DETERMINING THE RAINFED ARABLE PRODUCTION POTENTIAL OF CLIMATICALLY MARGINAL LAND IN THE NORTHWEST PROVINCE USING THE CYSLAMB LAND EVALUATION MODEL

by

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Declaration

I declare that this mini-dissertation describes my original work, except where specific acknowledgement is made to the work of others, and has not previously in its entirety or in part been submitted for a degree to any other university.

B.N Mbatani

Signature .... Date.................. 08 FEB 2001

ABSTRACT

This study consisted of two stages: First the validation of the Crop Yield Simulation and Land Assessment Model For Botswana (CYSLAMB) against the recorded maize yields in some parts of the Northwest Province (Potchefstroom, Setlagole and Ottosdal). The model was also calibrated to simulate maize yield under specific management systems of low plant density and conditions of acute water deficit prevailing in the study area. Statistical methods including D-index (index of agreement), RMSEs (root mean square error systematic), RMSEu (root mean square error unsystematic) and RMSE (root mean square error) recommended by Willmott (1982) for model evaluation were used to evaluate CYSLAMB. Results indicated that the model simulates yield with an acceptable level of accuracy under local conditions.

Secondly the CYSLAMB model was used as a quantitative method for screening the impact of existing and potential management systems on production in the study area. The model was used to predict maize yields for different planting dates. The ideal planting date being the one with a high probability of receiving planting rains and most importantly, a high probability of receiving a fair amount of rainfall (>20 mm) at silking (70 days after planting for mid-season cultivars). The model simulations were also run to investigate the effect of planting density on maize yield in Potchefstroom and Mmabatho over periods of 57 and 12 years respectively. Results indicated that maize yields were increased with reduced plant density during seasons with insufficient water supply. In Mmabatho simulations showed that 14000 plants.ha^{-1} gave a reasonable yield for good seasons (more than 4 tons.ha^{-1}) and during bad seasons low input farmers would be able to reach a break-even point (more than 1.5 ton.ha^{-1}). In Potchefstroom 14000 plants.ha^{-1} gave a reasonable yield (more than 1.8 ton.ha^{-1}) during below average seasons but during seasons of sufficient water supply higher yields are obtained at densities of more than 18000 plants.ha^{-1}.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The present systems of land use, land ownership and land management are controversial issues that pose serious challenges to policy making in South Africa. On the other hand the quality of land itself determines both its present and its potential use under improved crop, soil and water management. These determine to a large extent the sustainability of the production potential of land in order to sustain the increasing population in this country. South Africa is poorly endowed with agricultural resources, having only 13% arable land, most of which is very marginal for cropping (Laker, 1993). It is estimated that only 3 percent of the land in South Africa can be considered high potential agricultural land (Schoeman and Scotney, 1987). The arable potential in South Africa is low by world standards and in comparison to some other countries in Southern Africa (Mackenzie, 1994). Most of the soils in this country are very unstable and extremely sensitive to mismanagement, and hence have a big danger of irreversible loss in crop production capacity. This, together with the presence of tremendous spatial variation of these resources complicates even further the development of appropriate land use.

In South Africa aridity is the main factor that determines whether a region is suitable for intensive farming practices or not. About 65 percent of South Africa has an average annual rainfall of less than 500 mm, which is generally considered to be the minimum required for reliable rainfed cropping. Schoeman and Scotney (1987) commented on the marked seasonal fluctuations in the production trends of major crops such as maize, which according to these authors is attributed to the erratic rainfall patterns and poor selection of soil resources. It is estimated that in the Eastern Transvaal (Mpumalanga) some 40 000 ha of high potential land are being utilized for coal mining (CSIR Environmental Services, 1992). Although these areas will eventually be partly reclaimed, potential hazards that are associated with this type of coal mining are large.

On the other hand the growing demand for food requires that the country should assess its production potential. The heart of the challenge is to ensure optimum utilization of available land resources, without causing degradation. According to Hensley, Anderson, Botha, Van Staden, Singels, Prinsloo and Du Toit (2000), land currently cultivated in South Africa can be divided into three categories:

(i) Good arable land: Sustainable long-term productivity easily possible with a relatively wide range of production techniques.

(ii) Marginal arable land: Sustainable long-term productivity only possible with specific production techniques efficiently employed.

(iii) Poor arable land: An acceptable level of sustainable long-term productivity is not possible for a variety of reasons. For example, rainfall too low and /or erratic; water storage capacity of soils too low in relation to rainfall amount and distribution; soils too frequently waterlogged.

Smith (1998) has generated extensive information on the definition and demarcation of high potential land (which falls within the first category), for rainfed annual crop production in South Africa. More than 50% of the Northwest Province, comprising its western and central parts, is on climatic grounds regarded to be marginal for crop production, mainly due to erratic and very unpredictable rainfall. Crops suffer from moisture deficits and drought even during seasons of normal rainfall. Yet, it produces 35 percent of South Africa's maize output, despite the climatic constraints and will continue to produce a large portion of the country's food grain, especially white maize, to feed the expanding population in the years ahead. The natural resource base in this region is highly fragile compared to the sub-humid parts in the eastern side of the province. Farm prices are typically low relative to production costs, and they fluctuate widely depending on the size of the harvest, which in turn is a function of rainfall.

Agriculture generally competes with other economic sectors in the Northwest Province, e.g. mining and quarrying, army bases, tourism (game and wildlife reserves), human settlements and other industrialization structures for land. Given that the demand for food will increase by roughly 3 percent per annum, this will create greater pressure on land resources.

1.2 DESCRIPTION OF THE STUDY AREA

The Northwest Province of South Africa is a semi-arid agricultural region with a harsh climate falling into three distinct physiographic zones: Bushveld or Northern Transvaal, north of a line roughly coinciding with the 29th Latitude, Highveld south of that line and Southern Steppe to the west of the 26th Longitude. The entire province is said to be falling within the most acute desertification risk (Land and Agriculture Policy Centre, 1995). The average annual precipitation ranges from about 250 mm in the west to 700 mm in the east. The rain season lasts from October to March, with the peak of the rain season being February or March in the Southern steppe climatic region and January in the remainder of the province. Rainfall normally occurs in the form of showers and thunderstorms. Hail is sometimes associated with the thunderstorms and can cause severe damage to crops.

Sunshine hours vary from 70% of the potential maximum in the west to 85% in the east. In January the average daily maximum temperature varies from 33°C in the west to 27°C in the east and 32°C in the northeastern part. The daily minimum temperatures in the areas in January vary from 15 to 13 and 18°C respectively. The daily maximum temperatures during July vary from 17°C in the southern part of the province to 22°C in the northern Transvaal climatic region. The daily minimum temperatures vary from 0°C to 4°C in July. The greater part of the province is frost free, except for only six districts with the following recorded average number of frost days per annum: Christiana 47, Delareyville 60, Lichtenburg 58, Marico 33, Potchefstroom 48, Ventersdorp 54 days. The period within which frost can be expected lasts for about 100 days (June to August) in the west and 120 days (May to September) in the east. In the northern Transvaal region, frost occurs from June to August. Winds are usually northwesterly, attaining their maximum speed in the afternoon. During thunderstorms strong winds and dusty southwesterly winds of short duration are a common feature. In the northern Transvaal climatic region however, winds are mainly light to moderate and blow from the northeast except for short periods during thunderstorms (Land and Agriculture Policy Centre, 1995). The larger part of the province has even and flat topography. Soil loss is mainly by wind erosion. Water erosion is limited to areas with steep slopes. About 53% (805,000 ha) of the ploughed fields in the province are susceptible to surface soil erosion, mainly wind erosion. Only a small proportion of potential arable lands are suitable for cash cropping, while the rest is suitable for pastures only. The largest part of the province is suitable for extensive grazing only.

1.3 CROP PRODUCTION SYSTEMS IN THE NORTHWEST PROVINCE

This study focuses on the "non-ideal", low rainfall region of the Northwest Province. The most difficult situation facing farmers is the fact that there is a relatively small difference between yield and production costs especially during "bad" seasons. Farmers in this region who aim at a low to medium risk scenario will manage their crop such that during a "bad" (below average rainfall) season they can at least reach the point where they can recover the input costs or "break even". In a good (above average rainfall) season the yield obtained can exceed 3 tons per ha. This explains why this region would rather be regarded as "non-ideal" rather than unsuitable for crop production, especially with adapted crops and cultivars. The lower limit of these "non-ideal", moderate potential regions would be at an annual rainfall of approximately 450 mm, with high potential soils and appropriate management strategies.

Most of the farmers in the region of the Northwest Province receiving less than 500 mm mean annual rainfall (MAR) contend that, considering their low input level and low planting densities, a maximum economic yield of 1.5 tons of maize per ha is an appropriate target for a bad season. In a good rain season they normally get more than 3 ton per ha even with low inputs and planting densities. It can go up to over 4 tons per ha in a good year with higher inputs, but then it has a high risk. Therefore one would come to a conclusion that marginal land for maize production in this context is that which can maintain economic yield (1.5 tons per ha) at least 70% of the time, under specified climatic conditions as well as management practices. The latter include low plant density, appropriate planting dates and fertiliser application, improved cultivation techniques and other technological inputs such as adapted cultivars, weed and pest control. It follows suit that land that cannot maintain economic production as described here would be regarded as unsuitable for maize production. The following chapters explore a quantitative method to assess the crop production potential of marginal land in this region. As mentioned earlier, this is vital for risk management in fragile ecosystems.

1.4 MOTIVATION AND STUDY OBJECTIVES

The typical production situation in dryland areas, of low inputs, outputs and marketing channels as described by Day, Butcher and Hughes (1990) is true for the Northwest Province. The unpredictable rainfall is the most serious difficulty facing the farmers. Farmers cannot be certain when the first rains will occur or when there will be sufficient moisture in the soil for land preparation, planting and seed germination. They cannot be sure of the amount of rain they will receive for the season nor its distribution throughout the season. Coping with the rainfall situation is a fundamental concern to these farmers. Hence the objective of this study was to find ways to help the farmers have a technique to assist them in their decision-making. Failure of crops due to drought may be expected in one out of seven years for the country as a whole (Cooper (1990), cited by Land and Agriculture Policy Centre (1995)). The probability of drought occurring in marginal areas is said to be higher than 40% (Land and Agriculture Policy Centre, 1995). The use of different methodologies aimed at quantifying the risks that the farmers in these fragile ecosystems are faced with could be a major breakthrough. The development of more accurate estimates of the impact of improved resource management, e.g. by better integration of soils, climate, agronomic and economic information, will also lead to improved economic livelihood of farmers in the sub-optimal regions.

Of the total area of 11 904 351 ha of the Northwest Province, 23.7 percent is arable (Mackenzie, 1994). Considering the fact that arable land is a scarce factor of production in this part of the country, the sustainable use of such land is of prime importance. This will ensure sustainable food security for the population at large and most importantly, income security for those on the land. The scope for improving crop production is determined by the physical constraints of soils, climate and by the resources available to the farmers and their ability to utilize them effectively. Land evaluation techniques can be used to assess actual and potential land performance for arable farming (Bekker, Kristensen and Radcliffe, 1994). Under marginal conditions, such as due to interannual variability of rainfall, a conventional method of land evaluation resulting in qualitative land suitability classes is of limited value. Therefore a quantitative method, which uses actual rainfall data for individual years, is required (Bekker *et al.*, 1994).

Owing to the fact that the Northwest Province produces 35 percent of the country's maize, there is a need to quantify the risks associated with maize production in this climatically marginal region. This would therefore serve as the basis for sustainable land management alternatives for arable land use. Further, such quantification would lead to proper definition of what is meant by moderately suitable, marginally suitable and unsuitable land for maize production. Ideally, the question of sustainability and economic viability of maize production systems applicable in such areas would be the central issues of concern.

The main objectives of the study were as follows:

- Evaluation and use of the Crop Yield Simulation And Land Assessment Model for Botswana (CYSLAMB) model to quantify maize production potential in the Northwest Province.
- To describe and /or develop a procedure to determine the maize yield production potential of the climatically marginal land of the Northwest Province.
- To give a contextual definition of marginal land.

CHAPTER 2

LITERATURE REVIEW

2.1 DEFINITION OF MARGINAL LAND

The word "marginal" can be defined as that which is close to the limit, especially of profitability, something that is barely adequate. Marginal land is the expression of the quality of land as a function of soil productivity, climate and landform and to some extent the production economics as well as the management of resource inputs. Hence the definition of marginal land requires a carefully selected set of criteria and units to measure quality of land itself. According to Hensley *et al.* (2000), marginally arable land refers to that in which sustainable long-term productivity is only possible with specific production techniques efficiently employed.

Schoeman and Scotney (1987) defined agricultural potential as a measure of possible productivity per unit area per unit time, achieved with specified management inputs. This definition is very appropriate, considering the continuous technological innovations whereby plant and soil amelioration result in a tremendous improvement in crop yields. This implies that a portion of land may be regarded as marginal under a specified production system but may not necessarily be judged the same under a different production system. This also makes the spatial demarcation of such land more complicated because of the fact that there are no permanent boundaries as such.

According to Eswaran, Almaraz, Van den Bergh and Reich (1997) the production potential of an area is determined by the interaction between precipitation and evapotranspiration, crop characteristics and soil conditions. In other words potential is determined by the atmosphere-plant-soil (APS) system that, according to Hensley *et al.* (2000), depends on three natural resource factors, i.e. climate, topography and soils. Thus, for a given crop and level of management input it follows that agricultural potential is largely determined by climate, soil and terrain form, mainly slope. In South Africa research efforts have been focused on high potential land where higher yields can be obtained with a higher degree of certainty. Smith (1998) regarded high potential land in South Africa as comprising all areas with favourable climate, soils and terrain and where actual performance of adapted crops ranks high in national perspective. According to him the climatic lower limit for such land is approximately 700 mm mean annual rainfall (MAR). Less than 550 mm MAR was classified as unsuitable for crop production. Unsuitable land for maize crop production includes the non-arable soils with mechanical limitations such as large rocks, shallow soils on rock/ weathered rock as well as soils occurring on steep slopes and in streambeds.

Larson, Roloff and Larson (1988) defined marginal agricultural land as land with cropland soils that are inherently unproductive for agricultural crop production and are subject to significant soil productivity loss from erosion. However there are many instances whereby land is rendered marginal for crop production by other factors like water deficit, steep slopes, lack of effective soil rooting depth and extremely cold or hot temperatures. Thus the criteria for determining marginal land are not only based on soils, but also on climate as well as landform. The general perception is that at lower than 550 mm MAR, land is regarded as unsuitable for crop production. However, the maize yield potential of some soils occurring in such regions can be quite high even below 500 mm MAR for example in the Northwest Province, especially with adapted crops and appropriate management practices.

2.2 THE CONCEPT OF MARGINAL SOILS

The productivity of land for crop production is primarily a function of the production capacity of soil in the sense that it is only after the soil productivity has been determined that the inputs that are incurred on the evaluation of the other natural resources are justified. The nature and quality of soil is a function of the soil forming factors climate, topography, parent material, living organisms and time. It is difficult to define a marginal soil since soils occur as a continuum and are not neatly divided into groups in nature (McGee, 1984). According to him the term marginal soil is a very wide concept that could include several types and categories of soil and the marginality of soils could be ascribed to several factors mentioned earlier in this report.

The marginality of soil could also be described according to an economic and production oriented definition, which implies that the soil is considered to be marginal when the ratio of agricultural production to the inputs required to achieve it is low. The decision to cultivate marginal soils must be an economic one based on a reasonable possibility to make profit, which implies that cultivation of marginal soil is justified only after a thorough assessment of the economic implications in terms of inputs incurred as compared to expected output. Good quality management is a determining factor to ensure profitability of marginal soils. On the other hand land may be unsuitable for large scale mechanised cropping, but suitable for small scale non-mechanised farming, or *vice versa* (Laker, 1978). In other words improvement in cultivation techniques and other technological inputs such as new cultivars, weed and pest control, etc. could contribute towards production in marginal soils becoming profitable.

Quite large areas are covered by extremely unstable soils in South Africa; hence those marginal soils will have to bear the brunt of crop production (Laker, 1997). He emphasises the need for more research on the performance of different crops under low levels of management on various types of non-ideal and marginal soils. Many soils are vulnerable to various forms of degradation and require special treatment for use (Scotney, Volschenk and Van Heerden, 1990), putting more emphasis on shallow depth, extremes of texture, rockiness, severe wetness and high erosion hazards as the most important limitations. High vulnerability to degradation may also make a soil marginal. High potential land or soil becomes marginal either because of the erosion danger when it is located on too steep slopes or in a vlei where cultivation is inadmissible (Ludick, 1998).

Ludick (1998) described marginal land as low potential soil that cannot maintain economic production under certain climatic conditions, in spite of correct management practices. According to this author a specific soil that could be marginal for a certain crop, does not necessarily need to be so for all crops. For example in the former Highveld a clayey soil, with a depth of 400 mm and an average long term rainfall of 694 mm could be completely economical with regard to the production of grain sorghum or sunflower but could be marginal (risky) for maize production.

Likewise, a sandy soil with an E-horizon at 400 mm depth and a Soft Plinthic B horizon (indicating a fluctuating water table) which is located in the **summer** rainfall Eastern Highveld and has a long term average rainfall of 663 mm, will be marginal for maize and grain sorghum (summer crop) cultivation. Yet winter wheat could be economically produced on the same soil, because the extra water stored in the soil will benefit this crop grown in the non-rainy season.

A soil could become marginal if production costs rise or if the prices of products fall as well as if it does not produce economically in the long term during seasons with an average rainfall. Further a certain depth phase of a soil family could for instance be marginal in the North West, with a rainfall zone of 450 mm, but not marginal in an area with a 600 mm precipitation that is well distributed. The final decision as to whether the land or soil is suitable for dryland grain crop production is determined by the economy. Ludick (1998) explained marginal land or soil from the economic point of view in the following ways:

- The yield potential for grain production of land or soil should justify the production costs. If the expected income from the crop is lower than the production costs, then the land or soil will be classified as economically unsuitable for that particular crop.
- When a decision has to be made regarding which crop is to be cultivated on a certain piece of land, it is necessary to do gross margin analyses (gross income minus production costs). Taking into consideration constraints or limitations for each crop applicable to the production thereof, it can be decided which soil or portion of land is marginal for which crop.

2.3 CRITERIA USED TO DETERMINE THE PRODUCTION POTENTIAL OF LAND FOR RAINFED ANNUAL CROPPING

FAO (1983) described land evaluation as the assessment of land performance when used for specified purposes. It provides a rational basis for taking land-use decisions based on analysis of relations between land use and land, giving estimates of required inputs and projected outputs. According to FAO (1976), land comprises the physical environment, including climate, topography, soils, hydrology and vegetation to the extent that these influence potential for land use. Land is wider than just soils and landforms. However, the variation between these is often the main cause of differences between land mapping units within a local area. Hence it is impossible to assess the fitness of soils for land use in isolation from other aspects of the environment and it follows that it is land which is employed for suitability evaluation. Agricultural potential can be described as an expression of possible production per unit area over a period of time and the production techniques used to achieve this production (Schoeman and Scotney, 1987). Wright (1977) believes that in its simplest form, land evaluation involves the assessment of selected land characteristics for particular purposes, whereas Nix (1968) believes that land evaluation means assigning values to different land units or to crop management combinations, preferably in economic terms. Regardless of the different concepts all these authors agree that the procedures of land evaluation involve the interpretation of biological resource inventories in relation to categories of use.

The function of land evaluation is to bring about an understanding of the relationships between the conditions of the land and the manner in which it is utilised (Beek, 1980). Hence there is a need to predict favourable and adverse effects resulting from the use of land as well as the required management inputs. Land evaluation is also concerned with the present performance of land, particularly as this affects changes in the use of land and in some cases changes in land quality. Extremely important when determining the agricultural production potential of land, is to specify the level of management or production system, which will be applied to achieve the specified objectives. Beek (1977), cited by Laker (1978) highlighted the fact that there are levels of management, namely; (i) primitive or low level, (ii) intermediate and (iii) modern or sophisticated. According to Laker (1978) it is important to realise that some soils with high potential for crop production under sophisticated management if they are in areas where it is easy to acquire modern technological aids, may be very unfavourable for crop production under conditions of primitive, simple or intermediate technologies or if they are in areas where it is difficult or expensive to acquire modern technological aids. On the other hand, some soils with only moderate crop production potential under sophisticated management may be relatively good soils under primitive or simple management. The author further explains that

sometimes areas, which are unsuitable for crop production by means of mechanised techniques, are well suited for crop production under non-mechanised systems.
It follows that an indication of the management inputs required for achieving a stated potential must be given. FAO (1983) gives a generalised description of the three different levels of inputs and management:

i. Low input level: This is usually rainfed cultivation of presently grown mixture of crops. No significant use of purchased inputs such as artificial fertilizers, or improved seeds, pesticides or machinery. Use of local cultivars, fallow periods practised and no soil conservation. High family labour intensity with family based infrastructure. Very low to low capital intensity. This is common in the developing countries.

ii. Intermediate input level: These are methods practised by farmers who follow the advice of agricultural extension services but have limited technical knowledge and capital resources; improved agricultural techniques; inputs adequate to increase yields but not to achieve maximum yields or maximum economic return; some fallow and some conservation practises. Use of improved cultivars and possibly some use of chemical weed, disease or pest control. They depend on the availability of credit for capital resources. The market orientation is of subsistence with commercial sale of surplus.

iii. High input level: Methods applied at this level are based on advanced technology and high capital resources; fertilizers at levels of maximum economic return; chemical weed and pest control at advanced technical levels; modern mechanisation methods applied to maximise yields or economic returns. Appropriate conservation practices and investments in ecosystem management; high utilisation of credit; highly commercial market oriented; frequent exchanges with extension service and peers. Use of high yielding varieties.

For a given crop and level of management, agricultural potential is largely determined by the interaction of climate, soil and terrain. Natural agricultural resources may be employed as properties or criteria for evaluating the production capacity of a portion of land and therefore can also be applicable for defining marginal land. Only a few can be mentioned here. This is not a complete listing of everything involved.

2.3.1 CLIMATIC CONDITIONS

Climate is the basic criterion for distinguishing various units of utilisation and the suitability of different localities for different crops. According to Schoeman and Scotney (1987), precipitation and solar energy are two of the important factors that influence agricultural potential in the sense that the interaction between precipitation and temperature, crop characteristics and soil conditions determine the productivity of a given area. Rainfall determines mainly the availability of moisture for the growing crop, while radiation, temperature, humidity and wind determine the moisture usage by the crop (evapotranspiration) (Jordaan and Du Plessis, 1998). In addition to this, Scotney *et al.* (1990) highlighted that latitude and altitude together with oceanic influences are responsible for the wide range of climatic conditions. High summer temperatures also influence evapotranspiration. Miller (1979) listed the following climatic properties:

- Precipitation regime:- amount, duration, intensity and sequence of distribution.
- Temperature:- Solar energy flux and distribution during frost-free period.
- Air quality:- Wind velocity, duration, humidity and inversion potential.

Mantel and Kauffman (1995) listed the following climate based land qualities that determine to a greater degree the production potential of land:

- Hailstorms, wind and frost.
- Length of growing season.
- Drought hazards during growing season.

2.3.1.1 PRECIPITATION

Rainfall is the most important climatic factor and the greatest limiting factor for crop production in South Africa, particularly in the semi-arid and arid regions. The annual fluctuation of rainfall makes planning of a crop farming enterprise more difficult. Rainfall distribution over the season enables the decision maker to determine the best planting date and therefore allows him to avert the so-called mid-summer drought, which occurs during the most critical period of the crop's developing process (Jordaan and Du Plessis, 1998). Moisture deficiencies in the plant give rise to moisture stress conditions which could have great detrimental effects on production, should they occur during certain critical phases in the plant's developing process. For a production of 3 ton.ha^{-1} maize 350 – 450 mm rain is necessary during the growing season.

The effectiveness of rainfall is also an important factor. Large amounts of rain in areas with steep slopes or strongly crusting soils are not effective due to water run-off. Strongly crusting soils are widespread throughout South Africa. Infiltration is severely restricted in soils which form surface crusts or seals, thus causing soil profiles to be dry. This explains why Hattingh (1998) puts so much emphasis on the improvement of the infiltration rate of soils to improve the effectiveness of rainfall.

