EFFECT OF IN-FIELD WATER HARVESTING WITH DIFFERENT MULCHING PRACTICES ON CROP RESPONSE

by

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Submitted in partial fulfilment of the requirements of the degree

Magister Scientae Agriculturae

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University of the Free State
Bloemfontein

2001

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Dedicated to

My wife, Aynadis Melaku.

TABLE OF CONTENT

ACKNOWLEDGEMENTS

I wish to express my gratitude to my supervisor, Mr. G.M. Ceronio, and co-supervisor Mr. J.J. Botha for their motivation, guidance and support during all stages of this research work.

I would like to thank the Ethiopian Agricultural Research Organization, i.e. the Agricultural Research Training Project (ERO) for the financial support and the Amhara national regional state Bureau of Agriculture for offering me this training opportunity.

The University of the Free State, especially the Department of Agronomy and the Agricultural Research Council, Institute of Soil Climate and Water (Glen), who made their facilities available for this study.

I would like to extend my thanks to the ARC-ISCW (Glen) staff in general and to Mrs. J.J. Anderson, P.P. van Staden and Dr. L.D. van Rensburg in particular for their support and help in many ways. I also thank Mr. Mike Fair for taking time to help me with statistical analysis and all my friends who helped me in one way or another.

My deepest gratitude goes to my lovely wife, Aynadis Melaku and our sons, Mulugeta, Amanuel and Melaku for their patience, understanding and love. I also appreciate my brothers and sisters for their encouragement and support.

Finally, I would like to thank God for giving me the strength, wisdom and ability to accomplish this work.

CHAPTER 1

INTRODUCTION

In semi-arid regions water availability is a critical yield-limiting factor in dryland crop production (Arnon, 1975). This problem is caused by low and unfavorable distribution of rainfall through out the year (Boers, Zondervan & Ben-Asher, 1986), further accentuated by high water losses through evaporation from the soil surface (Es), runoff (R) and deep drainage (D) (Arnon, 1975; Arnon & Gupta, 1995). Optimizing rainfall use efficiency (RUE) is one approach to reduce the problem of water deficit in these regions, where irrigation is not an easy-to-practice technique for various socio-economic reasons (Boers *et al.*, 1986).

There is a wide range of techniques developed through research (Arnon, 1975) and tradition (Ojasvi, Goyal & Gupta, 1999) to optimize RUE. These include water harvesting (Boers & Ben-Asher, 1982; Boers *et al.*, 1986; Ojasvi *et al.*, 1999), no-till, fallow (Lamarca, 1996) and mulching (Davis, 1975; Unger, 1975; Unger, 1995; Ojasvi *et al.*, 1999). The main objective of using these practices is to minimize losses and to maximize water storage in the root zone for crop use. These practices make dryland crop production possible in areas where precipitation is as low as 100mm per annum (Arnon, 1975). However, these techniques are not always transferable from one set of conditions to another (Ojasvi *et al.*, 1999). This is because of wide variation in climate, topography and soils prevailing in a region.

A large area east of Bloemfontein, earmarked for African smallholders, is known to be marginal for crop production because of low and erratic rainfall and the dominance of clay soils, which are characterized by high water losses through R and Es (Hensley, Botha, Anderson, van Staden & du Toit, 2000).

For this area the efficacy of an in-field water harvesting production technique was tested by the Glen ARC-ISCW research team (Hensley *et al.*, 2000) and proved beneficial for increasing the productivity of selected crops such as maize and sunflower.

The production technique, developed by the ARS-ISCW research team that combine the advantage of in-field water harvesting, basin tillage, no-till and mulching (WHBM). It consists of a 2m wide runoff strip and a 1m water basin in which an organic mulches is applied. Water harvesting from the untilled 2m runoff strips serves to concentrate runoff water into the 1m wide basins between crop rows. Basins minimize overall runoff, and the mulch in the basins minimizes Es. Two years of experimental results showed the advantage of this practice over water harvesting without mulch in the basin (WHB). Yield increases with mulch placement in the basin (WHBM) were obtained due to reduced evaporation from the soil surface (Hensley *et al.*, 2000).

According to Boers *et al.* (1986), the water balance equation of mini-catchment water harvesting (in-field water harvesting) is a pooled equation of two units of the system, namely, the water balance of the runoff strip and the water balance of the basins. In the water balance, water losses from the soil surface by Es occur not only in the water basins, but also from the surface of the runoff strips.

The soil on the Glen/Bonheim ecotope is described as a dark brown clay soil, which contains a high proportion of smectite clay particles. Moreover, it has a high plasticity index (21 to 33), which cracks when it is dry and easily forms a crust when subjected to the impact of raindrops (Hensley *et al.*, 2000). Apparently, this soil property is considered to be an advantage to accentuate runoff, however, it may encourage soil movement from the runoff strips into the water basins.

Soil removal by runoff may change the topographic feature of the runoff strips by creating small depressions that reduce runoff production. In addition, the transported colloidal particles silt up the water basins and clog soil pores. This may reduce infiltration rates and delay water redistribution below the evaporative surface, which predisposes harvested water for evaporation.

Mulching practices that cover both runoff strips and water basins reduce evaporation from the soil surface and soil movement from the runoff strips into the basins by shielding soil particles from being detached by raindrop impact. In India, Ojasvi *et al.* (1999) reported increased runoff production by lining runoff strips with stone and pieces of marble. Lindstrom & Onstad (1982) (as cited in Ghidey & Alberts, 1998) presented experimental results that showed complete erosion control and improved runoff by mulch placement in no-till tillage systems.

On the other hand, mulches can also decrease runoff and encourage infiltration. Mulches improve the physical condition of the soil by harboring soil borrowing insects and earthworms (Unger, 1975). Mulches also obstruct runoff and provide time for water to infiltrate the soil and hence decrease runoff. This particular effect of mulching is not desirable for in-field water harvesting since it reduces runoff efficiency. However, crops can use water infiltrated in the soil profile from the runoff strips and a reduction in runoff efficiency may not cause proportional reduction in the growth and yield of crops.

Current knowledge of the effect of mulch placement on both the water basins and runoff strips on crop response is deficient. This knowledge is important for developing farmers east of Bloemfontein, and for small-scale farmers elsewhere working under similar circumstances and without access to irrigation. It is, therefore, important to under take research of this kind.

Crop response to mulching practices may depend on the type of mulch used in both the water basins and runoff strips. Ojasvi *et al.* (1999), for example, showed increased growth of jujube (*Zizyphus mauritiana*) with stone and pieces of marble lining than paper or polythene mulches. Allmaras & Nelson (1971) reported increased growth and yield of maize with interrow straw mulch placement, but Unger (1975) reported a reduced maize yield when using stone mulch in Texas due to low nitrogen mineralization. On the other hand, in the drier regions of Ethiopia, rock mulch increased maize grain, biomass and 1000 seed weight by about 44-87 % relative to the control (Getachew, 1987 as cited in Kidane & W/yesus, 1992). The physical properties of the mulch material may interfere with the water harvesting process. Organic mulches, for example, can absorb a higher quantity of water before reaching the soil than stones, and it may decrease runoff efficiency more than stones when placed on the runoff strips. Since this water is not easily available for uptake through plant roots under normal conditions, runoff reduction effects under organic mulches may cause reductions in crop growth and yield.

- The main aim of this study was to evaluate the effect of mulch placement on both the basins and runoff strips on the growth and yield response by maize and sunflowers,
- and the sub aim of the study was to determine the effect of mulching type (stone or organic) on the growth and yield response by the test crops.

CHAPTER 2

LITERATURE REVIEW

2.1 SEMI-ARID ENVIRONMENTS AND THEIR LIMITATIONS

In semi-arid areas, the major factors that determine the productivity of dryland crop production are water availability, temperature, chemical and physical soil properties and topography (Christiansen, 1979; Hensley *et al.*, 2000).

According to Arnon (1975) a semi-arid region is an area with a mixed climate, in which a long dry season alternates with a short humid season. In these regions, dryland crop production is practised during the humid months of the year, which are divided into three periods based on the ratio of precipitation to potential evapotranspiration, namely the pre-humid, the humid and the post-humid periods (Chocheme & Franquine, 1967 as cited in Arnon, 1975). Knowledge on these periods in a given area helps to maximize water use efficiency by selecting the appropriate planting date, and by adopting an efficient fertilization program (Arnon, 1975). However, the high variability of precipitation from season to season and from locality to locality is the primary factor that determines yield (Arnon, 1975; Rowland & Whiteman, 1993). In some seasons the amount and distribution of rainfall occurring in these regions favour high yields to be obtained by management practices capable of making most efficient use of the favourable conditions. During such seasons high yielding varieties and high fertilizer application rates are profitable. In other seasons water is a severely limiting factor so that drought resistance or tolerance and practices applicable for conditions of low water supply are best (Arnon, 1975). Thus, the water balance is the major climatic factor that affects crop productivity in this region (Dennett, 1984).

According to Hillel (1972), the water balance of a field is an itemised statement of all gains, losses and changes of water storage occurring in a given field with specified boundaries during a specified period. This definition emphasises the need of identifying items of gains and losses of the water balance for a given locality. The general water balance described by Hensley *et al.* (2000) for semi-arid areas is:

$$Ev = (P+\Delta S)-(Es+D+R) \tag{1}$$

Where

Ev = water available for plant growth and yield (mm)

P = precipitation (mm)

ΔS = water extracted from the root zone (mm)

R = runoff (mm)

Es = evaporation from the soil surface (mm)

D = deep drainage (mm)

According to these authors, the two important loss components of the water balance equation on high clay soils in semi-arid areas are Es and R.

2.1.1 Evaporation from the soil surface

High solar radiation and low vapour pressure of the atmosphere that entails high evaporation demand throughout the year characterise the climate of a semi-arid environment. Direct evaporation from the soil surface is a major pathway of water loss that accounts for 50 to 70% of the annual precipitation. This water loss is considered wasteful since it has no contribution to crop production (Jalota & Prihar, 1990). The seasonal ratio of Es to the total evapotranspiration (Es/ET) ranges from 0.26 to 0.56 (Villalobos & Fereres, 1990). For row crops such as maize it is estimated to be as high as 0.5 (50%) (Tanner *et al.*, 1960 as cited in Jalota & Prihar, 1990). Thus, reduction of Es will increase the fraction of crop ET available for transpiration (Jalota & Prihar, 1990).

Evaporation is a two-step phenomenon namely, thechanging of liquid water into vapour, and the escape of vapour into the atmosphere (Jalota & Prihar, 1990). According to these authors, three conditions are necessary for evaporation to take place. These are:

1. the supply of energy needed for the latent heat of vaporisation of water

2. the existence of a vapour pressure gradient between the evaporating surface and the surrounding atmosphere, and
3. the supply of water to the evaporating surface.

The first two conditions are external to the soil and are influenced by meteorological factors such as air temperature, wind velocity and radiation, which determine the evaporative demand. The process of evaporation from the soil surface is characterised by three phases, namely: the constant-rate stage, falling-rate stage and the reduced-evaporation-rate stage (Bond & Willis, 1969; Adams, Arkin & Ritchie, 1976; Jalota & Prihar, 1990). During the first stage when the surface is wet, evaporation is comparable to evaporation from a free water surface. During this stage, water moves to the soil surface in a liquid phase. In the falling-rate stage evaporation declines as the soil becomes drier and lags behind Eo. The soil begins to assume a regulatory role. At the reduced-evaporation-rate stage, water transfer occurs in the vapour phase by molecular diffusion, and the adsorptive forces acting over molecular distances at solid-liquid interfaces govern the flow of water (Jalota & Prihar 1990).

According to Arnon (1975) methods that involve to suppress evaporation are based on decreasing turbulent transfer of water vapour to the atmosphere, decreasing capillary continuity by rapid drying of the surface layer and decreasing the capillary flow and water holding capacity of the surface layer of the soil. The greatest potential of methods to suppress evaporation from the soil surface lies within the first and the second stages of evaporation (Bond &Willis, 1969; Arnon, 1975; Gardener, 1983).

2.1.2 Runoff

In semi-arid environments, the annual rainfall is not normally distributed throughout the growing season. Rain frequently comes in a few heavy showers of short duration. In some seasons more than 50% of the annual precipitation occurs in 10-15% of the rainy days (White, 1966 as cited in Arnon, 1975). This particular rainfall distribution and the impact of falling raindrops, which seals the soil pores with clay particles, reduces the infiltration rate and causes high runoff on unsaturated soils. Particularly the surface of many clay soils can easily be sealed, and their infiltration capacity reduced drastically, by a few minutes of heavy rainfall (Arnon, 1975).

The maintenance of high infiltration rates is an important objective of soil management aimed at reducing runoff, high precipitation use efficiency, and low soil losses by erosion. In drier areas, however, the amount of water that can be stored in soils such practices may still not be sufficient for crop production. Efforts should rather be made in the opposite direction, namely, to increase runoff and reduce infiltration in certain areas, to create a source of water for other areas (Arnon, 1975).

2.2 IN-FIELD WATER HARVESTING CROP PRODUCTION TECHNIQUE

2.2.1 Definitions and descriptions

There are two main methods of water harvesting, namely, conveying the water from the barren hillside to the adjacent relatively level land, and creating a micro relief within a more or less level field (Arnon, 1975). According to Boers *et al.* (1986), collecting runoff water from a catchment area at a distance greater than 100m require channels, dams or diversion systems, but collecting runoff water from an area at a distance of less than 100m does not require these structures. This latter technique is known as micro-catchment water harvesting or in-field water harvesting.

Depending on the method used to store water Ojasvi *et al.* (1999) grouped water harvesting techniques as direct water harvesting and storage water harvesting systems.
The direct water harvesting systems store water in the root zone of the soil profile. The storage water harvesting system used tanks or reservoirs to store runoff water and apply it to the crop area using some form of irrigation (Ojasvi *et al.*, 1999).

In-field water harvesting is a crop production technique that employs methods of inducing runoff from treated runoff strips and storing water in the root zone of an infiltration basin to meet crop water demand during the growing season (Boers *et al.*, 1986). This practice includes methods to induce, collect and store runoff water (Boers *et al.*, 1986).

Methods that involve a given water harvesting technique vary depending on local conditions, but they have three characteristics in common (Boers & Ben-Asher, 1982). All are dependant on local runoff induced on part of the land; require storage as an integral practice due to the ephemeral nature of runoff, and are small-scale operations that do not require construction of surface reservoirs. When applying such techniques, attention must also be awarded to agronomic practices that promote root growth (Allmaras & Nelson, 1971) and maximize runoff efficiency (Ojasvi *et al.*, 1999) to ensure optimal crop productivity.

2.2.2 Factors affecting runoff efficiency

The success or failure of rainwater harvesting depends largely on the quantity of water that can be harvested from the runoff strips under a given set of climatic conditions, because it determines the productivity of crops grown with this production technique (Boers & Ben-Asher, 1982). At Glen, for example, growth and yield of maize and sunflower were increased by inducing runoff through no-till and natural crusting of the soil surface of runoff strips, which created a minimum surface storage condition (Hensley *et al.*, 2000).

Runoff efficiency (RE) is defined as the total rainfall volume concentrated as safe-runoff from the runoff strips to the water basins (Boers & Ben-Asher, 1982; Ojasvi *et al.*, 1999). It depends on threshold retention of the catchment, which is the minimum amount of water required to initiate runoff from the runoff strips. Threshold water retention (TR) is dictated by factors such as the amount and intensity of rain, present water and infiltration capacity of the soil (Boers & Ben-Asher, 1982).

The over all water balance of in-field water harvesting is a pooled equation of two units, runoff strips and water basins (Boers *et al.*, 1986). Thus, runoff efficiency in terms of water balance elements of the runoff strips can be defined as:

$$R = P - TR \tag{2}$$

TR is the total amount of water taken up by the bulk soil of the runoff strips (mm) and is defined as follows,

$$TR = \theta_w + Es + Drs \tag{3}$$

Where,

θ_w = water-holding capacity of the surface soil (0-300mm depth) of runoff strips

Drs = the infiltrated water below 300mm soil depth of runoff strips (mm)

Runoff efficiency can be written as

$$RE = R/P \tag{4}$$

Substituting equation two for R in equation four gives equation five.

$$RE = 1-(TR)/P \tag{5}$$

Equation five shows that RE can be increased by decreasing TR by reducing infiltration through soil crusting (to minimize θ_w and Drs) or by reducing Es. Soil crusting increased runoff efficiency by 13-19% compared to the control but 80-87% of the rainfall was taken up by the bulk soil of the runoff strips (Hensley *et al.*, 2000) and lost by Es. The most important loss component from a crop water use viewpoint is Es (Jalota & Prihar, 1990). Water retained in the profile of the runoff strips may decrease RE but has the advantage of encouraging lateral root proliferation to access water far from the basins, which offsets its negative effect on RE. Allmaras & Nelson (1971) found that inter row straw mulch placement increased maize growth and yield during years of high temperature and water deficit due to increased lateral root proliferation towards the water conserved by mulching.

2.2.3 Methods to improve runoff efficiency (RE)

Various methods to increase runoff from runoff strips have been developed through research. These are based on three approaches, namely: (1) covering the ground with impermeable sheeting materials such as plastic films, rubbers or metal, (2) spraying water proofing and soil stabilizing chemicals to disperse soil colloids and seal soil pores (Arnon, 1975), and (3) lining the runoff strips with semi-permeable materials such as stones, marble and paper (Ojasvi *et al.*, 1999)

Methods such as covering the soil surface with plastic films, rubber or metal sheets are effective in enhancing runoff (Arnon, 1975; Unger 1975; Unger, 1995), but some of them such as plastic sheets need frequent renewal because of damage by wind and radiation. Others are too expensive for low value crops (Arnon, 1975; Ojasvi *et al.*, 1999). Waterproofing and the application of soil stabilizing chemicals, such as sodium bicarbonate sodium silanolate and silicon compounds, have been investigated thoroughly and are effective in runoff enhancement (Arnon, 1975). However, their effective life is 2-5 years (Ojasvi *et al.*, 1999) and they may cause severe erosion unless good erosion control is in place (Arnon, 1975; Arnon & Gupta, 1995).

2.3 MULCHING AND ITS ROLE IN DRYLAND FARMING

Two options can be used for increased food production in marginal areas. These are altering the environment to fit the need of the plant or altering plants to fit the environment (Christiansen, 1979). The latter includes methods of plant breeding, while the former consists of agronomic practices aimed at reducing environmental stress in crops. Techniques to modify the environment and enhance production can be categorized into those that alter the energy balance of a crop and its environment, and those that alter the mass balance of the crop (Barfield & Norman, 1983).

Mulching, according to Unger (1975) and Unger (1995), is defined as the application of any material on the soil surface that was grown and maintained in place, grown and modified before placement, or processed or manufactured and transported and applied to the soil surface. The effect of mulching on crop response is a result of the effect of mulches on various aspects of the soil environment and crop requirements. Soil environment aspects include soil water regime, soil biological regime, soil temperature regime and soil nutrient regime (Rowe-Dutton, 1957; Davis, 1975; Unger, 1975; Srivastava, Machedeo, Prbhakar, Lal & Alton, 1993; Unger, 1995). Different researchers used various plant and soil parameters to determine crop response. These include number of green leaves, plant height, leaf area index, stem thickness, aerial biomass, yield, harvest index and soil water content (Unger, 1971; Fairbourn, 1973; Gupta & Gupta, 1983; Unger, 1986; Unger, 1995; Ojasvi *et al.*, 1999; Agele, Iremiren & Ojeniyi, 2000; Deblonde & Ledent, 2001).

Unger (1995) contends that mulches increase crop yield in dry regions and decrease crop yield in humid regions of the USA. Yield increases reported in dry regions were associated with increased soil water, while yield reduction was a result of lower soil temperatures under the mulch. On the other hand, Agele *et al.* (2000), showed that temperature reduction and improved soil water regimes were the factors responsible for increased tomato yield with mulch. The application of wheat straw mulch increased wheat grain yields by 7 to 23% by improving the effect of irrigation (Zaman & Choudhori 1995) and maize yields increased by 7 to 12% when using reflective mulching materials (Pendleton, Pelers & Peek, 1966).

According to Unger (1975), a gravel mulch in Texas reduced grain sorghum yield, but the yield reduction was not due to lower soil water content or lower temperature. Adams (1965) noted that the reduction of sorghum yield under gravel mulch might be the result of a reduction in soil nitrate-nitrogen.

Water conservation and soil erosion control are undoubtedly the most important functions of mulches in semi-arid areas (Unger, 1975; Unger, 1995). These functions can be the result of effects such as increased infiltration by avoiding surface sealing (Mannering & Meyer, 1963; Adams, 1965) or by surface detention or damming of moving water (Adams, 1965) and by reducing the soil content of the runoff waters by protecting the soil particles from getting detached by raindrop impact (Mannering & Meyer, 1963). Michaels, Almers & Burkert (1988) showed the advantage of using mulches over shelterbelts to reduce wind erosion.

Mulches improve soil water regimes by prolonging the first stage of evaporation (Mannering & Meyer, 1963; Bond & Willis, 1969), by improving infiltration, and by reducing runoff (Mannering & Meyer, 1963).

Research elsewhere has shown that a high proportion of water originating from successive rain events was saved from evaporation by applying gravel (Fairbourn, 1973), pieces of marble and stones (Ojasvi *et al.*, 1999) or straw (Gupta & Gupta, 1983). This increased the amount of water concentrated in the cropping strips, which improved crop growth, yield and water use efficiency (Allmaras & Nelson, 1971; Gupta & Gupta, 1983; Ojasvi *et al.*, 1999).

Mulches can also decrease runoff and increase infiltration (Mannering & Meyer, 1963). However the runoff reduction effect was lower than the erosion reduction effect on crusted soils (Mannering & Meyer, 1963) and on soils under no-till tillage systems (Lindstrom & Onstad, 1982 as cited in Ghidey & Alberts, 1998). Evenari, Shunan & Tadmor (1971) presented a nomogram that shows the interaction between the amounts of precipitation and the practice of clearing stones from the cathchment on runoff efficiency. According to these authors, increasing runoff by stone clearing depends on amount of precipitation. Generally, the net effect of stone clearing on runoff yield decreases as the amount of precipitation increases from 50mm to 150mm.

2.4 CONCLUSION

Growth and dry matter production capacity of crops grown with an in-field water harvesting crop production technique depends on practices to enhance runoff and conserve water, and on the ability of the crops to utilize the water efficiently. Runoff efficiency values attained through soil crusting and no-till at Glen were of the order of 13 to 19%. Apparently, 80-87% of the rainfall was taken-up by the bulk soil during the processes of wetting, and subsequently evaporated without contributing to the yield.

Principles of runoff enhancement are based on suppressing soil infiltration rate and maintaining the soil surface wet between successive rainfall events. Soil crusting and using impermeable materials or hydrophobic substances can reduce infiltration and increase runoff. Organic material and stones, on the other hand, increase runoff by creating a semi-permeable and wet soil surface between successive rainfall events. Mulching materials also help to conserve water and withhold soil movement from runoff strips to basins. These effects of mulching combined with an in-field water harvesting production technique may assure sustainable crop production if the application of mulches, aimed at minimizing evaporation and soil movement from the runoff strips, have little or no effect negative effect on runoff output, and the overall system results in higher crop yields.

CHAPTER 3

MATERIALS AND METHODS

3.1 DESCRIPTION OF THE EXPERIMENTAL SITE

The experiment was conducted at the Glen research farm 25km north of Bloemfontein ($28^0 55' 13''$ latitude and $26^0 21' 12''$ longitude) on a Bonheim soil form belonging to the Onrus family. The climate of the ecotope was described by the ARC-ISCW Glen research team (Hensely *et al.*, 2000) and the data are presented in Table 3.1 and Figure 3.1. An ecotope can be described as a piece of land where the natural resource factors, climate, topography and soil, which influence the productivity of the atmosphere-plant-soil system are homogenous (MaCvicar, Scotney, Skinner, Niehaus, & Loubser, 1974).

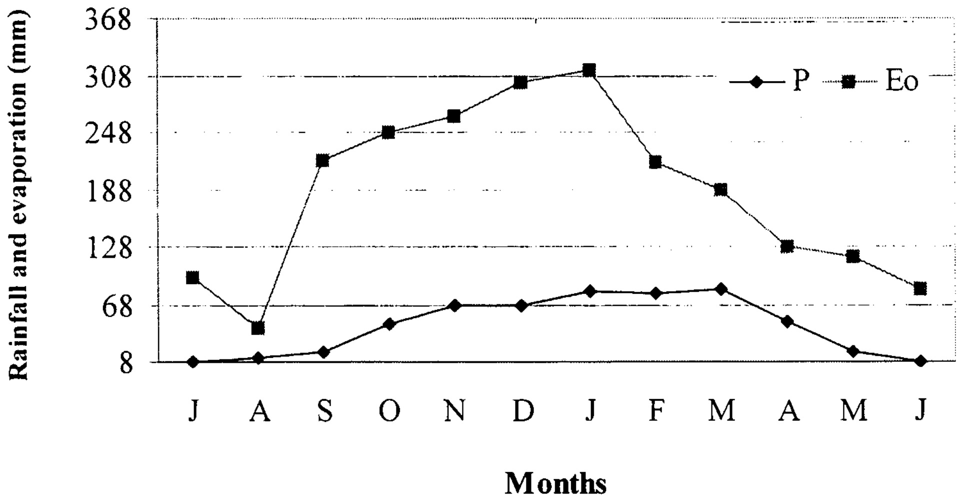

FIGURE 3.1: Long-term mean monthly rainfall (P) and evaporation (Eo) (class A-pan) at the Glen/Bonheim ecotope (Hensley *et al.*, 2000)

The climate is characterized by low rainfall (mean summer growing season, September-April, rainfall of 497 mm) and high potential evapotranspiration (1775 mm during the summer growing season). The aridity index of this ecotope is 0.25 and the monthly aridity indices during the growing season of maize and sunflower range between 0.19 in October and 0.45 in March. January is the hottest month with a mean daily maximum temperature of 30.9 ^{0}C.

April is the coolest month of the growing season with a daily mean minimum temperature of 7.7 ^{0}C.

The high temperature and evaporation and low precipitation prevailing from September to January may develop a serious water deficit in crops, causing stress, poor growth, and low yields.

The soil at the experimental site is classified as a Bonheim form, and is a dark brown clay soil with high plasticity index (between 21-33) and self-mulching properties. The soil has a high cation exchange capacity (24-25cmol$^+$ kg^{-1} soil). The underlying $CaCO_3$-enriched sandstone saprolite is sufficiently weathered to pose no significant impedance to root development to at least 1200mm depth. The soil has a high water holding capacity evident from its high drainaed upper limit (DUL) which mounts to 385 mm (Hensely *et al.*, 2000).

Because of its high plasticity index, the soil is easily crusted by raindrop impact. This soil property may accelerate soil movement and subsequent deposition in the basins, and this may change the topography of both sub-units of the system. From the viewpoint of sustainability, this may reduce both runoff and storage capacity of the runoff strips and the water basins, respectively. In the long term, it may cause land degradation.

The experimental plots gently sloped (1 %) in a westerly direction, and were laid out for testing water-harvesting techniques during 1996/97 crop season by the ARC-ISCW Glen research team. Thus, it consisted of established water harvesting structural units: runoff strips and water basins in a 2:1 ratio which extend westwards in the direction of the slope. In the fenced research site two adjacent 24 m x 36 m (864 m^2) experimental blocks were used to accommodate treatments.

TABLE 3.1: Long-term mean monthly and annual climate data[1] from the Glen/Bonheim ecotope (Hensley *et al.*, 2000)

	Jul.	Aug	Sep.	Oct.	Nov	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Mean
Rain (mm)	8	12	19	48	67	67	82	79	84	51	19	9	545
Eo (mm)	96	43	219	248	264	301	313	216	186	129	118	84	2217
Mean daily max. T .(°C)	17.8	20.6	24.5	26.8	28.4	30.3	30.9	29.4	27.2	23.8	20.6	17.6	24.8
Mean daily min.T.(°C)	-1.6	0.9	5.2	9.2	11.7	13.9	15.2	14.6	12.3	7.7	2.6	-1.2	7.5
Daily mean temp.(°C)	8.1	10.7	14.9	18.0	20.2	22.1	23.0	22.0	19.7	15.7	11.6	8.2	16.2
Aridity index	0.08	0.28	0.09	0.19	0.25	0.22	0.26	0.37	0.45	0.40	0.16	0.11	0.25

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[1] Monthly mean values represent 74 years of rainfall and temperature data, and 38 years of class A pan evaporation data.

3.2. EXPERIMENTAL DESIGN AND TREATMENTS

The experiment was conducted over two growing seasons namely, 1999/2000 and 2000/2001, using two adjacent experimental sites (24 m x 36 = 864 m^2) involving a randomized complete block design with three 24 m x 12 m (288 m^2) size replications, laid out perpendicular to the slope. Each replication consisted of four 6 m x 12 m (72 m^2) plots to which the four mulching treatments were assigned randomly. Maize and sunflower were grown separately on the two experimental blocks. During 2000/2001 the two crops were rotated while mulching treatments were maintained in place.

During the 1999/2000 growing season four mulching treatments were selected from the ongoing experiment of the ARC-ISCW-Glen group. Three of the mulching treatments were a combination of in-field water harvesting basin with organic mulch in the basin and organic or stone mulch on the runoff strips or bare runoff strips. The fourth treatment was the combination of WHB with stone mulch in the basin and organic mulch on the runoff strips. The former treatments were used to evaluate the effect of mulch placement both in the water basins and runoff strips, while the latter treatment was used to compare the effect of stone and organic mulches in the basins on crop responses. The organic mulch was a mixture of maize and sunflower stalks at the rate of 8 t ha^{-1}. The size of the stone mulch was approximately between 10-15 cm in diameter and it covered 70-80% of the soil surface. The mulch materials were placed perpendicular to the slope in the basins and parallel to the slope on the runoff strip (Figure 3.2). The four mulching treatments were:

1. WHB with organic mulch in the basins and organic mulch on the runoff strip (OO).
2. WHB with organic mulch in the basins and stone mulch on the runoff strips (OS).
3. WHB with organic mulch in the basins and bare runoff strips (OB).
4. WHB with stone mulch in the basins and organic mulch on the runoff strips (SO).

During the 1997/98 and 1998/99 seasons, the OB was compared with WHB without organic mulch in the basin and bare runoff strips. Two years results showed the advantage of mulching over no-mulch treatments (Hensley *et al.*, 2000). For this experiment, thus, OB, which was the best treatment during 1997-1999, was considered as a local control with which the other treatments were compared.

