Soil water availability and its influencing factors in Debre-Mewi, a sub-catchment in the Ethiopian highlands

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Abstract

Evaluation of soil water availability and its influencing factors in Debre-Mewi, a sub-catchment in the Ethiopian highlands

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The lack of infrastructure and water storage in Ethiopia makes farming almost entirely dependent on the rain, with devastating impacts in times of draughts. The water shortage followed by the food insecurity is the source of many problems in the area and the work towards securing food supplies and wealth for the people is of great importance. There has to be an increase in crop production to adapt to the increasing population. It is therefore essential to evaluate methods on how to increase the yield, such as the improvement of water and soil conservation techniques as well as possibilities for secondary crops and alternative land use.

This Minor Field Study was carried out during November and December 2009 and based in the Debre-Mewi catchment, located south of Bahir Dar in Northern Ethiopia. The main objective for the study was to evaluate whether the plant water availability in parts of the Debre-Mewi catchment is good enough to sustain a secondary crop. The other objectives were to find out if soil moisture is a limiting factor for crop production in the area and how the soil moisture is dependent on soil type, crop type and field location (elevation height) within the catchment.

During the study period of three weeks, soil moisture was measured once a week in fifteen, both primary and secondary, cropped fields at four different elevations by using a mobile TDR sensor. The spatial and time dependent variation in soil moisture was examined by kriging interpolation, using the geo statistical package GS+ and also analyzed with a statistical Anova analysis. The soil infiltration rates at the different slope locations were measured. Moreover, the plant water demand and availability as well as the potential crop production was evaluated by using a dynamic model called Aqua crop.

The evaluation of the results showed that the plant water availability is sufficient for secondary crops in some fields in the catchment. The kriging interpolation and the evaluation of mean values showed that the soil moisture content is around 30 percent higher in the lower parts of the catchment, where the soil type is Vertisol, compared to the upper parts where the soil consists of Nitisol. One reason for this is thought to be the better water holding capacity of Vertisols due to the higher amount of organic material compared to Nitisol. The analysis also showed a decrease of around 50 percent of the initial volumetric water content over time at all levels in the catchment during the study period. Variations in soil moisture between different cropped fields were observed at three elevations and at all sites tef had the highest amount of soil moisture. The statistical analysis indicates that these variations are significant.

The secondary crops should, according to this study, preferably be planted in the lower part of the Debre-Mewi catchment, where the soil is Vertisol, in a previously cropped tef field. The crops should be planted as soon as possible after harvest of the primary crop to retain as much soil moisture as possible in the ground.

Acknowledgements

First of all we would like to thank our Supervisor at the Swedish University of Agricultural Sciences, Assoc. Prof. Annemieke Gärdenäs, for her commitment and help throughout this study. From the early planning stage until the finishing of the final report she has been a great support. We would also like to thank our supervisor at the Cornell University in Bahir Dar, Assistant. Prof. Amy S. Collick, for providing us with a place to work, contacts and valuable information about the area.

Thanks to Kevin Bishop who provided us with a GPS and to Solomon Gebreyohannis for the time he gave us before our departure and also for the data he provided us with. Thanks to the SLU-consultative group on international agricultural research for the grant that funded our field equipment.

We are also very thankful for the help we got from the Amhara Regional Agricultural Research Institute (Adet, ARARI) for the assistance with our fieldwork, transportation to the catchment area and also for the important data they provided us with. Thanks to Assefa Zegeye who showed us the catchment area and told us about his work in the area. We would like to express our thanks to all the people who helped us at the Bahir Dar University and at the Cornell University in Bahir Dar; Prof. Tammo S. Steenhuis for the valuable guidance and information; Habtamu Tillahun who helped us to get permission for the field work; Dr. Birhanu who made us feel welcome and introduced us to other people at the university.

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Without your help this study would not have been possible.

/Helena & Kristina

Contents

1. Introduction

1.1 Background

Ethiopia is a land-locked country situated in East Africa and borders to Eritrea, Sudan, Kenya, Somalia and Djibouti. The population is around 85 million, which makes the country the third most populated in Africa (UN 2008). Ethiopia counts to the sub-Saharan African region with a tropical monsoon climate and with wide topographic variation (CIA 2009).

The strong seasonal variation in rainfall, with short wet periods followed by long, very dry periods makes it hard to ensure the large population with water for food production and other basic needs during the dry periods. Only 22 percent of the population has access to clean drinking water (Sida 2008) and according to the human development report 2007/2008 by UN 2008, the country is ranked 169 by the HDI (Human Development Index) out of 177 countries. This is a measure that describes the human development in three dimensions: life expectancy, education and living standard.

The lack of infrastructure and water storage in Ethiopia makes farming almost entirely dependent on the rain, with devastating impacts in times of draughts. The water shortage followed by the food insecurity is the source of many problems in the area, such as poverty and tensions between up-stream and down-stream populations within a catchment and also with neighboring countries.

Work towards securing food supplies and wealth for the people is of great importance to maintain peace in the area. There has to be an increase in crop production to adapt to the increasing population and this is becoming even more important with the expected climate change, which is thought to increase and possibly intensify the rainy season and thus make the draughts and floods more severe (IPCC 2007). It is therefore essential to evaluate methods on how to increase the yield, such as production of secondary crops, possibilities for alternative land use as well as the improvement of water and soil conservation techniques.

If the soil has suitable properties, the secondary crops are sowed as soon as the first rotation of crop has been harvested. This gives farmers a second chance to achieve a sufficient yield production in case the primary yields were poor. Secondary crops are for instance barley (*Hordeum vulgare*), chickpea (*Cicer arietinum*) and grass pea (*Lathyrus sativus*). Barley is usually planted twice in the same field while chickpea and grass pea are planted as secondary crops in fields where tef or maize has grown before. Both peas have good nitrogen-fixing capacities and are therefore not only grown to intensify food production but also to increase soil nutrition.

This study was carried out in Debre-Mewi in the Amhara Region in the northern part of Ethiopia. The Amhara Regional Agricultural Research Institute (ARARI) has an office in the village Adet in the vicinity of the studied catchment. ARARI are coordinating agricultural research projects in the region, within the areas of sustainable agriculture, rural development, food security, soil erosion and soil conservation (Global Development Network, 2010).

A number of thesis essays have been carried out to investigate the increased erosion in the area and the problems that it gives rise to, such as the formation of gullies. The soil erosion in the area is mainly caused by human activity and in the thesis ”Assessment of upland erosion processes and farmers perception of land conservation methods in Debre-Mewi catchment, near Lake Tana, Ethiopia" by Assefa Derebe Zegeye (2009), he explains that these problems could be managed with better use of land conservation methods. Today only a few of these methods are applied by farmers on a long term basis. The problems due to gully formations are discussed in the thesis "Assessment of hydrological controls on gully formation near Lake Tana, Northern Highlands of Ethiopia" by Tigist Yazie Tebebu (2009), where she states that gullies causes large problems for farmers in the area due to soil loss. She also implies that the negative effect gully formations have on soil resources leads to smaller yields and reduces the land for livestock.

1.2 Main objectives

Farmers in the study area (Debre-Mewi) are often limited to one rotation of crops per year. They usually plant before and during the rainy season (June until September) and harvest between October and December/January. There are some fields that are able to sustain a secondary crop, such as barley or chickpea, well into the dry season and these fields are green and have living vegetation, although other fields adjacent are dry, with bare soil and no living vegetation. One way to enhance the crop production and thereby the wealth in the area would be to investigate the possibilities for a secondary crop at other fields as well.

1. **Is the plant water availability sufficient for a secondary crop in the Debre-Mewi sub-catchment?**
   The main objective for this study is to evaluate whether the plant water availability in parts of the catchment is good enough to sustain a secondary crop such as grass pea or barley.

2. **Is soil moisture a limiting factor for crop production in the area and how does it depend on soil type, crop type and field location within the catchment?**
   We analyzed the importance of different factors influencing the demand and water availability of different crops. These factors are geohydrological aspects, such as location and elevation within the catchment, slope, soil characteristics and the plant water demand affected by the phenology of the crops in the catchment (time of sowing, emerging, grain filling and harvest).

We described the geohydrology, land use and management of the selected study area in the Debre-Mewi catchment. The soil moisture content was measured during a period of three weeks and the spatial and time dependent variation in soil moisture was analyzed by kriging. The soil infiltration rate was also measured during the same time span to evaluate the differences of soils in the catchment. Finally the plant water demand and availability were evaluated by using a simple dynamic model called Aqua crop (Steduto et al., 2008).

2. Methods and materials

2.1 Site description

Debre-Mewi sub-catchment area

Debre-Mewi catchment is situated at 11°20’55”N to 11°21’17’’N latitude and 37°25’00”E to 37°25’42’’E longitude in the western plateau of the Ethiopian Highlands, (figure 2.1). The catchment faces to the west and drains into the Blue Nile River, which is the major contributor of the Nile River System. It is located approximately 31 km south of Bahir Dar, the capital of the Amhara Region in Ethiopia and has an area of 16 ha ranging from 2184 to 2300 meters above sea level (Abiy, 2009). The average daily temperature varies between 9°C and 25°C, the evapotranspiration (PET) ranges from 110 to 125 mm (Tebebu, 2009) and the mean annual rainfall in the area is 1238 mm, of which more than 72% falls between June and September (Zegeye, 2009).