Hattingh (1998) states that a soil with a compacted layer at 20-40 cm depth will inhibit the penetration of water to the depths where it is needed. However, in the sandy soils of the western Highveld area, which includes the Northwest Province, subsurface compaction will not seriously limit water infiltration (Laker, 2000 personal communication). Instead, its effect is preventing root penetration into the layers below it; hence they cannot utilise water stored in these deeper layers. It is common under such conditions to find plants suffering severe drought stress in soils that are very moist (even at field capacity) in the lower layers. The roots are boxed into a very shallow soil layer with a very small total water storage capacity. High fine sand content is listed as one of the factors affecting the susceptibility of soils to compaction and soil crusting (Bennie and Krynauw, 1985).

2.3.1.2 TEMPERATURE

According to Jordaan and Du Plessis (1998), temperature is one of the key factors regulating growth, primarily through the direct influence on the rate of metabolic processes but also indirectly through influencing physical processes such as evapotranspiration. Temperature also determines the duration of the growing season, which in turn determines the selection of the crop cultivar suitable for a particular area. Differences in altitude and latitude, as well as rainfall and humidity, are the main factors responsible for the difference in temperature between various regions and even between different localities within a given area. High temperature combined with low humidity can impact negatively on crop production. At Vaalharts, close to the area of the study reported here, Boedt and Laker (1985) found that under such conditions maize plants wilt by 10:00 am even in irrigated soils that are at field capacity.

2.3.1.3 WIND

Strong winds interfere with the water utilisation of the plant in the sense that it carries off the vapour in the air, thereby causing the replacement of moist air with dry air, resulting in higher evapotranspiration. The plant that is subject to such conditions reduces its turgor pressure in the cells of the stomata and eventually these cells close completely with the consequent effect on water uptake. Strong wind can also cause great erosion damage especially on sandy soils. By far the most serious problems of wind erosion on arable land are caused by losses of plants due to sandblast, requirement of additional tillage to combat it and loss of fertility. According to Joubert and Ludick (1990), at least 2 million hectares of cultivated land in the western Highveld region is susceptible to wind erosion and a further 300 000 ha in the Ditsobotla, Lehurutse and Molopo districts within the study area.

2.3.2 TERRAIN FORM

Major proportions of the developing areas in Southern Africa are characterised by steeply undulating landscapes, which are dominated by slopes that are both steep and long. Further, in most developing areas of Southern Africa, especially in semi-arid and sub-humid regions, the lower landscape positions are dominated by very unstable duplex and pseudo-duplex soils which are extremely vulnerable to soil erosion (D'Huyvetter and Laker, 1985). Terrain form and slope have a marked influence on agricultural production potential and management practices. According to Miller (1979), slope gradient, complexity, length and aspect, are the major properties that affect workability, access and micro-climatic conditions of a particular piece of land. In the study area this is not a significant factor as it is dominated by large plains.

2.3.3 SOIL PROPERTIES

Miller (1979) listed the following soil properties that are applicable to defining classes of agricultural land quality:

- Texture: - particle size distribution, coarse fragments make-up.
- Organic matter: - cation exchange capacity (CEC), water holding capacity and biological activity.
- Structure: - tilth
- Consistency: - degree of firmness and friability.
- Pore space: - total, size, shape, water holding capacity and bulk density.
- Depth: - rooting volume, moisture storage capacity.
- Drainage: - behaviour of soils in ridding itself of excess water.
- Chemical properties: - CEC, pH, Eh, ESP, electrical conductivity, and base saturation.
- Mineralogy: - nature of clay fraction.
- Erodibility: - degree of erosion potential and actual erosion loss.

2.3.4 SOIL PHYSICAL FACTORS AFFECTING THE POTENTIAL OF SOILS

2.3.4.1 SOIL TEXTURE, STRUCTURE, INFILTRATION AND RUNOFF

Soil texture is an indication of the relative proportions of various particle size fractions in the soil, namely: sand, silt and clay. In sandy soils, i.e. soils in the sand, loamy sand and sandy loam texture classes, the sand grade (coarse, medium, fine) is also very important. Unless crusting plays a role, the general trend is that the infiltration capacity of a soil decreases with increasing clay content. Soils with high clay contents in their topsoil, especially swelling clays, have low infiltration capacities. Consequently they have high runoff, which means low rain efficiency. For this reason sandy soils have higher cropping potential than finer textured soils in areas where rainfall becomes marginal for cropping. However, the low plant available water storage capacities of deep, excessively drained **coarse** sandy soils must also be kept in mind (Laker, 2000 personal communication).

Soil structure refers to the arrangement of the primary soil units into secondary structural units or peds. A soil is referred to be structureless when there is no observable aggregation or natural lines of weakness. A strong structure is where peds are well formed and durable and distinctly separate from one another in an undisturbed soil. A weak structure occurs where peds are indistinct and poorly formed, whilst a moderate structure occurs where peds are well formed and durable, but not distinctly separate from one another in undisturbed soil (Hattingh, 1998).

Soils with high organic matter content possess soil structures superior to those of soils with a low organic matter mainly because the organic matter stabilizes the structural units against breakdown. Consequently, a soil with a good and stable crumb structure usually has a high infiltration rate and is not susceptible to crust formation. A soil with stable structural units is not readily susceptible to soil erosion. However, where coarse strong structure is encountered, roots cannot penetrate the structural units, but only penetrate in between units, which negatively affect the crop production potential of such soils (Hattingh, 1998).

2.3.4.2 FIELD CAPACITY, WILTING POINT AND PLANT AVAILABLE WATER

Field capacity (FC) is the amount of water held in the soil against the force of gravity and is also the upper point of plant available water. The FC values usually increase with increasing clay content. For example, a soil with high clay content will require much rain in spring before the soil reaches field capacity. For this reason Hattingh (1998) recommends that the coarser textured soils should be utilised first for spring planting, because these soils reach field capacity sooner. Once the soil has reached field capacity all subsequent rain will simply drain from the soil and be wasted if there is no crop to utilize some of the stored water to create space for further rains. However, in marginal rainfall areas like the Northwest Province, it hardly rains enough to bring the soils to field capacity before planting. Therefore if farmers have to wait until the soil water content reaches field capacity before they could plant, they would have to plant very late, which then shortens their growing season and reduces yields.

Soil dries out due to evaporation from the soil or transpiration by plants until the plants will start wilting to a point where plant growth is inhibited because of shortage of water unless the soil is again moistened. The wilting point (WP) value, like FC, rises as clay content increases. Hattingh (1998) also stated that soils with a high clay content need much rain in spring before exceeding the wilting point values. All water present in the soil below wilting point is not available for plants. The soil water content held between field capacity and wilting point is referred to as plant available water (PAW) and is the amount of water that the plant can utilise. Particularly clay and silt content influence the plant available water storage capacity of the soil. In sandy soils the sand grade is very important. At Vaalharts the **fine** sandy soils, with only about 10% clay, have plant-available water storage capacities of about 125 mm/m, which is very high.

2.3.4.3 EFFECTIVE SOIL DEPTH

"Effective soil depth" is defined as the depth to which roots can penetrate without being severely restricted by some limiting layer. This is thus the depth to which air, water and plant nutrients are available for plant growth. Soil must be able to store sufficient water in the root zone during early summer and also in autumn and late summer when the evapotranspiration of the plant is relatively low, to provide the water needed by the crop during times when the evapotranspiration is high and the rainfall is low. The latter situation occurs in the Northwest Province in the form of midsummer drought, usually in January when the water requirement of the maize plants is highest.

The maximum soil depth utilised by annual grain crops, such as maize, wheat and sorghum, is more than 2 metres in deep sandy soils (Boedt and Laker, 1985). Favourable soil conditions require that water and air should be present in favourable proportions and that the circumstances in the soil favour the absorption of plant nutrients. Effective depth is determined by the presence of layers in the soil which are restrictive to root penetration. These restrictive layers include strongly developed structure, stony, partly weathered material, high water table or impermeable horizons (Table 2.1). Under rainfed grain crop production, the importance of deep soils where enough water can be stored to overcome the periodic drought can never be over emphasised, especially when the rainfall is low and erratic. For example, in an area with high well-distributed precipitation, soils with 400 mm depth can produce a good crop yield, while the same soil will yield much less or nothing in a dry area. This shows the necessity of establishing a minimum plant-available water holding capacity for economical crop production. According to Hattingh (1998) the above even applies for areas with relatively high annual rainfall because in such areas plant populations are usually high. The optimum soil depth is dependant on the type of crop, plant population, annual rainfall and rainfall distribution.

Jordaan and Thiart (1998) estimated that if a quarter of the annual rainfall could be stored at the required soil depth in a profile, the problem with periodic drought would be overcome to a large degree. According to Laker (2000, personal communication) the proportion of the rainfall that can be stored in the soil is a function of (a) the water storage capacity of the soil and (b) the infiltration capacity of the soil. The latter determines the amount of water that will be absorbed by the soil during a rainstorm.

A large percentage of highly productive sandy soils in South Africa possess an impermeable layer (sandy clay to clay) at a depth of approximately 900-1500 mm, which restricts the further downward movement of water by forming a perched water table. The upward capillary movement of water becomes possible, thus increasing the amount of water available to the crop. Water can also move laterally in the zone just above these permeable layers and crops can receive subsoil water from adjoining areas where the subsoils are over saturated (Jordaan and Du Plessis, 1998). These situations are especially important where a fluctuating water table is found, as indicated by the presence of a soft plinthic B-horizon. In high rainfall areas such soils are often too wet during the rain season, but in drier areas crops do better on soils with such horizons than on soils without them because of the enhanced plant-available water. In the Northwest Province enhanced water availability to plants plays a major role in dryland crop production. Consequently more consistent yields during relatively dry seasons are also found in soils with soft carbonate horizons in this area (Louw, H., Unpublished provisional draft of a M.Sc. dissertation, University of Pretoria). This is because much plant-available water is stored in these soft carbonate layers.

TABLE 2.1 Restrictive layers in soil with an explanation for the nature of restriction imposed by each. (Jordaan and Thiart, 1998)

Restrictive layer	Nature of restriction
1. Rock	Root penetration prevented.
2. Weathered rock (gravel)	• As the gravel content increases the soil volume decreases accordingly. The water, air and nutrient holding capacity of the soil is lowered. Effective depth is taken above the layer that is predominantly gravel.
3. Hardpan or soft carbonate horizon	• This horizon is formed through chemical deposition of carbonates in arid and semi-arid regions. A continuous hardpan carbonate layer restricts root and water penetration while a broken one may allow some penetration, though very limited. Calcareous soils may also possess soft carbonate horizons consisting of much soft powder carbonate. Observations have indicated that plant roots can exploit much water from it.
4. Blocky and prismatic structures	• Due to the strong forces of aggregation (cohesion) within these structural units, root penetration through these structures is virtually impossible. Root penetration only occurs along planes between structural units. This implies a decrease in volume of soil from which air, water and nutrients can be extracted. Due to the swell and shrink property of some of these structural units toots may also be injured in this process. Blocky structure in subsoils: The revised South African soil classification system (Soil Classification Working Group, 1991) distinguishes at family level between sub-angular blocky and fine angular blocky structure on the one hand and medium to coarse angular blocky structure on the other hand. The latter indicates very unfavorable conditions for root development and the effective depth is taken to the top of such horizon. The former is not so restrictive to root penetration and can be included in the effective depth, but rated down somewhat (Laker, 2000 personal communication). Prismatic structure in subsoils: Such horizons are very restrictive to root penetration and the effective rooting depth is taken to the top of the horizon.
5. Soft plinthite (mottled grey clay)	• A fluctuating water table in a soil is responsible for this horizon. Red and yellow mottles develop because of the accumulation and localisation of iron and manganese oxides and hydroxides in a particular layer. Eventually they are transformed into iron and manganese concretions. See discussions in the text on the implications of the presence of such horizons under different rainfall conditions.
6. Hard plinthite	• This layer originated from iron and manganese concretions that were cemented together over a period of time to form a hard iron pan. It restricts root penetration.
7. Firm grey clay, pot clay, G-horizon.	As soon as a clay layer develops light grey, dull yellow and / or blue green colours, it is an indication of permanent waterlogged conditions. Such soils are permanently very poorly aerated and therefore extremely unfavorable for the development and functioning of roots. The effective depth is therefore taken where the clay starts to display such colours, which indicate reduced conditions.
8. Grey coloured sandy layers in the soil	• This layer is developed by the reduction of iron oxides, together with a lateral flow of water on top of a restrictive, less permeable layer. This process gives rise to the removal of iron oxides, organic matter and clay particles from this horizon, overlying a restrictive one.
9. Grey coloured sand throughout the whole profile	• The greyish colour of this sand is usually attributed to the colour of the parent material and is not because of an over saturation with water.
10. Plough pan/ tillage pan	• It is caused by the smearing effect due to the particular action of certain implements. This condition can also be caused by wheel compaction. Root penetration is impeded. Fortunately this restriction can be eliminated.
11. Chemical restrictions	• Examples are: Brackish conditions Aluminium toxicity is some instances where the pH of a soil is very low (<5).

2.3.5 SOIL BASED LAND QUALITIES

Mantel and Kauffman (1995) use criteria that are not very different from those mentioned above, but they put more emphasis on the assessment of land qualities to evaluate the crop production capacity of land.

- Potential total soil moisture: - This depends on the interaction between soil, plant, climate and such factors as farm management. According to these authors, potential total soil moisture determines whether the availability of water during the growing period restrains growth and development of a particular rainfed cultivated crop. According to Hattingh (1998) a soil must contain at least 120 mm of plant available water at planting for effective plant growth. If the soil is very dry at the start of the season, in an area where the rainfall is very erratic, it is uncertain whether crop production will be profitable. Hence it is of crucial importance to determine whether there will be enough moisture present in the profile at planting in order to support the crop throughout the growing season.
- Oxygen availability and rooting conditions: - Availability of oxygen for root growth varies considerably depending on the drainability of soil and depth to ground water table. This is a function of rainfall, seepage, soil permeability, surface infiltration rate, internal and lateral movement of water and external surface run off and run on (Mantel and Kauffman, 1995). The underlying factor is the effect of prolonged conditions of water saturation on crop growth. Water logging causes yield losses by creating anaerobic soil conditions.
- Nutrient availability and nutrient retention capacity: - This is basically a function of soil fertility conditions, e.g. effective cation exchange capacity (CEC), exchangeable bases, soil reaction (pH) and soil organic matter. Nutrient elements in a soil may occur in many forms, and are, depending on the certain conditions, more or less available to a crop. According to Mantel and Kauffman (1995), the availability of nutrients does not only depend on soil factors such as soil temperature, pH and moisture, but also on weather conditions and farm management practices. Crops themselves also differ in their demand for nutrients and some crops are more efficient in extracting elements than others.
- Conditions affecting germination and seedling emergence: - This is determined by the size of structure elements, topsoil structure type, sensitivity to surface crusting and surface stoniness. Soil crusting and surface sealing is fast being recognised as

a widespread and serious problem in both irrigated and cultivated areas in various parts of South Africa. Soil crusting leads to poor seedling emergence and poor water infiltration, causing reduced yields on dryland cultivated areas due to a drastic reduction in crop's ability to withstand dry periods. A soil with a good structure usually has a high infiltration rate and is not so susceptible to crust formation. Soil compaction confines plant roots to very shallow depths, making a crop extremely vulnerable to drought and causing poor plant nutrient utilisation.

- Excess salts –(salinity and sodicity): - The occurrence of excess salts is common in arid and semi-arid conditions. Salinity is the excess of free salts and sodicity is the saturation of a significant proportion of the exchange complex with sodium ions. Excessive salts are toxic to plants. They also reduce the water availability to plants through increased osmotic pressure and cause nutritional disorders (Mantel and Kauffman, 1995). Sodium is usually associated with instability of soil structure.
- Soil toxicity (e.g. high aluminium saturation): - This refers to the effects of excess of harmful elements. aluminium toxicity refers to the harmful effects of the high concentration of aluminium in the soil. This is recorded to be a problem in acid soils with a pH below 5.5, when measured in a soil: water suspension or pH 4.5 when measure in 1M KCl suspension. Nutrient excess in soils also results from injudicious fertilization or from the application of pesticides, fungicides and herbicides that raise the concentrations of elements such as P, Zn, N and Cu in soils.

2.4 CROP MODELLING IN LAND SUITABILITY EVALUATION

The principal objective of land suitability evaluation is to compare the performance of a number of land units under a limited number of production systems. Systematically incorporating information into computerized models will be necessary to make realistic projections about future productivity and environmental degradation. Ritchie (1991) justified the use of crop models by stating that they are the principal tools needed to bring agronomic sciences into the information age. Crop simulation models that are generally designed to simulate soil-plant-atmosphere processes at the field level are increasingly being used in the analysis of agricultural production systems (Moen, Kaiser and Riha, 1994).

The development of simulation models to be used in agricultural production systems involves the fitting of functional relationships, which make up the models, and the testing of these relationships and completed models against real-world data (Jones and Carberry, 1994). A reliable prediction of crop yield is essential in quantitative land evaluation studies. Model validation can show how well or badly a model performs in a particular circumstance (Sinclair and Seligman, 1996). This leads to increasing use of crop models as reliable tools in quantitative land evaluation.

Boote, Jones and Pickering (1996) indicated the most important aspects to consider about crop models before their application:

- What is the crop model really designed to respond to?
- What assumptions are made (e.g. what does a model respond to, what does it ignore?)
- For a given simulation comparison, what events occurred in the field that the model may not address?
- What are the limitations of inputs to run the model?
- What are the limitations of the model?

Ritchie (1991) defines crop simulation models as a combination of mathematical equations and logic used to conceptually represent a simplified crop production system. Quantitative assessment of risks related to climate is possible through the use of dynamic crop simulation models. When coupled to input information on soil, weather, and production management, properly validated models improve risk assessment compared to the use of precipitation information alone. According to Dumanski and Onofrei (1989), summary mechanistic models that follow the detailed mechanistic models in principle but simulate only those processes that are critical to describe an agroecosystem are the most realistic and practical tools for land evaluation. These models describe processes in a theoretically sound manner, they require considerably less input data and they are cheaper to run and easier to calibrate. This is why they recommend them to be useful for estimating yield performance over a long-term in terms of probability distributions and to study the effects of extreme events. The basic understanding of the relationship between rainfall, soil moisture levels and crop yields is a fundamental concern.

2.5 THE CYSLAMB MODEL

The Crop Yield Simulation and Land Assessment Model for Botswana (CYSLAMB) has been developed to serve the needs of land evaluation in a semi-arid environment. According to Bekker *et al.* (1994) CYSLAMB is a quantitative method of land suitability evaluation, which uses actual rainfall data for individual years to overcome the problem imposed by the interannual variability of rainfall. By modelling the interaction of environmental variables, physiological responses, inputs and management, CYSLAMB predicts yield of a particular crop production system on a specified land unit. CYSLAMB has been developed as land evaluation software, which is structured in a way that it can also be used to test the impact of changes in input level or management operations on crop yields. For agricultural land evaluation crop yields have proved to be the most reliable estimates of comparative marginal value. Observed or estimated crop yields are often used in physical land evaluation to provide information on land suitability and to monitor changes in productivity and land quality over time (Smith, 1998).

2.5.1 SUMMARY OF THE STRUCTURE AND OPERATION OF THE CYSLAMB PROGRAM

CYSLAMB as a land evaluation software models the performance of a selected crop under a predefined land unit typified by its soil and climatic characteristics, using actual effective rainfall figures for individual years. The simulation results are expressed in quantitative terms (kg.ha^{-1}). Yield levels that are exceeded in a certain proportion of years (yield probability) can be estimated as well as the risk of crop failure. CYSLAMB uses the input data on production systems and characteristics of the selected land unit to simulate crop biomass production and yield for every year required by the run. A theoretical maximum possible crop biomass production for the crop under specified management conditions is calculated assuming that there are no constraints due to soils and rainfall. Solar radiation and temperature determine this theoretical maximum. The model then calculates a moisture balance from the first dekad of each hydrological year, taking into account incident effective rainfall, bare soil evaporation or weed evapotranspiration and water losses due to percolation or runoff.

The criteria for the definition of a planting opportunity are based on effective incident rainfall and stored soil moisture. When these criteria are met, the crop /soil water balance is then simulated through the crop growth cycle. Periods of moisture stress are accounted for in the calculation of the moisture limited biomass production. The moisture limited biomass production is then adjusted to take account of the effects of drainage conditions, nutrient supply and toxicity. The amount of produce is derived multiplying the resulting net biomass production by the harvest index and applying a moisture correction factor.

The yields calculated by CYSLAMB are potential yields, which represent management situations without yield reductions due to pests, diseases and other adversaries. If the model is run over a number of years, the outputs can be analyzed statistically to give estimates of the yield exceeded at stated levels of probability and the risks of crop failure. For each land unit the physically most suitable production system (highest returns) can be assessed and therefore the most suitable land unit in a study area for a given crop production system can be determined. The impact of different scenarios, consisting of various management operations and input levels on the crop yields can be tested in order to make appropriate extension recommendations specific to particular land units. These recommendations can then be adjusted for specific farmer groups, defined on the basis of access to resources (Bekker *et al.*, 1994).

2.5.2 *SUMMARY OF FEATURES AND ADVANTAGES OF CYSLAMB*

CYSLAMB was developed to serve the needs of land use planners, hence it required a different perspective and set of priorities than other simulation models. Smith (1998) gave the following statements summarizing the features and advantages of CYSLAMB:

- The model is flexible (modular design), which implies that it can be applied to any crop production system, provided the essential crop characteristics are known and the management operations and inputs are defined.
- It is capable of validation – one of the principal advantages of quantitative land evaluation methodology expressing the results as crop yields.
- It has a simple and logical methodology.
- It expresses the prominent role of moisture stress in determining yield, which makes the model appropriate for use in other semi-arid regions.
- It is scale independent and therefore can be applied at micro (household) and macro (provincial/ national) level.
- It includes land related and non-land-related parameters for evaluation, which means that it takes into consideration other aspects relevant to production systems when making assessments.

2.5.3 BASIC ASSUMPTIONS ON THE WATER BALANCE OF A SOIL-PLANT SYSTEM FOR CYSLAMB

The complexity and importance of the processes in the soil-plant-atmosphere system, which consist of the six water balance processes, require that its functioning be well understood. According to Hensley *et al.* (2000) a reliable model makes it possible to describe how the system functions in the long term under the conditions of large annual fluctuations in the climate component of the system. The moisture balance module of this model has been subject to the most stringent testing because moisture stress is the single most important yield determining factor in the semi-arid environments for which the model was developed (De Wit, Tersteeg and Radcliffe, 1993).

Some of the basic assumptions made with regard to the development of the water balance equation at field level for the model include the following:

- It is assumed that at the level of a farmer's field, run off and run-on compensate each other (=0) in the sense that very low net losses of water occur in rural rangeland where run-off from one site normally results in run-on to another site of the same micro-environment. Run-off mostly results in infiltration or temporary surface storage somewhere else in the same field.

- The gains and losses due to lateral seepage at farm level are equal (=0).
- Ground water tables in Botswana usually occur at considerable depth often exceeding 30 m. Therefore the contribution of groundwater to the arable profile is omitted.

The latter assumption is rather questionable in the context of the study area considering the occurrence of the impermeable subsoil horizon viz. soft plinthite. Soils with such characteristics develop a zone of periodic saturation and have high water storage capacity. This moisture plays an important role in providing a favourable soil moisture regime in these drier regions of the country.

2.6 SENSITIVITY ANALYSIS AND CALIBRATION OF CYSLAMB

According to Boote *et al.* (1996), model calibration refers to adjusting certain model parameters or relationships to make the model work for a particular site or sites. Model validation determines whether the model works with totally independent data sets that are intended to find whether the model can accurately predict growth, yield and processes. A sensitivity analysis was conducted to see how the model (in terms of simulated yield) responded to changes effected in the crop characteristics.

These were the Kc factors (crop-coefficients) and the yield response factors (Ky). The values were adjusted to the point where results obtained showed a constant agreement with the observed yields. There was no available data that could be found on these cultivar specific factors. However, the values used are within reasonable estimates when compared with the generalised information on maize used in the ACRU model published by Smithers and Schulze (1995) (Tables 2.2 and 2.3). Crop coefficient (Kc) is the coefficient used to calculate potential maximum crop evapotranspiration (ET_m) from the evapotranspiration of a reference crop. According to De Wit *et al.* (1993), the main characteristics affecting Kc values are the adaptation to control crop transpiration, crop height, crop roughness, crop reflection, percentage groundcover, crop planting date, rate of crop development, length of growing season, and, especially during the early growth stage, the frequency of rainfall. As already mentioned earlier, planting in the western parts of the province is usually delayed until December, whereas in the eastern parts, early planting is usually expected to give better results. Table 2.4 shows the values used in the simulations for this exercise. One of the most important management decisions in the marginal areas is the choice of plant populations or plant density classes. For example, what is regarded as a low plant density in high and moderately high potential areas represents a high plant density class for the low potential areas.