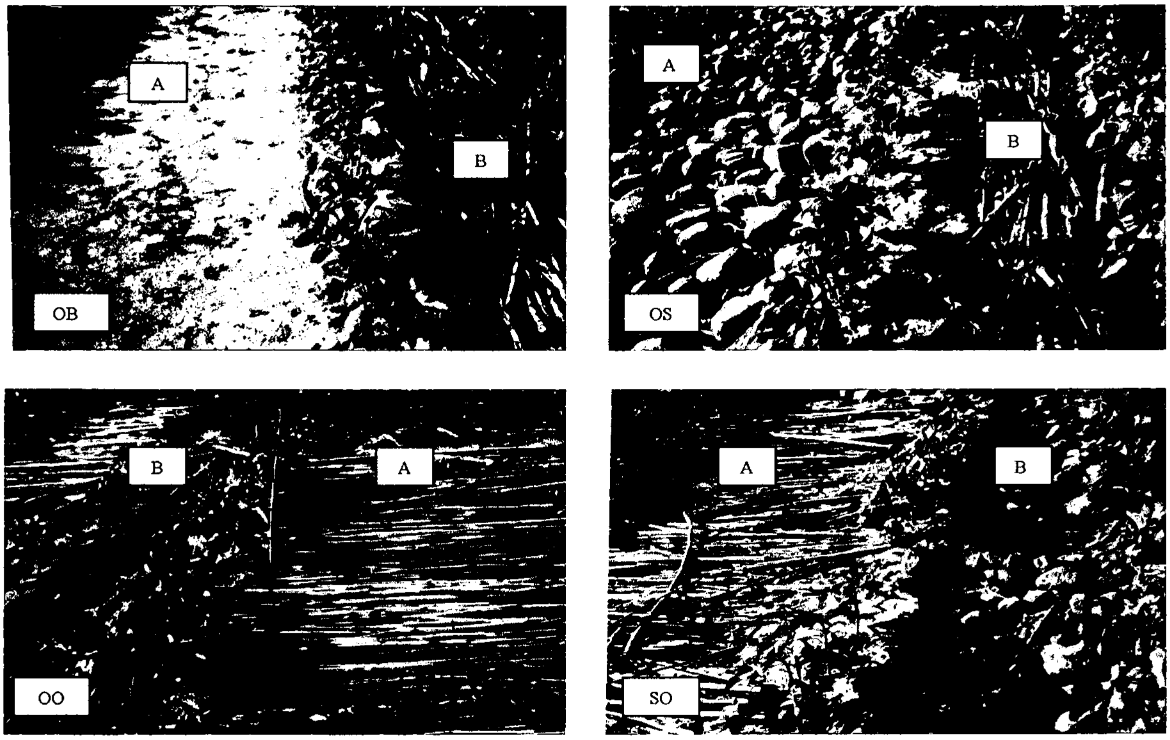

FIGURE 3.2: Four mulching treatments (OB, OO, OS and SO) and installed access tubes in the runoff strips (A) and the basins (B)

3.3 CROP MANAGEMENT

Maize, variety Phb 33-V08 and sunflower, variety SNK 74 were planted on the borders of the basins, perpendicular to the runoff strips in tramlines 1 m apart on the 7th and 28th of January 2000 and the 5th and 4th of January 2001, respectively. Plant populations of 18000 and 22000 plants ha^{-1} for maize and 33000 and 33300 plants ha^{-1} for sunflower were used during 1999/2000 and 2000/2001, respectively. Fertilization application was based on the analyses of soil samples taken prior to the growing seasons. During both seasons, nitrogen fertilizer in the form of ammonium nitrate was applied at a rate of 15 kg N ha^{-1} for both crops. Because of high P and K values found in the soil tests, phosphorus and potassium fertilizer application were not required. To ensure the desired plant population, three seeds were planted 30 and 20 cm for maize and sunflower respectively, in the row. Fertilizers were applied between seeds within the row during planting. Thinning was practiced to obtain the required plant population. The field was maintained free of weeds throughout the growing season. For maize Round-Up and 2,4-D herbicides were used to control weeds, Focus ultra and hand weeding was practiced for sunflower and pests were controlled when necessary when necessary.

3.4 MEASUREMENTS AND DETERMINATIONS

3.4.1 Soil parameters

3.4.1.1 Soil water content

The data for soil water content measurements were obtained from the ARC-ISCW Glen team. It was measured with a Campbell Paufire 503 DR neutron water meter using two access tubes installed in each treatment plot, which was calibrated for 0-300 mm, 300-600 mm, 600-900 mm and 900-1200 mm soil depths. One of the access tubes was positioned in the runoff strip and the other in the basin. A total of 12 and 18 neutron water meter readings were done at an average interval of 17 and 11 days during the 1999/2000 and 2000/2001 growing seasons, respectively. Average total profile water content ($mm.mm^{-1}$) was calculated for the periods during which the soil water content was below the drainage upper limit (385mm). For maize and sunflower these periods were 60 to 110 and 11 to 138 days after planting (DAP) during 1999/2000 and 3 to 88 and 52 to 78 DAP during 2000/2001, respectively. For these periods the effect of the treatments on the amount of water stored in the basins and runoff strips and the depth distribution of water in the rooting zone (1200 mm) were also compared. The content based on depth (Dw) was converted to volume using the following equation by Hillel, (1980).

$$\theta v = Dw/dt \qquad (6)$$

Where

θv = water content on volume basis ($m^3 .m^{-3}$)

Dw= water content on depth basis (mm)

dt = soil depth (mm)

3.4.2 Plant parameters

The following plant parameters were used to test the effect of mulch placement as well as mulch type on crop response:

3.4.2.1 Plant height and stem thickness

Plant height (mm) and stem thickness (mm) at maturity (during harvesting) were determined on a randomly selected sample of 12 plants per replication (n=144 season^{-1} crop type^{-1}) using a measuring tape and a caliper, respectively. Sample plants were selected from three tramlines and by excluded guard rows. The length of the main stem was measured from the soil surface to the tip of the tassel for maize, and to the top of the curvature of the stem for sunflower. The diameter of the main stem was measured approximately 50 mm above the soil surface for both crops. Mean plant height and stem thickness for each replication were obtained by calculating the arithmetic mean of the heights and diameters of the sample plants, respectively.

During the 2000/2001 growing season, measurements of plant height and stem thickness at 30, 40 and 70 DAP were done to determine the dimensional growth rate of the stem. Measurements were made on 12 sample plants per replication excluding the guard rows (n=144 crop^{-1}). Samples were selected at 30 DAP along the diagonal line of the plot and identified by counting South-North for subsequent measurement. The fourth and fifth, the tenth and eleventh and the eighteenth and nineteenth pair of plants in the first, second and third tramline, respectively were measured.

Plant height and stem thickness growth rates were calculated for individual sample plants using a crop growth rate relation (Equation 7 and 8), and the mean dimensional growth rates of each replication were calculated for the period between 0-30, 31-40 and 40-70 DAP.

$$HGR = \Delta H / \Delta T. \qquad (7)$$

$$TGR = \Delta D / \Delta T \qquad (8)$$

Where;

ΔH = change in plant height (DAP_n - height at DAP_0)

ΔD = change in plant stem thickness (DAP_n - thickness at DAP_0)

ΔT = period between measurements in days after planting (DAP_n -DAP_0)

HGR is height growth rate (mm d^{-1})

TGR is thickness growth rate (mm d^{-1})

DAP_n is days after planting of current measurement

DAP_0 is days after planting of the initial measurement

3.4.2.2 Leaf area index

During the 2000/2001 growing season, leaf length and width were measured from 12 randomly selected plants per replication. At 30 and 40 DAP only one fully unfolded leaves (leaves with visible auricle for maize; and leaves greater than 4mm length for sunflower) per sample plant were measured. At 70 DAP two leaves per plant, leaf at the mid-height and just below the head for sunflower; and leaf attached with the largest cob and above this cob for maize, were measured. The number of fully unfolded green leaves were also counted at 30,40 and 70 DAP.

Leaf area per plant for maize and sunflower was determined by using the leaf length-width relationship used by Elings (2000) (Equation 9) and the linear model evaluated by Bange, Hammer, Milroy & Rickert, (2000) (Equation 10), respectively. The leaf area index of maize and sunflower was determined with Equation (11) and Equation (12), respectively.

$$LA_m = (L*W*0.75)*NL \tag{9}$$

$$LA_s = (a*L*W+c)*NL \tag{10}$$

$$LAI_m = LA_m/(0.3*1.5) \tag{11}$$

$$LAI_s = LA_s/(0.2*1.5) \tag{12}$$

Where

LA_m is leaf area of individual maize plant (mm^2)

LA_s is leaf area of individual sunflower plant (mm^2)

L is leaf length of fully unfolded leaf (mm)

W is leaf width of fully unfolded leaf (mm)

NL is number of green leaves

a is the slope and c the intercept of the regression equation determined from the leaf length and width of sample plants

LAI_m and LAI_s are the leaf area index of maize and sunflower, respectively.

3.4.2.3 Biomass

During the 1999/2000 growing season, the aerial biomass ($kg.ha^{-1}$) at maturity was measured from 6 m x 9 m plots (three tramlines excluding the guard rows 3 m x 6 m) and weighed in the field using a spring scale. During 2000/2001, the biomass was measured from 12 randomly selected plants per replication. The samples were cut at the collar and weighed with an electronic scale. The biomass yield was calculated per hectare by multiplying mean biomass per plant by plant population density per hectare.

3.4.2.4 Grain yield and harvest index

Yield data were determined at ARC-ISCW Glen. They were determined by harvesting six rows (3 tramlines) each 4 m in length. The grain was dried to a moisture content of 13%. For maize, it was determined by harvesting ears from 12 randomly selected plants per replication and calculated using Equation 13. The number of ears per plant (NEPP) was obtained by dividing total number of ears collected from sample plants by the sample size (12). Number of seed-rows (SR) and seeds per row (SPR) were counted before shelling. Harvested seeds from each replication were collected in a separate bag and thousand seed weight (TSW) and grain moisture contents (GMC) determined by taking 12 samples from each bag. Seeds were counted using a seed counter (model tector BO 70 S-26301 Hoganas) and TSW was obtained by weighing a 1000 seeds using an electronic scale (model Mettler Pc 4000) and the weight was adjusted to a moisture content of 14%. Using a moisture meter calibrated for maize the GMC were determined. Harvest index was calculated with Equation 14.

$$GY = (NEPP*SR*SPR*TSW*PDPH)/1\,000\,000 \qquad (13)$$

Where

GY is grain yield $kg.ha^{-1}$

NEPP is number of ears per plant

SR is number of seed-rows per ear

SPR is number of seeds per row

PDPH is plant density per hectare

TSW is 1000 seeds weight in grams

$$HI = GY/BY \tag{14}$$

Where

HI is harvest index

GY is grain yield ($kg\ ha^{-1}$)

BY is total aerial biomass ($kg\ ha^{-1}$)

3.5 STATISTICS

Analysis of variance (ANOVA) was done in accordance with the randomized complete block design (RCBD) for each crop within season and combined over seasons. Prior to combined analysis, variance homogeneity of the two seasons data were tested with Hartley's test (F-max.= Larger MSE/Smaller MSE) (Rangaswamy, 1995). With the exception maize grain yield, the test had shown acceptable F-max. values ranging between 1.5 and 2 for the parameters included in the test. Because of the late start of this study (May 2000), repeated plant height and leaf area measurements were not done during the 1999/2000 season. As a result, statistical analysis over seasons was not done for these parameters.

The procedure of Tukey was used to compare the treatment means. Both the ANOVA and mean comparison were done at the 5% probability level using SAS software (SAS Institute, 1996).

CHAPTER 4

EFFECT OF MULCHING TECHNIQUES ON GROWTH AND YIELD RESPONSES OF MAIZE (*Zea mays* L.)

4.1 INTRODUCTION

Maize (*Z. mays* L.) described as "a marvelous strange plant" by Lyte (1619) (as cited in Fischer & Palmer, 1984) grows in a wider range of environments than any other cereals. It grows in areas with an annual precipitation ranging from 250mm to 5000mm and from sea level to 4000m above sea level (Waldren, 1983; Shaw, 1988).

In South Africa, maize ranks first both in area coverage and production ahead of other cereal crops such as wheat, sorghum, barley and rye. In the period 1989-91 approximately 4.5 million hectares were allocated to cereals, of which 4.1 million hectares were devoted to maize production (FAO, 1999). The most important maize producing provinces of South Africa referred to as the "Maize Triangle" by Giannino (1979) include the summer rainfall areas of the Free State province. According to the South African Department of Agriculture (1999) (as cited in Emmanuel, 2000), during the period of 1993-98 some 8.9 million tons of maize were produced annually in the country, of which 3 million tons (33%) were produced in the Free State Province.

In some semi-arid parts of the Free State Province, maize is grown as a rainfed crop during the summer months of December to April. In these areas, more than 57% of the annual rainfall is received during these months but it is generally low and erratic. The temperatures at the beginning of the growing months are high, leading to a high, atmospheric evaporation demand. This exacerbates the problem of water shortage, and adversely affects the growth and yield of crops.

Maize is one of the crops with a high dry matter production capacity under an in-field water harvesting crop production technique (Hensley *et al.*, 2000). The dry matter production capacity of maize is linearly and negatively correlated to the number of stress days, which is defined as the number of days since stress is imposed (Arnon, 1975). An improved soil water regime by water harvesting thus can have a dramatic change on the dry matter production capacity of maize.

Maize is most sensitive to water stress from the beginning of flowering until the end of grain formation (Shaw, 1988). Its ability to tolerate stress during this period depends on the distribution of soil water in the root zone (Allmaras & Nelson, 1971) and evaporation control on the soil surface during the vegetative growth stage (Waldren, 1983).

The depth penetration and lateral proliferation of the maize root system is known to depend on the distribution of soil water in the rooting zone. Waldren (1983), for example, contends that 64% of the root dry matter of irrigated maize is concentrated in the upper 300 mm, while in dryland maize only 39% is found in this layer. Lateral root expansion during water deficit is a potential drought avoiding mechanism of maize that takes place when the plants are grown under conditions of sub-optimal soil water supply (Allmaras & Nelson, 1971; Waldren, 1983).

Using an in-field water harvesting crop production technique, a higher proportion of the rainwater is concentrated in the basins than under conventional practices. Furthermore, water infiltrated in the soil on the runoff strips is lost through evaporation. As a result, the runoff strips are drier than the basins for most of the time during the growing season. This may limit the lateral proliferation of the maize root system and it may decrease the supply of available soil water from reserves somewhat far from the basins and hence a lower growth and yield will be obtained. This might be improved by practicing mulching. Larson (1964) (as cited in Allmaras & Nelson, 1971), for example, stated that the concept of a row area and interrow area for tillage of maize permits the management of the row area for greater early growth, and the interrow area for greater water intake and soil water storage.

4.2 RESULTS AND DISCUSSION

4.2.1 Rainfall distribution

The rainfall during the 1999/2000 season was 395 mm, and occurred over 81 days beginning on the 4th of November 1999. It was 55 mm less than the long-term average rainfall expected in this area (P_n). During 2000/2001, it was 268 mm and occurred over 57 days. This season's rainfall was 181 mm lower than P_n. The rainfall distribution and soil water extraction patterns of maize during 1999/2000 and 2000/2001 are illustrated in Figures 4.1 and 4.2, respectively. The cumulative rainfall for the various growth stages is listed in Table 4.1 for both seasons. The mean soil water content for the root zone (1200 mm), relative humidity, air temperatures and potential evaporation (class A-pan) are also presented according to growth stages in Tables 4.2.

The data showed that the two seasons were distinct with respect to the amount and distribution of the rainfall, the degree of soil water deficit developed in the soil and the evaporative demand of the atmosphere. The 1999/2000 growing season was characterised by a good start, well distributed and near to the long-term average rainfall. Figure 4.1 clearly show that the soil water content was above and near the drained upper limit throughout the 1999/2000 growing season. The mean water content for data below the drain upper limit was 375 mm, which was 95 % of the total available soil water for this soil. In contrast, the rainfall during 2000/2001 was characterised by a late start, lower in amount, and skewed in distribution towards the end of the growing season. The evaporative demand of the atmosphere during the 2000/2001 growing season (mean = 5.0 $mm.d^{-1}$) was higher than during the 1999/2000 growing season (4.03 $mm.d^{-1}$). The soil water extraction curve showed that the soil water content was below the drained upper limit from planting up to 88 DAP (Figure 4.2). The carryover water from sunflower (the rotation crop) was low (287 mm). Generally, this season was less favourable for crop growth than 1999/2000. These differences between the two seasons gave the opportunity to evaluate the responses of maize to the effect of mulching both during favourable and less favourable seasons.

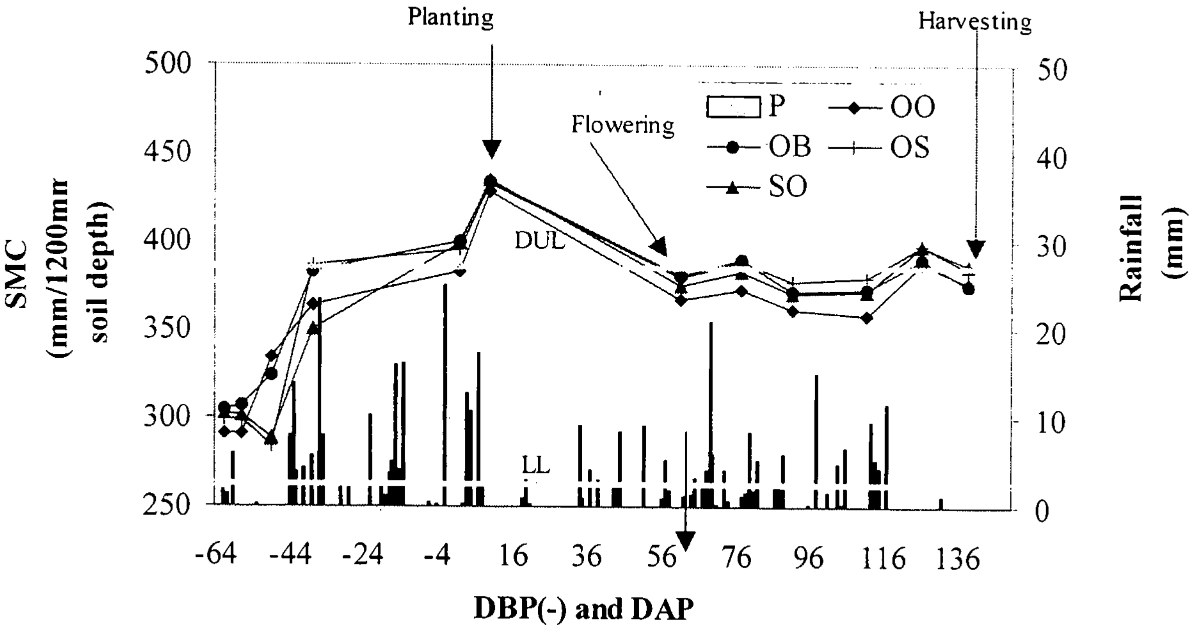

FIGURE 4.1: Rainfall distribution and average soil water content (SMC) for different treatments during the 1999/2000 growing season (DBP= days before planting and DAP= days after planting)

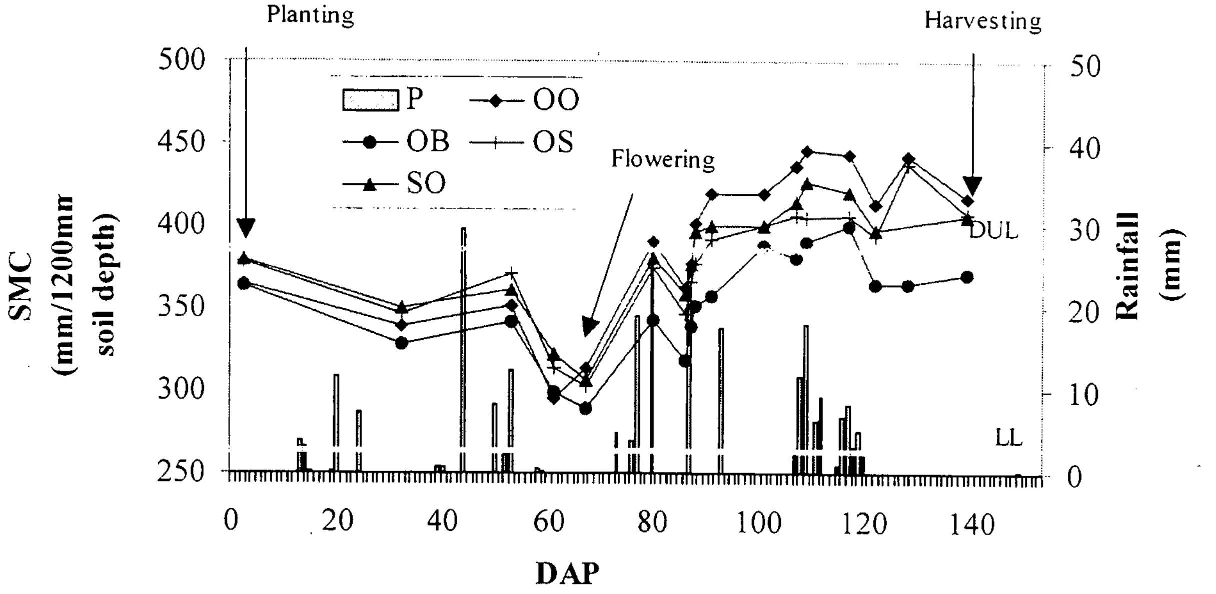

FIGURE 4.2: Rainfall distribution and soil water content (SMC) for different treatments during the 2000/2001 maize growing season

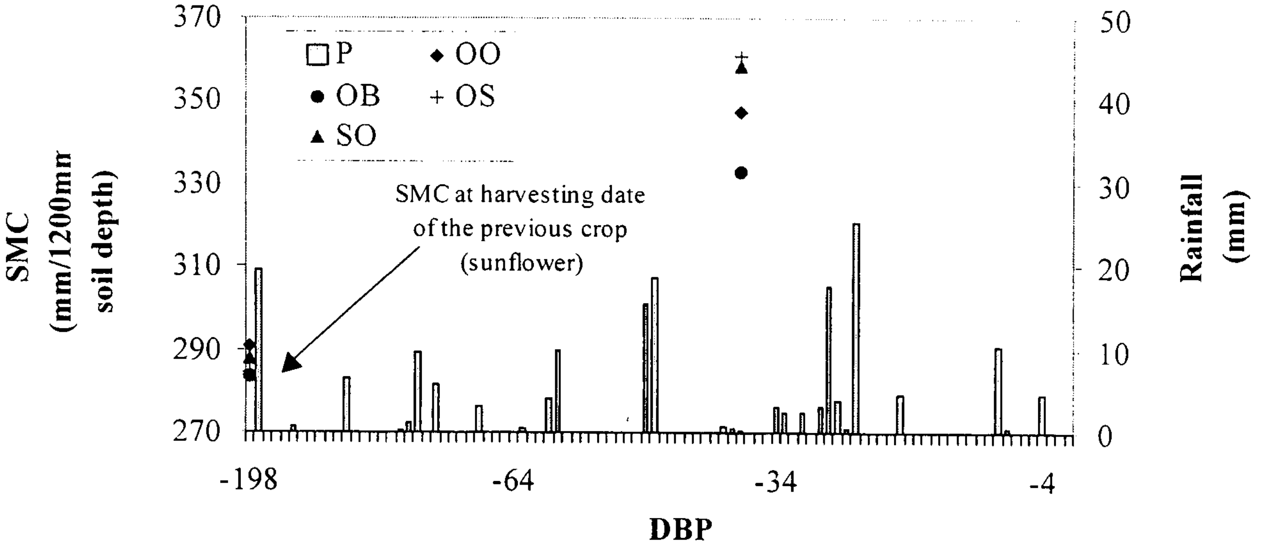

FIGURE 4.3: Rainfall distribution and soil water content (SMC) for different treatments at harvesting time of sunflower (carryover moisture) and 38 days before the planting date of maize during the 2000/2001 fallow period

TABLE 4.1: Amount and distribution of the rainfall as related to the growth stages of maize during the 1999/2000 and 2000/2001 growing seasons

Growth stage	1999/2000				2000/2001			
	Day/month/year	Rainfall (mm)	DAP	Proportion of total rainfall (%)	Date/month/year	Rainfall (mm)	DAP	Proportion of total rainfall (%)
Before planting	4/11/99-6/1/00	166	-	42	2/11/00-4/1/01	128	-	48
Planting to establishment	7/1/00-17/1/00	44	10	11	5/1/01-15/1/01	0	10	0
Vegetative	18/1/00-29/2/00	43	43	11	16/1/01-24/2/01	66	40	25
Flowering	1/3/00-20/3/00	51	20	13	25/2/01-16/3/01	16	20	6
Grain filling to maturity	21/3/00-6/6/00	90	78	23	17/3/01-8/5/01	58	53	22
Total (P_g)		394	151	100		268	135	100

TABLE 4.2: Average values of relative humidity (RH), daily temperatures (T), class-A evaporation (Eo) calculated in relation to the different growth stages of maize during the 1999/2000 and 2000/2001 growing seasons

Growth stage	1999/2000				2000/2001			
	DAP*	RH (%)	Eo (mm d^{-1})	T (^{O}C)	DAP*	RH (%)	Eo (mm d^{-1})	T (^{O}C)
Before planting	-64-0	55	5	21	-64-0	52.8	6	20
Planting to establishment	1-10	70	4	19	1-10	30.8	8	24
Vegetative	11-64	53	5	20	11-60	49.8	6	23
Flowering	65-74	61.5	4.0	19.1	61-70	49.3	6	22
Grain filling to maturity	75-138	66	3	14	71-136	72.7	3	15

* DAP = days after planting

TABLE 4.3: Total soil water content and its partition in the basins (WB) and runoff strips (RS) for the root zone (1200mm) between 60-110 DAP and 3-88 DAP during the 1999/2000 and 2000/2001 growing seasons of maize, respectively as affected by the different mulching treatments

Treatment	1999/2000			2000/2001		
	RS	WB	TOTAL	RS	WB	TOTAL
OS	385^{A}	377^{AB}	381^{A}	344^{A}	356^{A}	350^{A}
SO	386^{A}	365^{BC}	376^{B}	360^{A}	348^{A}	355^{A}
OO	373^{AB}	356^{C}	365^{C}	349^{A}	349^{A}	349^{A}
OB	365^{B}	393^{A}	379^{AB}	308^{B}	347^{A}	328^{B}
Mean	378	373	375	334	350	345
LSD(0.05)$_{T}$	14	17	5	23	NS	13

Means in the same column followed by the same letter are not significant at $\alpha=0.05$

NS= not significant at $\alpha=0.05$

4.2.2 Effect of mulching techniques on soil water content

Mulching treatments showed a significant effect on both the total water content of the root zone and on the partitioning of this water in the basins and runoff strips (Appendix 4.1.1a-4.1.2c). Significant differences among treatments were found between 60 to 110 DAP and 3 to 88 DAP during 1999/2000 and 2000/2001, respectively. The average soil water content during these periods of 1999/2000 and 2000/2001 were respectively 375 mm and 345 mm per 1200 mm soil depth and 50 % and 48 % of this water was in the soil profile of the runoff strips (Table 4.3).

During 1999/2000, the OO technique had significantly lower soil water in the root zone than OS, SO and OB (control). The SO treatment showed a significantly lower soil water content than OS, but was not significantly different from the control. During this season no significant difference was found between OS and the control. During 2000/2001, the total soil water content was significantly higher in OS, SO and OO treatments than in the control and no significant differences were found between OS, SO and OO (Table 4.3).

The OS technique showed significantly higher water content in the soil profile of the runoff strips than in the control during both seasons, but the OO technique had a significant higher soil water in the runoff strips than the control only during 2000/2001. The OS, on the other hand, showed no significant reduction in the amount of soil water stored in the basins during both seasons, whereas, the OO showed significantly lower soil water content in the basins than the control during 1999/2000. During both seasons, the OO and SO showed no significant differences in soil water storage in the basins (Table 4.3).

Results revealed that stone mulch placement on the runoff strip (OS) had no significant negative effect on the amount of water harvested in the basins, but this technique was more effective in conserving soil water in the runoff strips than bare runoff strips (OB). Although differences were not always statistically significant, the OO technique showed lower soil water content in the basins than the control. This indicated that the OO technique had some undesirable effect on the water harvesting processes, which reduced the RUE. Since the comparison between OO and SO showed no significant difference in soil water storage in the basins, the reduction could be attributable to the organic mulch placement on the runoff strips.

Experiments conducted on the same experimental site during 1999/2000 revealed that the annual runoff efficiency of organic mulch runoff plots was 72 % lower than stone mulched and 84 % lower than bare runoff plots (Botha, van Staden, Anderson, van Rensburg, Hensley & Macheli, 2001). This indicated that the bulk of the rainfall had been absorbed by the organic mulch material, and did not infiltrate into the soil profile of the runoff strips. This property of the organic mulches may favour soil water losses by evaporation. Unger & Stewart (1983) contend that organic mulches may not be as effective as stone (gravel) in evaporation control because of a higher water retention at the air-mulch interface, which favour water losses by evaporation.

Soil water depth distribution profiles for the said periods revealed that the OO mulching technique had a lower soil water content in the basins between 0-600 mm soil depth (Figure 4.4). Since more than 75 % of the water required for transpiration by dryland maize is derived from this depth (Waldren, 1983), lower growth and yield may be expected when using this mulching technique. However, the mean total water content during 1999/2000 (61 to 110 DAP) was 365 mm, which was 24 % above the first serious stress limit (SS) of maize determined by Hensley *et al.* (2000). As a result this technique showed no significant reduction of growth and yield during this season.

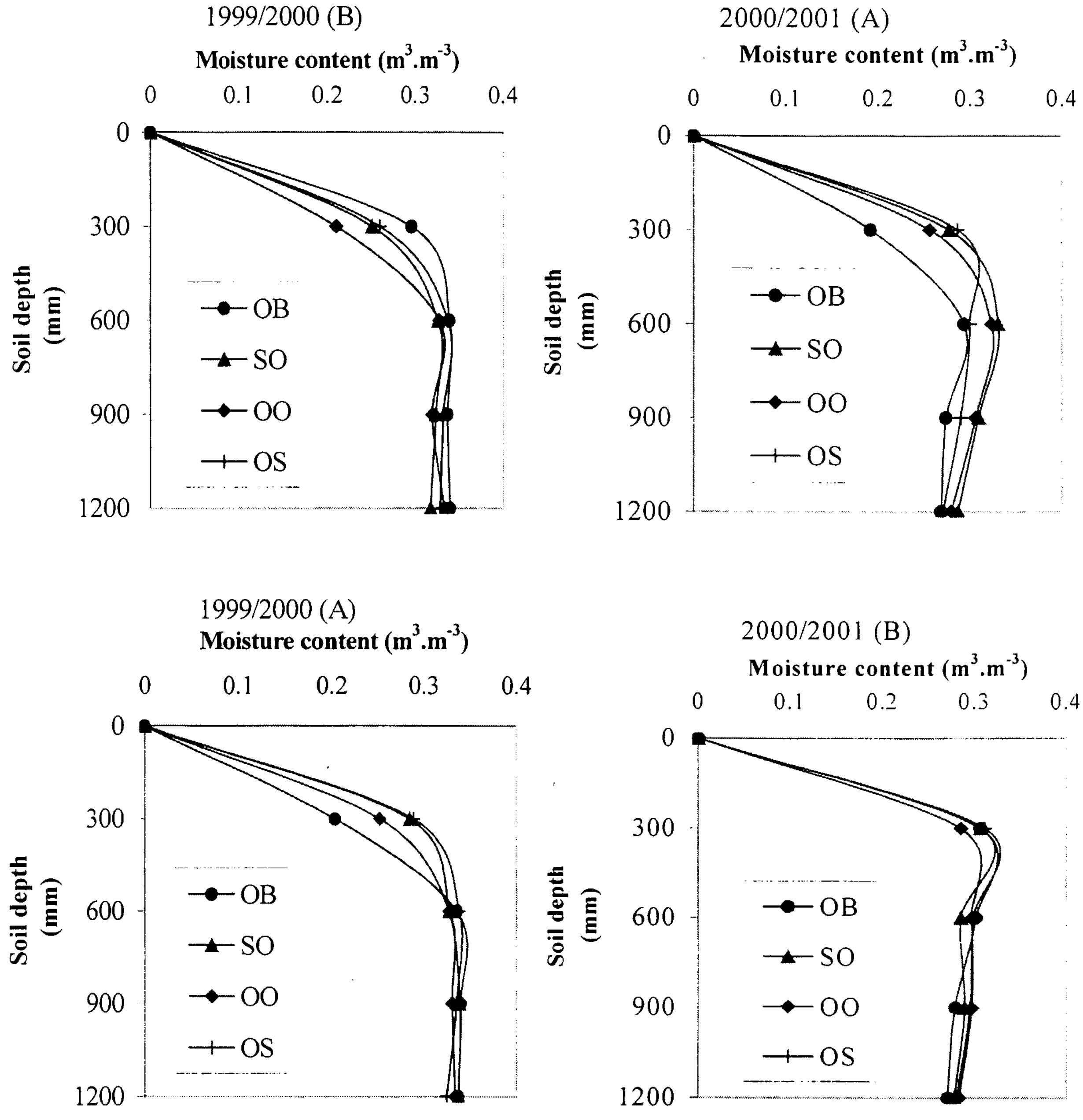

FIGURE 4.4: The depth distribution of the average soil water content in the root zone ($m^3.m^{-3}$) in the soil profile of the runoff strips (A) and basins (B) during the periods 60-110 and 3-88 DAP during the 1999/2000 and 2000/2001 growing seasons of maize, respectively

4.2.3 Effect of mulching techniques on plant growth

4.2.3.1 Plant height

Statistical analysis of plant height (PH) within season showed no significant differences between mulching treatments (P<0.059 and P<0.093 during 1999/2000 and 2000/2001, respectively) (Appendix 4.2.2-4.2.3a). From Figure 4.5, although not significant, there were differences in plant height between treatments during both seasons. The relative plant height for OO, OS and SO was 11%, 14%, 11% and 7%, 18%, 12% higher than the control during the 1999/2000 and 2000/2001 growing seasons, respectively (Table 4.4).

