Productivity of sorghum-cowpea intercropping system under drought stress

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Report of thesis research

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Summary

Productivity of sorghum-cowpea intercropping system under drought stress was studied. Specific objectives were to evaluate growth and productive advantages of this cropping system and to see how the relative competitive ability between the two crops was affected as a result of water shortage. The results of this experiment will be used as an indication to effects of drought stress on interaction between competition for water and competition for light by component crops of sorghum-cowpea intercropping in north Kordofan, western Sudan.

A pot experiment was conducted in a greenhouse in The Netherlands. Strip plot design with three replicates was used. Each replicate was divided into three vertical strips with three cropping systems (sole sorghum, sole cowpea and sorghum-cowpea intercropping), and three horizontal strips with three water supply levels (high, intermediate and low water supply level). Two plants were sown in each pot at the same date. The three different water supply levels were applied from 35 days after sowing on wards. Data on pot moisture status, biomass, LA, leaf photosynthetic rate and several features of plant growth and yield were collected and studied.

The research confirmed that sorghum a C4-species, is much better able to deal with water shortage than cowpea a C3-species. In the sorghum-cowpea intercropping treatment, cowpea was the tall and dominating species, irrespective of water supply level. The relative competitive ability of both species however, was clearly affected by water supply, sorghum was becoming a relatively higher competitor at the lower water supply levels.

Analysis of experimental results clearly demonstrated that the increase in relative competitive ability of sorghum at lower water supply levels did not only result from direct effects of water shortage and the difference in response of both species. The strong reduction of cowpea growth in condition of limited water supply increased the position of sorghum in competition for light. Through this indirect effect, the increase in relative competitive ability of sorghum at low water supply level was further strengthened.

Comparison of biomass productivity of the intercrop and sole crops of sorghum and cowpea showed that RYT at all water supply levels always slightly higher than one, indicating that productivity of the intercrop was at least equally good as that of the sole crops. For kernel yield however, there was one clear exception. At the lowest water supply level RYT was 1.2, Indicating a 20% increase in overall productivity. This shown increase was to a large extent caused by a mild reduction of HI of intercropped cowpea, whereas a strong reduction in HI of sole cowpea crop observed at this water supply level. This result clearly demonstrates that in intercrops the response of kernel yield might be very different from the response of total biomass due to additional effects on harvest indices.

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1. Introduction

1.1 Back ground

Sudan can be divided into several agroclimatological zones where food and cash crops are grown. The major field crops are cotton, sorghum, millet, sugarcane, wheat, ground nut, sesame, fruits and vegetables. About 4.1 million (ha) of the 10 million (ha) cropped land falls under the rainfed traditional farming practices by subsistance farmers (ISNAR 1988). In this area the length of the growing season depends on rain fall and water availability which is one of the major limiting factors for crop production. Intercropping is a common practice and usually highly desirable in this area especially with non mechanized harvested agriculture.

Sudan has a long river (The Nile), which crosses the whole country from the south to the north and plays an important role in irrigated agricultural schemes. The western part of the country is away from the Nile. Therefore in this part agriculture depends only on the rain fall which decreases gradually from south to north until it reaches an amount of about 400 mm per season in north Kordofan (the area to which this study related; Appendix 1). Further to the north the situation becomes worse and rainfall reaches about 0 mm per season in the heart of the desert. Due to fluctuation and unpredictive rain fall in addition to high evapotranspiration in north Kordofan the growing season is very short i.e. about three monthes or less and a sort of especial dry farming where water stress takes place, appeares. The stress takes place during different growth periods but usually starts after the seedling stage.

The soil type in north Kordofan is a sandy soil (generally called goz of western Sudan) which is light textured and exhibits serious mechanical movement by wind (Osman and Elamin, 1996). The natural vegetation consists of Acacia mixed woodland. The traditional farmer in this area uses simple cultural practices. Land preparation when carried out, consists of discing and /or ridging. Crops are sown by hand in small areas of land which sizes depend on the availability of labour to carry out weeding and other operations. The farmer usually uses his own stock of seeds, and a wide range of different varieties are planted. The farmer has never used seed dressings, pesticides or fertilizers, but only manure of the animals which are allowed to graze the non crop vegetation. Crops are manually harvested.

An old practice used by traditional subsistance farmers in order to overcome the problem of low rainfall is intercropping. The main reason of growing intercrops is to provide a good ground cover and to protect the area's sandy soil from erosion. Olasantan (1988b) observed that a good ground cover through intercropping reduces run off and increases infiltration. In addition to that, farmers experience shows that intercropping provides a balanced diet, enough forage for the animals and minimizes risk of crop failure. The combination of crops used in intercropping the sowing time of the seeds often vary from one place to another but most farmers prefer that the component crops have different root systems to avoid direct competition between these crops for water. Lakhani (1976) observed that the exploitation of soil moisture by crops of contrasting root extraction zones illustrates the efficient sharing of resources between component crops. Common intercropping combinations are sorghum-cowpea, millet-groundnut, sorghum-groundnut and sesame-groundnut. According to the aims of a farmer. The component crops are sown in alternate rows at the same time, and sometime as a relay intercrop.

Although mixed cropping is not a new concept, only lately is there a sustained interest in understanding the underlying processes and seeking ways to increase the productivity of such systems in tropical agriculture (Papendick et al., 1976; ICRISAT, 1981; Francis 1986).

This study deals with an intercrop consisting of sorghum and cowpea. Sorghum is a very important crop and represents the staple food for the people in Kordofan region. Cowpea on the other hand is cultivated as a source of protein for human consumption and as hay and fodder for animals.

This research deals with research questions related to the productivity of an intercropping system consisting of sorghum (a C4-species) and cowpea (a C3-species) under rainfed condition: What is the nature of interactions between these two plant species and how dus water availability affect competition relation between thses species. To addresses these questions this thesis reviews a pot experiment in a greenhouse in The Netherlands. The experiment deals with sorghum-cowpea intercropping under different water supply levels.

The study intends to give a better insight to cereals-legumes intercropping under semi arid regions and tries to study the advantages of this system which usually operates by traditional subsistance farmers and to compare the productivity of this system with that of available soil moisture.

1.2 Specific objectives

Although there have been specific suggestions that intercropping may result in more efficient use of water, there has been little factual evidence of whether or not the relative advantages of intercropping are affected by water supply. The main objectives of this experiment are:

1. To evaluate the actual growth and production advantages of intercropping between sorghum and cowpea at different water supply levels.
2. To see how the relative competitive ability between sorghum and cowpea is affected by water supply.

1.3 Review on water resource capture and utilization

Importance of water and its role in crop production

Water is the major component of green plants, accounting for 70-90% of the fresh weight of most non woody species and for about 50% of the fresh weight of woody species. Most of this water is contained in the cell where it provides a suitable medium for many biochemical reactions. Water may also act as substrate in these processes, being equally essential in this role as carbon dioxide in photosynthesis or nitrate in nitrogen metabolism. Water is an excellent solvent to transport nutrients and assimilates via xylum and phloem to leaves and roots, respectively. The water film covering paranchyma cells of the leaves serves as solvent for CO_2. An other important function of water is the maintenance of turgidity, which is essential for for cell expansion or growth and for maintaining the form of herbaceous plant. Turgor is also a pre-requisite in the regulation of stomatal aparture and the movements of leaves and other plant structures (Lovenstein et al.1995).

Crop yield is an end product of many plant growth processes which interact with enviroment. It is based on the genetic constitution of the plants, and for a given cultivar, it is commonly determined by the availability of enviromental resources (e.g solar radiation, CO_2, nutrients and water) (Fukai and Trenbath, 1993).

Final yield depends on the total biomass production and partitioning among plant parts. Crop biomass at maturity is the integral of crop growth rate over the whole crop duration, and biomass production is often examined by relating crop growth rate to plant and enviromental factors. When a particular resource is limiting growth, crop growth rate may most meaningfully be analysed in relation to the capture of resources and the efficiency with which it is converted to biomass. For example, when water availability is the major factor determining biomass production, growth rate may be analysed using water uptake by the crop and the crop water's water use efficiency.

Assimilate partitioning is another important process determining crop yield. A higher fraction assimilates to leaves will maximize light interception whereas higher partitioning to roots will assist the plant to utilize soil resources more thoroughly. Another important partitioning process is that involving the harvested organ. In cereal crops, HI is commonly about equal to the amount of assimilate produced during grain filling expressed as a fraction of the total biomass production. Any adverse conditions during grain filling will lower the HI, although this effect is partly compensated for whenever assimilates produced before anthesis and stored in vegetative organs are used to fill grains. Thus, overall efficiency of resources used in crop production may decrease sharply if exhaustion of some resources before maturity leads to severe stress during the growth of harvested organs (Wien and Simithson, 1981).

In potential perennial crops such as cassava and pigeonpea, not all the assimilates produced during the development of harvested organs are translocated to these organs, but stems continue to grow and new leaves appear. This growth of the vegetative parts is an essential investment for future plant development, but it may compete with the growth of the harvested organs. Thus HI and sometimes also yield may be increased by the action of factor inhibiting the growth of plant parts which compete with the growth of harvested organs. Water stress has such an effect in cassava (Connor et al., 1981).

A delay in flowering of component crops in a dry enviroment usually indicates that it is suffering severe water stress. For example, when sorghum at high plant densities and narrow row spacing (0.75 m) was intercropped with cowpea, there was a substantial delay in flowering in sorghum, but the effect of intercropping was small when sorghum was sown at low densities and wide row spacing (1.5 m) (Rees, 1986). If the intercrop is growing using only water stored in the profile, a delay in flowering of one component can mean that the water is exhausted before its seeds are filled (Rao and Willey, 1983b)

Water limitation

Crop productivity is often limited by the amount of limiting resources, and is mostly determined by how efficiently the crop can utilize it. In sole cropping, understanding of the relevant processes is enhanced by examining how crops capture the resources which are limiting crop growth, and how the resources are used in assimilate production. Partitioning of the assimilates among various plant parts, and particularly allocation to the harvested part, are important processes determining final yield (Fukai and Trenbath, 1993).

The effect on plant photosynthetic rate

Among the assimilatory processes, photosynthesis is important for determining growth and yield. The total photosynthate production is the result of multiplicative interaction between the photosynthetic rate and leaf area or the photosynthetic surface. Photosynthesis has two major components, the stomatal and the non-stomatal. Non-stomatal components include activities of the photosynthetic enzymes and light reactions. Water stress affects both the stomatal and non-stomatal components of photosynthesis. Initial photosynthetic reduction may be due to an increase in plant moisture stress arising from the decrease in the conductance of CO_2 through the stomata. Davies and Zhang, 1991 (as cited by Nilsen, 1996) also stated that the initial impact of water limitation on photosynthesis is usually stomatal closture. Stomata may close because of a root signal probably abscisic acid, or because of low turgor pressure in the guard cells (Rashke, 1975., Collatz, 1991 as cited by Nilsen, 1996). Stomata also close in response to increasing vapour pressure gradient between the leaf and air (VPG), although this may not be associated with a change in water potential (Turner, 1984 as cited by Nilsen, 1996). Stomatal closure induced by water limitation causes a depletion of carbon dioxide in the intercellular spaces (Ci). This is termed stomatal inhibition of photosynthesis. During the initial phases of water limitation, stomatal closure and non-stomatal inhibition occur concurrently (Nilsen and Orcutt, 1996).

Net photosynthesis is a balance of gross photosynthesis, respiration and photorespiration if present. Water stress reduces net photosynthate availability by reducing leaf area and increasing stomatal resistance. This is followed by a decrease in the activity of enzymes such as RuBPcase and in the photochemical activity of the chloroplast (Hsaio, 1973 and Boyer, 1976 as cited by Johnson, 1981).

As water limitation progresses, photosynthesis decreases before that of respiration; consequently, the ratio between photosynthesis and respiration decreases. The decrease in the ratio of photosynthesis to respiration, and potential increase in both photorespiration and dark respiration during water stress, have caused many authors to believe that water limitation could cause plant starvation. However, it is more likely that plants will suffer greater damage to the shoot system from metabolic effects of water limitation other than carbohydrate deprivation (Nilsen and Orcutt, 1996).

Adaptation of plants to water limitation

The ability of stomata to regulate water loss provides an important mechanism for reducing water loss during drought. Crop plants show a range in sensitivity of stomata to water deficits (Turner, 1982). Stomata also respond to atmospheric humidity (Lang, 1971 as cited by Turner, 1982) or, more correctly, to leaf-to-air vapour pressure deficit. However, the direct response of stomata to humidity must be distinguished from the direct response through a lowering of the leaf water potential (Turner, 1982). There is an increase in the responsiveness of stomata to humidity as leaf water content decreases (Jarvis, 1980 as cited by Turner, 1982).

Plant production may be adapted to water deficient conditions by either modifying growth rate or growth period as reflected in drought avoidance and tolerance. Drought avoidance is achieved in plants with a short generation cycle from germination/leafing out to maturity, starting growth immediately at the onset of rain to force maturity, before soil is exhausted (e.g. in the dry summer). Hence, high growth rates can be maintained over a shorter period. Since high growth rates require unrestricted gas exchange, stomatal regulation is likely to be absent in these plants. An adequate water supply under such conditions is realized by reducing critical soil water potential (SWP_{cr}) (particularly in annual species) or exploring a larger soil volume through an extensive root system (particularly in perennial species with leaf in the dry season, during which plants are not active). Plants may tolerate drought by reducing water loss by leaves (stomatal regulation, modified leaf exposure to radiation by leaf folding and rolling) or moderating water uptake by roots (increasing SWP_{cr} while developing an extensive root system). Hence, plant growth period can be extended into the dry season though at a lower growth rate. This concept also applies to plant species tolerating conditions of waterlogging (Lovenstein et al.1995).

The processes of capture and utilization

Water capture and utilization are examined by decomposing crop production (dry weight/unit area) in two aggregate processes:

$$CGR = WU * WUE \quad (1)$$

Dry weight/unit area = (unit mass of water uptake/unit area) * (dry weight/unit mass of water uptake).
Water capture or use (WU) is the first of these processes and water utilization efficiency (WUE) is the second process.
This type of analysis shows how crops are different in their ability to extract water from the soil, and in the efficiency with which they use water to produce biomass (Fukai and Trenbath, 1993).

In field research, WU has commonly been defined as the ET (evapotranspiration) component of water balance:

$$P + I = S_{init} - S_{fin} + R + D + ET \quad (2)$$

Where P (rain), I (irrigation), S_{init} (initial stored soil water) and S_{fin} (final stored soil water) are always measured. Runoff (R) and D (drainage) are occasinally measured or, with valid reason regarded as zero. The ET component is estimated by difference. When determined this way, it appears to be a widely accepted as well as a valid measure of WU. Morris and Garrity (1993) defined the pool from which WU is captured as seasonally available water (SAW). Using P, I, S_{init} and R from equation above, $SAW = P + I + S_{init} - R$.

One of the reasons for high productivity of intercrop with different of component crops duration is that in general the components grow actively at different times and hence competition for resources is less intense than when components have similar growth rhythm (Baker 1981; Okigbo 1981; Rao 1986). Over the whole growing season the resources are captured more completely and used more efficiently than in corresponding sole crops.

The late maturing crop also utilizes resources (e.g residual water) which might otherwise be wasted, and hence it acts at least as effectively as does a second crop in a double crop system (Rao and Willy 1983b). In fact it may be more efficient because in regions where the rainy season is short, the second crop in a double cropping system is subjected to risk of establishment failure and labour shortage where as intercropping is safer as all component crops are commonly planted early in the season where enviromental condition are favourable for crop establishment (Natarajan and Willy 1985). When farmers choose to grow together crops with similar duration they tend to combine them in replacement type intercrops. With no temporal difference to reduce competition between components, the farmer aims for a plant population pressure that is usually not higher in intercrop than in sole crops.

The interference between water and intercropping

The study of WU & WUE has shown that the benifit of intercropping can in most cases be attributed to increased WUE, not to greater WU. If WUE of intercrops frequently exceed those of sole crops then the mechanisms that influence water and CO_2 fluxes may account for the advantages. There are several ways by which intercropping may enhance WUE. Direct emperical observations are not available, but water balance theory suggests four logical insights (Morris and Garrity, 1993):

First, intercrops may capture a larger portion of evapotraspiration as transpiration than sole crops do. Water utilization efficiency by intercrops greatly exeeds water utilization efficiency by sole crops, often by more than 18% and by as much as 99%. Gains in WUE have been frequently observed in agronomic studies on sole crops due to improved crop management, for example, increased nutrient availability or greater plant density (Fischer and turner,1978). In these cases it is unlikely that WUE, expressed as mg CO_2 assimilated /g H_2O transpired, has significantly increased. Rather, most of the gains are due to an increase in transpiration as a fraction of evapotranspiration (T/ET), because expanded plant cover reduces soil evaporation, particularly during early vegetative development. The analogy with intercropping is clear, since intercrop combinations usually have a total plant density exceeding that of either sole crop and the early season leaf area indices of intercrops are generally greater, a higher proportion of light is intercepted by the canopy. Morris and Garrity (1993a) also reported that variation in plant density of species often affects water utilization efficiency. Reddy and Willey (1981) estimated increased WUE by a pearl millet + groundnut intercrop was entirely accounted for by greater T/ET.

The interception of more light by intercrops, especially during the vegetative development phase with a canopy composed of species contrasting in architecture, was also sited by others as a factor contributing to higher WUE (Natarajan and Willey 1980b; Kushwaha and De1987). In these cases it was also linked to the general notation that a lower portion of ET from an intercrop was lost by direct evaporation during early vegetative development. Under extreme water stress however, enhanced early canopy development can result in negative effect on WUE. Rees (1986b) found that the enlarged vegetative cover from intercropping increased early growth, but depleted water reserves more quickly in very dry conditions, exacerbating water stress during reproductive development and depressing WUE. Hulugalle and Lal (1986) reported that water stress reduced vegetative development of cowpea, and thereby reduced ground cover in intercrops treatments.

Second, a crop component with an inherently greater WUE may capture a large portion of water use by intercrop and in doing so, increases its contribution to yields of intercropping, thereby increasing ΔWUE. Comparison showed that relative yields of the physically dominating species tended to be larger than those of dominated species. In most studies the dominating crops were C_4 species with high WUE and the dominated were C_3 species with low WUE, but these characteristics were often confounded with architecture (above and below ground), N fixation ability, and maturity. A component crop that combines an inherently greater WUE and a physically dominating architecture that interferes with growth of dominated species, captures a large SAW share, should increase overall ΔWUE of intercrops.

Third, the intercrop enviroment, composed of two crops of differing stature and growth dynamics, may create characteristics that convey favorable direct effects on transpiration efficiency (i.e biomass produced per unit water transpired). The growth enviroment encountered by components in an intercrop is often strikingly different from that in sole crop, the nature and degree of the difference depending strongly on the plant type (e.g height) of the associated crop. The modification may have a significant impact on the growth and yield of the crop. The most obvious modification of the enviroment in an intercrop is where a short saturated component is shaded by a taller one, the consequent reduced capture of photosynthetically active radiation

(PAR) resulting in reduced growth and yield of the shorter crop. Shading may lead to increased plant height which can favour lodging. (Trenbath and Harper1973; Chui and Shibles 1984).

Shading also modifies other environmental conditions and this change may be beneficial to a shorter component crop, for example reduction of air temperature under shade may favour the growth of an understorey crop, particularly when the ambient temperature in a sole crop is supra-optimal (Midmore et al.,1988b) or when the sole crop is water stressed (Harris and Natarajan, 1987). The environmental modification can even be such that the yield of understorey crop is higher in intercropping than in sole cropping. This was found in the case of potato intercropped with maize planted at low density (Midmore et al., 1988a).

Air vapor saturation deficit has a dominant effect on WUE. The wind break condition produced by the taller canopy component tends to elevate relative humidity in the vicinity of the shorter crop component and the partial shade effect tends to reduce air temperature (IRRI,1978) these both tends to reduce delta-e. Radient energy loads on the dominated crop are reduced but this crop is usually a C_3 species with low light saturated photosythetic rates. Stomatal resistance increases in the dominated species in the intercrop, particularly with moisture stress (Chastain and Grabe, 1989). Water use efficiency tends always to increase as the stomatal resistance increases, particularly in C_3 (Jones 1976).

The soil enviroment is also modified by intercropping. Some effects (e.g a change in temperature) may last for only the duration of intercrop growth while others (e.g soil fertility) may persist for a long time after the intercrop is harvested (Stoop, 1986). The moisture enviroment immediately below the soil surface is commonly improved by intercropping. As the soil surface under an intercrop is not as exposed as in the sole crops, evaporative loss from it is reduced. In a drying cycle the moisture content of the surface soil layer is often higher under intercrop than under sole crop (Midmore et al.,1988b; Olasantan1988b; Ikeorgu et al 1989). Ensuring good ground cover by intercropping can also reduce run off and increase infiltration (Olasantan 1988b). Increase infiltration rate may also be caused by increased earth worm activity as the result of lower soil temperature (Hulugall and Ezumah 1991).

Fourth, WUE in the dominant crop is favored by the reduced boundary layer of its open canopy (Jones 1976). This effect is evident in studies of canopies composed of plants varying in height, in which air movement penetrates more thoroughly than in canopies of plant of uniform heights.

Intercrop canopies are typically rough due to differences in plant height and architecture among the component crops.