The Debre-Mewi catchment is characterized by chains of volcanic hills with three main categories of steepness. About 15 percent of the catchment has slope degrees between 13° and 30°, 65 percent of the catchment lies in the middle slope category (between 5° and 13°) and around 17 percent in the lower region (less than 5°) (Abiy, 2009)

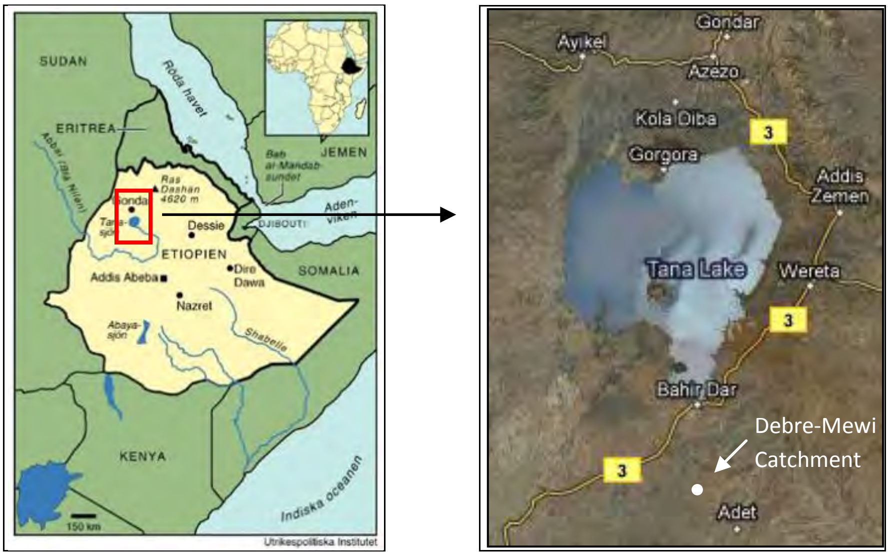

Figure 2.1 Ethiopia and Debre-Mewi Catchment near Bahir Dar (Google maps. 2010).

The land use in the area consists of cultivated land, wood lots, pasture and residential areas (Tebebu, 2009). The common primary crops grown in the catchment include maize (*Zea mays*), tef (*Eragrostis tef*), wheat (*Triticum*), barley (*Hordeum vulgare*), potato (*Solanum tuberosum*) and oil seeds (*Brassica napus*). Some farmers grow chickpea (*Cicer arietinum*), grass pea (*Lathyrus sativus*) and barley (*Hordeum vulgare*), as secondary crop and some have also planted eucalyptus (*Eucalytus*) next to the fields for the fast growth and low upkeep.

The dominant soil types in the Debre-Mewi area are Nitisols and Vertisols, (figure 2.2), and the underlain material consists of saprolite (oxidized basalt) (Tebebu, 2009). Generally, Nitisols are more common in the upper land and Vertisols in the lower parts of the catchment. A mixture of the two soil types is found at mid-slope positions. Nitisols are deep, well-drained, red, tropical soils with a clay content of 30 percent or more (FAO, 2006). The high water content and iron oxides have a major impact on forming the blocky aggregate soil structure and Nitisols are generally considered fertile and stable soils with good physical properties (Britannica, 2010). Vertisols consist of heavy clay (30% or more) with characteristic swelling and cracking properties. It is black in colour, has a higher content organic material compared to Nitisol and has a high natural fertility (FAO, 2006).

Figure 2.2 **Dominant soil types, Nitisol (left) and Vertisol (right)**

2.2 Experimental design

A 45 ha sub-catchment was selected within the Debre-Mewi catchment. The area was chosen based on its selection of crops on the fields in the area and soil properties. To make the study more representative for the whole catchment, fields sown with commonly grown crops such as, maize, tef and barley were of interest, (figure 2.3), as well as fields able to sustain secondary crops such as barley and grass pea, (figure 2.3). The sub-catchment was divided into four study sites, the upper catchment, the middle catchment, the middle-lower catchment and the lower catchment, to investigate the spatial variation in soil-moisture at different elevations in the catchment, (figure 2.4). Fifteen fields each with an area ranging between 300m^2 and 3000m^2, were selected for the soil moisture monitoring and three fields were selected to make infiltration tests, table 2.1

Figure 2.3 **Commonly grown primary crops (tef, maize, barley) and secondary crops (barley and grass pea).**

At each of the four elevations, fields of different crops but with similar slope characteristics were chosen to examine the crop related differences in soil moisture. Fields with comparable crops were selected at the four elevations to be able to compare up-slope and down-slope soil moisture dynamics. Fields of tef, barley and maize were selected at the upper site at an elevation of 2311-2320 m.a.s.l. (slope of 5°) and at the middle site at an elevation of 2286-2296 m.a.s.l. (slope of 8°). The fields selected at the middle-lower site, at an elevation of 2252-2280 m.a.s.l and a slope of 11°, were tef, maize, grass pea and also an additional field sown by secondary and intercropping grass pea and barley. At the lower location at 2238-2252 m.a.s.l. and slope of 8°, three fields covered by tef, maize and grass pea were selected, table 2.1, (figure 2.4), Appendix 1.

Table 2.1 Experimental design for soil moisture and infiltration tests.

	Tef	*Maize*	*Barley*	*Grass pea*	*Grass pea/Barley*
Upper	X	X	X^2Y		
Middle	X	XY	X		
Mid-Low	X	X		X^2Y	X#
Lower	X	X		XY	

X	**Soil Moisture test**	**X^2**	**Two Fields studied for soil moisture**
Y	**Infiltration test**	**#**	**Intercropped field**

More than one field of the same crop were studied at two of the slope locations, the upper barley and the mid-low grass pea. The reason for this was to get more accurate values as the fields were situated differently. Some of the fields got harvested at the start of the study period and a few fields got harvested during the study, (for details see Appendix 1). Since stubs remained in the fields after harvest this was not considered to have a great affect on the soil moisture content and the decision to keep measuring in these fields were made. Two of the fields also got ploughed during the study period, Appendix 1, and this did most likely affect the results which could have turned out differently if other fields had been selected. However, after consideration, the decision to keep measuring in the fields first chosen was made, both due to the language barrier, the time limit we had and also to the uncertainties a change of fields would have lead to. The source of error due to this is considered in the evaluation of the results.

The study period took place between the 2nd of December and the 18th of December year 2009. During these three weeks, the soil moisture was measured once a week in each field. The infiltration tests were carried out during the last week, twice at each slope location, in the secondary cropped fields.

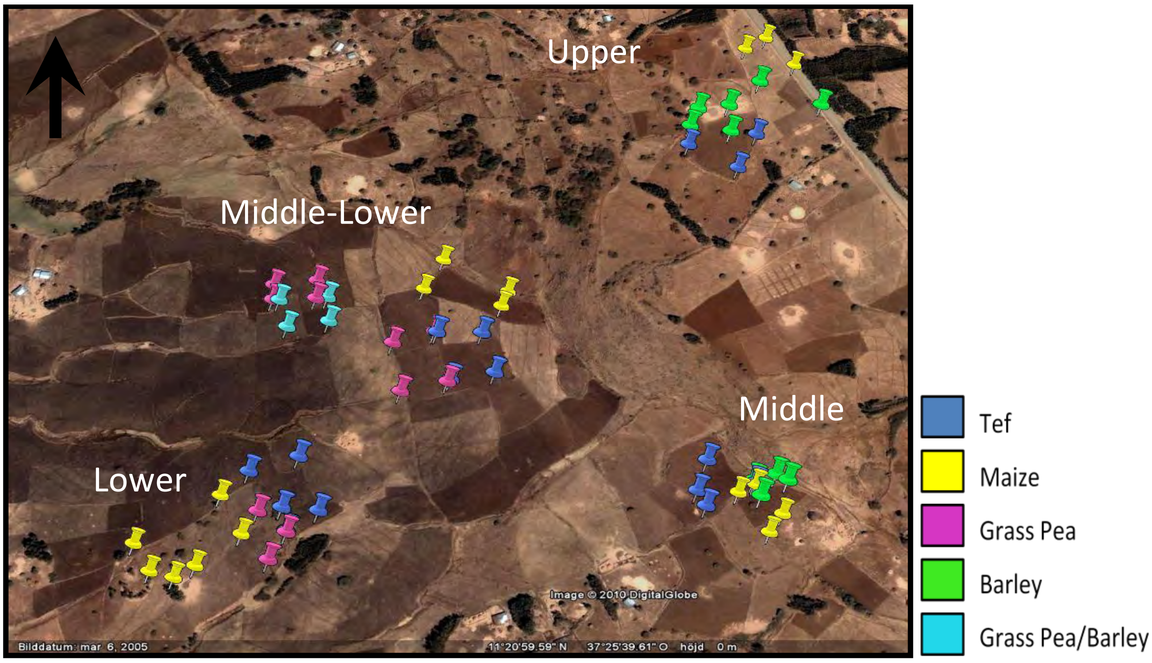

Figure 2.4 The four study sites and the different cropped fields (Google Earth 2009).

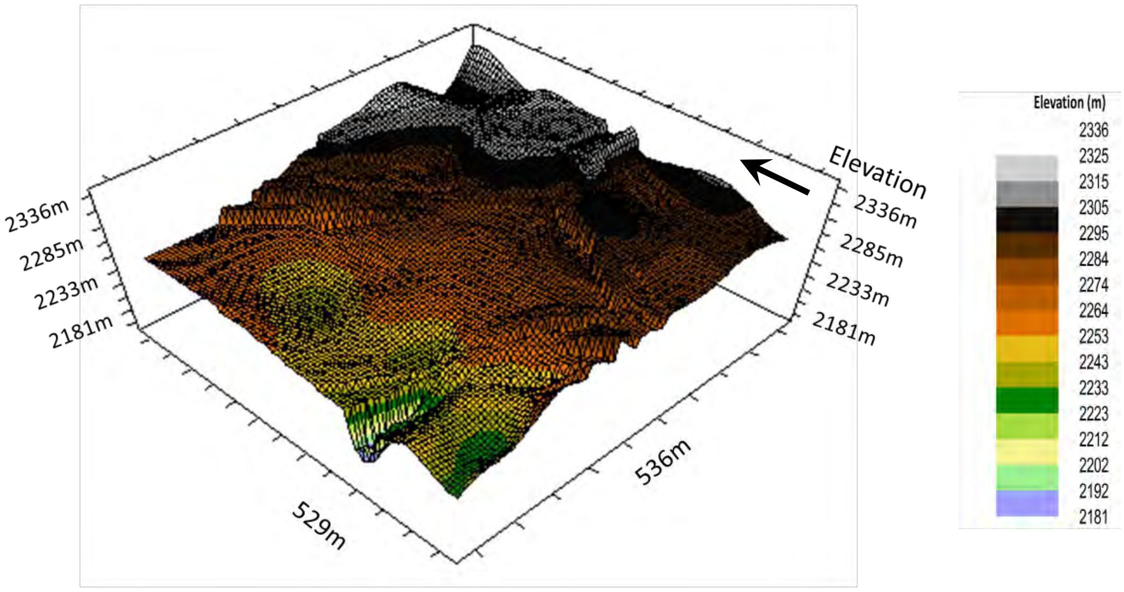

Figure 2.5 Elevation map of the study area.