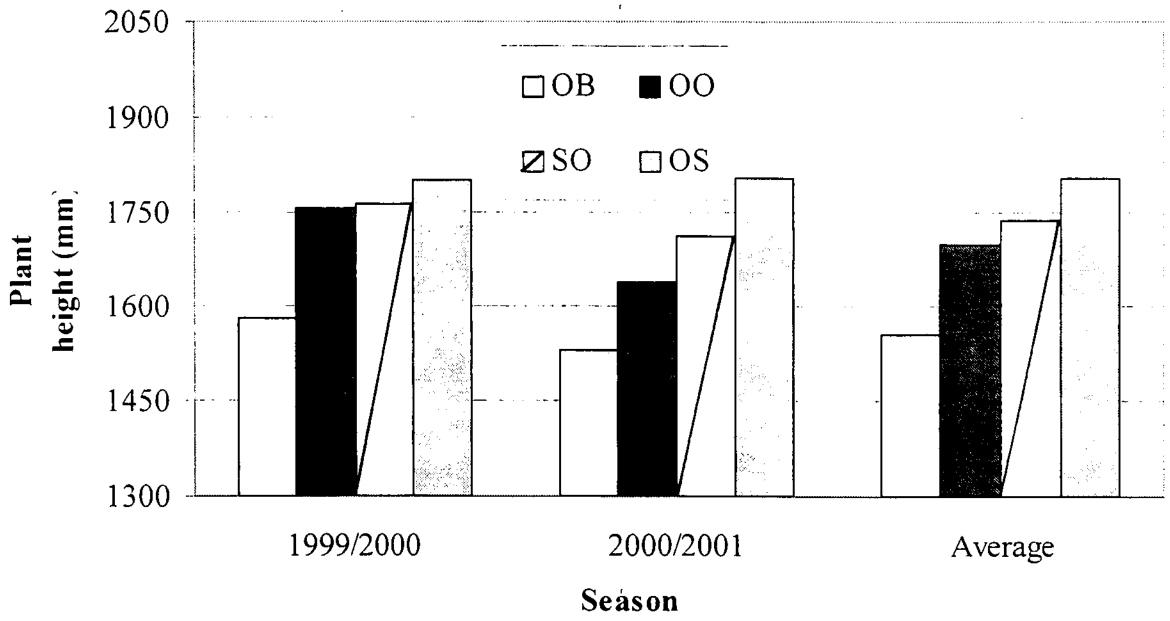

FIGURE 4.5: The effect of mulching treatments on plant height of maize at maturity during the 1999/2000 and 2000/2001 growing seasons

Analysis over seasons showed that mulching treatments significantly influenced plant height, but the main effect of seasons and the interaction between treatments and seasons had no significant effect on plant height (Appendix 4.2.1). The absence of a significant interaction indicated that the effect of mulching treatments did not vary from season to season. This could be particularly observed for the OS treatment, which showed almost equal plant height during the two seasons. As a result of this consistent effect, there was a significant difference between OS and the control for plant height between the two growing seasons. This analysis also showed significant difference between SO and the control, but no significant differences were found between OO and the control and between OS, SO and OO (Table 4.4).

During the 2000/2001 growing season the treatments showed significant differences in plant height growth rates from planting until 30 DAP and from 40 to 70 DAP, but there were no significant differences between mulching treatments from 30 to 40 DAP (Appendix 4.2.3b-4.2.3d). From 0 to 30 DAP the OO and SO showed lower height growth than OS and the control, whereas, from 40 to 70 DAP plants in the control plots showed lower growth rate than plants in OO, SO and OS. Significant differences, however, were found between OS and SO from 0 to 30 and between OS and the control from 40 to 70 DAP.

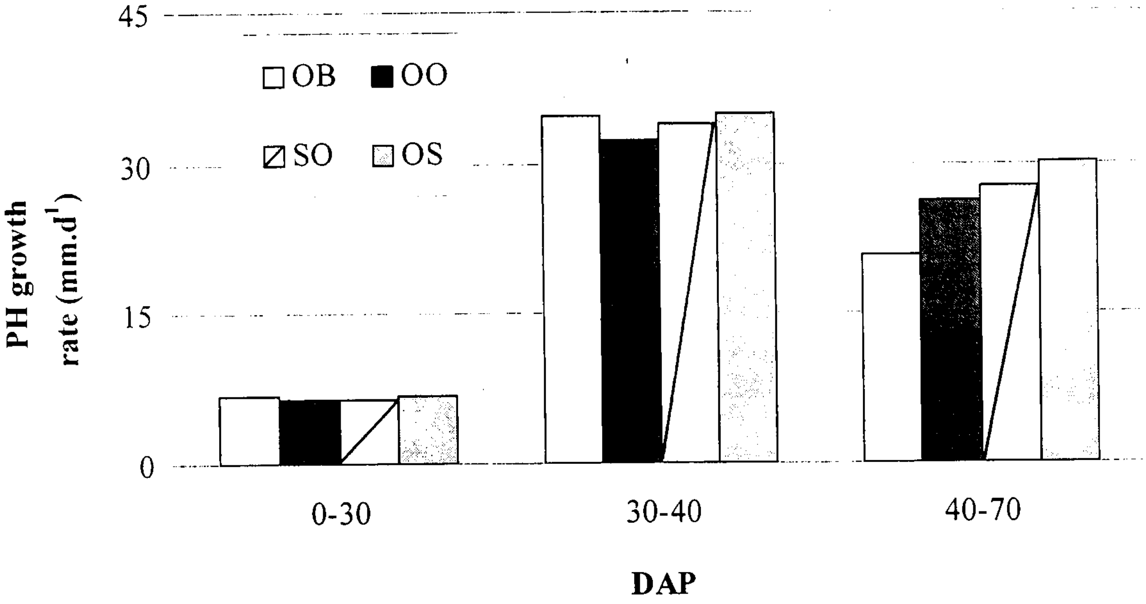

FIGURE 4.6: The effect of mulching treatments on maize plant height growth rate during the 2000/2001 growing season

The maximum rate of increase in plant height during this season was observed from 30 to 40 DAP and it was 34 mm.d^{-1} (Figure 4.6 and Table 4.4). Although there were no significant differences among treatments at this growth period, both the OS and OO treatments showed lower growth tendency than the control (mean = 34.8 mm.d^{-1}).

4.2.3.2 Stem thickness

Treatments had a significant effect on stem thickness (ST) during 1999/2000, but not during 2000/2001 (Appendix 4.3.2-4.3.3a). During 1999/2000, stems were significantly thicker in SO than in the control, but there were no significant differences for other comparisons (Table 4.5). Although there were no significant differences between treatments during 2000/2001, stems were thicker in OS and OO than the control (Figure 4.7). Repeated thickness measurements during this season showed no significant differences between treatments for stem thickness growth rates in all dates of measurements (Appendix 4.3.3b-4.3.3d). The stem thickness growth rate from 30 to 40 DAP, however, was higher in OS than in OO, SO and the control (Figure 4.8).

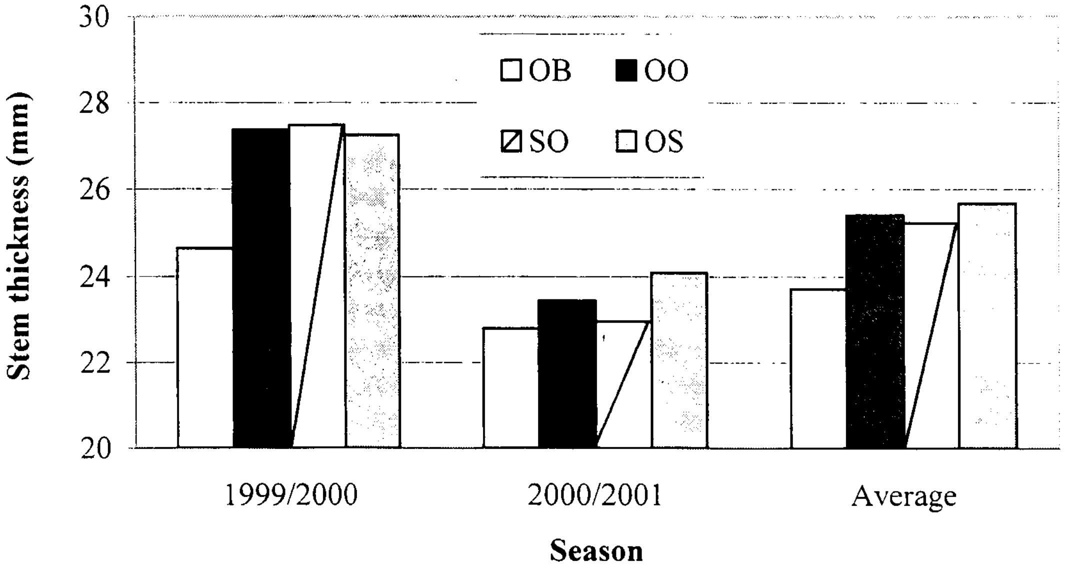

FIGURE 4.7: Effect of mulching treatments on stem thickness of maize during the 1999/2000 and 2000/2001 growing seasons

TABLE 4.4: Mean and relative plant height (MPH and RPH), plant height growth rates and relative height growth rates (MHGR and RHGR) of maize as affected by the different mulching treatments during the 1999/2000 and 2000/2001 growing seasons

Treatments	Plant height						Height growth rate					
	1999/2000		2000/2001		Average		2000/2001					
							0-30 DAP		30-40 DAP		40-70 DAP	
	MPH (mm)	RPH (%)	MPH (mm)	RPH (%)	MPH (mm)	RPH (%)	MHGR (mm d^{-1})	RHGR (%)	MHGR (mm.d^{-1})	RHGR (%)	MHGR (mm.d^{-1}))	RHGR (%)
OS	1801	114	1805	118	1803^{A}	116	6.9^{A}	101	35.0	101	30.1^{A}	144
OO	1756	111	1639	107	1698^{AB}	109	6.5^{AB}	95	32.3	93	26.3^{AB}	125
SO	1762	111	1711	112	1736^{A}	112	6.4^{B}	93	33.9	97	27.7^{AB}	132
OB	1581	100	1530	100	1556^{B}	100	6.9^{AB}	100	34.8	100	21.0^{B}	100
Mean	1725		1671		1698		6.7		34.0		26.3	
LSD$(0.05)_T$	NS		NS		165		0.5		NS		8.3	

Means in the same column followed by the same latter are not significant at α=0.05

NS=no significant differences

RPH and RHGR defined, respectively, as the ratio of the plant height and height growth rate in mulching treatment to the control in percentage

Statistical analysis over seasons showed that both treatments and seasons significantly affected the stem thickness, but there was no significant interaction between treatments and seasons (Appendix 4.3.1). Stems were significantly thicker during 1999/2000 than 2000/2001. This analysis also showed that the average stem thickness in OS and OO were significantly higher than in the control (mean = 23.7 mm), but there were no significant differences between OS, OO and SO and between SO and the control.

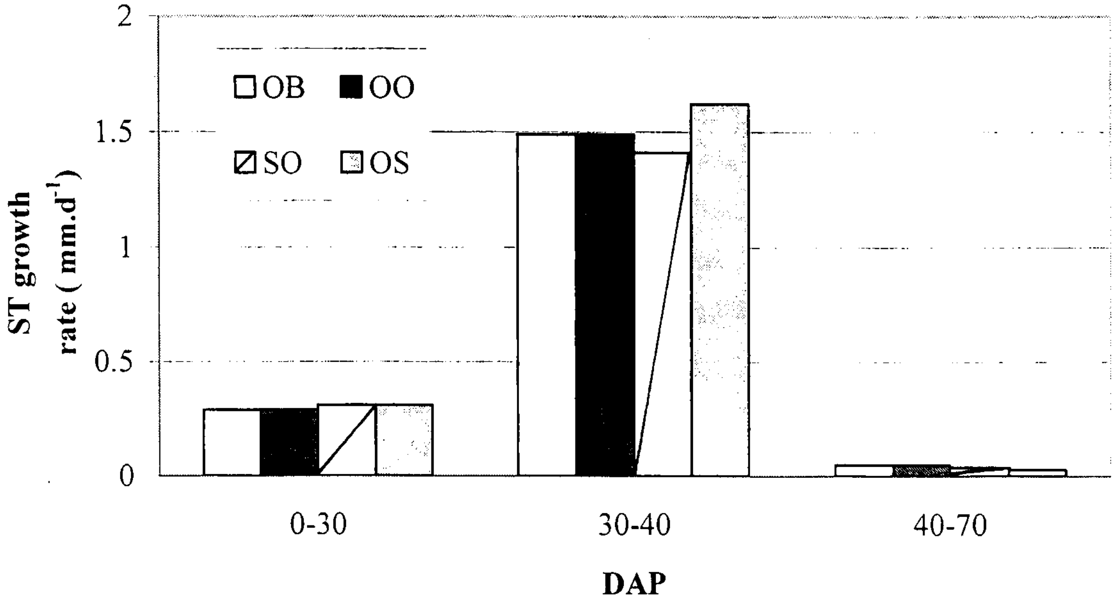

FIGURE 4.8: Effect of mulching treatments on maize stem thickness growth rate during 2000/2001 growing season

Although not always significant, results showed that stem thickness was generally higher in OS, SO and OO treatment plots than the control. Particularly, the OS and OO treatments showed significantly greater stem thickness than the control over seasons. Defining stem thickness as the dimension of the dry matter in the stem, its size at maturity is a function of the total dry matter stored in the stem during the vegetative stage subtracted by the amount of substrates translocated to the growing seeds during seed filling. Adelana & Milbourn (1972) found that in maize greater stem weight losses occurred when conditions after flowering were unfavourable.

Thicker stems at maturity in OS, SO and OO than the control, what ever the case may be, reflect the favourable growth conditions created by these mulching techniques compared to the control.

4.2.3.3 Leaf area index

Mulching treatments showed a significant effect on the leaf area index (LAI) at 70 DAP, but there were no significant differences between treatments at 30 and 40 DAP (Appendix 4.4.1a-4.4.1c). The LAI at 70 DAP was 21%, 12% and 11% higher in OS, OO and SO than in the control, respectively. AT this stage of growth, a significant difference was found between OS and the control (Table 4.6). The higher LAI in OS at 70 DAP was a result of significantly higher number of green leaves per plant and larger leaf size (Table 4.6). Although both the SO and OO had significantly higher number of green leaves per plant, the leaf area was comparable to the control. As a result, these techniques showed no significant differences for LAI when compared to the control. On the other hand, the number of green leaves per plant at 30 DAP was significantly higher in the control than in SO and OO mulching techniques and comparable with OS.

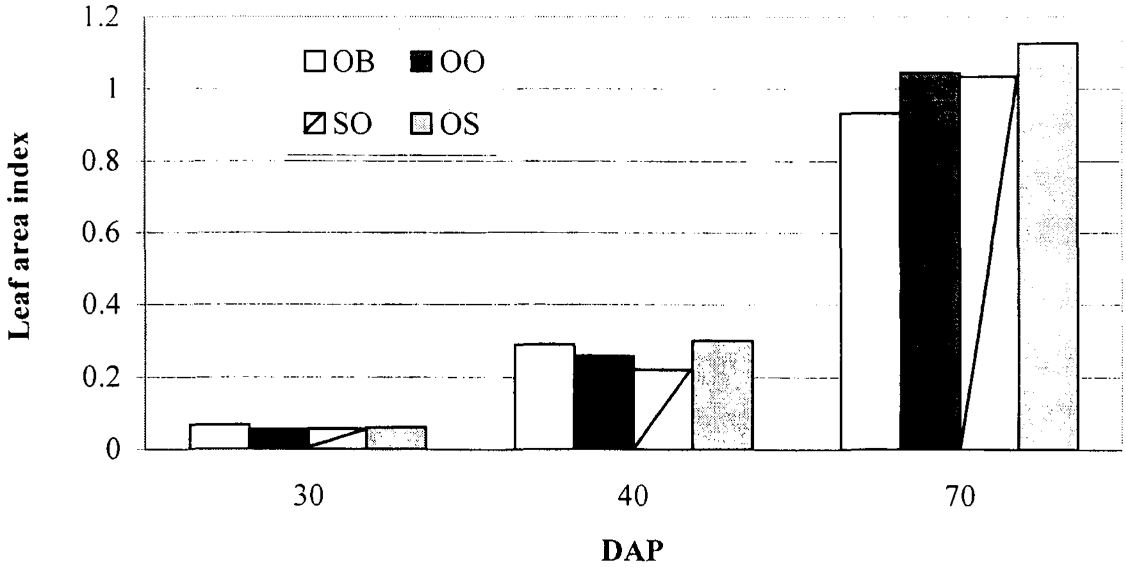

FIGURE 4.9: The effect of mulching treatments on leaf area index of maize at 30, 40 and 70 DAP during 2000/2001 growing season

TABLE 4.5: Effect of mulching treatments on the mean and relative stem thickness (MST and RST), thickness growth rates and relative thickness growth rates (MTGR and RTGR) of maize during the1999/2000 and 2000/2001 growing seasons

Treatments	Stem thickness						Stem thickness growth rates					
	1999/2000		2000/2001		Average		2000/2001					
							0-30 DAP		30-40 DAP		40-70 DAP	
	MST (mm)	RST (%)	MST (mm)	RST (%)	MST (mm)	RST (%)	MTGR (mm.d^{-1})	RTGR (%)	MTGR (mm.d^{-1})	RTGR (%)	MTGR (mm.d^{-1})	RTGR (%)
OS	27.3^{AB}	111	24.1	106	25.7^{A}	108	0.3	100	1.6	107	0.03	60
OO	27.4^{AB}	111	23.4	103	25.4^{A}	107	0.3	100	1.5	100	0.05	100
SO	27.5^{A}	111	23.0	101	25.2^{AB}	106	0.3	100	1.4	93	0.04	80
OB	24.7^{B}	100	22.8	100	23.7^{B}	100	0.3	100	1.5	100	0.05	100
Mean	26.7		23.3		25.0		0.3		1.5		0.04	
LSD(0.05)$_T$	2.8		NS		1.6		NS		NS		NS	

Means in the same column followed by the same letter are not significant at $\alpha=0.05$
NS=not significant

DAP= days after planting

RST and RTGR defined as for RPH and RHGR

TABLE 4.6: Effect of mulching treatments on the number of green leaves per plant (MNGP), leaf area index (LAI), relative number of green leaves (RNGL) and relative leaf area index (RLAI) of maize at 30, 40 and 70 DAP during the 2000/2001 growing season

Treatments	Number of green leaves per plant						Leaf area index					
	30 DAP		40 DAP		70 DAP		30 DAP		40 DAP		70 DAP	
	MNGP	RNGP (%)	MNGP	RNGP (%)	MNGP	RNGP (%)	LAI	RLAI (%)	LAI	RLAI (%)	LAI	RLAI (%)
OS	5.00^{AB}	98	5.16	96	11.6^{A}	107	0.06	89.7	0.3	100	1.1^{A}	121
OO	4.7^{B}	92	5.1	96	11.4^{A}	106	0.06	80.9	0.2	90	1.1^{AB}	112
SO	4.7^{B}	93	5.3	100	11.4^{A}	106	0.06	83.8	0.2	90	1.0^{AB}	111
OB	5.16^{A}	100	5.3	100	10.8^{B}	100	0.07	100	0.3	100	0.9^{B}	100
Mean	4.9		5.2		11.3		0.06		0.27		1.0	
$LSD(0.05)_T$	0.33		NS		0.53		NS		NS		0.15	

Means in the same column followed by the same letter are not significant at $\alpha=0.05$
NS=not significant
DAP= days after planting
RNGP and RLAI defined as for RPH and RHGR

4.2.4 Relationships between growth parameters

4.2.4.1 Plant height and stem thickness

Mulching treatments showed no significant influence on the height-thickness ratio during both seasons (Appendix 4.5.2 and 4.5.3). The over season analysis also showed no significant differences between treatments, but it indicated the significant influence of season on this parameter (Appendix 4.5.1). The seasonal effect on height-thickness ratio was a result of greater stem thickness reduction than the plant height during the 2000/2001 growing season. This may demonstrate that the size of the dry matter left in the stem at maturity was lower during 2000/2001, probably due to lower storage during the vegetative stage or higher reallocation during the grain filling stage.

TABLE 4.7: Relation between plant height (PH), stem thickness (ST) and number of green leaves (NGL) of maize at different growth periods during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Variables	Season	Growth period	Intercept	Slope	R^2	n
PH vs ST	1999/2000	Harvesting	3.5	0.0134^{**}	0.93^{**}	4
PH vs ST	2000/2001	Harvesting	16.9	0.0039^{ns}	0.62^{ns}	4
PH vs ST	2000/2001	30-70 DAP	11.1	0.0121^{***}	0.60^{**}	12
PH vs NGL	2000/2001	30-70 DAP	2.9	0.0060^{***}	0.93^{***}	12
PH vs NGL	2000/2001	30 DAP	0.2	0.0232^{*}	0.85^{*}	4
PH vs NGL	2000/2001	70 DAP	7.7	0.0028^{*}	0.84^{*}	4

* Significant at the $P<0.1$
** Significant at the $P<0.05$
*** Significant at the $P<0.01$
^{ns} not significant
DAP= days after planting

The absence of significant differences between treatments for height-thickness ratio might be explained by the linear relationship between plant height and stem thickness, which made the ratio constant both within and over seasons. This relation showed a higher coefficient of determination (0.9 and 0.6 during 1999/2000 and 2000/2001 respectively) (Figure 4.10). Both the slope and the determination coefficient, however, were significant only during 1999/2000 (Table 4.7 and Appendix 4.5.4a and b). The lower coefficient of determination during 2000/2001 might be due to the SO treatment that showed a higher stem thickness reduction than the plant height (the determination coefficient rose to 0.98 when the SO treatment was omitted from the regression analysis).

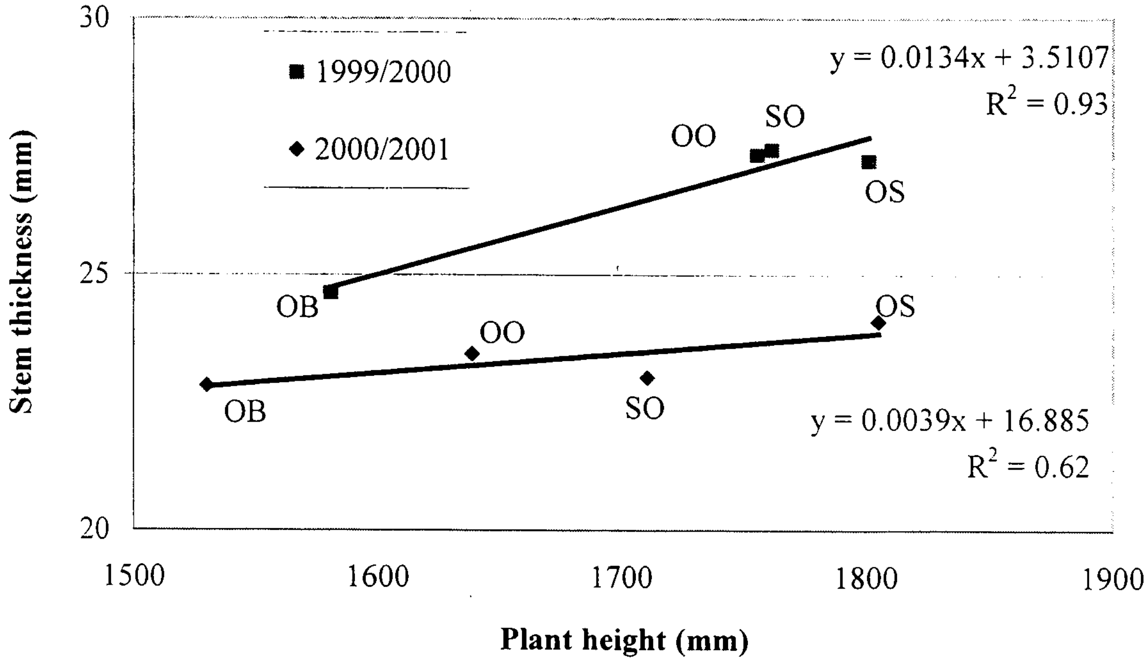

FIGURE 4.10: Relation between plant height and stem thickness of maize during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

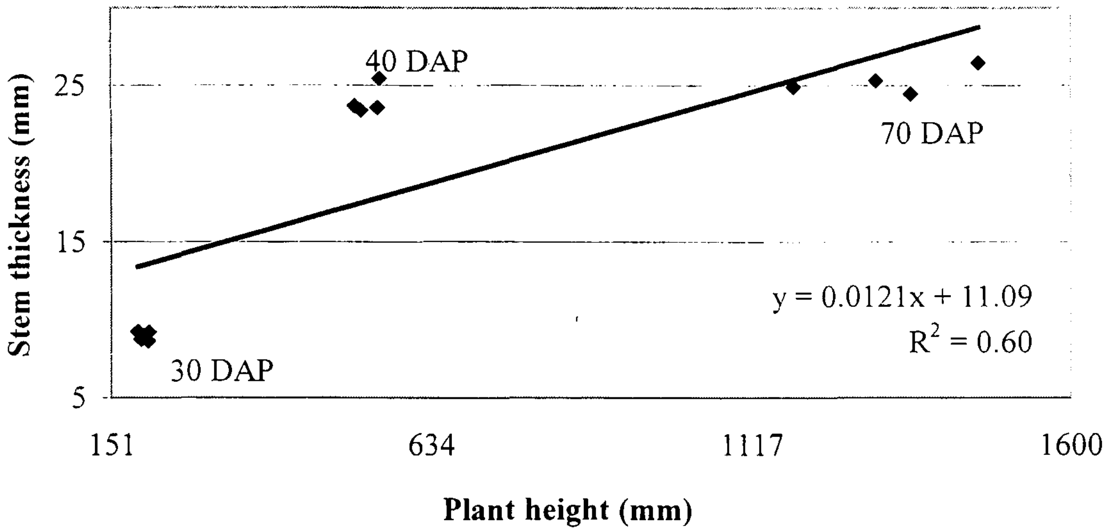

FIGURE 4.11: Effect of different mulching treatments on the relationship between plant height and stem thickness of maize from planting to 70 DAP during the 2000/2001 growing season

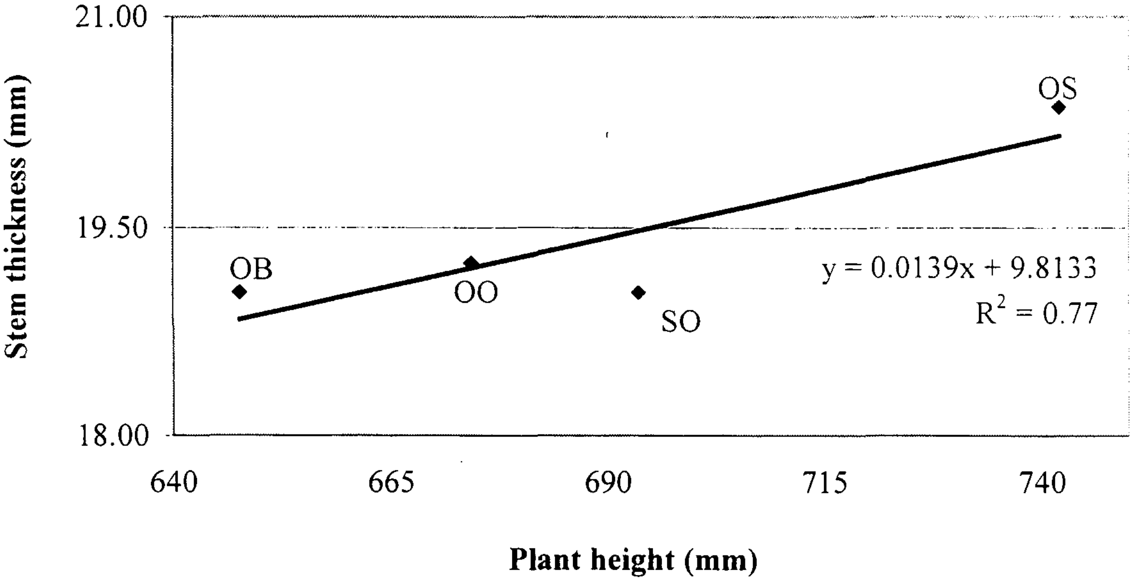

FIGURE 4.12: Effect of different mulching treatments on the relationship between plant height and stem thickness of maize from 30 to 70 DAP during the 2000/2001 growing season

The effect of mulching techniques during this period of growth is illustrated in Figure 4.12. As clearly seen, the OS, OO and SO had created more favorable conditions for stem growth than the control, but the OS technique was the best technique that showed higher plant height and stem thickness than all the other techniques

4.2.4.2 Plant height and number of green leaves

Plant height was linearly and positively correlated with number of green leaves per plant between 30 to 70 DAP (R^2=0.93) (Figure 4.13). The slope for this linear relation was significantly different from zero (Appendix 4.5a and Table 4.7). Separate regression analysis for each date of observations show the effect of mulching treatments in this relation. As illustrated in Figure 4.14, at 30 DAP a retarded growth and leaf production was observed in OO and SO mulching techniques, which are at the lower end of the regression line. During this period of growth the OS treatment also showed lower leaf production than the control. This relation, however, was changed at 70 DAP and stimulated growth was observed in OS, SO and OO than the control (Figure 4.15).

