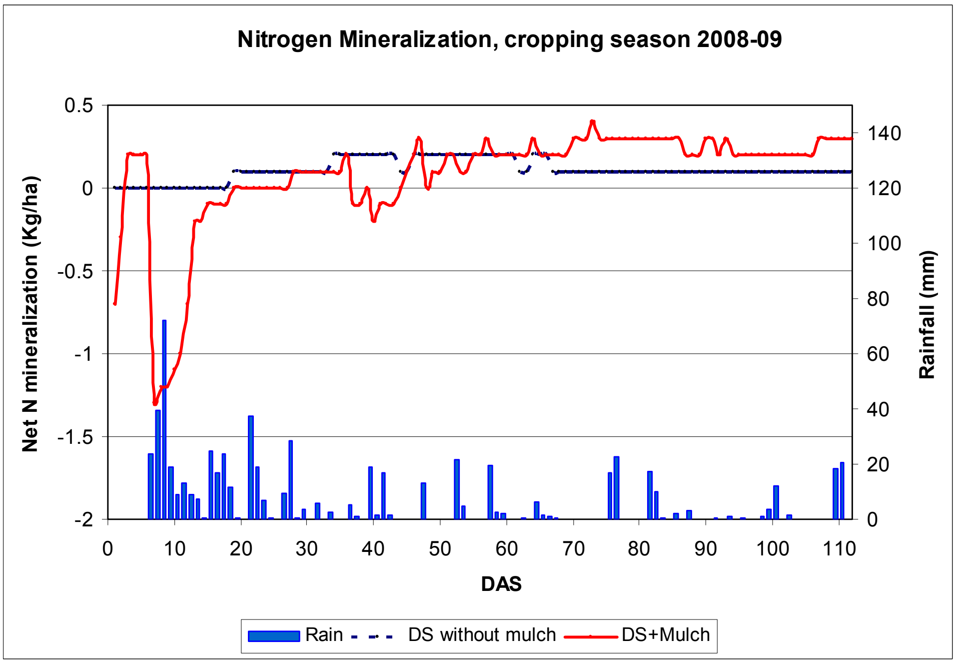



**Figure 4.20: APSIM simulation results on the nitrogen mineralization and immobilization in the maize cropping season 2008-09 under traditional tillage and direct seeding in Sussundenga.**

In Figure 4.20 negative values of net N mineralization indicate nitrogen immobilization and positive values indicate mineralization.

As discussed previously, decomposition of surface organic matter is affected by moisture, temperature, C:N ration and contact factor with the ground as presented and that, the mineralisation or immobilisation of mineral-N is determined as the balance between the release of nitrogen during decomposition and immobilisation during microbial synthesis and humification.

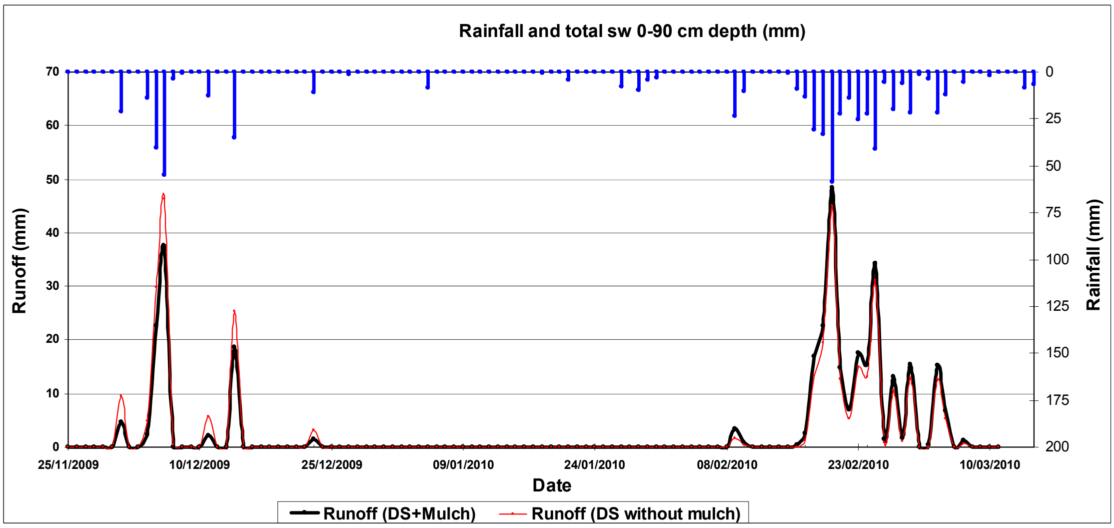



**Figure 4.21: APSIM runoff simulation results on maize under direct seeding in the presence of crop residues mulch or without mulch.**

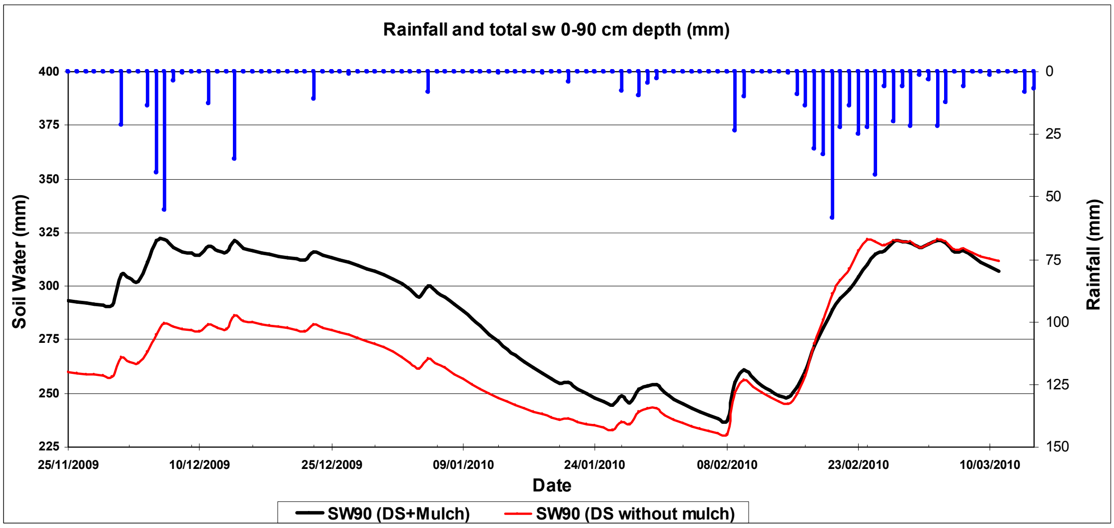



**Figure 4.22: APSIM soil water (SW90) simulation results on maize under direct seeding in the presence of crop residues mulch or without mulch.**

As a consequence of increased crop water uptake to about 5% yield was two folds higher with the crop residues in the drier season 2009-10 (APSIM simulation results).

The APSIM simulation results (shown in Table 4.21) comparing traditional tillage and conservation agriculture in Sussundenga, assuming that crop residues could be maintained, suggest that conservation agriculture may lead to lower maize yield in seasons with relatively good rainfall distribution; the results suggest that crop yield may increase in relatively drier cropping seasons what may lead to a stable yield and not a substantial increase to in maize yield.

### 4.4.6 The Main Results in the Simulation of Water Balance and Maize Yield with the APSIM model in Sussundenga

In this section maize crop yield was assessed in traditional tillage comparatively to conservation agriculture. For the this purpose APSIM model was calibrated using a High Fertilized Trial with maize crop and the model was later applied to assess the long term trial in conservation agriculture in Sussundenga over a period of two years, the cropping seasons of 2008-09 and 2009-10. The different treatments included continuous maize cropping with four seeding technologies, the traditional tillage with animal traction using a mouldboard plough (CP), direct seeding (DS), basins (BA), jab planter (JP) and; other three crop rotation settings, maize-sunflower intercropping with sunflower as a relay crop (MS), maize following sunflower in a maize-sunflower rotation (A_M), and maize following beans crop in a maize-sunflower-beans rotation (B_M). With the exception of the traditional tillage all other treatments were under conservation agriculture (CA). The study hypothesis was that the practice of conservation agriculture will improve soil water storage and increased maize crop yield compared to traditional tillage in Sussundenga, central Mozambique. As described previously, crop residues were absent in most of the cropping period due to high termites' activity. The model calibration was performed seeking to minimize the root mean standard error (RMSE) between the measured and simulated total soil water 0-90 cm depth (SW90).

The APSIM simulated SW90 matched well with the observed values as the simulated and observed maize yield, RMSE for calibration was 9.9 representing about 2.4% volume of water (deviation) during all the cropping season; in the simulation RMSE varied from 6.8 to 14.6 and simulated grain deviation was about 6%. Simulation results from the maize stover did not agree well with observed, probably due to the fact that maize stover was attacked by termites before the harvesting. Additional data on infiltration measurements in the trial site suggest that the APSIM model results maybe improved if the initial abstraction parameter (Ia) in the CN-equation used with the APSIM model would be adjustable and to allow for a lower Ia in this case study.

The simulations with the APSIM model assuming that crop residues could be maintained in the study site, traditional tillage was compared to conservation agriculture and led to a preliminary conclusion that conservation agriculture will lower maize crop yield in seasons with relatively good rainfall distribution and that yield may increase in relatively drier cropping seasons. Nitrogen immobilization was the reason for a lower maize yield under conservation agriculture; nevertheless, this still need to be supported by experimental results. Therefore, this suggests that conservation agriculture may lead to a more stable food production and not to a substantial increase in maize yield. In general, the APSIM model simulation supported the experimental results collected in the long term trial in Sussundenga, that yield in CA under the actual conditions of high termites' activity (without crop residues) will not differ from that of traditional tillage.

# 5 Conclusions and Recommendations

## 5.1 Conclusions

This study presents the results of a long term trial in conservation agriculture in Sussundenga, central Mozambique, from the year 2008 to 2010; maize crop under rainfed production was assessed with special emphasis to yield and soil water balance in the root zone. In the trial, continuous maize cropping as maize in rotation with sunflower and beans, were used with different seeding technologies. The different seeding technologies were the traditional tillage (CP) and other three seeding technologies under conservation agriculture (CA) that included the direct seeding (DS), basins (BA) and jab planter (JP). The APSIM model was satisfactory calibrated using an additional high fertilized plot in the study area and was used to simulate crop yield and water balance for the long term trial condition. The APSIM simulated yield and soil water matched well with the observed data and then the model was used to supplement the understanding of the diverse soil processes in the maize cropping systems.

- The results with four years of the long term trial in CA in Sussuendenga, in which CA plots lacked crop residues cover as a result of high termites' activities, did not show significant differences in maize yield compared to the traditional practice as between CA treatments either with continuous maize cropping or in rotation with sunflower and beans.

- This research did not show significant improvements in soil fertility indicators with the practice of CA, nor evidences in improved soil water management to overcome dry spells; the high termites' activity in the study area was the most evident reason for failure of CA to improve maize production.

- The calibrated APSIM model using experimental data of a high fertilized plot, in the trial site, predicted satisfactory the soil water and maize crop yield for the long term trial in CA in Sussundenga; the model was then used to study and supplement information in water balance in the trial plots resulting in a root mean standard error (RMSE) from 6.8 to 14.6 (2-4% volume of soil water) and simulated grain deviation was about 6% of the measured.

- The water balance study under rainfed maize crop production in the study area showed that, 47-52% of rain was lost through runoff; deep drainage accounted 5-7% in seasons with uneven rainfall distribution with implications in yield reduction over 3 times.

- As revealed in the water balance study, simulating with APSIM model more rain water abstraction using crop residues mulch, the low soil water retention capacity resulted to favour more drainage rather than crop water uptake; so that, improving only infiltration itself will not improve crop yield, so that, soil water retention need to be enhanced.

- The field results that showed no yield differences between the traditional tillage (reduced tillage) and different seeding technologies under CA, without crop residues, led to the conclusion that CA practices under the study conditions will not favour short term benefits; and adoption process among smallholder farmers, in central Mozambique, may face challenges as they oversee substantial and immediate results.

## 5.2 Recommendations

- The field experience with the different seeding technologies in the long term trial with conservation agriculture in Sussundenga suggested that the use of animal traction as a low energy option, in direct seeding, may contribute to labour saving on the peak labour demand at seeding; and that shall reduce the risk associated with a later or too early planting and seed lost, some of adaptive strategies traditionally used among smallholder farmers to manage the associated risk of crop failure.

- The problems with crop residues maintenance within the CA technology due to the cultural based open grazing in the fallow period or due to termites in most of the central region of Mozambique demand a prior adaptation of CA packages of soil and water management that can be easily implemented preferentially by animal traction.

- The simulations results with the APSIM model suggested that crop residues mulch, as simulated with maize residue, may result in nitrogen immobilization with implication to yield reduction in wet to moderately wet cropping seasons; further local experimental results are needed to investigate the extent of the process as cropping systems that can reduce the impact of termites' activities, enhance crop residues, improve soil organic matter and reduce nitrogen immobilization.

- The calibrated APSIM model may be used under similar (soil and climatic) conditions in central Mozambique for decision support in nitrogen fertilizer recommendation, or to simulate appropriate maize planting dates as possible impact of climatic changes in maize production.