Table 2.2 Generalised information of maize crop coefficients in Southern Africa (dryland condition) (Smithers and Schulze, 1995)

Planting Date	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*
October 10	1.01	0.56	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.37	0.80	1.08
October 20	1.07	0.79	0.37	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.64	1.04
November 1	1.10	0.95	0.46	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.46	0.92
November 10	1.07	1.02	0.62	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.37	0.79
November 20	1.07	1.00	0.47	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.70
December 1	1.01	1.08	0.70	0.36	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.48

Table 2.3 Seasonal distribution of crop coefficients used for maize planted early (October 2) or late (December 15) in all areas (after Green, 1985), cited by Smithers and Schulze (1995)

Crop Coefficient	Planting dates	
	October 1 Days after planting	December 15 Days after Planting
0.4	1 – 20	1 – 17
0.7	21 – 40	18 – 34
1.0	41 – 60	35 – 51
1.1	61 – 100	52 – 86
0.9	101 – 120	87 – 103
0.5.	121 – 140	104 - 120

Table 2.4 Crop (Kc.) coefficients used for the CYSLAMB runs.

Plant Density classes (Plants.ha^{-1})		Maize crop coefficients	
		Kc. 1	Kc.2
Low	<16000	0.38	0.30
Medium	16000-20000	0.49	0.45
High	>20000	0.90	0.85

Kc. 1: The coefficient used to calculate crop moisture requirements at the end of the vegetative stage.
Kc. 2: The coefficient used to calculate crop moisture requirements at the end of the ripening stage.

The yield response factor (Ky) expresses the sensitivity of the crop to moisture stress. According to Bekker *et al.* (1994) the response of yield to water stress relates relative yield decrease to relative evapotranspiration deficit, of which the latter may either occur continuously over the total growing period of the crop or over one of the individual growth periods. In general for the total growing period the decrease in yield relative to the increase in water deficit is proportionally greater (Ky>1) for more drought sensitive crops such as maize. For the individual periods, the decrease in yield due to water deficit during that growth period is relatively small for the vegetative and ripening periods, and relatively large for the flowering and yield formation periods.

The following values were applied in the runs for this study:

Early vegetative stage	(Ky1a)	:0.34
Late vegetative stage	(Ky1b)	: 0.52
Flowering	(Ky2)	: 0.70
Yield formation	(Ky3)	: 0.60
Ripening	(Ky4)	: 0.29
Flower and yield formation*	(Ky23)	: 1.10
Total crop cycle*	(Ky14)	: 1.38

* These are the compound Ky Factors used by CYSLAMB, in such a way that in the event of moisture stress exceeding 50% at flowering or during yield formation, Ky 23 is used rather than the two individual Ky factors for these stages. This is done to accommodate the ability of the crop to apportion the adverse effects of moisture stress over these two, highly critical yield response periods. The Ky14 is given as an average reduction occurring throughout all crop development stages.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 EVALUATION OF CYSLAMB MAIZE YIELD SIMULATION

The evaluation of CYSLAMB using statistical methods recommended by Willmott (1981) was done only for maize crop yields in the Northwest Province. The main objective was to verify the applicability of the model for the quantification of the risks associated with maize production in the marginal areas. The three stations used in this study, viz. Setlagole situated towards the west, Potchefstroom in the Southeast and Ottosdal in the central region, were chosen as they are representative of the environmental conditions prevailing in the Northwest Province and also because of the availability of input data required to run the model.

3.1.1 CRITERIA FOR MODEL EVALUATION

The simulated results were compared with the results obtained in field experiments, thereby testing the accuracy with which the model describes the actual system, thus evaluating its performance (Willmott, 1981; Du Toit, Booysen and Human, 1997). There are quite a number of quantitative methodologies for the evaluation of model performance in the literature. Amongst others the D-index (the index of agreement which is the measure of the degree to which the model's predictions are error free), mean absolute errors (MAE), systematic and unsystematic mean square errors (RMSEs and RMSEu respectively), are recommended for model evaluation by Willmott (1982). Willmott (1982) also recommended that researchers compute and report the root mean square error or the mean absolute error, as well as their systematic and unsystematic proportions or magnitudes and the average relative error represented by the index of agreement. The interpretation of these measures should be descriptive and based on scientific grounds; not on the basis of the measures of statistical significance. The average error produced by a model is encapsulated in the root mean squared error (RMSE) especially that it provides information about the actual size of the error produced by the model. Du Toit *et al.* (1997) also applied these methodologies in the evaluation of the CERES3 (Maize) model.

3.1.2 MATERIALS AND METHODS FOR EVALUATION

Trial records for the maize cultivar PAN 473 from the following three locations were used to obtain the observed maize yield and management practices indicated in Table 3.1:

Potchefstroom (Lat. 26°44′ S, Long. 27°06′ E: Alt. 1345 m a.s.l.): Hutton form soils (Soil Classification Working Group, 1991). Dark reddish brown apedal soil; medium sandy loam in the topsoil to medium sandy clay loam texture in the subsoil (Appendix 1.1.1-1.1.2). Three different planting dates in one season (1986), on soil with a depth of 1.2 m. A constant plant population of 18000 plants.ha^{-1} was used. Soil P content (Bray-1 method): 40 mg.kg^{-1}

Ottosdal (Lat. 26°57′S, Long. 26°00′ E: Alt. 1341 m a.s.l): Clovelly form soil (Soil Classification Working Group, 1991), brown to dark-brown apedal soil; coarse sandy loam to medium sandy clay loam texture (Appendix 1.2.1-1.2.2). Three different planting dates, but in three different seasons. Different population densities of 15000, 16000 and 19000 plants.ha^{-1}, respectively in the three different seasons. Soil P content: 20 mg.kg^{-1}

Setlagole (Lat. 26°18′ S, Long. 24°57′ E; Alt.1270 m a.s.l) Clovelly form soil, a yellow brown apedal soil (loamy fine sand texture) with a potentially very deep root zone (2.1 m deep) (Appendix 1.3.1-1.3.2). Two different planting dates in three seasons. Constant population density of 14000 plants.ha^{-1}. Soil P content: 23 mg.kg^{-1}.

The above information together with the dekad (10 day period) climate data including the actual rainfall, mean dekad minimum and maximum temperature, sunshine hours per dekad, rainfall frequency and Potential Evapotranspiration were included into the CYSLAMB runs to simulate maize yield potential at the sites. The simulated yields were compared with the observed yield using the statistical procedures proposed by Willmott (1981) to test the model performance. The specific parameters describing the programme environment within which the model was run in terms of plant density classes, crop co-efficient and crop yield response factors are as described in Chapter 2.

TABLE 3.1 Planting date, planting density and observed maize grain yields for experiments used for validation of CYSLAMB

Station name	Planting date (dekads)	Planting density (plants.ha^{-1})	Observed Yield (kg.ha^{-1})
POTCHEFSTROOM	Oct 2 1986	18000	3401
	Nov1 1986	18000	3322
	Nov3 1986	18000	1799
OTTOSDAL	Dec2 1990	15000	4399
	Dec1 1991	16000	781
	Nov3 1992	19000	3723
SETLAGOLE	Dec1 1993	14000	3800
	Nov2 1994	14000	750
	Nov2 1995	14000	4570

3.1.3 APPLICATION OF THE CYSLAMB MODEL

The model was applied to screen or test the impact of a number of management systems or decisions on maize yield production. Data on both physical and fertility status of soils that occur in the study area (Clovelly and Hutton, also shown in Appendix 1), as well as long term climatic data were captured into the model. Different input levels and management systems were also captured. The model was calibrated for this study to consider toxicity, salinity, nitrogen (N) and potassium (K) as not limiting and therefore not affecting yield. The model could respond to changes in phosphorus (P) and sodium (Na) content in the soil. The management systems that were simulated included the following:

- ⇒ The choice of suitable planting dates, whereby the model simulated maize yield at different planting dates (in dekads) over a period of 56 years in Potchefstroom and 13 years in Mmabatho. The date with the highest yield under a particular set of soil and climate conditions within a specific management operation was regarded as the suitable date for planting.
- ⇒ The model also simulated the effects of different levels of planting densities on maize yield under marginal rainfall conditions. The density class with the highest yield potential was regarded as ideal for the area (see density classes in Table 2.4)

⇒ Another simulation was run to determine the frequency of occurrence of a planting opportunity, whereby the specified conditions required to initiate planting were defined and captured into the model to simulate the probability of having those conditions met during the specified planting dekads. These simulations were run over 56 years in Potchefstroom and 13 years in Mmabatho.

3.2 PROCEDURES APPLIED FOR DETERMINING MANAGEMENT DECISIONS

As outlined in the previous chapters, the sustainability and production potential of natural resources in the fragile ecosystems depends to a large extent on the way they are managed. In such marginal rainfall areas as these, the erratic nature of rainfall, including the occurrence of dry and wet cycles, is the main point of concern for maize farmers. Some of the critical factors that need to be taken into consideration when deciding on crop management practices include the interaction between rainfall, timing of crop planting and soil properties (since the infiltration rate and the water holding capacity of the soil determine soil moisture). Further, the plant response to soil moisture, in turn, plays a significant role in crop yield in the sense that if plant demand for water exceeds available soil moisture levels, plants will experience moisture stress and in most cases yield will be negatively affected. Hence a marked difference in target yields between dry and wet cycles could be expected depending on soil type and rainfall regime (Du Pisani, 1985). The above factors will in turn determine to a large degree the appropriate plant populations to be used as well as the appropriate level of fertiliser application necessary to ensure an economic and sustainable crop production system.

3.2.1 IDENTIFICATION OF A PLANTING OPPORTUNITY

By definition a planting opportunity is identified when the pre-defined effective dekad rainfall and topsoil moisture conditions are fulfilled. The topsoil moisture content is more important than the amount of rainfall received, to ensure that planting is not initiated on soils with very low available water contents at planting. The planting opportunity in any particular season is usually limited due to the fact that the date of planting is one of the most important parameters affecting yield. Hence the choice of an appropriate planting date ensures that after a planting opportunity has been identified, the young plants are well established before the major rains fall and are also strong enough to resist possible dry spells during the growing season.

However, in resource poor farming systems, besides moisture determined planting opportunity the availability of resources such as labour or draught power and inputs determine the timing during which planting occurs. Consequently, planting is often spread over a certain period, for example over two or three dekads, in which case the model will simulate yield based on the specific dekad that suits the pre-defined moisture conditions. This in turn is another way of minimizing risk of crop failure due to poor germination. For the purpose of this study the model was allowed to simulate long-term maize yield taking only one planting opportunity into consideration.

For the purpose of this study the model was calibrated to identify the planting opportunity based on the requirements that the amount of rainfall received should exceed 10mm and/or available soil moisture content of 15 mm and above is required. This was done to accommodate the fact that sufficient amounts of rainfall are received before the actual planting date and in case of a good soil moisture storage germination can still take place. The rainfall amount of 10 mm seems very low considering the fact that at least 20-25 mm is the general required amount to initiate planting in most places. However, in marginal rainfall areas one needs to look beyond what is occurring at planting and forecast what is expected later in the season when the maize plant requires higher moisture levels.

3.2.2 DETERMINATION OF APPROPRIATE PLANTING DATES

In addition to the identification of planting opportunities, as described in Section 3.2.1, the soil must contain an adequate amount of plant-available water before planting in order to supplement rainfall during growth. High risk is a major problem in view of the uncertainty of the prediction of the rainfall pattern in a particular season. In low rainfall areas under dryland production the choice of planting date can be a hazardous process in the sense that the producer may be tempted to plant after the first summer rains while ignoring what is to be expected later in the season (De Bruyn, 1979). This part of the country usually experiences midsummer drought conditions around mid-January to February at Ottosdal, Setlagole, Mmabatho and surrounding areas in the western parts but in areas around Potchefstroom it occurs during late December and early January. Should this period coincide with the stage of crop growth when the crop is very sensitive to moisture stress, this will have drastic effects on maize yield. The management must be of such a nature that flowering (silking) does not coincide with midsummer drought. If sufficient moisture is retained in the profile the impact of moisture deficit is reduced until mid-January, after which the moisture demand of the maize crop demands that the profile be recharged with rainwater for sufficient growth.

A number of techniques have been developed in order to determine the most suitable planting dates in different parts of South Africa, including the study area. But the ideal method to give better estimates would be the one that considers amongst other factors: long term rainfall data, evapotranspiration and water holding capacity of different soils. A computer model like CYSLAMB, which includes such factors amongst others to simulate maize yield for different planting dates could give the appropriate planting date. The ideal planting date is the one that gives relatively high yield at high probability. For this study the CYSLAMB model was used to simulate yield over the period of 57 years (available climate data) in Potchefstroom on well-drained Hutton soil, 1.2 m deep and 100 mm/m available water content. The simulations were run starting from the third dekad in October (Oct3) to the third dekad in December (Dec3). A similar exercise was conducted for the Mmabatho area on Clovelly soil, 2.1 m deep with water holding capacity of 100 mm/m. The simulations were run from November (Nov1 dekad) to January (Jan1 dekad).

3.2.3 DETERMINATION OF THE APPROPRIATE PLANT POPULATION

Low plant populations in combination with wide rows and adapted cultivars as well as low inputs are some of the major management practices that make it possible to produce reasonable maize yields under climatically marginal conditions. In low plant populations the roots, being supplied with adequate assimilate by the well-illuminated lower leaves, provide sufficient cytokinins to the shoots where they attract assimilate to the various sinks. In the ear this may promote growth of large and many kernels (Wilson and Allison, 1976). Whereas in large densities, according to these authors, during drought stress the supply to the shoots is probably restricted because of the reduced root activity resulting from the shortage of assimilate, aggravated in the drought-stressed plant by the dry soil conditions. According to the research findings by Van Averbeke (1991) one of the implications of the practice of adjusting planting density in maize as an applied management tool is that during dry years a farmer would get better yield at low planting density and avoid total yield failure, while possibly sacrificing bumper yield in good years. In this study, the effects of low plant populations on maize yield production were determined for Potchefstroom and Mmabatho using CYSLAMB. Simulations were run for densities of 10 000 to 30 000 plants ha^{-1} in Potchefstroom on three different planting dates (Nov3 to Dec2). For Mmabatho, simulations were run for densities of 10 000 up to 20 000 plants ha^{-1}.

3.2.4 THE FARMER'S MANAGEMENT SYSTEMS

For the purpose of this study, the management systems adopted by different farmers in the study area were regarded to be very important. Informal interviews were conducted with some farmers (both large-scale commercial and small scale commercial) in order to learn how and why they manage their farms. Farmers were asked about the cultivars they plant at what populations, their planting dates, fertiliser applications, the kinds of soils on their farms. Where yield records for previous seasons were available, these were also taken into consideration to see if the simulated yields were close to the yields obtained by the farmers. (Appendix 3 contains a checklist with most of the questions that were asked during consultations held with the farmers.)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 MODEL EVALUATION / VALIDATION

Comparisons of the individual observed results and the corresponding ones simulated with the CYSLAMB model are presented in Table 4.1. Results are given for simulations using (a) the total crop cycle as a unit and (b) using individual crop development stages separately. The statistical analysis parameters for these are given in Table 4.2.

According to Willmott (1981), the index of agreement (D-index) can vary between 0.0 and 1.0, where a computed value of 1.0 indicates perfect agreement between the observed and predicted observation, and 0.0 connotes one of a variety of complete disagreements. Therefore, the D-index of 0.98 for the simulation using the ***total crop cycle*** in this case (Table 4.2), shows a perfect performance of the CYSLAMB model under these conditions. With respect to a `good` model, the systematic difference or RMSEs should approach zero while the unsystematic difference (RMSEu) approaches RMSE (Willmott, 1982). The RMSEs value of 245 kg.ha^{-1}, RMSEu of 303 kg.ha^{-1} and the RMSE value of 389 kg.ha^{-1} are indications of an excellent model performance so far. The slight overprediction (122 kg.ha^{-1} or 4.1%) of average yield by simulations based on total crop cycle by CYSLAMB is insignificant. Not only are the average yields very similar, but also the simulated and observed minimums were similar, as was also the case with the maximums. In addition the observed and simulated minimums were for the same season at the same experimental site. This was also the case for the observed and simulated maximums.

Overall the simulations based on ***individual periods*** gave slightly poorer results than those based on the total crop cycle, but still gave good results (Table 4.2). This method underpredicted the average yield by 191 kg.ha^{-1} or 6.5%. Its simulated maximum also differed by a wider margin from the observed value than in the case of simulation by means of the whole crop cycle. The minimum simulated by means of the individual periods method differed very widely from the observed minimum (i.e. by no less than 75%). In addition the simulated and observed minimums were not for the same year or site, neither were the simulated and observed maximums. There was a specific, very important, scenario where the individual periods method gave a much better simulation than the total crop cycle method. This is discussed later.

Table 4.1 Planting date, planting density (plants.ha^{-1}) and observed and simulated grain yield (kg.ha^{-1})

Station name	Planting date (dekads)	Planting density	Observed Yield	Simulated yield with CYSLAMB	
				Total crop cycle	Individual crop development stages
POTCHEFSTROOM	Oct 2 1986	18000	3401	3460	2320
	Nov1 1986	18000	3322	3340	3210
	Nov3 1986	18000	1799	2860	1900
OTTOSDAL	Dec2 1990	15000	4399	4480	4390
	Dec1 1991	16000	781	950	1310
	Nov3 1992	19000	3723	2770	2700
SETLAGOLE	Dec1 1993	14000	3800	3930	3239
	Nov2 1994	14000	750	840	1400
	Nov2 1995	14000	4570	4670	4350

Table 4.2 Statistical measures of CYSLAMB yield simulation performance

	Observed yield (kg.ha^{-1})	Simulated yield with CYSLAMB (kg.ha^{-1})	
		Total crop cycle	Individual crop development stages
Minimum	750	840	1310
Maximum	4570	4670	4390
Mean	2949	3071	2758
Std Dev	1469	1456	1146
Slope		1.03	1.18
Intercept		-311	-304
MAE		218	476
RMSE		389	606
RMSEs		245	435
RMSEu		303	422
D-Index		0.98	0.94
r^2		0.95	0.85

Du Toit *et al.* (1997), suggested that, since the differences described by RMSEs are a linear function, this could be easily decreased by new parameterization, such as changing soil parameters, genetic coefficients or re-calibrating existing functions. Jones and Kiniry (1986), as cited by Du Toit *et al.* (1997), suggested that input errors are more likely, and in practical terms a more serious source of poor model predictions than are logic or calibration errors. These facts were clearly shown by the model response during model sensitivity analysis. Sensitivity analysis was conducted on the following: soil parameters like depth, available water content, available P level and yield response factors (Ky). Nitrogen and potassium contents were assumed to be not limiting in this exercise. The Ky factors define the plant's sensitivity to moisture stress during specific stages in the development of the crop.

One of the attributes associated with CYSLAMB is that it uses the Ky factors to calculate crop biomass reduction due to moisture stress in two ways:

- Multiplied for all four individual crop development periods, namely; vegetative period, flowering, yield formation and ripening. In addition to the Ky factors for individual yield response periods, CYSLAMB uses the compound Ky factors. If either during flowering or during the yield formation period a moisture stress of more than 50% is encountered, a compound Ky factor is used (rather than the two individual Ky for these stages) to estimate the yield response for the combined two periods. This is done to accommodate the ability of most crops to apportion the adverse effects of moisture stress over these two, highly critical, yield response periods. This accounts for the effect of sink-source relationship, as will be explained later. Estimated yield results multiplied for individual crop development periods are usually much lower and show exaggerated moisture stress except for bad seasons when the model simulated higher yield than that observed. This partly explains the underestimated maximum (4390 kg ha^{-1}) when compared with the observed maximum of 4570 kg ha^{-1} versus the overestimated minimum yield (1310 kg ha^{-1}) when compared to the observed minimum (750 kg ha^{-1}).

- Estimated over the total crop growth period, whereby the total crop biomass reduction is given as an average reduction that occurred throughout all crop development stages. The compound Ky factor used in this case estimates the overall effect of moisture stress. The yield results based on these simulations are generally very slightly over predicting the yield (Table 4.2).

One of the basic assumptions included in the model is that for the individual growth periods the decrease in crop yield due to water deficit during a particular period is relatively small for the vegetative and ripening period, and relatively large for the flowering and yield formation periods (De Wit *et al.,* 1993), as specified in section 2.6.

4.1.1. POTCHEFSTROOM

For the first two planting dates the observed yields were very similar (Table 4.1). Simulation with CYSLAMB, using the total crop cycle approach, in both cases gave values that were practically identical to the observed yields, which was an excellent performance. The observed yield for the third planting date was barely 50% of those for the first two planting dates. In this case the total crop cycle approach grossly overestimated the yield. In contrast, simulation with the individual periods approach grossly underestimated the yield for the first planting date, but quite accurately simulated the poor yield for the third planting date.

The simulated results show that the season started with sufficient moisture at planting for the first two planting dates. However, 60 to 70 days after the Oct2 planting (the first planting date), when these plants were at high moisture stress sensitive stages, more than 50% stress was simulated. Thereafter the conditions became better again until 130 days after planting, when the stress went up again during a low moisture stress sensitive stage (Figures 4.1 to 4.4). These figures illustrate the rainfall distribution during the season as well as the simulated ET_a and ET_m. The former is the actual water loss from a specified crop and soil, taking account of water availability and the latter is the maximum potential water loss from a specified crop and from soil when water is not limiting. Clearly, the individual periods approach totally underestimated the ability of the plants to recover during subsequent favourable periods from the stress experienced during the early season sensitive stages. For the third planting date (the third dekad of November) the late summer moisture stress was reported to have occurred during silking (Du Toit *et al.,* 1997).

In this case, clearly the total crop cycle approach totally overestimated the ability of the crop to recover during late season from stress during the extremely drought sensitive silking stage. The model simulated moisture stress of more than 60% within 80 days after planting. The stressful conditions continued until the end of the season (Figures 4.5 and 4.6.)