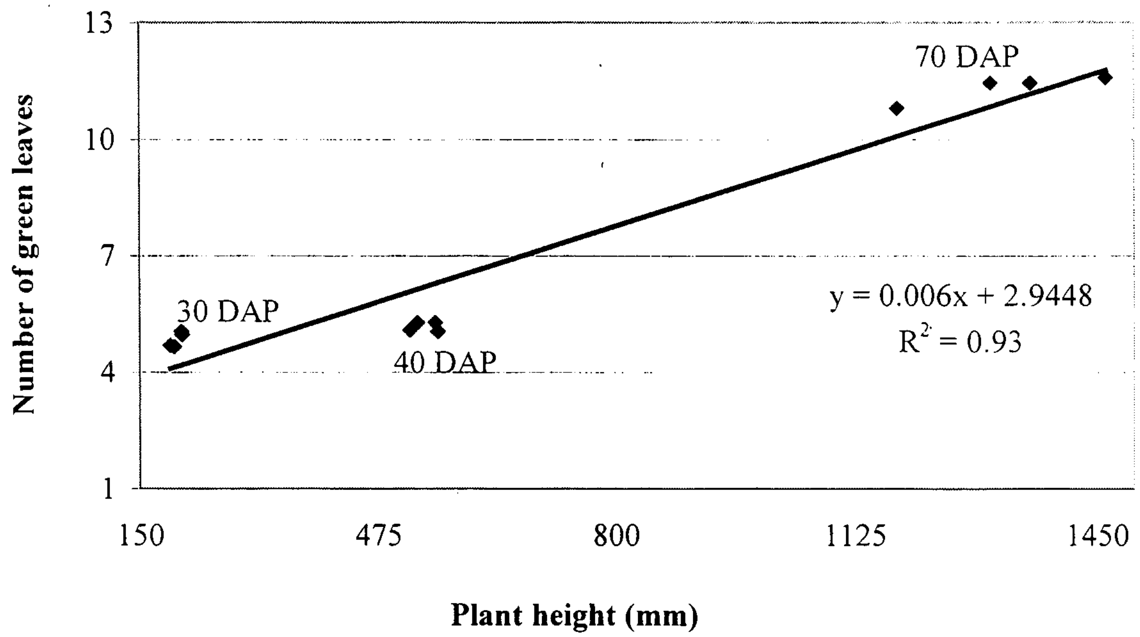

FIGURE 4.13: Relationship between plant height and number of green leaves of maize from 30 to 70 DAP during the 2000/2001 growing season

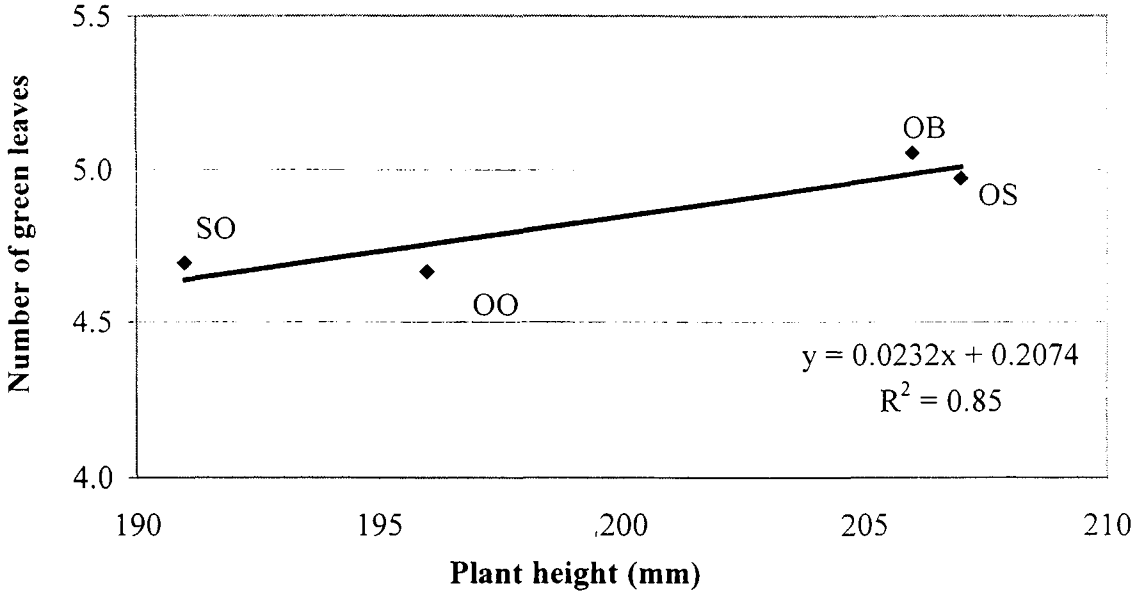

FIGURE 4.14: Effect of different mulching treatments on the relation between plant height and number of green leaves of maize at 30 DAP during the 2000/2001 growing season

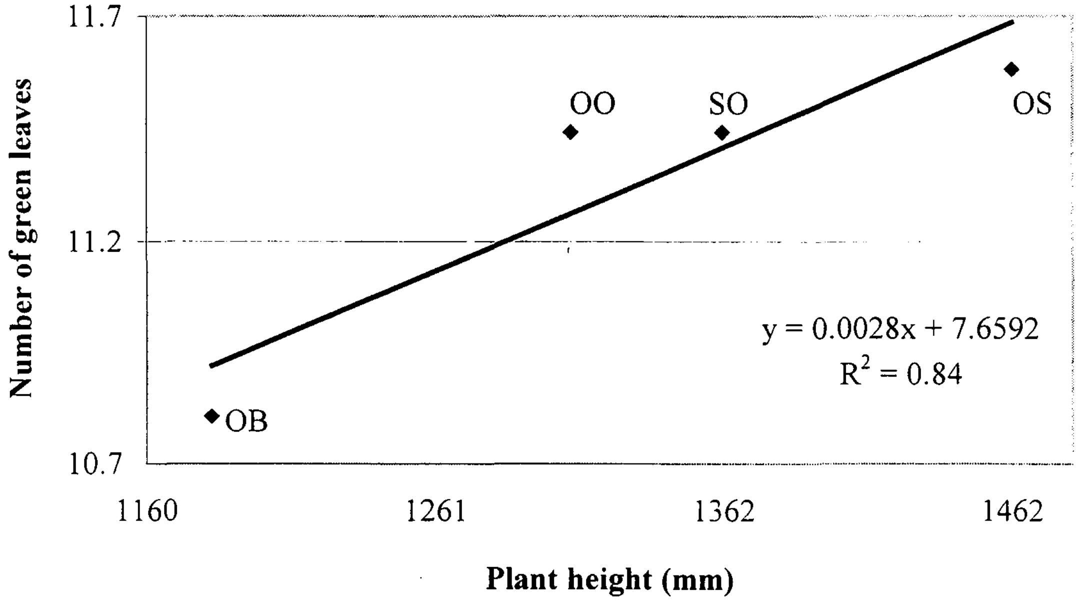

FIGURE 4.15: Effect of different mulching treatments on the relation between plant height and number of green leaves at 70 DAP during the 2000/2001 growing season

4.2.5 Effect of mulching techniques on yield and harvest index

4.2.5.1 Aerial biomass

Treatments showed no significant effect on the aerial biomass during the 1999/2000 growing season, but significantly influenced the biomass during the 2000/2001 growing season (Appendix 4.6.2-4.6.3). During this season, the OS and OO showed a significantly higher biomass than the control and there was no marked difference between OS and OO. The SO treatment also showed no significant difference when compared to OO and the control, but it had a significantly lower biomass than the OS technique (Table 4.8). Although the differences between treatments were not significant, the biomass during 1999/2000 tended to be higher in OS, OO and SO compared to the control (Figure 4.16). Consequently, the differences between treatments were significant over seasons, but the existence of the main effect of seasons and the interaction between treatments and seasons were not established (Appendix 4.6.1). The average biomass production capacity of maize was significantly higher in OS (mean=8066 kg.ha^{-1}) compared to all the other treatments. The OO and the SO treatments also showed significantly higher biomass than the control and there was no marked difference between OO and SO over seasons (Table 4.8).

Results revealed that the application of mulch in the basins and on the runoff strips increased the biomass production capacity of maize compared to mulch placement only in the basins. This effect was consistent during the two seasons. The maximum biomass over seasons, however, was obtained in OS and this revealed the advantage of stone mulch placement over organic mulch placement (OO) or bare runoff strips (OB). The OO and SO techniques showed no significant differences both within and over seasons. This showed that the type of mulch (stone or organic) in the basins was not as important as on the runoff strips.

TABLE 4.8: Effect of different mulching treatments on the mean aerial biomass yield (MBY) and relative biomass (RBY) of maize during the 1999/2000 and 2000/2001 growing seasons

Treatments	1999/2000		2000/2001		Average	
	MBY (kg.ha^{-1})	RBY (%)	MBY (kg.ha^{-1})	BY (%)	MBY (kg.ha^{-1})	RBY (%)
OS	7913	128	8219^{A}	151	8066^{A}	139
OO	7138	116	6955^{AB}	127	7046^{B}	121
SO	7453	121	6643^{BC}	122	7048^{B}	121
OB (Control)	6168	100	5455^{C}	100	5812^{C}	100
Mean	7168		6818		6993	
LSD(0.05)$_{T}$	NSD		1456		1004	

Means in the same column followed by the same letter are not significant at α=0.05

NS=not significant

RBY is defined as for RPH

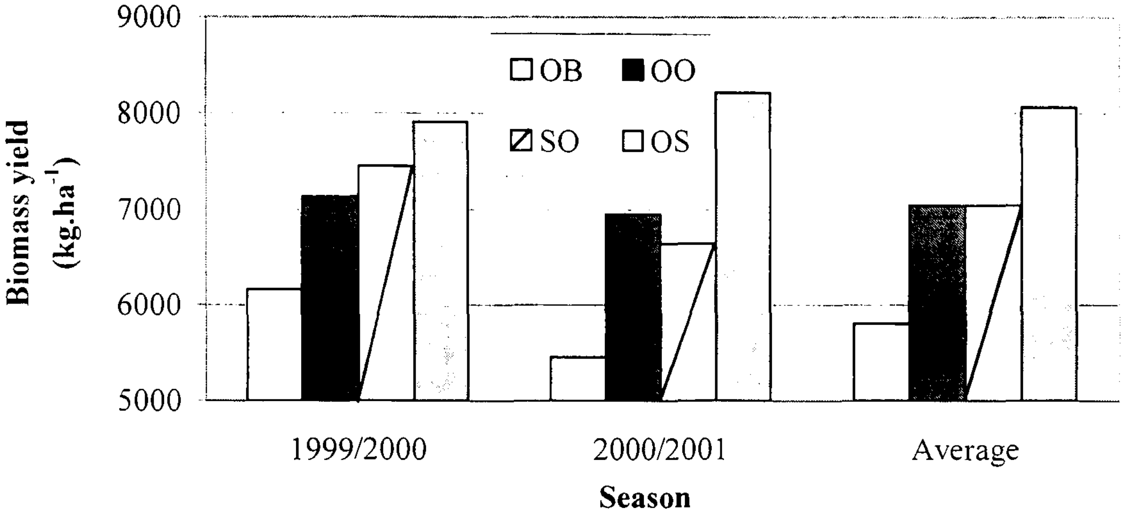

FIGURE 4.16: Effect of mulching treatments on aerial biomass of maize during the 1999/2000 and 2000/2001 growing seasons

4.2.5.2 Grain yield

Statistical analysis within season showed no significant differences between treatments for grain yield, number of seeds per ear and thousand seed weight during 1999/2000, but there were significant differences between treatments for grain yield and number of ears per plant during 2000/2001 (Appendix 4.7.2a-4.7.3c). During this season, the grain yield in OS, OO and SO were, respectively 33%, 14% and 16% higher than the control (mean=2269 kg.ha^{-1}). A statistical significant difference for grain yield during 2000/2001 was found between OS and the control, but there were no significant differences between OO, SO and the control and between OS, SO and OO (Table 4.9).

Statistical analyses over seasons showed that grain yield was significantly lower during 2000/2001 than 1999/2000 (Appendix 4.7.1a). This lower yield resulted in a significantly lower number of seeds per ear and lower thousand seed weight (Appendix 4.7.1b-4.7.1c). The number of seeds per ear and thousand seed weight during 1999/2000 were 11% and 27% higher than during 2000/2001. Although this analysis showed no significant differences between treatments, the average yield benefit from OS, OO and SO were, respectively 24%, 12% and 19% higher than the control. As illustrated in Figure 4.17, the differences between treatments and the control were consistent during both seasons. The absence of significant difference between treatments over season might be due to the heterogeneity of the error variances for the two seasons data (MSE=438 and 179, during 1999/2000 and 2000/2001, respectively Appendix 4.7.2a and 4.3a).

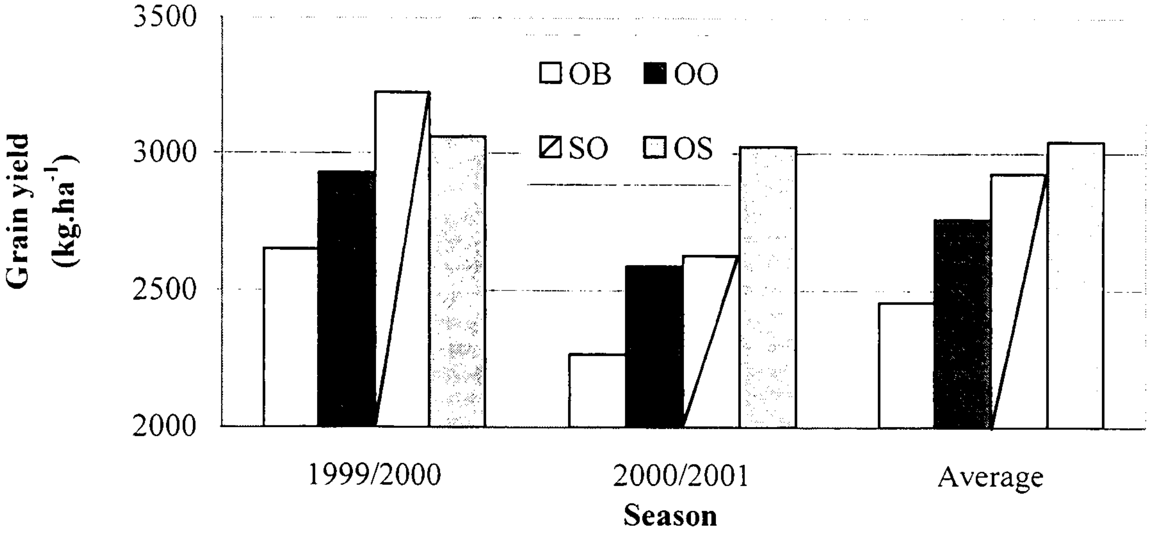

FIGURE 4.17: Effect of mulching treatments on grain yield of maize during the 1999/2000 and 2000/2001 growing seasons

TABLE 4.9: Effect of different mulching treatments on the mean grain yield (MGY) and relative grain yield (RGY) of maize during the 1999/2000 and 2000/2001 growing season

Treatment	1999/2000		2000/2001		Average	
	MGY (kg.ha^{-1})	RGY (%)	MGY (kg.ha^{-1})	RGY (%)	MGY (kg.ha^{-1})	RGY (%)
OS	3061	116	3025^{A}	133	3043	124
OO	2928	110	2589^{AB}	114	2758	112
SO	3224	122	2627^{AB}	116	2926	119
OB (Control)	2650	100	2269^{B}	100	2459	100
Mean	2966		2628		2797	
LSD(0.05)$_{T}$	NS		505		NS	

Means in the same column followed by the same letter are not significant at α=0.05

NS=not significant

RGY is defined as for RPH

TABLE 4.10: Effect of different mulching treatments on the mean number of ears per plant (MNEP), number of seeds per ear (MNSE) and thousand seed weight (MTSW) of maize during the 1999/2000 and 2000/2001 growing season

Treatment	1999/2000			2000/2001			Average		
	MNEP	MNSE	MTSW	MNEP	MNSE	MTSW	MNEP	MNSE	MTSW
OS	1.00	610	279	1.06^A	591	221	1.03^A	601	250
OO	1.00	608	293	1.00^A	531	223	1.00^A	568	258
SO	0.97	643	294	1.00^A	563	221	0.99^A	603	253
OB (Control)	0.89	598	279	0.83^B	528	234	0.86^B	564	256
Mean	0.97	615	286	0.97	553	225	0.97	584	254
LSD$(0.05)_T$	NS	NS	NS	0.10	NS	NS	0.11	NS	NS

Means in the same column followed by the same letter are not significant at $\alpha=0.05$

NS=not significant

4.2.5.3 Harvest index

The harvest index (HI) was generally lower in OS, OO and SO than the control (Figure 4.18). Statistical analysis both within and over seasons, however, showed no significant differences between treatments for HI (Appendix 4.9.1-4.9.3). This demonstrates that treatments had no effect on the balance between grain yield and the biomass both within and over seasons. The higher growth and biomass production observed in OS, OO and SO mulching techniques thus was beneficial for grain production.

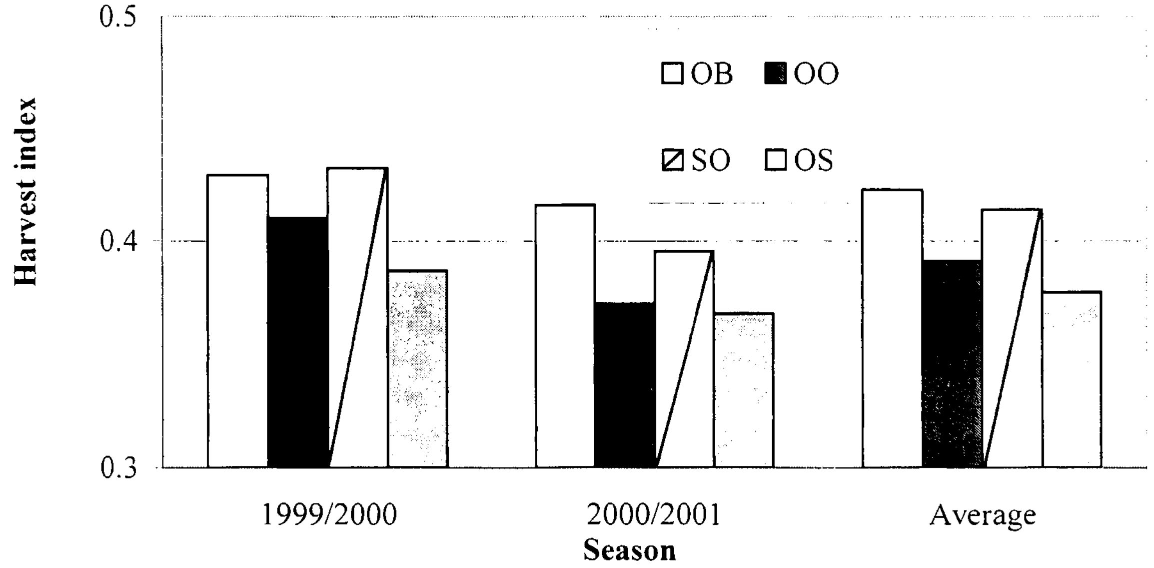

FIGURE 4.18: Effect of mulching treatments on the harvest index of maize during the 1999/2000 and 2000/2001 growing seasons

TABLE 4.11: Effect of different mulching treatments on the harvest index of maize during the 1999/2000 and 2000/2001 growing seasons

Treatments	Harvest index		
	1999/2000	2000/2001	Average
OS	0.39	0.37	0.38
OO	0.41	0.37	0.39
SO	0.43	0.40	0.41
OB	0.43	0.42	0.42
Mean	0.41	0.39	0.40
LSD(0.05)$_T$	NS	NS	NS

NS= not significant

4.3 CONCLUSION

An experiment to determine the effect of different mulching treatments (mulch in the basins and on the runoff strips) on growth and yield responses of maize with an in-field water harvesting crop production technique was conducted on the Glen/Bonheim ecotope over a two year period.

Plant height and stem thickness at maturity were measured during two seasons to evaluate whether growth was inhibited or stimulated by different mulching techniques. Plant height and stem thickness growth rates as well as the LAI at 30, 40 and 70 DAP were also determined during the 2000/2001 growing season to evaluate the effect of mulching treatments during the early growth stages of maize. Biomass and grain yields were also assessed. The soil water regime created by mulching during the two growing seasons was evaluated from soil water content measurements obtained from ARC-ISCW Glen group.

Although differences were not always statistically significant, results showed that growth and yield of maize were higher in OS, SO and OO than in the control. There were no marked differences between OS, SO and OO for plant height and stem thickness at maturity. Early growth of maize, however, was higher in OS than SO and OO. The maximum biomass and grain yield over seasons was also obtained in OS compared to all other treatments. This technique also showed higher moisture conservation in the runoff strips. but, unlike, the OO treatment, it showed no significant reduction in the amount of rainwater collected in the basins.

From these results, it is, therefore, concluded that the application of stone mulch on the runoff strips was most effective in terms of improving growth and yield of maize. Application of organic mulch on the runoff strips seemed to have a negative effect on the water harvesting process, however, no significant reduction on growth and yield were found, and it may be beneficial for sustainable crop production when compared to bare runoff strips. In all cases, stone and organic mulch placements in the basins showed no differences for the parameters considered and the choice may depend on the availability of stone or organic mulch.

CHAPTER 5

EFFECT OF MULCHING TECHNIQUES ON GROWTH AND YIELD RESPONSE OF SUNFLOWER (*Helianthus annus* L)

5.1 INTRODUCTION

During the 1970's South Africa was the leading sunflower (*Helianthus annus* L) producing country in Africa (Putt, 1978). The annual statistics released by the FAO (1999) showed that in the year 1999 some 1.18 million hectares of land was devoted to sunflower production in Africa, 70% of this land located in South Africa. In terms of area coverage sunflower production in this country increased from 0.5 million ha between 1989-91 to 0.828 million ha in 1999 (65.6% increase) (FAO, 1999).

In marginal rainfall areas crop water use is the primary factor that determine the type of crop to be grown. Particularly, for an in-field water harvesting crop production technique crop water use plays a central role to maximize RUE. In view of this, sunflower is one of the crops that can add diversity to this type of production technique. This is mainly because of its ability to extract soil water to lower water potential levels than most small grain cereals (Halverson, Black, Krupinsky, Merrill and Tanaka, 1999). Although sunflower is sensitive to water stress, particularly, during flowering, the higher water extraction capacity of the root system confers mechanism of drought avoidance and makes this crop perform well under drought conditions (Robinson, 1978). This characteristic of sunflower helps to maximize RUE through reduced drainage losses, which may take place otherwise. An experiment in Argentina showed that the water extraction capacity of sunflower was much higher than most other crops including maize (Dardanelli, Bachmeier, Sereno & Gill, 1997).

In addition to a strong taproot, it also has prolific laterals that grow as long as 1500 mm in the top 300 mm soil (Knowles, 1978). Because of these characteristics, the crop responds well to water conservation practices. A two years study at Glen, South Africa, for example, showed that under an in-field water harvesting crop production technique. the dry matter production capacity of sunflower was higher than wheat and sorghum (Hensley *et al.*, 2000).

As a row crop, however, sunflower may loose large amounts of rainwater from the soil surface between rows by Es. These losses would be particularly high under an in-field water harvesting crop production technique, where a 2 m runoff strips are left between crop rows. In addition to this, soil movement from the runoff strip to the water basins and subsequent deposition in the basins was higher for bare runoff strips than mulched runoff strips (Botha *et al.*, 2001). This may affect the water redistribution process and the storage capacity of the basins. Consequently, the fraction of rainwater used by the crop will be lower leading to lower RUE, poor growth and lower yields.

For an in-field water harvesting crop production technique, mulch placement in both the basins and runoff strips may be a possibility to minimize these problems and realize improved growth and higher yields.

5.2 RESULTS AND DISCUSSION

5.2.1 Rainfall distribution

The rainfall during 1999/2000 was 377 mm and occurred over a period of 75 days beginning on the 25th of November 1999. It was 72 mm lower than the long-term average rainfall of this area (P_n). The rainfall during 2000/2001 was 383 mm, which fell in just 59 days. This season rainfall was 66 mm lower than P_n of the area.

From Figure 5.1 and 5.2, the 1999/2000 and 2000/2001 growing seasons differed mainly with respect to rainfall distribution and the pattern of soil water deficit development. Both the initial soil water content and the distribution of the rainfall were more favourable for crop growth during 1999/2000 than 2000/2001. The percentage of the growing season rainfall that fell before planting and during establishment, vegetative, flowering and seed filling stages of growth was, respectively 52%, 0%, 29%, 3% and 16% during 1999/2000 and 34%, 0%, 22%, 0.1% and 45% during 2000/2001 (Table 5.1). Although there was no rain from planting until 10 DAP, the soil water content during this period of growth was above the drained upper limit during both seasons, probably because of a higher pre-plant rainfall and residual soil water left by the previous maize crop. The residual soil water available to sunflower during 2000/2001 from the 1999/2000 maize crop is depicted in Figure 5.3. The average soil water content at harvesting time of maize was 380 mm and this was raised to 439 mm during the fallow period.

The soil water extraction curves of sunflower illustrated in Figure 5.1 and 5.2 for 1999/2000 and 2000/2001 showed two distinct patterns. In spite of a well distributed rainfall during 1999/2000, the soil water content for all treatments showed a high water deficit that developed in the soil from 55 DAP to crop maturity. The high soil water depletion may be explained by the high soil water extraction capacity of the sunflower plant. Dardanelli *et al.* (1997) experimentally showed that the water extraction capacity of sunflower was higher than that of alfalfa, maize and peanut. These authors found that the water extraction front velocity in a silty loam soil ranged from 44 $mm.d^{-1}$ for sunflower to 25 $mm.d^{-1}$ for peanut. In contrast to this, the soil water content during 2000/2001 was raised above the drained upper limit from 88 DAP onwards. For this season this may not be unexpected since the higher amounts of rainfall (45%) occurred after flowering during which both the crop and the atmospheric demand for water was lower than it was during the vegetative growth stage. The climatic data presented in Table 5.2 showed that the evaporative demand of the atmosphere was higher during 2000/2001 than 1999/2000. During 2000/2001, the atmospheric demand for water decreased after flowering (Eo 2.5 $mm.d^{-1}$) because of high humidity (70%) and low temperatures (14 ^{0}C).

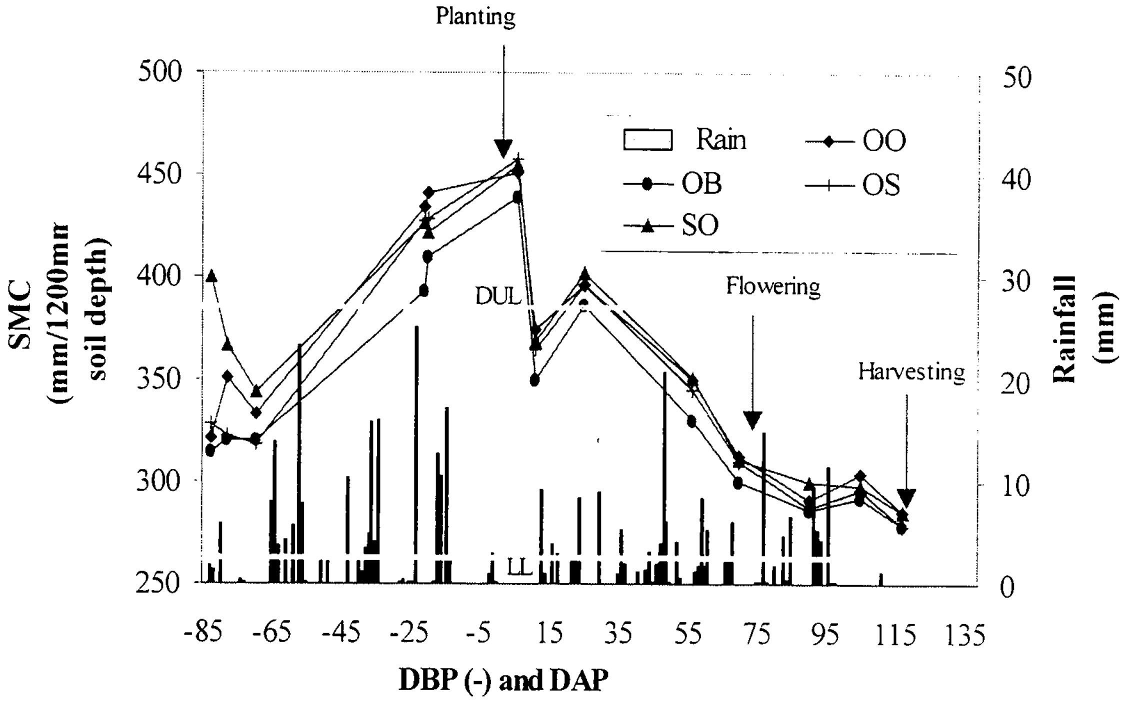

FIGURE 5.1: Rainfall distribution and soil water content (SMC) during the 1999/2000 growing season of sunflower (DBP and DAP: days before and after planting, respectively)

5.2.2 Effect of mulching techniques on soil water content

Mulching had a significant effect on the total soil water content during the 1999/2000 growing season, but not during the 2000/2001 growing season (Appendix 5.1.1a-5.1.2a). During the 1999/2000 growing season, the total soil water content for the OO, SO and OS treatments were significantly higher than OB (the control treatment). During this season the SO and OO techniques also showed a significantly higher soil water content than OS (Table 5.3).

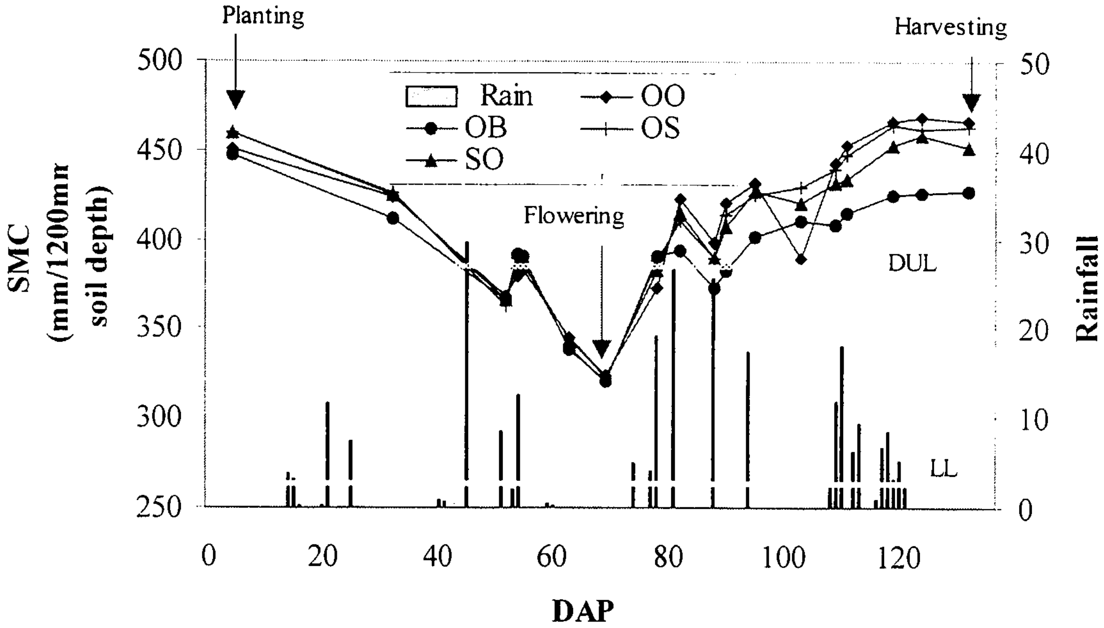

FIGURE 5.2: Rainfall distribution and soil water content (SMC) for the root zone (1200mm) during the 2000/2001 growing season of sunflower

Mulching treatments also had a significant influence on the amount of water stored in the runoff strips during both seasons, but only during the 2000/2001 season were there significant differences in the soil water content of the basins (Appendix 5.1.1b-5.1.2c). During both seasons, the amounts of water stored in the runoff strips were significantly higher in OO, SO and OS than in the control, but there were no significant differences between OO, SO and OS. The control had a significantly higher soil water content in the basins than the OO treatment during the 2000/2001 season, but was not significantly different from the soil water content in the OS and SO treatments for both seasons (Table 5.3).