2.3 Measurement of the spatial variability of soil moisture using TDR

Time Domain Reflectrometry (TDR) is a highly accurate measurement technique for measuring porous media water (Jones et. al, 2010). The soil moisture is obtained as volumetric water content (VWC) which is the ratio of the volume of water in a given volume of soil to the total soil volume.

The TDR probe generates a fast-rise pulse and sends it down two parallel rods that are inserted into the ground. The soil´s dielectric permittivity controls the velocity of the electromagnetic pulse as it travels along the rods. Water is the main determinant of this permittivity and a smaller velocity of the pulse thus represents a higher water content of the soil. The wave is reflected at the rod ends and the travel time of the pulse is measured and converted into volumetric water content (Evett S, 2003).

In this field study, the portable *Field Scout TDR 300* was used (Spectrum Technologies 2010), connected with two rods of two lengths (7.6cm and 20cm). Before using the TDR instrument in the field area, it was calibrated with soil moisture data from soil samples that were taken from a similar type of soil in an adjacent catchment and dried at 105˚C for 48 hours.

Rods of the length 7.6cm were used to make measurements in all fields since the ground was too hard to use the longer, 20cm rods. In each field measurements with the TDR300 were made starting from the middle point and progressing to the borders forming square shapes with an increasing distance to the middle point as well as between the sampling points (e.g. distance between sampling points 4 m, 8 m, 16 m), (figure 2.6). The distances were measured with a rope and the total number of sampling points in a field depended on the field’s size. It varied from 13 to 40 with an average of 24 sampling points in one field. At places where some values seemed to be out of the ordinary, two values were taken to minimize the occurrence of outliers in the data set.

The Field Scout has an integrated data logger that can record data from different sites, which later can be downloaded using the supplied software. The TDR was connected to a GPS which made it possible to obtain the geographic information simultaneously as the VWC was measured. The average VWC over the fields was also calculated.

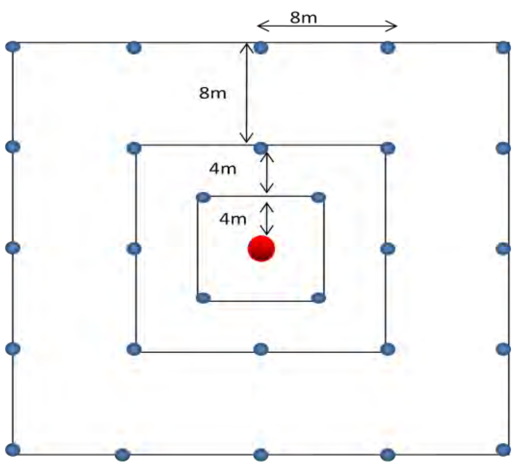

Figure 2.6 Experimental design of spatial variability.

2.4 Global Positioning System - GPS

The GPS (Global Positioning System) used in this study was a *Garmin GPSMAP76* (Garmin, 2010). The GPS measures longitude, latitude and altitude at its current position using information from satellites, with an accuracy of approximately 10 m. The world geographic system, WGS84 was used as coordinate system. The GPS-positions were gathered in the corners of the selected fields, and at most of the locations where VWC was measured, (figure 2.6). The geographic data were later analyzed with ArcGIS and the software GS+ (Gamma Design, 2010), (figure 2.7).

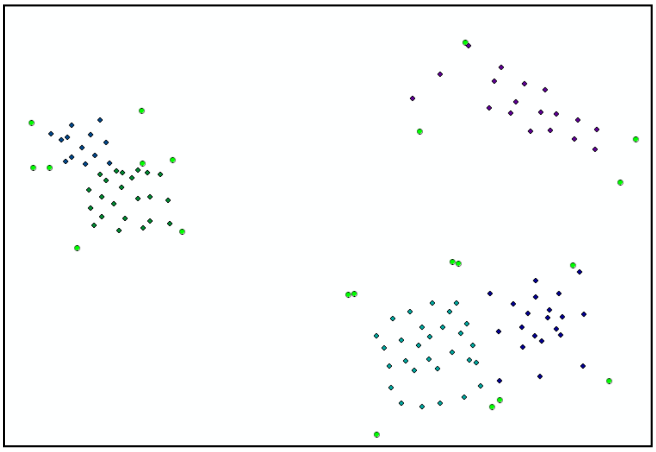

Figure 2.7 An ArcMap (ArcGIS 2009) illustration over the GPS-positions at the five middle-lower fields. Corners are coloured bright green and the smaller dots are located where VWC was measured.

2.5 Statistical analysis

A double factor variance analysis was carried out with a two-way Anova test in Excel. This was to evaluate whether there is a significant relation between soil moisture content and crop type and/or elevation height where the field is situated in the catchment. The analysis was undertaken using a significance of 0.05 which implies an accuracy of 95 percent.

Tests evaluating the variation between the crops at each slope location, as well as tests evaluating each crop type at the different slope locations during the three weeks, were also carried out.

Since maize and tef were the only two crops found at all sampling sites, the Anova analysis evaluating the soil moisture differences due to elevation was based on the maize and tef fields. Tests comparing two elevations at a time were carried out with data from maize, tef and one secondary cropped field within one site.

2.6 Data evaluation using kriging interpolation

The points obtained from the GPS and the soil moisture data from the TDR were imported into the geo-statistic package GS+ (Gamma Design, 2009) with latitude and longitude as x- and y- coordinates, respectively. In GS+, the interpolation method Kriging was used to estimate the soil moisture content in the areas between the sampled points. The interpolation method was applied to the four slope locations at once as well as for each location separately to evaluate the spatial variance in soil moisture due to crop type and due to geohydrological aspects such as soil type and elevation.

Kriging is a geostatistical interpolation method that uses semiovariograms and histograms to predict values between sampled points and thereby attains values in non-sampled points. This method is based on the assumption that measurements of a parameter are more likely to be similar if the sampling points are closer together than further apart (Gardner et al., 1991). By this means the method takes into account the true autocorrelation and thereby the dependency structure in the data set, which is described in a semivariogram (Oliver et al., 1991). The variogram is a graph that describes the variance between two points as a function of their positions and then adapts a function that describes the spatial variation of a variable, (figure 2.8). The “range” in the variogram represents the occurrence of spatial variance within the data set and is the part of the function where the semivariance increases rapidly with an increasing separation distance. Hence a steeper function indicates a stronger spatial dependence at small distances (Oliver et al.1991). The “sill” is the level where the function flattens out and reaches an asymptotic value, this value should be equal to the variance of the population if the variable is stationary. The “nugget” of the variogram is where the function intercepts with the x-axis. The range below this value is called the nugget variance.

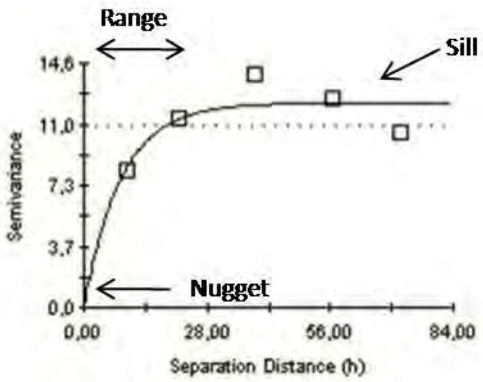

Figure 2.8 Variogram showing range, nugget and sill.

The kriging method weights the sampled values to different extents according to the variogram, as it predicts values at new points in the interpolation process (Oliver et al., 1991). Since the values beyond the “range” in the variogram can not contribute with any valuable information to the interpolation, the range should be the maximum distance between a sampled value and a predicted value in the kriging interpolation (Oliver et al., 1991).

An advantage with using the method kriging instead of other interpolation methods is that it takes the distribution of the points from which the interpolation is made into account and is thought to be more reliable than other methods (Harrie, 2008).

2.7 Infiltration Capacity Tests

The infiltration tests were carried out at four different elevation heights in the catchment. This made it possible to compare the infiltration capacities of the soil types at the study sites. Due to the shortage of water in the area and also to the limited time period in which the study was undertaken, only eight infiltration tests were carried out in total.

The tests were performed using both single and double ring infiltrometers, with 25 cm and 13 cm diameter for the outer and inner ring, respectively. The lack of water in the area made it difficult to use the standard large infiltration rings and instead a method applied by the Bahir Dar University, where the rings are made from metal cans from which the bottom part has been removed, was used, (figure 2.9).

The metal rings were pressed to around 10 cm into the ground with a piece of board. Both rings were filled with water and the rate by which the water infiltrated into the ground was measured until it reached a constant velocity. This took approximately one hour for each infiltration test. A plastic ruler was used to examine the water depth.

Figure 2.9 Infiltration test in one of the grass pea fields.