The model estimated a 65% crop biomass reduction between 56-135 days and a total of 74% when multiplied for the 4 individual crop development stages. In this case the compound Ky23 factor was used to estimate biomass reduction, which combined these two periods to accommodate the ability of maize to apportion the adverse effects of moisture stress over these two stages. Hence these results were so accurate. The simulations over the total crop-growing period showed moisture stress of 61%, which greatly reduced the effect of the severe moisture stress conditions during the critical periods, hence the overestimated yield. (See Appendix 2 for the details of this simulation.) During the particular season the third planting date (the third dekad of November) coincided with moisture stress during silking. The individual stage approach in this case correctly simulated the serious effect of the drought stress during the very sensitive silking stage and the inability of the crop to recover from this damage later in the season. Obviously farmers need to avoid such a situation. For this purpose they need to know when such mid-summer drought can be expected in most years. The planting date can then be adjusted so as to avoid silking coinciding with the drought period in most years. This aspect will be discussed in detail in Section 4.2

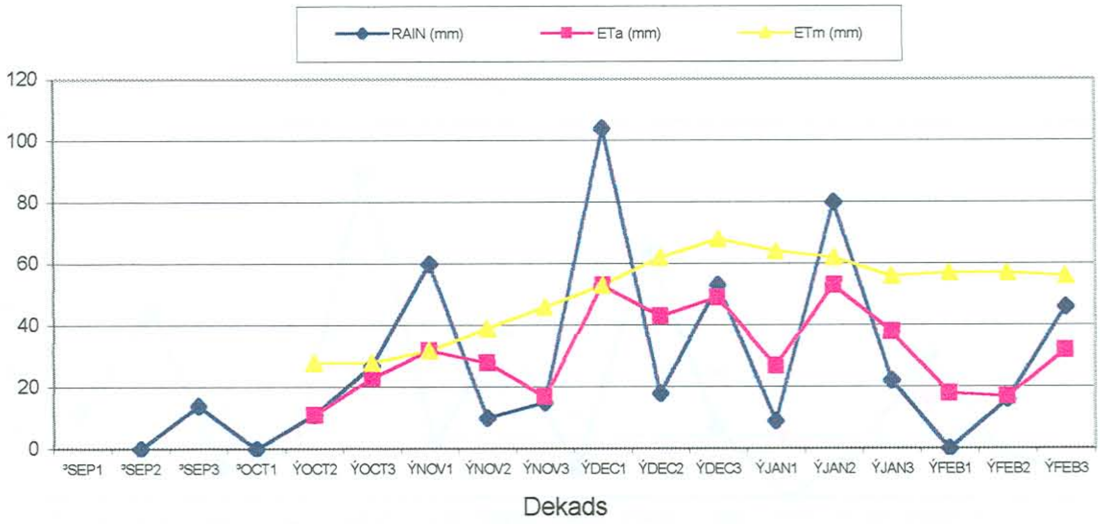


Fig. 4.1 Dekad Rainfall distribution and Simulated ETa & ETm 1986 season in Potchetstroom (Oct 2 planting)

Fig 4.2 Simulated moisture stress (%) Oct2 planting in 1986 season in Potchefstroom

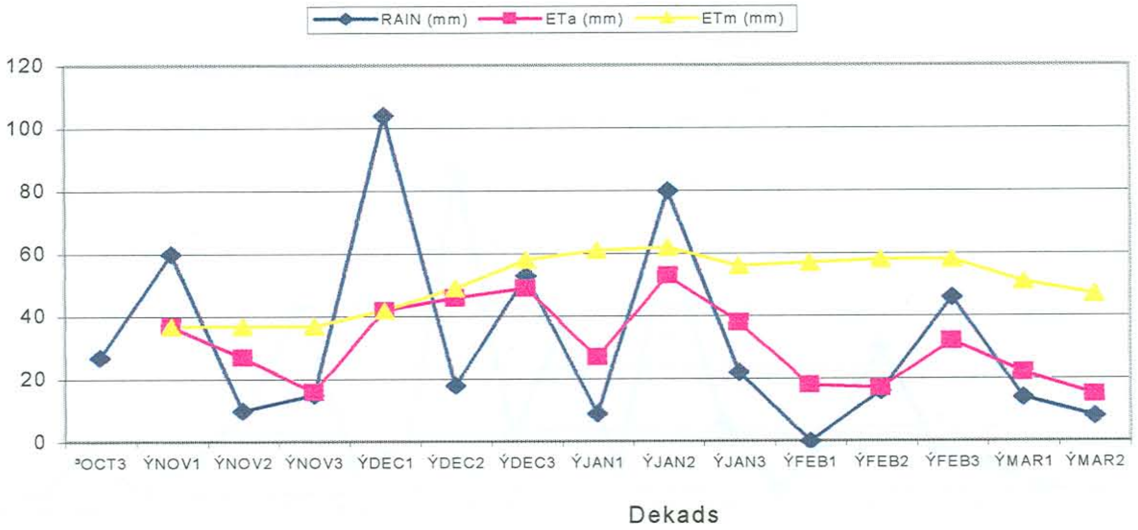


Fig 4.3 Dekad Rainfall Distribution Simulated ETa and ETm 1986 season in Potchefstroom (Nov1 planting)

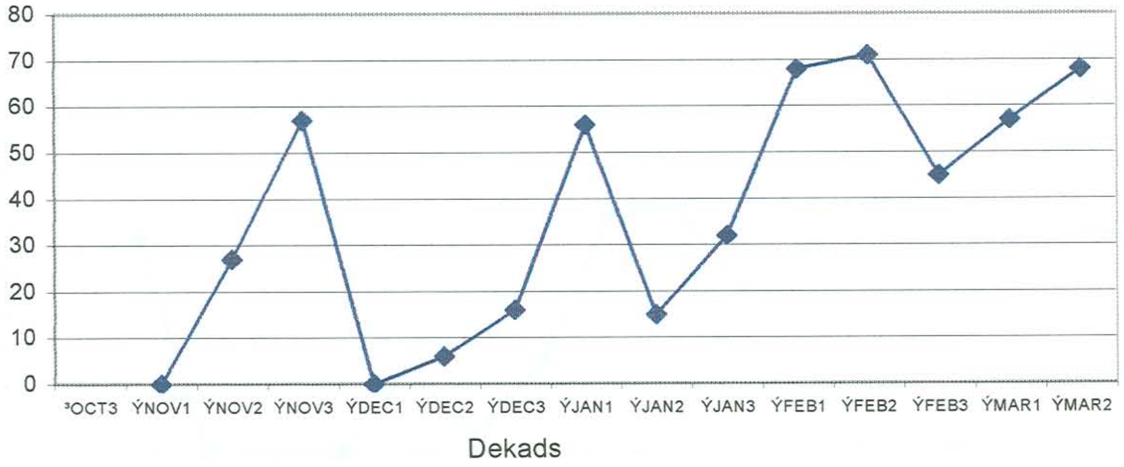


Fig 4.4 Simulated moisture stress (%) Nov 1 Planting 1986 season in Potchefstroom

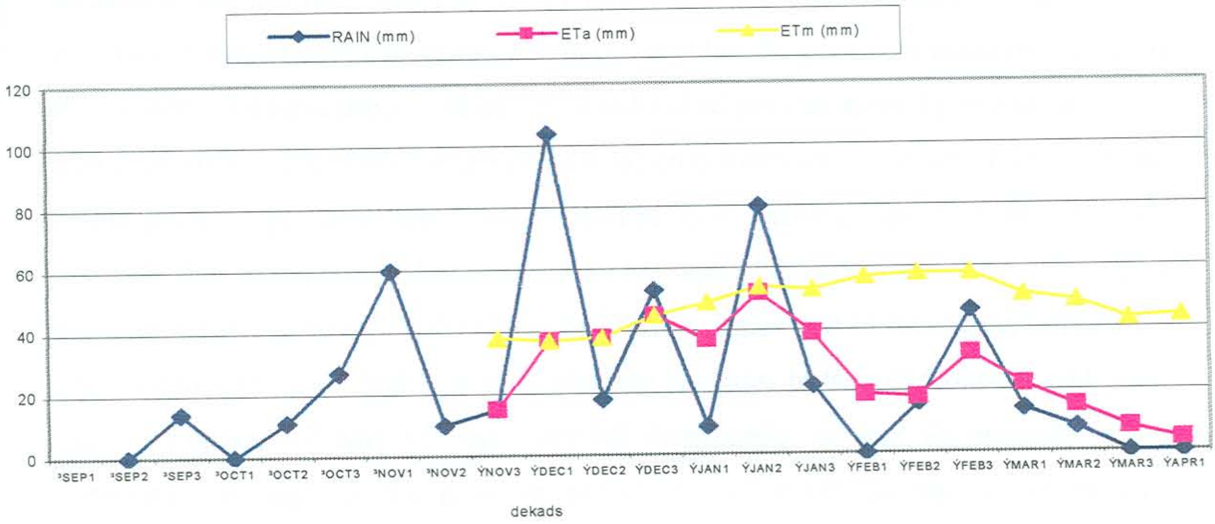


Fig 4.5 Dekad Rainfall Distribution Simulated ETa and ETm 1986 season in Potchefstroom (Nov3 planting)

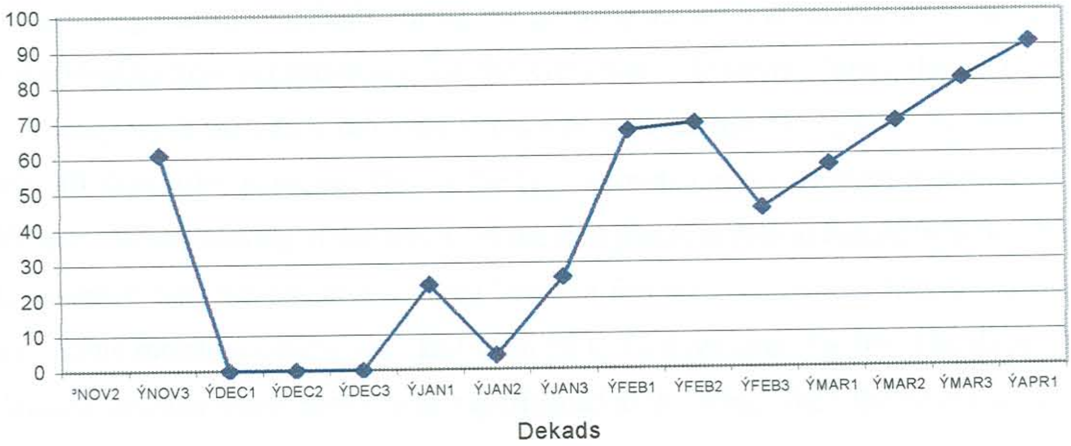


Fig 4.6 Simulated moisture stress (%) Nov 3 Planting 1986 season in Potchefstroom

4.1.2. OTTOSDAL

For the 1990/91 season the reports from the trial indicated that the higher yield measured resulted from cob prolificacy of the cultivar that manifests in good years (Du Toit, personal communication). Both the simulations gave very accurate results in this season. The simulated yield based on individual periods agreed perfectly with the observed yield. The model simulated a total crop biomass reduction of 35% for the whole growing period (from day 1-145). The most striking aspect of this season's results is that an actual yield of nearly 4.5 $t.ha^{-1}$ was obtained in this good year with a planting density of only 15 000 $plants.ha^{-1}$. This implies that in these area farmers do not have to embark on high risk high planting densities to benefit from the odd good year. Figures 4.7 and 4.8 show rainfall distribution as well as moisture stress distribution throughout the growing period. An excellent distribution of rainfall contributed a lot in reducing moisture stress during critical crop growth stages, hence a good yield was obtained.

During in the 1991/92 season, simulated Et_m remained much higher than the previous year until very late in the season (Figure 4.9). This is not unusual for this area. Looking at the rainfall distribution over the season compared to the simulated ET_a, it is surprising that most dekads during the growing season had rainfall exceeded Et_a if one considers how exceptionally low the yield was. However, during the first dekad in January more than 80% moisture stress was experienced during this season, within only 40 days after planting. This is the typical mid-summer drought experienced in this area. When looking at the results of the first planting date at Potchefstroom, it can be assumed that the plants recovered because fortunately the next four dekads had favourable moisture conditions. But from 50 to 60 days later, i.e. 90 –100 days after planting, another stress period was experienced at the stage when the plants were the most sensitive to moisture stress, which might have had the most impact in yield reduction. More rainfall (30mm) came very late in April, but could not really impact much on yield. By just looking at the graphs in Figures 4.9 and 4.10, the farmer could have achieved a better yield by just changing the planting date. The question would be how could he know beforehand at what stage such a condition would occur later in the season? This justifies the need for land users to find out the probability of getting such stress situations during specific periods in a particular area by using the rainfall data from the previous years. This will enable them to plan ahead according to the amount of risk they are willing to take.

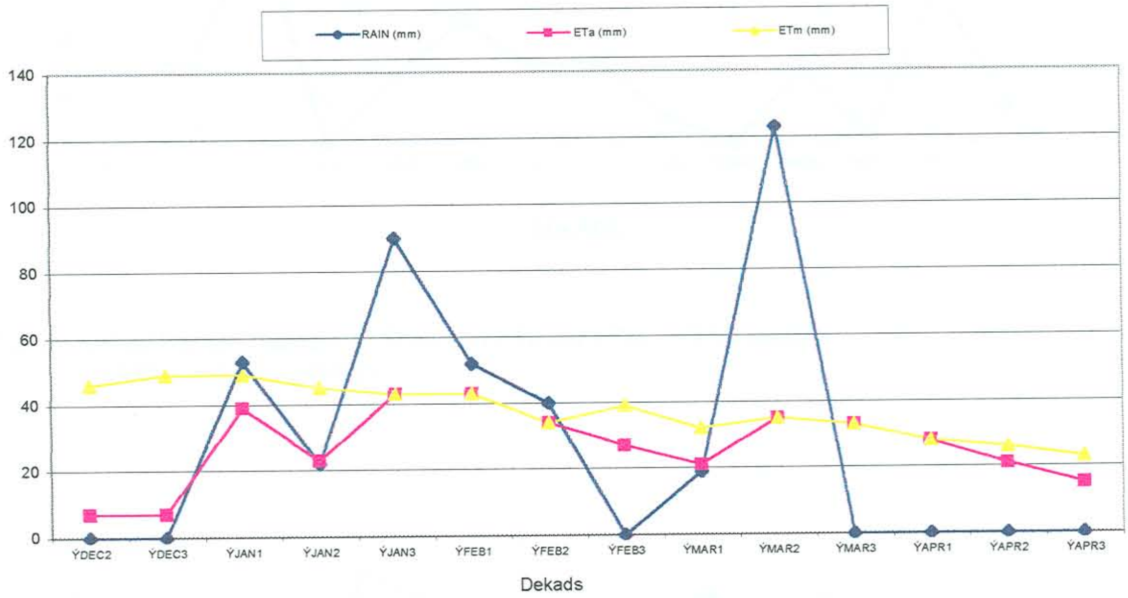


Fig 4.7 Dekad Rainfall Distribution Simulated ETa and ETm 1990/91 season in Ottosdal (Dec2 planting)

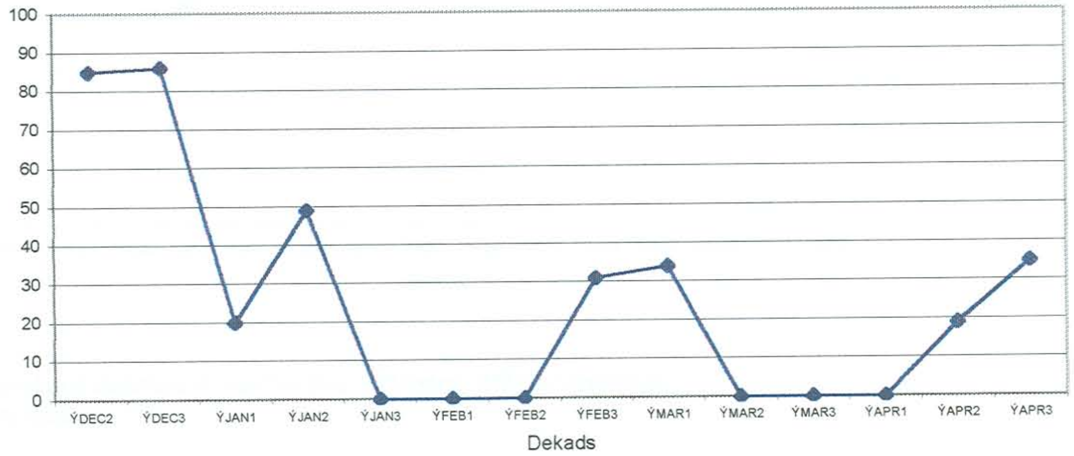


Fig 4.8 Simulated moisture stress (%) Dec2 Planting 1990/91 season in Ottosdal

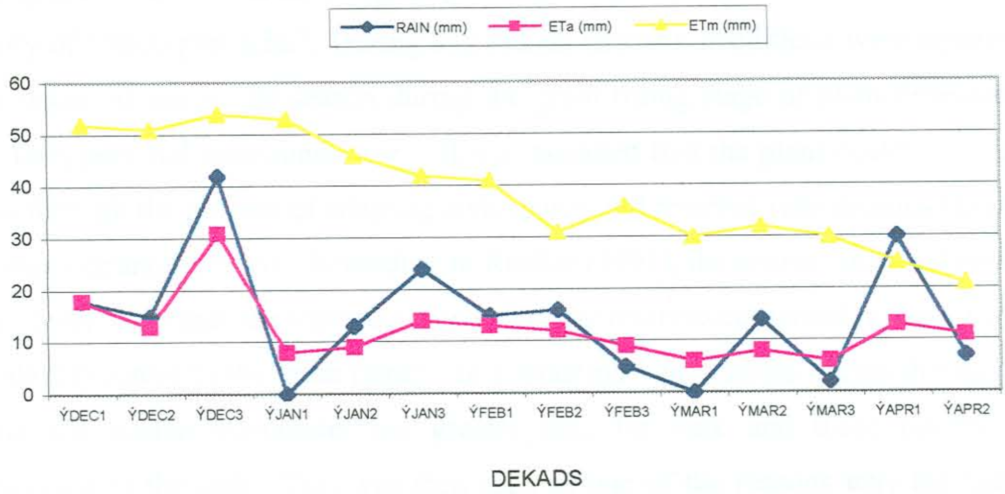


Fig 4.9 Dekad Rainfall Distribution Simulated ETa and ETm 1991/92 season
in Ottosda (Dec1 planting)

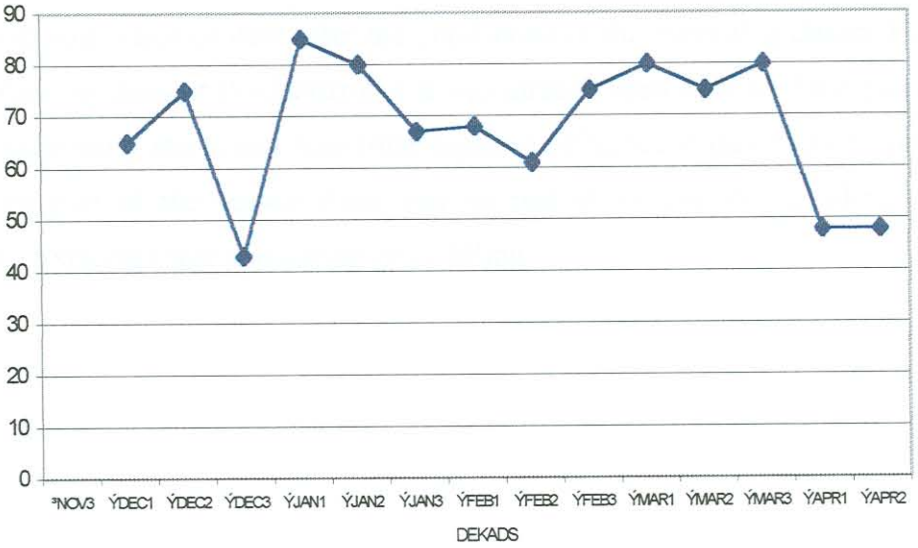


Fig 4.10 Simulated moisture stress (%) Dec 1 Planting 1991/92 season in
Ottosdal

During the 1992/93 season, a higher yielding cultivar (PAN 6479) was planted at a density of 19000 plants.ha^{-1}. During this season stressful conditions were reported to have occurred late in the season during the grain filling stage of plant development (Du Toit, personal communication). It was assumed that the plant could survive the stress through the process of adapting sink/source and reserves relationships (Du Toit, personal communication). According to Ritchie (1991), the source, sink and reserves relationship describes the transportation of energy reserves contained in other parts of the plant (source) to the grain (sink). In a situation where stress occurs during grain filling the source assimilates are greater than the sink and these reserves are transported to the sink. This was then seen as one of the reasons why the yield in such a season at Ottosdal could be as high as it was. The climatic data for Ottosdal for this season does not support this perception of late season stress, however (Figures 4.11 and 4.12). The only severe stress period was early in the season at 50 to 60 days after planting, which was immediately followed by a high rainfall dekad. At 80 days after planting there was again a significant stress period, but this was moderated by the high soil water content after the good rains of the preceding dekad. For the first two planting dates at Potchefstroom it was already seen how well the plants recover from such early stress and how little negative influence it then has on yield. During the late part of the season there was no real stress period, including during the sensitive silking stage and during grain filling.

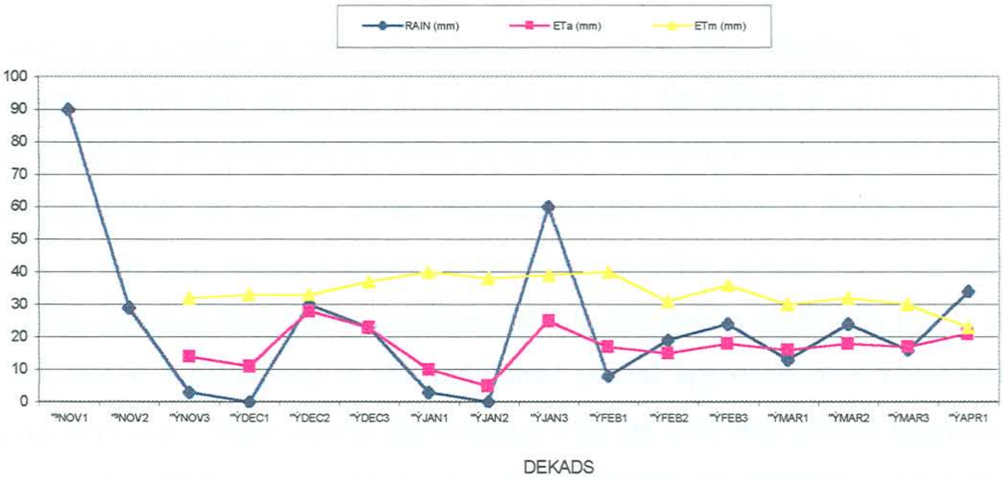


Fig 4.11 Dekad Rainfall Distribution Simulated ETa and ETm 1992/93 season in Ottosdal (Nov3 planting)

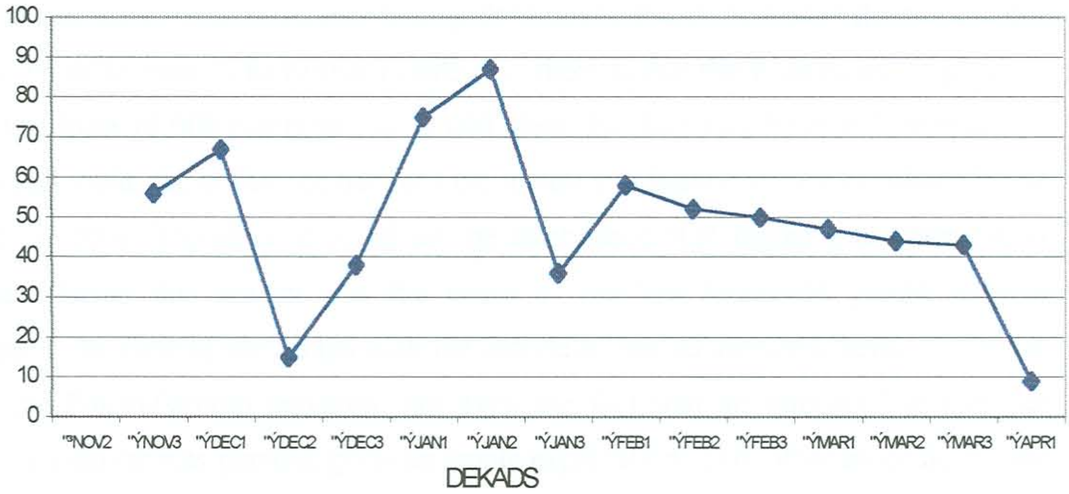


Fig 4.12 Simulated moisture stress (%) Nov3 Planting 1992/923season in Ottosdal

Simulation results for both the total crop cycle and individual period approaches overestimated the yield reduction due to moisture stress during this season, and hence simulated lower yields than was observed. For the simulation based on individual periods this was similar to the situation for the first two planting dates at Potchefstroom, where this approach also overestimated the effect of early season stress and simulated a too low yield. Even the degree to which it underestimated the yield was very similar for the two cases, underestimating it by 32% at Potchefstroom and by 28% in this case. Overestimation of the negative effect of early season stress during seasons in which favourable conditions later in the season enable the plants to recover, is clearly a deficiency in the individual period approach of CYSLAMB which needs attention. Unfortunately the situation with the total crop season approach is not so clear cut: At Potchefstroom it very well simulated the recovery after early season stress, but in this case at Ottosdal it was as poor as the individual period approach.

The cause of the differences between simulated and actual yields, especially for the total crop cycle approach, could not be established at this stage. However 11 simulations were run at different planting densities to test if the higher density did not cause the difference. The results (Table 4.3) showed that the wide range of planting densities from 10 000 plants.ha^{-1} to 20 000 plants.ha^{-1} had very little influence on the simulated yield, the difference between the lowest and highest values simulated being less than 10%. Therefore it could not be established that higher plant population planted during this season was the cause of the low simulated yields, as was suspected. In view of the results with the individual period approach being so similar with the Potchefstroom situation, not even the fact that an improved and higher yielding cultivar was planted, gives an ample explanation. This situation could be due to a number of reasons that could not be explored in this study.