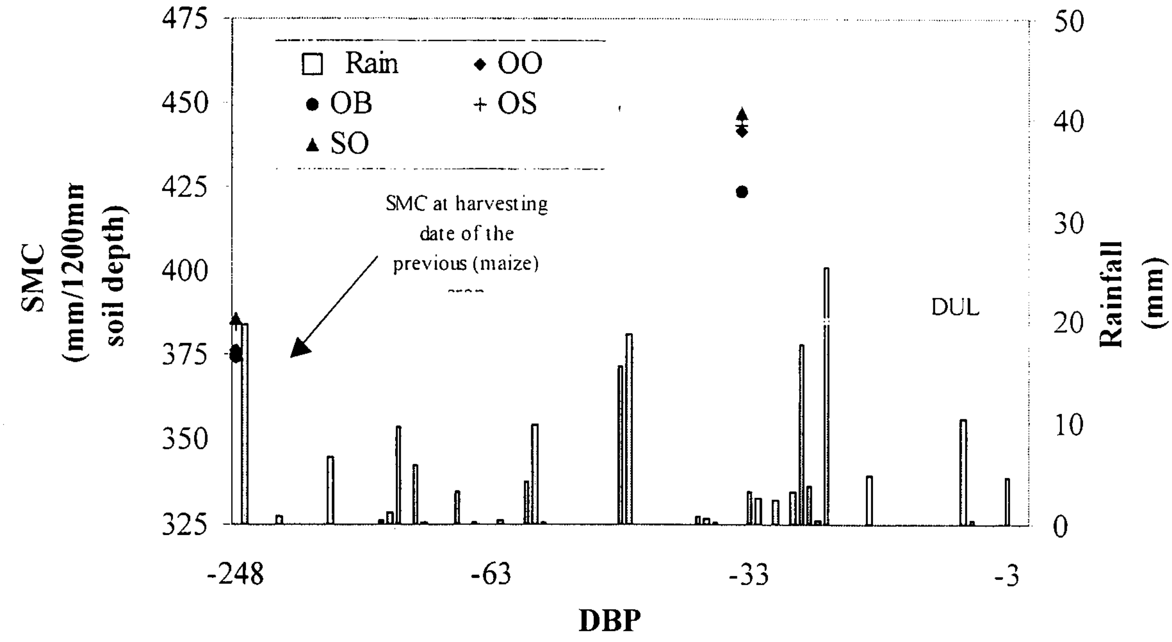

Figure 5.3: Soil water content (SMC) at harvesting date of maize (residual water) and 38 days before the planting date of sunflower and rainfall distribution during the 2000/2001 fallow period

TABLE 5.1: Amount and distribution of rainfall related to the growth stages of sunflower during the 1999/2000 and 2000/2001 growing seasons

Growth stage	1999/2000					2000/2001				
	DAP	Day/month/year	Rainfall (mm)	No. rainy days	Proportion of total rainfall	DAP	Day/month/year	Rainfall (mm)	No. rainy days	Proportion of total rainfall (%)
Before planting	-64-0	25/11/99-7/1/00	197	30	52	-64-0	1/11/00-3/1/01	128	21	33
Planting to establishment	1-10	28/1/00-7/2/00	0	0	0	1-10	4/1/01-14/1/01	0	0	0
Vegetative	11-64	8/2/00-11/4/00	109	27	29	11-60	15/1/01-5/3/01	82	17	21
Flowering	65-74	12/4/00-14/6/00	11	3	3	61-70	6/3/01-15/3/01	1	2	0.1
Grain filling to maturity	75-138	21/3/00-6/6/00	61	15	16	71-136	16/3/01-20/5/01	173	19	45
Total			378	75	100			384	59	100

TABLE 5.2: Climatic data from Glen meteorological station related to the different growth periods for sunflower during the 1999/2000 and 2000/2001 growing seasons

Growth stage	1999/2000				2000/2001			
	DAP	RH (%)	Eo (mm.d^{-1})	T (^{O}C)	DAP	RH (%)	Eo (mm.d^{-1})	T (^{O}C)
Before planting	-64-0	64	4.4	20	-64-0	53	6.1	20
planting to establishment	1-10	44	6.8	23	1-10	31	8.3	25
Vegetative	11-64	62	4.0	19	11-60	49	6.3	23
Flowering	65-74	64	3.2	16	61-70	55	4.9	22
Grain filling to maturity	75-138	64	2.5	12	71-136	70	3.1	16

DAP= days after planting

RH is mean daily relative humidity, Eo is mean daily class A-pan evaporation and T is daily mean temperature

Results showed that the OO, SO and OS techniques were equally effective in conserving soil water in the runoff strips, but their effect on soil water storage in the basins and on the total soil water content was not the same during the two seasons. During the favourable 1999/2000 season, both organic and stone mulch placements on the runoff strips had no significant negative effect on the soil water regime of the basins, but these techniques had respectively a 7%, and 4% higher water content in the runoff strips than the control. Consequently, the total soil water content in OO, OS and SO techniques, respectively, was 4%, 2% and 4% higher than in the control. During the 2000/2001 season, organic mulch placement on the runoff strips significantly reduced soil water storage in the basins compared to the control. Although the difference was not significant, stone mulch also showed a lower soil water content in the basins than the control during this season (Table 5.3). As a result, water conservation with organic and stone mulch placement in the runoff strips made no significant positive contribution to the total water content in the root zone. During both seasons, the comparisons between OO (organic mulch in the basins) and SO (stone mulch in the basins) showed no significant differences (Table 5.3). The absence of significant difference between these treatments may indicate that from a water harvesting view point, the type of mulch in the runoff strips is more important than the kind of mulch in the basins.

In addition to the total soil water content and its storage partitioning, the effect of mulching was also reflected in the depth of water distribution in the soil profile of both the runoff strips and basins. Figure 5.3 shows the mean water content, expressed as volume of water per volume of soil, plotted against soil depth for the period 11-138 and 52-78 DAP during the 1999/2000 and 2000/2001 seasons, respectively. It can be seen that the differences between treatments were more pronounced in the top 600 mm of soil than lower down. During both seasons, the top 600 mm of the soil in the runoff strips was wetter in the OO, SO and OS techniques than in the control and the differences were larger during the dry 2000/2001 season than during 1999/2000. During 2000/2001, the control treatment also showed a higher soil water content in the basins to a depth of 600 mm than OS, SO and OO techniques.

The higher near-surface soil water content on the runoff strips under organic and stone mulches may be due to reduced evaporation, whereas the difference between the mulching techniques and the control in terms of soil water content of the basins may be due to reduced runoff caused by mulching of the runoff strip. Botha *et al.* (2001) experimentally showed that organic and stone mulch placement on the runoff strip reduced runoff into the basins compared to the treatment with a bare runoff strip. Further these authors reported that organic mulch reduced runoff toward the basins more than stones.

TABLE 5.3: Effect of different mulching treatments on the total soil water content and its partition in the runoff strips (RS) and water basins (WB) for the root zone (1200mm) between 11 to 138 and 52 to 78 days after planting during the 1999/2000 and 2000/2001 growing seasons of sunflower, respectively

Treatment	1999/2000			2000/2001		
	RS	WB	Total	RS	WB	Total
OS	314.5^{A}	325.8	320.1^{B}	361.1^{A}	368.4^{AB}	364.7
OO	323.3^{A}	327.8	325.5^{A}	359.2^{A}	364.9^{B}	362.1
SO	322.1^{A}	328.9	325.5^{A}	363.4^{A}	366.1^{AB}	364.7
OB	302.1^{B}	325.1	313.6^{C}	346.8^{B}	385.7^{A}	366.1
Mean	315.5	326.9	321.2	357.62	371.1	364.4
$LSD(0.05)_{T}$	10.75	NS	5.3	12.19	20.0	NS

Means in the same column followed by the same letter are not significant at $\alpha=0.05$
NS = not significant at $\alpha=0.05$

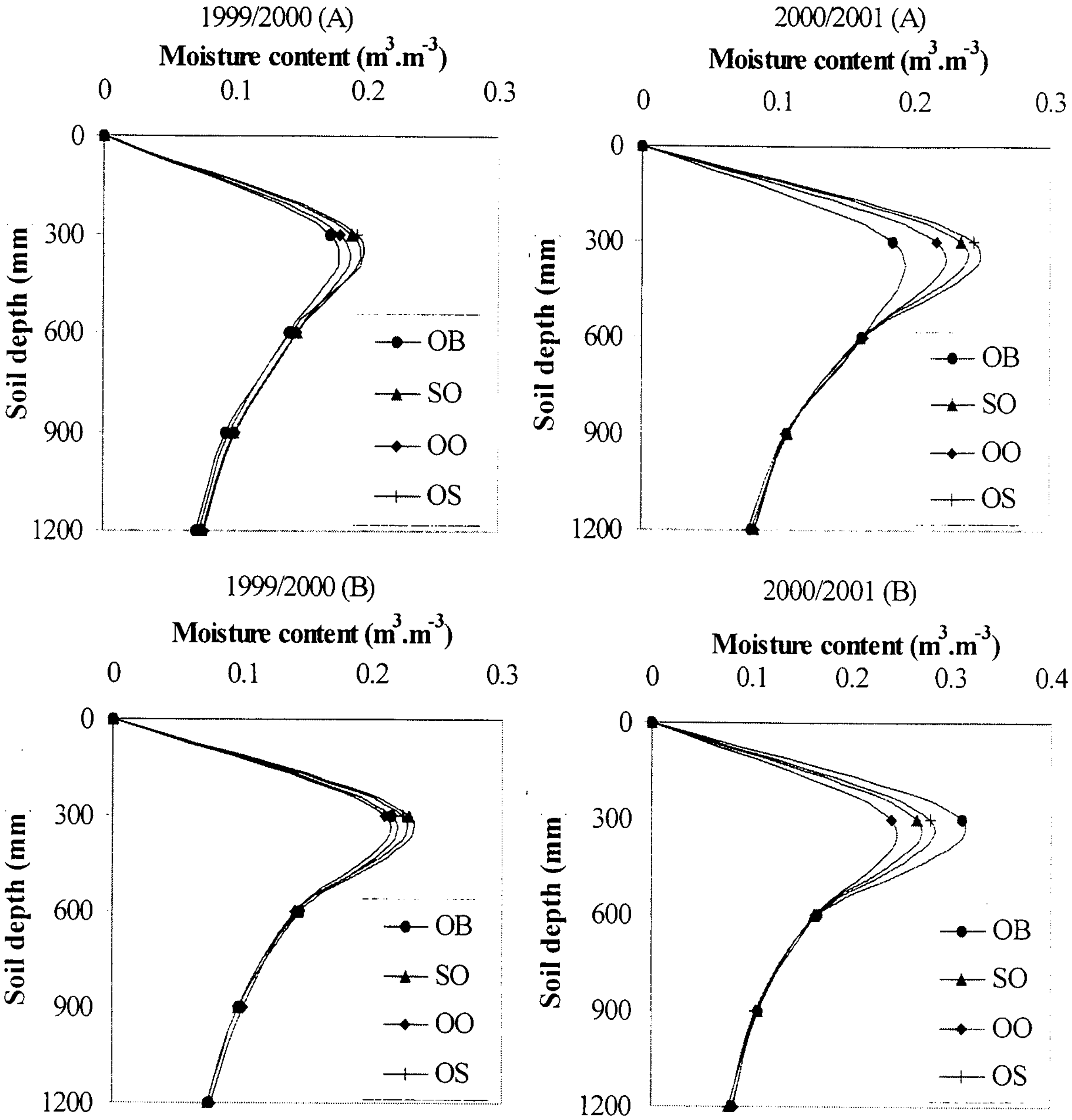

FIGURE 5.4: Effect of different mulching treatments on the depth distribution of the average soil water content (m^3m^{-3}) in the soil profile of the runoff strip (A) and basin (B) for the period 11-144 and 52-78 DAP during the 1999/2000 and 2000/2001 growing seasons for sunflower, respectively

5.2.3 Effect of mulching techniques on plant growth

5.2.3.1 Plant height

Mulching significantly influenced plant height during both seasons (Appendix 5.2.2-5.2.3a). Plant height in SO, OO and OS treatment plots were respectively, 15%, 11% and 9% higher than the control during 1999/2000 and 14% 10% and 14% higher than the control during 2000/2001. However, only SO and OO showed significant differences to the control during 1999/2000. During both seasons differences between SO, OS and OO treatments were not statistically significant (Table 5.4).

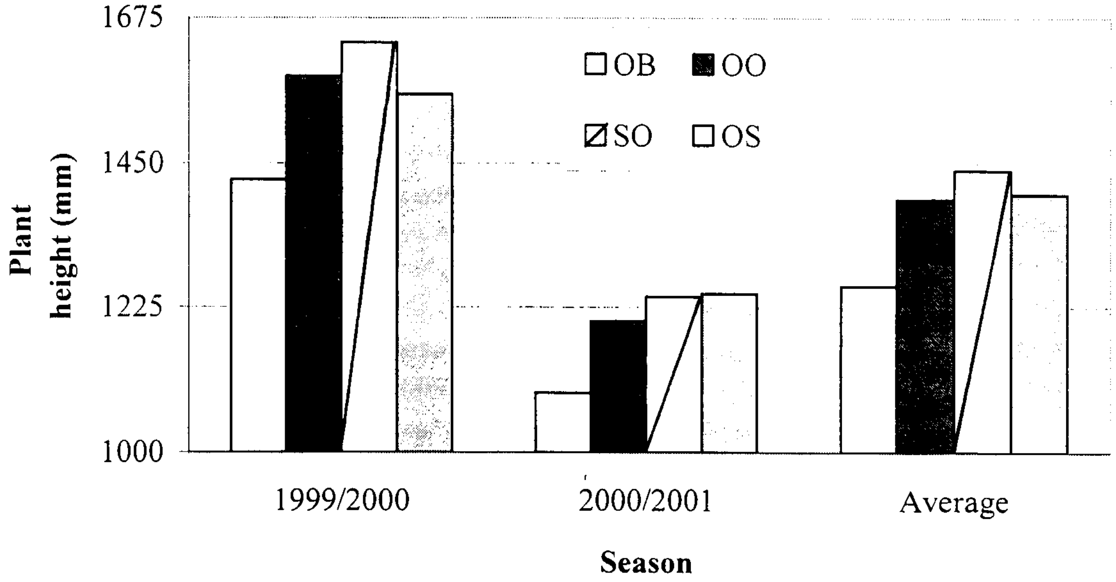

FIGURE 5.5: Effect of mulching treatments on the height of sunflower plants during the 1999/2000 and 2000/2001 growing seasons

Statistical analysis for plant height growth rates from planting to 70 DAP during the 2000/2001 growing season showed no significant differences between treatments (Appendix 5.2.3b-5.2.3d). The maximum height growth rate during 2000/2001 was observed between 30 to 40 DAP (Figure 5.6). During this period the plant height growth rate of OS, SO and OO were, respectively, 21%, 39% and 8% higher than the control.

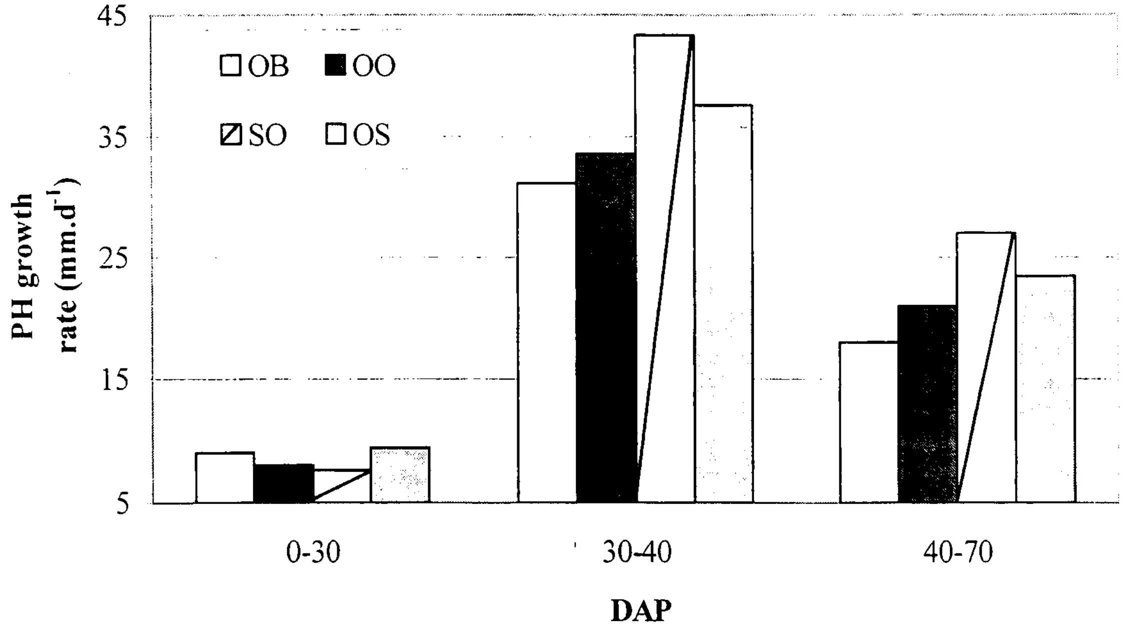

FIGURE 5.6: Effect of mulching treatments on sunflower plant height growth rate during the 2000/2001 growing season

A significant effect of mulching treatments on plant height was found in the over season analysis. This analysis revealed that mulching treatments and seasons significantly influenced plant height, but the interaction between mulching treatments and seasons showed no significant effect (Appendix 5.2.1). Plants were generally taller during 1999/2000 than during 2000/2001 and over the two seasons plants in OS, SO and OO, were respectively 11%, 14% and 11% taller than those in the control, and these differences were statistically significant (Table 5.4).

5.2.3.2 Stem thickness

Mulching treatments had no significant effect on stem thickness during 1999/2000, but had a significant effect during the 2000/2001 growing season (Appendix 5.3.2-5.3.3a).

During 2000/2001 the stems of plants in SO, OS and OO were respectively 18%, 13% and 5% thicker than in the control. However, only the SO technique showed a significant difference compared to the control (Table 5.5). During this season the higher stem thickness growth rate was observed between 30 to 40 DAP (Figure 5.8). Although the differences among treatments were not significant, the SO, OS and OO techniques, respectively, showed 15%, 6% and 5% higher stem thickness growth rates than the control. As illustrated in Figure 5.8, stem thickness growth rates were higher in the OS treatment than in the control at all stages of growth, whereas the OO showed slightly reduced stem thickness growth rate compared to the control between planting and 30 DAP.

Analysis of variance of stem thickness over seasons showed no significant differences between treatments, but it showed the significant effect of seasons on stem thickness (Appendix 5.3.1). Stems were significantly thicker during 1999/2000 than during 2000/2001. The absence of significant differences between treatments indicated that neither of the treatments was consistent in stimulating stem thickness growth during the two seasons. From Figure 5.7 it can be seen that the stem thickness in SO was lower than in OO and OS during 1999/2000, but this treatment had a larger stem thickness than OS and OO during 2000/2001. No significant interaction between mulching treatments and seasons was found in the over season analysis (Appendix 5.3.1)

TABLE 5.4: Effect of different mulching treatments on mean plant height (MPH), relative plant height (RPH), height growth rates (HGR) and relative height growth rate (RHGR) of sunflower as affected by the different mulching treatments during the 1999/2000 and 2000/2001 growing seasons

Treatments	Plant height						Height growth rate					
	1999/2000		2000/2001		Average		2000/2001					
							0-30 DAP		30-40 DAP		40-70 DAP	
	MPH (mm)	RPH (%)	MPH (mm)	RPH (%)	MPH (mm)	RPH (%)	MHGR ($mm.d^{-1}$)	RHGR (%)	MHGR ($mm.d^{-1}$)	RHGR (%)	MHGR ($mm.d^{-1}$)	RHGR (%)
OS	1557^{AB}	109	1247^{A}	114	1402^{A}	111	9.4	103	37.6	121	23.5	130
OO	1585^{A}	111	1204^{A}	110	1394^{A}	111	8.0	88	33.6	108	21.0	116
SO	1637^{A}	115	1242^{A}	114	1439^{A}	114	7.6	84	43.3	139	27.1	150
OB	1425^{B}	100	1093^{A}	100	1259^{B}	100	9.1	100	31.1	100	18.0	100
Mean	1551		1196		1373		8.5		36.4		22.4	
$LSD(0.05)_T$	148.11		157.37		93		NS		NS		NS	

Means in the same column followed by the same letter are not significant at $\alpha=0.05$

NS=not significant

DAP= days after planting

RPH and RHGR defined, respectively, as the ratio of the plant height and height growth rate in mulching treatment to the control in percentage

TABLE 5.5: Effect of different mulching treatments on mean stem thickness (MST), relative stem thickness (RST), thickness growth rate (TGR) and relative thickness growth rate (RTGR) of sunflower as affected by the different mulching treatments during the 1999/2000 and 2000/2001 growing seasons

Treatments	Stem thickness						Stem thickness growth rates					
	1999/2000		2000/2001		Average		0-30 DAP		30-40 DAP		40-70 DAP	
	MST (mm)	RST (%)	MST (mm)	RST (%)	MST (mm)	RST (%)	MTGR ($mm.d^{-1}$)	RSTGR (%)	MTGR ($mm.d^{-1}$)	RSTGR (%)	MSTGR ($mm.d^{-1}$)	RSTGR (%)
OS	25.03	113	21.92^{AB}	113	23.47	113	0.16	107	1.37	106	0.14	175
OO	24.86	112	20.31^{AB}	105	22.58	109	0.14	93	1.35	105	0.09	113
SO	23.42	105	22.86^{A}	118	23.14	111	0.15	100	1.49	115	0.11	138
OB	22.22	100	19.39^{B}	100	20.81	100	0.15	100	1.29	100	0.08	100
Mean	23.88		21.12		22.50		0.15		1.38		0.11	
LSD(0.05)$_T$	NS		3.03		NS		NS		NS		NS	NS

Means in the same column followed by the same letter are not significant at α=0.05

NS=not significant

DAP= days after planting

RST and RTGR defined the same as RPH

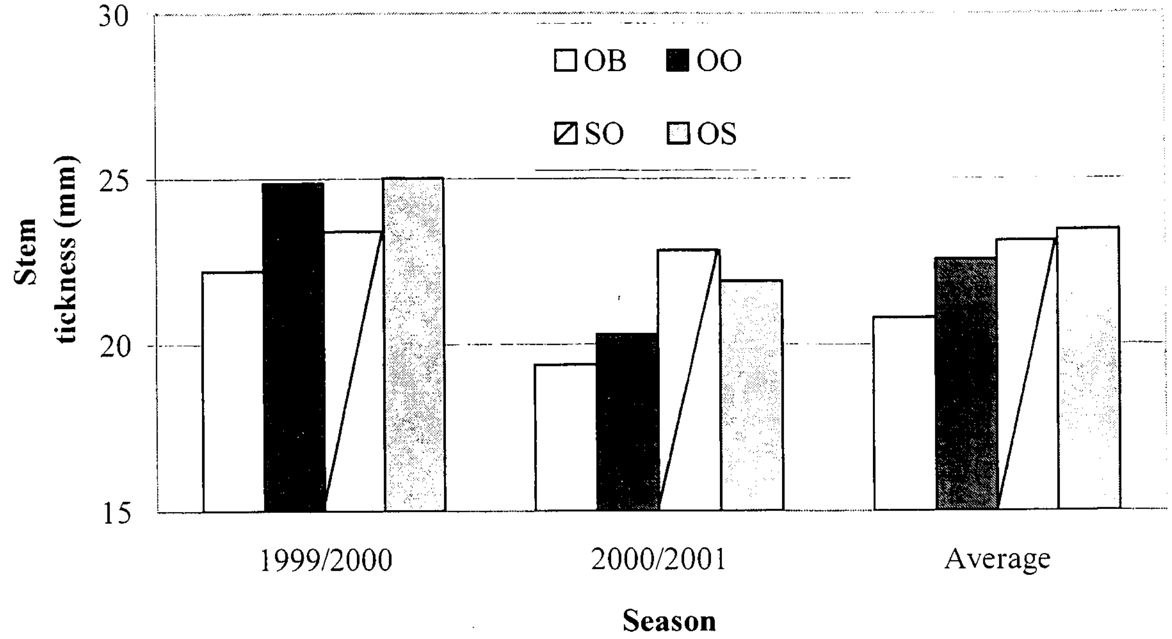

FIGURE 5.7: Effect of mulching treatments on sunflower stem thickness during the 1999/2000 and 2000/2001 growing seasons

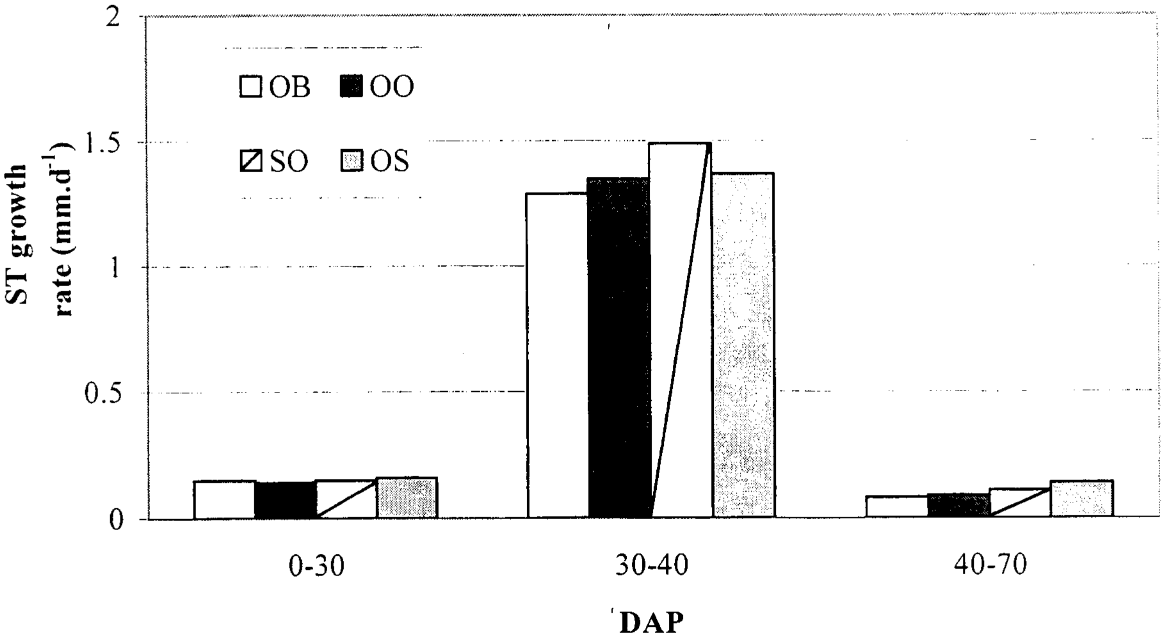

FIGURE 5.8: Effect of mulching treatments on sunflower stem thickness growth rate during 2000/2001 growing season

5.2.3.3 Leaf area index

Mulching treatments showed a significant effect on leaf area index (LAI) and leaf area per plant at 30 DAP, but had no significant effect at 40 and 70 DAP. The number of green leaves per plant was not affected by treatments on all dates of measurement (Appendix 5.4.1a-5.4.3c). At 30 DAP, the LAI were respectively 24% and 10% higher in OS and SO than in the control. The OO technique, on the other hand showed a 3% lower LAI than the control at this stage of growth (Table 5.6). A significant difference in LAI was found between OS and OO. The maximum LAI during the 2000/2001 growing season was observed at 40 DAP (Figure 5.9). At this stage of growth the SO, OS and OO, respectively showed a 36%, 19% and 11% higher leaf area index than the control (Table 5.6).

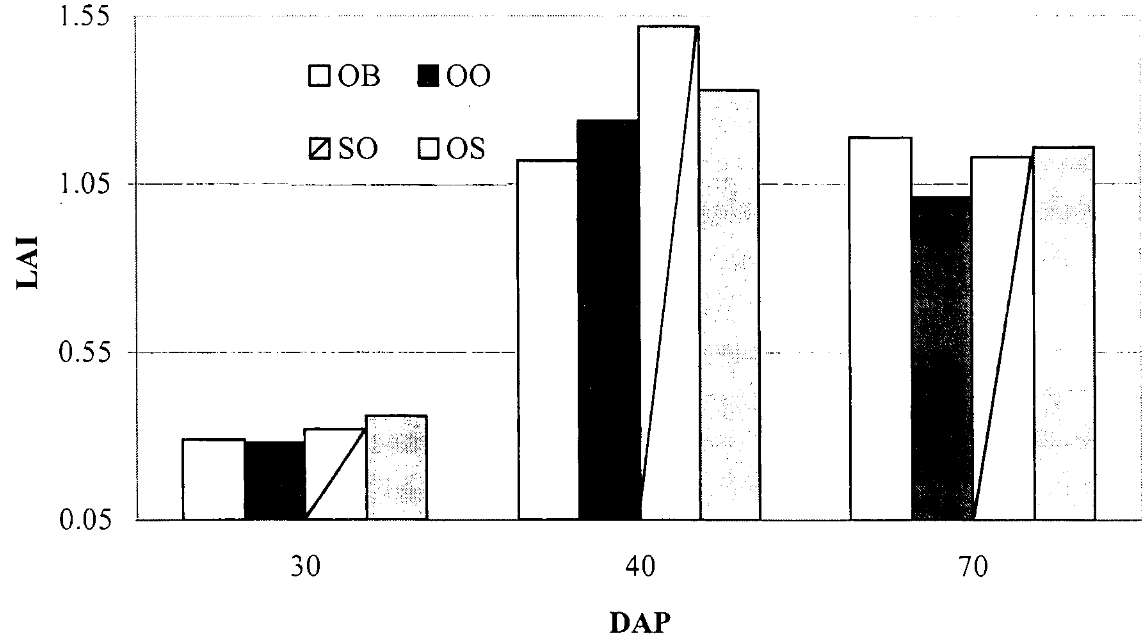

FIGURE 5.9: Effect of mulching treatments on leaf area index (LAI) of sunflower at 30, 40 and 70 DAP during 2000/2001 growing season

TABLE 5.6: Effect of different mulching treatments on the mean number of green leaves per plant (MNGL), relative number of green leaves per plant (RNGP), leaf area index (LAI) and relative leaf area index (RLAI) of sunflower at 30, 40 and 70 days after planting during the 2000/2001 growing season

Treatments	Number of green leaves per plant						Leaf area index					
	30 DAP		40 DAP		70 DAP		30 DAP		40 DAP		70 DAP	
	Mean	RNGP (%)	Mean	RNGP (%)	Mean	RNGP (%)	Mean	RLAI	Mean	RLAI	Mean	RLAI
OS	12.19	105	20.89	106	15.75	98	0.36^{A}	124	1.33	119	1.16	97
OO	11.28	98	19.97	101	15.56	97	0.28^{B}	97	1.24	111	1.01	85
SO	11.78	102	21.83	111	16.69	104	0.32^{AB}	110	1.52	136	1.13	95
OB	11.56	100	19.75	100	16.03	100	0.29^{AB}	100	1.12	100	1.19	100
Mean	11.70		20.61		16.01		0.31		1.30		1.12	
LSD(0.05)$_{T}$	NS		NS		NS		0.07		NS		NS	

Means in the same column followed by the same letter are not significant at α=0.05
NS=not significant

5.2.4 Relationships between growth parameters

5.2.4.1 Plant height and stem thickness

Mulching treatments showed no significant effect on height-thickness ratio both within and over seasons, but the seasonal main effect had a significant influence on this parameter (Appendix 5.5.1-5.5.3). The height-thickness ratio was significantly lower during 2000/2001 than it was during 1999/2000. This significant reduction on height-thickness ratio during 2000/2001 may indicate that the plant height was more affected by the unfavourable season than the stem thickness. Consequently, plants were thicker with respect to their height during 2000/2001 than during 1999/2000.