2.8 Simulation in Aqua Crop

Aqua Crop is a model used to simulate model crop water productivity developed by the Land and Water Division of the Food and Agricultural Organization of the United Nations (FAO). The model simulates the harvest depending on water availability and is suitable for conditions where water is a limiting factor in crop production. The parameters used are relatively few and easy to determine. These include maximum and minimum temperature, precipitation, evapotranspiration and atmospheric CO_2, crop type, planting date, soil type and initial conditions of the soil water content. Also field management and irrigation methods can be added to evaluate the potential yield.

The weather data needed for the simulation were provided by ARARI. This included precipitation and temperature data for 2008 and 2009, obtained from a close by rain station in Adet. Data for mean evapotranspiration were obtained from Solomon Gebreyohannis, who has conducted studies in Koga catchment, situated in the same region. The parameters concerning crop characteristics, such as sowing date and rooting depth were provided by Aqua Crop and also by personal communication with Amy S. Collick, and the atmospheric CO_2 were taken from Aqua Crop. Soil properties were added in line with the properties of the soils in the study area.

FAO has crop files for several crops. In the files provided, there were no crop files that could represent tef or grass pea but the “Default Maize Calender” (Davis, 1 June 96) was selected to represent the Ethiopian maize. In the Debre-Mewi catchment barley is grown as a secondary crop in some fields and is usually planted as a secondary crop in fields where it has also been grown as a primary crop. In Aqua Crop, barley is not available in the crop data base, and therefore wheat was selected as it was considered to be the crop with most similar properties to barley. The crop file used in the simulation was the “Default Wheat, GDD” (Valenzo, 23 Nov 07). Since the growing cycle for wheat as a secondary crop run from October to March, the climate data used were from the end of 2008 and the start of 2009. The rooting depths were adjusted to the local conditions, of 30cm, for both maize and wheat (Amy Collick, pers. comm).

According to the thesis "Assessment of Upland Erosion Processes and farmer´s perception of Land Conservation in Debre-Mewi Catchment, Near Lake Tana, Ethiopia" by Assefa Derebe Zegeye, from May 2009, maize was planted on the 11th of June. Therefore the parameter; "Day One after Sowing" was set to the 12th of June 2009. Maize reached maturity from the 21st of October and the simulation period was therefore set to run from 1st of June to 31st of December. Since June is part of the rainy season, the initial conditions of soil moisture content was set to be saturated at the surface and drier in the deeper parts, although, since no empirical data were available on the initial volumetric water content, a few simulations were run with different initial soil moisture contents at the depth of 8 cm and either 20 or 30 cm. These depths were chosen with regards to the rooting depth and the length of the available rods for the TDR.

The exact planting date for wheat, which represents barley, was unknown and simulations were therefore carried out for different growing cycles. For wheat grown as a primary crop the same sowing date as the one for maize was used and the soil moisture content at the end of the maize simulation was used as initial values for the secondary cropped wheat. In the cases where no yields were obtained, simulations with an irrigation method applied were carried out (Aqua crop, standard irrigation file). However, at this time, irrigation is not an option in the Debre-Mewi catchment due to the water shortage in the area during dry season and the lack of water conservation methods. These simulations were thus only used as a comparison to the non-irrigated fields to evaluate if soil moisture is the limiting factor for yield production in the area.

3. Results

3.1 Soil Moisture

3.1.1 Trend analysis

The average soil moisture contents at different levels are shown in (figure 3.2). The soil moisture content decreased over time at all four levels. The soils lost about 50 percent of the initial soil moisture over the measuring period, at the upper site from around 30 percent to 10 percent and at the lower site from around 50 percent to 25 percent volumetric water content.

Fields sown with tef had the highest amount of soil moisture content at all locations except at the middle-lower site, where the secondary cropped grass pea field (grass pea 2) and the intercropped grass pea/ barley field had the highest soil moisture content, (figure 3.2c).

Maize and barley had similar soil moisture content in the upper and middle locations (figure 3.2ab). At the middle-lower elevation the maize field had a lower amount of soil moisture than the secondary cropped fields, (figure 3.2c), but at the lower location the maize field had a higher soil moisture content compared to the secondary cropped field of grass pea, (figure 3.2d).

The soil moisture content was at its highest in the lower part of the catchment in all cropped fields (45-50% VWC) and was overall decreasing when progressing upwards to higher elevations to get to a minimum at the upper elevation (25-30%) during the first week of sampling, (figure 3.2). The differences between the heights remained during the following two weeks of the study. However, in the maize field, the differences became less with time, (figure 3.1a), and in the tef fields, at the middle location, there was a higher amount of soil moisture compared to the middle-lower slope location week one and two, (figure 3.1c).

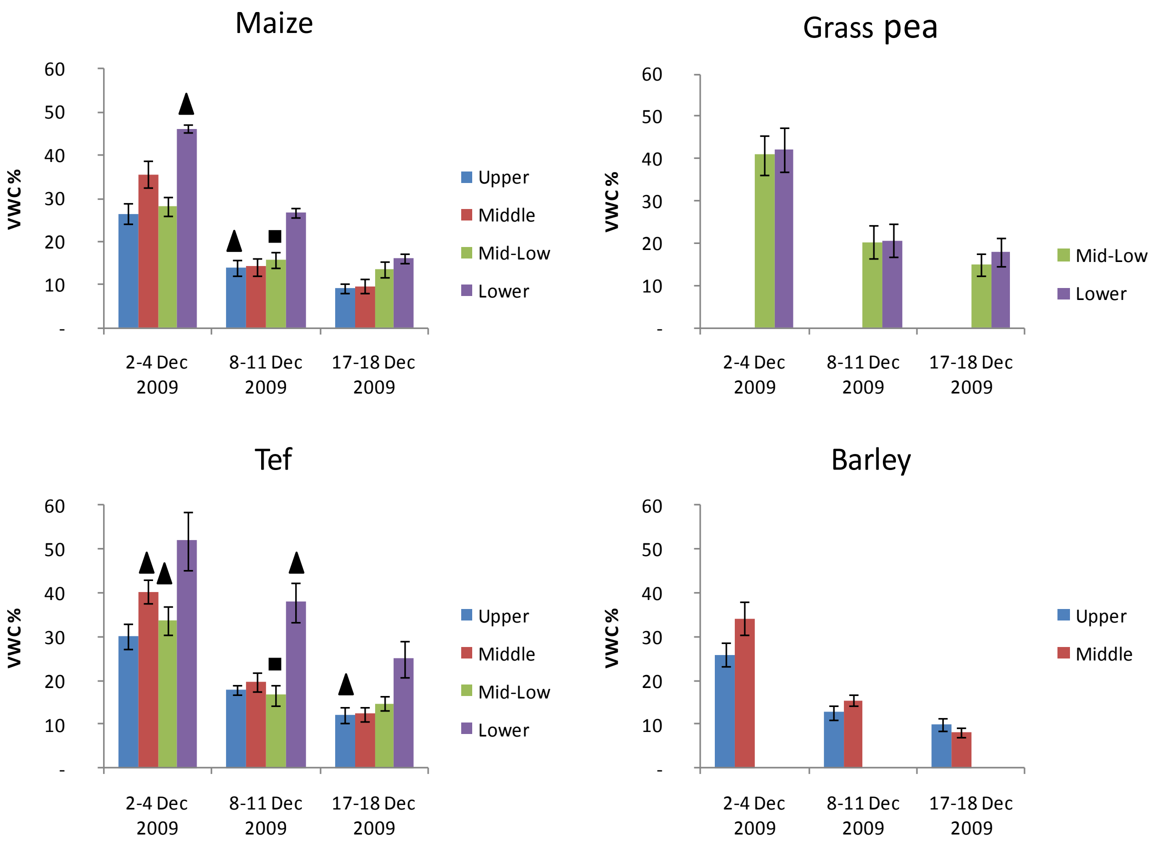

Figure 3.1 The average spatial and temporal variation of soil moisture in the different cropped fields. a) Maize, b) Grass pea, c) Tef, d) Barley. Standard deviation denoted by error bars. Triangular symbols: Field harvested, Square symbols: Field ploughed