- The field measurements of runoff using the mini-rainfall method showed that the initial soil water abstraction (Ia) maybe lower than that presented by the traditional CN-model (Ia=0.2S), so that, if this factor can be adjustable in the APSIM model, simulation results may improve further the water balance results.

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**Annex A: Detailed Description on Plots Management and Harvesting Procedures.**

**Plot management**:

1. ***Duration*:** Long term trial is intended to be continued as long as possible – at least 5 years
2. ***Plot size*:** 40 plots, 24 m x 18 m, each = 432m$^2$.
3. ***Residue*:** If surface residues have been grazed and/or removed from the area, then apply 2.5-3 t/ha of stover (preferably maize) to the CA treatments (Treatments 2-10). If there are residues in the field, they should be retained in Treatments 2- 10, but incorporated in Treatment 1 (Check). After the first year all crop residues should remain on the CA fields. Residues from farmer's check (Treatment 1) may be removed or grazed.
4. ***Variety:***

   Maize: A maize hybrid was be used.

   Sunflower: Use a local variety.

   Beans: Use an erect bean variety

   Mucuna, Sunnhemp and Fodder radish: Use available varieties

5. ***Seeding date.***
   - *Maize:* Seed all plots as soon as possible after the start of the rains (any time after Mid November when at least 30mm are in the soil profile)
   - *Sunflower:*
     Sole crop, seed the sunflower at the beginning of January, depending on moisture content;
     Relay cropping, seed the sunflower when the canopy starts to open up (2-3 weeks after silking)
   - *Beans:* Seed the beans at a suitable time at the end of February
   - *Mucuna:* When maize starts wilting
   - *Sunnhemp:* At the same time as maize
   - *Fodder radish:* At the same time as maize

6. ***Seeder calibration and basins preparation***:

- Maize: The direct seeder should be calibrated before seeding. Use the maize seed plate that fits your maize seed. If the maize grain is too big, you will have to enlarge the cells in the seed plate with a metal file. For maize, the middle black gear (underneath the seed hopper) should be used aiming at a seed rate of about 44,444 plant/ha at 90 cm spacing. For fertilization in maize, only one big yellow cog should be used. This will give a fertilizer rate of about 163 kg/ha at 90 cm row spacing.

• Sunflower and beans: seeder calibration has to be tried and tested on site

• Basin Management:
Basins should be prepared before seeding and basal fertilizer incorporated in them.
Basins should be approximately 15cm square (15cm x 15cm) and 15 cm deep.
Spacing: 90 cm between rows, 50 cm between basins in the row.
Prepare a string with bottle caps crimped onto it every 60cm.
Lay the string along the plot, align the badza (hoe) with the bottle cap and make a 15 x 15 x 15 cm hole. This may take 3 badza strokes.
Make a measure for the basal fertilizer, add this to each hole as soon as possible (before planting) and cover with some soil.
Wait until a good rain fills up the basins.
When the water subsides, put 3-4 maize seeds per basin, and cover with the rest of the soil.

### 7. *Plant Populations:*

Maize: 90cm between rows, 50 cm between planting stations, 3 seed per station, **thin to 2 living plants per station** . This will give a plant population of 44.444 plants/ha.
Basins should be prepared at a spacing of 90cm x 50cm; 3 seed per basin, thin to 2 living plants per basin

Sunflower: 90cm between rows, 20 cm between plants. Seeded with animal traction seeder aiming at 55,000 plants/ha

Beans: 45 cm between rows; 15cm between plants. Seeded with animal traction seeder aiming at 148,000 plant/ha

Mucuna: 90cm rows, 50cm between plants in the middle of two maize rows

Sunnhemp: dribble in 45 cm lines, approximately 5 cm between plants

Fodder radish: dribble in 45 cm lines, approximately 5 cm between plants

***Note: From year 2008, all plots with maize will be relay-cropped with Mucuna pruriens (when maize starts wilting), all sunflower plots will have a pre-ceding sunnhemp crop (Crotalaria juncea), all beans plots will have a pre-ceding fodder radish (Raphanus sativus) crop.***

### 8. *Basal Fertilizer:*

Maize:165 kg/ha Compound D (7-14-7) at planting (7.4 g/station in treatments 1, 3 and 4, specific fertilizer cups will be delivered).

Sunflower: 165 kg/ha Compound D at planting (3.0 g/station)

Beans: 165 kg/ha Compound D at planting using the animal traction seeder

*No basal fertilizer to the cover crops*

**9. *Weed control:***

- Existing weeds should be weeded before the establishment of the trial
- Apply glyphosate at 3 l/ha as a general spray if weeds are present at seeding. This spraying may be done before planting (1-7 days before seeding) or after planting but BEFORE the maize emerges.
- Manual weed control after crop emergence

***Top-dressing*:**

Maize: 200 kg/ha of Urea applied as split application; 4 + 7 weeks after planting. In Treatments 1, 3 and 4 apply 4.6 grams per planting station at each application.
In other treatments (planted with the direct seeder) use the following procedure:
Calculate the plant population 3-4 weeks after crop emergence (after thinning!) by counting 2 central rows of each plot. According to plant population calculated make fertilizer cups to put urea fertilizer (200kg/ha) in two applications 4 and 7 weeks after planting

Sunflower
Calculate the plant population 3-4 weeks after crop emergence (after thinning!) by counting 2 central rows of each plot. According to plant population calculated make fertilizer cups to put urea fertilizer (200kg/ha) in two applications 4 and 7 weeks after planting (

Beans:
*No top-dressing required*

*No top-dressing to the cover crops*

**10. *Disease control*:**
Serious outbreaks of disease should be identified, and controlled if necessary using economic criteria (commercial criteria)

**11. *Pest control*:**
If pests are observed in sufficient quantity to warrant control, then apply a recommended pesticide.

**12. Equipment and Data collection (additional protocols are available):**

1. Rainfall recorded daily
2. Record dates of all activities, and of 50% plant emergence, 50% tasseling, 50% silking and 50% physiological maturity
3. Land condition at seeding: type of residues, % ground cover. General observation over the trial area.

4. Soil samples will be taken on six measuring points in each plot in 5 layers (0-10cm,10-20cm, 20-30cm, 30-60cm, 60-90cm). Soil sampling is carried out before the season and at harvest.
5. Soil moisture probes will be installed in treatments 1-10 in 3 replications and constantly measured
6. Infiltration will be measured using a mini-rainfall simulator. Additional protocols are available
7. Plant populations. Plant counts on two central rows of each plot approximately 3 weeks after planting.
8. Grain and biomass yields. Follow the harvest procedure:

**Harvest procedure:**

On all plots: **8 samples** per treatment, each **5m x 2** rows. **Record the distance** between four rows at each sample site (very important to get the exact row spacing!). (**H5**)

Cut harvest samples at ground level.

Maize:

1. Count no of maize plants (H1) and no of cobs (H2) of each sample.
2. Weigh total maize stalks and leaves of each sample without cobs (H3)
3. Weigh the cobs from each sample (H4)
4. Take 2 cobs at random from each sample (= 16 cobs) and weigh them immediately (H6)
5. Take 1 plant (stalk) from each sample (from the 8 samples = 8 stalks)
6. Cut the stalks into small pieces and take a representative sub-sample of approximately 500-1000g, and weigh the sub-sample immediately and exactly (to the nearest gram) (H11)

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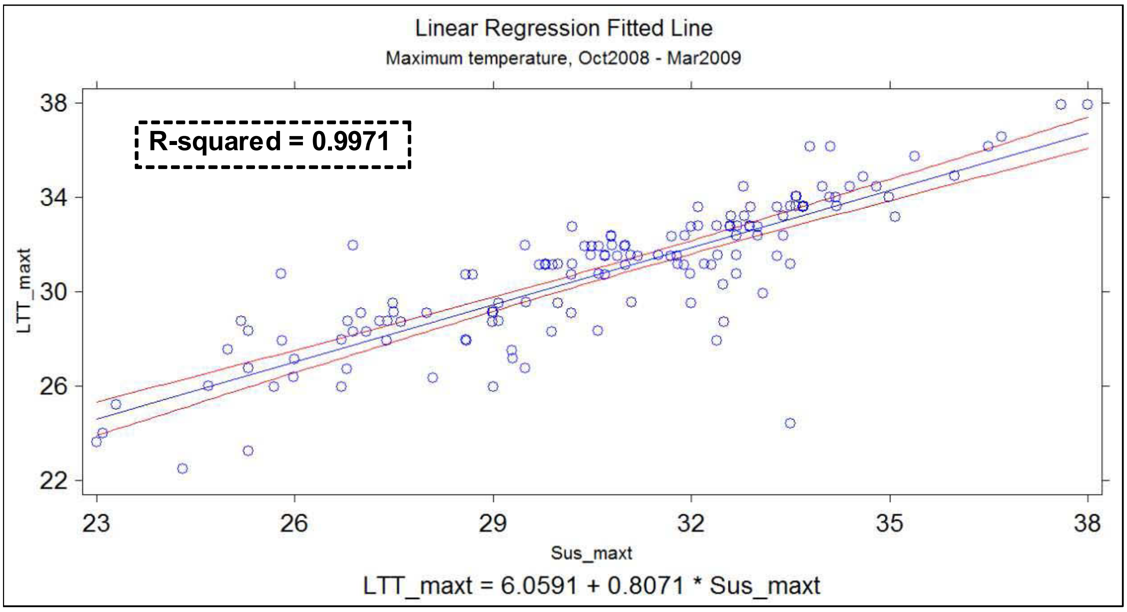
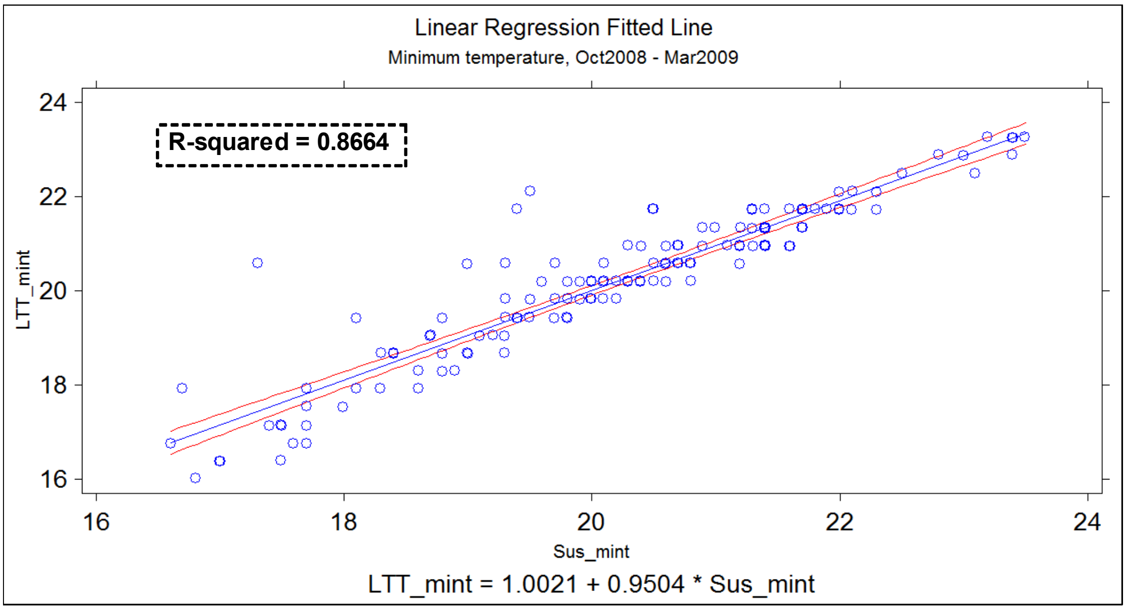
7. Air dry the cob sub-samples and stalk sub-sample
8. Re-weigh the cobs exactly (to the nearest gram) (H7)
9. Shell the 20 cobs and weigh the grain (H8) and the cores (H9)
10. Measure the moisture of the grain with the moisture meter (H10)
11. Re-weigh the stalk sub-sample exactly (to the nearest gram) (H12)