TABLE 4.3 - Simulated yield at different plant densities for Ottosdal (for 1992/93 season)

Run	Plant density (plants/ha)	Yield.p (kg/ha)	Yield.t (kg/ha)
1	10000	2590	2590
2	11000	2630	2630
3	12000	2620	2620
4	13000	2660	2660
5	14000	2710	2710
6	15000	2750	2750
7	16000	2580	2650
8	17000	2620	2690
9	18000	2660	2730
10	19000	2700	2770
11	20000	2370	2510

4.1.3 SETLAGOLE

For the 93/94 season, sufficient water was reported in this station to produce good yields (Hensley *et al.,*2000). The simulation based on the whole growing period for this season gave accurate results, but the individual periods simulated yields of nearly 0.6 tons.ha^{-1} less than the observed. Most of the rain during this season came early (65, 44, 21 and 18mm during dekads Oct1, Oct2, Oct3 and Nov1 respectively). The model simulated 10mm available moisture at planting despite the fact that only 1mm rain was received. High moisture stress was simulated within 10 to 20 days, after which the conditions became very good again until 90 days when moisture stress became worse again (Figures 4.13 and 4.14). The model simulated 49% crop yield reduction between 71-125 days after planting and a further 14% reduction after 126 days. (See Appendix 2 for the details of this simulation)

The 1994/95 season was very dry, with only four storms over the whole growing season. Some rainfall came very late in the season after flowering and as expected the yield was very low (Hensley *et al*, 2000). The simulated ET$_m$ remained higher for most of the season except for the two storms in Jan2 and Mar3, the same with ET$_a$ except for the three storms Dec3, Jan2 and Mar3 dekads, unlike the previous year (Figures 4.15 and 4.16). Simulated moisture stress remained high during most of the season. A crop yield reduction was simulated between 26-45 days after planting and continued to increase up to 71% between 71-125 days. A total of 88% crop yield reduction was simulated for the whole growing period whilst a to total of 81% was simulated for the individual periods. The simulations during this season were similar to those for the Ottosdal 1991 season except for the fact that unlike the Ottosdal season, during this particular season in Setlagole there was no better planting date that the farmer could have chosen to get a better yield. The whole season was very dry.

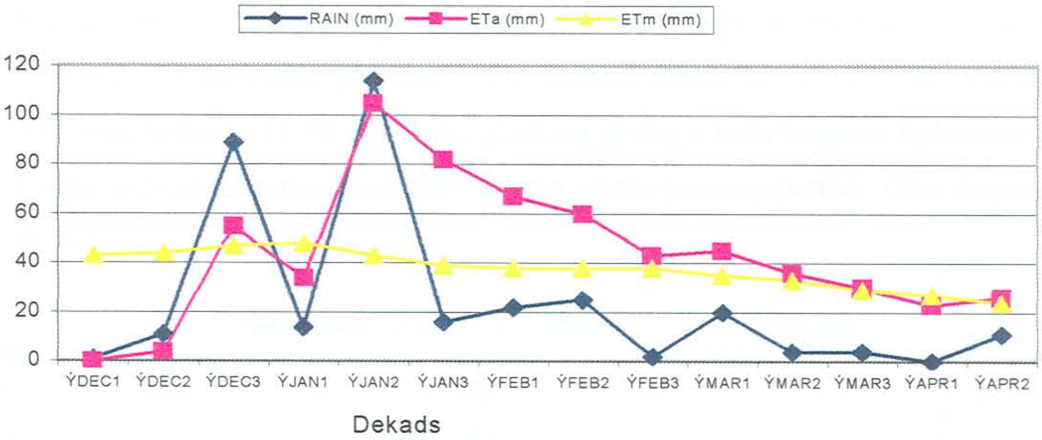


Fig 4.13 Dekad Rainfall Distribution Simulated ETa and ETm 1993/94 season in Setlagole (Dec1 planting)

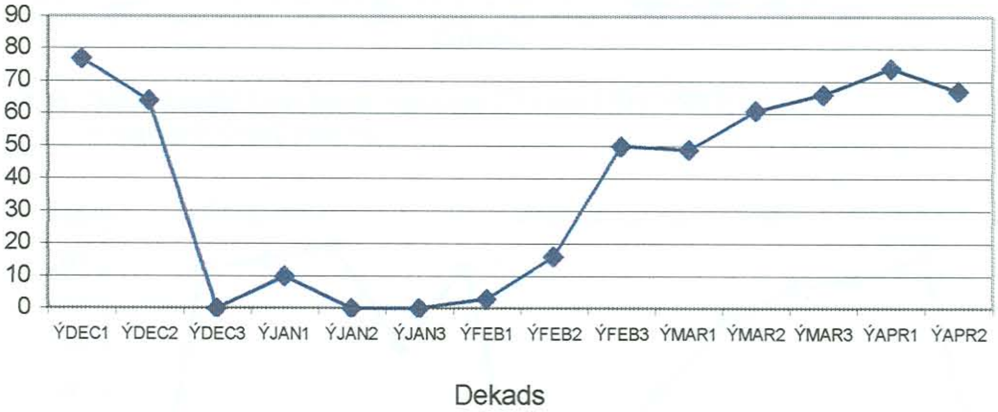


Fig 4.14 Simulated moisture stress (%) Dec 1 Planting 1993/94 season in Setlagole

The 1995/96 season was a very wet season with good and well distributed rain. Again a very good yield of 4.6 $t.ha^{-1}$ was obtained in such a good year with a planting density of only 14 000 $plants.ha^{-1}$. The simulations for this season showed an excellent performance by the model. The highest moisture stress of 89% was simulated within 20 days after planting, however this had no effect on the yield (Figures 4.17 and 4.18). Again, 50 and 55% moisture stress was simulated in early February 90 and 100 days after planting which resulted to a crop biomass reduction of 17% (91-125 days after planting). The highest simulated crop biomass reduction of 23% was between 71-90 days after planting giving a total biomass reduction of 42% for the individual periods and 38% for the whole growing period. (See Appendix 2.3 for details.)

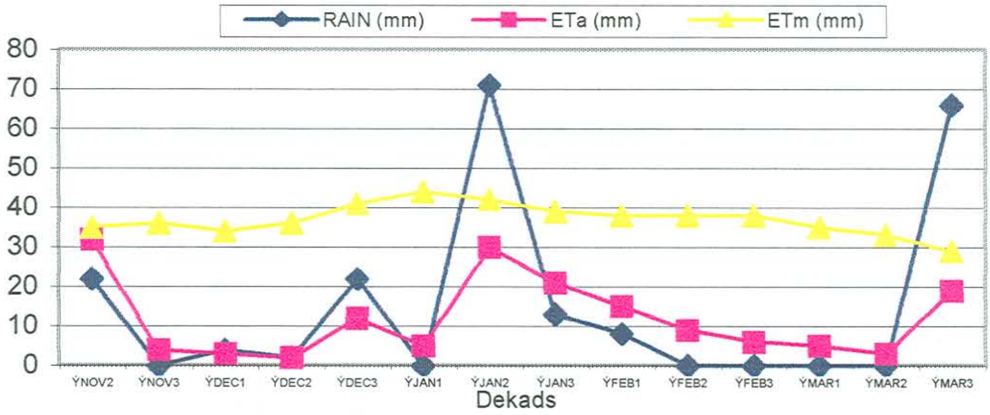


Fig 4.15 Dekad Rainfall Distribution Simulated ETa and ETm 1994/95 season in Setlagole (Nov2 planting)

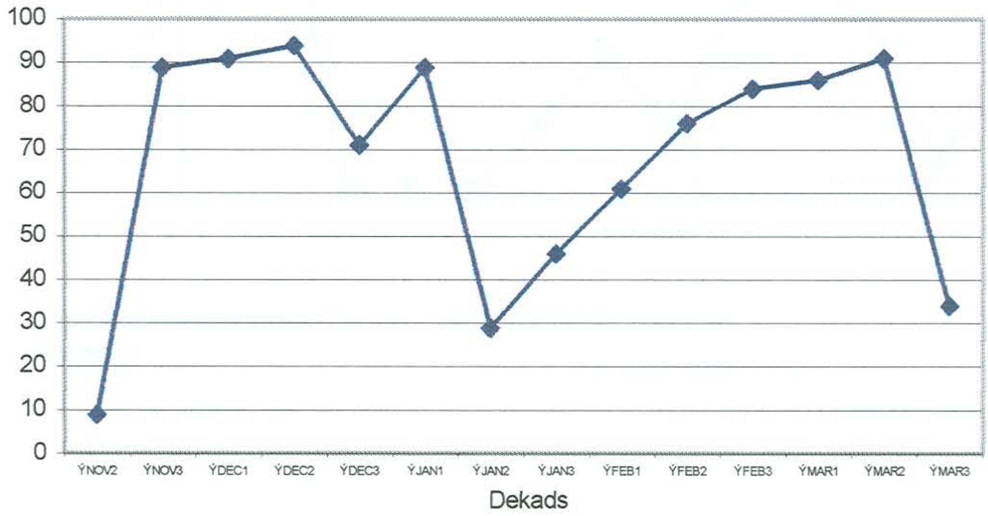


Fig 4.16 Simulated moisture stress (%) Nov2 Planting 1994/95 season in Setlagole

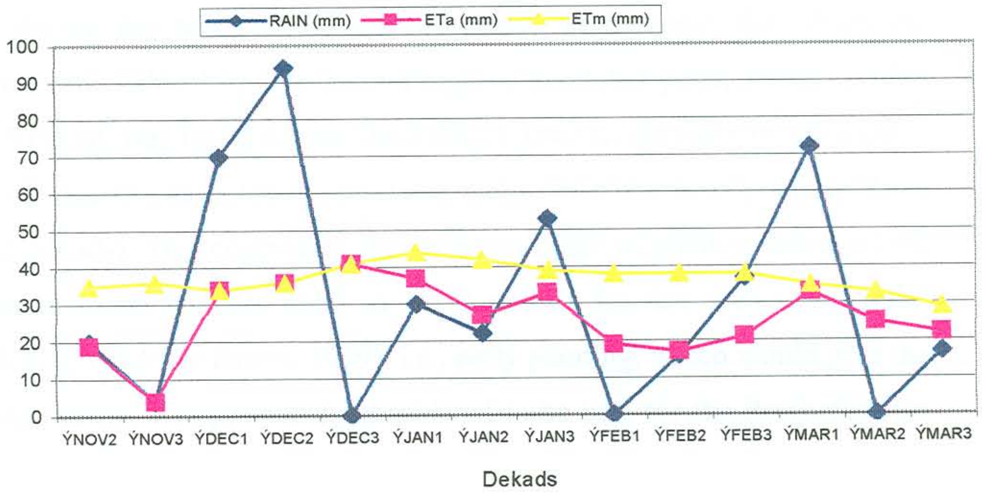


Fig 4.17 Dekad Rainfall Distribution, Simulated ETa and ETm 1995/96 season in Setlagole (Nov2 planting)

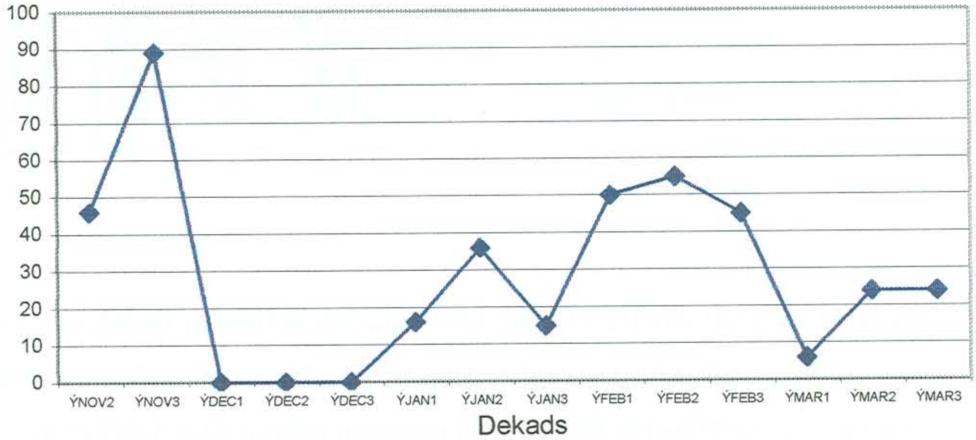


Fig 4.18 Simulated moisture stress (%) Nov 2 planting 1995/96 season in Setlagole

4.2 DETERMINATION OF SUITABLE PLANTING DATES

For ***Potchefstroom*** the results indicate that the highest simulated yield was obtained with planting during the Nov3 dekad for the period of 57 years for which the simulations were run (Table 4.4). The second highest simulated yield, almost as high as for the Nov3 dekad, was found for the Dec2 dekad. Overall the early planting dates (Oct3 and Nov1 dekads) gave lower simulated yields than the later planting dates (Nov2 to Dec3 dekads). This contradicts the optimum range of planting dates, which has been reported to be between Oct3 to Nov2 dekads for this area (Du Pisani, Erasmus and Koch, 1982; De Bruyn, 1979), i.e., early planting, which would give the longest growing season, was previously considered to be best for the Potchefstroom area.

Table 4.4 Yield potential of different planting dates at different probabilities in Potchefstroom

Run	Planting date	YLD.p (kg.ha^{-1}) probability		YLD.t (kg.ha^{-1}) probability		Crop:	Maize
1	Dekad	75%	50%	75%	50%	Variety:	PAN 473
2	Oct-03	740	1460	660	2000	Plant density:	18000 Plants per ha
3	Nov-01	820	1450	820	2140	Rainfall station:	Potchefstroom
4	Nov-02	820	1660	1190	2500	Synoptic station:	Potchefstroom
5	Nov-03	1100	2250	1580	3380	Soil Unit:	Hutton (1,2m depth),
6	Dec-01	870	1930	1230	2590		AWC 100mm/m
7	Dec-02	1150	1980	1470	3160		

Looking at the mean dekad rainfall distribution and 50% PET from the past 57 years in this area, it is seen that favourable moisture conditions occur during Dec2 and again from Jan2 until Feb1 with surplus moisture during Jan3 dekad (Figures 4.19 and 4.20), while the period inbetween (Dec3 and Jan1) experience serious water deficits, the latter indicating the typical mid-summer drought of the region. The surplus in Mar3 occurs too late to affect maize yield. The moisture deficits during Dec3 and Jan1 are the most problematic if the maize crop was planted at such a date that would flower during this period (i.e. if the maize crop was planted during Oct3 and Nov1 dekads). The latter will have a serious negative impact on the yield. The importance of making sure that the wet periods coincide with the stages when the maize plant is very sensitive to moisture stress, as suggested by De Bruyn (1979), and that it is avoided that these stages coincide with drought periods, can never be over-emphasized. This gives logic to the simulation results because planting in Nov3 ensures that the maize plant reaches the flowering stage during Jan3 in Potchefstroom. Also all the late plantings will give flowering after the mid-summer drought, explaining the higher simulated yields for the late plantings than for the early plantings.

De Bruyn and De Jager (1978) found that the mid-season maize cultivars required 77 days to reach 50% flowering and 145 days to mature. Using this as a basis for determining the appropriate planting date, they found that in the eastern side of the Northwest Province, mid-season maize cultivars gave better yields when planted as early as the first dekad (10 days period) of November (Nov1). Towards the western part of the province planting later towards mid December gave better yields according to them. They further suggested that in these more arid regions, planting should be somewhat delayed in order that flowering commences after the expected mid summer drought. Figure 4.19 clearly displays how this period occurs in Potchefstroom with a sudden decline of rainfall from Dec2 to Jan1, whereas the moisture demand as indicated by PET is steadily increasing before declining again from Dec3 until the end of the growing period. Overall it is clear that Potchefstroom fits in better with the late planting strategy of De Bruyn and De Jager (1978) for the western part of the Northwest Province than with their early planting strategy for the eastern part of the province.

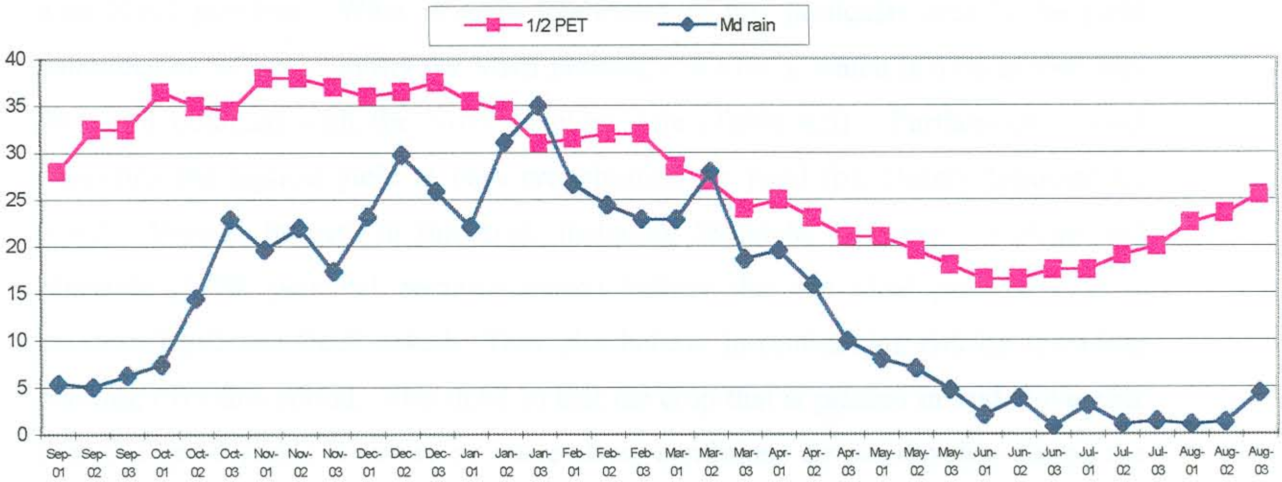


Fig. 4.19 Mean Dekad rainfall (mm) and ½ PET for 56 years in Potchefstroom

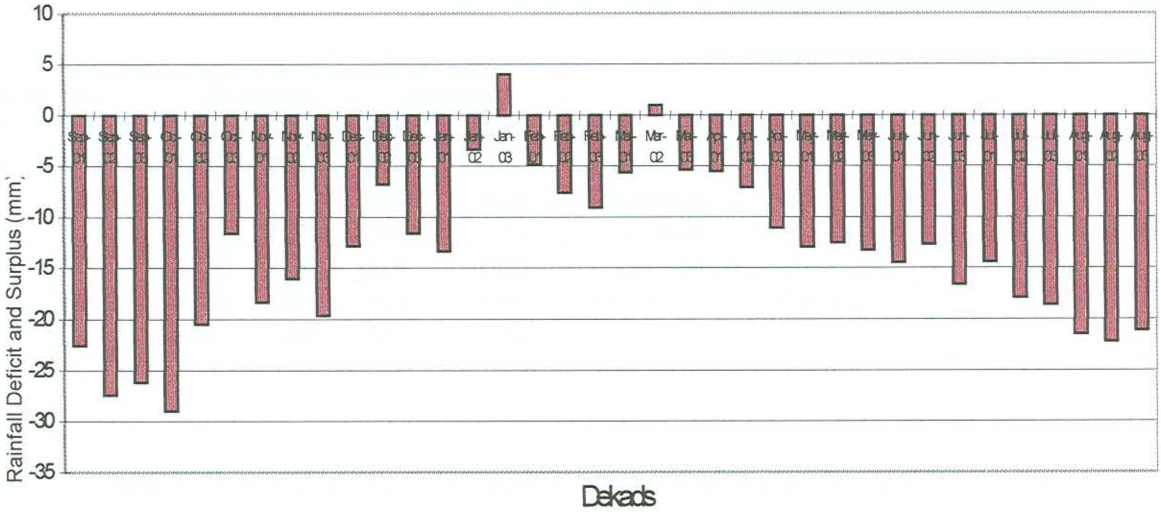


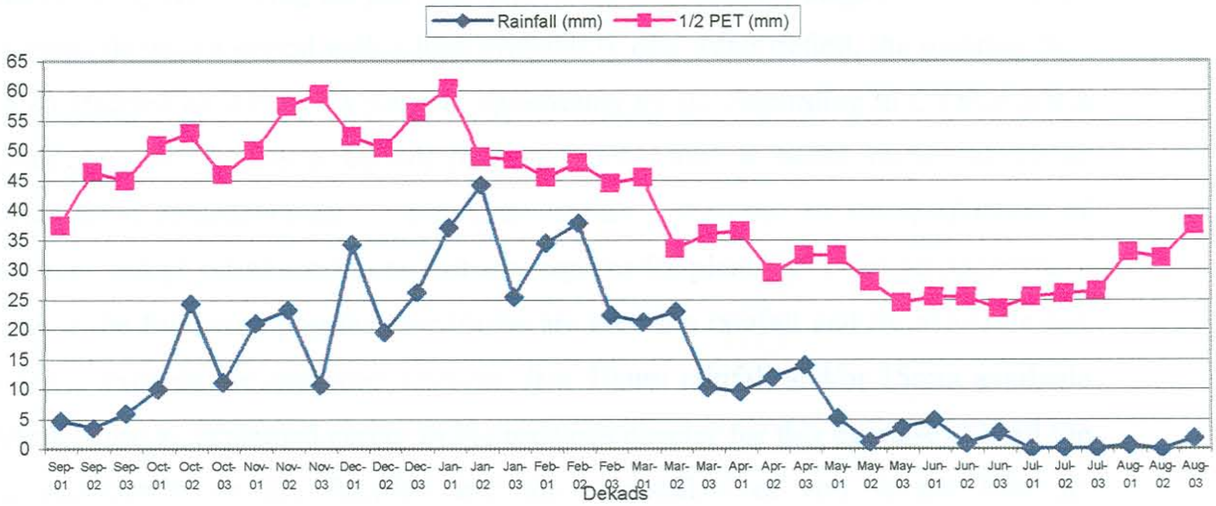
Fig. 4.20 Distribution of Mean Dekad Rainfall surplus and Deficit (56 years in Potchefstroom)

The highest yield simulated at 75% probability (yield (t)) for the ***Mmabatho*** area was with Nov1 planting. What is more interesting in this particular area is the yield simulated at 50% probability for Nov3 planting (>4 t.ha^{-1}), which is 67% higher than the yield obtained with the Nov1 planting date (Table 4.5). Furthermore, Nov3 maintains the highest yield at both probabilities for yield (p), closely followed by Nov2. Several farmers in this area, including Simolola, Penyenye, Mohapi and Mereotle (1999, personal communication) believe that the ideal planting date is between Nov2 and Dec2 dekads. They also believe in minimizing risk by spreading planting over this period. This done so that the crop that is planted in mid November can give good yields if severe moisture stress conditions do not develop during the critical flowering stage, but in the event of the January drought damaging this crop then the late crop can survive the critical stress conditions. By doing that the farmer spreads his opportunities rather than losing everything to drought conditions (Penyenye, 1999, personal communication).

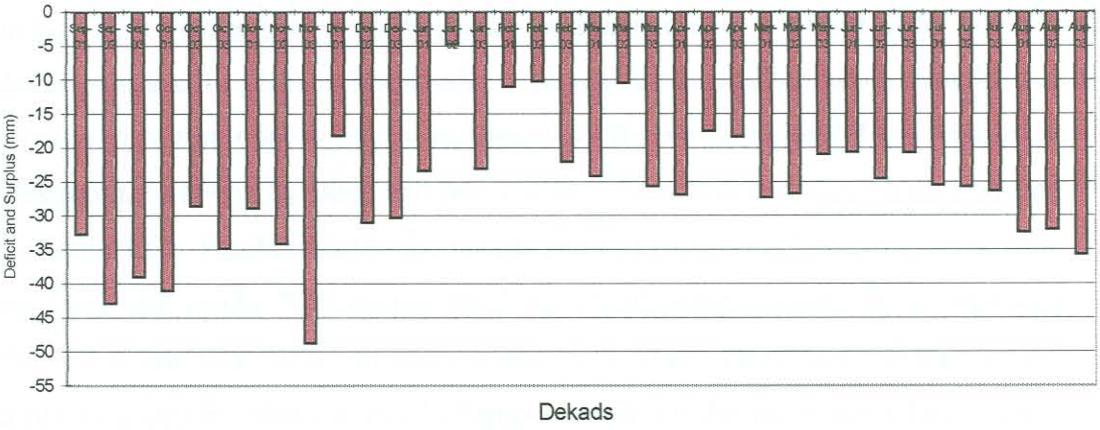
Table 4.5. Yield potential of different planting dates at different probabilities in Mmabatho

Run	Planting date	YLD.p (kg.ha^{-1}) probability		YLD.t (kg.ha^{-1}) probability			
1	Dekad	75%	50%	75%	50%	Crop:	Maize
2	Nov 1	1100	2920	2190	2630	Variety:	PAN 473
3	Nov 2	1160	3400	1660	2820	Plant density:	14000 plants/ha
4	Nov 3	1640	3570	1860	4380	Rainfall station:	Mmabatho
5	Dec 1	1620	1980	1270	2680	Synoptic station:	Mmabatho
6	Dec 2	1320	1810	1530	2990	Soil unit:	Clovelly
7	Dec 3	940	1240	740	1850		

Rainfall and PET distribution at Mmabatho shows that the moisture deficit is worse than at Potchefstroom. (Compare Figures 4.21 and 4.22 with Figures 4.19 and 4.20.) The fact that higher yields are simulated for Mmabatho than for Potchefstroom therefore seems anomalous. There is no actual anomaly, however. The explanation is that the simulations were done for different plant populations, i.e., 18 000 plants per hectare for Potchefstroom and 14 000 plants per hectare for Mmabatho. These were the planting densities used in the field trials at the two sites. If similar planting densities are used for the two sites, simulations for Potchefstroom always give higher yields than the comparative simulation for Mmabatho (see Section 4.4).