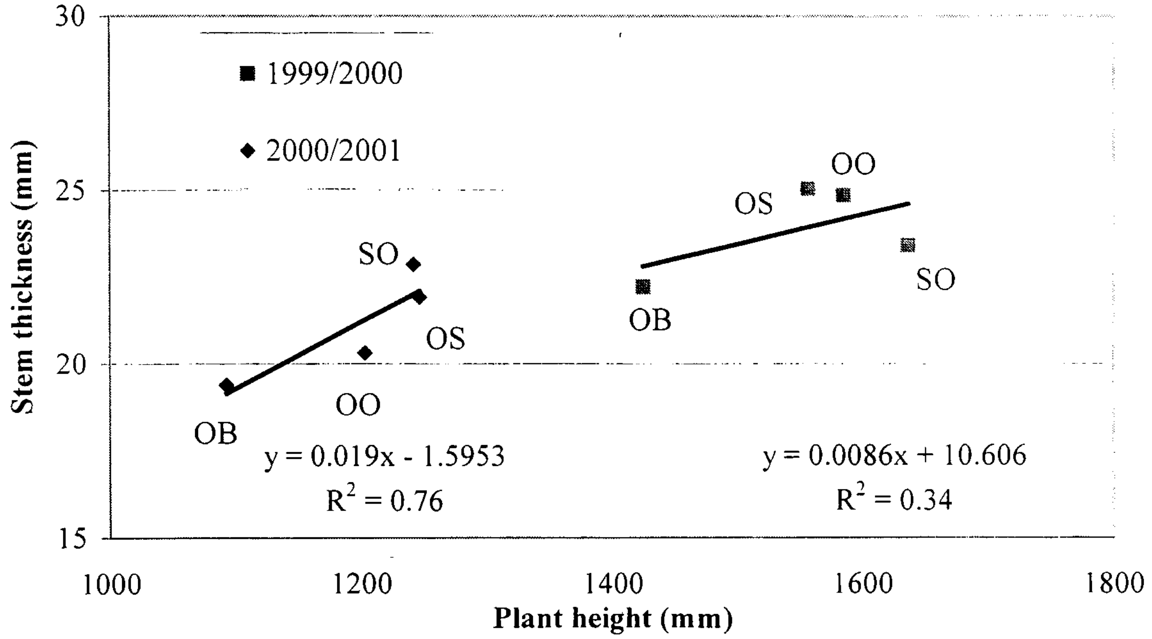

FIGURE 5.10:Relationship between plant height and stem thickness of sunflower during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

The strong seasonal effect on plant height is clearly seen from Figure 5.10, which is obtained by regressing stem thickness on plant height. Both the slope and determination coefficients were not statistically significant during both seasons showing that plant height and stem thickness were not linearly related. The slope and coefficient of determination, however, were higher during 2000/2001 than 1999/2000 (Table 5.7).

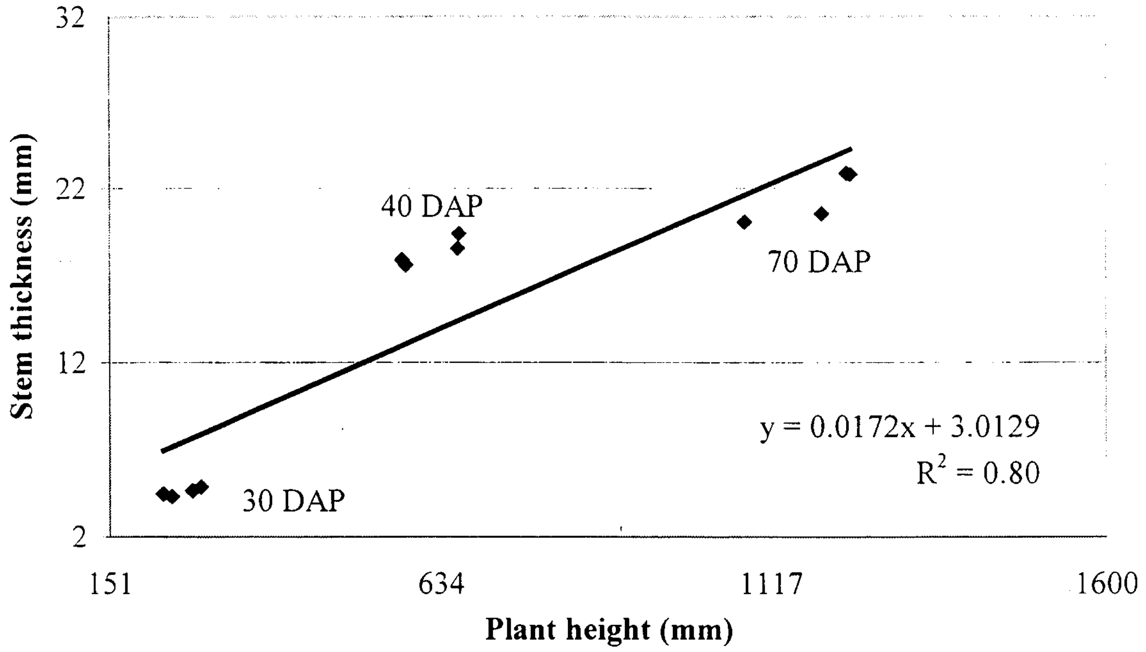

FIGURE 5.11:Relation between sunflower plant height and stem thickness from 30 to 70 days after planting (DAP) during the 2000/2001 growing season

The higher correlation during 2000/2001 and the lower correlation during 1999/2000 may reveal different growth patterns of the plant during the two seasons. According to Knowles (1978), the stem thickness of the sunflower plant is a function of the number of nodes, whereas, the plant height is a function of both the number of nodes and the length of internodes. Thus, the higher stem thickness with respect to plant height during 2000/2001 might be a result of inhibited internode elongation because of lower water availability during the vegetative growth stage (from 52 to 78 DAP).

In addition to the plant height and stem thickness, the effects of mulching techniques were also reflected on the relation between these growth parameters. The OS, SO and OO techniques showed stimulated stem growth than the control and was located at the right end of the regression trend line during both seasons (Figure 5.10). This trend was also the same during the early stem growth period (from planting to 70 DAP) (Figure 5.11 and 5.12) except that the slope of the regression line from planting to 70 DAP was significant (Table 5.7 and Appendix 5.5.4.c).

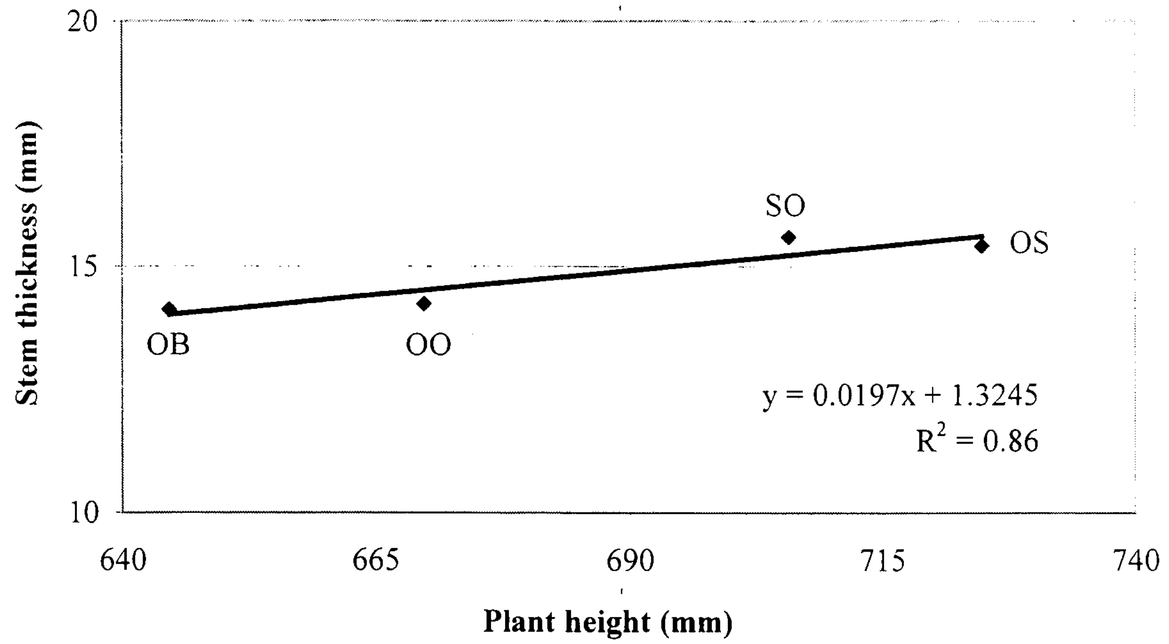

FIGURE 5.12:Effect of the different mulching treatments on the relation between sunflower plant height and stem thickness from planting to 70 DAP during the 2000/2001 growing season

5.2.4.3 Plant height and number of green leaves

The slope of the linear relation between plant height and number of green leaves per plant was significant from planting to 40 DAP, but was not significant from planting to 70 DAP (Appendix 5.5.5a-5.5.5b). The zero-slope for the linear relation between plant height and number of green leaves from planting to 70 DAP may be because of leaf senescence between 40 to 70 DAP. The mean number of green leaves per plant at 70 DAP was 22% lower than at 40 DAP (Mean=20.6 leaves plant^{-1}) (Table 5.6).

TABLE 5.7: Relationship between plant height (PH), stem thickness (ST) and number of green leaves (NGL) for sunflower at different growth periods during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Variables	Season	Growth period	Intercept	Slope	R^2	N
PH vs ST	1999/2000	Harvesting	10.61	0.0085^{ns}	0.34^{ns}	4
PH and ST	2000/2001	Harvesting	-1.60	0.0189^{ns}	0.76^{ns}	4
PH and ST	2000/2001	30-70 DAP	3.01	0.017^{***}	0.80^{***}	12
PH and NGL	2000/2001	30-70 DAP	13.64	0.0036^{ns}	0.14^{ns}	12
PH and NGL	2000/2001	40 DAP	9.03	0.0187^{*}	0.83^{*}	4

* Significant at the P<0.1

** Significant at the P<0.05

*** Significant at the P<0.01

^{ns} not significant

DAP= days after planting

The coefficient of determination for the growth period from planting to 40 DAP was high (R^2=0.83), but significant only at the P< 0.1 level (Table 5.7). The effect of mulching treatments in this relation is illustrated in Figure 5.14 and Figure 5.15. The OS showed a higher plant height and leaf production than the control both at 30 and 70 DAP (Figure 5.15). At 40 DAP plants of the SO treatment showed a better growth than the control, but this technique maintained lower plant height and leaf development than the control at 30 DAP (Figure 5.14). The OO technique, on the other hand, inhibited stem growth and leaf development both at 30 and 40 DAP.

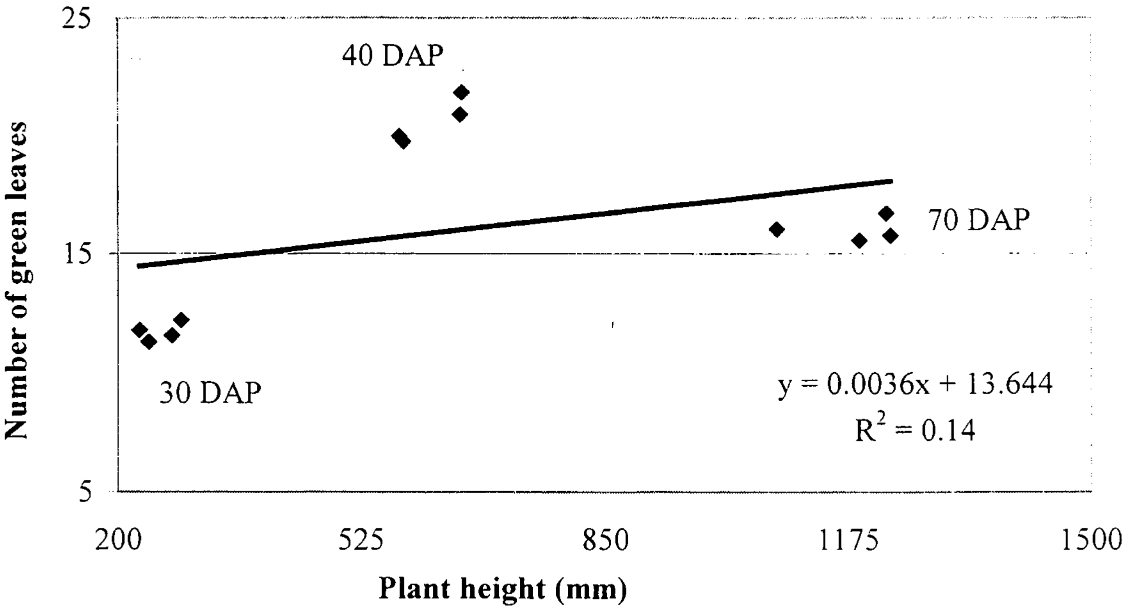

FIGURE 5.13:Relationship between plant height and number of green leaves per sunflower plant from 30 to 70 days after planting (DAP) during 2000/2001

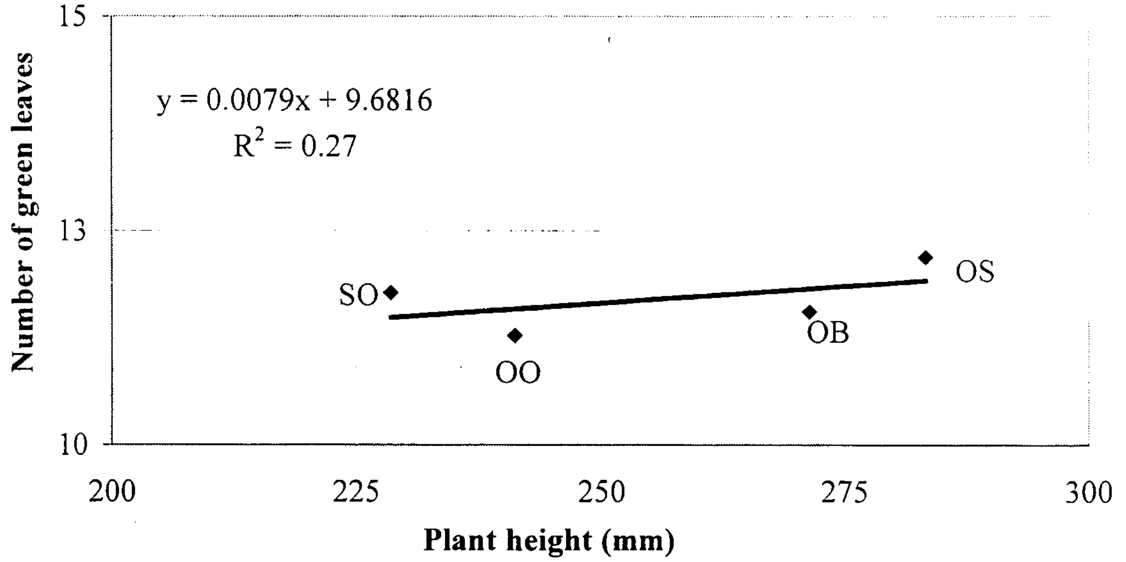

FIGURE 5.14:Effect of the different mulching treatments on the relation between plant height and number of green leaves per sunflower plant at 30 DAP during the 2000/2001 growing season

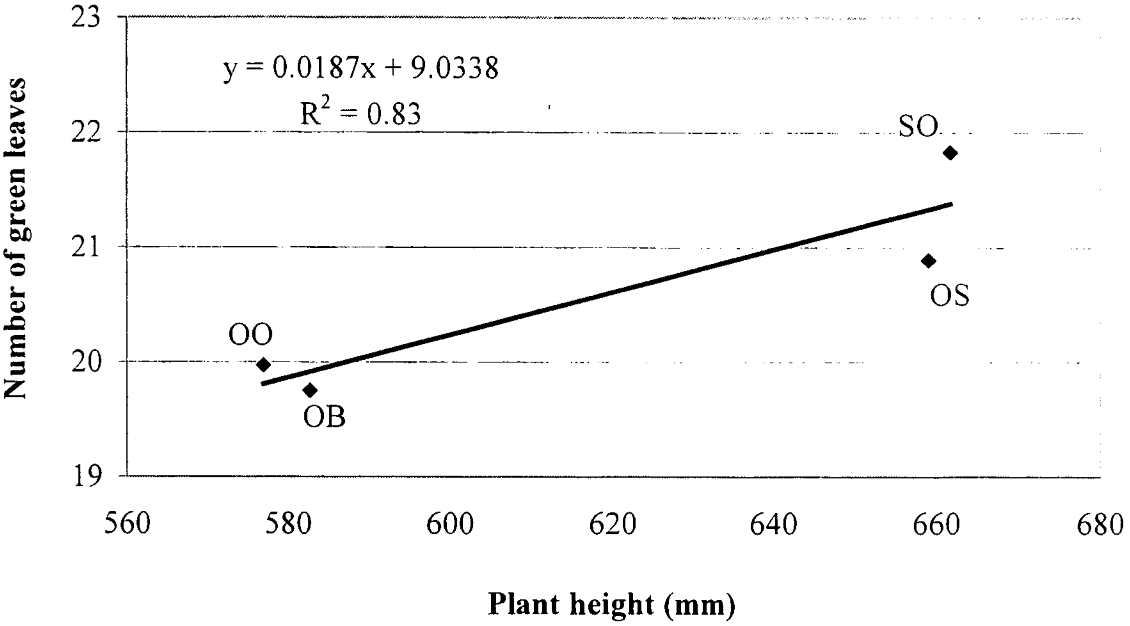

FIGURE 5.15:Effect of the different mulching treatments on the relation between plant height and number of green leaves per sunflower plant at 40 DAP during the 2000/2001 growing season

5.2.5 Effect of mulching techniques on yield and harvest index

5.2.5.1 Aerial biomass

Mulching treatments showed a significant effect on the aerial biomass during both seasons (Appendix 5.6.2-5.6.3). During the 1999/2000 growing season, the biomass yield in OO, OS and SO treatment plots were respectively 36%, 35% and 25% higher than the control (mean=5296 kg.ha^{-1}). During 2000/2001, the biomass in the OO, OS and SO were respectively 33%, 44% and 45% higher than in the control (mean=4101 kg.ha^{-1}). Except for the biomass yield in the OO technique during 2000/2001, mulching treatments were higher compared to the control but there were no differences among SO, OO and OS (Table 5.8).

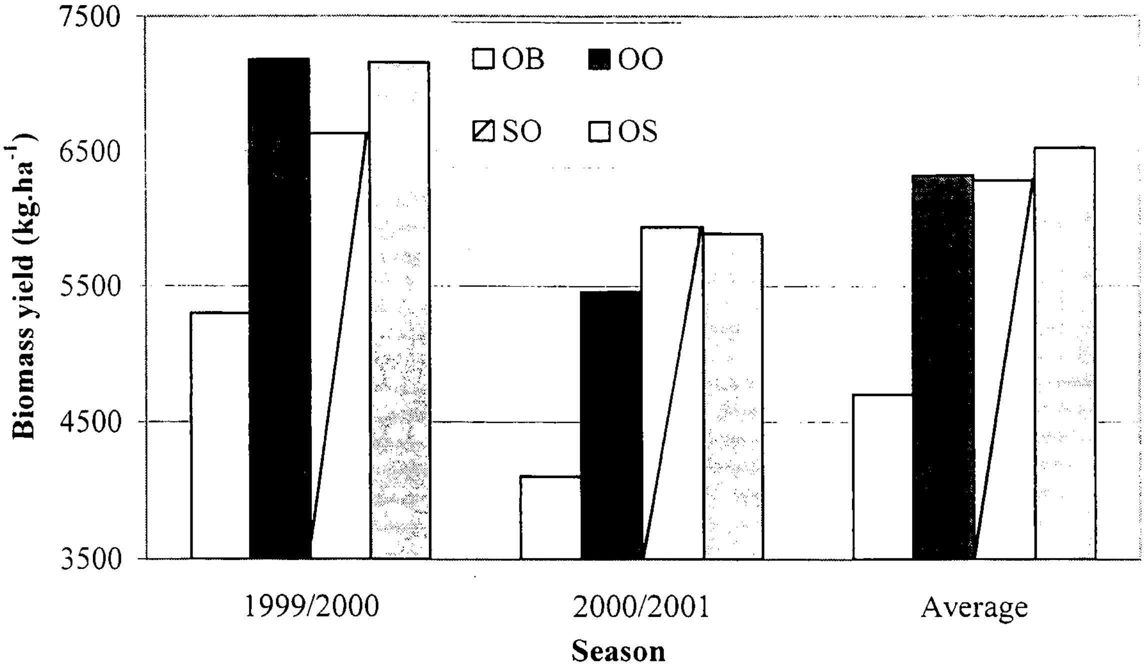

FIGURE 5.16: Effect of mulching treatments on the aerial biomass yield of sunflower during the 1999/2000 and 2000/2001 growing seasons

Statistical analysis for biomass yield over seasons also showed that the main effect of mulching treatments and seasons had a significant influence, but the interaction between mulching and seasons had no significant effect on biomass (Appendix 5.6.1). The two seasons average biomass in the OO, OS and SO were respectively, 34%, 39% and 34% higher than in the control (mean=4699kg.ha^{-1}) (Table 5.8). From Figure 5.16, it is evident that the biomass yield was lower during 2000/2001 than 1999/2000. Although the interaction between techniques and seasons was not significant, the OO and the control treatments tended to produce a lower biomass than the OS and SO. The relative biomass yields was higher in OS and SO and lower in OO treatment plots during the unfavourable 2000/2001 than during 1999/2000 (Table 5.8).

5.2.5.2 Grain yield

Mulching treatments showed a significant effect on grain yield during 1999/2000, but had no significant influence during 2000/2001 (Appendix 5.7.2-5.7.3). During 1999/2000, the seed yield of OO, OS and SO were respectively 23%, 29% and 24% higher than in the control

(Mean=1592kg.ha^{-1})). During this season all mulching treatments yields were significantly different from the control, but there were no significant differences among OO, SO and OS (Table 5.9). Although the differences between treatments during 2000/2001 were not significant, the OO, OS and SO, respectively showed 6%, 13% and 7% higher seed yields than the control (Mean=1526kg.ha^{-1}).

Statistical analysis over seasons also showed that the main effect of mulching technique treatments and seasons had a significant influence on grain yield (Appendix 5.7.1). The mean grain yield was reduced significantly by 14% during the unfavourable 2000/2001 season. This seasonal main effect showed no significant interaction with mulching, and the yield reduction was almost the same in all treatments. The seed yield over seasons was 15%, 21% and 16% higher in OO, OS and SO, respectively than in the control (mean=1559 kg.ha^{-1}) and the differences were statistically significant (Table 5.9).

5.2.5.3 Harvest index

Mulching treatments showed no significant differences for harvest index (HI) during both seasons (Appendix 5.8.2-5.8.3). During both seasons the mulching treatments showed a lower HI than the control. Particularly, during the second season, the HI of SO, OS and OO were respectively 23%, 22% and 19 lower than the control. The difference between treatments for HI was significant over seasons (Appendix 5.8.1). This analysis showed that the two seasons average harvest index in the OO technique was significantly lower than the control, but it showed no significant differences for other comparisons (Table 5.18).

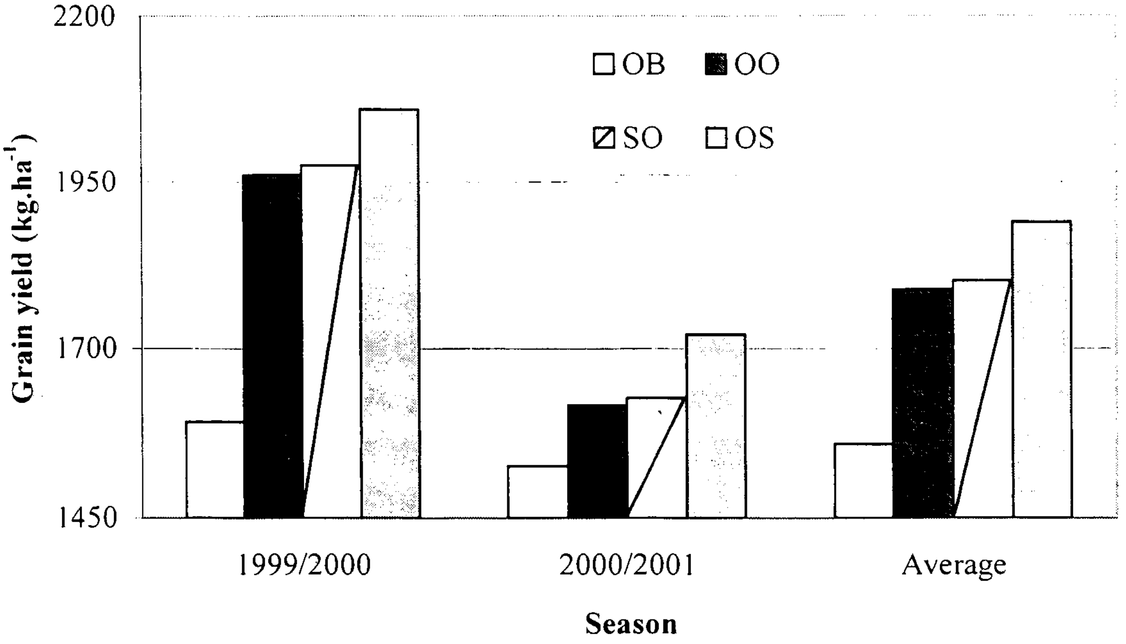

FIGURE 5.17: Effect of mulching treatments on grain yield of sunflower during the 1999/2000 and 2000/2001 growing seasons

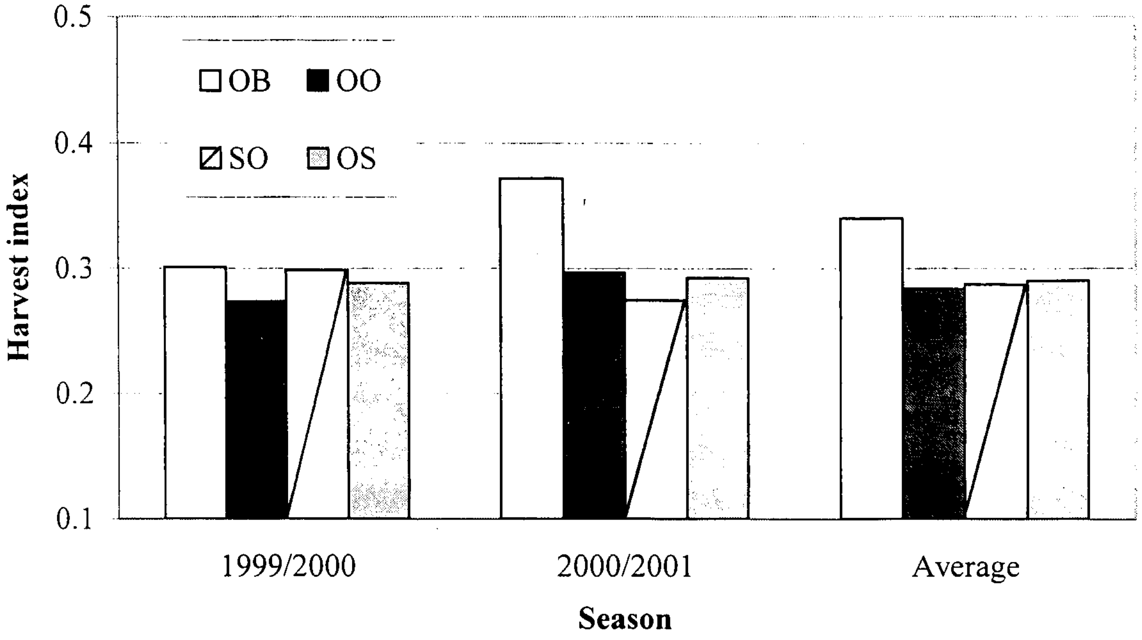

FIGURE 5.18: Effect of mulching treatments on harvest index of sunflower during the 1999/2000 and 2000/2001 growing seasons

TABLE 5.8: Effect of different mulching treatments on the mean aerial biomass yield (MBY) and relative biomass (RBY) of sunflower during the 1999/2000 and 2000/2001 growing seasons (defined as the ratio of the biomass yield in mulching technique treatments to the control in percentage)

Treatments	1999/2000		2000/2001		Average	
	MBY (kg.ha^{-1})	RBY (%)	MBY (kg.ha^{-1})	RBY (%)	MBY (kg.ha^{-1})	RBY (%)
OS	7152^{A}	135	5891^{A}	144	6522^{A}	139
OO	7177^{A}	136	5457^{AB}	133	6317^{A}	134
SO	6623^{A}	125	5938^{A}	145	6280^{A}	134
OB (Control)	5296^{B}	100	4101^{B}	100	4699^{B}	100
Mean	6562		5347		5954	
LSD$(0.05)_T$	939		1415		728.2	

Means in the same column followed by the same letter are not significant at α=0.05

NS=not significant

TABLE 5.9: Effect of different mulching treatments on the mean grain yield (MGY) and relative grain yield (RGY) of sunflower during the 1999/2000 and 2000/2001 growing seasons (RGY is defined as for RBY)

Treatment	1999/2000		2000/2001		Average	
	MGY (kg.ha^{-1})	RSY (%)	MGY (kg.ha^{-1})	RSY (%)	MGY (kg.ha^{-1})	RSY (%)
OS	2059^{A}	129	1721	113	1890^{A}	121
OO	1961^{A}	123	1616	106	1788^{A}	115
SO	1975^{A}	124	1628	107	1801^{A}	116
OB (Control)	1592^{B}	100	1526	100	1559^{B}	100
Mean	1897		1623		1760	
LSD$(0.05)_{T}$	306		NS		162	

Means in the same column followed by the same letter are not significant at $\alpha=0.05$

NS=not significant

TABLE 5.10: Effect of different mulching treatments on the harvest index of sunflower during the 1999/2000 and 2000/2001 growing seasons

Treatments	Harvest index		
	1999/2000	2000/2001	Average
OS	0.29	0.29	0.29^{AB}
OO	0.27	0.30	0.28^{B}
SO	0.30	0.27	0.29^{AB}
OB	0.30	0.37	0.34^{A}
$LSD(0.05)_T$	NS	NS	0.05

Means in the same column followed by the same letter are not significant at $\alpha=0.05$
NS=not significant

5.3 CONCLUSION

A two-year study was conducted to determine the effect of mulching techniques, which were applied to both the basin and runoff strip, on growth and yield response of sunflowers produced using an in-field water harvesting crop production technique. During the two seasons plant height and stem thickness at maturity were measured to determine whether growth was stimulated or inhibited. Plant height and stem thickness growth rates and leaf area index were determined during 2000/2001 to evaluate early growth response of sunflower to mulching treatments. The aerial biomass and grain yield was also assessed. The soil water regime created by the different mulches was evaluated from data obtained from ARC-ISCW Glen group.