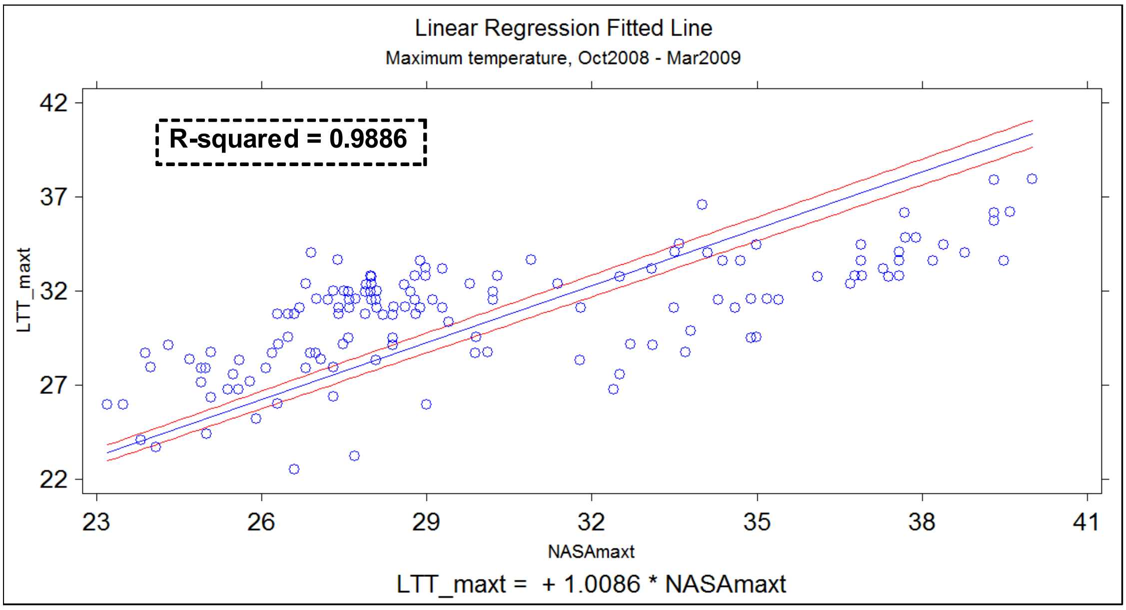
**Annex B: Liner Regression Analysis for the Gap Filling in the Meteorological Data.**

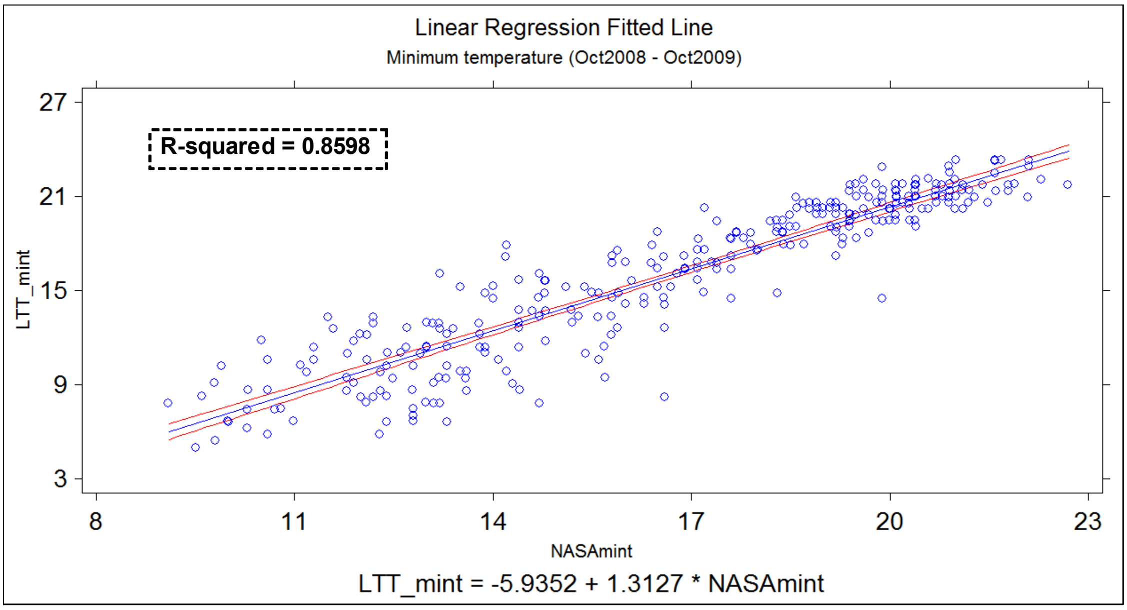
Maximum and Minimum Air temperatures – Regression analysis between the data collected in the trial site and at the Sussundenga Agro-Climatic Station data



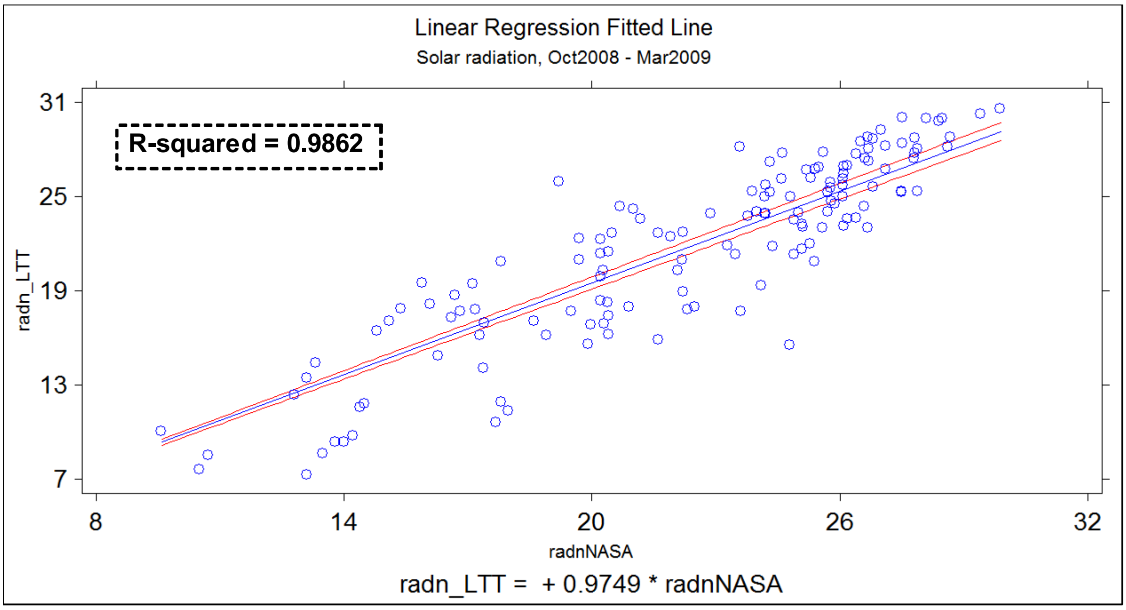



Maximum and Minimum Air Temperatures – Regression analysis between the data on the trial site and NASA data



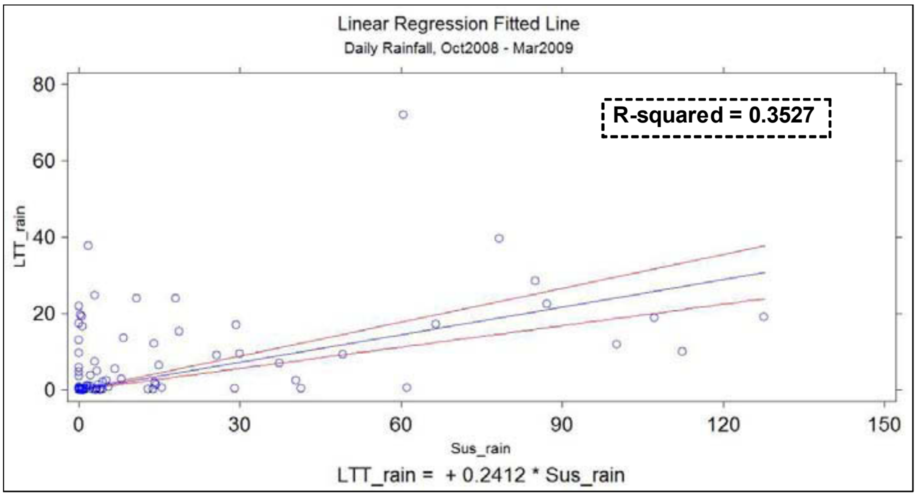



Incoming Solar Radiation – Regression analysis between the data on the trial site and NASA data

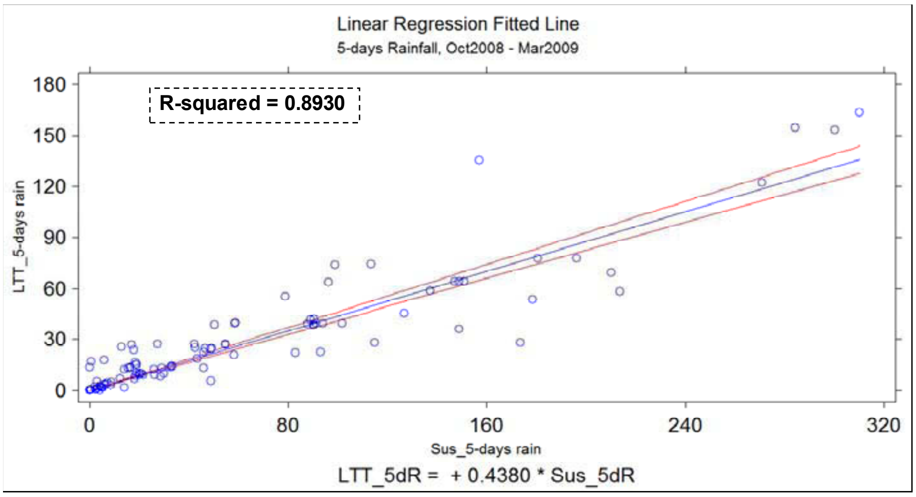



***Rainfall – Regression analysis between the data on the trial site and Sussundenga Agro-Climatic Station data***

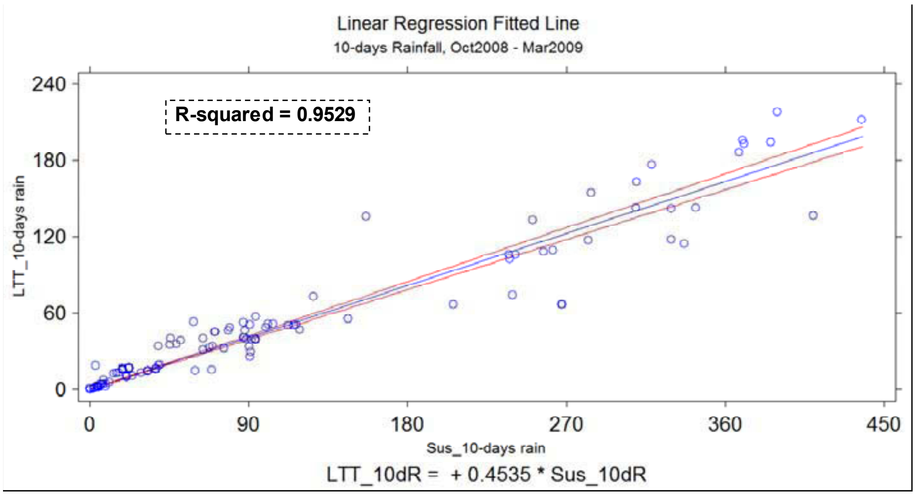
Day rainfall data from the trial site and the agro-climatic station 1Km distant did not show good correlation, showing that spatial variability of rainfall was very high; the agro-climatic station is closer to a hillside than the trial site. Therefore a 5-day total rainfall or more days correlated well. It was then used a total 5-day rainfall regression analysis throw the origin 0-0 for the gap filling. The consequences of this is that, if this is used for the gap filling of a long period, water balance studies may be reliable only for 5 day or more time step period.



Linear Regression Fitted Line
Daily Rainfall, Oct2008 - Mar2009
R-squared = 0.3527
LTT_rain
Sus_rain
0
20
40
60
80
0
30
60
90
120
150
LTT_rain = + 0.2412 * Sus_rain

Linear Regression Fitted Line
5-days Rainfall, Oct2008 - Mar2009
R-squared = 0.8930
LTT_5-days rain
Sus_5-days rain
0
30
60
90
120
150
180
0
80
160
240
320
LTT_5dR = + 0.4380 * Sus_5dR

Linear Regression Fitted Line
10-days Rainfall, Oct2008 - Mar2009
R-squared = 0.9529
LTT_10-days rain
Sus_10-days rain
0
60
120
180
240
0
90
180
270
360
450
LTT_10dR = + 0.4535 * Sus_10dR

## Annex C: Observed and APSIM Simulated Soil Water for different Treatments in the Long Term Trial in Sussundenga.

This Annex presents in graphs the observed and APSIM simulated total soil water in the 0-90 cm depth (SW90) in the different treatments studied with results of root mean standard error (RMSE) and used CN2Bare indicated in the text (Table 4.6.5), for the cropping seasons 2008-09 and 2009-10. For each treatment two graphs are shown, one with rainfall, observed and simulated SW90, from maize seeding to maturity, and the other shows the simulated and observed SW90 with error bars. The treatments are:

- CP: Check plot, traditional farmers practice, continuous maize
- DS: Direct seeding, continuous maize
- BA: Basins, continuous maize
- JP: Jab planter, continuous maize
- MS: Direct seeding, maize with sunflower as relay crop
- A_M: Direct seeding maize in rotation with sunflower
- B_M: Direct seeded maize after beans in the rotation maize-sunflower-beans