The definitive contribution of the four mechanisms impinging up on enhanced WUE in intercrops can not be established on the basis of current empirical evidence. There is a reasonable basis to assume that increased T/ET is largely responsible for the phenomenon in some cases. But ΔWUE can exceed 50% and it is not likely that enhanced T/ET alone would account for difference of this magnitude.

2. Materials and methods

2.1 Experimental set up

Experimental design and treatments

A strip plot design with 3 replicates was used. Each replicate was divided into 3 vertical and 3 horizontal strips. The vertical strips included three cropping systems. The horizontal strips included three different water supply levels. Every water supply level contained 6 pots of each cropping system. Pots had a size of (25 * 25 cm^2) and a height of 35 cm. The total number of pots used for conducting the experiment was 330 pots from which 162 pots (3 * 3 * 3 * 6) were used for observations and measurements and 168 were used as border pots.

The three cropping systems used were:

Crop 1 = *Sorghum grown in monoculture*
Crop 2 = *Intercropping between sorghum and cowpea*
Crop 3 = *Cowpea grown in monoculture*

The three water supply levels used were:

M1 = *High water supply level*
M2 = *Intermediate water supply level*
M3 = *Low water supply level*

Randomization took place for the water supply levels. Monoculture sorghum variety *Sorghum bicolor (L.) Moench* and monoculture cowpea variety *Vigna unguiculata (L) Walp* were randomized to be on the left or on the right of each replicate. Intercropping was put in the middle between sole sorghum and sole cowpea for each replicate to have a comparable situation under different water supply levels (Appendix 2).

2.2 Cultural practices and greenhouse conditions

2.2.1 Location, climate and soil

In the period from 9 June-5 October 1998, the experiment was carried out in the Netherlands under tropical greenhouse conditions where temperature and humidity were under control. During the growing period temperature, humidity and light intensity were recorded. Results are summerized in (Fig. 1, 2 and 3). The soil used for this experiment was a mixture of black sandy soil and white sand in a ratio of 1:2. The average amount of oven dry soil was 17.43 kg/pot.

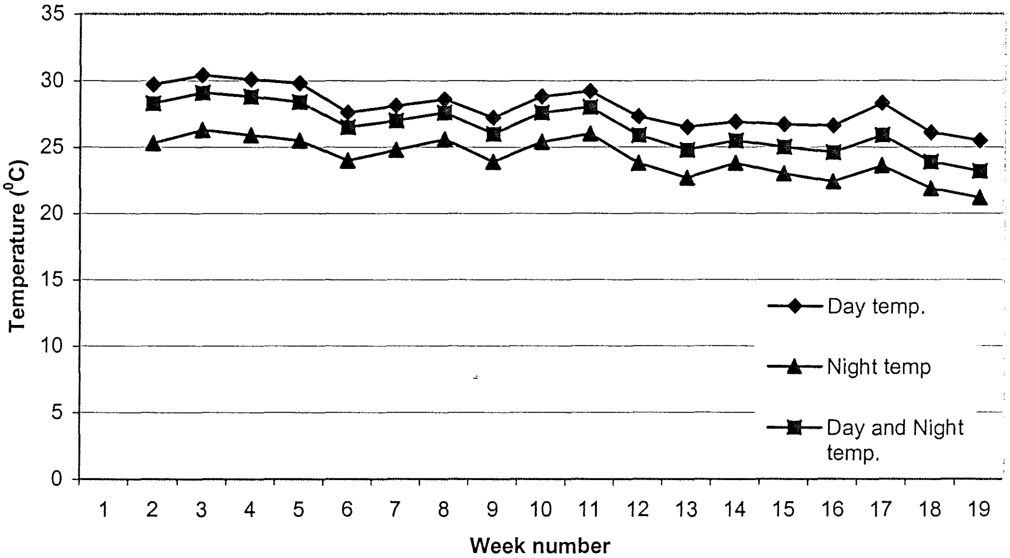

Fig 1. Weekly average temperature in the greenhouse during the growing period (9June-5 October 1998)

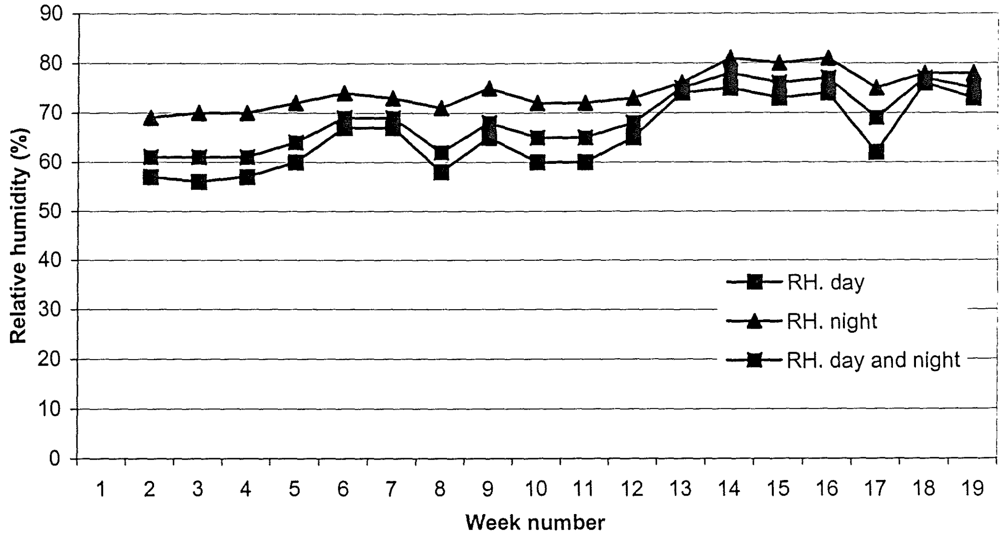

Fig.2. Weekly average relative humidity in the greenhouse during the growing period (9 June-5 October 1998)

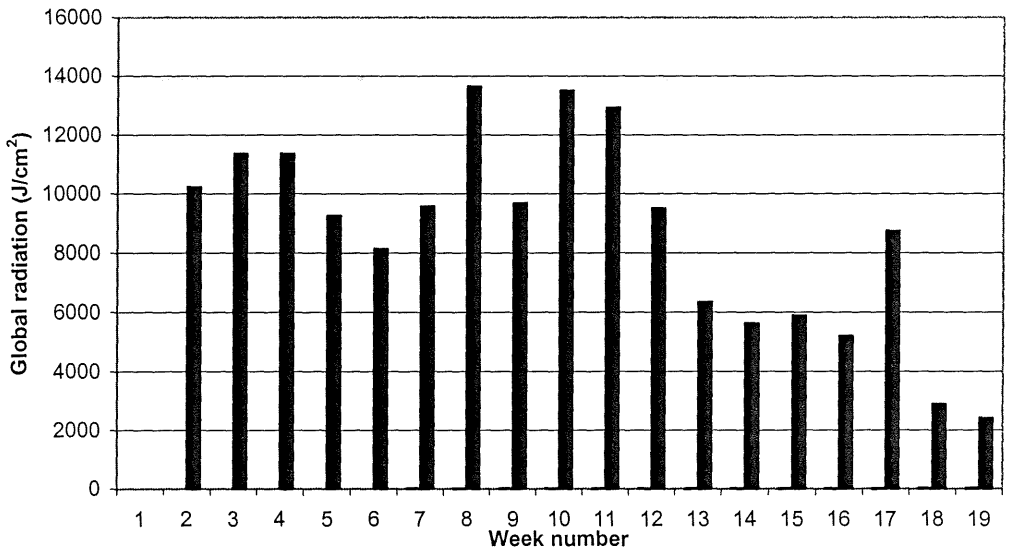

Fig.3. Weekly global radiation out side the greenhouse during the growing period (9 June-5 October 1998).

2.2.2 Sowing and germination

Sowing of the experiment took place on June 9, 1998. Seeds were sown by hand in small holes in a ratio of three seeds per pot for sole sorghum and cowpea, and two seeds of each crop in intercropping. Cowpea germination was 100% while only three sorghum seeds failed to germinate and emerge. 10 days after emergence the plants were thinned to two plants in each pot. In intercropping pots a 1:1 ratio of sorghum:cowpea was maintained.

2.2.3 Fertilizer application

A commercial fertilizer (Kristalon) which contained NPK (18-18-18), Mg (3) and additional micronutrients, was applied to all pots of the experiment on a weekly basis starting from the first week of sowing until final harvest. The fertilizer was solved in water (2g/l) and 400 ml of this solution was applied to each pot on a weekly basis. The total amount of the nutrients applied during the growing period was 368 kg/ha NPK and 61 kg/ha Mg.

2.2.4 Weeding and pesticides used

Ten days after emergence of the plants a hand weeding took place once. Biological control against spider mite and thrips was applied regularly. Two insect species were applied *Amblyseius cucumeris* was used against spider mite and *Phytoseiulus persimilis* against thrips.
64 days after sowing the experiment was sprayed by a mixture insecticide of Torque (against adult spider mite) and Nissorun (against spider mites eggs), since biological control was not efficient to control spider mite. Mice poison was used against mice which appeared during the last 6 weeks of the experiment.

2.2.5 Water supply levels

The whole experiment recieved sufficient water during the seedling phase of the plant. From 35 days after sowing on, application of different water levels was started. Three different water supply levels M1 (= high), M2 (= intermediate) and M3 (= low) water supply level were maintained. A sample of 27 pots (3 replicates * 3 cropping systems * 3 water supply levels) were weighed every week to keep track of the water availability in each treatment. Water supply was adjusted as to maintain a more or less constant amount of water available in pots of M1. Water supply in M2 and M3 set at 2/3 and 1/3 of the water supply in M1, respectively. Initially water was applied every three days in an amount of 1200, 800, 400 ml water respectively. From 53 DAS amount of water supply was increased through adjusting M1, M2, and M3 amount to (1500, 1000, 500 ml water) and frequency (every two days). From 82 DAS till end of the experiment (118 DAS) the amount of water maintained was the same, but frequency was set at every three days.

2.3 Data collection and observations

2.3.1 Soil sampling

Soil samples were taken at 21, 22, 44, 45 and 115 days after sowing. Initially soil samples were taken at two consecutive days, one day and two days after irrigation. At 115 DAS, soil samples were taken at two days after irrigation only. An auger was used for taking a representative soil sample by pushing it until the bottom of the pot. The soil sample was put in a paper bag and weighed before and after drying in an oven at 105^0 C for overnight. Water content in the pots of the different cropping systems under different water regimes was calculateted.

Undisturbed soil samples were taken by the end of the experiment using a special auger for determination of field capacity and permanent wilting point.

2.3.2 SPAD measurements

SPAD which positively correlates with the cholorophyll in a leaf was measured using SPAD-502 cholorophyll meter (Minolta) at 58 days after sowing. From each treatment combination (cropping system * water supply level), 6 pots were used (2 pots/replicate * 3 replicates). For each plant in the intercropping and one of the two plants in monoculture the third and fourth leaves from the top were measured. For each leaf the average of 4 readings taken through the entire of the leaf was calculated.

2.3.3 Number of leaves

Number of leaves was counted 6 times in the interval between day 43 and 65 after sowing. The counting included the youngest leaves that had their leaf blade expanded to 50% or more. From each treatment combination (cropping system * water supply level), 6 pots (2 pots/replicate * 3 replicate) were uesd. At 65 DAS counting of the leaves was stopped because for sorghum the flag leaf had appeared. Cowpea had many branches and it was difficult to count the leaves after that stage.

2.3.4 Plants length

The plants length of a representative sample per treatment combination of 6 pots (2 pots/replicate * 3 replicate) was measured at 23 days after sowing. Thereafter an other two different sample sizes (3 and 6 pots per treatment combination) of sole and intercropped sorghum were measured at 60 and 67 DAS respectively. The plant was measured from the base of the stem to the youngest visible ligule. The length of cowpea was measured once at 23 DAS, thereafter it was difficult to be measured because cowpea was growing in spiral form.

2.3.5 Photosynthesis measurements

Maximum photosynthesis for a single leaf was measured for each treatment combination, 6 pots (2 pots/replicate * 3 replicates) were used for measurements in two times period (49-52) DAS and (63-66) DAS (Appendix 3 and 4 respectively). Every period the measurements took four days. Measurements of each replicate took one day and the extra day used for repeating the measurements of replicate one in the first period and replicate three in the second period. An infra red gas analyser (Model LCA-2 and PLC-N leaf chamber, Analytical development Co., ADC, Ltd. Hoddesdon, England) was used. Measurements took place at the middle of the cowpea leaf and half way along the length of sorghum leaf.

CO_2 at a concentration 377 ppm was supplied from a gas cylinder. The air pressure and temperature of the photosynthesis room were 1010 millibars and 25^0 C in average. A photosynthesis photon flux density of 2280 μ mol.m^{-2} s^{-1} was supplied by two halogen lamps provided with a special filter to let through only the spectrum of light between 400-700 nm, (photosynthetically acive radiation PAR).The leaf chamber had an area of 2.5 * 2.5 cm^2 and an air flow rate of 350 ml.min^{-1} was maintained into the chamber.

Each plant was first subjected to high light intensity for 15 minutes before measuring its maximum leaf photosynthetic rate. Thereafter the leaf was put in the leaf chamber and stayed there for ±15 minutes, to give a stable reading. For each plant, two leaves (number 3 and 4 counted from the top of the plant) were used. Measurements were done one and two days after irrigation. The soft ware programme (Bladfot.6) was used for computing the rate of photosynthesis, transpiration and stomatal conductivity.

2.3.6 Intermediate harvest

On August 4, 1998 an intermediate harvest was started. Harvests took 3 days (one day for each replicate). From each treatment combination (cropping system * water supply level), 6 pots were harvested (2 pots/replicate * 3 replicates). The plants were cut above the pot soil and seperated into stem, green leaves, dead leaves and inflorescences. Leaf area was measured using a leaf area meter (Model LI 3100, Lambda instrument corporation, Nebrasca,USA). Plant roots were seperated from the soil using water pressure. All plant material was put in an oven at 70^0C for over night. Plant parts were weighed seperately and total biomass dry weight was calculated by adding the dry weight of all plants parts.

Border pots were harvested to attain an estimate of the fraction water in fresh material. For this, the average fresh weight of monoculture sorghum and monoculture cowpea was obtained. Plants were put in an oven until completely dry at 70^0C for one night after which total dry weight was determined. The fraction water in plants was used to estimate fresh plant weight of the pot that were weighed weekly to keep track of soil moisture status of the various treatments. Fresh plant weight was latter subtracted to obtain available soil moisture. For the same reason soil dry weight of these pots was determined to have an estimate of average soil dry weight per pot. For this purpose soil was seperated from the roots and put in an oven at 105^0 C for over night.

2.3.7 Final harvest

Final harvest was carried out at 118 days after sowing. Sorghum ears were cut from the plants and cowpea pods were collected. Data on leaf area and biomass were determined in the same way as described for the intemediate harvest. Ears and pods were put in an oven at 70^0C for over night and threshed afterwards. Harvest index was calculated by taking the ratio between grain yield and total shoot biomass. Seeds for each plant in intercrop were weighed and counted. For monoculture, seeds of each pot were weighed and counted together. The data were used to calculate 1000 seeds weight. Relative yield total of the intercrop, and relative yields of the component crops were calculated for total biomass and grain yield, using the following formula:

$$RYT = RYs + RYc = Y_{S\ mix}/Y_{S\ mon} + Y_{C\ mix}/Y_{C\ mon}$$

In which:

RYT = Relative yield total

RYs = Relative yield of sorghum

RYc = Relative yield of cowpea

$Ys_{mix.}$ = Yield of sorghum intercropped with cowpea

$Ys_{mon.}$ = Yield of sorghum grown in monoculture

$Yc_{mix.}$ = Yield of cowpea intercropped with sorghum

$Yc_{mon.}$ = Yield of cowpea grown in monoculture

2.3.8 Statistical analysis

Data of intermediate harvests, photosynthesis measurements and final harvests were subjected to analysis of variance using Genstat statistical package. ANOVA tables, LSD,CV% and means of different observations were prepared for further comparisons.

3. Results

3.1 Moisture status at different treatments

3.1.1Water supply

Table 1. Average daily water supply (ml/day) at three different water supply levels (M1= high, M2 = intermediate and M3 = low) throughout the growing period 9 June- 1 October 1998.

Water supply level	0-35 DAS	35-53 DAS	53-82 DAS	82-114 DAS
M1	260 ml	400 ml	750 ml	500 ml
M2	260 ml	266 ml	500 ml	333 ml
M3	260 ml	133 ml	250 ml	166 ml

Table1. shows that until 35 DAS, plants at all water supply levels received the same amout of water. From 35 DAS on, different amout of water was applied in a ratio 3:2:1 for the water supply levels M1 (= high), M2 (= intermedaite) and M3 (= low) respectively.

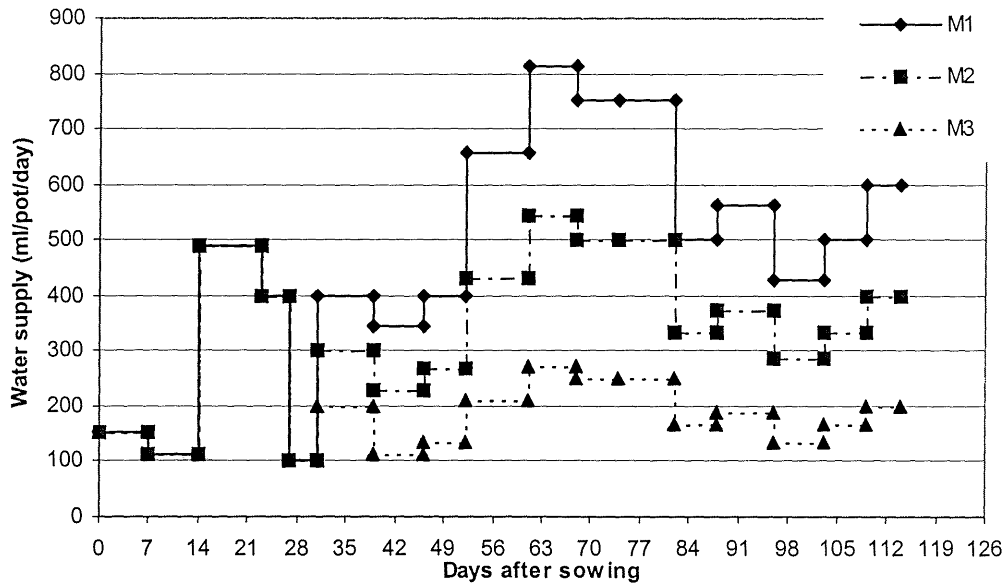

Fig.4. Average daily water supply for about weekly periods in between determination of total pot weights for three different water supply levels (M1 = high, M2 = intermediate and M3 = low) throughout the growing period(9June-1October 1998).

3.1.2 Sorghum grown in monoculture

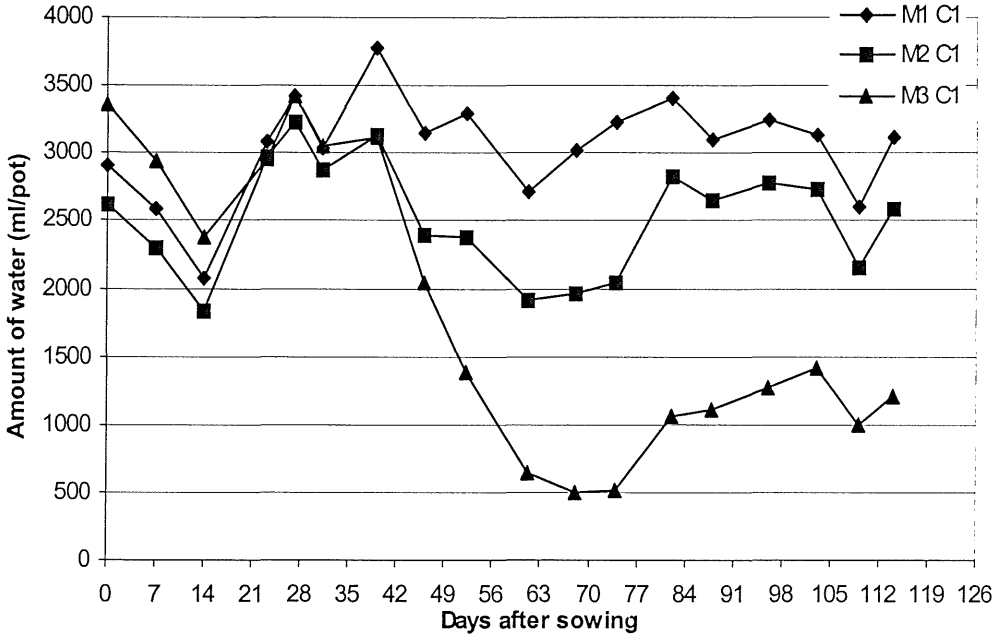

Fig.5. Estimated amount of water in pots of sorghum grown in monoculture, at three different water supply levels (M1 = high, M2 = intermediate and M3 = low) throughout the growing period (9 June-1October).