4.21 Mean Dekad Rainfall (mm) ½ PET over 16 years in Mmabatho



4.22 Distribution of mean dekad rainfall surplus and deficit for 16 years in Mmabatho

4.3 DETERMINATION OF PLANTING OPPORTUNITIES

Apart from synchronizing the planting date so that the sensitive stage of the crop does not coincide with a period with a high probability of a water deficit, the planting date is also affected by whether a planting opportunity exists. According to CYSLAMB a planting opportunity is a user-defined parameter and is based on a variety of management considerations. These are further determined by the availability of resources and physical conditions that are required for planting. Planting opportunity exists if the following physical conditions are met: the rainfall and /or available soil moisture exceeds the indicated amounts, (i.e. 10mm rainfall and/or 15mm available soil moisture as explained earlier in the previous chapter for this exercise). If all the required conditions are fulfilled and the workability of soil is not limiting, CYSLAMB regards the particular dekad as a planting opportunity and starts simulating a crop cycle (Radcliffe, Tersteeg and De Wit, 1994).

Simulations were run for each dekad from Oct2 to Dec2 to determine the frequency of occurrence of a planting opportunity during each dekad over a period of 55 years in Potchefstroom and 13 years in Mmabatho. The results showed that more than 55% of the time a planting opportunity was identified during Oct3 and Dec1 dekad in Potchestroom, followed by Dec2 and Nov2 with 55% or less and Nov3 with less than 50% (Table 4.6). For Mmabatho the results showed that more than 80% of the time during Dec1 and nearly 70% during Dec2 dekads planting opportunity is identified but the rest is less than 50%. In other words Oct3, Dec1, Dec2 and Nov2 give very good planting opportunities in Potchefstroom, while on the other hand Dec1, Dec2 and Oct3 give very good planting opportunities in Mmabatho. However, the decision maker should consider the conditions that are likely to prevail later in the season, because some of these dates with beautiful planting opportunities may cause the very sensitive silking stage of the plants to coincide with the severely moisture stressed periods later in the season. Nov3 seems to be giving a low chance of a planting opportunity (47% in Potchefstroom and 38% in Mmabatho), but the potential for a good yield when planting is done during this dekad (Section 4.2) should be kept in mind. Strategies, such as fallowing, to ensure adequate plant-available water in the soil to enable planting during this dekad, should therefore be a high priority.

Table 4.6 Probability of getting a planting opportunity from Oct2 to Dec2 dekads in Potchefstroom

CROP YIELD STATISTICS 1942 - 1998 POTCHEFSTROOM (kg/ha planted/year)					
OCT2	(18 cropping years out of 55 years)[3]				
Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	0	1530	3420	6610	7430
YLD.t exceeds	340	3570	4460	6990	743 0
OCT3	(30 cropping years out of 55 years)[3]				
Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	0	2180	4000	5700	7400
YLD.t exceeds	0	3330	4300	5770	7260
NOV1	(22 cropping years out of 54 years)[3]				
Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	340	1510	3600	6380	7340
YLD.t exceeds	1730	3450	4110	6450	7190
NOV2	(28 cropping years out of 54 years)[3]				
Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	40	1850	3860	6400	7280
YLD.t exceeds	1640	3270	4590	6110	6840
NOV3	(25 cropping years out of 53 years)[3]				
Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	480	3040	5550	6560	7210
YLD.t exceeds	830	4470	5550	6270	7070
DEC1	(30 cropping years out of 53 years)[3]				
Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	750	2800	4490	6200	7130
YLD.t exceeds	1190	3920	5350	6060	7050
DEC2	(29 cropping years out of 53 years)[3]				
Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	250	2210	4800	6630	7050
YLD.t exceeds	1730	3530	5150	6140	6840

Table 4.7 Probability of getting a planting opportunity from Oct2 to Dec2 dekads in Mmabatho

CROP YIELD STATISTICS 1985 - 1998 MMABATHO
(kg/ha planted/year)

OCT2 (3 cropping years out of 13 years)^3

Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	4490	4490	4800	6440	6440
YLD.t exceeds	4490	4490	4950	5690	5690

OCT3 (7 cropping years out of 13 years)^3

Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	570	1170	2800	3600	4650
YLD.t exceeds	1400	1770	3090	4580	4950

NOV1 (5 cropping years out of 13 years)^3

Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	350	350	2630	3500	4990
YLD.t exceeds	2700	2700	3060	3350	4170

NOV2 (6 cropping years out of 13 years)^3

Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	410	490	3760	5530	6860
YLD.t exceeds	1300	2240	3320	4720	6200

NOV3 (5 cropping years out of 13 years)^3

Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	2000	2000	3210	4670	6860
YLD.t exceeds	2360	2360	4670	4740	6270

DEC1 (11 cropping years out of 13 years)^3

Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	330	1060	1690	3600	6340
YLD.t exceeds	760	1830	3100	4030	5760

DEC2 (8 cropping years out of 13 years)^3

Probability	Max.	75%	50%	25%	Min.
YLD.p exceeds	530	750	1250	6600	6740
YLD.t exceeds	2090	2640	3410	5610	5610

4.4 DETERMINATION OF APPROPRIATE PLANTING DENSITIES

The simulation results show that at 75% probability low plant densities from 10000 up to 14000 plants.ha^{-1} at Potchefstroom gave reasonably high yields at all three planting dates (Table 4.9). However at higher plant densities higher yields are simulated at 50% probability, which also shows the amount of yield that the farmer would forfeit during good years if he chooses low plant populations. During Nov3 and Dec1, unlike Dec3 planting, the simulated yield (t) at 50% probability continues to increase up to 16000 plants.ha^{-1} unlike yield (p) where it starts declining above 14000 plants.ha^{-1}. During Nov3 dekad the simulated yield (p) is equal to yield (t) at 50% probability up to the density of 14000 plants.ha^{-1}. At maximum probability simulated yield (p) is much higher than the simulated yield (t) which indicates that moisture stress on maize during this dekad as compared to other is not as much during the stages in which maize is most sensitive (at individual crop growth stages), hence the impact on yield is not much. Yet, the impact of moisture stress when considered as an average over the whole period is much higher, hence the lower yield (t) is simulated. The details on the later are shown in Appendix 4, Table 11.

For Mmabatho generally higher yields are simulated at lower plant density from 10000 to 14000 plants.ha^{-1}, above which the simulated yield becomes lower even at 50% probability and lower (unlike Potchefstroom) as the plant density increases (Table 4.9). The results for Nov1 and Nov3 show that if the farmer plants early (Nov1) he stands a chance a getting more than 2 ton.ha^{-1} at 75% probability in a not so good year. The farmer would forfeit a high yield that he could obtain in the event of a good year if he had chosen to plant later (Nov3). Nov2 seems to be on the borderline in the sense that break-even yield (1.5 t.ha^{-1}) at 75% probability is obtained during a not so good year but an even better yield than what he could get from Nov1 planting during a good year at low density.

Table 4.8 simulated maize yield at different plant populations, during Nov3, Dec1 and Dec2 dekads (1942-1997), Potchefstroom

Nov3, planting dekad

Run	Pl.dens.	YLD.p ($kg.ha^{-1}$) probability		YLD.t ($kg.ha^{-1}$) probability	
	(/ha)	75%	50%	75%	50%
1	10000	2430	5000	3380	5000
2	12000	2460	5160	3490	5160
3	14000	2540	5340	3610	5340
4	16000	2330	4760	2770	5350
5	18000	1100	2250	1580	3380
6	20000	1130	2320	1620	3470
7	22000	1170	2380	1660	3570
8	24000	1200	2440	1670	3670
9	26000	1230	2510	1720	3760
10	28000	1260	2570	1760	3850
11	30000	1260	2630	1810	3950

Dec1, 1942-1997

Run	Pl.dens.	YLD.p ($kg.ha^{-1}$) probability		YLD.t ($kg.ha^{-1}$) probability	
	(/ha)	75%	50%	75%	50%
1	10000	2640	4490	3040	4690
2	12000	2730	4640	3140	4850
3	14000	2760	4800	3240	5010
4	16000	1850	4070	2850	5020
5	18000	1150	1980	1470	3160
6	20000	1180	2040	1510	3250
7	22000	1220	2090	1520	3340
8	24000	1250	2150	1560	3420
9	26000	1280	2210	1600	3510
10	28000	1310	2260	1640	3600
11	30000	1340	2320	1680	3690

Dec2, 1947-97

Run	Pl.dens.	YLD.p ($kg.ha^{-1}$) probability		YLD.t ($kg.ha^{-1}$) probability	
	(/ha)	75%	50%	75%	50%
1	10000	1730	4190	2120	4580
2	12000	1790	4330	2190	4730
3	14000	1850	4470	2260	4890
4	16000	1620	3740	2040	4390
5	18000	770	1960	700	2690
6	20000	790	2020	720	2770
7	22000	810	2080	740	2850
8	24000	830	2130	760	2920
9	26000	850	2180	760	3000
10	28000	880	2240	780	3070
11	30000	880	2290	800	3140

Table 4.9 simulated maize yield at different plant populations, during Nov1, Nov2 and Nov3 dekads. 1985-1997 Mmabatho

Nov1,					
Run	Pl.dens.	YLD.p (kg.ha^{-1}) probability		YLD.t (kg.ha^{-1}) probability	
	(/ha)	75%	50%	75%	50%
1	10000	1020	2780	2050	2510
2	12000	1060	2880	2120	2540
3	13000	1070	2870	2150	2580
4	14000	1100	2920	2190	2630
5	15000	800	2150	1630	2000
6	16000	810	2180	1650	2030
7	17000	820	2220	1680	2060
8	18000	360	910	200	430
9	19000	360	920	200	440
10	20000	360	940	200	440
Nov2,					
Run	Pl.dens	YLD.p (kg.ha^{-1}) probability		YLD.t (kg.ha^{-1}) probability	
	(/ha)	75%	50%	75%	50%
1	10000	1090	3180	1560	2700
2	12000	1120	3290	1610	2790
3	13000	1140	3340	1640	2780
4	14000	1160	3400	1660	2820
5	15000	790	2350	1080	2280
6	16000	800	2390	1100	2310
7	17000	820	2420	1110	2350
8	18000	350	1050	0	830
9	19000	360	1070	0	840
10	20000	360	1090	0	830
Nov3,					
Run	Pl.dens.	YLD.p (kg.ha^{-1}) probability		YLD.t (kg.ha^{-1}) probability	
	(/ha)	75%	50%	75%	50%
1	10000	1540	3350	1740	4100
2	12000	1590	3460	1800	4240
3	13000	1620	3520	1830	4310
4	14000	1640	3570	1860	4380
5	15000	1380	2390	1310	3560
6	16000	1400	2430	1330	3540
7	17000	1420	2470	1350	3590
8	18000	660	890	0	1440
9	19000	660	910	0	1460
10	20000	670	920	0	1490

From the above simulation results it is obvious that for Potchefstroom higher plant densities, above 14000 plants.ha^{-1}, are still a reasonable decision in the event of a good season, but lower plant densities perform very well at higher probabilities. The selected planting density will, therefore, very much be a function of how much risk the farmer can afford or is willing to take. A slightly different situation occurs in the Mmabatho area in the sense that the lower densities are much better than higher plant densities because even in good years higher densities do not give better yield. This stands to reason considering that the Mmabatho area is even drier than Potchefstroom. The farmers from the western and southwestern parts of the province (Gouws, from Mareetsane, Laas, Van Niekerk from Delareyville, Swanepoel, Geldenhuys from Setlagole and Doeglenberg from Wolmaranstad, 1999 personal communication) also recommended lower plant densities (12000 – 14000 plants.ha^{-1}), based on their experience. Tables 11 and 12 in Appendix 4 give more comprehensive yield probability results of the two areas.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The review of literature revealed that the production systems and potential in the marginal and sub-optimal areas in South Africa have not been thoroughly investigated. Consequently, most of the production technologies applied in these areas are directly imported from the high potential areas and are therefore inappropriate. In South Africa most of these areas contribute a lot to agricultural production, especially dryland maize production, and such neglect usually led to mismanagement and ultimately degradation of these important yet fragile ecosystems. In marginal production areas of South Africa, production is not only limited by agro-ecological characteristics of land but the farmer's circumstances also play a major role. The impact of changes in input level or management operations on crop yields becomes more important in land suitability evaluation, especially if production is carried out close to the margins of ecological suitability.

Successful crop production under marginal climatic conditions in the study area also largely depends on soil water characteristics; the way soils take up and store rainwater, the water holding capacity of the solum as well as the underlying layers. The role of underlying layers in impeding drainage beyond crop rooting depth is also of paramount importance. For example soils in the study area with soft plinthic horizons or soft carbonate subsoil have exceptionally good soil climates and normally have high agricultural production potential specifically for rainfed crop production. It has been documented that such soils increase the probability of sustained high maize yields, especially in these dryer areas. There is a need to quantify the contribution of these deeper horizons to meet the water needs of the crops.

The importance of qualitative and economic land evaluation in order to bring about an understanding of the relationships between the conditions of the land and the manner in which it can be utilized to ensure sustainability can never be over-emphasized. This is especially true if the outputs from such evaluations can be well understood and used as management tools by the land users. Simulation models have been developed and successfully applied in land evaluation. Summary mechanistic models have been documented to be the most realistic and practical tools for land evaluation, especially if such models are properly calibrated and validated to suit the local conditions. A valuable property of crop models is their ability to utilise long-term climate data to provide long-term yield simulations, which can serve to evaluate the interannual yield variability and quantification of risk in the specification of land suitability (De Wit *et al*, 1993). Further, simulation models enable the modification and evaluation of input and management specifications of the production system to ensure appropriate extension and land use recommendations.

The results from the evaluation of the CYSLAMB model for the climatically marginal areas of the Northwest Province showed that the model has reasonably good applicability in the study area as it provided the yield estimates within acceptable levels of accuracy, which is fundamental to agricultural land evaluation. The simulated grain yield showed good agreement with observed values (R^2 = 0.95(t) and =0.85(p)). Due to the erratic nature of rainfall, the extreme seasonal yield fluctuation is the typical situation that the maize producers in the study area are faced with. Lower plant densities as well as low input levels are amongst the management strategies applied by the farmers in the area to ensure efficient moisture use and yet aim to achieve maximum profit. The model seemed to cope reasonably well with these situations. However the simulations based on the individual crop development stages, i.e., yield(p), tended to over-predict the yield during dryer seasons whilst underestimating the yield in wet seasons whilst the yield(t) based on total crop growth period gave results that are much closer to the observed. Amongst the factors in the model causing this situation is that at yield(p) the effect of moisture stress is considered according to the sensitivity of maize at a particular stage of growth. In which case, should the stress occur more during a stage when maize is more sensitive to moisture stress conditions, then the negative impact on yield will be stronger accordingly. With the yield(t) simulations the impact of moisture stress is spread over the whole period which tends to marginalize the impact that moisture stress would have if it were to occur during the most sensitive stages of crop growth.

Besides the good results obtained during this evaluation, this model can be quite useful in the sense that it operates with commonly available inputs and non-specialists can easily understand its user-defined parameters. However the soil moisture balance sub-routine of the model has not been validated for South African conditions especially in the light of the existence of the unique soil characteristics that contribute a lot to dryland agriculture in climatically marginal areas. It would therefore be desirable if the model could be calibrated to also cater for such exceptions and also include other factors such as the impact of soil moisture carried over from one season to the next in its moisture balance calculations. A soil moisture budget model, which takes account of the carryover of soil moisture from one season to the next, could give reliable yield predictions for different planting dates as well as different soil water holding capacities. The management system employed in crop production is also very important. Choosing the appropriate planting dates for instance revealed a substantial difference in yield potential in the study area. The results showed that planting should be delayed in order to allow flowering to commence after the expected mid-summer drought. However, due to great fluctuation in annual precipitation and distribution, no strict adherence is encouraged to the suggested planting dates in this report. But, should adequate rain occur for planting, it is very important to determine what conditions can be expected later on in the season if the particular precipitation is used for planting. A decision can thus be made on whether planting should occur or be delayed.

Results obtained from the plant population simulations showed that when water was limiting, yield potential peaked at a distinct optimum density of 14000 plants.ha^{-1} and declined at higher densities. As water became more abundant during wet seasons, higher yields were simulated at higher plant densities. The production risks associated with dryland maize production in this area can be minimized by choosing the appropriate management systems to ensure that the farmer is able to get a fair yield during good seasons and also "break-even" during below average seasons. Ideally the most convenient approach if it were possible for the maize farmers in the marginal land is to plan differently for a dry cycle than wet cycle, thereby reconsidering factors such as mentioned in this study, viz: planting dates, plant populations, target yields, associated production practices and possible non-utilization of certain marginal soils as also suggested by Du Pisani (1985).

The importance of tillage systems that contribute to minimizing the soil moisture stress can never be overemphasized. An example of such system is fallowing, by means of which water from a previous rain season is stored in the soil to supplement the rain falling during the cropping season. In a classical 27-year study in an area with only 400mm per annum average rainfall in the USA Smika (1970) compared a wheat-fallow system with continuous wheat. In the continuous wheat system 10 out of the 27 years had complete crop failures, while no crop failures occurred with the wheat-fallow system. Average yields, calculated back to a per year basis was nearly double for the wheat-fallow system than with the continuous wheat. Other highly desirable tillage systems are those that will, amongst other things, enhance water infiltration, suppress subsequent evaporation, reduce run-off rates and eliminate soil layers that restrict root penetration into deeper soil layers where water is stored.

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APPENDIX 1

PROFILE DESCRIPTIONS AND ANALYTICAL DATA

1.1	POTCHEFSTROOM:	HUTTON / VENTERSDORP 1.1.1 Profile description 1.1.2 Analytical data
1.2	OTTOSDAL:	CLOVELLY/ MOOILAAGTE 1.2.1 Profile description 1.2.2 Analytical data
1.3	SETLAGOLE:	CLOVELLY/ SETLAGOLE 1.3.1 Profile description 1.3.2 Analytical data

APPENDICES

APPENDIX 1

PROFILE DESCRIPTIONS AND ANALYTICAL DATA

1.1 POTCHEFSTROOM: HUTTON / VENTERSDORP
- 1.1.1 Profile description
- 1.1.2 Analytical data

1.2 OTTOSDAL: CLOVELLY/ MOOILAAGTE
- 1.2.1 Profile description
- 1.2.2 Analytical data

1.3 SETLAGOLE: CLOVELLY/ SETLAGOLE
- 1.3.1 Profile description
- 1.3.2 Analytical data

Appendix 1.1.1 Soil Profile Description For Potchefstroom

General			
Profile No	: P219	Soil Form	: Hutton
Map	: 2626 Wes-Rand	Soil Family	: Ventersdorp
Latitude & Longitude	: 26°44′36″/ 27°10′12″	Surface rock	: None
Land type No.	: Bc 25	Surface stoniness	: None
Climate zone	: 31S	Occurrence of flooding	: None
Altitude	: 1364m	Wind erosion	: Slight wind
Terrain unit	: Foot slope	Water erosion	: None
Slope	: 3%	Vegetation	: Grassveld
Slope shape	: Straight	Water table	: None
Aspect	: West	Described by	: R.W. Bruce
Micro-relief	: None	Date described	: 1977-03
Parent and underlying material	: Single, Local colluvium derived from Daspoort quartzite.	Weathering of underlying material	:

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	: 0-350	Moist; moist 100% dark reddish brown 2.5 YR3/4; medium sandy loam; massive; slightly firm; very few medium soft insect casts; gradual smooth boundary.	Orthic
B21	: 350-760	Moist; moist 100% dark reddish brown 2.5YR3/4; medium sandy clay loam; apedal; slightly firm; diffuse smooth boundary.	Red apedal
B22	: 760-1200	Moist; moist 100% dark red 10YR3/6; medium sandy clay loam; apedal; slightly firm.	Red apedal

1.1.2 Soil Analytical Data for Potchefstroom

	Horizon name and depth (mm)		
	A1(0-350mm)	B1(350-760)	B2 (760-1200)
Particle size distribution (%)			
>2mm	0.0	0.0	1.00
C sand	5.00	7.00	7.00
M sand	33.0	36.0	30.0
F sand	40.0	33.0	36.0
C silt	8.0	4.0	4.0
Clay	12.0	21.0	25.0
Texture	SaLm	SaClLm	SaClLm
Chemical analysis			
C (%)	0.5	0.3	0.2
Resistance (ohm)	2800	2600	3000
pH H_2O	5.7	5.8	6.4
pH $CaCl_2$	4.9	5.2	5.7
Exchangeable/ Extractable cation/ cmol (+) kg^{-1} soil			
Na	0.10	0.00	0.10
K	0.20	0.10	0.00
Ca	1.60	2.00	1.90
Mg	0.60	0.90	0.80
S value	2.70	3.00	2.80
Cation exchange capacity (CEC)	4.50	5.07	4.30

Appendix 1.2.1 Soil Profile Description For Ottosdal

General			
Profile No	: P205	Soil Form	: Clovelly
Map	: 2624BB Wes-Rand	Soil Family	: Mooilaagte
Latitude & Longitude	: 26°50′24″/ 26°33′48″	Surface rock	: None
Land type No.	: Bc 23	Surface stoniness	: None
Climate zone	:31S	Occurrence of flooding	: None
Altitude	: 1341m	Erosion	: Sheet, class 1
Terrain unit	: Foot slope	Vegetation/ Land use	: Agronomic cash crop
Slope	: 1%	Water table	: None
Slope shape	: Straight	Described by	: R.W. Bruce
Aspect	: East	Date described	: 1977-03
Micro-relief	: None	Weathering of underlying material	:
Parent and underlying material	:Single, Local colluvium overlying Ventersdorp lava.		