The two seasons were different with respect to the amount and distribution of the rainfall. The 1999/2000 growing season were characterised by early onset and well-distributed rainfall. In contrast, the 2000/2001 season is characterised by late onset and skewed distribution of rain towards the end of the growing season. The evaporative demand of the atmosphere was higher during 2000/2001 than 1999/2000. These differences between the two seasons provided the opportunity to evaluate crop response to mulching treatments under both favourable and less favourable conditions of water supply.

The beneficial effect of organic or stone mulch placement on the runoff strip over the control was shown by the higher amount of soil water conserved in the soil profile of the runoff strip. The additional amounts of soil water conserved in the soil profile of the runoff strip by applying stone and organic mulches were respectively 4% and 7% during 1999/2000 and 4% and 3% during 2000/2001. Except for the organic mulch during 2000/2001, no significant differences were found between mulch placement and bare runoff strips for soil water content in the basins. Experimental results, on the other hand, showed that organic and stone mulch placement on the runoff strip reduced runoff concentration to the basin by 84% and 45%, respectively, during 1999/2000 and 90% and 29% during 2000/2001 compared to the bare runoff strips (Botha *et al*, 2001). This indicated that the storage efficiency was lower when basins are combined with bare than mulched runoff strips.

Results on growth and yield parameters of sunflower showed that mulching techniques applied to both the basin and runoff strips were beneficial, and lead to higher growth and grain yields than mulch placement in basins only. The average plant height over two seasons in SO, OS and OO were, respectively 14%, 11% and 11% higher than in OB (control). Although the effect of mulching on the stem thickness was not significant over seasons, mean stem thickness was 13%, 11% and 9% higher in OS, SO and OO, respectively, than in the control. As a result, relative to the control, the aerial biomass and seed yield was increased by using these techniques. The pooled mean biomass yield in OS, SO and OO were, respectively 39%, 34% and 34% higher than in the control. Similarly, the seed yields of OS, SO and OO were respectively 21%, 16% and 15% higher than in the control.

The harvest index was generally lower in SO, OO and OS than in the control. However, significant differences over seasons were found only between OO and the control. The average harvest index over two seasons in OO was 18% lower than in the control. This might be because of the higher biomass yield in OO technique during the favourable 1999/2000 season.

Although the differences were not significant, the OO technique showed lower stem growth, biomass and grain yield than both OS and SO during the unfavourable 2000/2001 season. During the favorable 1999/2000, this technique (OO) had a higher biomass, but a lower grain yield that led to a lower harvest index than OS and SO. Although there was no significant interaction between mulching and season, the effect of the OO technique on growth and yield appeared less stable than in SO and OS.

From these results, it is concluded that the SO and OS techniques promoted growth and seed yield of sunflowers under an in-field water harvesting crop production technique.

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSION

Water is a major factor limiting dryland crop production in some semi-arid areas of the Free State Province of South Africa, because of low and erratic rainfall aggravated by high water losses through Es, R and D. For these areas, the ARC-ISCW research team at Glen developed a crop production technique that combined the advantages of rain water harvesting, basin tillage and mulching (WHBM) to enable farmers to increase production for selected crops such as maize and sunflower grown under conditions of limited precipitation (Hensley *et al.*, 2000). With this crop production technique, mulches are applied in the basins to minimize Es. However, the 2 m no-till runoff strips between crop rows are bare to promote runoff to the basins. High water losses by Es and soil movement towards the basins are inevitable consequences of bare runoff strips, and these may adversely affect growth and yield, in the short term, and hinder the sustainability of the production technique, in the long-term, because of the erosion hazard.

Application of mulches in both the basins and runoff strips can minimise water losses by Es and soil movement to the basins, thereby increasing the growth and yield of crops. However, mulches can also reduce runoff concentration to the basins and lower the amount of water stored in the soil profile of the basins, thus reducing the effectiveness of the technique. The primary reason of conducting this study was to evaluate these effects of mulching on crop responses.

A two year experiment was conducted on a heavy clay soil, to test whether mulch application in both the basins and runoff strips has an effect on growth and yield responses of maize and sunflower.

The two experimental seasons, 1999/2000 and 2000/2001, were different with respect to the amount and distribution of the rainfall and the evaporative demand of the atmosphere. The 1999/2000 season was characterised by an early onset of the rain and relatively high and well distributed rainfall throughout the growing season. In contrast. the rainfall during the 2000/2001 growing season was characterised by a late onset and was lower and erratic distributed than during the previous season. The evaporative demand of the atmosphere, as evaluated from a class A-pan, was higher during 2000/2001 (mean=5mm.d^{-1}) than 1999/2000 (mean=4mm.d^{-1}). The differences between the two seasons offered the opportunity to evaluate the effect of mulching on crop responses during both favourable and less favourable conditions of water supply.

During both seasons, soil water measurements showed the decrease of significant differences between OS (organic mulch in the basins and stone mulch on the runoff strip) and OB (organic mulch in the basin and bare runoff strip) in terms of soil water storage in the basins. This founding applied to both maize and sunflowers. The absence of significant differences between OS and the control demonstrated that stone mulch placement on the runoff strips had no negative implication on the water harvesting process. Runoff measurements during the same seasons however showed that runoff concentration was lower from stone mulched than bare runoff strips (Botha *et al.*, 2001).

The OO technique, on the other hand, had a significant lower soil water content in the basins during the 1999/2000 growing season for maize plots and during 2000/2001 for sunflower plots than in the control. During both seasons, the comparison between OO and SO showed no significant differences in soil water storage in the basins, irrespective of crop type. These results indicated that organic mulch placement on the runoff strip may have a higher interference during the water harvesting process unlike stone mulch placement, but organic mulching has the same effect as stone when it is applied in the basins.

The beneficial effect of organic or stone mulch placement on the runoff strip was demonstrated clearly by the soil water content measurement in the runoff strips. The OS technique showed significantly higher soil water content in the runoff strips than the control. This result was consistent during the two seasons, irrespective of crop type. Though the differences were not always significant, the OO technique also showed a significantly higher soil water content in the runoff strips than the control. These results demonstrated that both organic and stone mulch placements on the runoff strips assisted in minimizing water losses by Es, and hence increase RUE. This result is consistent with work done by Ojasvi *et al.* (1999) who measured an increase in soil water content when lining the catchment with stone or marble.

Maize growth parameters showed that with the exception of stem thickness during the 1999/2000 growing season, mulching treatments had no significant differences on plant height and stem thickness within seasons. However, plants in OS, SO and OO tended to be taller and thicker than in the control during both seasons. As a result of this consistent effect, significant differences between treatments were found in the over season analysis. The two seasons average plant height in OS and SO was significantly taller than in the control, whereas, the stem thickness was significantly thicker only in OS compared to the control. The OO technique, on the other hand, showed no significant difference for both plant height and stem thickness over seasons.

The growth stimulating effect of OS, SO and OO was also reflected in the biomass and grain yield production of maize. Generally, the biomass and grain yield was higher in OS, SO and OO than the control. The OS technique was significantly superior in biomass production than all the other treatments over seasons. The SO and OO treatments also showed a significantly higher biomass than the control. Significant differences for seed yield of maize over seasons were only found between OS and the control.

Applications of mulches in both the basins and runoff strips consistently resulted in higher growth and yield than mulch placement in the basins only. Significant responses within seasons were found during the unfavourable 2000/2001 season. During this season significantly higher biomass and grain yield were found in the OS treatment than in the control. This indicated that maize responded better to the effect of mulching during conditions of low water supply. Although the experimental conditions were not exactly the same, Allmaras & Nelson (1971) also found that mulch placement between crop rows increased early growth and subsequent yield of maize during seasons with high temperatures and low water supply. These authors, however, found maize growth and yield to be reduced by interrow mulching during seasons of low temperature and high water availability. Although the soil water availability was high during 1999/2000, growth and yield reductions were not observed in this experiment. Statistical analysis over season revealed that the interaction between mulching techniques and seasons had no significant influence on any of the growth and yield parameters of maize and sunflowers. This result revealed that the effect of mulching treatments did not vary during the two seasons.

The growth and yield responses of sunflowers were similar to those of maize, both within and over seasons. This was regarded to be an advantage, because it allows farmers to use the same technique in a maize-sunflower rotation. Unlike maize, sunflowers showed a significant positive response to runoff strip mulching during the favorable 1999/2000 growing season. During this season, the plant height was significantly higher in OS and SO than in the control. Both the biomass and grain yields were significantly higher in OS, SO and OO than the control. These differences in the degree of response between the two crops might be due to late planting (27/01/00) and higher water extraction capacity of sunflower than maize (Dardanelli, *et al.*, 1997), which led sunflower to a progressive water deficit starting from 11 DAP. The growth and yield variations between treatments during this season coincided with the differences between treatments for total water content in the root zone from 11 DAP to maturity. During this period of growth, treatments also showed significant differences in total soil water content in maize plots, but these occurred at a higher available soil water level (mean total available soil water of 91%).

In this experiment it was observed that growth and yield responses of maize and sunflower were insensitive to the type of mulch in the basins and runoff strips. Organic mulch on the runoff strips (OO), however inhibited stem growth and reduced LAI relative to the control from planting to 30 DAP (one year data). Although this growth inhibition was not manifested in the final biomass and grain yield, it may indicate that the lower soil water content of the basins created by this mulching technique may not be favourable for early growth of maize and sunflower when compared to stone mulch placement on the runoff strips.

From the results of maize and sunflower, it is concluded that the application of mulches in both the basins and runoff strips had a beneficial effect on growth and yields. Although the type of mulch showed no significant influence on the biomass and seed yield production capacity of maize and sunflower, organic mulch placement on the runoff strip (OO) may not be favourable for early growth and development, probably, because of its effect on the soil water regime of the basin. Thus it is better to practice the OS technique to obtain reasonable yields.

Finally, knowledge on the effect of these treatments on root growth and lateral distribution was not generated. This knowledge may be essential to determine appropriate fertilizer placement methods. Since a considerable proportion of the soil water is found in the runoff strips, the nutritional status of the runoff strips might be important, particularly during the later growth stages of maize and sunflower. This needs to be studied.

SUMMARY

It is well known that in semi-arid areas the growth and yield response of crops depend largely on the amount of rainwater stored in the root zone. Integrating rainwater harvesting and mulching may be an approach to maximize water storage and to minimize water losses through evaporation and runoff. This may improve crop growth and yield. A two year study was conducted to determine the effect of an in-field water harvesting with mulch application in both the basins and runoff strips on growth and yield response of maize (*Zea mays* L.) and sunflower (*Helianthus annus* L.).

The experiment was conducted at the Glen experimental farm, 25 km north Bloemfontein ($28^0 55'13''$ latitude and $26^0 21'12''$ longitude) on a heavy clay soil (Bonheim soil form). It consisted of four mulching treatments. Three of the mulching treatments were a combination of rainwater harvesting basin (RWHB) with organic mulch in the basin and organic (OO) or stone (OS) mulch on the runoff strip or bare runoff strips (OB). The fourth treatment was the combination of RWHB with stone mulch in the basin and organic mulch on the runoff strips (SO). The organic mulch was a mixture of maize and sunflower stalks at the rate of 8 t.ha^{-1}. The size of the stones in the mulch was approximately 10 to 15 cm in diameter, and they covered 70-80 % of the soil surface.

Two adjacent, 24 m x 36 m (288 m^2), experimental sites were used to accommodate the four treatments in a completely randomized block design with three replications. Maize, variety Phb 33-V08 and sunflower, variety SNK 74 were planted in a tramline with spacing 1m x 2m on the 7th and 28th of January 2000 and the 5th and 4th of January 2001, respectively. During the two seasons, maize and sunflower were grown in rotation, whereas treatments were maintained in place.

The soil water content, rainfall and evaporation demand of the atmosphere were evaluated from the data obtained from ARC-ISCW (Glen). Plant height and stem thickness at maturity were measured to determine whether growth was stimulated or inhibited. Stem growth rates

and leaf area indexes were determined during 2000/2001 to evaluate early growth responses of the tested crops. The aerial biomass and grain yield of maize and sunflower were also assessed.

The two seasons were different with respect to the amount and distribution of the rainfall, soil water patterns and evaporative demand of the atmosphere. The 1999/2000 growing season was more favourable for crop growth and yield than 2000/2001.

Results of soil water measurements showed that the applications of stone or organic mulch on the runoff strips were beneficial to conserve water in the soil profile of the runoff strips irrespective of crop type. Although it is not always significant, organic mulch placement on the runoff strip reduced the amount of water stored in the basins. This effect was not observed when the runoff strips were mulched with stones.

Although not statistically significant, the growth and yield of maize were higher in OS, SO and OO treatments than in the control (OB). Maximum biomass and grain yield over seasons was obtained in the OS. All plant parameters studied showed that the interaction between mulching and seasons had no significant influence on the growth and yield of maize. Although differences were not always statistically significant, the OS technique seemed to be the best for crop growth and yield. Similar results were obtained for sunflowers, which was regarded as an advantage for farmers enabling them to exercise maize-sunflower rotation without changing mulching practices.

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APPENDIX 4

APPENDIX 4.1.1a: Analysis of variance of total soil moisture content (mm/1200mm soil depth) between 60-110 DAP during the 1999/2000 growing season as influenced by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1082.88	180.48	33.80	0.0001
Error	9	48.06	5.34		
Corrected Total	15	1130.94			
		R-Square	C.V	Root MSE	Mean
		0.957502	0.616138	2.310904	75.0625

Source	DF	SS	MS	F Value	Pr > F
REP (DAP)	3	453.69	151.23	28.32	0.0001
Mulching	3	629.19	209.73	39.27	0.0001

APPENDIX 4.1.1b: Analysis of variance of soil moisture storage in the soil profile of the basins (mm/1200mm soil depth) between 60-110 DAP during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	4356.38	726.06	11.85	0.0008
Error	9	551.56	61.28		
Corrected Total	15	4907.94			
		R-Square	C.V.	Root MSE	Mean
		0.8873	2.1012	7.8282	372.56

Source	DF	SS	MS	F Value	Pr > F
DAP	3	1299.19	433.06	7.07	0.0097
Mulching	3	3057.19	1019.06	16.63	0.0005

APPENDIX 4.1.1c: Analysis of variance of soil moisture storage in the soil profile of the runoff strips (mm/1200mm soil depth) between 60-110 DAP during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1662.375000	277.062500	6.52	0.0068
Error	9	382.562500	42.506944		
Corrected Total	15	2044.937500			
		R-Square	C.V.	Root MSE	Mean
		0.812922	1.729086	6.519735	377.0625

Source	DF	SS	MS	F Value	Pr > F
DAP	3	360.187500	120.062500	2.82	0.0992
Mulching	3	1302.187500	434.062500	10.21	0.0030

APPENDIX 4.1.2a: Analysis of variance of total soil moisture content (mm/1200mm soil depth) between 3-88 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	24004.56	2400.46	28.43	0.0001
Error	21	1773.16	84.44		
Corrected Total	31	25777.72			
		R-Square	C.V.	Root MSE	Mean
		0.931214	2.660319	9.188907	345.4063

Source	DF	SS	MS	F Value	Pr > F
DAP	7	20598.47	2942.64	34.85	0.0001
Mulching	3	3406.09	1135.36	13.45	0.0001

APPENDIX 4.1.2b: Analysis of variance of soil moisture storage in the soil profile of the basins (mm/1200mm soil depth) between 3-88 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	33579.50	3357.95	33.26	0.0001
Error	21	2120.00	100.95		
Corrected Total	31	35699.50			
		R-Square	C.V.	Root MSE	Mean
		0.940615	2.871742	10.04751	349.8750

Source	DF	SS	MS	F Value	Pr > F
DAP	7	33214.50	4744.93	47.00	0.0001
Mulching	3	365.00	121.67	1.21	0.3322

APPENDIX 4.1.2c: Analysis of variance of soil moisture storage in the soil profile of the runoff strips (mm/1200mm soil depth) between 3-88 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	24077.06250	2407.70625	10.05	0.0001
Error	21	5032.90625	239.66220		
Corrected Total	31	29109.96875			
		R-Square	C.V.	Root MSE	Mean
		0.827107	4.546974	15.48103	340.4688

Source	DF	SS	MS	F Value	Pr > F
DAP	7	11808.21875	1686.88839	7.04	0.0002
TR	3	12268.84375	4089.61458	17.06	0.0001

APPENDIX 4.2.1: Over season analysis of variance of maize plant height (mm) during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	240405.0000	21855.0000	2.37	0.0767
Error	12	110601.5000	9216.7917		
Corrected Total	23	351006.5000			
		R-Square 0.684902	C.V. 5.653121	Root MSE 96.00412	Mean 698.250

Source	DF	SS	MS	F Value	Pr > F
Mulching (M)	3	197167.5000	65722.5000	7.13	0.0053
Season (S)	1	17280.6667	17280.6667	1.87	0.1960
REP(S)	4	15047.8333	3761.9583	0.41	0.7994
S*M	3	10909.0000	3636.3333	0.39	0.7593

APPENDIX 4.2.2: Analysis of variance of maize plant height (mm) during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	96181.58333	19236.31667	2.91	0.1132
Error	6	39717.33333	6619.55556		
Corrected Total	11	135898.91667			
		R-Square 0.707744	C.V. 4.716332	Root MSE 81.36065	Mean 1725.083

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	87040.91667	29013.63889	4.38	0.0588
REP	2	9140.66667	4570.33333	0.69	0.5372

APPENDIX 4.2.3a: Analysis of variance of maize plant height (mm) during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	126942.75	25388.55	2.15	0.1894
Error	6	70884.167	1814.028		
Corrected Total	11	197826.917			
		R-Square	C.V.	Root MSE	Mean
		0.641686	6.503008	108.6924	1671.417

Source	DF	SS	MS	F Value	Pr F
Mulching	3	121035.5833	40345.1944	3.42	0.0936
REP	2	5907.1667	2953.5833	0.25	0.7865

APPENDIX 4.2.3b: Analysis of variance of height growth rate ($mm.d^{-1}$) from planting to 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.74195833	0.14839167	4.18	0.0554
Error	6	0.21293333	0.03548889		
Corrected Total	11	0.95489167			
		R-Square	C.V.	Root MSE	Mean
		0.777008	2.830374	0.188385	6.655833

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.62009167	0.20669722	5.82	0.0328
REP	2	0.12186667	0.06093333	1.72	0.2573

APPENDIX 4.2.3c: Analysis of variance of height growth rate (mm.d^{-1}) from 30 to 40 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	17.42110833	3.48422167	1.56	0.2990
Error	6	3.36258333	2.22709722		
Corrected Total	11	30.78369167			
		R-Square	C.V.	Root MSE	Mean
		0.565920	4.387855	1.492346	4.01083

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	14.03069167	4.67689722	2.10	0.2017
REP	2	3.39041667	1.69520833	0.76	0.5075

APPENDIX 4.2.3d: Analysis of variance of height growth rate (mm.d^{-1}) from 40 to 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	139.3716667	27.8743333	3.23	0.0930
Error	6	51.8083333	8.6347222		
Corrected Total	11	191.1800000			
		R-Square	C.V.	Root MSE	Mean
		0.729008	11.17296	2.938490	6.30000

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	135.2866667	45.0955556	5.22	0.0413
REP	2	4.0850000	2.0425000	0.24	0.7964

APPENDIX 4.3.1: Over seasons analysis of variance of maize stem thickness (mm) at maturity during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	90.31646250	8.21058750	9.44	0.0003
Error	12	10.44030000	0.87002500		
Corrected Total	23	100.75676250			
		R-Square	C.V.	Root MSE	Mean
		0.896381	3.730446	0.932751	5.00375

Source	DF	SS	MS	F Value	Pr > F
Mulching (M)	3	13.74647917	4.58215972	5.27	0.0150
Season (S)	1	67.50260417	67.50260417	77.59	0.0001
REP(CS)	4	3.12203333	0.78050833	0.90	0.4955
S*M	3	5.94534583	1.98178194	2.28	0.1317

APPENDIX 4.3.2: Analysis of variance of maize stem thickness (mm) as affected by the different mulching treatments during the 1999/2000 growing season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	17.93884167	3.58776833	3.73	0.0701
Error	6	5.77325000	0.96220833		
Corrected Total	11	23.71209167			
		R-Square	C.V.	Root MSE	Mean
		0.756527	3.676505	0.980922	26.68083

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	16.73482	5.57827500	5.80	0.0332
REP	2	1.204016	0.60200833	0.63	0.5665

APPENDIX 4.3.3a: Analysis of variance of maize stem thickness (mm) as affected by the different mulching treatments during the 2000/2001 growing season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	4.87501667	0.97500333	1.25	0.3900
Error	6	4.66705000	0.77784167		
Corrected Total	11	9.54206667			
		R-Square	C.V.	Root MSE	Mean
		0.510897	3.780880	0.881953	23.32667

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	2.95700000	0.985667	.27	0.3670
REP	2	1.91801667	0.959008	1.23	0.3560

APPENDIX 4.3.3b: Analysis of variance of stem thickness growth rate ($mm.d^{-1}$) from planting to 30 DAP as affected by the different mulching treatments during the 2000/2001 growing season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.00150000	0.00030000	1.69	0.2703
Error	6	0.00106667	0.00017778		
Corrected Total	11	0.00256667			
		R-Square	C.V.	Root MSE	Mean
		0.584416	4.469274	0.013333	0.298333

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.00123333	0.00041111	2.31	0.1758
REP	2	0.00026667	0.00013333	0.75	0.5120

APPENDIX 4.3.3c: Analysis of variance of stem thickness growth rate (mm.d^{-1}) from 30 to 40 DAP as affected by the different mulching treatments during the 2000/2001 growing season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.08622500	0.01724500	2.34	0.1654
Error	6	0.04426667	0.00737778		
Corrected Total	11	0.13049167			
		R-Square	C.V.	Root MSE	Mean
		0.660770	5.710404	0.085894	504167

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.06595833	0.02198611	2.98	0.1183
REP	2	0.02026667	0.01013333	1.37	0.3228

APPENDIX 4.3.3d: Analysis of variance of stem thickness growth rate (mm.d^{-1}) from 40 to 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.00141667	0.00028333	0.40	0.8333
Error	6	0.00425000	0.00070833		
Corrected Total	11	0.00566667			
		R-Square	C.V.	Root MSE	Mean
		0.250000	61.41815	0.026615	0.043333

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.00060000	0.00020000	0.28	0.8366
REP	2	0.00081667	0.00040833	0.58	0.5902

APPENDIX 4.4.1a: Analysis of variance of leaf area index at 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.00050833	0.00010167	3.33	0.0878
Error	6	0.00018333	0.00003056		
Corrected Total	11	0.00069167			
		R-Square	C.V.	Root MSE	Mean
		0.734940	9.342605	0.005528	0.059167

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.00029167	0.00009722	3.18	0.1059
REP	2	0.00021667	0.00010833	3.55	0.0963

APPENDIX 4.4.1b: Analysis of variance of leaf area index at 40 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.01527500	0.00305500	0.36	0.8582
Error	6	0.05075000	0.00845833		
Corrected Total	11	0.06602500			
		R-Square	C.V.	Root MSE	Mean
		0.231352	34.38101	0.091969	0.267500

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.01162500	0.00387500	0.46	0.7215
REP	2	0.00365000	0.00182500	0.22	0.8119

APPENDIX 4.4.1c: Analysis of variance of leaf area index at 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.08071667	0.01614333	5.91	0.0257
Error	6	0.01638333	0.00273056		
Corrected Total	11	0.09710000			
		R-Square	C.V.	Root MSE	Mean
		0.831274	5.048765	0.052255	1.035000

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.06056667	0.02018889	7.39	0.0193
REP	2	0.02015000	0.01007500	3.69	0.0902

APPENDIX 4.4.2a: Analysis of variance of number of green leaves at 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.39551667	0.07910333	5.88	0.0261
Error	6	0.08075000	0.01345833		
Corrected Total	11	0.47626667			
		R-Square	C.V.	Root MSE	Mean
		0.830452	2.393605	0.116010	4.846667

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.35180000	0.11726667	8.71	0.0132
REP	2	0.04371667	0.02185833	1.62	0.2731

APPENDIX 4.4.2b: Analysis of variance of number of green leaves at 40 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.21651667	0.04330333	3.25	0.0919
Error	6	0.07995000	0.01332500		
Corrected Total	11	0.29646667			
		R-Square	C.V.	Root MSE	Mean
		0.730324	2.231327	0.115434	5.173333

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.12920000	0.04306667	3.23	0.1031
REP	2	0.08731667	0.04365833	3.28	0.1092

APPENDIX 4.4.2c: Analysis of variance of number of green leaves at 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3.18369167	0.63673833	18.28	0.0014
Error	6	0.20900000	0.03483333		
Corrected Total	11	3.39269167			
		R-Square	C.V.	Root MSE	Mean
		0.938397	1.648857	0.186637	11.31917

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	1.08982500	0.36327500	10.43	0.0085
REP	2	2.09386667	1.04693333	30.06	0.0007

APPENDIX 4.4.3a: Analysis of variance of leaf area (mm^2) at 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	85276241.17	17055248.23	5.72	0.0278
Error	6	17898660.50	2983110.08		
Corrected Total	11	103174901.67			
		R-Square	C.V.	Root MSE	Mean
		0.826521	6.301732	1727.168	27407.83

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	66144803.00	22048267.67	7.39	0.0194
REP	2	19131438.17	9565719.08	3.21	0.1129

APPENDIX 4.4.3b: Analysis of variance of leaf area (mm^2) at 40 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	3091011337	618202267	0.36	0.8616
Error	6	10423616589	1737269432		
Corrected Total	11	13514627926			
		R-Square	C.V.	Root MSE	Mean
		0.228716	34.31127	41680.56	121477.8

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	2446292431	815430810	0.47	0.7145
REP	2	644718906	322359453	0.19	0.8352

APPENDIX 4.4.3c: Analysis of variance of leaf area (mm^2) at 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	16014626403	3202925281	5.64	0.0287
Error	6	3409373740	568228957		
Corrected Total	11	19424000144			
		R-Square	C.V.	Root MSE	Mean
		0.824476	5.068109	23837.55	470344.2

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	11860585596	3953528532	6.96	0.0222
REP	2	4154040807	2077020404	3.66	0.0916

APPENDIX 4.5.1: Over season analysis of variance of maize height-thickness ratio during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	500.5960000	45.5087273	2.53	0.0627
Error	12	215.7257333	17.9771444		
Corrected Total	23	716.3217333			
		R-Square	C.V.	Root MSE	Mean
		0.698842	6.160325	4.239946	68.82667

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	69.4316333	23.1438778	1.29	0.3234
Season (CS)	1	259.9100167	259.9100167	14.46	0.0025
REP(CS)	4	95.2168667	23.8042167	1.32	0.3164
S*M	3	76.0374833	25.3458278	1.41	0.2879

APPENDIX 4.5.2: Analysis of variance of plant height-stem thickness ratio during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	74.4236	14.8847	0.80	0.5903
Error	6	112.334	18.7224		
Corrected Total	11	186.758			
		R-Square	C.V.	Root MSE	Mean
		0.398502	6.602415	4.326948	65.53583

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	12.77455	4.25818611	0.23	0.8741
REP	2	61.64906	30.82453333	1.65	0.2692

APPENDIX 4.5.3: Analysis of variance of maize plant height-stem thickness ratio during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	166.2623583	33.2524717	1.93	0.2233
Error	6	103.3908667	17.2318111		
Corrected Total	11	269.6532250			
		R-Square	C.V.	Root MSE	Mean
		0.616578	5.756053	4.151122	72.11750

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	132.6945583	44.2315194	2.57	0.1503
REP	2	33.5678000	16.7839000	0.97	0.4302

APPENDIX 4.5.4a: Analysis of variance for the linear relation between maize plant height and stem thickness at maturity during the 1999/2000 growing season as affected by the different mulching treatments

Sources	DF	SS	MS	F	P>F
Regression	1	5.20	5.20	28.14	0.033
Residual	2	0.37	0.18		
Total	3	5.57			

APPENDIX 4.5.4b: Analysis of variance for the linear relation between maize plant height and stem thickness at maturity during the 2000/2001 growing season as affected by the different mulching treatments

	DF	SS	MS	F	P>F
Regression	1	0.6008	0.6007	3.215	0.215
Residual	2	0.3738	0.1869		
Total	3	0.9745			

APPENDIX 4.5.4c: Analysis of variance for the linear relation between maize plant height and stem thickness from planting to 70 DAP during the 2000/2001 growing season

	DF	SS	MS	F	P>F
Regression	1	397.432	397.43	14.93	0.0031
Residual	10	266.253	26.625		
Total	11	663.685			

APPENDIX 4.5.5a: Analysis of variance for the linear relation between maize plant height and number of green leaves from planting to 70 DAP during the 2000/2001 growing season

	DF	SS	MS	F	P>F
Regression	1	99.562	99.562	136.04	3.81541E-07
Residual	10	7.3186	0.7319		
Total	11	106.88			

APPENDIX 4.5.5b: Analysis of variance for the linear relation between maize plant height and number of green leaves at 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

	DF	SS	MS	F	P>F
Regression	1	0.09795	0.098	11.51	0.07697
Residual	2	0.01702	0.009		
Total	3	0.11497			

APPENDIX 4.5.5c: Analysis of variance for the linear relation between maize plant height and number of green leaves 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

	DF	SS	MS	F	P>F
Regression	1	0.3072	0.3072	10.636	0.0825
Residual	2	0.0578	0.0289		
Total	3	0.3650			

APPENDIX 4.6.1: Over season analysis of variance of pooled mean for aerial biomass production (kg.ha^{-1}) during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	18897608.23	1717964.38	5.00	0.0049
Error	12	4120598.05	343383.17		
Corrected Total	23	23018206.28			
		R-Square	C.V.	Root MSE	Mean
		0.820985	8.379671	585.9891	6992.984