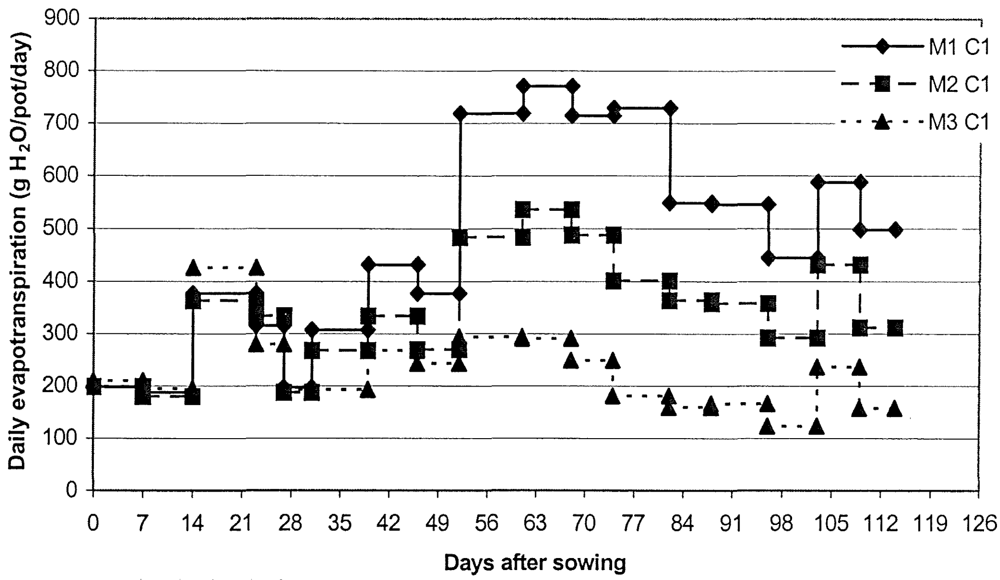

Fig.6. Estimated daily evapotranspiration (g H_2O/pot/day) of the pots of sorghum grown in monoculture as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) throughout the growing period (9June-1October 1998)

3.1.3 Cowpea grown in monoculture

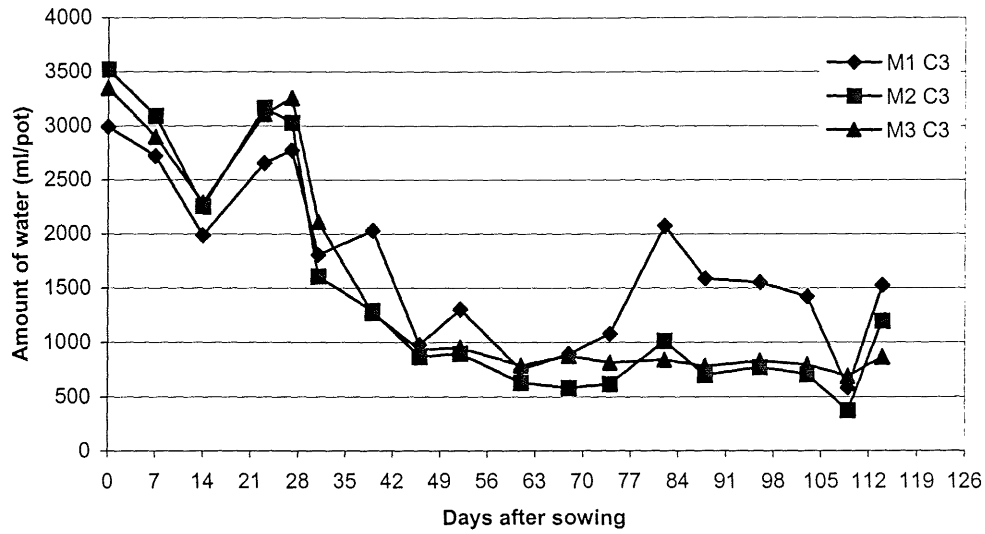

Fig.7. Estimated amount of water in pots of cowpea grown in monoculture, for three different water supply levels (M1 = high, M2 = intermediate and M3 = low) throughout the growing period (9 June-1October).

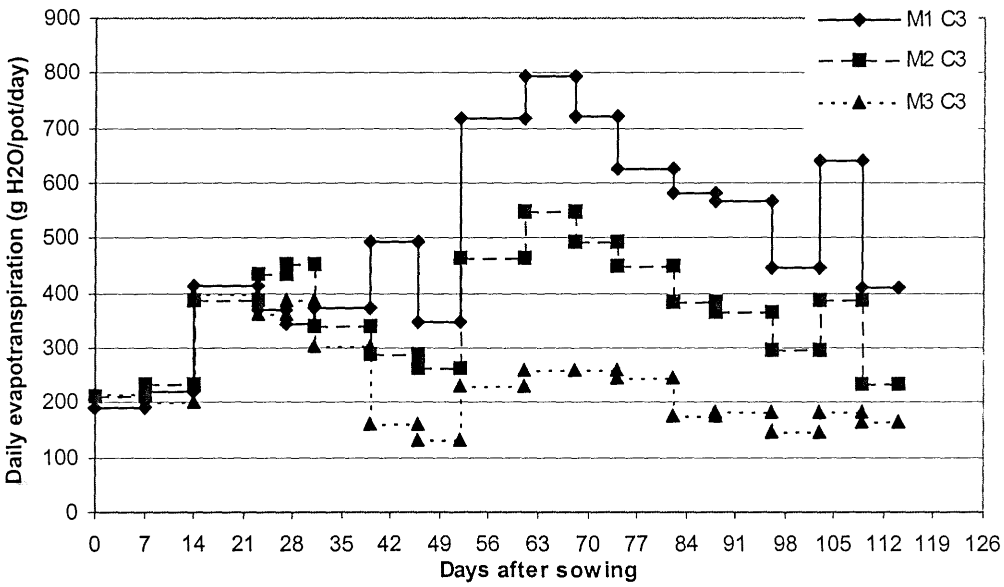

Fig.8. Estimated daily evapotranspiration (g H_2O/pot/day) of the pots of cowpea grown in monoculture as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) throughout the growing period (9June-1October 1998)

3.1.4 Intercropping between sorghum and cowpea

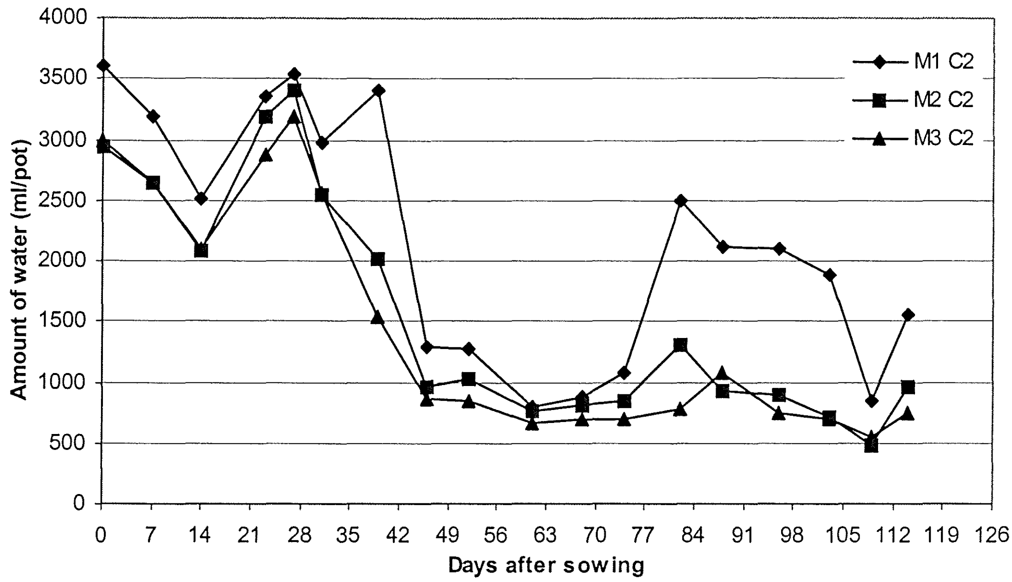

Fig.9. Estimated amount of water in pots of intercropping between sorghum and cowpea, for three different water supply levels (M1 = high, M2 = intermediate and M3 = low) throughout the growing period (9 June-1October).

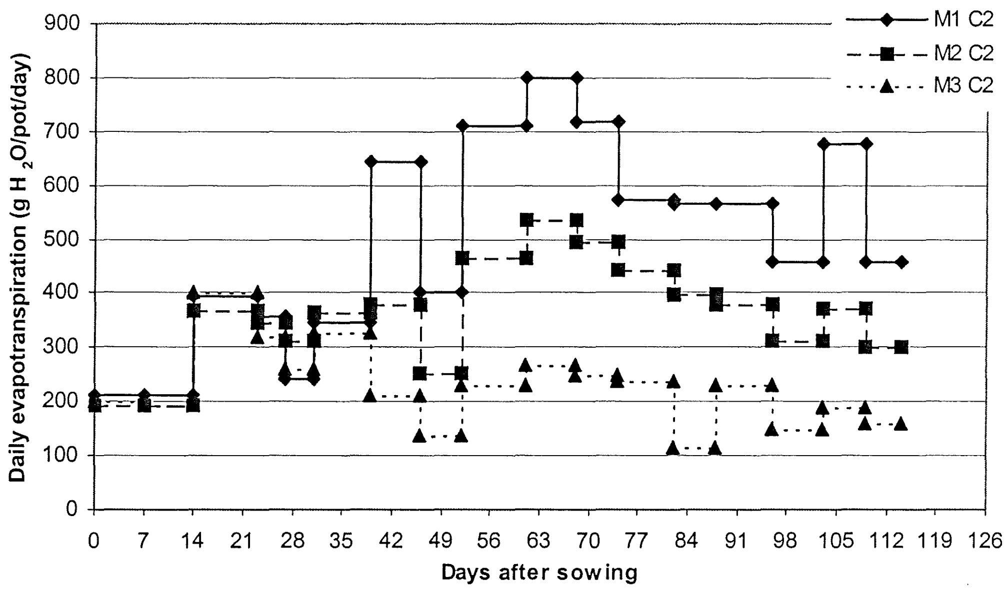

Fig.10. Estimated daily evapotranspiration (g H_2O/pot/day) of the pots of intercropping between sorghum and cowpea as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) throughout the growing period (9June-1October 1998).

For sorghum grown in monoculture different amount of water in pots at each water supply level was maintained (fig.5). For cowpea grown in monoculture the amount of water in pots at all water supply levels was not very different, though at the last period of the experiment M1 had a higher value compared with M2 and M3 (fig. 7). Similarly for intercropping between sorghum and cowpea, under all water supply levels, differences between amount of water in pots were observed only at M1 (fig.9).

A comparison between (fig. 6, 8 and 10) shown that evapotranspiration of the three cropping systems was dictated by amount of water supply. Only small differences were observed between different cropping systems (Table. 2).

Table.2. Estimated total evapotranspiration (total ET; gDm/gH_2O) and estimated daily evapotranspiration (daily ET; $gDm/gH_2O/day$) of the three cropping systems as affected by water supply levels (M1 = high, M2 = intermediate and M3 = low water supply level) through out the growing period 9June-1October 1998.

Water supply level	Sorghum grown in monoculture		Cowpea grown in monoculture		Sorghum-cowpea intercropping	
	Total ET gDm/gH_2O	Daily ETg Dm/ g H_2O/d	Total ET g Dm/g H_2O	Total ET $gDm/gH_2O/d$	Total ET gDm/gH_2O	Daily ET gDm/gH2O/d
M1	54662	480	56326	494	56910	499
M2	39595	347	41884	367	41535	364
M3	26414	232	26746	235	26498	232

3.2 Effects of water supply level on sorghum

3.2.1 Intermediate harvest

Total biomass

Table 3. Total biomass (g/plant) and biomass partitioning of sorghum grown in monoculture and sorghum intercropped with cowpea as affected by water supply level (M1= high, M2 = intermediate and M3 = low) at intermediate harvest.

water supply level	Total biomass (g/plant)	Fraction shoot	Fraction stem	Fraction leaf	Fraction green leaf	Fraction dead leaf	Fraction root	Root/ shoot ratio
Sorghum grown in monoculture								
M1	16.87 aB[1]	0.89 aA	0.46 bB	0.54 aA	0.54 aA	0.00 aA	0.11 aA	0.12 aA
M2	17.06 aB	0.85 aA	0.42 aB	0.58 bA	0.58 bA	0.00 aA	0.15 bA	0.18 aA
M3	16.50 aB	0.82 aA	0.41 aA	0.59 bA	0.59 bA	0.00 aA	0.18 bA	0.21 aA
Sorghum grown in intercropping								
M1	6.73 aA	0.85 aA	0.38 aA	0.62 aB	0.61 aB	0.01 aA	0.15 aA	0.17 aA
M2	7.49 aA	0.85 aA	0.37 aA	0.63 aB	0.62 aA	0.01 aA	0.15 aA	0.17 aA
M3	5.93 aA	0.81 aA	0.37 aA	0.63 aA	0.61 aA	0.03 bB	0.19 aA	0.24 aA
LSD_1 ($P < 0.05$)	3.71	0.07	0.03	0.03	0.04	0.02	0.07	0.1
LSD_2 ($p < 0.05$)	6.2	0.05	0.04	0.04	0.04	0.01	0.05	0.07
CV%	14.2	2	5.4	3.6	3.8	91	11.4	14.2

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).
Note:
LSD_1 = For comparing means within the same cropping system (using small letters).
LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 3. shows that the total biomass of sorghum plants grown in monoculture at 56 DAS, was not affected by water supply level. Although there was no effect on biomass production, water supply level had a clear effect on biomass partitioning. Fraction shoot tended to decrease with a reduced water supply level, though this effect was not statistically significant. Fraction root increased with a reduced water supply level and gave significantly higher values at M2 and M3 than at M1. Root /shoot ratio tended to increase with a reduced water supply level, but these differences were not significant. Within the shoot, fraction total leaf increased with a reduced water supply level and showed significantly higher values at M2 and M3 than at M1. Fraction stem decreased with a reduced water supply level and it was significantly higher at M1 than at M2 and M3. At this stage, no dead leaves were observed.

Also for sorghum intercropped with cowpea total biomass was not affected by water supply level. Similarly biomass partitioning was not affected by water supply level. Although fraction root and root/shoot ratio tended to increase at the lowest water supply level (M3). Only fraction dead leaf was significantly increased at M3 compared to M1 and M2.

Under all water supply levels, sorghum in monoculture gave significantly higher total biomass than sorghum intercropped with cowpea. Fraction shoot, fraction root and root/shoot ratio were not affected by the type of cropping system. Fraction stem was significantly higher for sorghum grown in monoculture at M1 and M2 compared to sorghum grown in intercropping at the same water supply levels. This increase of fraction stem material was also reflected in a reduced fraction leaf. For sorghum in intercropping at the lowest water supply level many leaves were dead resulting in a significantly higher fraction dead leaf material.

Leaf area

Table 4. Total leaf dry weight (g/plant), leaf area (LA; cm^2/plant) and specific leaf area (SLA;cm^2/g) of sorghum grown in monoculture and sorghum intercropped with cowpea as affected by water supply level (M1= high, M2 = intermediate and M3 = low) at intermediate harvest.

Water supply level	Total leaf dry weight (g/plant)	LA (cm^2/plant)	SLA (cm^2/g)
Sorghum grown in monoculture			
M1	8.14 aB[1]	2440 aB	300.6 aA
M2	8.28 aB	2430 aB	298.8 aA
M3	7.94 aB	2165 aB	276.1 aA
Sorghum grown in intercropping			
M1	3.56 aA	1236 abA	364.2 aB
M2	4.05 aA	1328 bA	332.6 aA
M3	3.03 aA	0912 aA	320.7 aB
LSD_1 ($P < 0.05$)	1.57	375.5	53.1
LSD_2 ($P < 0.05$)	2.26	411.7	47.1
CV%	10.1	9.6	6.4

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).
Note:
LSD_1 = For comparing means within the same cropping system (using small letters).
LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 4. shows that the total per plant leaf dry weight of sorghum grown in monoculture was not affected by water supply level. Leaf area (LA) and specific leaf area (SLA) were not significantly affected by water supply level, though LA and SLA tended to reduce at the lowest water supply level.

Also for sorghum grown in intercropping the per plant total leaf dry weight was not affected by a reduced water supply level. Leaf area at the lowest water supply level was significantly reduced compared to that at the intermediate supply level (M2). Specific leaf area (SLA) tended to decrease with a reduced water supply level, but the differences were not statistically significant.

Under all water supply levels, sorghum intercropped with cowpea gave significantly lower leaf dry weight and leaf area (LA) than sorghum grown in monoculture. Specific leaf area (SLA) of sorghum grown in intercropping was significantly higher than SLA of sorghum grown in monoculture at the same water supply level, except for the intermediate water supply level, where this difference was not significant.

3.2.2 Final harvest

Total biomass

Table 5. Total biomass (g/plant) and biomass partitioning of sorghum grown in monoculture and sorghum intercropped with cowpea as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at final harvest.

Water supply level	Total biomass (g/plant)	Fraction shoot	Fraction stem	Fraction leaf	Fraction green leaf	Fraction dead leaf	Fraction ear	Fraction root	Root/ shoot ratio
Sorghum grown in monoculture									
M1	52.41 aB[1]	0.91 bA	0.36 aA	0.20 aA	0.20 aA	0.01 aA	0.44 aB	0.09 aB	0.10 aA
M2	56.20 aB	0.90 abA	0.36 aB	0.21 aA	0.19 aA	0.01 aA	0.44 aA	0.10 abB	0.11 aB
M3	46.24 aB	0.89 aA	0.34 aB	0.23 aA	0.22 aA	0.01 aA	0.43 aA	0.11 bB	0.13 bB
Sorghum grown in intercropping									
M1	14.44 aA	0.93 aB	0.33 aA	0.33 aB	0.30 bB	0.03 aA	0.34 aA	0.07 aA	0.08 aA
M2	14.92 aA	0.93 aB	0.28 aA	0.34 aB	0.28 abB	0.05 abB	0.38 abA	0.07 aA	0.08 aA
M3	17.96 aA	0.93 aB	0.27 aA	0.30 aB	0.23 aA	0.07 bB	0.43 bA	0.07 aA	0.08 aA
LSD_1 ($P < 0.05$)	10.22	0.01	0.07	0.05	0.06	0.03	0.08	0.01	0.02
LSD_2 ($P < 0.05$)	10.92	0.01	0.06	0.04	0.04	0.02	0.07	0.01	0.02
CV%	6	0.7	10.8	6.6	9.3	54.7	6.00	8.00	8.70

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).
Note:
LSD_1 = For comparing means within the same cropping system (using small letters).
LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 5. shows that the total biomass of sorghum grown in monoculture was not significantly affected by water supply level. Fraction shoot slightly decreased at a reduced water supply level and gave a significantly lower value in M3 than at M1. On the other hand, fraction root increased with a reduced water supply level and gave a significantly higher value at M3 than at M1. Root/shoot ratio was also increased with a reduced water supply level. A significantly higher value was observed at M3 compared to M1 and M2. Dry matter partitioning within the shoot was not significantly affected by water supply level.

For sorghum intercropped with cowpea the total biomass tended to increase with a reduced water supply level, but the differences were not statistically significant. Fraction shoot, fraction root and root/shoot ratio were not affected by water supply level. Fraction leaf and fraction stem tended to decrease at the lowest water supply level. Fraction green leaf decreased with a reduced water supply level and gave a significantly lower value at M3 than at M1 due to a significant increase in the fraction dead leaf material. Fraction ear increased with a reduced water supply level reflected in a significant difference between M1 and M3.

Under all water supply levels, the total biomass of sorghum intercropped with cowpea was significantly lower than that of sorghum grown in monoculture. Total plant weight in monoculture was about three times as high. Fraction shoot was significantly higher for sorghum grown in intercropping at all water supply levels. Fraction root was significantly higher for sorghum grown in monoculture than for sorghum intercropped with cowpea. As a result root/shoot ratio of sorghum grown in monoculture was significantly higher than that of sorghum grown in intercropping, although at M1 this difference was not significant. Within the shoot, fraction leaf was significantly higher for sorghum grown in intercropping than for sorghum grown in monoculture. Fraction green leaf of sorghum grown in intercropping under M1 and M2 were significantly higher than for sorghum grown in monoculture under these water supply levels. For sorghum grown in intercropping many leaves were dead under M2 and M3 resulting in a significantly higher fraction dead leaf than for sorghum grown in monoculture under these water supply levels. Fraction stem was significantly lower for sorghum grown in intercropping under M2 and M3 compared to sorghum grown in monoculture. Fraction ear of sorghum grown in monoculture under M1 was significantly higher than of sorghum grown in intercropping under M1.

Leaf area

Table 6. Total leaf dry weight (g/plant), leaf area (LA; cm^2/plant) and specific leaf area (SLA;cm^2/g) of sorghum grown in monoculture as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at final harvest.