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	: 0-260	Moist; moist 100% dark brown 7.5YR3/2; course sandy loam; massive; slightly firm; very few medium indurated iron-manganese nodules; very few small quartz fragments; gradual smooth boundary.	Orthic
B2	: 260-600	Moist; moist 100% brown to dark brown 7.5YR4/4; medium sandy clay loam; apedal; slightly firm; few medium indurated iron-manganese nodules; few small quartz and ferricrete fragments; abrupt smooth boundary.	Yellow-brown apedal
IIC	: 600-700	Many medium indurated iron-manganese nodules with common small quartz, lava and ferricrete fragments	

1.2.2 Soil Analytical Data for Ottosdal

	Horizon name and depth (mm)	
	A1 (0-260mm)	B2 (260-600)
Particle size distribution (%)		
>2mm	1.0	14.0
C sand	19.0	12.0
M sand	21.0	15.0
F sand	38.0	39.0
Silt	5.0	5.0
Clay	14	25.0
Texture	SaLm	SaClLm
Chemical analysis		
C (%)	0.5	0.4
Resistance (ohm)	3000	2700
pH H_2O	5.9	6.2
pH $CaCl_2$	5.2	5.4
Exchangeable/ Extractable cation/ cmol (+) kg^{-1} soil		
Na	0.00	0.10
K	0.20	0.00
Ca	2.40	3.70
Mg	1.30	1.90
S value	3.90	5.70
Cation exchange capacity (CEC)	5.70	6.50

Appendix 1.3.1 Soil Profile Description For Setlagole

General			
Profile No	:	Soil Form	: Clovelly
Map	: 2624BBMosita	Soil Family	: Setlagole
Latitude & Longitude	: 26°18′22″/ 24°57′49″	Surface rock	: None
Land type No.	: Ah17	Surface stoniness	: None
Climate zone	:8S	Occurrence of flooding	: None
Altitude	: 1270m	Wind erosion	: Slight wind
Terrain unit	: Foot slope	Water erosion	: None
Slope	: 1%	Vegetation/ Land use	: Agronomic cash crop
Slope shape	: Straight	Water table	: None
Aspect	: North-west	Described by	: C.J.J. Schmidt
Micro-relief	: None	Date described	: 1991-12
Parent material	: Single, Aeolian	Weathering of underlying material	:
Underlying material	: Aeolian sand	Alteration of underlying material	: Generalized

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	: 0-460	Moist; dry, brownish yellow 10YR6/8; moist, yellowish brown 10YR5/6; disturbed; loamy fine sand; apedal massive; friable; few normal fine pores; water absorption: 1 second; few roots; gradual smooth transition.	Orthic
B1	: 460-800	Moist; dry, brownish yellow 10YR6/8; moist, brownish yellow10YR 6/6; undisturbed; loamy fine sand; apedal massive; friable; few normal fine pores; water absorption: 1second; few roots; gradual smooth transition.	Yellow-brown apedal
B2	: 800-2000	Moist; dry, yellow 10YR7/8; moist, brownish yellow 10YR 6/8; undisturbed; loamy fine sand; apedal massive; friable; few normal fine pores; water absorption: 1 second; few roots	Yellow-brown apedal

1.3.2 Soil Analytical Data for Setlagole

	Horizon name and depth (mm)		
	Ap (0-460mm)	B1 (460-800)	B2 (800-2000)
Particle size distribution (%)			
>2mm	0.0	0.0	0.0
C sand 2-0.5 mm	6.7	6.5	4.8
M sand 0-0.25 mm	11.9	11.5	8.0
F sand 0.25-0.106 mm	51.9	46.2	46.5
Vf sand 0.106-0.05 mm	18.6	22.0	24.5
C silt 0.05-0.02 mm	3.0	3.4	4.3
F silt 0.02-0.002mm	1.0	1.5	1.2
Clay <0.002mm	6.3	8.7	10.4
Texture	FiSa	LmFiSa	LmFiSa
Chemical analysis			
C (%)	0.20	-	-
Resistance (ohm)	4200	4400	4000
pH H_2O	6.84	6.10	6.50
pH KCl	5.58	4.68	5.06
Exchangeable/ Extractable cation/ cmol (+) kg^{-1} soil			
Na	0.01	0.02	0.02
K	0.19	0.18	0.18
Ca	1.17	1.09	0.92
Mg	0.40	0.37	0.63
S value	1.77	1.66	1.75
T value (CEC)	1.90	2.11	2.02

APPENDIX 2

CYSLAMB SIMULATION REPORTS

2.1 POTCHEFSTROOM

2.2 OTTOSDAL

2.3 SETLAGOLE

2.1.1 POTCHEFSTROOM REPORT 1

CYSLAMB Report 1

SUMMARY OF CHARACTERISTICS EVALUATED:

Crop: Maize Variety	: PAN473	Soil unit	: Hutton 20% Clay
Produce	: Grain	Soil textural class	: Medium
Target plant density	: 18000 (/ha)	Soil drainage class	: Well
Management system	: Sample2	Soil depth for Maize	: 1.20 (m)
Weed infestation	: 0% of max.	Water holding capacity	: 154 (mm/m)
Early ploughing from	: SEP1 to SEP3	Residual water at SEP1	: -9 (mm)
When topsoil storage	: 0 (mm)	Topsoil control depth	: 0.50 (m)
Planting opportunities	: 1	Available N (Undef.)	: -9 (ppm)
Planting occurs from	: OCT2 to OCT2	Available P (Bray-I)	: 40 (ppm)
when topsoil storage	: 10 (mm)	Available K (Undef.)	: -9 (ppm)
and dekad rainfall	: 10 (mm)	Weighted average pH-H2O	: 7.0 (pH)
Weeding occurs after	: 30 days	Weighted average ECe	: -9.0 (mS/cm)
Irrigation capacity	: 0 (mm/day)	Weighted average ESP	: -9 (%)
Irrigation frequency	: 0.00(/dekad)	Weeds maximum evapotr.	: %-9.00 x ET0
Synoptic station	: C19869	Weeds max. cover after	: -9 days
Rainfall station	: C19869	Range of rainfall years	: 1986/1986

(-9 = unknown / missing value)

SOIL MOISTURE BALANCE 1986/1987

DEK	ST.D (cm)	δST (mm)	RAIN (mm)	IRRI (mm)	MOIS (mm)	Eb (mm)	ETw (mm)	ETa (mm)	ST (mm)	MBRZ (mm)	Surpl (mm)	W.FR (cm)	ETm (mm)	STRESS (%)
³SEP1	50								0	0		0		
³SEP2	50		0		0	0			0	0	0	0		
³SEP3	50		14		14	14			0	0	0	0		
³OCT1	50		0		0	0			0	0	0	0		
Ý ÀÄ>	0	0		0	0				0	0		0		
ÝOCT2	22	0	11	0	11			11	0	0	0	7	28	61
ÝOCT3	39	0	27	0	27			23	4	0	0	18	28	18
ÝNOV1	57	0	60	0	64			32	32	0	0	42	32	0
ÝNOV2	75	0	10	0	42			28	14	0	0	42	39	28
ÝNOV3	93	0	15	0	29			17	12	0	0	42	46	63
ÝDEC1	111	0	104	0	116			53	63	0	0	77	53	0
ÝDEC2	120	0	18	0	81			43	38	0	0	77	62	31
ÝDEC3	120	0	53	0	91			49	42	0	0	77	68	28
ÝJAN1	120	0	9	0	51			27	24	0	0	77	64	58
ÝJAN2	120	0	80	0	104			53	51	0	0	77	62	15
ÝJAN3	120	0	22	0	73			38	35	0	0	77	56	32
ÝFEB1	120	0	0	0	35			18	17	0	0	77	57	68
ÝFEB2	120	0	16	0	33			17	16	0	0	77	57	70
ÝFEB3	120	0	46	0	62			32	30	0	0	77	56	43

DEK: dekad, ST.D: storage/rooting depth, δST: storage increase due to δST.D,
RAIN: rainfall, IRRI: irrigation, MOIS: avail. moisture, Eb: bare soil evap.,
ETw: weed evapotransp., ETa: crop evapotransp., ST: rest moisture up to ST.D,
MBRZ: rest moisture below ST.D, Surpl: moisture surplus, W.FR: wetting front,
ETm: maximum crop evapotransp., STRESS: crop moisture stress in current DEK.

CROP BIOMASS REDUCTION DUE TO MOISTURE STRESS: (planting at OCT2 of 1986)

Period (days after planting)	26- 45	46-70	71-90	71-125	91-125	126-145
Crop biomass reduction	10%	14%	32%	-	29%	19%

Total Crop biomass reduction, multipied for the 5 individual periods = **70%**
Total Crop biomass reduction for the whole growing period (day 1-145) = **55%**

OVERALL RESULTS 1986 - 1987

CROP BIOMASS REDUCTION, DUE TO THE SOIL - nutrient status : 0% (NUTRI)
- salinity (ECe) : 0% (SALIN)
- sodicity (ESP) : 0% (SODIC)
- alkalinity (pH) : 0% (ALKAL)

CROP PRODUCTION FIGURES PER IDENTIFIED PLANTING OPPORTUNITY:

YR	DEK	P.NBP (kg/ha)	IRRI (mm)	M.p (%)	M.t (%)	SURP (%)	NBP.p (kg/ha)	HI.p (%)	YLD.p (kg/ha)	NBP.t (kg/ha)	HI.t (%)	YLD.t (kg/ha)
1986	Oct2,	13900	0	70	55	0	4170	49	2320	6260	49	3460

YR & DEK: date of planting; P.NBP: potential net biomass production; IRRI: irrigation; M.p/t: biomass reduction due to moisture stress, multiplied for all individual crop development periods (M.p), or estimated over the total crop growing period (M.t); SURP: biomass reduction due to moisture surplus; NBP.p/t: net biomass production, after correcting P.NBP for M.p/t, SURP, NUTRI, SALIN, SODIC and ALKAL; HI.p/t: harvest index for NBP.p/t; YLD.p/t: yield, harvested from NBP.p/t (moisture content of harvested produce is 12%).

2.1.2 POTCHEFSTROOM REPORT 2

CYSLAMB Report 2

SUMMARY OF CHARACTERISTICS EVALUATED:

Crop: Maize Variety	: PAN473	Soil unit	: Hutton 20% Clay
Produce	: Grain	Soil textural class	: Medium
Target plant density	: 18000 (/ha)	Soil drainage class	: Well
Management system	: Sample2	Soil depth for Maize	: 1.20 (m)
Weed infestation	: 0% of max.	Water holding capacity	: 154 (mm/m)
Early ploughing from	: SEP1 to SEP3	Residual water at SEP1	: -9 (mm)
when topsoil storage	: 0 (mm)	Topsoil control depth	: 0.50 (m)
Planting opportunities	: 1	Available N (Undef.)	: -9 (ppm)
Planting occurs from	: Nov1 to Nov1	Available P (Bray-I)	: 40 (ppm)
when topsoil storage	: 10 (mm)	Available K (Undef.)	: -9 (ppm)
and dekad rainfall	: 10 (mm)	Weighted average pH-H2O	: 7.0 (pH)
Weeding occurs after	: 30 days	Weighted average ECe	: -9.0 (mS/cm)
Irrigation capacity	: 0 (mm/day)	Weighted average ESP	: -9 (%)
Irrigation frequency	: 0.00(/dekad)	Weeds maximum evapotr.	: %-9.00 x ET0
Synoptic station	: C19869	Weeds max. cover after	: -9 days
Rainfall station	: C19869	Range of rainfall years	: 1986/1986

(-9 = unknown / missing value)

SOIL MOISTURE BALANCE 1986/1987

³DEK	ST.D	δST	RAIN	IRRI	MOIS	Eb	ETw	ETa	ST	MBRZ	Surpl	W.FR	ETm	STRESS
³	(cm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm)	(mm)	(%)
³SEP1	50								0	0		0		
³SEP2	50		0		0	0			0	0	0	0		
³SEP3	50		14		14	14			0	0	0	0		
³OCT1	50		0		0	0			0	0	0	0		
³OCT2	50		11		11	11			0	0	0	0		
³OCT3	50		27		27	27			0	0	0	0		
Ý ÀÄ>	0	0		0	0				0	0		0		
ÝNOV1	22	0	60	0	52			37	14	8	0	27	37	0
ÝNOV2	39	8	10	0	32			27	5	0	0	27	37	27
ÝNOV3	57	0	15	0	20			16	4	0	0	27	37	57
ÝDEC1	75	0	104	0	108			42	66	0	0	72	42	0
ÝDEC2	93	0	18	0	84			46	38	0	0	72	49	6
ÝDEC3	111	0	53	0	91			49	42	0	0	72	58	16
ÝJAN1	120	0	9	0	51			27	24	0	0	72	61	56
ÝJAN2	120	0	80	0	104			53	51	0	0	72	62	15
ÝJAN3	120	0	22	0	73			38	35	0	0	72	56	32
ÝFEB1	120	0	0	0	35			18	17	0	0	72	57	68
ÝFEB2	120	0	16	0	33			17	16	0	0	72	58	71
ÝFEB3	120	0	46	0	62			32	30	0	0	72	58	45
ÝMAR1	120	0	14	0	44			22	22	0	0	72	51	57
ÝMAR2	120	0	8	0	30			15	15	0	0	72	47	68

DEK: dekad, ST.D: storage/rooting depth, δST: storage increase due to δST.D,
RAIN: rainfall, IRRI: irrigation, MOIS: avail. moisture, Eb: bare soil evap.,
ETw: weed evapotransp., ETa: crop evapotransp., ST: rest moisture up to ST.D,
MBRZ: rest moisture below ST.D, Surpl: moisture surplus, W.FR: wetting front,
ETm: maximum crop evapotransp., STRESS: crop moisture stress in current DEK.

CROP BIOMASS REDUCTION DUE TO MOISTURE STRESS: (planting at NOV1 of 1986)

Period (days after planting)	26- 45	46- 70	71Ä-90	71-125	91-125	126-145
Crop biomass reduction	4%	9%		45%	-	13%

Total Crop biomass reduction, multipied for the 4 individual periods = **58%**
Total Crop biomass reduction for the whole growing period (day 1Ä145) = **56%**

OVERALL RESULTS 1986 – 1987

CROP BIOMASS REDUCTION, DUE TO THE SOIL - nutrient status : 0% (NUTRI)
- salinity (ECe) : 0% (SALIN)
- sodicity (ESP) : 0% (SODIC)
- alkalinity (pH) : 0% (ALKAL)

CROP PRODUCTION FIGURES PER IDENTIFIED PLANTING OPPORTUNITY:

YR	DEK	P.NBP	IRRI	M.p	M.t	SURP	NBP.p	HI.p	YLD.p	NBP.t	HI.t	YLD.t
		(kg/ha)	(mm)	(%)	(%)	(%)	(kg/ha)	(%)	(kg/ha)	(kg/ha)	(%)	(kg/ha)
1986	Nov1,	13720	0	58	56	0	5760	49	3210	6040	49	3340

YR & DEK: date of planting; P.NBP: potential net biomass production; IRRI: irrigation; M.p/t: biomass reduction due to moisture stress, multiplied for all individual crop development periods (M.p), or estimated over the total crop growing period (M.t); SURP: biomass reduction due to moisture surplus; NBP.p/t: net biomass production, after correcting P.NBP for M.p/t, SURP, NUTRI, SALIN, SODIC and ALKAL; HI.p/t: harvest index for NBP.p/t; YLD.p/t: yield, harvested from NBP.p/t (moisture content of harvested produce is 12%).

2.1.3 POTCHEFSTROOM REPORT 3

CYSLAMB Report3

SUMMARY OF CHARACTERISTICS EVALUATED:

Crop: Maize Variety : PAN473
Produce : Grain
Target plant density : 18000 (/ha)
Management system : Sample2c
Weed infestation : 0% of max.
Early ploughing from : SEP1 to SEP3
When topsoil storage : 0 (mm)
Planting opportunities : 1
Planting occurs from : NOV3 to NOV3
When topsoil storage : 10 (mm)
And dekad rainfall : 10 (mm)
Weeding occurs after : 30 days
Irrigation capacity : 0 (mm/day)
Irrigation frequency : 0.00(/dekad)
Synoptic station : C19869
Rainfall station : C19869

Soil unit : Hutton 20%Clay
Soil textural class : Medium
Soil drainage class : Well
Soil depth for Maize: 1.20 (m)
Water holding capacity: 154 (mm/m)
Residual water at SEP1: -9 (mm)
Topsoil control depth: 0.50 (m)
Available N (Undef.) : -9 (ppm)
Available P (Bray-I): 40 (ppm)
Available K (Undef.) : -9 (ppm)
Weighted average pH-H2O: 7.0 (pH)
Weighted average ECe: -9.0 (mS/cm)
Weighted average ESP: -9 (%)
Weeds maximum evapotr. : %-9.00 x ET0
Weeds max. Cover after: -9 days
Range of rainfall years: 1986/1986

(-9 = unknown / missing value)

SOIL MOISTURE BALANCE 1986/1987

³DEK	ST.D	δST	RAIN	IRRI	MOIS	Eb	ETw	ETa	ST	MBRZ	Surpl	W.FR	ETm	STRESS
³	(cm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm)	(mm)	(%)
³SEP1	50								0	0		0		
³SEP2	50		0		0	0			0	0	0	0		
³SEP3	50		14		14	14			0	0	0	0		
³OCT1	50		0		0	0			0	0	0	0		
³OCT2	50		11		11	11			0	0	0	0		
³OCT3	50		27		27	27			0	0	0	0		
³NOV1	50		60		60	37			23	0	0	40		
³NOV2	50		10		33	33			0	0	0	0		
Ý ÀÄ>	0	0		0	0				0	0		0		
ÝNOV3	22	0	15	0	15			15	0	0	0	10	38	61
ÝDEC1	39	0	104	0	78			37	40	26	0	57	37	0
ÝDEC2	57	26	18	0	84			38	46	0	0	57	38	0
ÝDEC3	75	0	53	0	99			45	54	0	0	66	45	0
ÝJAN1	93	0	9	0	63			37	26	0	0	66	49	24
ÝJAN2	111	0	80	0	106			52	54	0	0	70	54	4
ÝJAN3	120	0	22	0	76			39	37	0	0	70	53	26
ÝFEB1	120	0	0	0	37			19	18	0	0	70	57	67
ÝFEB2	120	0	16	0	34			18	16	0	0	70	58	69
ÝFEB3	120	0	46	0	62			32	30	0	0	70	58	45
ÝMAR1	120	0	14	0	44			22	22	0	0	70	51	57
ÝMAR2	120	0	8	0	30			15	15	0	0	70	49	69
ÝMAR3	120	0	0	0	15			8	7	0	0	70	43	81
ÝAPR1	120	0	0	0	7			4	3	0	0	70	44	91

DEK: dekad, ST.D: storage/rooting depth, δST: storage increase due to δST.D,
RAIN: rainfall, IRRI: irrigation, MOIS: avail. Moisture, Eb: bare soil evap.,
ETw: weed evapotransp., ETa: crop evapotransp., ST: rest moisture up to ST.D,
MBRZ: rest moisture below ST.D, Surpl: moisture surplus, W.FR: wetting front,
ETm: maximum crop evapotransp., STRESS: crop moisture stress in current DEK.

CROP BIOMASS REDUCTION DUE TO MOISTURE STRESS: (planting at NOV3 of 1986)

Period (days after planting)	26-40	41-55	56-90	56-135	91-135	136-140
Crop biomass reduction	4%	8%		65%		16%

Total Crop biomass reduction, multiplied for the 4 individual periods = 74%
Total Crop biomass reduction for the whole growing period (day 1-145) = 61%

OVERALL RESULTS 1986 - 1987

CROP BIOMASS REDUCTION, DUE TO THE SOIL - nutrient status : 0% (NUTRI)
- Salinity (ECe) : 0% (SALIN)
- Sodicity (ESP) : 0% (SODIC)
- Alkalinity (pH) : 0% (ALKAL)

CROP PRODUCTION FIGURES PER IDENTIFIED PLANTING OPPORTUNITY:

YR	DEK	P.NBP	IRRI	M.p	M.t	SURP	NBP.p	HI.p	YLD.p	NBP.t	HI.t	YLD.t
		(kg/ha)	(mm)	(%)	(%)	(%)	(kg/ha)	(%)	(kg/ha)	(kg/ha)	(%)	(kg/ha)
1986	Nov3,	13156	0	74	61	0	3420	49	1900	5130	49	2860

YR & DEK: date of planting; P.NBP: potential net biomass production; IRRI: Irrigation; M.p/t: biomass reduction due to moisture stress, multiplied for all individual crop development periods (M.p), or estimated over the total crop growing period (M.t); SURP: biomass reduction due to moisture surplus; NBP.p/t: net biomass production, after correcting P.NBP for M.p/t, SURP, NUTRI, SALIN, SODIC and ALKAL; HI.p/t: harvest index for NBP.p/t; YLD.p/t: yield, harvested from NBP.p/t (moisture content of harvested produce is 12%).

2.2.1 OTTOSDAL REPORT 1

CYSLAMB Report 4

SUMMARY OF CHARACTERISTICS EVALUATED:

Crop: Maize Variety	:	PAN473	Soil unit	:	Cv 15% Clay
Produce	:	Grain	Soil textural class	:	Medium
Target plant density	:	15000 (/ha)	Soil drainage class	:	Well
Management system	:	Sample2c	Soil depth for Maize	:	1.80 (m)
Weed infestation	:	0% of max.	Water holding capacity	:	152 (mm/m)
Early ploughing from	:	SEP1 to SEP3	Residual water at SEP1	:	-9 (mm)
When topsoil storage	:	0 (mm)	Topsoil control depth	:	0.50 (m)
Planting opportunities	:	1	Available N (Undef.)	:	-9 (ppm)
Planting occurs from	:	DEC2 to DEC2	Available P (Bray-I)	:	10 (ppm)
When topsoil storage	:	10 (mm)	Available K (Undef.)	:	-9 (ppm)
And dekad rainfall	:	10 (mm)	Weighted average pH-H2O	:	7.0 (pH)
Weeding occurs after	:	30 days	Weighted average Ece	:	-9.0 (mS/cm)
Irrigation capacity	:	0 (mm/day)	Weighted average ESP	:	-9 (%)
Irrigation frequency	:	0.00(/dekad)	Weeds maximum evapotr.	:	%-9.00 x ET0
Synoptic station	:	C19891	Weeds max. cover after	:	-9 days
Rainfall station	:	OT9004	Range of rainfall years	:	1990/1990

(-9 = unknown / missing value)

SOIL MOISTURE BALANCE 1990/1991

³DEK	ST.D	δST	RAIN	IRRI	MOIS	Eb	ETw	Eta	ST	MBRZ	Surpl	W.FR	ETm	STRESS
³	(cm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm)	(mm)	(%)
³SEP1	50								0	0		0		
³SEP2	50		0		0	0			0	0	0	0		
³SEP3	50		0		0	0			0	0	0	0		
³OCT1	50		0		0	0			0	0	0	0		
³OCT2	50		0		0	0			0	0	0	0		
³OCT3	50		0		0	0			0	0	0	0		
³NOV1	50		0		0	0			0	0	0	0		
³NOV2	50		0		0	0			0	0	0	0		
³NOV3	50		0		0	0			0	0	0	0		
³DEC1	50		70		70	52			18	0	0	46		
Ý ÀÄ>	0	-18		0	0				0	18		46		
ÝDEC2	19	7	0	0	7			7	0	11	0	46	46	85
ÝDEC3	39	8	0	0	8			7	1	3	0	46	49	86
ÝJAN1	58	3	53	0	57			39	18	0	0	46	49	20
ÝJAN2	77	0	22	0	40			23	17	0	0	46	45	49
ÝJAN3	97	0	90	0	107			43	64	0	0	70	43	0
ÝFEB1	116	0	52	0	116			43	73	0	0	76	43	0
ÝFEB2	135	0	40	0	113			34	79	0	0	76	34	0
ÝFEB3	154	0	0	0	79			27	52	0	0	76	39	31
ÝMAR1	174	0	19	0	71			21	50	0	0	76	32	34
ÝMAR2	180	0	123	0	173			35	138	0	0	114	35	0
ÝMAR3	180	0	0	0	138			33	105	0	0	114	33	0
ÝAPR1	180	0	0	0	105			28	77	0	0	114	28	0
ÝAPR2	180	0	0	0	77			21	56	0	0	114	26	19
ÝAPR3	180	0	0	0	56			15	41	0	0	114	23	35

DEK: dekad, ST.D: storage/rooting depth, δST: storage increase due to δST.D,
RAIN: rainfall, IRRI: irrigation, MOIS: avail. moisture, Eb: bare soil evap.,
ETw: weed evapotransp., ETa: crop evapotransp., ST: rest moisture up to ST.D,
MBRZ: rest moisture below ST.D, Surpl: moisture surplus, W.FR: wetting front,
ETm: maximum crop evapotransp., STRESS: crop moisture stress in current DEK.

CROP BIOMASS REDUCTION DUE TO MOISTURE STRESS: (planting at DEC2 of 1990)

Period (days after planting)	26- 45	46- 70	71- 90	71-125	91-125	126-145
Crop biomass reduction	10%	0%	20%		1%	9%

Total Crop biomass reduction, multipied for the 5 individual periods = 36%
Total Crop biomass reduction for the whole growing period (day 1Ä145) = 35%

OVERALL RESULTS 1990 - 1991

CROP BIOMASS REDUCTION, DUE TO THE SOIL - available P: 5% (NUTRI)
- Salinity (ECe): 0% (SALIN)
- Sodicity (ESP): 0% (SODIC)
- Alkalinity (pH): 0% (ALKAL)

CROP PRODUCTION FIGURES PER IDENTIFIED PLANTING OPPORTUNITY:

YR	DEK	P.NBP	IRRI	M.p	M.t	SURP	NBP.p	HI.p	YLD.p	NBP.t	HI.t	YLD.t
		(kg/ha)	(mm)	(%)	(%)	(%)	(kg/ha)	(%)	(kg/ha)	(kg/ha)	(%)	(kg/ha)
1990	Dec2,	12700	0	36	35	0	7720	50	4390	7840	50	4450

YR & DEK: date of planting; P.NBP: potential net biomass production; IRRI: Irrigation; M.p/t: biomass reduction due to moisture stress, multiplied for all individual crop development periods (M.p), or estimated over the total crop growing period (M.t); SURP: biomass reduction due to moisture surplus; NBP.p/t: net biomass production, after correcting P.NBP for M.p/t, SURP, NUTRI, SALIN, SODIC and ALKAL; HI.p/t: harvest index for NBP.p/t; YLD.p/t: yield, harvested from NBP.p/t (moisture content of harvested produce is 12%).