***Cropping Season 2008-09***

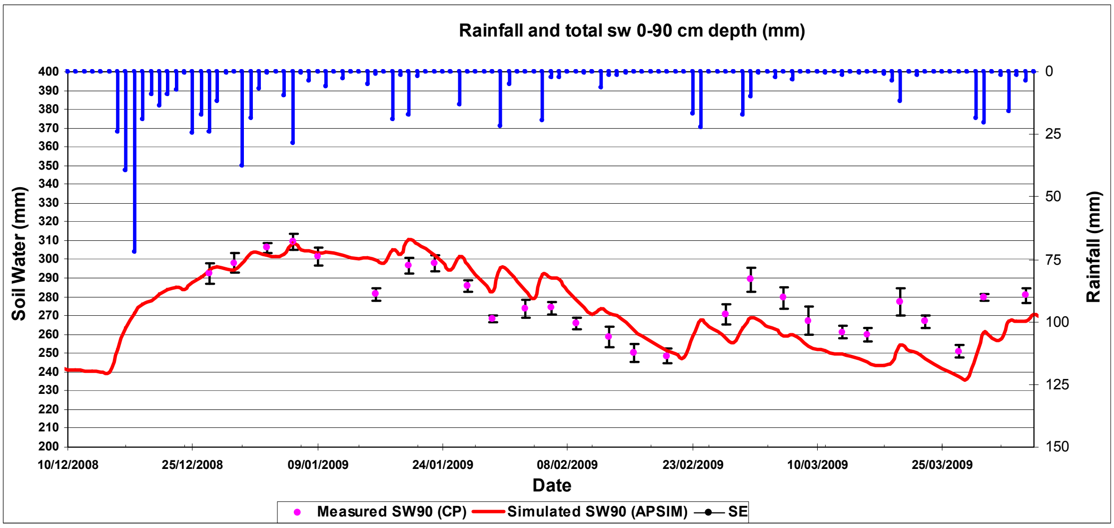



**Figure A 1: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2008-09, in traditional farmers practice (CP) treatment; SE is the standard error.**

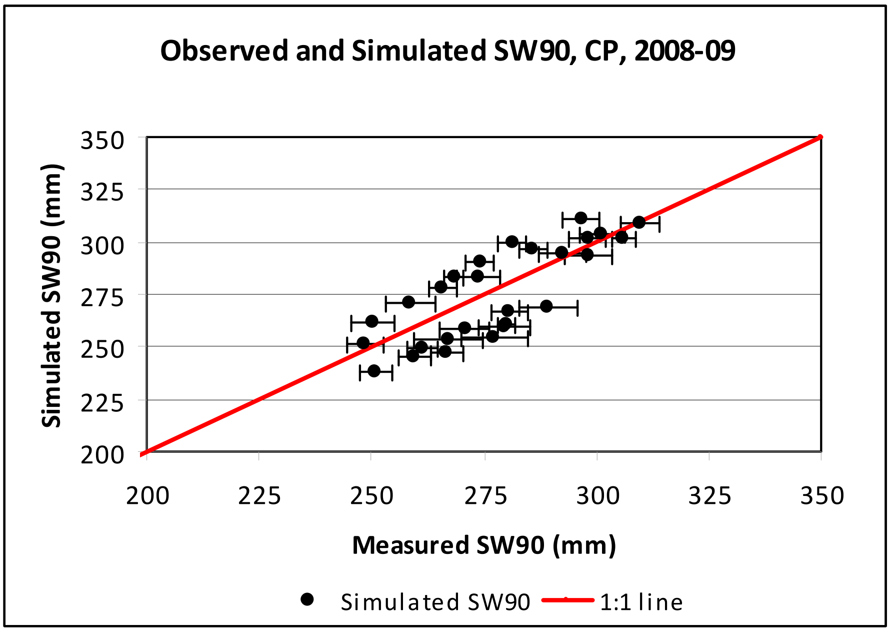



**Figure A 2: Observed and simulated soil water (SW90) in the farmers practice (CP) treatment, in the cropping season 2008-09; bars indicate the standard error in the measured values.**

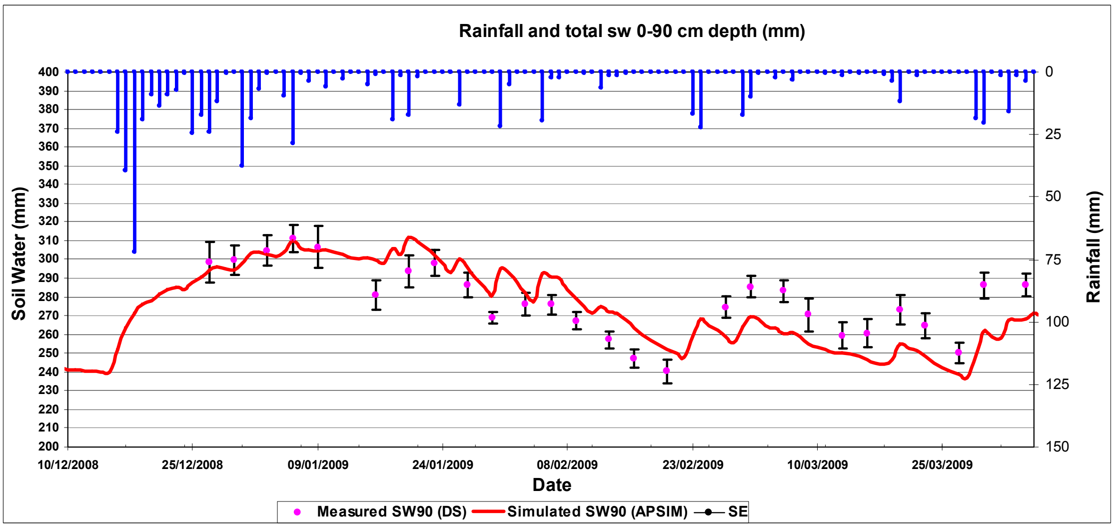



**Figure A 3: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2008-09, in direct seeding treatment (DS); SE is the standard error.**

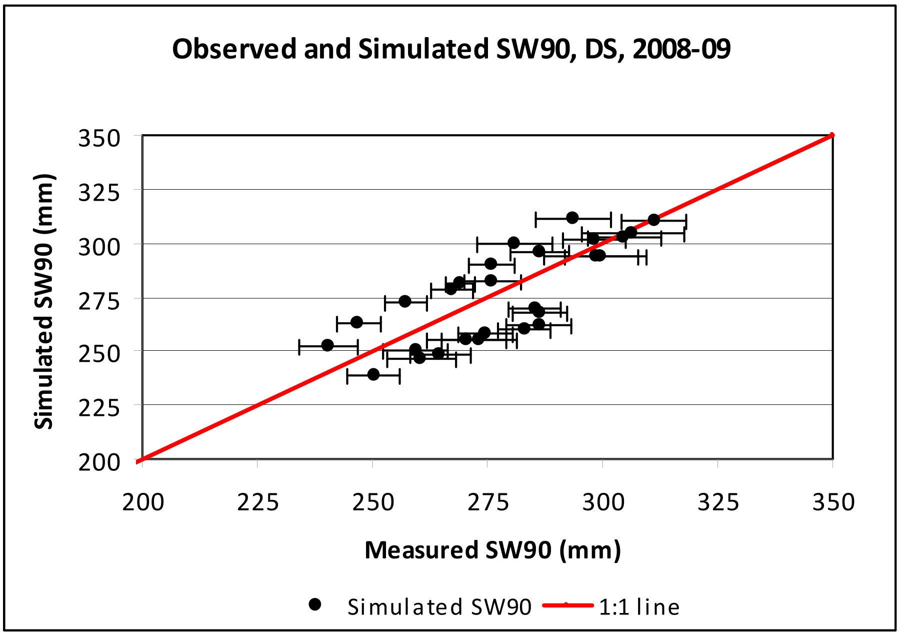



**Figure A 4: Observed and simulated soil water (SW90) in direct seeding treatment (DS), cropping season 2008-09; bars indicate the standard error in the measured values.**

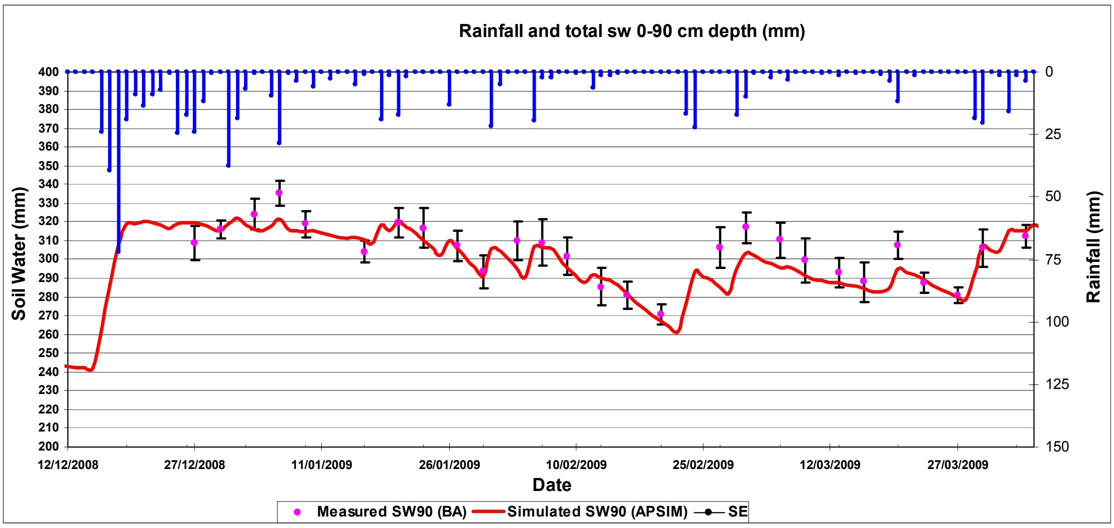



**Figure A 5: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2008-09, in basin treatment (BA); SE is the standard error.**

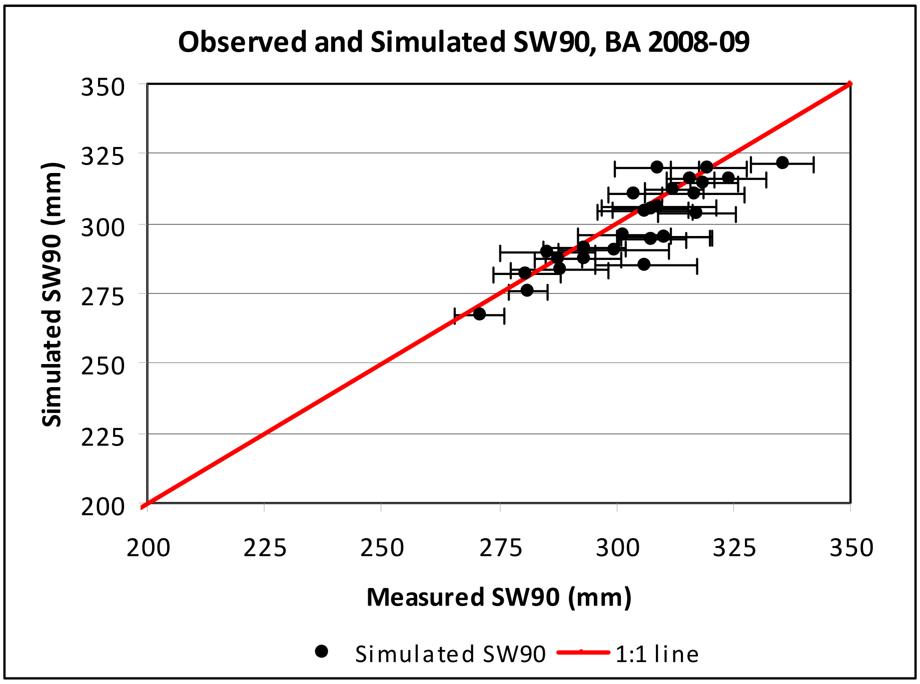



**Figure A 6: Observed and simulated soil water (SW90) in basin treatment (BA), cropping season 2008-09; bars indicate the standard error in the measured values.**

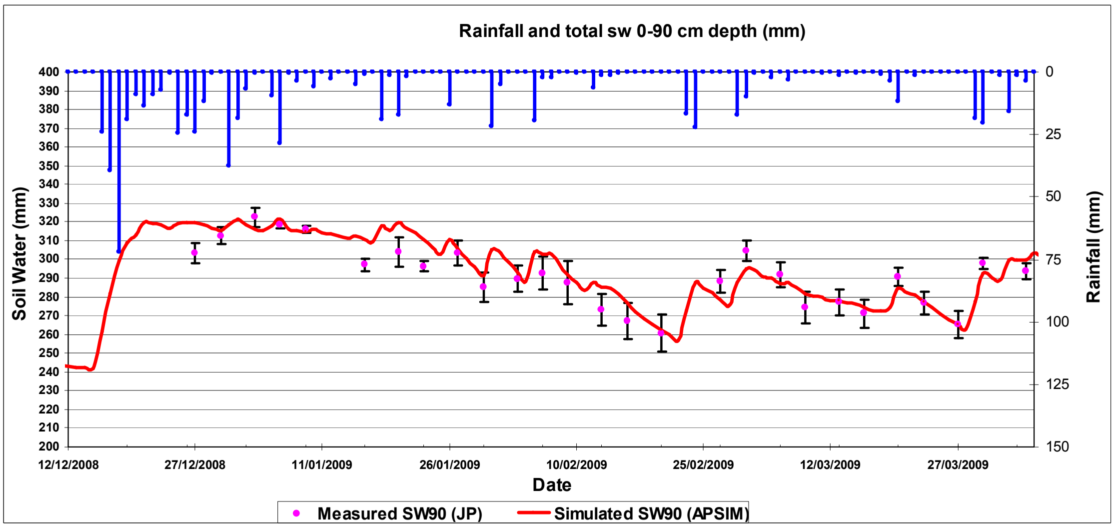



**Figure A 7: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2008-09, in jab planter treatment (JP); SE is the standard error.**