Water supply level	Total leaf dry weight (g/plant)	LA (cm^2/plant)	SLA (cm^2/g)
Sorghum grown in monoculture			
M1	9.46 aB[1]	2199 aB	245.1 aA
M2	10.27 aB	2377 bB	248.0 aA
M3	9.33 aB	2107 aB	241.1 aA
Sorghum grown in intercropping			
M1	4.28 aA	1235 aA	323.2 aB
M2	4.43 aA	1194 aA	334.5 aB
M3	5.03 aA	1195 aA	316.1 aB
LSD_1 ($P < 0.05$)	1.4	228.9	42.29
LSD_2 ($P < 0.05$)	0.6	193.2	38.11
CV%	3.8	7.3	7.2

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).
Note:
LSD_1 = For comparing means within the same cropping system (using small letters).
LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 6. shows that the per plant total leaf dry weight of sorghum grown in monoculture was not affected by water supply level. For leaf area a significantly higher value was observed at M2 than at M1 and M3. Specific leaf area (SLA) was not significantly affected by water supply level.

For sorghum intercropped with cowpea the per plant total leaf dry weight tended to increase with a reduced water supply level, though the differences were not significant. Leaf area and specific leaf area were not significantly affected by a reduction in water supply level.

Under all water supply levels, the per plant total leaf dry weight and leaf area of sorghum grown in intercropping were significantly lower than of sorghum grown in monoculture. On the other hand, specific leaf area (SLA) of sorghum grown in intercropping was significantly higher than that of sorghum grown in monoculture. As a result the relative difference in leaf area between cropping systems was smaller than the difference in leaf dry weight.

Marketable yield

Table 7. Seed yield (12% moisture;g/plant), number of seeds, weight of dry chaff (g), weight of 1000 seeds (12% moisture;g) and harvest index (HI) of sorghum grown in monoculture and sorghum intercropped with cowpea as affected by water supply level (M1 = high, M2 = intermediate and M3 = low).

Water supply level	Seed yield (12%) Moisture (g/plant)	Number of seeds/ plant	Weight of dry chaff (g/plant)	Weight of 1000 Seeds (12%m;g)	HI
Sorghum grown in monoculture					
M1	17.95 aB[1]	906 aB	5.19 aB	19.81 aB	0.38 aB
M2	19.69 aB	941 aB	4.60 aB	20.86 aB	0.39 aB
M3	15.23 aB	725 aB	4.05 aB	23.75 bB	0.37 aA
Sorghum grown in intercropping					
M1	3.59 aA	288 aA	1.43 aA	12.35 aA	0.26 aA
M2	4.32 aA	343 aA	1.73 aA	12.12 aA	0.29 aA
M3	5.60 aA	478 aA	2.19 aA	11.56 aA	0.33 aA
LSD^1 ($P < 0.05$)	5.27	276	1.16	3.92	0.08
LSD^2 ($P < 0.05$)	3.01	179	1.03	3.61	0.06
CV%	11.7	16	17	14.4	6.3

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).
Note:
LSD_1 = For comparing means within the same cropping system (using small letters).
LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 7. shows that the seed yield (expressed at 12% moisture) of sorghum grown in monoculture was not significantly affected by water supply level. The weight of dry chaff per plant also decreased with a reduced water supply level, but the differences were not statistically significant. Number of seeds per plant tended to decrease at the lowest water supply level. Weight of 1000 seeds increased at a reduced water supply level and was significantly higher at M3 than at M1 and M2. Harvest index was not significantly affected.

For sorghum intercropped with cowpea, seed yield, number of seeds, weight of dry chaff, weight of 1000 seeds and HI were not significantly affected by water supply level. However, seed yield, number of seed and HI tended to increase with a reduced water supply level.

Under all water supply levels, seed yield, number of seeds per plant, weight of dry chaff and weight of 1000 seeds of sorghum grown in intercropping were significantly lower than that of sorghum grown in monoculture. Harvest index of sorghum grown in monoculture under M1 and

M2 was significantly higher than that of sorghum grown in intercropping. Only at the lowest water supply level no significant difference was observed.

3.2.3 Results of photosynthesis measurements

First period

Table 8. Maximum leaf photosynthetic rate (Pmax;$mgCO_2/m^2/s$), leaf transpiration rate ($mgH_2O/m^2/s$) and stomatal conductance (mm/s) of sorghum grown in monoculture and sorghum intercropped with cowpea as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) measured at 49-52 DAS.

Water supply level	Pmax. ($mgCO^2/m^2/s$)	Leaf transpiration rate (mg $H_2O/m^2/s$)	Stomatal conductance (mm/s)
Sorghum grown in monoculture			
M1	1.22 aB[1]	69.99 aA	8.98 aA
M2	1.26 aB	79.27 aA	12.10 aB
M3	1.27 aB	76.72 aB	10.97 aB
Sorghum grown in intercropping			
M1	0.95 bA	62.72 aA	6.26 aA
M2	0.88 bA	59.42 aA	6.00 aA
M3	0.63 aA	45.84 aA	3.59 aA
LSD_1 ($P < 0.05$)	0.20	19.35	3.36
LSD_2 ($P < 0.05$)	0.26	21.59	3.96

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$)

Note:

LSD_1 = For comparing means within the same cropping system (using small letters)

LSD_2 = For comparing means within the same water supply level (using capital letters)

Table 8. shows that the maximum leaf photosynthetic rate, transpiration rate and stomatal conductance of sorghum leaves grown in monoculture were not affected by water supply level. For sorghum intercropped with cowpea maximum leaf photosynthetic rate decreased with a reduced water supply level and gave a significantly lower value at the lowest water supply level. Leaf transpiration rate and stomatal conductance tended to decrease at the lowest water supply level, but these differences were not statistically significant.

Under all water supply levels, the maximum leaf photosynthetic rate of sorghum leaves grown in intercropping was significantly lower than that of sorghum leaves grown in monoculture. At the lowest water supply level, leaf transpiration rate of sorghum intercropped with cowpea was significantly lower than that of sorghum grown in monoculture. At M2 and M3 stomatal conductance of sorghum grown in intercropping was significantly lower than of sorghum grown in monoculture.

Second period

Table 9. Maximum leaf photosynthetic rate (Pmax;mgCO_2/m^2/s), leaf transpiration rate (mgH_2O/m^2/s) and stomatal conductance (mm/s) of sorghum grown in monoculture and sorghum intercropped with cowpea as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) measured at 63-66 DAS.

Water supply level	Pmax. (mgCO^2/m^2/s)	Leaf transpiration rate (mg H_2O/m^2/s)	Stomatal conductance (mm/s)
Sorghum grown in monoculture			
M1	1.15 bB[1]	76.6 aA	8.46 aA
M2	1.18 bB	80.0 aA	8.55 aA
M3	0.74 aA	50.3 aA	4.48 aA
Sorghum grown in intercropping			
M1	0.89 bA	66.4 aA	5.93 aA
M2	0.74 abA	56.4 aA	4.48 aA
M3	0.61 aA	38.3 aA	3.47 aA
LSD_1 ($P < 0.05$)	0.27	29.9	9.11
LSD_2 ($P < 0.05$)	0.19	26.51	7.73

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$)

Note:

LSD_1 = For comparing means within the same cropping system (using small letters)

LSD_2 = For comparing means within the same water supply level (using capital letters)

Table 9. shows that the maximum leaf photosynthetic rate of sorghum leaves grown in monoculture was decreased with a reduced water supply level and gave significantly lower value at the lowest water supply level. Leaf transpiration rate and stomatal conductance tended to decrease at the lowest water supply level.

For sorghum grown in intercropping maximum leaf photosynthetic rate was significantly lower at M3 than at M1. Leaf transpiration and stomatal conductance were decreased with a reduced water supply level, but the differences were not significant.

Under M1 and M2 sorghum grown in monoculture had a significantly higher maximum leaf photosynthetic rate than sorghum grown in intercropping at the same water supply level.

Under all water supply levels, leaf transpiration rate and stomatal conductance of sorghum grown in monoculture were not significantly different from that of sorghum grown in intercropping.

3.2.4 Growth measurements

Sorghum Leaf

In (fig.11) it is shown that the number of leaves per sorghum plant grown in monoculture was not affected by water supply level. At the lowest water supply level, the number of leaves of sorghum intercropped with cowpea tended to decreased. LA of sorghum grown in monoculture at the lowest water supply level, decreased as a result of death of some leaves. LA of sorghum intercropped with cowpea was not affected by water supply level. Although there was no big effect on the number of leaves, there was a clear decrease in per plant leaf area of sorghum grown in intercropping (Fig. 12). This decrease was also reflected in the average leaf size of sorghum grown in intercropping (Fig. 13). Leaf size of sorghum grown in monoculture was hardly affected by water supply level (Fig.13). Specific leaf area (SLA) of leaves grown in intercropping was higher (Fig. 14), whereas SPAD, which positively correlates with cholorophyll in a leaf, was reduced (Fig.15). SLA was hardly affected by water supply level, but SPAD was slightly decreased with a reduced water supply level.

In (fig.16) It is shown that the length of sorghum plants grown in monoculture at the lowest water supply level was decreased compared to the other two water supply levels (M1 and M2). Plant length of sorghum grown in intercropping was not affected by water supply level, but under all water supply levels, sorghum plants grown in intercropping were shorter than sorghum plants grown in monoculture.

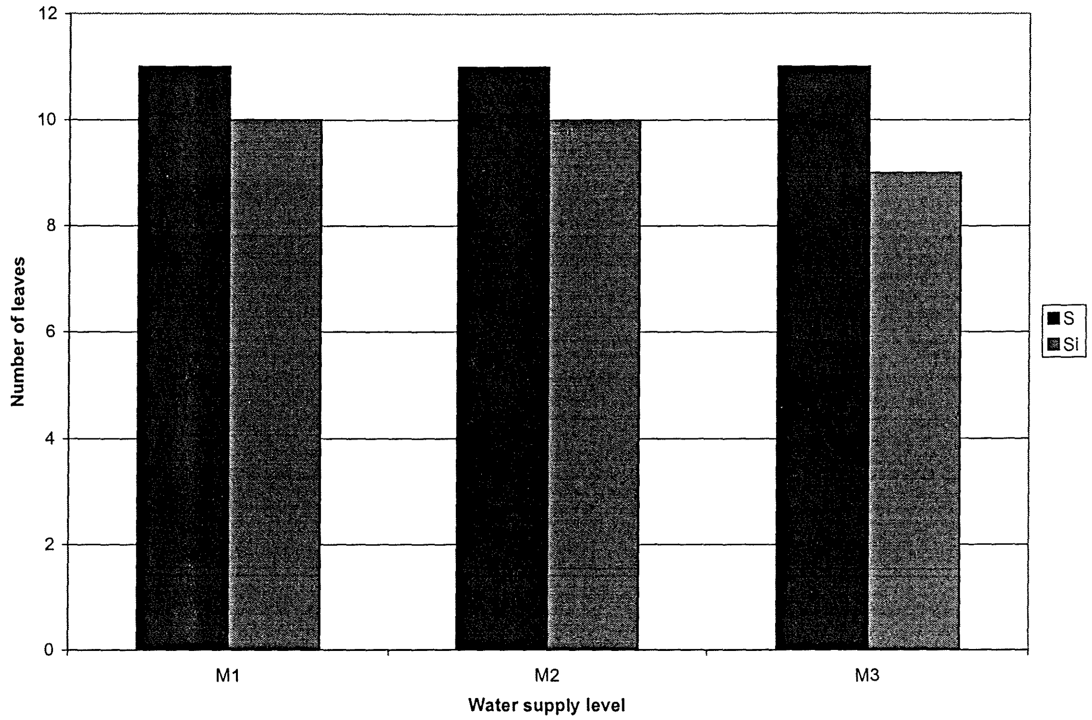

Fig. 11. Average number of leaves of sorghum grown in monoculture (S) and sorghum intercropped with cowpea (Si) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at 65 days after sowing (after the appearance of the flag leaf).

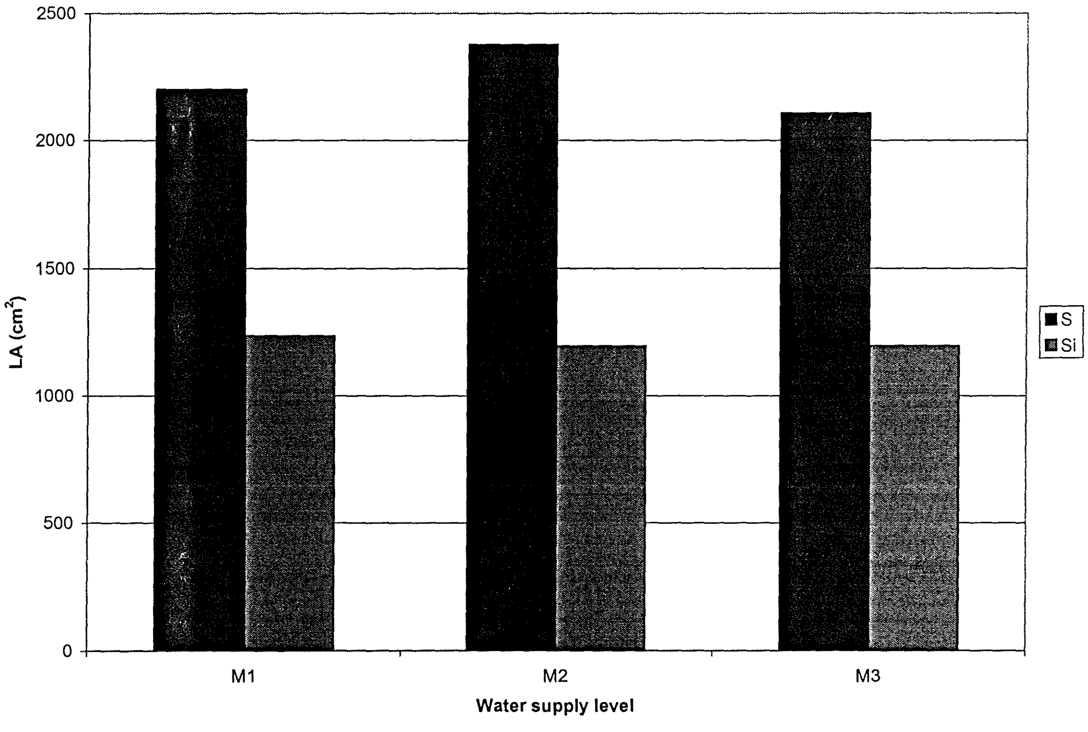

Fig. 12. Average leaf area (LA;cm²/plant) of sorghum grown in monoculture (S) and sorghum grown in intercropping with cowpea (Si) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at final harvest.

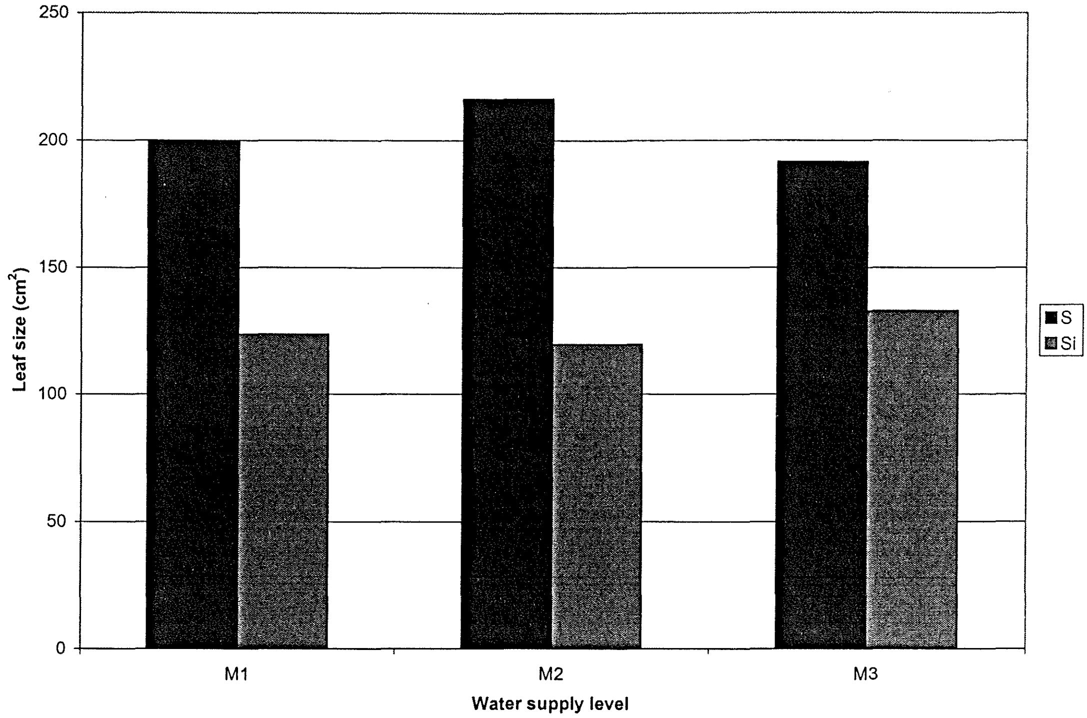

Fig.13. Average leaf size (cm^2) of sorghum grown in monoculture (S) and sorghum intercropped with cowpea (Si) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at final harvest.

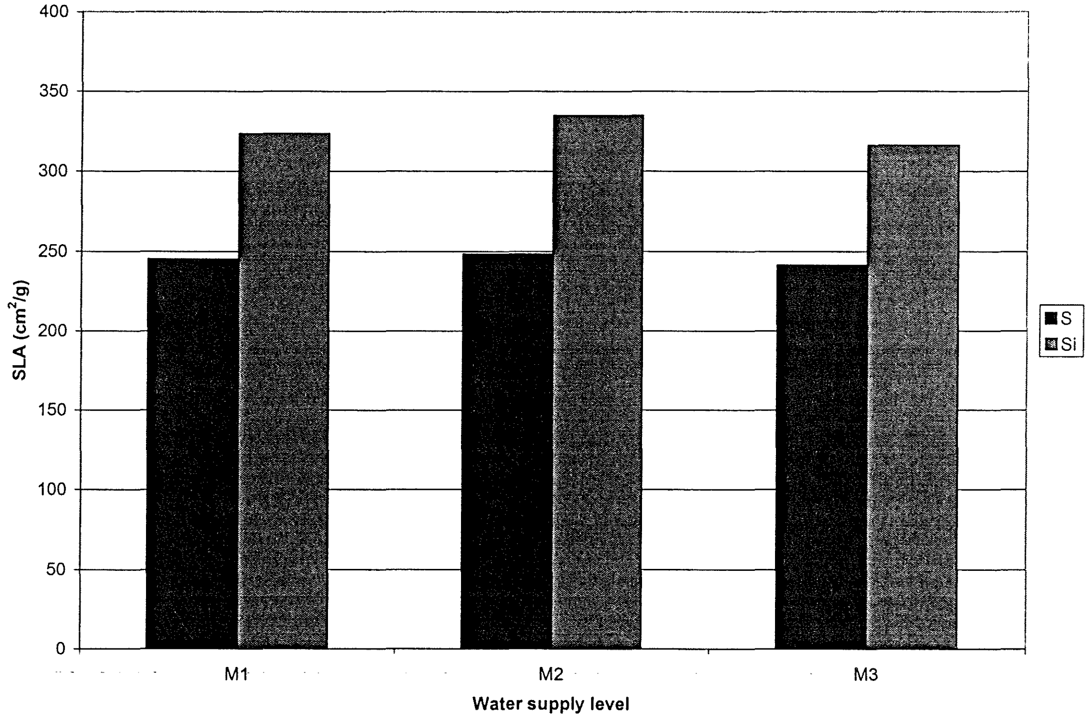

Fig. 14. Average specific leaf area (SLA;cm^2/g) of sorghum grown in monoculture (S) and sorghum intercropped with cowpea (Si) as affected by water supply level (M1 = high, M2 intermediate and M3 = low) at final harvest.

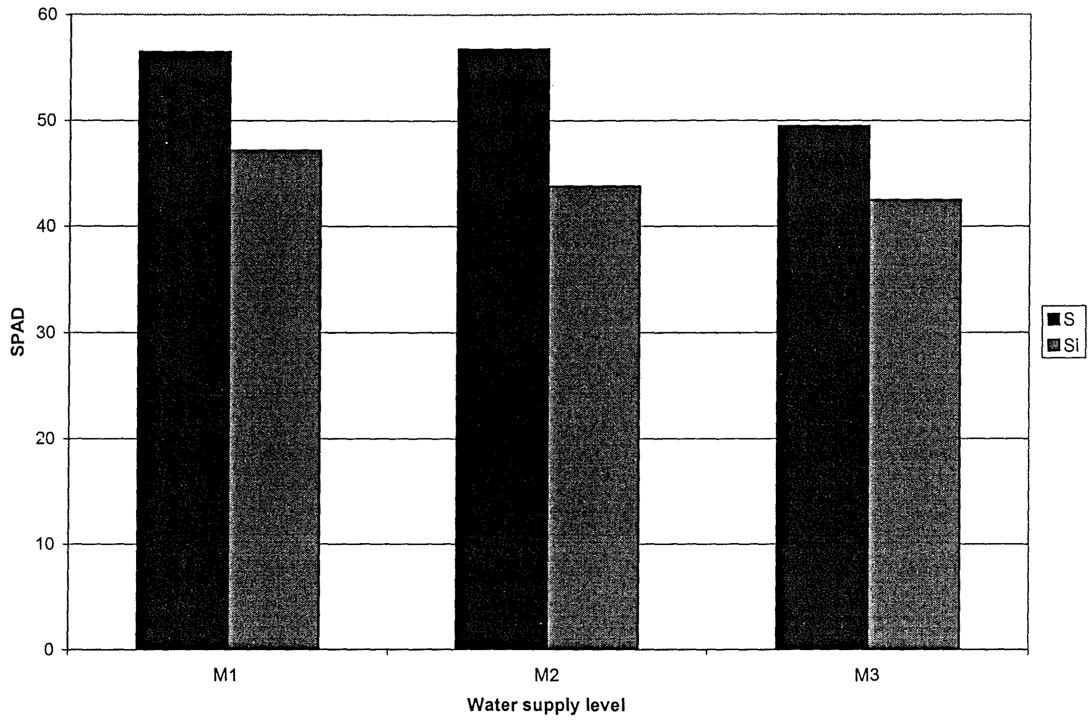

Fig. 15. Average SPAD of leaves of sorghum grown in monoculture (S) and sorghum intercropped with cowpea (Si) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at 58 DAS.