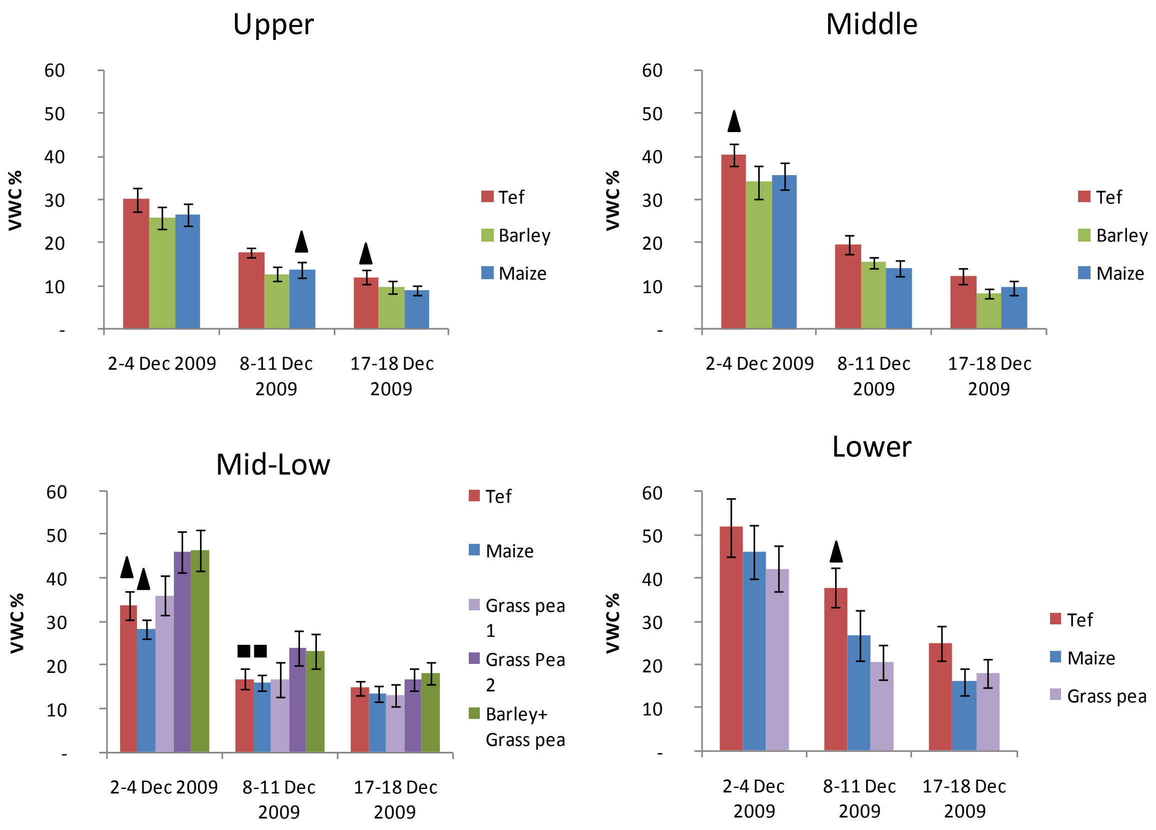

Figure 3.2 Time and crop type dependent variation of soil moisture at the four study sites. a) Upper, b) middle, c) Middle-Lower, d, Lower. Standard deviation denoted by error bars. Triangular symbols: Field harvested, Square symbols: Field ploughed

3.1.2 Statistical analysis

The statistical Anova analysis confirmed the trends of the preceding section as it showed that the differences in soil moisture content between the sample occasions were highly significant (F >F-crit. $p \leq 0.05$) and it also implied that differences in soil moisture content between the different cropped fields were significant, table 3.2 (see appendix 2 for more detailed data).

The analysis of the soil moisture variation in different cropped fields, at each level separately, showed significant differences between the fields at all locations except at the middle-lower location, where there were no significant differences between the fields. The differences over time were also significant, table 3.2

The analysis concerning the variation in soil moisture at the same cropped fields at different slope locations showed that there are significant differences in soil moisture between the elevations for maize and tef, but not for barley or grass pea. It also showed that there were significant variations in soil moisture over the three weeks at all four elevations.

The Anova analysis concerning the four elevations and the pair wise comparison between maize and tef fields showed that the elevation had a significant influence on soil moisture content during the first and second week but during the third week there were no significant differences, table 3.2. The analysis also showed a significant soil moisture difference in the maize and tef cropped fields during the first week as the tef fields were moister, but during the second and third week there were no particular differences between the fields.

The comparison between maize, tef and barley showed significant differences in week one. There were also significant differences between the upper and middle elevation the first week, but no significant differences between the two sites the second and third week, table 3.2

The comparison between the middle-lower elevation and the lower elevation, as well as the test carried out on differences between tef, maize and grass pea fields at these sites, showed no significant differences in soil moisture, due to elevation or crop type, table 3.2

Table 3.1 The spatial and temporal variance in soil moisture. Different letters indicates significant difference in soil moisture ($p<0.05$). Lower case letters are read top-down.

Week	*Upper*	*Middle*	*Middle-Lower*	*Lower*
1	A	B	C	C
2	D	D	E	E
3	F	F	F	F
Week	*Maize*	*Tef*	*Barley*	*Grass Pea*
1	A	B	C	AB
2	D	D	F	D
3	G	G	G	G
	Upper	*Middle*	*Middle-Lower*	*Lower*
Maize	Aa	Bd	Cg	Dh
Tef	Eb	Fe	Gg	Hi
Barley	Ic	If		
Grass pea			Jg	Jj

Table 3.2 Results from the statistical analysis. A = There are no significant differences, B = There are significant differences. **significance of 99%, *significance of 95%, N.S = Not significant.

			p value
Week *(1,2,3)*		B	**
Crop type *(tef ,maize, barley, grass pea)*		B	**
Tef Week *(1,2,3)*		B	**
Tef Sites *(Upper, middle, mid-low, lower)*		B	**
Maize Week *(1,2,3)*		B	**
Maize Sites *(Upper, middle, mid-low, lower)*		B	*
Barley Week *(1,2,3)*		B	*
Barley Sites *(Upper, middle)*		A	N.S
Grass pea Week *(1,2,3)*		B	**
Grass pea Sites *(middle-lower, lower)*		A	N.S
Upper Week *(1,2,3)*		B	**
Upper Crop *(tef, maize, barley)*		B	**
Middle Week *(1,2,3)*		B	**
Middle crops *(tef , maize, barley)*		B	**
Middle-lower Week *(1,2,3)*		B	**
Middle-Lower *(tef, maize, grass pea)*		A	N.S
Lower Week *(1,2,3)*		B	**
Lower *(tef, maize, grass pea)*		B	*
	Week		
Crop type *(tef, maize)*	1	B	**
	2	A	N.S
	3	A	N.S
Site *(upper,middle,middle-lower,lower)*	1	B	**
	2	B	*
	3	A	N.S
Crop type *(tef, maize, barley)*	1	B	*
	2	B	*
	3	A	N.S
Site *(upper , middle)*	1	B	**
	2	A	N.S
	3	A	N.S
Crop *(tef, maize, grass pea)*	1	A	N.S
	2	A	N.S
	3	A	N.S
Site*(middle- lower, lower)*	1	A	N.S
	2	A	N.S
	3	A	N.S

3.1.3 Kriging results

The results from the kriging interpolation are presented as coloured maps, where the colours illustrate the spatial variation of soil moisture over the study area, (figure 3.3). The corresponding data are presented in table 3.3. There was a great variation in soil moisture content between the upper slope location and the lower slope location during the first week. The soil moisture content ranged from 20 percent at the higher elevation up to 60 percent VWC at the lower site and elevation the first week. The maps over the second and third week in the study period illustrate similar results, but the variation between the upper and lower location became less as the soil dried up, and the range became from five percent at the upper elevation to 35 percent VWC at the lower location, (figure 3.3).

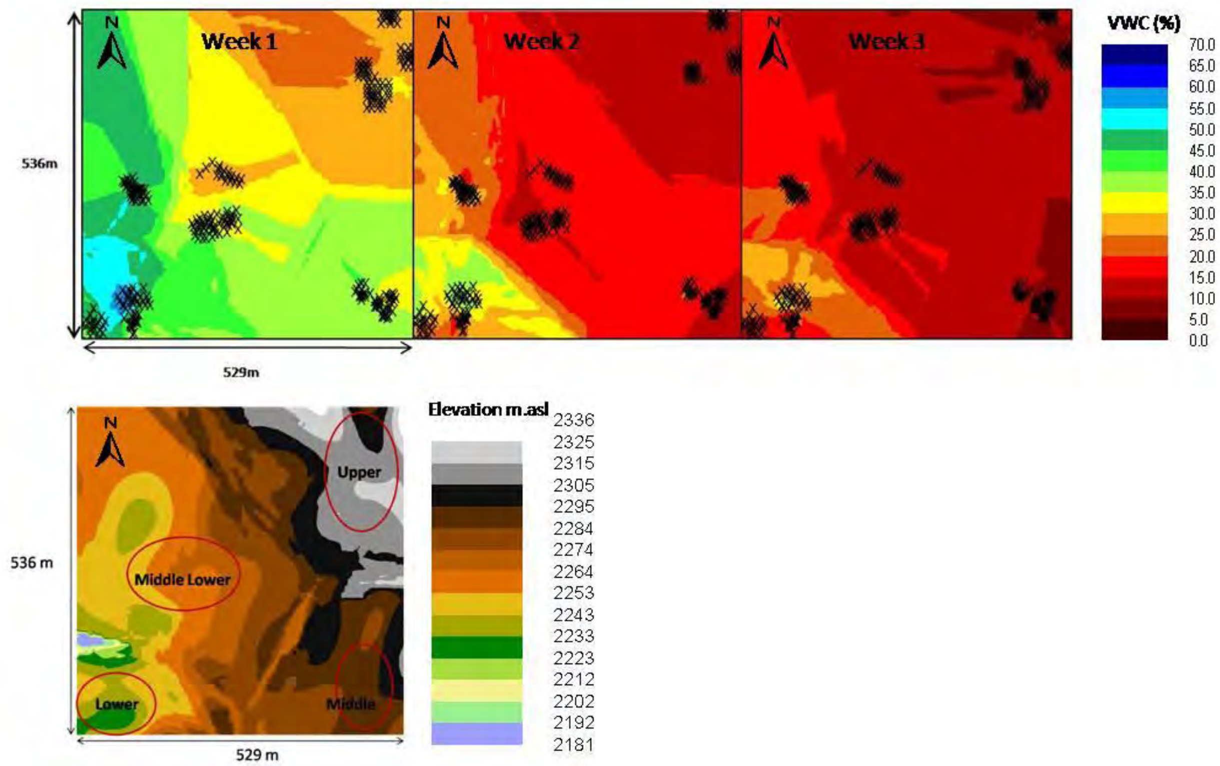

Figure 3.3 Illustration of the negatively correlated relation between altitude in the area and volumetric water content. Top: Spatial variation of soil moisture at the four study sites. Bottom: Elevation map of the catchment area.

The kriging results from the interpolation of each site individually are shown in (figure 3.5). The kriging interpolation was able to explain the spatial variance at three slope locations, but at the middle-lower location it failed, table 3.3. The low r^2-value indicates non-significant results and the maps for this location are therefore not taken into account in the analysis of the spatial variation of soil moisture.