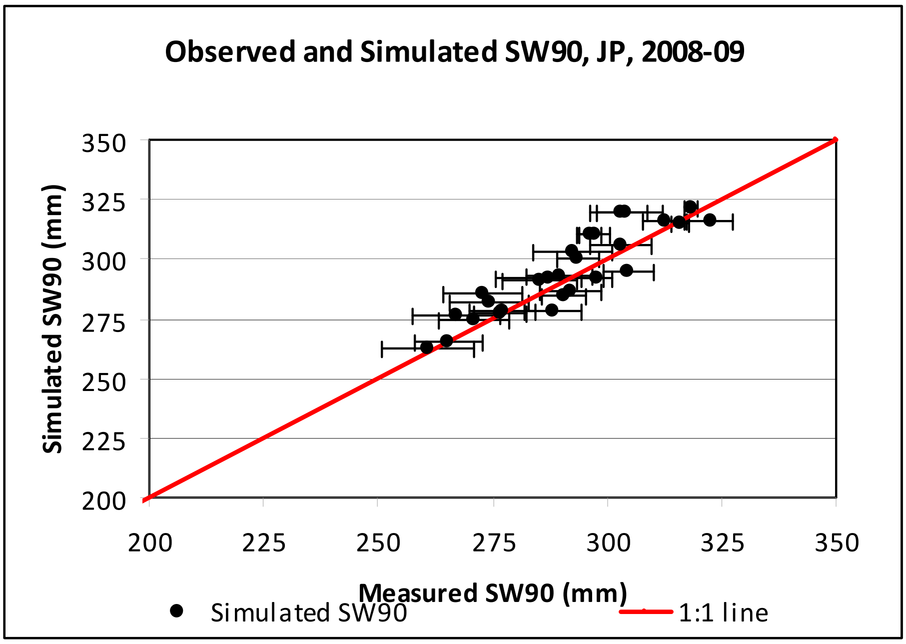



**Figure A 8: Observed and simulated soil water (SW90) in jab planter treatment (JP), cropping season 2008-09; bars indicate the standard error in the measured values.**

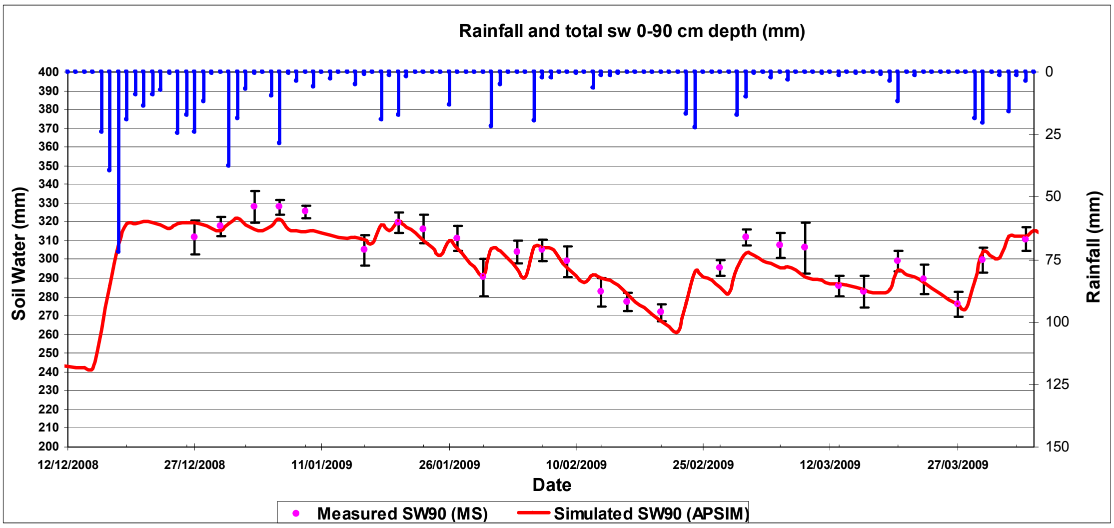



**Figure A 9: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2008-09, in direct seeded maize with sunflower as relay crop (MS) treatment; SE is the standard error.**

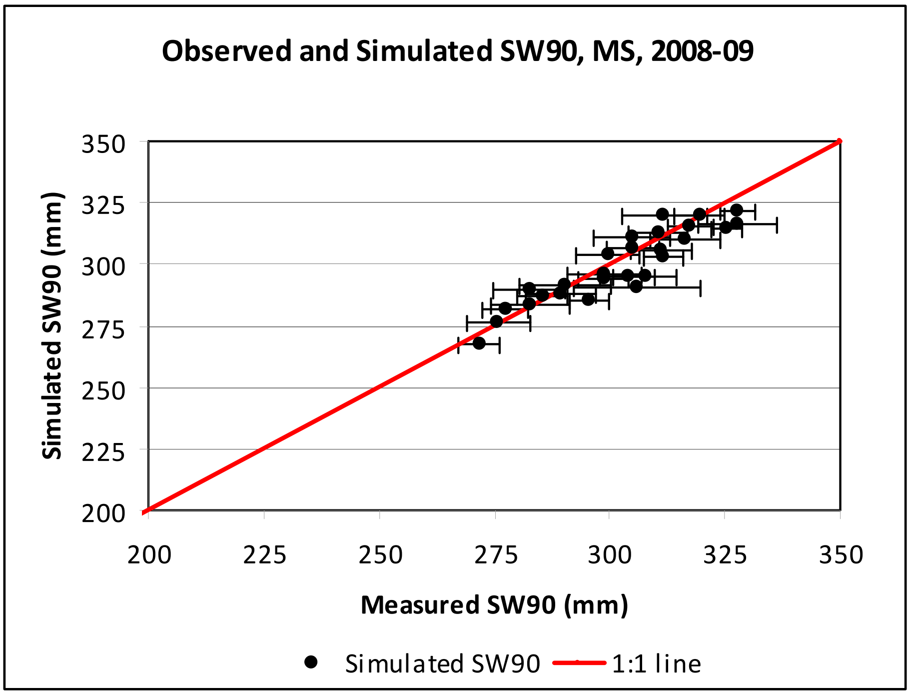



**Figure A 10: Observed and simulated soil water (SW90) in direct seeded, maize with sunflower as relay crop (MS) treatment, cropping season 2008-09; bars indicate the standard error in the measured values.**

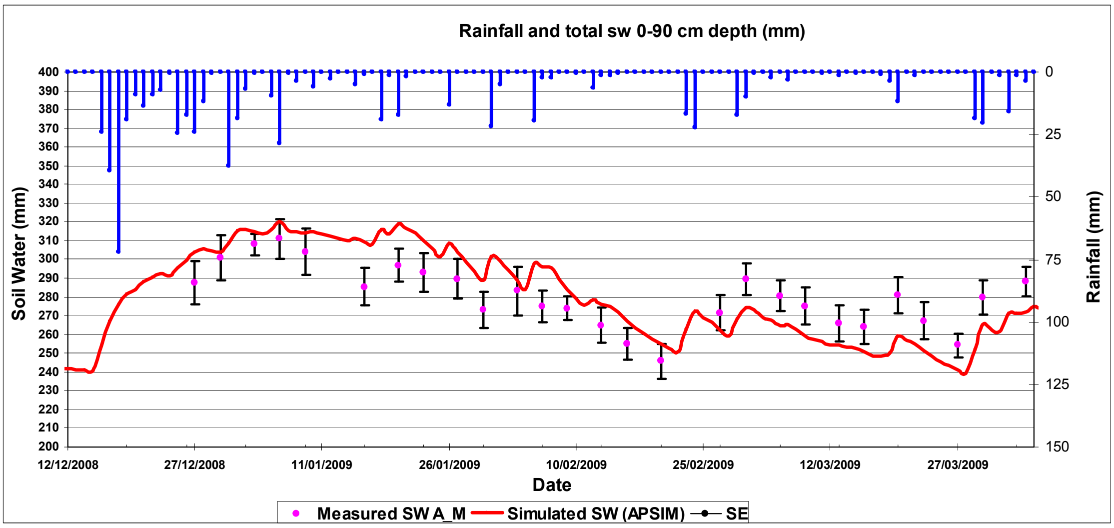



**Figure A 11: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2008-09, in direct seeded maize in rotation with sunflower (A_M) treatment; SE is the standard error.**

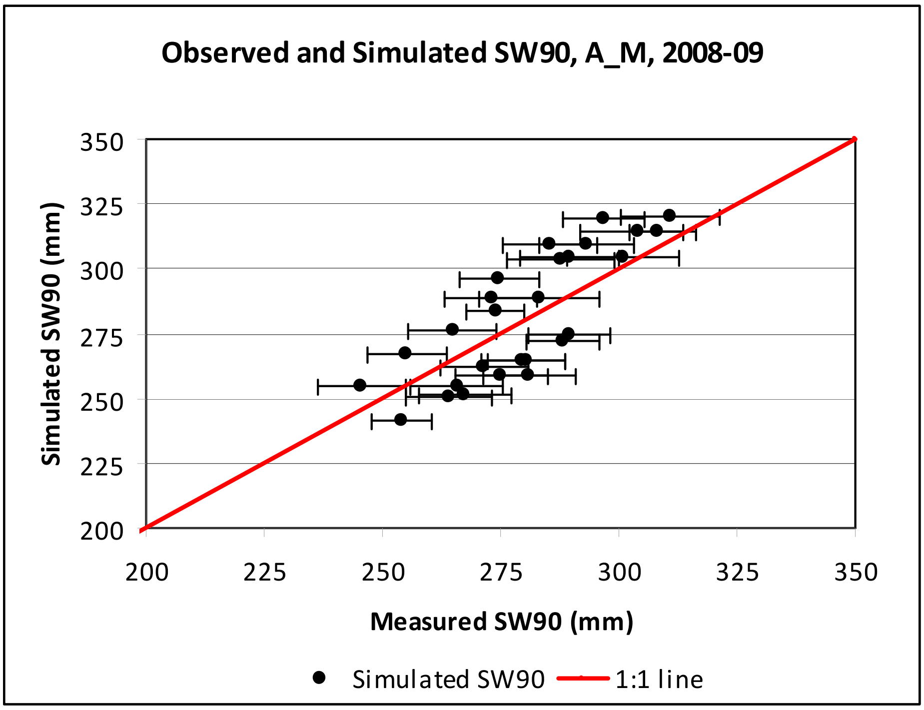



**Figure A 12: Observed and simulated soil water (SW90) in direct seeded maize in rotation with sunflower (A_M) treatment, cropping season 2008-09; bars indicate the standard error in the measured values.**

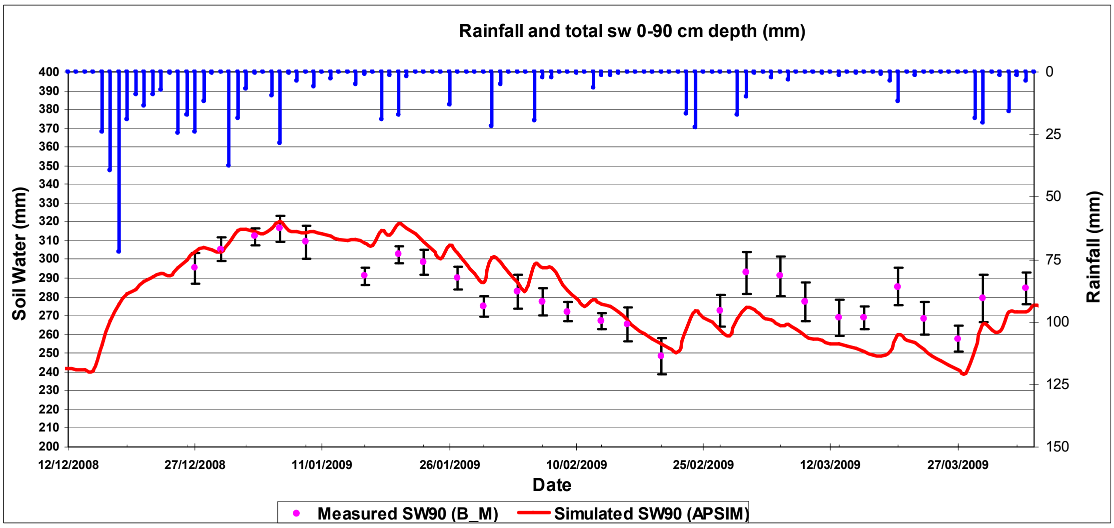



**Figure A 13: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2008-09, in direct seeded maize after beans in the rotation maize-sunflower-beans (B_M) treatment; SE is the standard error.**