Plants length

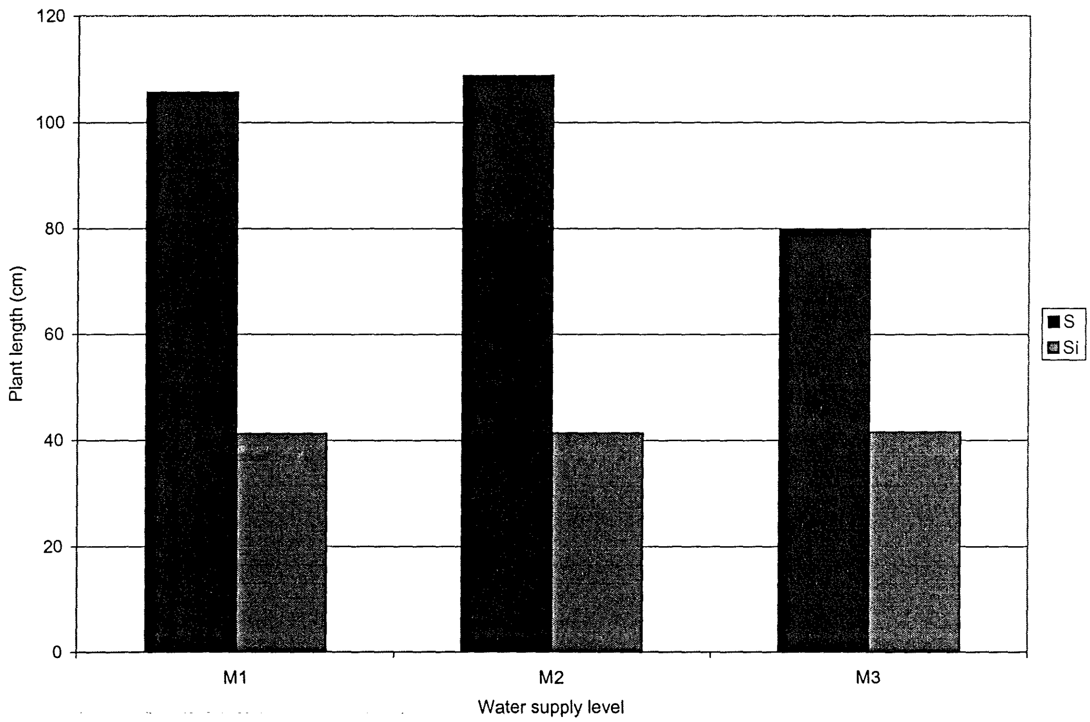

Fig.16. Average plant length of sorghum grown in monoculture (S) and sorghum intercropped with cowpea (Si) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at 67 DAS.

3.3 Effects of water supply level on cowpea

3.3.1 Intermediate harvest

Total biomass

Table 10. Total biomass (g/plant) and biomass partitioning of cowpea grown in monoculture and cowpea intercropped with sorghum as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at intemediate harvest.

Water supply level	Total biomass (g/plant)	Fraction shoot	Fraction stem	Fraction leaf	Fraction green leaf	Fraction dead leaf	Fraction root	Root/ shoot ratio
Cowpea grown in monoculture								
M1	27.02 bA[1]	0.96 aA	0.51 aA	0.48 aA	0.48 aA	0.00 aA	0.04 aA	0.04aA
M2	22.96 bA	0.96 aA	0.51 aA	0.48 aA	0.48 aA	0.00 aA	0.04 aA	0.04aA
M3	15.11 aA	0.95 aA	0.51 aA	0.47 aA	0.44 aA	0.04 bA	0.05 aA	0.05aA
Cowpea grown in intercropping								
M1	48.79 bB	0.95 aA	0.51 aA	0.48 aA	0.48 aA	0.00 aA	0.04 aA	0.05aA
M2	32.55 aB	0.96 aA	0.53 aA	0.46 aA	0.46 aA	0.00 aA	0.04 aA	0.05aA
M3	27.53 aB	0.95 aA	0.51 aA	0.49 aA	0.42 aA	0.06 bA	0.05 aA	0.05aA
LSD_1 ($P < 0.05$)	6.08	0.01	0.03	0.03	0.06	0.02	0.01	0.01
LSD_2 ($P < 0.05$)	4.86	0.01	0.03	0.02	0.04	0.02	0.01	0.01
CV%	12.4	0.3	3.2	3	4.7	69.2	6.3	6.6

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).

Note:

LSD_1 = For comparing means within the same cropping system (using small letters).

LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 10. shows that the total biomass of cowpea grown in monoculture decreased with a reduced water supply level and was significantly lower at M3 compared to M1 and M2. Biomass partitioning and root/shoot ratio were not significantly affected by water supply level. At the lowest water supply level leaves started to die earlier, resulting in a significantly higher fraction dead leaf.

Similarly, for cowpea grown in intercropping the total biomass decreased with a reduced water supply level. At the highest water supply level, a significantly higher value was observed. Root/shoot ratio and biomass partitioning were not affected by a reduced water supply level except for fraction dead leaf, which was significantly higher at the lowest water supply level.

Under all water supply levels, cowpea intercropped with sorghum gave a significantly higher total individual plant biomass than that of cowpea grown in monoculture. Root/shoot ratio of cowpea was not significantly affected by the type of cropping system. Cowpea grown in intercropping showed the same pattern of biomass partitioning as cowpea grown in monoculture.

Leaf area

Table 11. Total leaf dry weight (g/plant), leaf area (LA; cm^2/plant) and specific leaf area (SLA;cm^2/g) of cowpea grown in monoculture and cowpea intercropped with sorghum as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at intermediate harvest.

Water supply level	Total leaf dry weight (g/plant)	LA (cm^2/plant)	SLA (cm^2/g)
Cowpea grown in monoculture			
M1	12.42 bA[1]	5042 bA	409.3 aA
M2	10.55 bA	4291 bA	412.3 aA
M3	6.79 aA	3020 aA	485.6 bA
Cowpea grown in intercropping			
M1	22.56 bB	8467 bB	383.3 aB
M2	14.28 aB	5967 aB	417.7 abB
M3	12.71 aB	5014 aB	463.7 bB
LSD_1 ($P < 0.05$)	3.62	1179.1	60.25
LSD_2 ($P < 0.05$)	2.9	938.6	50.46
CV %	16.3	12.9	6.4

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).

Note:

LSD_1 = For comparing means within the same cropping system (using small letters).

LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 11. shows that the per plant values of both leaf dry weight and leaf area of cowpea grown in monoculture decreased with a reduced water supply level, significantly lower value was observed at M3 compared with M1 and M2. The relative differences in leaf area between water supply levels was smaller than the differences in leaf dry weight, since specific leaf area (SLA) significantly higher at the lowest water supply level.

Also for cowpea grown in intercropping the total leaf dry weight decreased with a reduced water supply level. Total leaf dry weight at M1 was significantly higher thanat M2 and M3. Leaf area (LA) had the same trend, significantly higher value was observed at M1 compared with M2 and M3. Similar to the monoculture, the relative differences in leaf area between water supply levels were smaller than those in leaf dry weight, since specific leaf area (SLA) increased with a reduced water supply level and was significantly lower at M1 than at M3.

Under all water supply levels, cowpea intercropped with sorghum gave a significantly higher leaf area (LA) and total leaf dry weight than cowpea grown in monoculture. Specific leaf area (SLA) was not significantly different between both cropping systems.

3.3.2 Final harvest

Total biomass

Table 12. Total biomass (g/plant) and biomass partitioning of cowpea grown in monoculture and cowpea intercropped with sorghum as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at final harvest.

Water supply level	Total biomass (g/plant)	Fraction shoot	Fraction stem	Fraction leaf	Fraction green leaf	Fraction dead leaf	Fraction pod	Fraction root	Root/ shoot ratio
Cowpea grown in monoculture									
M1	68.69 cA[1]	0.98 aA	0.31 aA	0.19 aA	0.18 aA	0.01aA	0.50 bA	0.02 aA	0.02 aA
M2	56.19 bA	0.98 aA	0.31 aA	0.20 aA	0.19 aA	0.01aA	0.49 bA	0.02 aA	0.03 aA
M3	34.61 aA	0.97 aA	0.36 bA	0.26 bB	0.25 bB	0.01aA	0.38 aA	0.03 aA	0.03 aA
Cowpea grown in intercropping									
M1	130.28 cB	0.97aA	0.33 aA	0.19 aA	0.19 aA	0.00 aA	0.48 aA	0.03 aA	0.03 aA
M2	102.31 bB	0.97aA	0.30 aA	0.18 aA	0.17 aA	0.01 abA	0.52 aA	0.03 aA	0.03 aA
M3	57.68 aB	0.97aA	0.32 aA	0.23 bA	0.21 aA	0.02 bA	0.45 aB	0.03 aA	0.03 aA
LSD_1 ($P < 0.05$)	7.1	0.01	0.04	0.03	0.04	0.01	0.07	0.01	0.01
LSD_2 ($P < 0.05$)	6.61	0.01	0.04	0.02	0.03	0.01	0.06	0.01	0.01
CV%	4.7	0.4	6.7	5.4	7.4	49.5	6.9	13.1	13.2

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).
Note:
LSD_1 = For comparing means within the same cropping system (using small letters).
LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 12. shows that the total biomass of cowpea grown in monoculture decreased with a reduced water supply level and that there were significant differences between all water supply levels. Fraction shoot, fraction root and root/shoot ratio were not significantly affected by water supply level. Within the shoot, fraction leaf, fraction green leaf and fraction stem were increased with a reduced water supply level and gave significantly higher values at M3 than at M1 and M2. Fraction dead leaf was not affected by water supply level. On the other hand fraction pod decreased with a reduced water supply level and gave a significantly lower value at M3 than at M1 and M2.

For cowpea intercropped with sorghum the total biomass also decreased with a reduced water supply level and significant differences were observed between the various water supply levels. Fraction shoot, fraction root and root/shoot ratio were not affected by water supply level. Within the shoot, fraction leaf increased with a reduced water supply level and gave a significantly higher value at M3 than at M1 and M2. Fraction dead leaf increased with a reduced water supply level, resulting in a significantly higher value at M3 compared to M1. Fraction stem and fraction pod were not significantly affected by water supply level.

Under all water supply levels, the total per plant biomass of cowpea grown in intercropping was significantly higher than that of cowpea grown in monoculture. Fraction shoot, fraction root and root/shoot ratio were not affected by the type of cropping system. For dry matter partitioning within the shoot, only significant differences between cropping systems were observed at the lowest water supply level. Intercropping fraction leaf and fraction green leaf were significantly lower, whereas fraction pod was significantly higher. Fraction dead leaf and fraction stem were not affected by the type of cropping system.

Leaf area

Table 13. Total leaf dry weight (g/plant), leaf area (LA; cm^2/plant) and specific leaf area (SLA;cm^2/g) of cowpea grown in monoculture and cowpea intercropped with sorghum as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at final harvest.

Water supply level	Total leaf dry weight (g/plant)	LA (cm^2/plant)	SLA (cm^2/g)
Cowpea grown in monoculture			
M1	12.77 bA	5750 bA	471.0 bB
M2	10.70 abA	4465 aA	434.3 aB
M3	8.78 aA	3545 aA	424.0 aA
Cowpea grown in intercropping			
M1	24.44 cB	10490 cB	438.7 bA
M2	17.88 bB	6920 bB	407.8 a A
M3	12.74 aB	4847 aB	411.3 a A
LSD_1 ($P < 0.05$)	2.82	1297.3	24.23
LSD_2 ($P < 0.05$)	2.11	1055.6	18.44
CV%	7.9	9.5	3.5

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).
Note:
LSD_1 = For comparing means within the same cropping system (using small letters).
LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 13. shows that the per plant total leaf dry weight of cowpea grown in monoculture decreased with a reduced water supply level. At M3 a significantly lower value was observed than at M1. Leaf area (LA) also decreased with a reduced water supply level and gave significantly higher values at M1 than at M2 and M3. The relative differences in LA between water supply levels were bigger than the differences in leaf dry weight, since specific leaf area was significantly higher at the highest water supply level.

For cowpea intercropped with sorghum both total leaf dry weight and leaf area (LA) decreased with a reduced water supply level and significant differences were observed between all water supply levels. Similarly as for monoculture, the relative differences in LA between water supply levels were bigger than that in leaf dry weight, since also here specific leaf area (SLA) decreased with a reduced water supply level and gave significantly lower values at M2 and M3 than M1.

Under all water supply levels, the total per plant leaf dry weight and leaf area (LA) were significantly higher for cowpea grown in intercropping than for cowpea grown in monoculture. Also specific leaf area (SLA) of cowpea intercropped with sorghum under M1 and M2 were significantly lower than of cowpea grown in monoculture under these water supply levels.

Marketable yield

Table 14. Seed yield (13% moisture;g/plant), number of seeds, weight of 1000 seeds (13% moisture;g), weight of dry chaff (g) and harvest index (HI) of cowpea grown in monoculture and cowpea intercropped with sorghum as affected by water supply level (M1 = high, M2 = intermediate and M3 = low).

Water supply level	Seed yield (13%) Moisture (g/plant)	Number of seeds/ plant	Weight of dry Chaff (g/plant)	Weight of 1000 Seeds (13%m;g)	HI
Cowpea grown in monoculture					
M1	29.96 bA[1]	237 cA	7.02 bA	126.77 aA	0.45 bA
M2	24.17 bA	181 bA	5.67 bA	133.51 aA	0.45 bA
M3	11.52 aA	79 aA	2.44 aA	145.73 bA	0.35 aA
Cowpea grown in intercropping					
M1	54.79 cB	422 cB	12.88 cB	129.89 aA	0.44 aA
M2	45.83 bB	338 bB	11.35 bB	135.62 aA	0.47 aA
M3	22.90 aB	158 aB	4.94 aB	145.25 bA	0.42 aB
LSD_1 ($P < 0.05$)	6.19	51	1.51	8.51	0.07
LSD_2 ($P < 0.05$)	5.63	45	1.36	6.74	0.06
CV%	9.59	10.5	12.4	2.7	6.7

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$).
Note:
LSD_1 = For comparing means within the same cropping system (using small letters).
LSD_2 = for comparing means within the same water supply level (using capital letters)

Table 14. shows that both seed yield (expressed at 13% moisture) and weight of dry chaff of cowpea grown in monoculture decreased with a reduced water supply level, resulting in significant difference between M3 on the one hand and M1 and M2. Number of seeds per plant decreased significantly with a reduced water supply level. Weight of 1000 seeds on the other hand increased with a reduced water supply level. Values observed at M3 were significantly higher than at M1 and M2. Harvest index was significantly lower at the lowest water supply level.

For cowpea intercropped with sorghum, seed yield, weight of dry chaff and number of seeds decreased with a reduced water supply level. Significant differences between all water supply levels were observed. Weight of 1000 seeds increased with a reduced water supply level, though only the differences between M3 and, M1 and M2 were significant. Harvest index (HI) was not affected by water supply level.

Under all water supply levels, seed yield, number of seeds, and weight of dry chaff were significantly higher for cowpea grown in intercropping than for cowpea grown in monoculture. Weight of 1000 seeds was not affected by the type of cropping system. Harvest index of cowpea under M3 was significantly higher in intercropping than in monoculture.

3.3.3 Results of photosynthesis measurements

First period

Table 15. Maximum leaf photosynthetic rate (Pmax;mgCO_2/m^2/s), leaf transpiration rate (mgH_2O/m^2/s) and stomatal conductance (mm/s) of cowpea grown in monoculture and cowpea intercropped with sorghum as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) measured at 49-52 DAS.

Water supply level	Pmax. (mgCO^2/m^2/s)	Leaf transpiration rate (mg H_2O/m^2/s)	Stomatal conductance (mm/s)
Cowpea grown in monoculture			
M1	0.38 bA[1]	56.49 bA	5.85 bA
M2	0.32 bA	33.38 aA	2.52 abA
M3	0.12 aA	21.32 aA	1.51 aA
Cowpea grown in intercropping			
M1	0.31 bA	44.79 bA	3.57 aA
M2	0.27 abA	38.74 abA	3.52 aA
M3	0.10 aA	19.32 aA	1.14 aA
LSD_1 ($P < 0.05$)	0.20	19.35	3.36
LSD_2 ($P < 0.05$)	0.26	21.59	3.96

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$)

Note:

LSD_1 = For comparing means within the same cropping system (using small letters)

LSD_2 = For comparing means within the same water supply level (using capital letters)

Table 15. shows that the maximum leaf photosynthetic rate of cowpea grown in monoculture decreased with a reduced water supply level. Photosynthetic rate at M3 was significantly lower than at the other water supply levels. Leaf transpiration was significantly higher at the highest water supply level. Stomatal conductance was also reduced with a reduced water supply level, but only a significant difference was observed between M1 and M3.

Also for cowpea intercropped with sorghum, maximum leaf photosynthetic rate and leaf transpiration decreased with a reduced water supply level. Significant differences were observed between M1 and M3. Stomatal conductance tended to decrease at the lowest water supply level.

Under all water supply levels, maximum leaf photosynthetic rate, leaf transpiration rate and stomatal conductance were not significantly affected by the type of cropping system.

Second period

Table 16. Maximum leaf photosynthetic rate (Pmax; $mgCO_2/m^2/s$), leaf transpiration rate ($mgH_2O/m^2/s$) and stomatal conductance (mm/s) of cowpea grown in monoculture and cowpea intercropped with sorghum as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) measured at 63-66 DAS.

Water supply level	Pmax. ($mgCO^2/m^2/s$)	Leaf transpiration rate (mg $H_2O/m^2/s$)	Stomatal conductance (mm/s)
Cowpea grown in monoculture			
M1	0.24 aA[1]	48.9 aA	9.30 aA
M2	0.13 aA	31.6 aA	2.06 aA
M3	0.22 aA	31.0 aA	2.30 aA
Cowpea grown in intercropping			
M1	0.31 aA	56.5 aA	7.48 aA
M2	0.26 aA	50.9 aA	4.22 aA
M3	0.16 aA	26.7 aA	1.80 aA
LSD_1 ($P < 0.05$)	0.26	29.92	9.11
LSD_2 ($P < 0.05$)	0.19	26.51	7.73

[1] Means in the same column followed by the same letters are not significantly different according to LSD test ($P < 0.05$)

Note:

LSD_1 = For comparing means within the same cropping system (using small letters)

LSD_2 = For comparing means within the same water supply level (using capital letters)

Table 16. shows that the maximum leaf photosynthetic rate of cowpea grown in monoculture was not significantly affected by water supply level. Leaf transpiration rate and stomatal conductance were tended to decrease with a reduced water supply level.

Similarly, for cowpea intercropped with sorghum maximum leaf photosynthetic rate, leaf transpiration rate and stomatal conductance tended to decreased with a reduced water supply level, though no significant differences were observed. Under all water supply levels, maximum leaf photosynthetic rate, leaf transpiration rate and stomatal conductance were not significantly affected by the type of cropping system.

3.3.4 Growth measurements

Cowpea leaf

In (fig.17) it is shown that the number of leaves of both cowpea grown in monoculture and cowpea intercropped with sorghum was decreased with a reduced water supply level. Under all water supply levels, cowpea plants grown in intercropping had more leaves than cowpea grown in monoculture. For LA at the intermediate and final harvest (fig.18 and 19) the same trend was observed. At the lowest water supply level, LA of cowpea intercropped with sorghum was the same at the intermediate and final harvest, since many leaves were dead. Individual leaf size (base on LA at intermediate harvest) was little affected by cropping system or water supply level (fig.20). Therefore, the difference in number of leaves was the main factor in the differences in LA. The leaf characteristic SLA of both cowpea grown in monoculture and cowpea intercropped with sorghum decreased with a reduced water supply level. Under all water supply levels, cowpea grown in intercropping had a lower SLA (fig.21). On the other hand SPAD which positively correlates with cholorophyll in a leaf, for cowpea grown in monoculture was higher at M1 compared to M2 and M3. For cowpea intercropped with sorghum SPAD decreased with a reduced water supply level. Under all water supply levels, SPAD was higher for cowpea grown in intercropping except at M3 where it was higher for cowpea grown monoculture (fig. 22).