The maps illustrate the significant variance of soil moisture content over time during the study period as the fields dried up, as well as the decreasing soil moisture content with increasing elevation heights in the catchment.

Two variograms are shown to illustrate the failure of the kriging method in the middle-lower area, (figure 3.4). The variogram to the left is from the upper site, week two and the variogram to the right from the middle-lower site, week one. When the variogram turns out flat as for the middle-lower sites, this indicates that there is no spatial dependence in the data set (Oliver et al. 1991) and hence the kriging will not weight the values differently. The outcome will consist of mean values of the data in the surroundings of new points (Oliver et al.1991) and this is the reason for the r^2- value being as low as zero and the interpolation not being able to illustrate the spatial variation in soil moisture at this location.

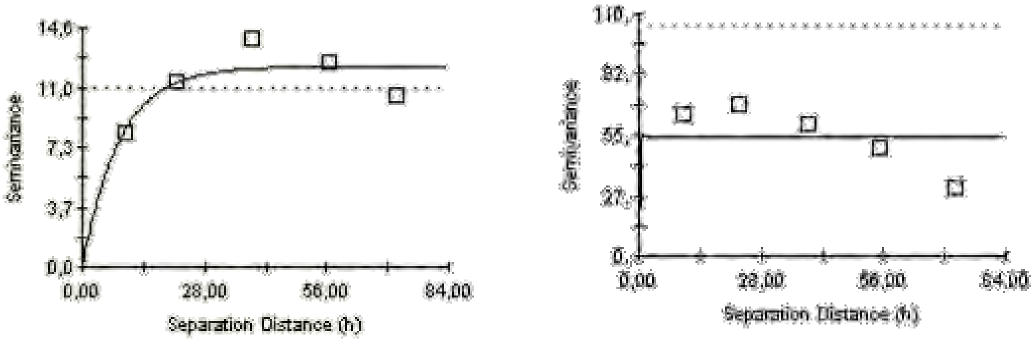

Figure 3.4 Left: variogram from the upper site week 2. Right: variogram from the middle-lower site week 2.

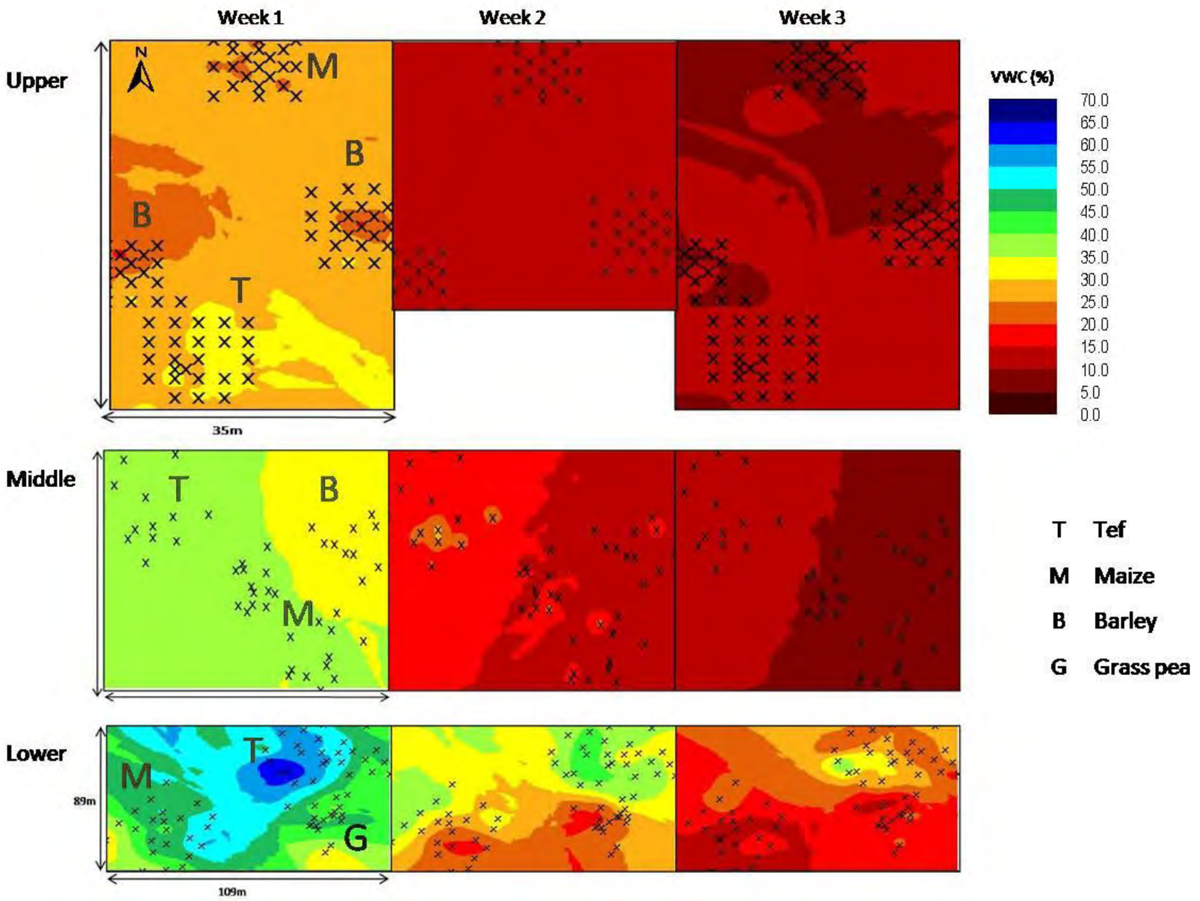

Figure 3.5 Spatial variation of soil moisture at the upper, middle and lower elevation during the study period.

Table 3.3 Data from the kriging interpolation.

Level	Week	Nugget variance Co	Sill. Co+C	Prop. C/Co+ C	Range	Residual SS	r^2	Active Lag Distance	Uniform Interval
Upper	1	18.9	37.8	0.50	46.8	35.2	0.56	80	16
	2	0.01	12.2	0.99	25.5	6.82	0.64	80	16
	3	0.01	31.0	1.00	329.4	122	0.85	80	16
Middle	1	9.10	42.9	0.79	18.9	38.1	0.49	70	16
	2	8.60	47.2	0.82	183.9	14.5	0.94	70	16
	3	8.93	22.4	0.60	106.2	0.925	0.97	70	16
Middle -Lower	1	0.10	54.2	0.10	0.60	893	0.0	80	16
	2	0.10	33.0	0.10	0.60	749	0.0	80	16
	3	0.01	18.8	0.10	0.60	309	0.0	80	16
Lower	1	24.2	177.2	0.86	27.00	663	0.72	80	16
	2	22.8	157.8	0.86	30.30	808	0.67	80	16
	3	0.10	79.6	0.10	37.80	354	0.72	80	16

3.2 Infiltration test

The infiltration rings that were used during the infiltration tests were considerably smaller than the infiltration rings that are commonly used during these tests. This makes the resulting rate by which the water infiltrated the soils uncertain and cannot be viewed as the exact infiltration rates for the soils. However, since the tests were carried out in similar ways, with the same equipment, the velocities are comparable and provide a measure on the soil properties of the different soils in relation to each other.

The infiltration tests showed a higher infiltration rate at higher elevations where the main soil type is Nitisol. The infiltration rate then gradually decreased when descending from the upper site to the lower site to become its lowest in the lower area where the soil type is Vertisol, (figure 3.6).

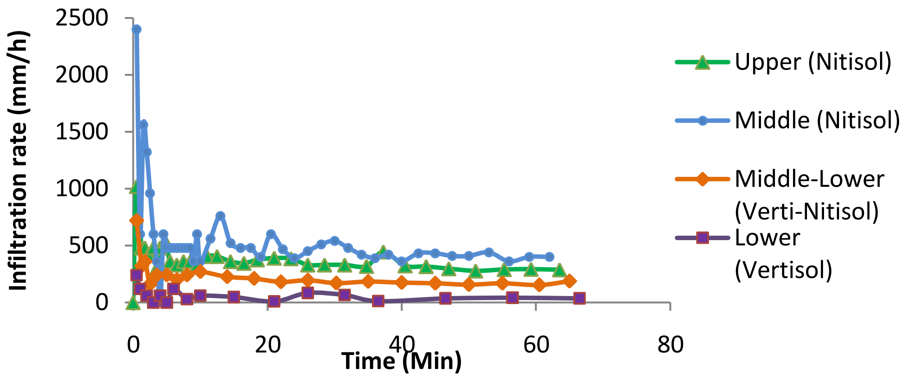

Figure 3.6 Infiltration rates at the four study sites.

3.3 Simulation

The results from the simulations in Aqua Crop are presented in table 3.4, and a table of all runs that were made are found in Appendix 3.

The simulation run for maize with saturated soil returned a biomass of 22.8 ton/ha and a yield of 11 ton/ha, which is 91% of the potential biomass. The same results were obtained when a lower soil moisture content was used as the initial value. The initial value did not affect the yield in the simulation as long as the maize crop was planted around June. The precipitation during the growing season was enough to generate a good yield nonetheless. Even when the initial values were set unrealistically low for it being the rainy season, the yield tuned out to be 89% of the potential biomass.

For the simulations carried out for wheat during the rainy seasons the results turned out similar to the ones from the maize simulation. The actual produced biomass was 97% of the potential biomass which equals a biomass of 15.3 ton/ha and a yield of 7.5 ton/ha. Exactly the same results were gained even though the initial values of soil moisture were set to much lower.

For wheat as a secondary crop in the simulation and with the use of the soil moisture values from the end of the simulation period for the primary cropped wheat, the simulation returned no yield. The same result was obtained when simulating with saturated soil in November. Not until irrigation was applied to the fields, yields were obtained in the simulations (Aqua crop, Standard irrigation file).