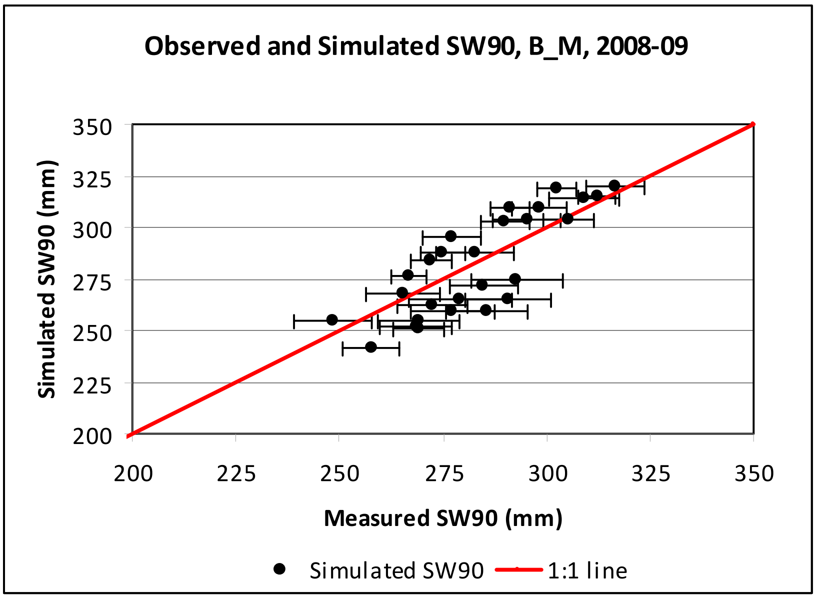



**Figure A 14: Observed and simulated soil water (SW90) in direct seeded maize after beans in the rotation maize-sunflower-beans (B_M) treatment, cropping season 2008-09; bars indicate the standard error in the measured values.**

***Cropping Season 2009-10***

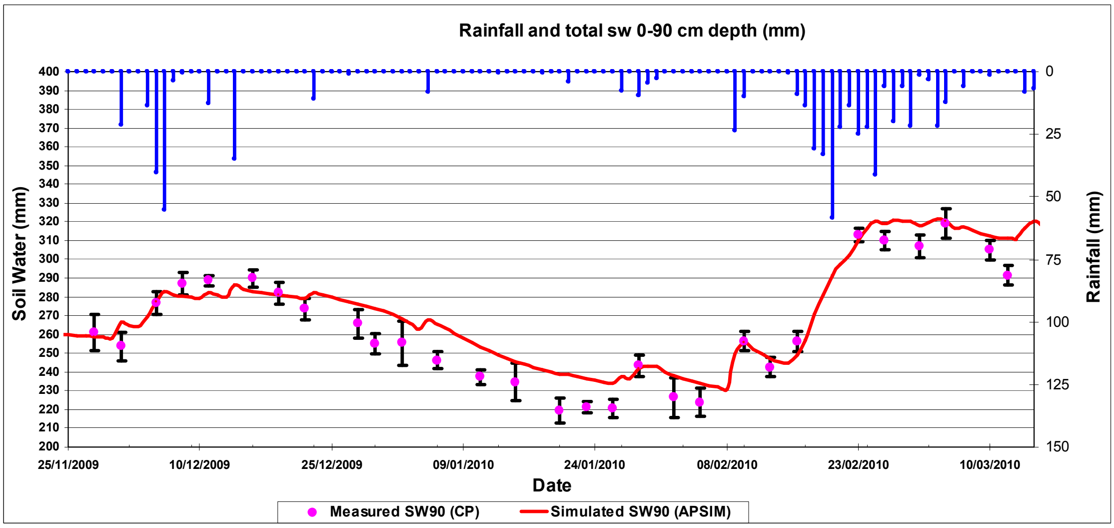



**Figure A 15: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2009-10, in traditional farmers practice (CP) treatment; SE is the standard error.**

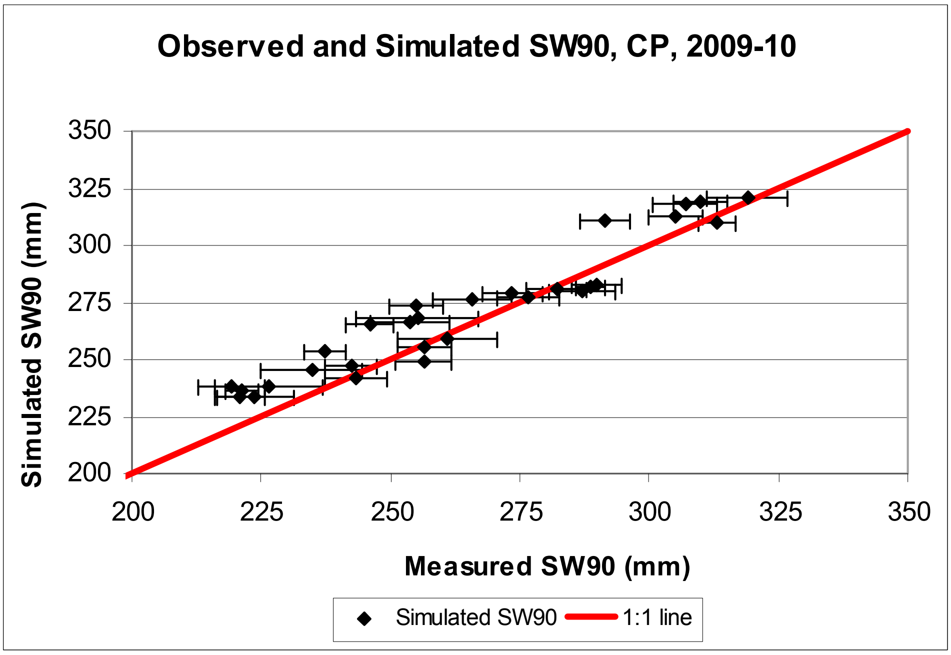



**Figure A 16: Observed and simulated soil water (SW90) in the farmers practice (CP) treatment, in the cropping season 2009-10; bars indicate the standard error in the measured values.**

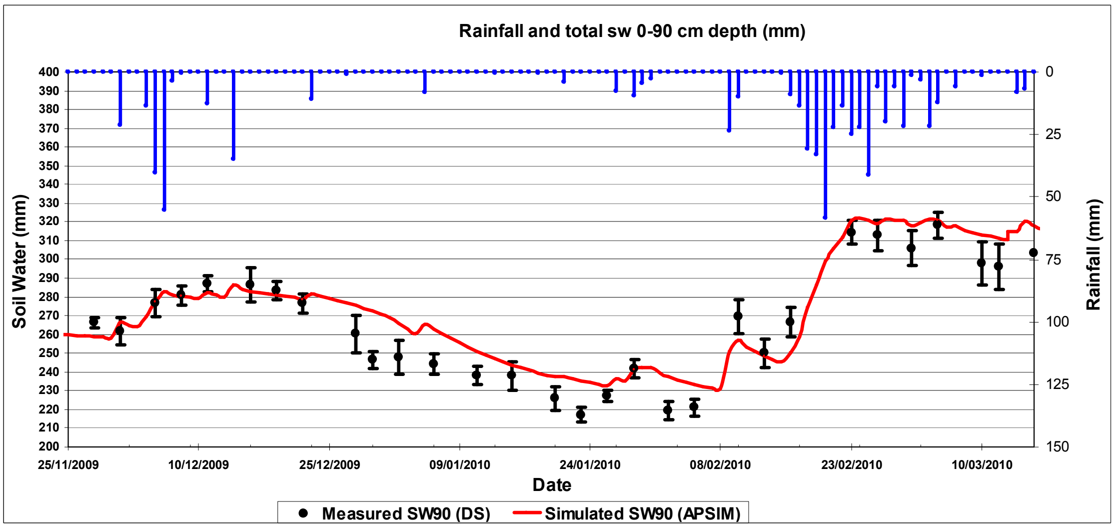



**Figure A 17: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2009-10, in direct seeding treatment (DS); SE is the standard error.**

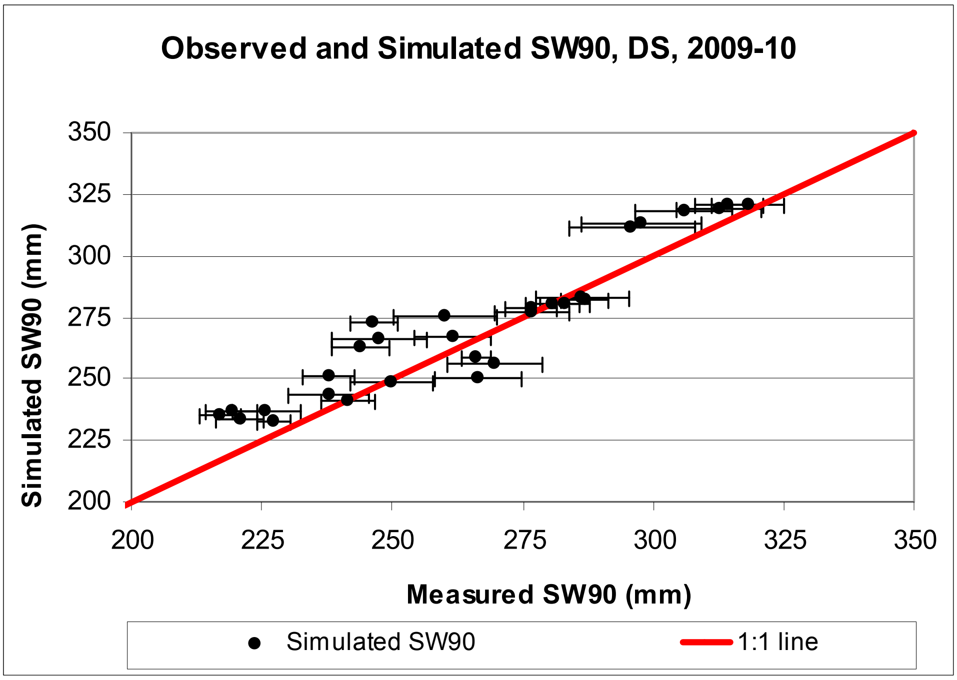



**Figure A 18: Observed and simulated soil water (SW90) in direct seeding treatment (DS), cropping season 2009-10; bars indicate the standard error in the measured values.**

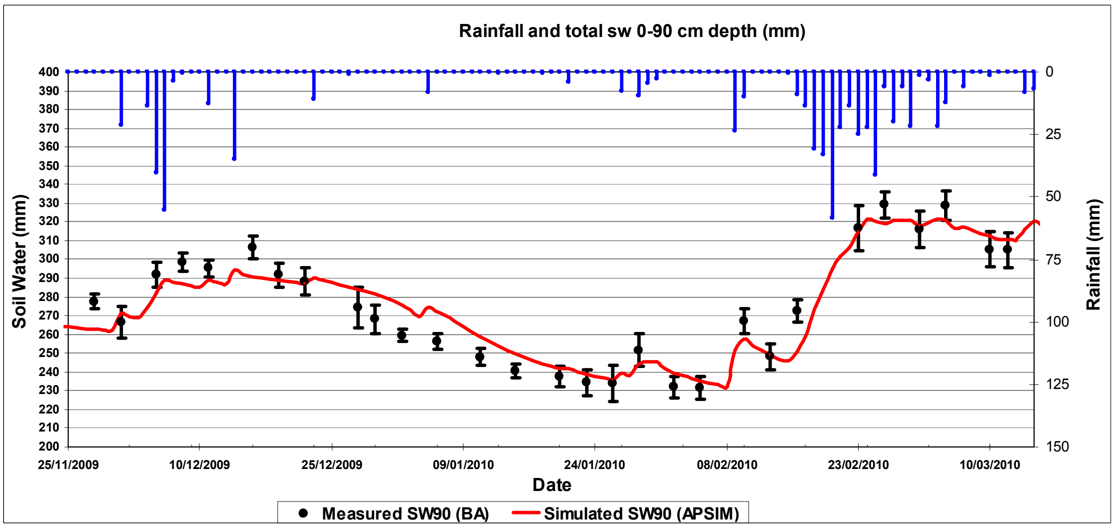



**Figure A 19: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2009-10, in basin treatment (BA); SE is the standard error.**