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	15318235.69	5106078.56	14.87	0.0002
CS	1	733142.67	733142.67	2.14	0.1697
REP(CS)	4	1644311.66	411077.92	1.20	0.3616
CS*Mulching	3	1201918.20	400639.40	1.17	0.3629

APPENDIX 4.6.2: Analysis of variance of aerial biomass production (kg.ha^{-1}) during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	5117497.422	1023499.484	2.43	0.1552
Error	6	2528382.628	421397.105		
Corrected Total	11	7645880.050			
		R-Square	C.V.	Root MSE	Mean
		0.669314	9.056553	649.1511	167.750

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	4910593.657	1636864.552	3.88	0.0741
REP	2	206903.765	103451.882	0.25	0.7898

APPENDIX 4.6.3: Analysis of variance of aerial biomass production (kg.ha^{-1}) during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	13046840.39	2609368.08	9.83	0.0074
Error	6	1592425.93	265404.32		
Corrected Total	11	14639266.32			
		R-Square	C.V.	Root MSE	Mean
		0.891222	7.555866	515.1741	6818.200

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	11609514.42	3869838.14	14.58	0.0037
REP	2	1437325.97	718662.98	2.71	0.1452

APPENDIX 4.7.1a: Over season analysis of variance of grain yield (kg.ha^{-1}) during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	2593129.903	235739.082	2.10	0.1085
Error	12	1344369.484	112030.790		
Corrected Total	23	3937499.386			
		R-Square	C.V.	Root MSE	Mean
		0.658573	11.96842	334.7100	2796.611

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	1155857.358	385285.786	3.44	0.0519
CS	1	685409.921	685409.921	6.12	0.0293
REP(CS)	4	511615.668	127903.917	1.14	0.3833
CS*Mulching	3	240246.956	80082.319	0.71	0.5618

APPENDIX 4.7.1b: Over season analysis of variance of number of seed per ear during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	41281.39002	3752.85364	2.97	0.0372
Error	12	15176.27857	1264.68988		
Corrected Total	23	56457.66858			
		R-Square	C.V.	Root MSE	Mean
		0.731192	6.090048	35.56248	583.9442

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	7617.87418	2539.29139	2.01	0.1667
CS	1	22600.11627	22600.11627	17.87	0.0012
REP(CS)	4	7285.97737	1821.49434	1.44	0.2802
CS*Mulching	3	3777.42220	1259.14073	1.00	0.4280

APPENDIX 4.7.1c: Over season analysis of variance of thousand seed weight (g) during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	26538.19851	2412.56350	4.22	0.0100
Error	12	6858.65928	571.55494		
Corrected Total	23	33396.85780			
		R-Square	C.V.	Root MSE	Mean
		0.794632	9.408385	23.90722	254.1054

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	232.99805	77.66602	0.14	0.9367
CS	1	24342.955	4342.95	42.59	0.0001
REP(CS)	4	783.94332	195.98583	0.34	0.8439
CS*Mulching	3	1178.30205	392.76735	0.69	0.5770

APPENDIX 4.7.1d: Over season analysis of variance of number of ears per plant during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.12736667	0.01157879	2.69	0.0516
Error	12	0.05163333	0.00430278		
Corrected Total	23	0.17900000			
		R-Square	C.V.	Root MSE	Mean
		0.711546	6.868645	0.065596	0.955000

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.08516667	0.02838889	6.60	0.0070
CS	1	0.00666667	0.00666667	1.55	0.2370
REP(CS)	4	0.01843333	0.00460833	1.07	0.4129
CS*Mulching	3	0.01710000	0.00570000	1.32	0.3121

APPENDIX 4.7.2a: Analysis of variance of grain yield (kg.ha^{-1}) during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	699810.5558	139962.1112	0.73	0.6273
Error	6	1152731.5533	192121.9256		
Corrected Total	11	1852542.1092			
		R-Square	C.V.	Root MSE	Mean
		0.377757	14.78001	438.3172	2965.608

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	531890.4292	177296.8097	0.92	0.4847
REP	2	167920.1267	83960.0633	0.44	0.6650

APPENDIX 4.7.2b: Analysis of variance of number of seeds per ear during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	4168.027500	833.605500	0.69	0.6484
Error	6	7227.741667	1204.623611		
Corrected Total	11	11395.769167			
		R-Square	C.V.	Root MSE	Mean
		0.365752	5.646817	34.70769	614.6417

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	3427.495833	1142.498611	0.95	0.4745
REP	2	740.531667	370.265833	0.31	0.7463

APPENDIX 4.7.2c: Analysis of variance of thousand seed weight (g) during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1406.940833	281.388167	0.29	0.8997
Error	6	5738.588333	956.431389		
Corrected Total	11	7145.529167			
		R-Square	C.V.	Root MSE	Mean
		0.196898	10.81494	30.92622	285.9583

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	645.7891667	215.2630556	0.23	0.8757
REP	2	761.1516667	380.5758333	0.40	0.6882

APPENDIX 4.7.2d:Analysis of variance of number of ears per plant during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.03833333	0.00766667	1.62	0.2848
Error	6	0.02833333	0.00472222		
Corrected Total	11	0.06666667			
		R-Square	C.V.	Root MSE	Mean
		0.575000	7.362689	0.068718	0.933333

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.02666667	0.00888889	1.88	0.2335
REP	2	0.01166667	0.00583333	1.24	0.3554

APPENDIX 4.7.3a: Analysis of variance of grain yield production (kg.ha^{-1}) during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1207821.717	241564.343	7.57	0.0143
Error	6	191543.620	31923.937		
Corrected Total	11	1399365.337			
		R-Square	C.V.	Root MSE	Mean
		0.863121	6.799801	178.6727	2627.617

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	864163.5900	288054.5300	9.02	0.0121
REP	2	343658.1267	171829.0633	5.38	0.0458

APPENDIX 4.7.3b: Analysis of variance of number of seeds per ear during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	14508.90167	2901.78033	2.19	0.1836
Error	6	7944.10500	1324.01750		
Corrected Total	11	22453.00667			
		R-Square	C.V.	Root MSE	Mean
		0.646190	6.576766	36.38705	553.2667

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	7965.920000	2655.306667	2.01	0.2148
REP	2	6542.981667	3271.490833	2.47	0.1649

APPENDIX 4.7.3c: Analysis of variance of thousand seed weight (g) during the 2000/2001 as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	786.3608333	157.2721667	0.84	0.5671
Error	6	1124.8483333	187.4747222		
Corrected Total	11	1911.2091667			
		R-Square	C.V.	Root MSE	Mean
		0.411447	6.160462	13.69214	222.2583

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	764.1091667	254.7030556	1.36	0.3419
REP	2	22.2516667	11.1258333	0.06	0.9429

APPENDIX 4.7.3c: Analysis of variance of thousand seed weight (g) during the 2000/2001 as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.09416667	0.01883333	13.56	0.0032
Error	6	0.00833333	0.00138889		
Corrected Total	11	0.10250000			
		R-Square	C.V.	Root MSE	Mean
		0.918699	3.822338	0.037268	0.975000

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.08916667	0.02972222	21.40	0.0013
REP	2	0.00500000	0.00250000	1.80	0.2441

APPENDIX 4.8.1: Over season analysis of variance of pooled mean for harvest index during the 1999/2000 and, 2000/2001 growing seasons as affected by the different mulching treatment

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.01318333	0.00119848	0.88	0.5807
Error	12	0.01635000	0.00136250		
Corrected Total	23	0.02953333			
		R-Square	C.V.	Root MSE	Mean
		0.446388	9.189724	0.036912	0.401667

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.00773333	0.00257778	1.89	0.1848
CS	1	0.00326667	0.00326667	2.40	0.1475
REP(CS)	4	0.00151667	0.00037917	0.28	0.8864
CS*Mulching	3	0.00066667	0.00022222	0.16	0.9191

APPENDIX 4.8.2: Analysis of variance of harvest index during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.00525000	0.00105000	0.68	0.6534
Error	6	0.00921667	0.00153611		
Corrected Total	11	0.01446667			
		R-Square	C.V.	Root MSE	Mean
		0.362903	9.482239	0.039193	0.413333

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.00393333	0.00131111	0.85	0.5137
REP	2	0.00131667	0.00065833	0.43	0.6699

APPENDIX 4.8.3: Analysis of variance of harvest index during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.00466667	0.00093333	0.79	0.5957
Error	6	0.00713333	0.00118889		
Corrected Total	11	0.01180000			
		R-Square	C.V.	Root MSE	Mean
		0.395480	8.841094	0.034480	0.390000

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	0.00446667	0.00148889	1.25	0.3712
REP	2	0.00020000	0.00010000	0.08	0.9204

APPENDIX 5

APPENDIX 5.1.1a: Analysis of variance of total soil moisture content (mm/1200mm soil depth) between 11-138 DAP during the 1999/2000 growing season as influenced by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	49684.13893	4968.41389	344.64	0.0001
Error	21	302.74284	14.41633		
Corrected Total	31	49986.88177			
		R-Square	C.V.	Root MSE	Mean
		0.993944	1.182152	3.796884	321.1841

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	771.95123	257.31708	17.85	0.0001
DAP	7	48912.18770	6987.45539	484.69	0.0001

APPENDIX 5.1.1b: Analysis of variance of soil moisture storage in the soil profile of the basins (mm/1200mm soil depth) between 11-138 DAP during the 1999/2000 growing season as influenced by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	59197.66663	5919.76666	186.54	0.0001
Error	21	666.42277	31.73442		
Corrected Total	31	59864.08940			
		R-Square	C.V.	Root MSE	Mean
		0.988868	1.723444	5.633331	326.8647

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	72.78021	24.26007	0.76	0.5267
DAP	7	59124.88642	8446.41235	266.16	0.0001

APPENDIX 5.1.1c: Analysis of variance of soil moisture storage in the soil profile of the runoff strips (mm/1200mm soil depth) between 11-138 DAP during the 1999/2000 growing season as influenced by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	43133.94942	4313.39494	72.54	0.0001
Error	21	1248.73137	59.46340		
Corrected Total	31	44382.68080			
		R-Square	C.V.	Root MSE	Mean
		0.971864	2.444137	7.711251	315.5000

Source	DF	SS	MS	F Value	Pr > F
DAP	7	40839.95935	5834.27991	98.12	0.0001
TR	3	2293.99007	764.66336	12.86	0.0001

APPENDIX 5.1.2a: Analysis of variance of total soil moisture content (mm/1200mm soil depth) between 52-78 DAP during the 2000/2001 growing season as influenced by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	15053.90698	1881.73837	89.02	0.0001
Error	15	317.07622	21.13841		
Corrected Total	23	15370.98320			
		R-Square	C.V.	Root MSE	Mean
		0.979372	1.261567	4.597653	364.4400

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	54.87273	18.29091	0.87	0.4806
DAP	5	14999.03425	2999.80685	141.91	0.0001

APPENDIX 5.1.2b: Analysis of variance of soil moisture storage in the basins (mm/1200mm soil depth) between 52-78 DAP during the 2000/2001 growing season as influenced by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	21670.88127	2708.86016	18.73	0.0001
Error	15	2169.50240	144.63349		
Corrected Total	23	23840.38366			
		R-Square	C.V.	Root MSE	Mean
		0.908999	3.239327	12.02637	371.2613

Source	DF	SS	MS	F Value	Pr > F
Mulching	3	1700.17138	566.72379	3.92	0.0300
DAP	5	19970.70989	3994.14198	27.62	0.0001

APPENDIX 5.1.2c: Analysis of variance of moisture storage in the runoff strips (mm/1200mm soil depth) between 52-78 DAP during the 2000/2001 growing season as influenced by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	12323.05347	1540.38168	28.71	0.0001
Error	15	804.77992	53.65199		
Corrected Total	23	13127.83338			
		R-Square	C.V.	Root MSE	Mean
		0.938697	2.048199	7.324752	357.6192

Source	DF	SS	MS	F Value	Pr > F
DAP	5	11338.17318	2267.63464	42.27	0.0001
TR	3	984.88028	328.29343	6.12	0.0063

APPENDIX 5.2.1: Over season analysis of variance for sunflower plant height (mm) during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	906984.0000	82453.0909	28.21	0.0001
Error	12	35073.8333	2922.8194		
Corrected Total	23	942057.8333			
		R-Square	C.V.	Root MSE	Mean
		0.962769	3.935917	54.06311	1373.583

Source	DF	SS	MS	F Value	Pr > F
Seasons (CS)	1	754021.5000	754021.5000	257.98	0.0001
Rep(CS)	4	33394.8333	8348.7083	2.86	0.0709
Mulching (M)	3	112315.5000	37438.5000	12.81	0.0005
CS*M	3	7252.1667	2417.3889	0.83	0.5040

APPENDIX 5.2.2: Analysis of variance of sunflower plant height (mm) as affected by the different mulching treatments during 1999/2000

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	105033.0000	21006.6000	7.65	0.0139
Error	6	16474.6667	2745.7778		
Corrected Total	11	121507.6667			
		R-Square	C.V.	Root MSE	Mean
		0.864415	3.378840	52.40017	1550.833

Source	DF	SS	MS	F Value	Pr > F
REP	2	31824.66667	15912.33333	5.80	0.0397
Mulching	3	73208.33333	24402.77778	8.89	0.0126

APPENDIX 5.2.3a: Analysis of variance of sunflower plant height (mm) during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	47929.50000	9585.90000	3.09	0.1009
Error	6	18599.16667	3099.86111		
Corrected Total	11	66528.66667			
		R-Square	C.V.	Root MSE	Mean
		0.720434	4.653920	55.67640	1196.333

Source	DF	SS	MS	F Value	Pr > F
REP	2	1570.16667	785.08333	0.25	0.7842
Mulching	3	46359.33333	15453.11111	4.99	0.0455

APPENDIX 5.2.3b: Analysis of variance of height growth rate ($mm.d^{-1}$) from planting to 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	7.54414167	1.50882833	1.42	0.3375
Error	6	6.37315000	1.06219167		
Corrected Total	11	13.91729167			
		R-Square	C.V.	Root MSE	Mean
		0.542070	12.06941	1.030627	8.539167

Source	DF	SS	MS	F Value	Pr > F
REP	2	1.06511667	0.53255833	0.50	0.6290
Mulching	3	6.47902500	2.15967500	2.03	0.2108

APPENDIX 5.2.3c: Analysis of variance of height growth rate (mm.d^{-1}) from 30 to 40 DAP during the 2000/2001 growing season as affected by the different mulching technique treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	259.8565750	51.9713150	1.55	0.3023
Error	6	201.0279167	33.5046528		
Corrected Total	11	460.8844917			
		R-Square	C.V.	Root MSE	Mean
		0.563821	15.90380	5.788320	36.39583

Source	DF	SS	MS	F Value	Pr > F
REP	2	5.6378167	2.8189083	0.08	0.9204
Mulching	3	254.2187583	84.7395861	2.53	0.1537

APPENDIX 5.2.3d: Analysis of variance of height growth rate (mm.d^{-1}) from 40 to 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	140.4751583	28.0950317	2.73	0.1269
Error	6	61.7981333	10.2996889		
Corrected Total	11	202.2732917			
		R-Square	C.V.	Root MSE	Mean
		0.694482	14.33636	3.209313	22.38583

Source	DF	SS	MS	F Value	Pr > F
REP	2	8.0266667	4.0133333	0.39	0.6933
Mulching	3	132.4484917	44.1494972	4.29	0.0614

APPENDIX 5.3.1: Over season analysis of variance of sunflower stem thickness at maturity (mm) during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	98.2655	8.93322727	3.48	0.0211
Error	12	30.8119	2.56765833		
Corrected Total	23	129.0774			
		R-Square	C.V.	Root MSE	Mean
		0.761291	7.121740	1.602391	22.50000

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Season	1	45.81606667	45.81606667	17.84	0.0012
REP(Season)	4	14.79603333	3.69900833	1.44	0.2801
Mulching	3	25.35556667	8.45185556	3.29	0.0581
Season*Mulching	3	12.29783333	4.09927778	1.60	0.2419

APPENDIX 5.3.2: Analysis of variance of sunflower stem thickness (mm) during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	25.06458333	5.01291667	1.26	0.3885
Error	6	23.90998333	3.98499722		
Corrected Total	11	48.97456667			
		R-Square	C.V.	Root MSE	Mean
		0.511788	8.358905	1.996246	23.88167

Source	DF	SS	MS	F Value	Pr > F
REP	2	9.36121667	4.68060833	1.17	0.3711
Mulching	3	15.70336667	5.23445556	1.31	0.3539

APPENDIX 5.3.3a: Analysis of variance of sunflower stem thickness (mm) during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	27.38485000	5.47697000	4.76	0.0419
Error	6	6.90191667	1.15031944		
Corrected Total	11	34.28676667			
		R-Square	C.V.	Root MSE	Mean
		0.798700	5.078665	1.072529	21.11833

Source	DF	SS	MS	F Value	Pr > F
REP	2	5.43481667	2.71740833	2.36	0.1751
Mulching	3	21.95003333	7.31667778	6.36	0.0271

APPENDIX 5.3.3b: Analysis of variance of stem thickness growth rate ($mm.d^{-1}$) from planting to 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.00071667	0.00014333	0.75	0.6163
Error	6	0.00115000	0.00019167		
Corrected Total	11	0.00186667			
		R-Square	C.V.	Root MSE	Mean
		0.383929	9.028939	0.013844	0.153333

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.00011667	0.00005833	0.30	0.7484
Mulching	3	0.00060000	0.00020000	1.04	0.4388

APPENDIX 5.3.3c: Analysis of variance of stem thickness growth rate (mm.d^{-1}) from 30 to 40 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.07561667	0.01512333	2.48	0.1502
Error	6	0.03665000	0.00610833		
Corrected Total	11	0.11226667			
		R-Square	C.V.	Root MSE	Mean
		0.673545	5.677179	0.078156	1.376667

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.01201667	0.00600833	0.98	0.4271
Mulching	3	0.06360000	0.02120000	3.47	0.0910

APPENDIX 5.3.3d: Analysis of variance of stem thickness growth rate (mm.d^{-1}) from 40 to 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.01095000	0.00219000	3.54	0.0779
Error	6	0.00371667	0.00061944		
Corrected Total	11	0.01466667			
		R-Square	C.V.	Root MSE	Mean
		0.746591	23.33310	0.024889	0.106667

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.00501667	0.00250833	4.05	0.0771
Mulching	3	0 .00593333	0.00197778	3.19	0.1053

APPENDIX 5.4.1a: Analysis of variance of leaf area index at 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.01315	0.002630	3.90	0.0641
Error	6	0.00405	0.000675		
Corrected Total	11	0.01720			
		R-Square	C.V.	Root MSE	Mean
		0.764535	8.380891	0.025981	0.310000

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.00195	0.00097500	1.44	0.3075
Mulching	3	0.01120	0.00373333	5.53	0.0366

APPENDIX 5.4.1b: Analysis of variance of leaf area index at 40 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.27702500	0.05540500	1.35	0.3593
Error	6	0.24666667	0.04111111		
Corrected Total	11	0.52369167			
		R-Square	C.V.	Root MSE	Mean
		0.528985	15.58684	0.202759	1.300833

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.01626667	0.00813333	0.20	0.8256
Mulching	3	0.26075833	0.08691944	2.11	0.1998

APPENDIX 5.4.1c: Analysis of variance of leaf area index at 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.29868333	0.05973667	4.18	0.0553
Error	6	0.08568333	0.01428056		
Corrected Total	11	0.38436667			
		R-Square	C.V.	Root MSE	Mean
		0.777079	10.65390	0.119501	1.121667

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.24211667	0.12105833	8.48	0.0179
Mulching	3	0.05656667	0.01885556	1.32	0.3521

APPENDIX 5.4.2a: Analysis of variance of number of green leaves per plant at 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1.70309167	0.34061833	0.89	0.5387
Error	6	2.28380000	0.38063333		
Corrected Total	11	3.98689167			
		R-Square	C.V.	Root MSE	Mean
		0.427173	5.272743	0.616955	11.70083

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.35606667	0.17803333	0.47	0.6475
Mulching	3	1.34702500	0.44900833	1.18	0.3932

APPENDIX 5.4.2b: Analysis of variance of number of green leaves per plant at 40 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	13.12085000	2.62417000	1.79	0.2500
Error	6	8.82071667	1.47011944		
Corrected Total	11	21.94156667			
		R-Square	C.V.	Root MSE	Mean
		0.597991	5.882517	1.212485	20.61167

Source	DF	SS	MS	F Value	Pr > F
REP	2	4.96121667	2.48060833	1.69	0.2622
Mulching	3	8.15963333	2.71987778	1.85	0.2388

APPENDIX 5.4.2c: Analysis of variance of number of green leaves per plant at 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	2.42920833	0.48584167	2.09	0.1976
Error	6	1.39381667	0.23230278		
Corrected Total	11	3.82302500			
		R-Square	C.V.	Root MSE	Mean
		0.635415	3.010951	0.481978	16.00750

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.21345000	0.10672500	0.46	0.6522
Mulching	3	2.21575833	0.73858611	3.18	0.1060

APPENDIX 5.4.3a: Analysis of variance of leaf area per plant (mm^2) at 30 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1253307180	250661436	3.76	0.0690
Error	6	400185227	66697538		
Corrected Total	11	1653492407			
		R-Square	C.V.	Root MSE	Mean
		0.757976	8.800073	8166.856	92804.42

Source	DF	SS	MS	F Value	Pr > F
REP	2	203092698	101546349	1.52	0.2919
Mulching	3	1050214482	350071494	5.25	0.0409

APPENDIX 5.4.3b: Analysis of variance of leaf area per plant (mm^2) at 40 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	24879865125	4975973025	1.37	0.3539
Error	6	21871459362	3645243227		
Corrected Total	11	46751324487			
		R-Square	C.V.	Root MSE	Mean
		0.532175	15.46954	60375.85	390288.7

Source	DF	SS	MS	F Value	Pr > F
REP	2	1427216472	713608236	0.20	0.8273
Mulching	3	23452648653	7817549551	2.14	0.1958

APPENDIX 5.4.3c: Analysis of variance of leaf area per plant (mm^2) at 70 DAP during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	27476466297	5495293259	4.24	0.0538
Error	6	7782244328	1297040721		
Corrected Total	11	35258710625			
		R-Square	C.V.	Root MSE	Mean
		0.779282	10.66955	36014.45	337544.1

Source	DF	SS	MS	F Value	Pr > F
REP	2	22218909045	11109454523	8.57	0.0175
Mulching	3	5257557252	1752519084	1.35	0.3438

APPENDIX 5.5.1:Over season analysis of variance for the height-thickness ratio of sunflower during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	677.4276792	61.5843345	3.76	0.0158
Error	12	196.6564833	16.3880403		
Corrected Total	23	874.0841625			
		R-Square	C.V.	Root MSE	Mean
		0.775014	6.477791	4.048214	62.49375

Source	DF	SS	MS	F Value	Pr > F
Season	1	460.1628375	460.1628375	28.08	0.0002
REP(season)	4	69.1526500	17.2881625	1.05	0.4200
Mulching	3	28.3140458	9.4380153	0.58	0.6417
Season*Mulching	3	119.7981458	39.9327153	2.44	0.1151

APPENDIX 5.5.2: Analysis of variance of for the height- thickness ratio of sunflower as affected by the different mulching treatments during the 1999/2000 growing season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	126.2240250	25.2448050	1.80	0.2481
Error	6	84.3828000	14.0638000		
Corrected Total	11	210.6068250			
		R-Square	C.V.	Root MSE	Mean
		0.599335	5.607945	3.750173	66.87250

Source	DF	SS	MS	F Value	Pr > F
REP	2	9.0632000	4.5316000	0.32	0.7363
Mulching	3	117.1608250	39.0536083	2.78	0.1327

APPENDIX 5.5.3: Analysis of variance of the height- thickness ratio of sunflower as affected by the different mulching treatments during the 2000/2001 growing season

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	91.04081667	18.20816333	0.97	0.5016
Error	6	112.27368333	18.71228056		
Corrected Total	11	203.31450000			
		R-Square	C.V.	Root MSE	Mean
		0.447783	7.443464	4.325769	58.11500

Source	DF	SS	MS	F Value	Pr > F
REP	2	60.08945000	30.04472500	1.61	0.2764
Mulching	3	30.95136667	10.31712222	0.55	0.6657

APPENDIX 5.5.4a: Analysis of variance for the linear relation between sunflower plant height and stem thickness at maturity as affected by the different mulching treatments during the 1999/2000 growing season

	DF	SS	MS	F	Significance F
Regression	1	1.793639	1.793639	1.040025	0.415098
Residual	2	3.449224	1.724612		
Total	3	5.242863			

APPENDIX 5.5.4b: Analysis of variance for the linear relation between sunflower plant height and stem thickness at maturity as affected by the different mulching treatments during the 2000/2001 growing season

	DF	SS	MS	F	Significance F
Regression	1	5.569849	5.569849	6.342537	0.128068
Residual	2	1.756347	0.878174		
Total	3	7.326196			

APPENDIX 5.5.4c: Analysis of variance for the linear relation between sunflower plant height and stem thickness from planting to 70 DAP during the 2000/2001 growing season

	DF	SS	MS	F	Significance F
Regression	1	525.1137	525.1137	38.87164	9.7E-05
Residual	10	135.0891	13.50891		
Total	11	660.2028			

APPENDIX 5.5.5a: Analysis of variance for the linear relation between sunflower plant height and number of green leaves from planting to 70 DAP during the 2000/2001 growing season

	DF	SS	MS	F	Significance F
Regression	1	22.73849	22.73849	1.624173	0.231329
Residual	10	140.0004	14.00004		
Total	11	162.7389			

APPENDIX 5.5.5b: Analysis of variance for the linear relation between sunflower plant height and number of green leaves from planting to 40 DAP as affected by the different treatments during the 2000/2001 growing season

	df	SS	MS	F	Significance F
Regression	1	270810.9	270810.9	632.1275	2.61E-07
Residual	6	2570.471	428.4119		
Total	7	273381.4			

APPENDIX 5.6.1: Over season analysis of variance of the aerial biomass production capacity of sunflower (kg.ha^{-1}) during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	24297274.46	2208843.13	12.24	0.0001
Error	12	2165914.50	180492.87		
Corrected Total	23	26463188.96			
		R-Square	C.V.	Root MSE	Mean
		0.918154	7.135098	424.8445	5954.292

Source	DF	SS	MS	F Value	Pr > F
Season	1	8858565.04	8858565.04	49.08	0.0001
Rep(season)	4	1812068.17	453017.04	2.51	0.0973
Mulching	3	2818939.12	4272979.71	23.67	0.0001
Season*Mulching	3	807702.13	269234.04	1.49	0.2667

APPENDIX 5.6.2: Analysis of variance of the aerial biomass production capacity of sunflower (kg.ha^{-1}) during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	7769146.500	1553829.300	14.09	0.0029
Error	6	661895.167	110315.861		
Corrected Total	11	8431041.667			
		R-Square	C.V.	Root MSE	Mean
		0.921493	5.061669	332.1383	6561.833

Source	DF	SS	MS	F Value	Pr > F
REP	2	768330.167	384165.083	3.48	0.0991
Mulching	3	7000816.333	2333605.444	21.15	0.0014

APPENDIX 5.6.3: Analysis of variance of the aerial biomass production capacity of sunflower (kg.ha^{-1}) during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	7669562.917	1533912.583	6.12	0.0238
Error	6	1504019.333	250669.889		
Corrected Total	11	9173582.250			
		R-Square	C.V.	Root MSE	Mean
		0.836049	9.363996	500.6694	5346.750

Source	DF	SS	MS	F Value	Pr > F
REP	2	1043738.000	521869.000	2.08	0.2057
Mulching	3	6625824.917	2208608.306	8.81	0.0129

APPENDIX 5.7.1: Over season analysis of variance of grain yield of sunflower (kg.ha^{-1}) during the 1999/2000 and 2000/2001 growing seasons as affected by mulching technique treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	955186.0000	86835.0909	9.78	0.0002
Error	12	106543.3333	8878.6111		
Corrected Total	23	1061729.3333			
		R-Square	C.V.	Root MSE	Mean
		0.899651	5.354786	94.22638	1759.667

Source	DF	SS	MS	F Value	Pr > F
Season	1	451004.1667	451004.1667	50.80	0.0001
Rep(season)	4	58792.6667	14698.1667	1.66	0.2244
Mulching	3	358386.3333	119462.1111	13.46	0.0004
Season*mulching	3	87002.8333	29000.9444	3.27	0.0592

APPENDIX 5.7.2: Analysis of variance of grain yield of sunflower (kg.ha^{-1}) during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	435360.4167	87072.0833	7.45	0.0149
Error	6	70115.8333	11685.9722		
Corrected Total	11	505476.2500			
		R-Square	C.V.	Root MSE	Mean
		0.861288	5.699311	108.1017	1896.750

Source	DF	SS	MS	F Value	Pr > F
REP	2	46845.5000	23422.7500	2.00	0.2154
Mulching	3	388514.9167	129504.9722	11.08	0.0074

APPENDIX 5.7.3: Analysis of variance of grain yield of sunflower (kg.ha^{-1}) during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	68821.41667	13764.28333	2.27	0.1739
Error	6	36427.50000	6071.25000		
Corrected Total	11	105248.91667			
		R-Square	C.V.	Root MSE	Mean
		0.653892	4.802109	77.91823	1622.583

Source	DF	SS	MS	F Value	Pr > F
REP	2	11947.16667	5973.58333	0.98	0.4270
Mulching	3	56874.25000	18958.08333	3.12	0.1093

APPENDIX 5.8.1: Over season analysis of variance of harvest index of sunflower during the 1999/2000 and 2000/2001 growing seasons as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.02445000	0.00222273	2.31	0.0827
Error	12	0.01153333	0.00096111		
Corrected Total	23	0.03598333			
		R-Square	C.V.	Root MSE	Mean
		0.679481	10.30530	0.031002	0.300833

Source	DF	SS	MS	F Value	Pr > F
Season	1	0.00201667	0.00201667	2.10	0.1731
Rep(season)	4	0.00406667	0.00101667	1.06	0.4187
Mulching	3	0.01138333	0.00379444	3.95	0.0359
Season*mulching	3	0.00698333	0.00232778	2.42	0.1165

APPENDIX 5.8.2: Analysis of variance of harvest index of sunflower during the 1999/2000 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.00375000	0.00075000	1.07	0.4605
Error	6	0.00421667	0.00070278		
Corrected Total	11	0.00796667			
		R-Square	C.V.	Root MSE	Mean
		0.470711	9.089128	0.026510	0.291667

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.00211667	0.00105833	1.51	0.2951
Mulching	3	0.00163333	0.00054444	0.77	0.5492

APPENDIX 5.8.3: Analysis of variance of harvest index of sunflower during the 2000/2001 growing season as affected by the different mulching treatments

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.01868333	0.00373667	3.06	0.1027
Error	6	0.00731667	0.00121944		
Corrected Total	11	0.02600000			
		R-Square	C.V.	Root MSE	Mean
		0.718590	11.26469	0.034921	0.310000

Source	DF	SS	MS	F Value	Pr > F
REP	2	0.00195000	0.00097500	0.80	0.4922
Mulching	3	0.01673333	0.00557778	4.57	0.0541