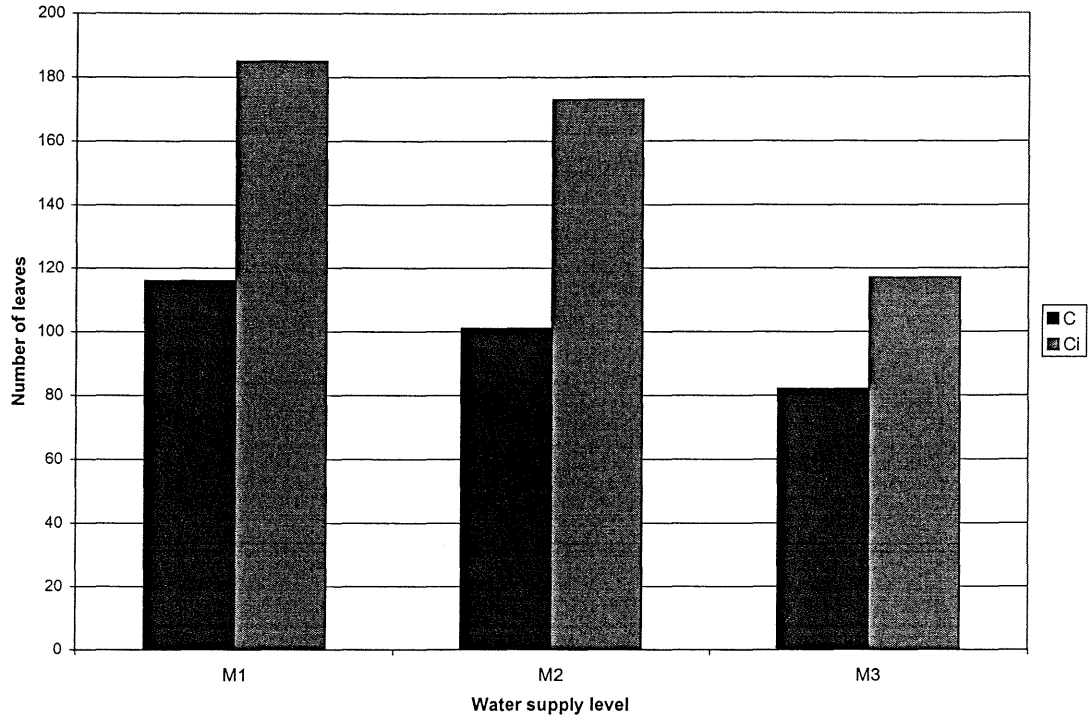

Fig. 17. Average number of leaves of cowpea grown in monoculture (C) and cowpea intercropped with sorghum (Ci) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at 65 DAS.

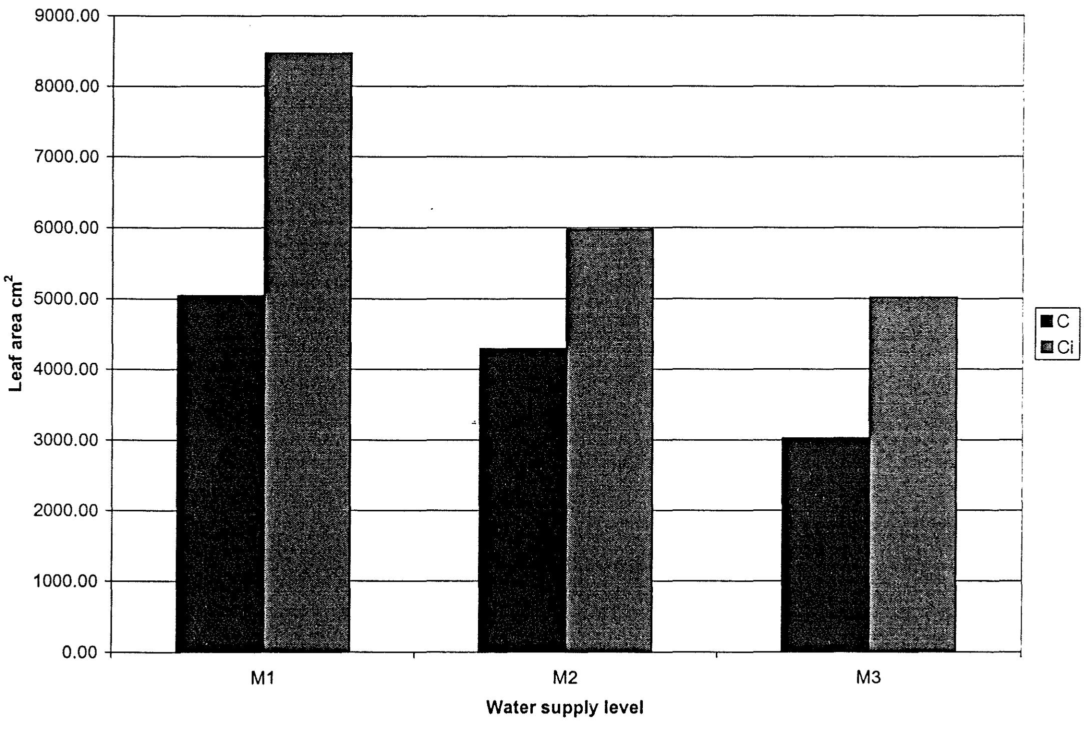

Fig. 18. Average leaf area (LA;cm²/plant) of cowpea grown in monoculture (C) and cowpea intercropped with sorghum (Ci) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at intermediate harvest.

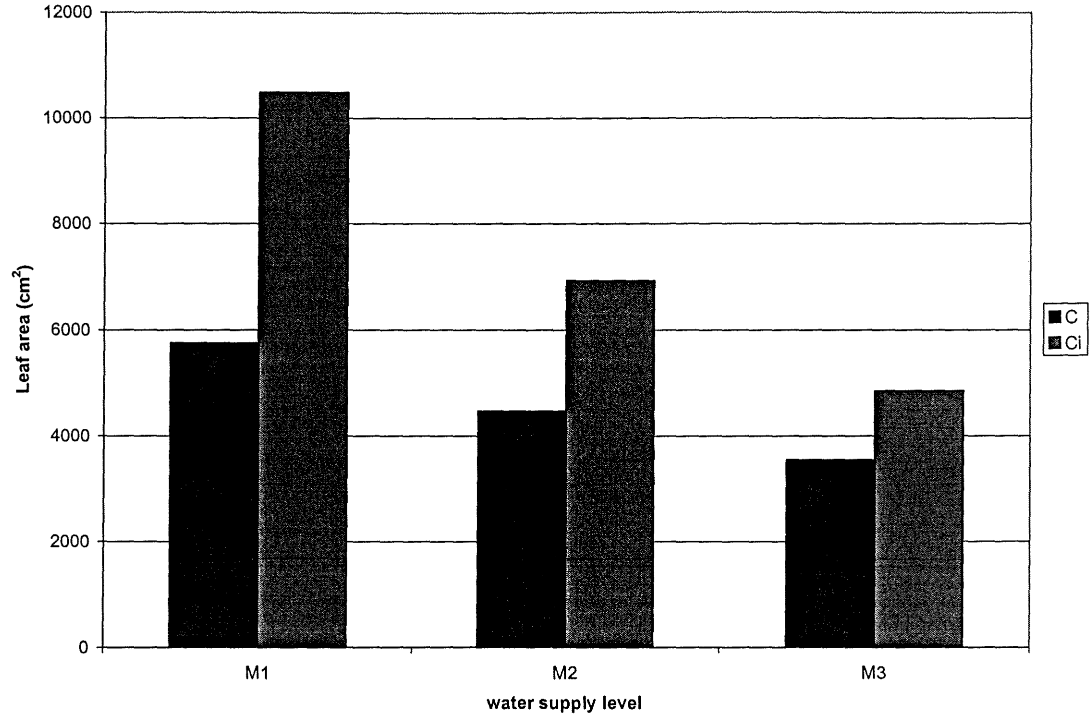

Fig. 19. Average leaf area (LA;cm²/plant) of cowpea grown in monoculture (C) and cowpea intercropped with sorghum (Ci) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at final harvest.

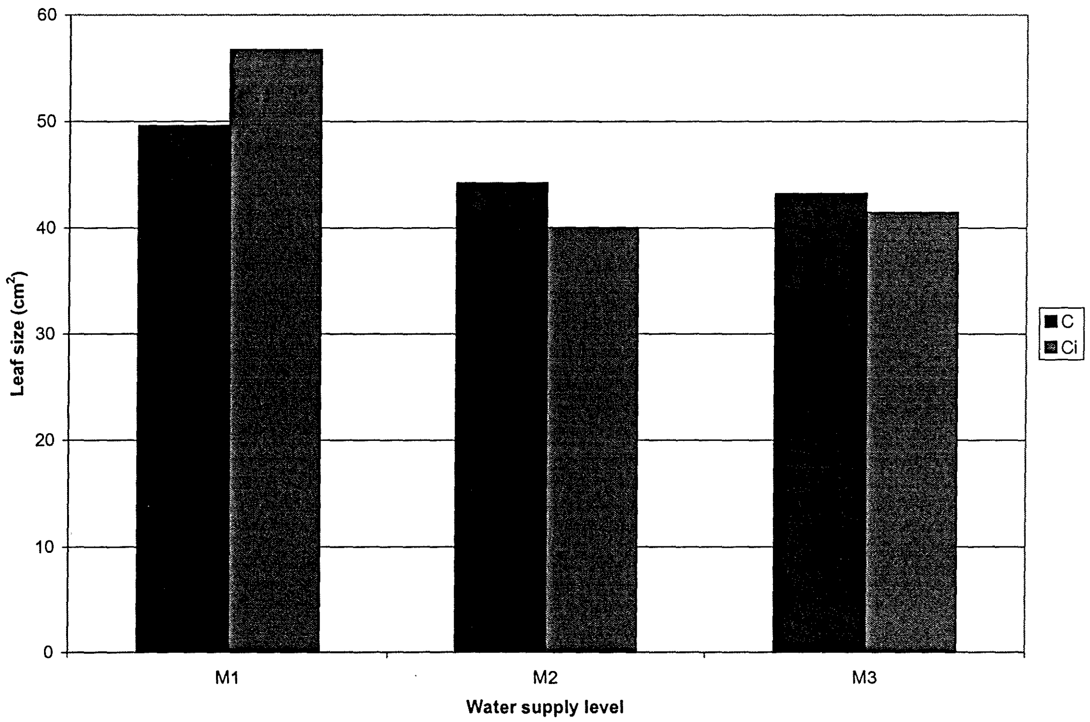

Fig. 20. Average leaf size (cm²) of cowpea grown in monoculture (C) and cowpea intercropped with sorghum (Ci) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at 65 DAS.

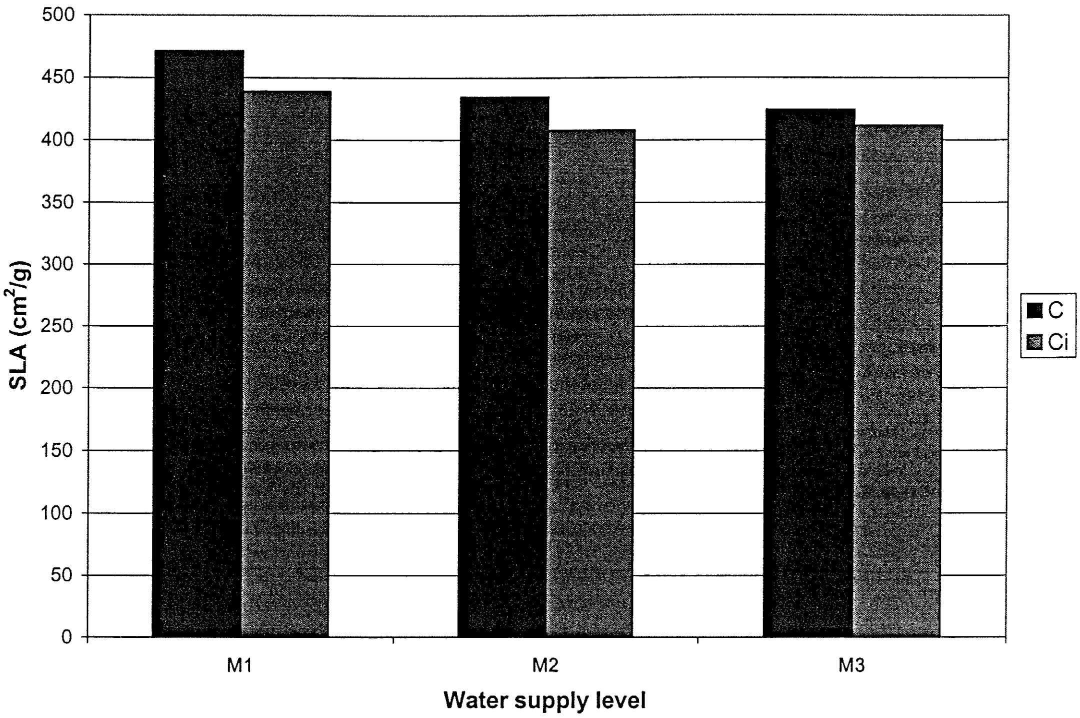

Fig. 21. Average specific leaf area (SLA;cm²/g) of cowpea grwon in monoculture (C) and cowpea intercropped with sorghum (Ci) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at final harvest.

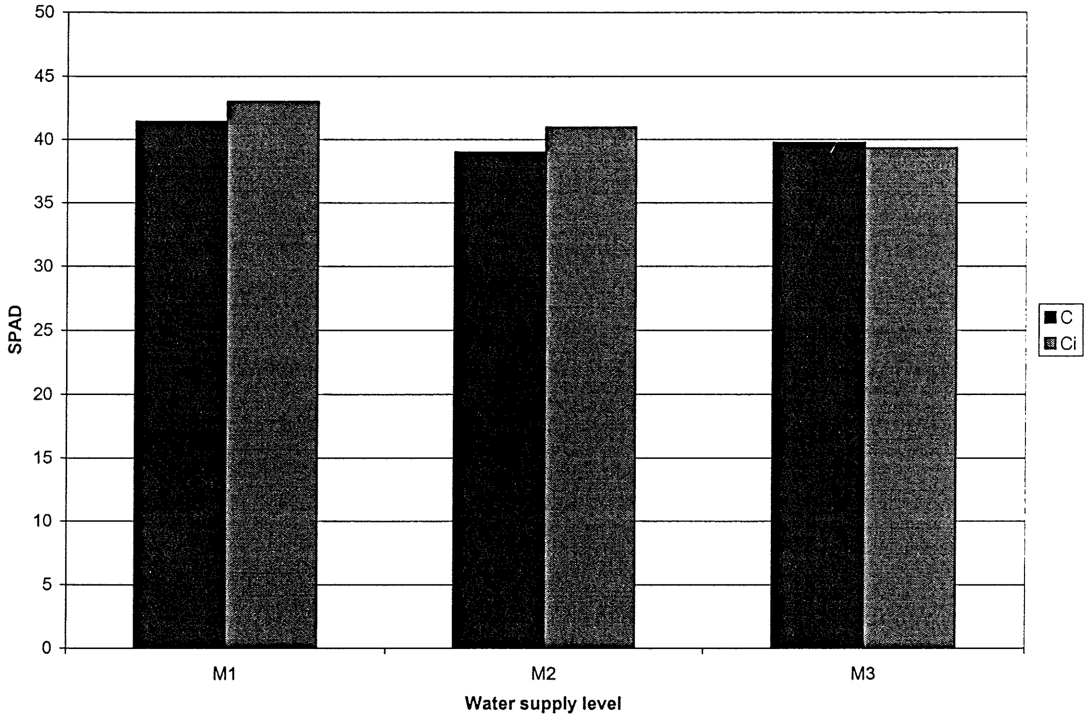

Fig 22. Average SPAD of the leaf of cowpea plants grown in monoculture (C) and cowpea intercropped with sorghum (Ci) as affected by water supply level (M1 = high, M2 = intermediate and M3 = low) at 58 DAS.

3.4 Calculation of water use

CGR = WU * WUE

Dry weight /unit area = unit mass of water up take/area * dry weight/unit mass of water up take

WUE = dry weight/unit mass of water up take

- *For sorghum grown in monoculture*

At M1 : WUE = 103.2/54662.15 = 0.001888 g Dm/g H_2O

At M2: WUE = 112.4/39595.38 = 0.002839 g Dm/g H_2O

At M3: WUE = 92.5/26414.09 = 0.003502 g Dm/g H_2O

- *For cowpea grown in monoculture*

At M1: WUE = 137.38/56326.24 = 0.002439 g Dm/g H_2O

At M2: WUE = 112.38/41884.95 = 0.002683 g Dm/g H_2O

At M3: WUE = 69.23/26746.35 = 0.002598 g Dm/g H_2O

- *For intercropping between sorghum and cowpea*

At M1: WUE = (14.44+130.3)/56910.05 = 0.002543 g Dm/g H_2O

At M2: WUE = (14.92+102.3)/41535.2 = 0.002822 g Dm/g H_2O

At M3: WUE = (17.96+57.7)/26498.69 = 0.002855 g Dm/g H_2O

3.5 Results of intercropping

3.5.1 Intermediate harvest

Table 17. Biomass of sorghum in monoculture (A;g/pot), biomass of sorghum in intercropping (B;g/pot), relative yield of sorghum (RYs), biomass of cowpea in monoculture (C;g/pot), biomass of cowpea in intercropping (D;g/pot), relative yield of cowpea (RYc) and relative yield total (RYT) of total biomass at intermediate harvest, as affected by water supply level (M1 = high, M2 = intermediate and M3 = low).

Water supply level	A = S-biom. (g/pot)	B = Si-biom. (g/pot)	RYs = B/A	C = C-biom. (g/pot).	D = Ci-biom (g/pot).	RYc = D/C	RYT = RYs+RYc
M1	33.75 a[1]	6.73 a	0.21 a	54.00 c	48.79 b	0.91 a	1.12 a
M2	34.12 a	7.49 a	0.23 a	45.90 b	32.55 a	0.72 a	0.95 a
M3	32.99 a	5.93 a	0.18 a	30.20 a	27.53 a	0.91 a	1.09 a
LSD (P < 0.05)	9.97	3.76	0.12	8.11	9.4	0.29	0.23
CV%	13.1	24.7	25.6	8.2	11.4	15.1	9.8

[1] Means in the same column followed by the same letters are not significantly different according to LSD test (P < 0.05).

Table 17. shows that the total biomass (g/pot) of both sorghum grown in monoculture and sorghum grown in intercropping was not significantly affected by water supply level. Similarly, relative yield of sorghum was not significantly affected by water supply level.

For cowpea biomass (g/pot) of plants grown in monoculture, significant differences were observed between all water supply levels, but for cowpea grown in intercropping a significantly higher value was obsereved only at the highest water supply level. The relative decrease in biomass (g/pot) of cowpea grown in intercropping between M1 and M2 was bigger than for cowpea grown in monoculture. As a result relative yield of cowpea plants grown at M2 was decreased compared to M1 and M3. Under all water supply levels, relative yield total (RYT) of total biomass was around unity. The share of sorghum in biomass production was less than 20% while the share of cowpea was more than 80%.

3.5.2 Final harvest

Table 18. Biomass of sorghum in monoculture (A;g/pot), biomass of sorghum in intercropping (B;g/pot), relative yield of sorghum (RYs), biomass of cowpea in monoculture (C;g/pot), biomass of cowpea in intercropping (D;g/pot), relative yield of cowpea (RYc) and relative yield total (RYT) of total biomass at final harvest, as affected by water supply level (M1 = high, M2 = intermediate and M3 = low).

Water supply level	A = S-biom (g/pot)	B = Si-biom (g/pot)	RYs = B/A	C = C-biom. (g/pot)	D = Ci-biom (g/pot)	RYc = D/C	RYT= Rys +RYc
M1	103.2 a[1]	14.44 a	0.14 a	137.38 c	130.3 c	0.954 a	1.10 a
M2	112.4 a	14.92 a	0.13 a	112.38 b	102.3 b	0.913 a	1.04 a
M3	92.5 a	17.96 a	0.20 b	69.23 a	57.7 a	0.834 a	1.03 a
LSD (P < 0.05)	26.49	7.88	0.05	14.75	9.53	0.14	0.11
CV%	11.4	22	14.1	6.1	4.3	6.7	4.5

[1] Means in the same column followed by the same letters are not significantly different according to LSD test (P < 0.05).

Table 18. shows that at final harvest the biomass (g/pot) of sorghum grown in intercropping at the lowest water supply level increased while that of sorghum grown in monoculture decreased. As a result relative yield of sorghum biomass at the lowest water supply level was significantly higher than that at M1 and M2.

For cowpea total biomass (g/pot) of both plants grown in monoculture and in intercropping, significant differences were observed between all water supply levels. As a result relative yield of cowpea tended to decrease with a reduced water supply level. The relative decrease in relative yield of cowpea was bigger than the increase in sorghum relative yield. Therefore relative yield total of biomass slightly decreased with a reduced water supply level. The share of sorghum in biomass production was less than 20% while the share of cowpea was more than 80%.

Table 19. Kernel yield of sorghum in monoculture (A;g/pot), kernel yield of sorghum in intercropping (B;g/pot), relative yield of sorghum (RYs), kernel yield of cowpea in monoculture (C;g/pot), kernel yield of cowpea in intercropping (D;g/pot) relative yield of cowpea (RYc) and relative yield total (RYT) of kernel yield, as affected by water supply level (M1 = high, M2 = intermediate and M3 = low). Kernel yield expressed at 12% moisture for sorghum and 13% moisture for cowpea.