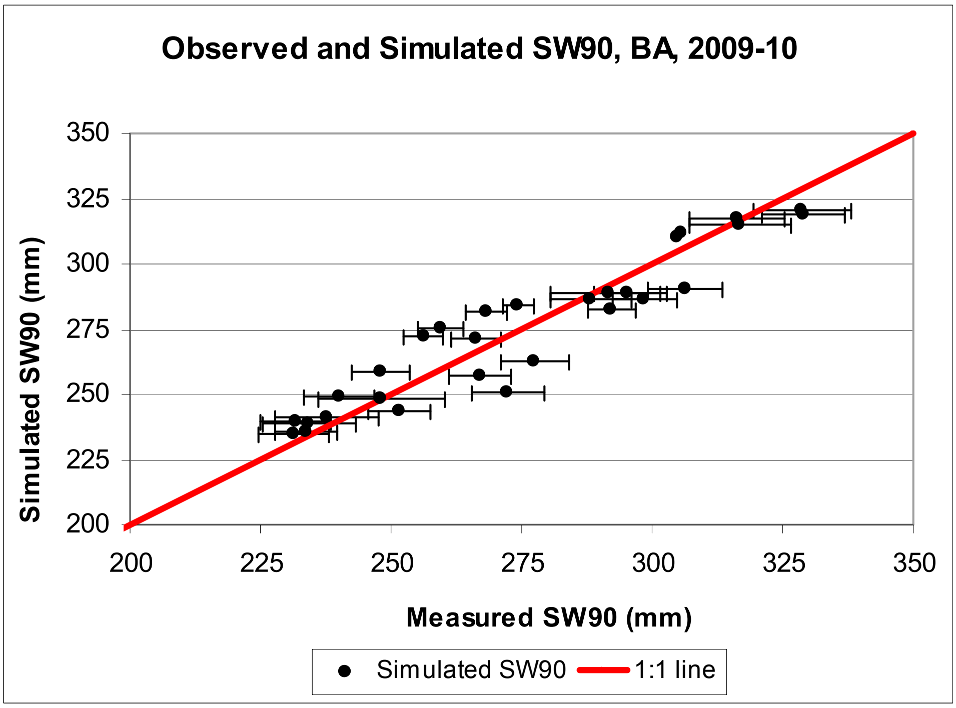



**Figure A 20: Observed and simulated soil water (SW90) in basin treatment (BA), cropping season 2009-10; bars indicate the standard error in the measured values.**

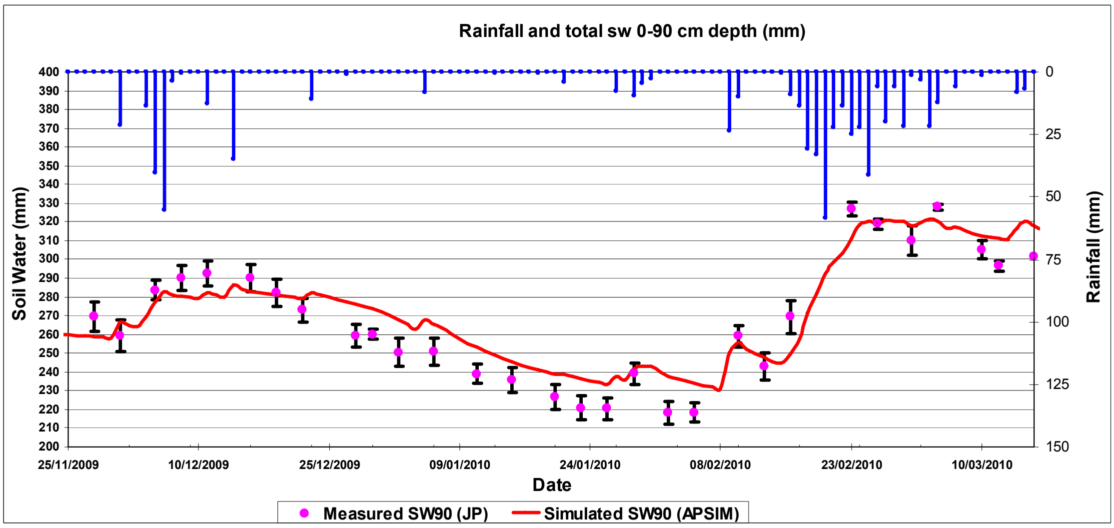



**Figure A 21: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2009-10, in jab planter treatment (JP); SE is the standard error.**

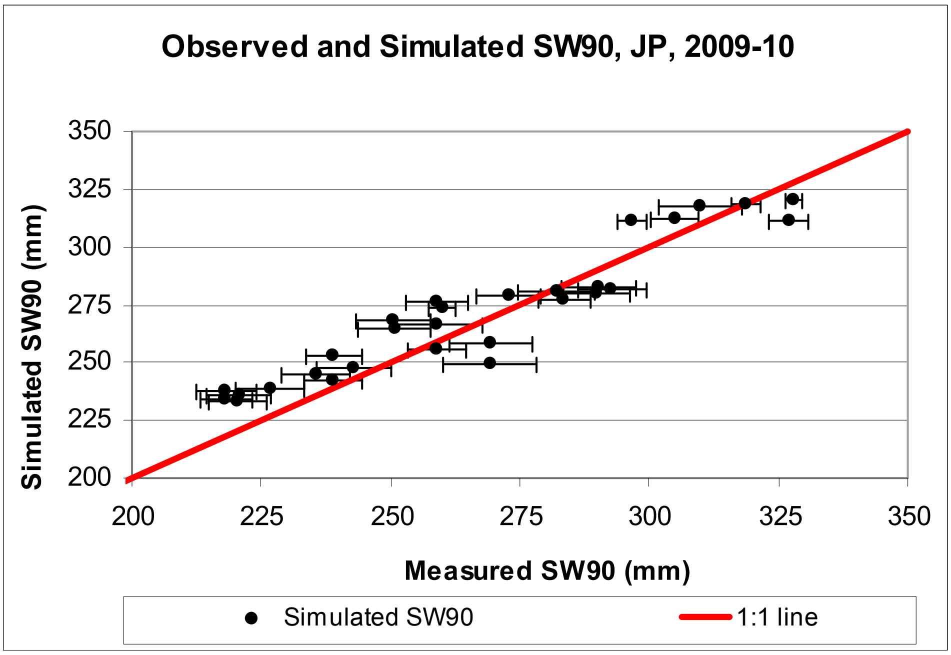



**Figure A 22: Observed and simulated soil water (SW90) in jab planter treatment (JP), cropping season 2009-10; bars indicate the standard error in the measured values.**

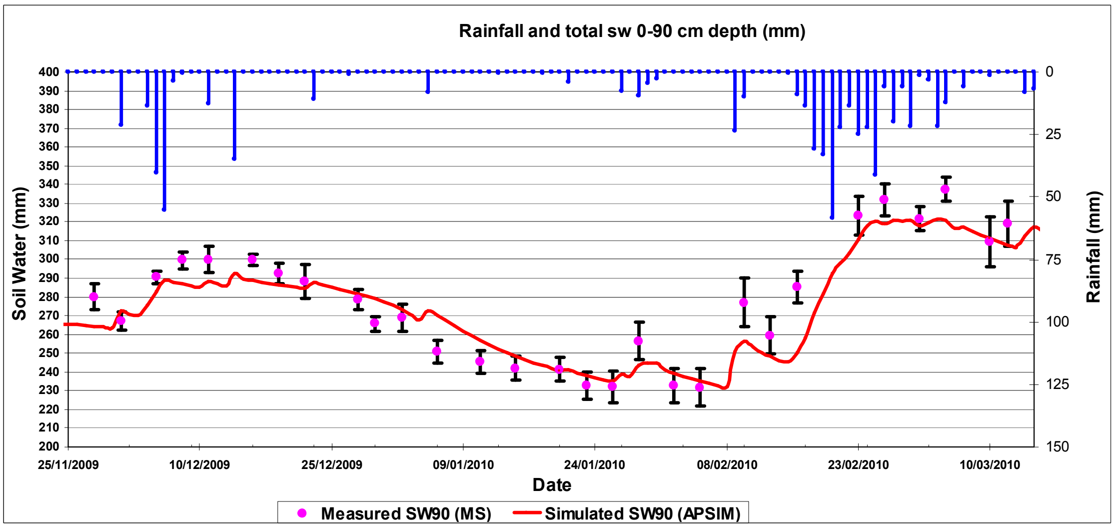



**Figure A 23: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2000-10, in direct seeded maize with sunflower as relay crop (MS) treatment; SE is the standard error.**

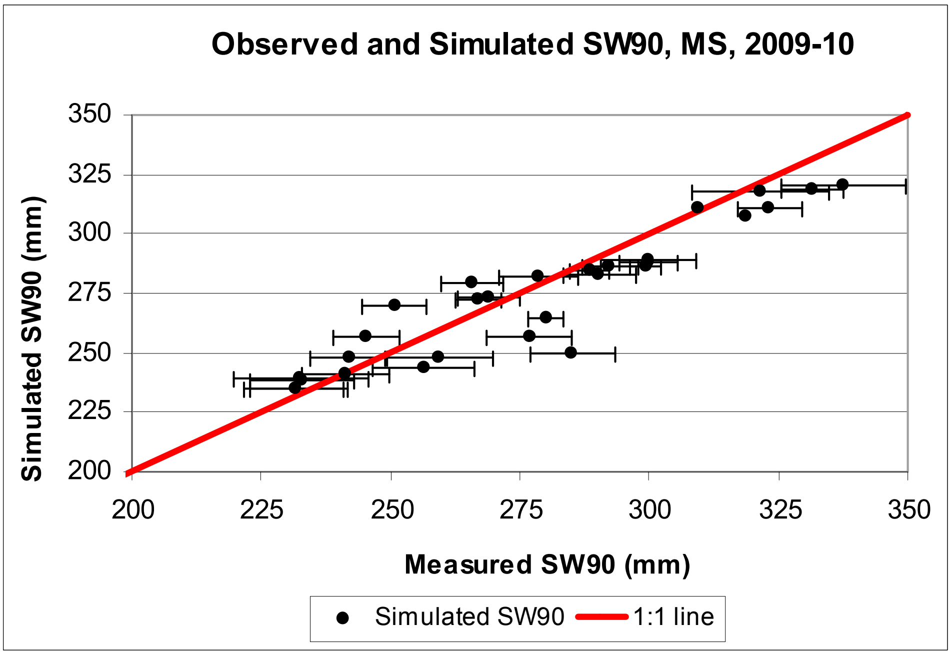



**Figure A 24: Observed and simulated soil water (SW90) in direct seeded, maize with sunflower as relay crop (MS) treatment, cropping season 2009-10; bars indicate the standard error in the measured values.**

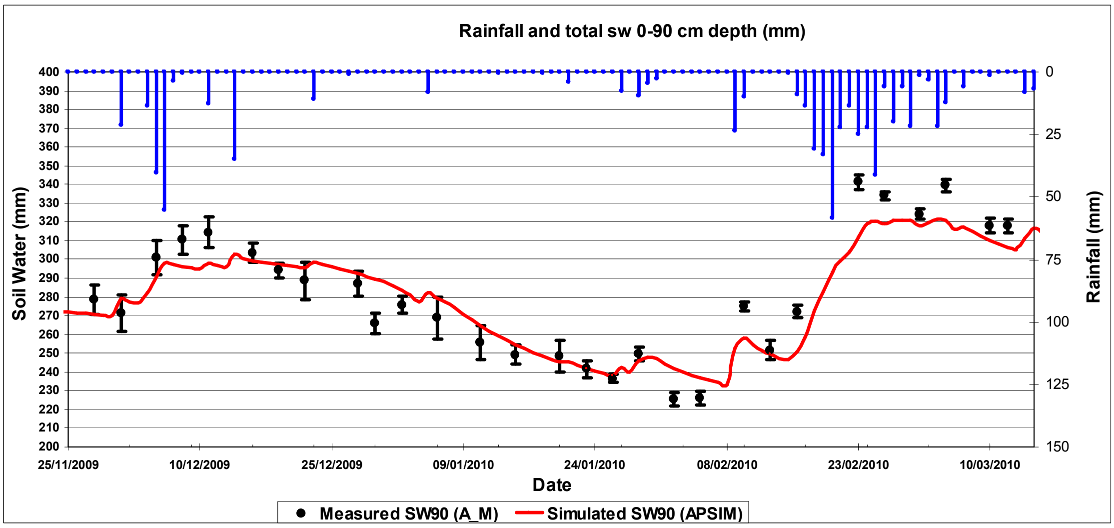



**Figure A 25: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2009-10, in direct seeded maize in rotation with sunflower (A_M) treatment; SE is the standard error.**

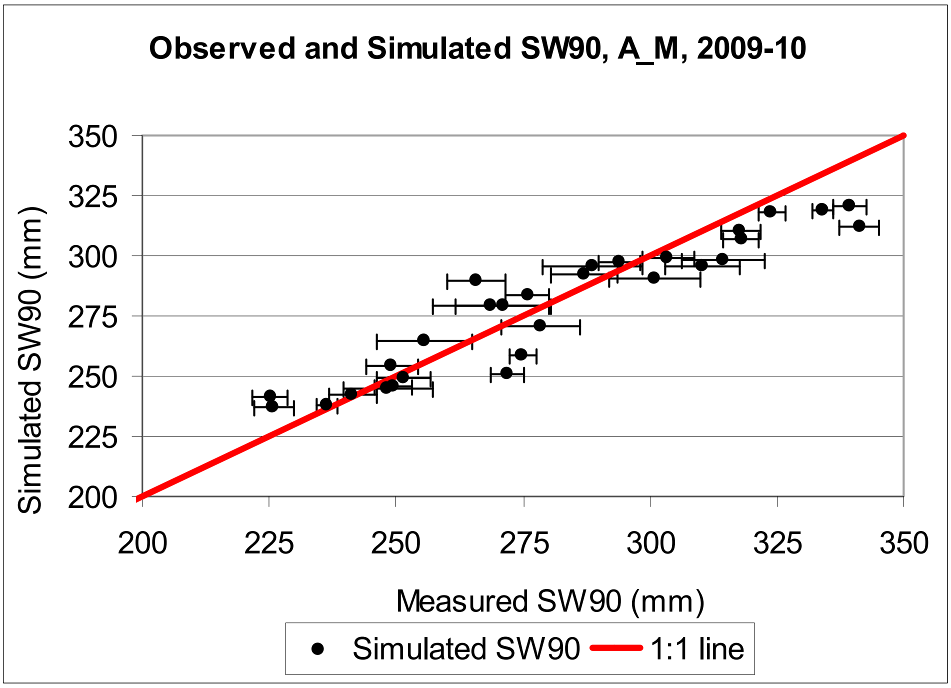



**Figure A 26: Observed and simulated soil water (SW90) in direct seeded maize in rotation with sunflower (A_M) treatment, cropping season 2009-10; bars indicate the standard error in the measured values.**