Table 3.4 Results from Simulation in Aqua Crop.

Initial Conditions	Crop production	
Maize (Growing Cycle 12 June - 21st Oct)	**Biomass (ton/ha)**	**Yield (ton/ha)**
Soil Water Profile at Saturation (50%)	22.8	11
Soil Water Profile at Field Capacity (39%)	22.8	11
Wet Top Soil (30%) and dry sub soil (15%)	22.8	11
Depth 0.08 m: 50% Depth 0.2 m: 20%	22.8	11
Depth 0.08 m: 50% Depth 0.2 m: 15%	22.5	10.8
Depth 0.08 m: 50% Depth 0.3 m: 5-25%	22.8	11
Depth 0.08 m: 39% Depth 0.2 m: 30%	22.8	11
Depth 0.08 m: 39% Depth 0.2 m: 25%	22.6	10.8
Depth 0.08 m: 39% Depth 0.2 m: 20%	22	10.5
Depth 0.08 m: 39% Depth 0.3 m: 25-35%	22.8	11
Depth 0.08 m: 39% Depth 0.3 m: 20%	22.7	10.9
Depth 0.08 m: 39% Depth 0.3 m: 15%	22.3	10.7
Wheat (Growing Cycle: 12th June - 23rd Oct)	**Biomass (ton/ha)**	**Yield (ton/ha)**
Soil Water Profile at Saturation (50%)	15.3	7.5
Soil Water Profile at Field Capacity (39%)	15.3	7.5
Wet Top Soil (30%) and dry sub soil (15%)	15.3	7.5
Depth 0.08 m: 50% Depth 0.2 m: 10-30%	15.3	7.5
Depth 0.08 m: 50% Depth 0.3 m: 5-25%	15.3	7.5
Depth 0.08 m: 39% Depth 0.2 m: 15-30%	15.3	7.5
Depth 0.08 m: 39% Depth 0.2 m: 10%	15.2	7.5
Depth 0.08 m: 39% Depth 0.3 m: 10-35%	15.3	7.5
Wheat (Growing Cycle: 31st Oct - 16th March)		
Dry Top Soil (10%) and wet sub soil (30%)	0	0
Soil Water Profile at Saturation (50%)	1	0
Depth 0.05 m: 40% Depth 0.25 m: 39%	1	0
Depth 0.05 m: 40% Depth 0.25 m: 39% + irrigation	15.9	7.6
Wheat (Growing Cycle: 15th Nov - 30th March)		
Depth 0.05 m: 20% Depth 0.25 m: 39%	0.3	0
Depth 0.05 m: 20% Depth 0.25 m: 39% + irrigation	15.9	7.6

4. Discussion

4.1 Soil moisture trend analysis

The significant indications on differences in soil moisture between the different cropped fields at all slope locations, as well as between the slope locations, that have been revealed during this study are valuable in the evaluation of possibilities for secondary crops at certain fields in the Debre-Mewi catchment.

The decrease of soil moisture content over time at all levels in the catchment can be explained by the small amount of rain that fell before the study period and by the weather conditions with no precipitation during the three weeks measurements were taken.

The trend analysis as well as the kriging interpolation both showed major differences between higher and lower elevations in the catchment, and in comparison to the elevation map over the study area it is evident that the elevation at which the fields are situated in the catchment has a major impact on the soil moisture content. This conclusion is enhanced by the statistical analysis which shows significant differences between the different elevations as well.

It is though hard to say if the gradual increase in soil moisture content at lower elevations in the catchment is due to better soil properties at these elevations or due to other geohydrological aspects.

As the soil type gradually changed from Nitisol at the upper slope position to Vertisol at the lower position, the infiltration rate gradually decreased. This is contrary to the soil moisture analysis, where the soil moisture increased with a lower elevation in the catchment, since a higher soil moisture content should be an indication of a higher infiltration rate. This can be explained by the Vertisol being a blacksoil with a higher amount of organic material than the red soil, Nitisol. The higher amount of organic material would increase the soil's water holding capacity and thereby the amount of soil moisture would be higher in comparison to the Nitisol.

Other reasons for the higher amount of soil moisture content at the lower slope locations could be the more shallow bedrock at the lower location, which would help to retain the moisture in the soil. There could also be places where the water table is shallower, which would make it easier for plants to reach the moisture and hence return a better yield. There is also the explanation that the water stored in the catchment eventually would leak down-slope and moisture then would accumulate in lower areas (Amy Collick, pers.comm. 2010).

The different soil types at the upper two locations compared to the lower two locations would make the two upper sites and the two lower sites more pair wise similar. This would explain the significant variation between the maize and tef fields when comparing all locations, as well as the insignificant variation between the secondary cropped fields of barley and grass pea, as they were only present at two locations each, barley at the upper and middle location and grass pea at the middle-lower and lower location. This is also the likely reason why there are no significant differences between maize, grasspea and tef at the middle-lower site compared to the lower site.

The slope being higher at the middle and middle lower sites could have a negative effect on the soil moisture content as the water travels downhill as runoff before the water has time to infiltrate. This would explain the smaller difference in soil moisture between the upper and middle areas compared to the difference between the middle and lower areas.

At all sites tef had the highest amount of soil moisture. This gives indications that these fields are most capable in sustaining a secondary crop. The reason for the higher amount of soil moisture in the tef fields compared to the secondary cropped fields of barley and grass pea could be tef´s more dense canopy cover which would prevent evaporation of soil moisture while both the grass pea and barley fields have bare soil exposed to direct sunlight. The lower soil moisture content in the fields sown with maize compared to fields sown with tef could be explained by the lower aerodynamic barrier due to the higher height of maize, which increases evaporation. Another explanation is the large cracks found in the maize fields, (figure 4.1). These cracks works as macro pores through which water can quickly be transported to deeper depths.

There are a few deviations from the trends noticed, such as the tef fields at the middle location having a higher soil moisture content compared to the fields at the middle-lower site and also the larger amount of soil moisture in the secondary cropped fields at the middle-lower location. These could be explained by the fact that a few of the fields got harvested and ploughed during the study period which would have decreased the soil moisture in these fields due to the higher sun exposure. The different slopes in which the fields are placed also contribute to these deviations from the trends, see appendix 1 for exact conditions.

Figure 4.1 Cracks found in the lower maize fields.

4.2 Simulation

The simulations for both maize and wheat showed that the precipitation during the growing season was enough to generate a good yield nonetheless the initial soil moisture. This seems to be in line with the observations, since the plants did get enough water during the rainy season but there might be other factors that could disturb the actual yield in this area, such as erosion problems and lack of nutrition due to the eucalyptus plantations in the adjacent areas.

The results turned out differently when the simulation was run with wheat as a secondary crop. This implies a growing cycle from November to March and the amount of rain that fell during this period was insignificant. That no yields were obtained until irrigation was applied to the fields is contrary to what we observed, since no irrigation was applied and yields were nonetheless obtained. Even when the initial conditions were set to saturation in the dry period, which is not realistic, no yields were obtained.

This result is also contrary to the results obtained from the other analysis that was made during this study. It is highly likely that some of the secondary cropped fields in this area will produce a yield since we both saw the crops develop during this study and farmers in the area must have a reason to keep planting secondary crops in these fields. The non-realistic results and the failures of the simulations are probably due to the fact that the simulation was carried out with a lack of knowledge of the specific crop types and soil characteristics in the area.

Application of irrigation in the area would most likely improve the yield but this is not a practical option today, considering the shortage of water and lack of water conservation methods in the area at the moment.

5. Conclusions

The methods used to analyze soil moisture content in fields in the Debre-Mewi catchment during this study all provided similar results. They all showed significant indications on differences in soil moisture between the different cropped fields at all slope locations, as well as between the slope locations.

The kriging interpolation and the evaluation of soil moisture mean values from each of the fifteen fields showed a decrease in soil moisture at higher elevations and also during the time period in which the study was undertaken. This is thought to be due to the better properties of the soil, Vertisol at the lower catchment compared to Nitisol at the upper catchment. The two methods also showed higher soil moisture contents in the primary cropped tef fields at three locations. The statistical analysis confirmed that these differences are significant.

It was shown that the plant water availability is sufficient for secondary crops at some fields in the catchment. Farmers in the area have proved that it is possible to plant secondary crops in all parts of the catchment, but according to this study, the secondary crops should preferably be planted in the lower part of the catchment, where the soil consists of Vertisol and has the most favourable properties for producing a sufficient yield. The crops should preferably be planted on a previously cropped tef field, rather than a previously cropped maize field, since the tef fields are shown to have higher amounts of soil moisture. The secondary crops should be planted as soon as possible after harvest of the primary crop to retain as much soil moisture as possible in the ground.

Soil moisture is a limiting factor for crop production during the dry season, but other factors such as erosion problems and lack of nutrition may also affect the yield. This study showed that the soil moisture content is dependent on the elevation height within the catchment and/or the soil type as the soil moisture content was higher in the lower parts of the catchment.

The simulations in Aqua crop determined that soil moisture is not a limiting factor for crop production during the rainy season and hence for the primary yields. The fields are though, according to the simulations, only able to sustain a secondary crop if irrigation is applied during the dry season, which is contrary to our own observations and the results obtained from the other analysis that were made in this study.

Aqua Crop is most certainly a good help in predicting potential yields, but with regards to the short time span in which this study was conducted as well as to the language barrier in the field, too few parameters were known for the simulations and the knowledge of the different crops and soil characteristics was not sufficient and made it difficult to obtain realistic results from the simulations.

For future work in this area it would be of interest to collect more data during a longer period of time both for the soil moisture analysis and for the simulations, and also to continue the work in Aqua crop and perform a larger number of simulations with crop files that contain more precise information for the specific crops in the area. It would also be of interest to make a more in-depth study of the area and also undertake interviews with farmers to get a greater understanding on what it is that makes these fields special and why farmers choose to plant secondary crops in these fields.