Water supply level	A = S-Yield (g/pot)	B = Si-Yield (g/pot)	RYs. Kernel (B/A)	C = C-yield (g/pot)	D = Ci-yield (g/pot)	RYc. kernel (D/C)	RYT = Rys+Ryc
M1	35.90 a[1]	3.59 a	0.10 a	58.92 c	54.8 b	0.93 a	1.03 a
M2	39.08 a	4.32 a	0.10 a	48.35 b	45.8 b	0.96 a	1.06 a
M3	30.47 a	5.60 a	0.19 b	23.05 a	22.9 a	1.01 a	1.20 a
LSD (P < 0.05)	13.96	3.9	0.06	6.07	9.86	0.27	0.24
CV%	17.50	38.5	21.20	6.10	10.60	12.4	9.80

[1] Means in the same column followed by the same letters are not significantly different according to LSD test (P < 0.05).

Table 19. shows that at the lowest water supply level the kernel yield (g/pot) of sorghum grown in monoculture decreased, but the differences were not significant. On the other hand, kernel yield (g/pot) of sorghum intercropped with cowpea increased with a reduced water supply level. As a result relative kernel yield of sorghum increased with a reduced water supply level and significantly higher value was observed at M3 compared with M1 and M2. At the lowest water supply level the relative biomass yield of sorghum (Table.18) was more or less the same compared to the relative yield of sorghum kernel yield (Table.19), since HI was not significantly different compared to that of monoculture sorghum (Table.7).

For cowpea the kernel yield (g/pot) of cowpea grown in monoculture decreased with a reduced water supply level and significant differences were observed between all water supply levels. Also the kernel yield of cowpea grown in intercropping decreased with a reduced water supply level and significantly lower value was observed at M3 compared with M1 and M2. The relative difference in yield of cowpea grown in intercropping was smaller than that of cowpea grown in monoculture. As a result the relative yield of cowpea kernel increased with a reduced water supply level but the differences were not statistically significant. At M3 the relative yield of cowpea biomass (Table.18) was smaller than that of kernel yield (Table.19), since HI was significantly increased compared with that of monoculture cowpea at M3 (Table.14).

Relative yield total increased with a reduced water supply level as a result of the increase in the relative yield of sorghum and relative yield of cowpea. RYT had a value of more than one under all water supply levels, but the highest value was observed at the lowest water supply level. This result was different compared to that of biomass, where RYT was slightly decreased with a reduced water supply level. The share of sorghum in kernel yield was about 8% at the highest and intermediate water supply level and 16% at the lowest water supply level.

4. Discussion

The discussion is divided in four main sections. The first one deals with moisture status in the pot and evapotranspiration under different treatments. The second section reports on the effects of water supply level on growth and productivity of monocultures of sorghum and cowpea. In the third section attention is given to the sorghum-cowpea intercrop and the interference between water and intercropping. Finally, the results of the present research are discussed in relation with intercropping between sorghum and cowpea practices under rainfed conditions in Kordofan, western Sudan .

1. Moisture status in the experiment

Initially, the pots in the experiment received a similar amount of water. From 35 DAS on, three different water supply levels in the ratio 3:2:1 were used for moisture levels M1 (= high), M2 (= intermediate) and M3 (= low), respectively. The intention was to maintain the soil water status of pots in M1 at such a level, that shortage of water could be avoided. Treatments M2 and M3 should then represent situations with intermediate and low water supply. The results showed that for sorghum grown in monoculture water supply in treatment M1 was adequate, since the estimated amount of water in the pots shortly before watering always fluctuated between 2500-3500 ml/pot. For M3 this amount reduced to 500 ml/pot between 60 and 80 DAS, indicating that in this period water supply was inadequate to meet demand. For M2 the available amount was around 2000 ml/pot. This indicates that for M2 the supplied amount of water was nearly always adequate to meet demand.

For cowpea monoculture and for intercropping the situation was different. Here the differences in soil moisture status of the pots between moisture treatments were much smaller. From 50-75 DAS soil moisture status shortly before watering in all treatments was low indicating that in this period water supply could not meet demand. After 75 DAS soil moisture status in M1 for both cowpea in monoculture and intercrop gradually recovered. However it might be concluded that the initial intention to maintain moisture level in treatment M1 at an adequate level throughout the growing season was not met. Consequently, it can not be excluded that also the crops in M1 suffered from water stress during part of the growing season.

The maximum amount of water that could be maintained in the pots was about 3-4 litre. Total water supply ranged from 55-26 litre/pot for M1 and M3, respectively. This shows that the buffering capacity of the pot was relatively small and consequently evapotranspiration was mainly dictated by the amount of water supplied. Observed differences in crop production between cropping systems at a similar water supply level will therefore mainly reflect the ability of plants to utilize water for dry matter production.

2. Monoculture sorghum and cowpea

A comparison of monocultures at different water supply levels demonstrates that sorghum is much better able to deal with a limited water supply than cowpea. This is obvious from various observations. The earlier discussed soil moisture status of pots contain in fact a first indication. Both at M1 and M2 soil moisture status of pots with monoculture of sorghum was clearly higher than those of pots with monoculture of cowpea. This observation indicates that sorghum plants require less water than cowpea plants. Another clear indication is found when the effect of a limited water supply on biomass production is compared for both monocultures. At the intermediate harvest at 56 DAS, which was about 3 weeks after the different water supply levels were initiated, biomass production of sorghum grown in monoculture was not at all affected by water supply level. The effect was also small at final harvest, since no significant differences were found and only at the lowest water supply level biomass tended to decrease. On the other hand, at 56 DAS a clear effect of water supply level on cowpea was observed. At the lowest water supply level, biomass production was significantly decreased. The effect on cowpea biomass production was even stronger at final harvest, where significant differences were observed between all water supply levels.

Comparison of water use efficiency (WUE) showed that sorghum increased its WUE with a reduced water supply level. At the highest water supply level WUE of sorghum was 0.0019 gDM/gH_2O, while at the lowest water supply level it reached a value of 0.0035 gDM/gH_2O. As a result, sorghum is able to keep a more or less stable biomass production level for a wide range of water supply levels. For cowpea, WUE was constant and about 0.0025 gDM/gH_2O. As a result biomass production decreased linearly with a reduction in water supply. This is in agreement with observation of Shouse et al. (1982) who observed that cowpea dry matter production under limited water conditions was linearly related to crop water use and relatively insensitive to the timing of water deficit.

At the lowest water supply level sorghum seed yield was slightly decreased, whereas HI was more or less stable. For cowpea at the lowest water supply level, both seed yield and HI were decreased and significant differences were observed compared with M1 and M2. These reductions resulted from a significant decrease in number of seeds/plant at the lowest water supply level, which resulted from a decreased number of pods/plant and a decreased number of seeds/pod. Shouse et al. (1982) also observed that seed yield was highly correlated to pod density, indicating that any stress which influences flowering or pod setting will adversely affect yield.

The ability to withstand relatively low levels of water supply without reflecting it on dry matter production might partly be related to the ability of sorghum to adjust its dry matter allocation pattern in response to environmental change. Initially, at 56 DAS, fraction root and fraction leaf of monoculture sorghum at M3 were significantly increased. The adjustment of dry matter allocation was even stronger at final harvest, when, both at M2 and M3, in addition to a significant decrease in fraction shoot, significant increases in fraction root and root/shoot ratio were observed. For cowpea dry matter allocation pattern was moderately changed by a limited water supply level. Ntare et al.(1993) also observed that most cowpea cultivars had a stable partitioning pattern in a range of environments.

Another explanation for the ability of sorghum to deal with relatively low levels of water supply can be found when the results of leaf photosynthetic rate measurements are analysed. For sorghum both assimilation and transpiration rate per unit leaf area were clearly higher than for cowpea. Most important however was that leaf assimilation/transpiration ratio (A/T) for sorghum was higher than for cowpea. This ratio was about 0.024 mg CO_2/mg H_2O for sorghum, irrespective of water supply level, while for cowpea a value of about 0.010 mg CO_2/mg H_2O was obtained.

Leaf area (LA) of sorghum was not affected by water supply level, only at the lowest water supply level LA tended to decrease. The leaf characteristics SLA and SPAD of sorghum leaf were not affected by water supply level, though SPAD at the lowest water supply level also tended to decrease. For cowpea at the lowest water supply level LA was significantly decreased compared to that at M1. Both SLA and SPAD of cowpea leaf decreased with a reduced water supply level. The decreased SLA of cowpea leaf indicates that the plants started to create thicker leaves as a result of water stress.

3. Interference between water and intercropping

At the highest water supply level of sorghum-cowpea intercropping, competition between sorghum and cowpea was mainly for light. This was observed from the amount of water maintained in the pots, which showed that there was no clear water shortage at this water supply level. Leaf photosynthetic rate of intercropped cowpea was not different from that of monoculture, while that of intercropped sorghum was significantly decreased compared with monoculture sorghum. This reduction in photosynthetic rate could be completely accounted for by the increased SLA of intercropped sorghum. SLA was increased as a response to light stress compared to monoculture sorghum. When assimilation rate was expressed on the basis of leaf weight similar values were obtained for both monoculture and intercropping. The increased in the SLA of intercropped sorghum was most likely a response to light stress caused by competition from cowpea.

From the observations on monocultures it was shown that cowpea had a higher LA and a stronger height growth than sorghum. Both characteristics are important determinants for the ability to compete for light. Consequently, in intercropping at M1, cowpea was completely dominating sorghum. Sorghum was suffering mainly from light stress, as a result of shading by the tall cowpea plants. Light stress on sorghum led to a substantial reduction in biomass and plants size of intercropped sorghum compared with monoculture. Biomass production of intercropped sorghum was reduced by about 80% compared with monoculture sorghum, while that of intercropped cowpea increased by about 90% compared with monoculture cowpea. Fukai and Trenbath (1993) also observed that the severe competition between two component crops can result in a strongly reduced biomass and yield of one component. Also the size of intercropped sorghum was reduced. At 67 DAS plant height of sorghum in intercropping was reduced to about 65 cm, while that of monoculture was about 105 cm. For intercropped cowpea, no differences in plant length were observed. Related to the fact that LA and plant height are important factors for light competition, it was clear that sorghum was completely supressed by cowpea. At this water supply level, RYT of biomass was 1.12 indicating that there was an increase in total biomass production of about 12% compared with sole crops. RYT of kernel yield was not increased compared with sole crops, mainly because HI of intercropped sorghum was significantly decreased from 0.38 to 0.26.

At the intermediate water supply level (M2), competition between sorghum and cowpea was not only for light, but also for water. The amount of water maintained in the pots was clearly decreased compared with that at M1. This decrease resulted from a decrease in water supply level by 1/3 compared to that of M1. For both species, leaf photosynthetic rate was decreased as a result of water limitation. Leaf photosynthetic rate of intercropped sorghum was significantly decreased compared to that of monoculture crop at adequate water supply level (M1), while that of intercropped cowpea only tended to reduce, and no significant reduction compared to monoculture cowpea at M1 was observed. Flowering of intercropped sorghum was delayed with about 12 days in comparison to that of monoculture at M1. Rees (1986) reported that a delay in flowering in dry environments usually indicates that plants are suffering severe water stress.

As a result of the reduced water supply biomass production of intercropped cowpea was decreased by more than 20% compared with that at M1. LA was also significantly decreased compared to that of intercropped cowpea at M1. At final harvest LA was reduced to 69.2 dm^2/plant, while at M1 it was 104.9 dm^2/plant. Also at this water supply level sorghum was still dominated by cowpea. For intercropped sorghum however, reduction of water supply had two effects. First, a direct negative effect of water shortage on plant growth and secondly an indirect positive effect through the growth reducing effect of water shortage on cowpea, which increased the relative competitive ability of sorghum for light. Initially the direct effect of a reduced water supply was relatively less than the positive effect resulting from growth reduction of cowpea. This situation led to an improved growth and productivity of intercropped sorghum compared to that at M1. At final harvest, there was a balance between both effects and biomass production at M2 was nearly the same as production of intercropped sorghum at M1. For cowpea, biomass production at 56 DAS and at final harvest was decreased. RY at final harvest only tended to reduce, but no significant reduction was observed. At final harvest RYT of biomass and kernel yield were nearly the same. Though RYT's were larger than one, no significant increases in production were observed.

At the lowest water supply level (M3), competition was also for both water and light. The amount of water present in the pots 2-3 days after watering was decreased to a comparable level than in M2. Considering that in M3 water supply level was reduced to only 1/3 of that in M1, it is obvious that the plants in these pots suffered from water shortage to an even larger extent than in M2. This reduction of water supply in the pots negatively affected both species. At 52 DAS leaf photosynthetic rate of both species was severely reduced compared with that of monocultures of sorghum and cowpea at adequate water supply. Also crop phenology was affected. Flowering of intercropped sorghum was delayed with about 13 days compared to that of monoculture sorghum at M1. This is in agreement with observations at ICRISAT (1982), where flowering of sorghum was progressively delayed as the intensity of water stress increased.

As a result of the poor water supply, biomass production of intercropped cowpea at final harvest was decreased by more than 55% compared to that of M1. At the same time LA of intercropped cowpea was significantly decreased. At final harvest LA of intercropped cowpea was reduced to 48.5 dm^2 /plant, while that at M1 was 104.9 dm^2/plant. Also at this water supply level sorghum was still the dominated crop. However, at final harvest the competitive ability of sorghum was clearly increased compared to that at M1 and M2. This indicates that the direct effect of a reduced water supply was relatively less than the positive effect due to the growth reduction of cowpea. Biomass production of intercropped sorghum was increased by about 25% compared to that at M1, while seed yield was even increased by 55% compared to that at M1. The larger increase in seed yield was caused by the fact that HI in M3 was not significantly reduced compared to sorghum grown in monoculture, whereas HI at M1 was significantly reduced. RY of sorghum biomass at the intermediate harvest was low, although not significantly different from that at M1 and M2. At final harvest RY of sorghum biomass and kernel yield increased compared to M1 and M2. For cowpea at 56 DAS and later at final harvest RY of biomass was not significantly affected compared to that at M1 and M2. RY of cowpea kernel yield slightly increased compared with M1 and M2. Although intercropped cowpea was severely affected by water shortage, HI was significantly increased compared to that of monoculture cowpea at M3. Fukai and Trenbath (1993) also observed that in a dry environment HI of intercrop may be increased.

At final harvest, RYT of biomass was slightly more than one. This value was not different from RYT obtained at M1 and M2, though the contribution of sorghum was clearly increased and the contribution of cowpea clearly reduced. RYT of kernel yield was 1.2 indicating a 20% increase compared with sole crops. This increased RYT of kernel yield was mainly due to the increased HI of cowpea combined with the relatively good performance of sorghum.

4. Relevance for sorghum-cowpea intercropping in rainfed conditions of Kordofan

This research showed that sorghum which is a C4-species is much better able to deal with a limited water supply than cowpea which is a C3 species. Main emphasis in the pot-experiment was on how this difference in ability to deal with water shortage was affecting the relative competitive ability of both species in intercropping. For all water supply levels the taller cowpea-plants were the dominating crop, whereas the shorter sorghum plants were always dominated. Still, water supply level had a clear effect on the relative competitive ability of both species. When there was no water shortage cowpea was completely dominating on sorghum. As water supply decreased, growth of cowpea decreased linearly and a reduction in competitive ability of cowpea for light was observed. As a result, sorghum experienced two effects from a reduced water supply. A direct negative effect due to water shortage, and an indirect positive effect, resulting from the negative effect of water shortage on growth of cowpea. The indirect positive effect of a reduced water supply was stronger than the direct negative effect. As a result, the relative competitive ability of sorghum increased at lower water supply levels, and this effect was so strong that even the absolute growth and productivity of intercropped sorghum at the lowest water supply level was better than that of intercopped sorghum at the highest water supply level. At the lowest water supply level sorghum share in the overall production was increased. Although relative biomass production of this intercropping was not different from that at adequate water supply level, kernel yield was increased by 20% compared to sole crops. This increase in kerenel yield resulted from a high HI of cowpea and a good sorghum performance.

In a field of Kordofan sorghum-cowpea intercropping system has two main differences compared to this pot experiment. First, cowpea varieties grown there are creeping varieties. Therefore sorghum-plants are the dominating crop, whereas cowpea-plants are the dominated crop. Second, the roots of cowpea grown in the field goes deep in the soil and exploits more water from deeper layers. This advantage of root system for cowpea grown in the field was also observed by Rees (1986) who reported that stronger competitive ability by cowpea was most likely related to its greater ability to root to depth. In the field when water stress appeares the growth of sorghum reduces. Cowpea experiences two effects a direct negative effect due to water shortage, and an indirect positive effect resulting from the negative effect of water shortage on growth of sorghum. The effect of water shortage on cowpea is expected to be mild than that observed in this research due to the advantages of root system for cowpea. At the same time the relative competitive ability of cowpea for light increases, thereby its growth and productivity improves. Also in the field a relatively high percentage of overall yields is expected to be from sorghum due to higher sorghum share, indicating a more satisfied yield to a farmer because sorghum is the staple food in Kordofan region. The fact that in this experiment rooting depth was limited becaues of a restricted pot size also had a clear advantage. It offered an opportunity to focus on the effects of water uptake and water use efficiency without a confounding effect of differences in water availability due to different rooting depth.

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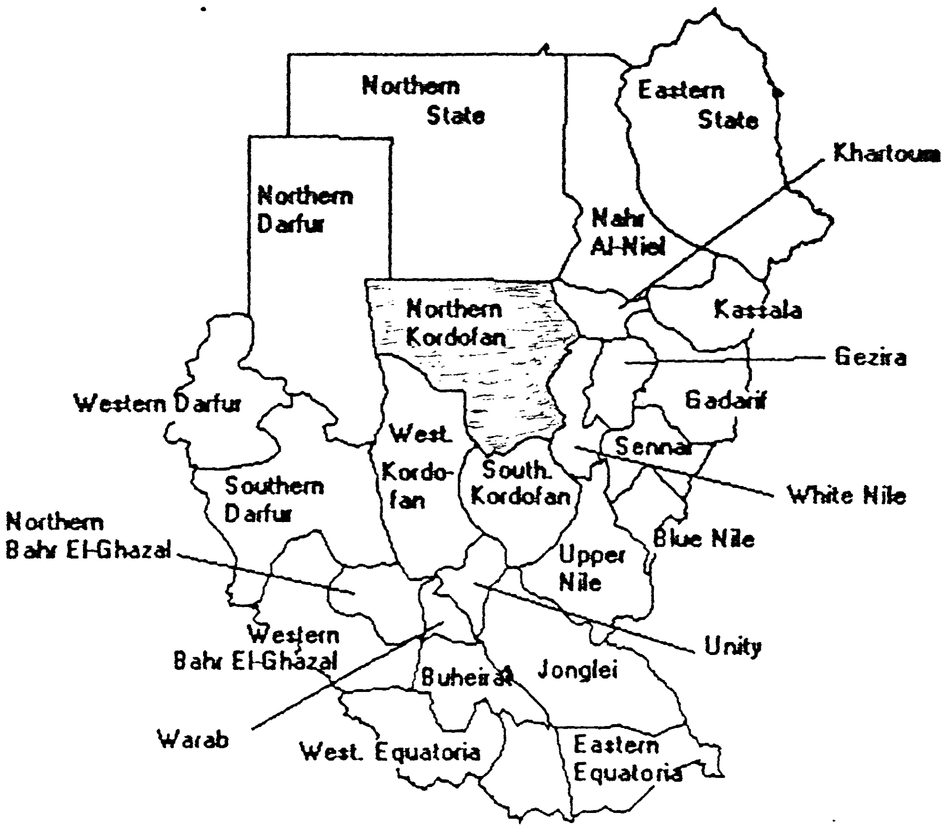
6. Appendices

6.1 Appendix 1: Sudan map



6.2 Appendix 2: Experimental design

	* 32	* 32	* 32	* 32	* 32	* 32	* 32	* 32	* 33	* 33	* 33	* 33	* 33	* 33	* 32	* 31	* 31	* 31	* 31	* 31	* 31	* 31
R1	* 32	1 32	2 32	3 32	4 32	5 32	6 32	* 32	19 33	20 33	21 33	22 33	23 33	24 33	* 32	37 31	38 31	39 31	40 31	41 31	42 31	* 31
	* 32	7 22	8 22	9 22	10 22	11 22	12 22	* 22	25 23	26 23	27 23	28 23	29 23	30 23	* 22	43 21	44 21	45 21	46 21	47 21	48 21	* 21
	* 22	13 12	14 12	15 12	16 12	17 12	18 12	* 12	31 13	32 13	33 13	34 13	35 13	36 13	* 12	49 11	50 11	51 11	52 11	53 11	54 11	* 11
	* 12	* 12	* 12	* 12	* 12	* 12	* 12	* 12	* 13	* 13	* 13	* 13	* 13	* 13	* 12	* 11	* 11	* 11	* 11	* 11	* 11	* 11

	* 33	* 33	* 33	* 33	* 33	* 33	* 33	* 32	* 31	* 31	* 31	* 31	* 31	* 31	* 32	* 32	* 32	* 32	* 32	* 32	* 32	* 32
	* 33	55 33	56 33	57 33	58 33	59 33	60 33	* 32	73 31	74 31	75 31	76 31	77 31	78 31	* 32	91 32	92 32	93 32	94 32	95 32	96 32	* 32
R2	* 23	61 23	62 23	63 23	64 23	65 23	66 23	* 22	79 21	80 21	81 21	82 21	83 21	84 21	* 22	97 22	98 22	99 22	100 22	101 22	102 22	* 22
	* 13	67 13	68 13	69 13	70 13	71 13	72 13	* 12	85 11	86 11	87 11	88 11	89 11	90 11	* 12	103 12	104 12	105 12	106 12	107 12	108 12	* 12
	* 13	* 13	* 13	* 13	* 13	* 13	* 13	* 12	* 11	* 11	* 11	* 11	* 11	* 11	* 12	* 12	* 12	* 12	* 12	* 12	* 12	* 12

	* 11	* 11	* 11	* 11	* 11	* 11	* 11	* 12	* 12	* 12	* 12	* 12	* 12	* 12	* 12	* 13	* 13	* 13	* 13	* 13	* 13	* 13
	* 11	109 11	110 11	111 11	112 11	113 11	114 11	* 12	127 12	128 12	129 12	130 12	131 12	132 12	* 12	145 13	146 13	147 13	148 13	149 13	150 13	* 13
R3	* 21	115 21	116 21	117 21	118 21	119 21	120 21	* 22	133 22	134 22	135 22	136 22	137 22	138 22	* 22	151 22	152 22	153 22	154 23	155 23	156 23	* 23
	* 31	121 31	122 31	123 31	124 31	125 31	126 31	* 32	139 32	140 32	141 32	142 32	143 32	144 32	* 32	157 33	158 33	159 33	160 33	161 33	162 33	* 33
	* 31	* 31	* 31	* 31	* 31	* 31	* 31	* 32	* 32	* 32	* 32	* 32	* 32	* 32	* 32	* 33	* 33	* 33	* 33	* 33	* 33	* 33

The number on the left of each pot is the pot number.