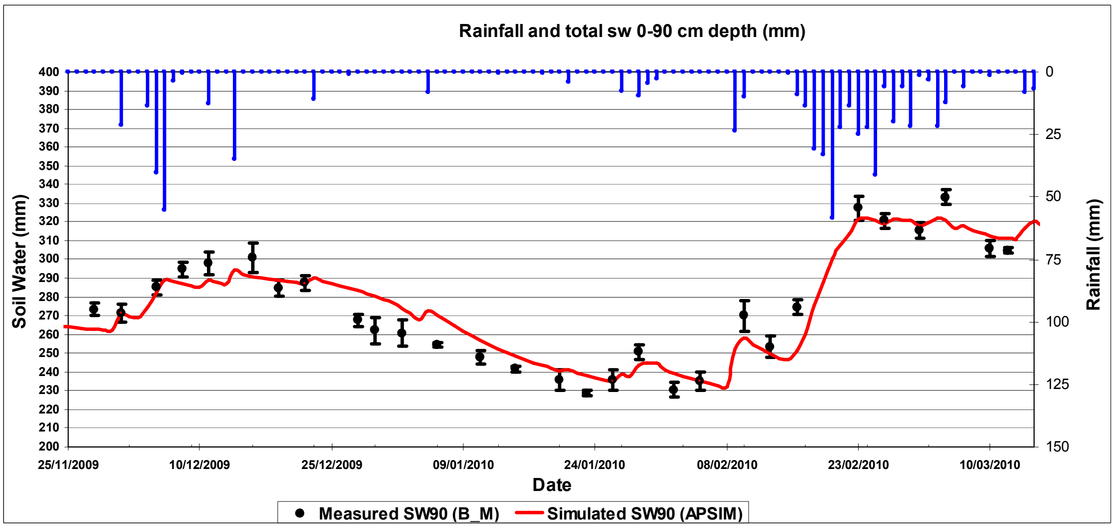



**Figure A 27: Rainfall, Measured and APSIM simulated soil water (SW90), cropping season 2009-10, in direct seeded maize after beans in the rotation maize-sunflower-beans (B_M) treatment; SE is the standard error.**

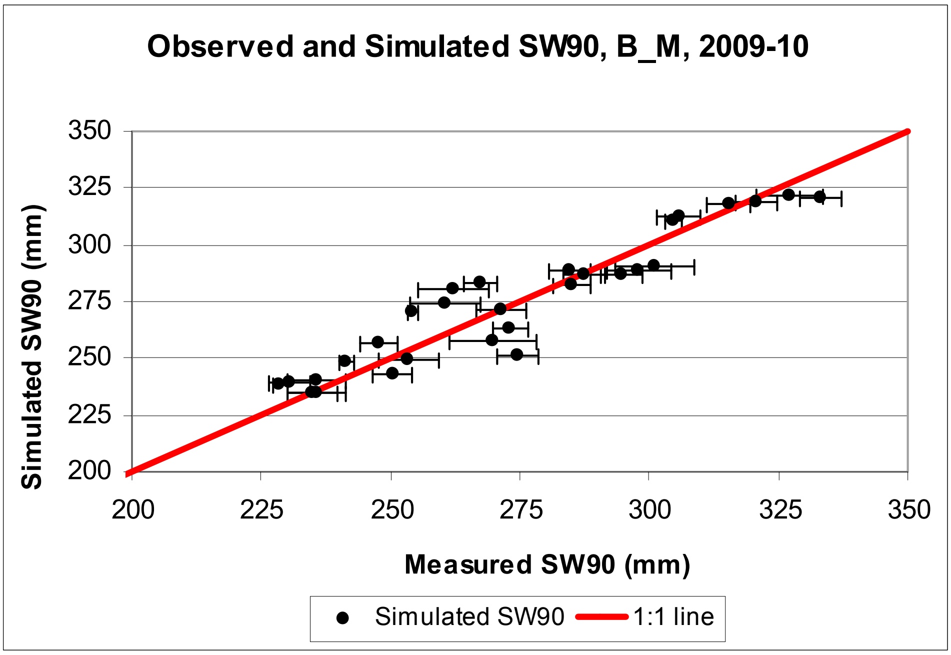
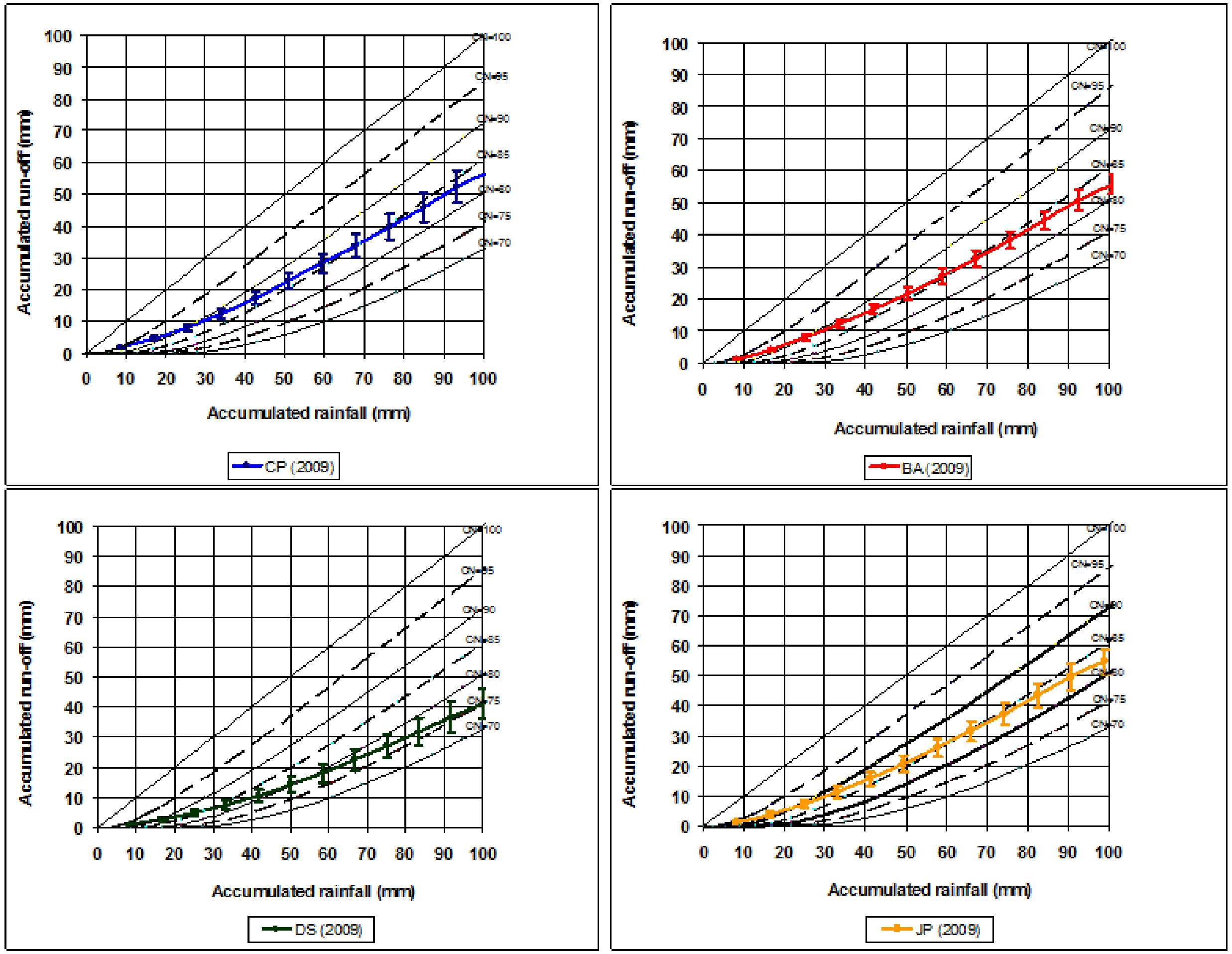
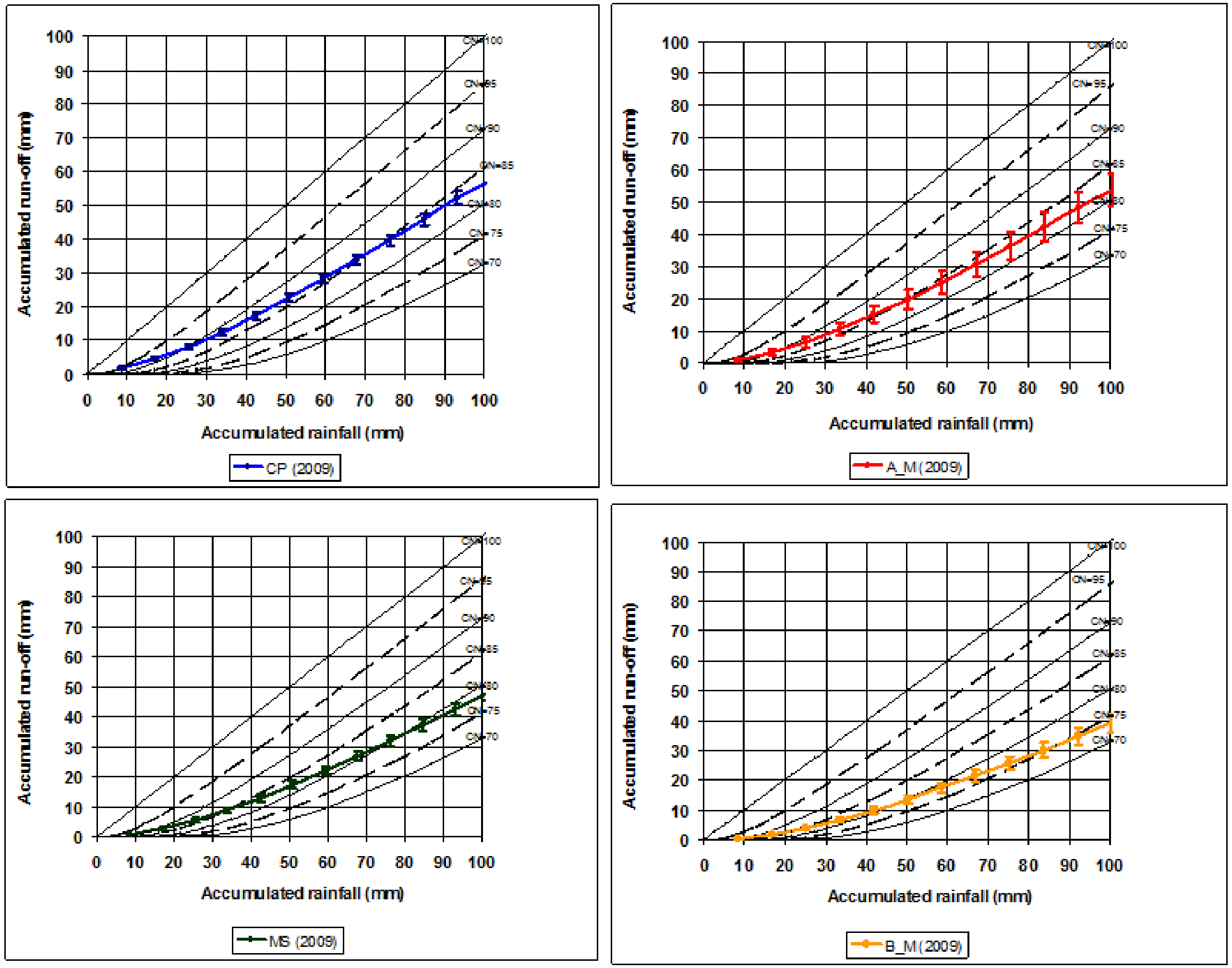



**Figure A 28: Observed and simulated soil water (SW90) in direct seeded maize after beans in the rotation maize-sunflower-beans (B_M) treatment, cropping season 2009-10; bars indicate the standard error in the measured values.**

**Annex D: Runoff Measurement Results with the Mini-rainfall in the Year 2009 in the Long Term Trial Plots in Sussundenga**




Accumulated run-off (mm)
Accumulated rainfall (mm)
CN=100
CN=95
CN=90
CN=85
CN=80
CN=75
CN=70
CP (2009)
A_M (2009)
MS (2009)
B_M (2009)