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Appendix 1.

Characteristics of the studied fields in the catchment.

Site	Latitude	Longitude	Altitude (m asl)	Slope	Soil type	Sowing Time	Crop state		
							Week 1	Week 2	Week 3
Upper			**2311-2320**	**5°**	**Nitisol**				
Tef	11.351758	37.428490	2312	8°		July			Harvested
Barley 1	11.352300	37.429109	2313	6°		Nov			
Maize	11.352755	37.428975	2302	4°		June		Harvested	Harvested
Barley 2	11.352050	37.428444	2311	7°		Nov			
Middle			**2286-2296**	**12°**	**Nitisol**				
Barley	11.348334	37.428820	2293	13°		Nov			
Tef	11.348312	37.428382	2284	14°		July	Harvested		
Maize	11.348152	37.428747	2291	9°		June			
Mid-Low			**2252-2280**	**11°**	**Verti-nitisol**				
Grasspea 1	11.349462	37.425887	2264	12°		Nov			
Tef	11.349538	37.426284	2266	14°		July	Harvested	Ploughed	Ploughed
Maize	11.350224	37.426285	2268	16°		June	Harvested	Ploughed	Ploughed
Grasspea 2 + Barley	11.350166	37.424769	2250	8°		Nov			
Grasspea 2	11.349961	37.424881	2251	8°		Nov			
Lower			**2238-2252**	**8°**	**Vertisol**				
Tef	11.348196	37.424854	2243	6°		July		Harvested	Harvested
Grasspea	11.347992	37.424748	2238	6°		Nov			
Maize	11.347769	37.424128	2233	8°		June			

Appendix 2

Data from the statistical Anova analysis

Parameters	**Week**	**F**	**p-value**	**F-crit**
Crop type *(Tef. Maize)*	1	117.1101	0.0016881	10.12796
	2	6.306704	0.086837	10.12796
	3	5.386519	0.1030007	10.12796
Sites *(Upper,middle,middle-lower, lower)*	1	418.8404	0.0001972	9.276628
	2	14.11921	0.0282973	9.276628
	3	7.337212	0.0679262	9.276628
Crop type *(Tef, Maize, Barley)*	1	31.97155	0.0303292	19
	2	20.17922	0.0472161	19
	3	7.646382	0.1156553	19
Site *(Upper, Middle)*	1	261.9672	0.0037956	18.51282
	2	5.250276	0.1490309	18.51282
	3	0.153118	0.7333268	18.51282
Crops *(Tef, Maize, Grass pea)*	1	0.364903	0.732653	19
	2	0.511453	0.6616151	19
	3	1.433462	0.4109372	19
Site *(Middle- Lower, Lower)*	1	4.921351	0.1567687	18.51282
	2	3.255811	0.2129366	18.51282
	3	4.595763	0.1652695	18.51282

Parameters	Week	F-crit	F	p- value
Weeks *(1,2,3)*		4.5	98.2	**
Crop type *(Tef, Maize.Barley, Grass pea)*		3.8	10.5	**
Crop type *(Tef, Maize)*	1	10.1	117.1	**
	2	10.1	6.3	N.S
	3	10.1	5.4	N.S
Sites *(Upper, Middle, Middle-lower, Lower)*	1	9.3	418.8	**
	2	9.3	14.1	*
	3	9.3	7.3	N.S
Crop type *(Tef, Maize, Barley)*	1	19.0	32.0	*
	2	19.0	20.2	*
	3	19.0	7.6	N.S
Site *(Upper, Middle)*	1	18.5	262.0	**
	2	18.5	5.3	N.S
	3	18.5	0.2	N.S
Crops *(Tef, Maize, Grass pea)*	1	19.0	0.4	N.S
	2	19.0	0.5	N.S
	3	19.0	1.4	N.S
Site *(Middle- Lowe, Lower)*	1	18.5	4.9	N.S
	2	18.5	3.3	N.S
	3	18.5	4.6	N.S

Appendix 3.

Results from all simulations in Aqua Crop.

Maize (Growing Cycle 12 June - 21st Oct) *Simulation Period: 1st June - 31st Dec 2009*	Biomass (ton/ha)	Yield (ton/ha)	Biomass Actual produced	Biomass Potential	HI (Harvest Index)	HI - adjusted	Water Content in end of Simulation					
							Depth: 5 cm			Depth: 95 cm		
Initial Conditions							15-Oct	31-Oct	15-Nov	15-Oct	31-Oct	15-Nov
Soil Water Profile at Saturation (50%)	22.8	11	91%	100%	48	48%	39.4	21.4	12.8	39.8	39	39
Soil Water Profile at Field Capacity (39%)	22.8	11	91%	100%	48	48%	39.4	21.4	12.8	39.8	39	39
Wet Top Soil (30%) and dry sub soil (15%)	22.8	11	91%	100%	48	48%	39.4	21.4	12.8	39.8	39	39
							Depth: 5 cm			Depth: 25 cm		
Depth 0.08 m: 50% Depth 0.2 m: 15%	22.5	10.8	90%	100%	48	48%	39.4	21.4	12.8	42.1	39	39
Depth 0.08 m: 50% Depth 0.2 m: 10%	22.3	10.7	89%	100%	48	48%	39.1	21.4	12.8	41.4	39	39
Depth 0.08 m: 50% Depth 0.3 m: 5-25%	22.8	11	91%	100%	48	48%	39.4	21.4	12.8	41.4	39	39

Depth 0.08 m: 39% Depth 0.2 m: 30%	22.8	11	91%	100%	48	48%	39.4	21.4	12.8	41.4	39	39		
Depth 0.08 m: 39% Depth 0.2 m: 25%	22.6	10.8	90%	100%	48	48%	39.4	21.4	12.8	41.4	39	39		
Depth 0.08 m: 39% Depth 0.2 m: 20%	22	10.5	88%	100%	48	48%	39.4	21.4	12.8	41.4	39	39		
Depth 0.08 m: 39% Depth 0.2 m: 15%	0	0												
Depth 0.08 m: 39% Depth 0.3 m: 25-35%	22.8	11	91%	100%	48	48%	39.4	21.4	12.8	41.4	39	39		
Depth 0.08 m: 39% Depth 0.3 m: 20%	22.7	10.9	91%	100%	48	48%	39.4	21.4	12.8	41.4	39	39		
Depth 0.08 m: 39% Depth 0.3 m: 15%	22.3	10.7	89%	100%	48	48%	39.4	21.4	12.8	41.4	39	39		

Wheat **(Growing Cycle: 12th June - 23rd Oct)** ***Simulation Period: 1st June - 31st Dec***	**Biomass (ton/ha)**	**Yield (ton/ha)**	**Biomass Actual produced**	**Biomass Potential**	**HI (Harvest Index)**	**HI - adjusted**	**Water Content in end of Simulation**							
							Depth 5 cm				**Depth: 25 cm**			
Initial conditions							**24-Oct**	**31-Oct**	**15-Nov**	**30-Nov**	**24-Oct**	**31-Oct**	**15-Nov**	**30-Nov**
Soil Water Profile at Saturation (50%)	15.3	7.5	97%	100%	48	48.8%	36.4	40.1	19.8	12.7	39.2	39	39	39

Soil Water Profile at Field Capacity (39%)	15.3	7.5	97%	100%	48	48.8%	36.4	40.1	19.8	12.7	39.2	39	39	39
Wet Top Soil (30%) and dry sub soil (15%)	15.3	7.5	97%	100%	48	48.8%	36.4	40.1	19.8	12.7	39.2	39	39	39
Depth 0.08 m: 50% Depth 0.2 m: 10-30%	15.3	7.5	97%	100%	48	48.8%	36.4	40.1	19.8	12.7	39.2	39	39	39
Depth 0.08 m: 50% Depth 0.3 m: 5-25%	15.3	7.5	97%	100%	48	48.8%	36.4	40.1	19.8	12.7	39.2	39	39	39
Depth 0.08 m: 39% Depth 0.2 m: 15-30%	15.3	7.5	97%	100%	48	48.8%	36.4	40.1	19.8	12.7	39.2	39	39	39
Depth 0.08 m: 39% Depth 0.2 m: 10%	15.2	7.5	97%	100%	48	49.3%	36.4	40.1	19.8	12.7	39.2	39	39	39
Depth 0.08 m: 39% Depth 0.3 m: 10-35%	15.3	7.5	97%	100%	48	48.8%	36.4	40.1	19.8	12.7	39.2	39	39	39
Wheat **(Growing Cycle: 31st Oct - 16th March)** ***Simulation Period: 1st Oct - 31st March***	**Biomass (ton/ha)**	**Yield (ton/ha)**	**Biomass Actual produced**	**Biomass Potential**	**HI (Harvest Index)**	**HI - adjusted**								
Initial conditions														
Dry Top Soil (10%) and wet sub soil (30%)	0	0												

Soil Water Profile at Saturation (50%)	1	0	6%	100%	0	0
Depth 0.05 m: 40% Depth 0.25 m: 39%	1	0	6%			
Depth 0.05 m: 40% Depth 0.25 m: 39% + irrigation	15.9	7.6	99%	100%	48	48%
Wheat **(Growing Cycle: 15th Nov - 30th March)** ***Simulation Period: 1st Oct - 31st March***	**Biomass (ton/ha)**	**Yield (ton/ha)**	**Biomass Actual produced**	**Biomass Potential**	**HI (Harvest Index)**	**HI - adjusted**
Initial conditions						
Depth 0.05 m: 20% Depth 0.25 m: 39%	0.3	0	2%	100%	0	0
Depth 0.05 m: 20% Depth 0.25 m: 39% + irrigation	15.9	7.6	99%	100%	48	48%