The number on the right of each pot is a combination of cropping system and water supply level as following.

Crops:

1 = Sorghum, 2 = Intercrop, 3 = Cowpea

Water supply levels:

1 = High, 2 = Intermediate, 3 = Low

* = Border pot

R1, R2 and R3 = Replicate 1, 2 and 3

6.3 Appendix 3: Photosynthesis measurements at 49-52 DAS

Date	Time	Replicate	Moisture	Plant	Pot nr.	Plot nr.	Rec. nr.	Pmax.	Transp.	Stom.con.	CO2 out	CO2 stom.
270798	1602	1	1	S	51	12	0	0.706	51.799	3.612	303.8	119.6
270798	1621	1	1	S	51	12	1	1.105	67.963	5.891	283.7	101.4
270798	1411	1	1	C	39	9	0	0.502	74.043	7.124	313.3	243.7
270798	1427	1	1	C	39	9	1	0.539	72.464	6.799	312	234.1
270798	1526	1	1	Si	45	11	0	1.027	73.262	6.914	287.9	141.4
270798	1541	1	1	Si	45	11	1	1.158	73.1	7.246	281.4	123.2
270798	1456	1	1	Ci	45	10	0	0.407	49.49	3.494	320.8	211.4
270798	1457	1	1	Ci	45	10	1	0.406	52.542	3.832	320.5	220.5
270798	1119	1	2	S	15	4	0	1.239	75.7	9.718	276.7	146.9
270798	1135	1	2	S	15	4	1	1.144	75.669	9.248	281.6	156.3
270798	926	1	2	C	3	1	1	0.535	26.872	1.734	399.2	118.2
270798	944	1	2	C	3	1	2	0.596	40.983	3.161	332.6	157.5
270798	1044	1	2	Si	9	3	0	0.976	62.336	5.92	291.7	132.1
270798	1058	1	2	Si	9	3	1	1.012	61.985	5.919	289.8	124.3
270798	1007	1	2	Ci	9	2	0	0.458	61.193	6.203	318.8	247.1
270798	1024	1	2	Ci	9	2	1	0.528	67.828	7.545	314.8	245.6
270798	1336	1	3	S	33	8	0	1.404	89.3	11.366	267.7	138.5
270798	1352	1	3	S	33	8	1	1.187	77.403	7.838	279.4	128.2
270798	1154	1	3	C	21	5	0	0.104	18.658	1.05	335.4	245.9
270798	1207	1	3	C	21	5	1	0.116	21.781	1.215	334.2	247.9
270798	1259	1	3	Si	27	7	0	0.894	63.342	4.792	293.2	114.4
270798	1314	1	3	Si	27	7	1	0.632	47.063	3.01	308	111.9
270798	1224	1	3	Ci	27	6	0	0.135	27.616	1.558	332.8	254.1
270798	1239	1	3	Ci	27	6	1	0.133	21.68	1.112	335	226.4
280798	1337	2	1	S	87	20	0	1.348	83.181	15.078	270.1	172.6
280798	1354	2	1	S	87	20	1	1.31	78.214	12.873	273.3	165.5
280798	1144	2	1	C	75	17	0	0.132	27.803	1.728	334.3	264.5
280798	1205	2	1	C	75	17	1	0.121	21.285	1.236	335.2	246.2
280798	1254	2	1	Si	81	19	0	1.123	70.482	8.68	282.5	152.4
280798	1310	2	1	Si	81	19	1	0.896	58.017	5.611	294.7	140.6

Date	Time	Replicate	Moisture	Plant	Pot nr.	Plot nr.	Rec. nr.	Pmax.	Transp.	Stom.con.	CO2 out	CO2 stom.
280798	1228	2	1	Ci	81	18	0	0.096	24.564	1.505	334.6	276.9
280798	1239	2	1	Ci	81	18	1	0.191	29.016	1.848	330.4	236.2
280798	1554	2	2	S	105	24	0	1.431	83.482	13.727	266.4	154.7
280798	1605	2	2	S	105	24	1	1.456	94.447	20.115	264	180.1
280798	1415	2	2	C	93	21	0	0.053	14.41	0.769	337.5	276.1
280798	1430	2	2	C	93	21	1	0.152	20.752	1.208	332.9	219.2
280798	1516	2	2	Si	99	23	0	0.77	45.2	3.552	302.2	99.3
280798	1533	2	2	Si	99	23	1	0.779	44.561	3.646	300.2	100
280798	1445	2	2	Ci	99	22	0	0.114	21.881	1.272	335.5	254.1
280798	1456	2	2	Ci	99	22	1	-0.015	15.288	0.829	340.8	356.7
280798	1107	2	3	S	69	16	1	1.18	65.309	7.724	280.1	128.5
280798	1125	2	3	S	69	16	2	1.357	78.395	12.234	271.2	154.4
280798	923	2	3	C	57	13	0	0.02	10.432	0.569	344.6	313.2
280798	937	2	3	C	57	13	1	-0.015	7.348	0.381	344	379.1
280798	1029	2	3	Si	63	15	0	0.445	27.955	1.804	318.9	93.8
280798	1048	2	3	Si	63	15	1	0.495	35.558	2.466	315.9	130.7
280798	1006	2	3	Ci	63	14	0	-0.017	3.013	0.149	342.8	441.6
280798	1010	2	3	Ci	63	14	1	0.025	22.013	1.321	340.2	322.8
300798	939	3	1	S	111	25	0	1.22	70.852	9.399	277.8	146.1
300798	953	3	1	S	111	25	1	1.067	68.196	8.438	284.8	158.1
300798	1137	3	1	C	123	28	0	0.305	56.572	5.264	323.2	267.6
300798	1153	3	1	C	123	28	1	0.435	76.135	10.938	313.6	272.4
300798	1011	3	1	Si	117	26	0	0.686	51.704	4.471	306.1	160.5
300798	1032	3	1	Si	117	26	0	0.793	55.559	5.177	299.5	152.7
300798	1052	3	1	Ci	117	27	0	0.37	58.106	5.802	319	257.4
300798	1114	3	1	Ci	117	27	1	0.269	49.991	4.276	323.7	264.3
300798	1211	3	2	S	129	29	0	1.293	82.252	13.545	271.9	169.8
300798	1229	3	2	S	129	29	1	1.083	71.567	9.13	281.9	162.1
300798	1358	3	2	C	141	32	0	0.276	45.786	3.857	322.2	255
300798	1410	3	2	C	141	32	1	0.198	32.421	2.309	327.1	248.5
300798	1249	3	2	Si	135	30	0	0.709	61.078	6.412	300.3	192.6
300798	1306	3	2	Si	135	30	1	0.915	62.816	6.492	292.6	155.1
300798	1322	3	2	Ci	135	31	0	0.534	84.921	15.846	309.4	272.3
300798	1337	3	2	Ci	135	31	1	0.738	103.21	41.816	297.1	271.5

Date	Time	Replicate	Moisture	Plant	Pot nr.	Plot nr.	Rec. nr.	Pmax.	Transp.	Stom.con.	CO2 out	CO2 stom.
300798	1425	3	3	S	147	33	0	1.194	60.139	6.733	276.4	102.9
300798	1441	3	3	S	147	33	1	1.228	74.439	11.355	273.5	161
300798	1603	3	3	C	159	36	0	0.332	47.325	3.814	320.8	239
300798	1614	3	3	C	159	36	1	0.398	50.723	4.329	316	229.1
300798	1457	3	3	Si	153	34	0	0.719	57.147	5.39	300.5	172.4
300798	1515	3	3	Si	153	34	1	0.369	41.938	3.183	318.7	210.9
300798	1533	3	3	Ci	153	35	0	0.227	29.914	1.99	326.7	222.2
300798	1549	3	3	Ci	153	35	1	0.193	25.346	1.591	328.2	217.7
310798	1536	1	1	S	51	48	0	0.917	60.798	5.792	294	141
310798	1547	1	1	S	51	48	1	1.3	78.897	10.773	273.6	148.9
310798	1345	1	1	C	39	45	0	0.387	52.366	4.762	320	242.6
310798	1400	1	1	C	39	45	1	0.513	71.228	8.937	312.4	254.5
310798	1454	1	1	Si	45	47	0	0.946	59.525	5.941	292.2	138.2
310798	1507	1	1	Si	45	47	1	0.986	60.123	6.045	289.4	131.4
310798	1422	1	1	Ci	45	46	0	0.295	41.955	3.206	325	239.3
310798	1438	1	1	Ci	45	46	1	0.405	52.686	4.618	318.8	235.5
310798	1112	1	2	S	15	40	0	1.157	72.58	9.414	280.8	156.1
310798	1128	1	2	S	15	40	1	1.282	78.447	11.94	273.5	160.9
310798	918	1	2	C	3	37	0	0.365	41.527	3.473	323.9	225.6
310798	934	1	2	C	3	37	1	0.39	44.324	3.672	320.9	221.2
310798	1029	1	2	Si	9	39	0	0.977	70.818	8.59	290.6	176.4
310798	1046	1	2	Si	9	39	1	0.887	66.592	7.502	294.4	177.4
310798	954	1	2	Ci	9	38	0	0.282	46.697	3.764	326.2	255.7
310798	1011	1	2	Ci	9	38	1	0.493	59.921	5.891	315.3	234.3
310798	1315	1	3	S	33	44	0	1.355	84.018	14.967	270.8	172.2
310798	1328	1	3	S	33	44	1	1.272	84.74	15.536	274.2	184.5
310798	1143	1	3	C	21	41	0	0.007	8.463	0.438	341.4	326.4
310798	1158	1	3	C	21	41	1	0.006	5.799	0.292	340.3	322.4
310798	1245	1	3	Si	27	43	0	0.969	57.527	5.466	291.7	121.3
310798	1257	1	3	Si	27	43	1	0.509	36.19	2.59	314.5	133.1
310798	1215	1	3	Ci	27	42	0	0.101	16.393	0.917	335.8	236.3
310798	1230	1	3	Ci	27	42	1	0.018	8.588	0.442	341.2	305.4

6.4 Appendix 4: Photosynthesis measurements at 63-66 DAS

Date	Time	Replicate	Moisture	Plant	Pot nr.	Plot nr.	Rec. nr.	Pmax.	Transp.	Stom. con.	CO2 out	CO2 stom.
110898	1335	2	1	S	85	8	0	1.347	90.625	9.671	273.7	130.2
110898	1348	2	1	S	85	8	1	1.496	108.462	15.388	265.7	157.9
110898	1159	2	1	C	73	5	0	0.458	98.172	18.29	317.9	289.4
110898	1215	2	1	C	73	5	1	0.593	121.065	45.024	309.6	289.8
110898	1305	2	1	Si	79	7	0	0.828	62.983	4.209	300.3	112.3
110898	1319	2	1	SI	79	7	1	1.006	74.005	5.673	291.1	118.1
110898	1231	2	1	Ci	79	6	0	0.488	113.241	20.943	316.8	289.3
110898	1245	2	1	Ci	79	6	1	0.536	115.944	21.041	312.5	282.4
110898	1545	2	2	S	103	12	0	1.253	96.417	8.923	276.9	133
110898	1602	2	2	S	103	12	1	1.141	93.832	8.319	282.8	143.4
110898	1405	2	2	C	91	9	0	0.271	86.288	6.725	327.3	287.2
110898	1437	2	2	C	91	9	2	0.2	59.766	3.332	332.2	275.2
110898	1514	2	2	Si	97	11	0	0.763	67.377	4.005	304	121.5
110898	1528	2	2	Si	97	11	1	0.678	71.043	4.272	305.8	153.2
110898	1444	2	2	Ci	97	10	0	0.436	109.735	12.301	317.9	280
110898	1457	2	2	Ci	97	10	1	0.454	91.174	7.606	318	257.9
110898	1118	2	3	S	67	4	0	0.8	51.485	3.718	303.6	101.1
110898	1136	2	3	S	67	4	1	0.86	60.574	4.634	299.4	122.1
110898	940	2	3	C	55	1	0	0.196	31.69	2.13	337.3	253
110898	952	2	3	C	55	1	1	0.253	34.648	2.358	332.3	233.6
110898	1043	2	3	Si	61	3	0	0.651	43.12	2.974	308.9	105.2
110898	1057	2	3	Si	61	3	1	0.686	46.683	3.229	309.5	111
110898	1012	2	3	Ci	61	2	0	0.219	27.903	1.762	334.2	220.9
110898	1026	2	3	Ci	61	2	1	0.29	35.004	2.323	329.5	214.8
120898	1134	3	1	S	109	16	0	0.885	58.029	4.651	313.7	132.1
120898	1149	3	1	S	109	16	1	1.258	88.544	10.885	287.3	-597.1
120898	924	3	1	C	121	13	0	0.369	50.3	3.717	365.8	272.6
120898	942	3	1	C	121	13	1	0.183	39.138	2.485	369.4	301.4
120898	1048	3	1	Si	115	15	0	0.773	63.936	5.31	316.7	176.6
120898	1107	3	1	Si	115	15	1	0.977	76.534	6.892	302.9	163.1

Date	Time	Replicate	Moisture	Plant	Pot nr.	Plot nr.	Rec. nr.	Pmax.	Transp.	Stom. con.	CO2 out	CO2 stom.
120898	1012	3	1	Ci	115	14	0	0.133	27.466	1.568	363.5	286.2
120898	1026	3	1	Ci	115	14	1	0.166	29.561	1.703	351.2	262.5
120898	1349	3	2	S	127	20	0	1.131	80.683	6.743	297.4	131.5
120898	1403	3	2	S	127	20	1	1.38	94.066	9.168	284.7	130.8
120898	1206	3	2	C	139	17	0	-0.02	8.877	0.38	363.8	411.4
120898	1223	3	2	C	139	17	1	-0.033	7.629	0.308	355.9	453.7
120898	1317	3	2	Si	133	19	0	0.565	50.872	2.842	324.5	138.3
120898	1333	3	2	Si	133	19	1	0.385	36.609	1.758	337.8	135.8
120898	1242	3	2	Ci	133	18	0	0.241	39.503	2.115	345.5	240.2
120898	1254	3	2	Ci	133	18	1	0.12	25.833	1.195	347.4	255.6
120898	1532	3	3	S	145	24	0	0.342	30.838	1.394	331.3	106.3
120898	1546	3	3	S	145	24	1	0.168	25.768	1.123	340.3	204
120898	1412	3	3	C	157	21	0	0.006	12.493	0.497	355.8	344.4
120898	1418	3	3	C	157	21	1	-0.024	10.643	0.414	355.3	407.2
120898	1507	3	3	Si	151	23	0	0.011	11.312	0.436	354.7	331.6
120898	1512	3	3	Si	151	23	1	-0.052	5.035	0.185	362.1	616.3
120898	1443	3	3	Ci	151	22	0	-0.132	8.233	0.303	358.1	752.4
120898	1444	3	3	Ci	151	22	1	-0.106	9.9	0.367	358.9	620.7
130898	1548	1	1	S	50	36	0	1.096	67.098	6.763	285.5	126.8
130898	1600	1	1	S	50	36	1	0.953	63.526	6.229	292.6	143.8
130898	1356	1	1	C	38	33	0	0.006	17.849	1.004	341.6	335.8
130898	1411	1	1	C	38	33	1	0.124	27.704	1.729	335.7	270.5
130898	1514	1	1	Si	44	35	0	0.997	70.453	7.741	290.7	162.9
130898	1533	1	1	Si	44	35	1	0.679	54.327	4.593	306.6	166.1
130898	1433	1	1	Ci	44	34	0	0.385	51.587	4.154	321.7	234
130898	1451	1	1	Ci	44	34	1	0.506	70.238	7.832	316.6	252.4
130898	1320	1	2	S	16	32	0	1.376	79.373	11.932	271	150.3
130898	1337	1	2	S	16	32	1	1.166	73.279	9.635	282.3	159.4
130898	1150	1	2	C	4	29	0	0.155	23.268	1.482	334	238.9
130898	1202	1	2	C	4	29	1	0.236	27.561	1.825	330.1	212.4
130898	1250	1	2	Si	10	31	0	1.27	71.242	8.996	276.9	134.6
130898	1303	1	2	Si	10	31	1	0.769	55.123	5.197	302.2	160.5
130898	1219	1	2	Ci	10	30	0	0.174	33.095	2.278	332.9	262.6
130898	1234	1	2	Ci	10	30	1	0.278	42.153	3.264	328.3	249.1

Date	Time	Replicate	Moisture	Plant	Pot nr.	Plot nr.	Rec. nr.	Pmax.	Transp.	Stom. con.	CO2 out	CO2 stom.
130898	1105	1	3	S	34	28	0	1.269	68.071	8.814	278.5	133.9
130898	1131	1	3	S	34	28	1	0.968	57.856	5.935	292.3	134.7
130898	913	1	3	C	22	25	0	0.42	41.189	3.476	330	217.4
130898	928	1	3	C	22	25	1	0.377	45.301	3.843	327.8	235.7
130898	1026	1	3	Si	28	27	0	0.605	32.813	2.481	312.7	88.5
130898	1048	1	3	Si	28	27	1	1.216	62.345	7.614	281.6	123.8
130898	945	1	3	Ci	28	26	0	0.281	35.017	2.545	330.8	229.2
130898	1004	1	3	Ci	28	26	1	0.288	30.189	2.054	330.8	202.5
140898	1516	3	1	S	109	48	0	1.182	68.649	7.112	281	117.4
140898	1540	3	1	S	109	48	1	0.994	67.855	6.976	290.5	150.6
140898	1342	3	1	C	121	45	0	0.101	21.289	1.263	336.3	263.9
140898	1353	3	1	C	121	45	1	0.097	15.458	0.867	337	235.9
140898	1443	3	1	Si	115	47	0	0.873	62.115	6.02	296.3	155.9
140898	1459	3	1	Si	115	47	1	0.972	66.536	7.021	291.3	155.4
140898	1412	3	1	Ci	115	46	0	0.165	26.437	1.662	333.3	243.2
140898	1426	3	1	Ci	115	46	1	0.068	17.539	0.955	339.3	275.5
140898	1310	3	2	S	127	44	0	1.082	67.186	8.349	285.2	155.8
140898	1323	3	2	S	127	44	1	0.888	54.828	5.322	295.2	135.3
140898	1147	3	2	C	139	41	0	0.183	27.152	1.767	333.7	239.6
140898	1201	3	2	C	139	41	1	0.032	12.111	0.677	341.6	299.7
140898	1239	3	2	Si	133	43	0	0.754	47.691	4.092	301.7	128.1
140898	1253	3	2	Si	133	43	1	0.7	51.178	4.679	306.2	164.2
140898	1218	3	2	Ci	133	42	0	0.062	18.31	1.082	339.1	287.8
140898	1221	3	2	Ci	133	42	1	0.316	47.191	3.887	324.6	248.3
140898	1107	3	3	S	145	40	0	0.681	49.96	4.502	308	164.8
140898	1126	3	3	S	145	40	1	0.848	57.658	5.732	299.3	156.7
140898	919	3	3	C	157	37	0	0.284	36.862	2.957	333.7	244.9
140898	937	3	3	C	157	37	1	0.271	35.32	2.694	331.5	238.6
140898	1035	3	3	Si	151	39	0	0.765	45.593	4.074	304.6	127.9
140898	1049	3	3	Si	151	39	1	0.996	59.702	6.775	292.9	149.3
140898	958	3	3	Ci	151	38	0	0.301	36.813	2.799	329	229.5
140898	1018	3	3	Ci	151	38	1	0.164	30.779	2.213	335.5	267.8