2.2.2 OTTOSDAL REPORT 2

CYSLAMB Report 5

SUMMARY OF CHARACTERISTICS EVALUATED:

Crop: Maize Variety	: PAN473	Soil unit	: Cv 15% Clay
Produce	: Grain	Soil textural class	: Medium
Target plant density	: 16000 (/ha)	Soil drainage class	: Well
Management system	: Sample2c	Soil depth for Maize	: 1.80 (m)
Weed infestation	: 0% of max.	Water holding capacity	: 152 (mm/m)
Early ploughing from	: SEP1 to SEP3	Residual water at SEP1	: -9 (mm)
When topsoil storage	: 0 (mm)	Topsoil control depth	: 0.50 (m)
Planting opportunities	: 1	Available N (Undef.)	: -9 (ppm)
Planting occurs from	: DEC1 to DEC1	Available P (Bray-I)	: 10 (ppm)
When topsoil storage	: 10 (mm)	Available K (Undef.)	: -9 (ppm)
and dekad rainfall	: 10 (mm)	Weighted average pH-H2O	: 7.0 (pH)
Weeding occurs after	: 30 days	Weighted average ECe	: -9.0 (mS/cm)
Irrigation capacity	: 0 (mm/day)	Weighted average ESP	: -9 (%)
Irrigation frequency	: 0.00(/dekad)	Weeds maximum evapotr.	: %-9.00 x ET0
Synoptic station	: C19891	Weeds max. cover after	: -9 days
Rainfall station	: C19891	Range of rainfall years	: 1991/1991

(-9 = unknown / missing value)

SOIL MOISTURE BALANCE 1991/1992

DEK	ST.D	δST	RAIN	IRRI	MOIS	Eb	ETw	ETa	ST	MBRZ	Surpl	W.FR	ETm	STRESS
	(cm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm)	(mm)	(%)
³AUG3	50								0	0		0		
³SEP1	50		0		0	0			0	0	0	0		
³SEP2	50		0		0	0			0	0	0	0		
³SEP3	50		45		45	15			30	0	0	30		
³OCT1	50		0		30	16			14	0	0	30		
³OCT2	50		9		23	23			0	0	0	0		
³OCT3	50		25		25	25			0	0	0	0		
³NOV1	50		4		4	4			0	0	0	0		
³NOV2	50		2		2	2			0	0	0	0		
³NOV3	50		11		11	11			0	0	0	0		
ÝDEC1	19	0	18	0	18			18	0	0	0	12	52	65
ÝDEC2	39	0	15	0	15			13	2	0	0	12	51	75
ÝDEC3	58	0	42	0	44			31	13	0	0	29	54	43
ÝJAN1	77	0	0	0	13			8	5	0	0	29	53	85
ÝJAN2	97	0	13	0	18			9	9	0	0	29	46	80
ÝJAN3	116	0	24	0	33			14	19	0	0	29	42	67
ÝFEB1	135	0	15	0	34			13	21	0	0	29	41	68
ÝFEB2	154	0	16	0	37			12	25	0	0	29	31	61
ÝFEB3	174	0	5	0	30			9	21	0	0	29	36	75
ÝMAR1	180	0	0	0	21			6	15	0	0	29	30	80
ÝMAR2	180	0	14	0	29			8	21	0	0	29	32	75
ÝMAR3	180	0	2	0	23			6	17	0	0	29	30	80
ÝAPR1	180	0	30	0	47			13	34	0	0	31	25	48
ÝAPR2	180	0	7	0	41			11	30	0	0	31	21	48

DEK: dekad, ST.D: storage/rooting depth, δST: storage increase due to δST.D,
RAIN: rainfall, IRRI: irrigation, MOIS: avail. Moisture, Eb: bare soil evap.,
Etw: weed evapotransp., ETa: crop evapotransp., ST: rest moisture up to ST.D,
MBRZ: rest moisture below ST.D, Surpl: moisture surplus, W.FR: wetting front,
Etm: maximum crop evapotransp., STRESS: crop moisture stress in current DEK.

CROP BIOMASS REDUCTION DUE TO MOISTURE STRESS: (planting at DEC1 of 1991)

Period (days after planting)	26--45	46-70	71- 90	71-125	91-125	126-145
Crop biomass reduction	11%	18%		72%		10%

Total Crop biomass reduction, multiplied for the 4 individual periods = 81%
Total Crop biomass reduction for the whole growing period (day 1-145) = 86%

OVERALL RESULTS 1991 - 1992

CROP BIOMASS REDUCTION, DUE TO THE SOIL - available P : 5% (NUTRI)
- salinity (ECe) : 0% (SALIN)
- sodicity (ESP) : 0% (SODIC)
- alkalinity (pH) : 0% (ALKAL)

CROP PRODUCTION FIGURES PER IDENTIFIED PLANTING OPPORTUNITY:

YR	DEK	P.NBP	IRRI	M.p	M.t	SURP	NBP.p	HI.p	YLD.p	NBP.t	HI.t	YLD.t
		(kg/ha)	(mm)	(%)	(%)	(%)	(kg/ha)	(%)	(kg/ha)	(kg/ha)	(%)	(kg/ha)
1991	Dec1,	13070	0	81	86	0	2360	49	1310	1740	48	950

YR & DEK: date of planting; P.NBP: potential net biomass production; IRRI: irrigation; M.p/t: biomass reduction due to moisture stress, multiplied for all individual crop development periods (M.p), or estimated over the total Crop growing period (M.t); SURP: biomass reduction due to moisture surplus; NBP.p/t: net biomass production, after correcting P.NBP for M.p/t, SURP, NUTRI, SALIN, SODIC and ALKAL; HI.p/t: harvest index for NBP.p/t; YLD.p/t: Yield, harvested from NBP.p/t (moisture content of harvested produce is 12%).

2.2.3 OTTOSDAL REPORT 3

CYSLAMB Report 6

SUMMARY OF CHARACTERISTICS EVALUATED:

Crop: Maize Variety	: PAN473	Soil unit	: Cvot15
Produce	: Grain	Soil textural class	: Medium
Target plant density	: 19000 (/ha)	Soil drainage class	: Well
Management system	: Sample2c	Soil depth for Maize	: 1.80 (m)
Weed infestation	: 0% of max.	Water holding capacity	: 152 (mm/m)
Early ploughing from	: SEP1 to SEP3	Residual water at SEP1	: -9 (mm)
when topsoil storage	: 0 (mm)	Topsoil control depth	: 0.50 (m)
Planting opportunities	: 1	Available N (Undef.)	: -9 (ppm)
Planting occurs from	: NOV3 to NOV3	Available P (Bray-I)	: 10 (ppm)
when topsoil storage	: 0 (mm)	Available K (Undef.)	: -9 (ppm)
and dekad rainfall	: 0 (mm)	Weighted average pH-H2O	: 7.0 (pH)
Weeding occurs after	: 30 days	Weighted average ECe	: -9.0 (mS/cm)
Irrigation capacity	: 0 (mm/day)	Weighted average ESP	: -9 (%)
Irrigation frequency	: 0.00(/dekad)	Weeds maximum evapotr.	: %-9.00 x ET0
Synoptic station	: C19891	Weeds max. cover after	: -9 days
Rainfall station	: C19891	Range of rainfall years	: 1992/1992

(-9 = unknown / missing value)

SOIL MOISTURE BALANCE 1992/1993

DEK	ST.D	δST	RAIN	IRRI	MOIS	Eb	ETw	ETa	ST	MBRZ	Surpl	W.FR	ETm	STRESS
	(cm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm)	(mm)	(%)
^{3}AUG3	50								0	0		0		
^{3}SEP1	50		0		0	0			0	0	0	0		
^{3}SEP2	50		0		0	0			0	0	0	0		
^{3}SEP3	50		0		0	0			0	0	0	0		
^{3}OCT1	50		10		10	10			0	0	0	0		
^{3}OCT2	50		7		7	7			0	0	0	0		
^{3}OCT3	50		0		0	0			0	0	0	0		
^{3}NOV1	50		90		76	43			40	7	0	59		
^{3}NOV2	50		29		69	35			35	6	0	59		
ÝNOV3	19	12	3	0	15			14	1	26	0	59	32	56
ÝDEC1	39	13	0	0	14			11	3	13	0	59	33	67
ÝDEC2	58	12	30	0	45			28	17	1	0	59	33	15
ÝDEC3	77	1	23	0	41			23	18	0	0	59	37	38
ÝJAN1	97	0	3	0	21			10	11	0	0	59	40	75
ÝJAN2	116	0	0	0	11			5	6	0	0	59	38	87
ÝJAN3	135	0	60	0	66			25	41	0	0	59	39	36
ÝFEB1	154	0	8	0	49			17	32	0	0	59	40	58
ÝFEB2	174	0	19	0	51			15	36	0	0	59	31	52
ÝFEB3	180	0	24	0	60			18	42	0	0	59	36	50
ÝMAR1	180	0	13	0	55			16	39	0	0	59	30	47
ÝMAR2	180	0	24	0	63			18	45	0	0	59	32	44
ÝMAR3	180	0	16	0	61			17	44	0	0	59	30	43
ÝAPR1	180	0	34	0	78			21	57	0	0	59	23	9

DEK: dekad, ST.D: storage/rooting depth, ëST: storage increase due to ëST.D,
RAIN: rainfall, IRRI: irrigation, MOIS: avail. Moisture, Eb: bare soil evap.,
ETw: weed evapotransp., ETa: crop evapotransp., ST: rest moisture up to ST.D,
MBRZ: rest moisture below ST.D, Surpl: moisture surplus, W.FR: wetting front,
ETm: maximum crop evapotransp., STRESS: crop moisture stress in current DEK.

CROP BIOMASS REDUCTION DUE TO MOISTURE STRESS: (planting at NOV3 of 1992)

Period (days after planting)	26- 45	46-70	71- 90	71-125	91-125	126-145
Crop biomass reduction	7%	16%	-	50%	-	5%

Total Crop biomass reduction, multipied for the 4 individual periods = **63%**
Total Crop biomass reduction for the whole growing period (day 1Ä145) = **62%**

OVERALL RESULTS 1992 – 1993

CROP BIOMASS REDUCTION, DUE TO THE SOIL - available P : 5% (NUTRI)
- salinity (ECe) : 0% (SALIN)
- sodicity (ESP) : 0% (SODIC)
- alkalinity (pH) : 0% (ALKAL)

CROP PRODUCTION FIGURES PER IDENTIFIED PLANTING OPPORTUNITY:

YR	DEK	P.NBP	IRRI	M.p	M.t	SURP	NBP.p	HI.p	YLD.p	NBP.t	HI.t	YLD.t
		(kg/ha)	(mm)	(%)	(%)	(%)	(kg/ha)	(%)	(kg/ha)	(kg/ha)	(%)	(kg/ha)
1992	NOV3^3	13780	0	63	62	0	4840	49	2700	4970	49	2770

YR & DEK: date of planting; P.NBP: potential net biomass production; IRRI: Irrigation; M.p/t: biomass reduction due to moisture stress, multiplied for All individual crop development periods (M.p), or estimated over the total Crop growing period (M.t); SURP: biomass reduction due to moisture surplus; NBP.p/t: net biomass production, after correcting P.NBP for M.p/t, SURP, NUTRI, SALIN, SODIC and ALKAL; HI.p/t: harvest index for NBP.p/t; YLD.p/t: Yield, harvested from NBP.p/t (moisture content of harvested produce is 12%).

2.3.1 SETLAGOLE REPORT 1

CYSLAMB Report7

SUMMARY OF CHARACTERISTICS EVALUATED:

Crop: Maize Variety	: PAN473	Soil unit	: Cv 10%C
Produce	: Grain	Soil textural class	: Medium
Target plant density	: 14000 (/ha)	Soil drainage class	: Well
Management system	: Sample2c	Soil depth for Maize	: 2.10 (m)
Weed infestation	: 0% of max.	Water holding capacity	: 148 (mm/m)
Early ploughing from	: SEP1 to SEP3	Residual water at JUL3	: -9 (mm)
When topsoil storage	0 (mm)	Topsoil control depth	: 0.50 (m)
Planting opportunities	: 1	Available N (Undef.)	: -9 (ppm)
Planting occurs from	: DEC1 to DEC1	Available P (Bray-I)	: 23 (ppm)
When topsoil storage	: 0 (mm)	Available K (Undef.)	: -9 (ppm)
And dekad rainfall	: 0 (mm)	Weighted average pH-H2O	: 6.6 (pH)
Weeding occurs after	: 30 days	Weighted average ECe	: -9.0 (mS/cm)
Irrigation capacity	: 0 (mm/day)	Weighted average ESP	: -9 (%)
Irrigation frequency	: 0.00(/dekad)	Weeds maximum evapotr. %	: -9.00 x ET
Synoptic station	: MADIBOGO	Weeds max. cover after	: -9 days
Rainfall station	: MADIBOGO	Range of rainfall years	: 1993/1993

(-9 = unknown / missing value)

SIMULATED SOIL MOISTURE BALANCE 1993/1994

DEK	ST.D	δST	RAIN	IRRI	MOIS	Eb	ETw	ETa	ST	MBRZ	Surpl	W.FR	Etm	STRESS
	(cm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm)	(mm)	(%)
³JUL2	50							0	0			0		
³JUL3	50		0		0	0		0	0	0		0		
³AUG1	50		0		0	0		0	0	0		0		
³AUG2	50		0		0	0		0	0	0		0		
³AUG3	50		2		2	2		0	0	0		0		
³SEP1	50		0		0	0		0	0	0		0		
³SEP2	50		0		0	0		0	0	0		0		
³SEP3	50		1		1	1		0	0	0		0		
³OCT1	50		65		65	19		46	0	0		44		
³OCT2	50		44		74	39		42	9	0		61		
³OCT3	50		21		63	38		28	6	0		61		
³NOV1	50		18		46	42		8	2	0		61		
³NOV2	50		0		8	10		0	0	0		0		
³NOV3	50		15		15	15		0	0	0		74		
ÝDEC1	19	9	1	0	10		10	0	26	0		74	43	77
ÝDEC2	39	9	11	0	20		16	4	17	0		74	44	64
ÝDEC3	58	9	89	0	102		47	55	8	0		74	47	0
ÝJAN1	77	8	14	0	77		43	34	0	0		74	48	10
ÝJAN2	97	0	114	0	148		43	105	0	0		85	43	0
ÝJAN3	116	0	16	0	121		39	82	0	0		85	39	0
ÝFEB1	135	0	22	0	104		37	67	0	0		85	38	3
ÝFEB2	154	0	25	0	92		32	60	0	0		85	38	16
ÝFEB3	174	0	2	0	62		19	43	0	0		85	38	50
ÝMAR1	193	0	20	0	63		18	45	0	0		85	35	49
ÝMAR2	210	0	4	0	49		13	36	0	0		85	33	61
ÝMAR3	210	0	4	0	40		10	30	0	0		85	29	66
ÝAPR1	210	0	0	0	30		7	23	0	0		85	27	74
ÝAPR2	210	0	11	0	34		8	26	0	0		85	24	67

DEK: dekad, ST.D: storage/rooting depth, δST: storage increase due to δST.D,
RAIN: rainfall, IRRI: irrigation, MOIS: avail. Moisture, Eb: bare soil evap.,
ETw: weed evapotransp., ETa: crop evapotransp., ST: rest moisture up to ST.D,
MBRZ: rest moisture below ST.D, Surpl: moisture surplus, W.FR: wetting front,
ETm: maximum crop evapotransp., STRESS: crop moisture stress in current DEK.

CROP BIOMASS REDUCTION DUE TO MOISTURE STRESS: (planting at DEC1 of 1993)

Period (days after planting)	26- 45	46- 70	71- 90	71- 125	91- 125	126- 145
Crop biomass reduction	1%	0%	-	49%	-	14%

Total Crop biomass reduction, multiplied for the 4 individual periods = **56%**
Total Crop biomass reduction for the whole growing period (day 1Ä145) = **46%**

OVERALL RESULTS 1993 – 1994

CROP BIOMASS REDUCTION, DUE TO THE SOIL	Nutrient status	0% (NUTRI)
	Salinity (ECe)	0% (SALIN)
	Sodicity (ESP)	0% (SODIC)
	Alkalinity (pH)	0% (ALKAL)

CROP PRODUCTION FIGURES PER IDENTIFIED PLANTING OPPORTUNITY:

YR	DEK	P.NBP	IRRI	M.p	M.t	SURP	NBP.p	HI.p	YLD.p	NBP.t	HI.t	YLD.t
		(kg/ha)	(mm)	(%)	(%)	(%)	(kg/ha)	(%)	(kg/ha)	(kg/ha)	(%)	(kg/ha)
1993	Dec1,	12930	0	56	46	0	5690	50	3239	6980	50	3930

YR & DEK: date of planting; P.NBP: potential net biomass production; IRRI: irrigation; M.p/t: biomass reduction due to moisture stress, multiplied for all individual crop development periods (M.p), or estimated over the total crop growing period (M.t); SURP: biomass reduction due to moisture surplus; NBP.p/t: net biomass production, after correcting P.NBP for M.p/t, SURP, NUTRI, SALIN, SODIC and ALKAL; HI.p/t: harvest index for NBP.p/t; YLD.p/t: yield, harvested from NBP.p/t (moisture content of harvested produce is 12%).

2.3.2 SETLAGOLE REPORT 2

CYSLAMB Report 7

SUMMARY OF CHARACTERISTICS EVALUATED:

Crop: Maize Variety	:	PAN473	Soil unit:	Cv	10%Clay
Produce	:	Grain	Soil textural class:	Medium	
Target plant density	:	14000 (/ha)	Soil drainage class:	Well	
Management system	:	Sample2b	Soil depth for Maize:	2.10 (m)	
Weed infestation	:	0% of max.	Water holding capacity:	148 (mm/m)	
Early ploughing from	:	SEP1 to SEP3	Residual water at JUL3:	-9 (mm)	
When topsoil storage	:	0 (mm)	Topsoil control depth:	0.50 (m)	
Planting opportunities	:	1	Available N (Undef.) :	-9 (ppm)	
Planting occurs from	:	NOV2 to NOV2	Available P (Bray-I):	23 (ppm)	
When topsoil storage	:	0 (mm)	Available K (Undef.) :	-9 (ppm)	
And dekad rainfall	:	0 (mm)	Weighted average pH-H2O:	6.6 (pH)	
Weeding occurs after	:	30 days	Weighted average ECe :	-9.0 (mS/cm)	
Irrigation capacity	:	0 (mm/day)	Weighted average ESP (%) :	-9 (%)	
Irrigation frequency	:	0.00(/dekad)	Weeds maximum evapotr.(%) :	%-9.00 x ET0	
Synoptic station	:	MADIBOGO	Weeds max. cover after :	-9 days	
Rainfall station	:	MADIBOGO	Range of rainfall years:	1994/1994	

(-9 = unknown / missing value)

SOIL MOISTURE BALANCE 1994/1995

DEK	ST.D (cm)	δST (mm)	RAIN (mm)	IRRI (mm)	MOIS (mm)	Eb (mm)	Etw (mm)	ETa (mm)	ST (mm)	MBRZ (mm)	Surpl (mm)	W.FR (cm)	ETm (mm)	STRESS (%)
³JUL2	50								0	0		0		
³JUL3	50		0		0	0			0	0	0	0		
³AUG1	50		0		0	0			0	0	0	0		
³AUG2	50		0		0	0			0	0	0	0		
³AUG3	50		0		0	0			0	0	0	0		
³SEP1	50		0		0	0			0	0	0	0		
³SEP2	50		0		0	0			0	0	0	0		
³SEP3	50		0		0	0			0	0	0	0		
³OCT1	50		0		0	0			0	0	0	0		
³OCT2	50		0		0	0			0	0	0	0		
³OCT3	50		3		3	3			0	0	0	0		
³NOV1	50		11		11	11			0	0	0	0		
ÝNOV2	19	15	22	0	37			32	5	0	0	18	35	9
ÝNOV3	39	0	0	0	5			4	1	0	0	18	36	89
ÝDEC1	58	0	4	0	5			3	2	0	0	18	34	91
ÝDEC2	77	0	2	0	4			2	2	0	0	18	36	94
ÝDEC3	97	0	22	0	24			12	12	0	0	18	41	71
ÝJAN1	116	0	0	0	12			5	7	0	0	18	44	89
ÝJAN2	135	0	71	0	78			30	48	0	0	53	42	29
ÝJAN3	154	0	13	0	61			21	40	0	0	53	39	46
ÝFEB1	174	0	8	0	48			15	33	0	0	53	38	61
ÝFEB2	193	0	0	0	33			9	24	0	0	53	38	76
ÝFEB3	210	0	0	0	24			6	18	0	0	53	38	84
ÝMAR1	210	0	0	0	18			5	13	0	0	53	35	86
ÝMAR2	210	0	0	0	13			3	10	0	0	53	33	91
ÝMAR3	210	0	66	0	76			19	57	0	0	53	29	34

DEK: dekad, ST.D: storage/rooting depth, δST: storage increase due to δST.D,
RAIN: rainfall, IRRI: irrigation, MOIS: avail. Moisture, Eb: bare soil evap.,
ETw: weed evapotransp., ETa: crop evapotransp., ST: rest moisture up to ST.D,
MBRZ: rest moisture below ST.D, Surpl: moisture surplus, W.FR: wetting front,
ETm: maximum crop evapotransp., STRESS: crop moisture stress in current DEK.

CROP BIOMASS REDUCTION DUE TO MOISTURE STRESS: (planting at NOV2 of 1994)

Period (days after planting)	26- 45	46- 70	71- 90	71-125	91-125	126-145
Crop biomass reduction	13%	15%		71%		11%

Total Crop biomass reduction, multiplied for the 4 individual periods = 81%
Total Crop biomass reduction for the whole growing period (day 1Ä145) = 88%

OVERALL RESULTS 1994 - 1995

CROP BIOMASS REDUCTION, DUE TO THE SOIL

Nutrient status	0%	(NUTRI)
Salinity (ECe)	0%	(SALIN)
Sodicity (ESP)	0%	(SODIC)
Alkalinity (pH)	0%	(ALKAL)

CROP PRODUCTION FIGURES PER IDENTIFIED PLANTING OPPORTUNITY:

YR	DEK	P.NBP (kg/ha)	IRRI (mm)	M.p (%)	M.t (%)	SURP (%)	NBP.p (kg/ha)	HI.p (%)	YLD.p (kg/ha)	NBP.t (kg/ha)	HI.t (%)	YLD.t (kg/ha)
1994	Nov2,	13210	0	81	88	0	2510	49	1400	1590	48	840

YR & DEK: date of planting; P.NBP: potential net biomass production; IRRI: irrigation; M.p/t: biomass reduction due to moisture stress, multiplied for all individual crop development periods (M.p), or estimated over the total crop growing period (M.t); SURP: biomass reduction due to moisture surplus; NBP.p/t: net biomass production, after correcting P.NBP for M.p/t, SURP, NUTRI, SALIN, SODIC and ALKAL; HI.p/t: harvest index for NBP.p/t; YLD.p/t: yield, harvested from NBP.p/t (moisture content of harvested produce is 12%).

3.2.3 SETLAGOLE REPORT 3

CYSLAMB Report 8

SUMMARY OF CHARACTERISTICS EVALUATED:

Crop: Maize Variety	:	PAN473	Soil unit	:	Cv 10%Clay
Produce	:	Grain	Soil textural class	:	Medium
Target plant density	:	14000 (/ha)	Soil drainage class	:	Well
Management system	:	Sample2b	Soil depth for Maize	:	2.10 (m)
Weed infestation	:	0% of max.	Water holding capacity	:	148 (mm/m)
Early ploughing from	:	SEP1 to SEP3	Residual water at JUL3	:	-9 (mm)
When topsoil storage	:	0 (mm)	Topsoil control depth	:	0.50 (m)
Planting opportunities	:	1	Available N (Undef.)	:	-9 (ppm)
Planting occurs from	:	NOV2 to NOV2	Available P (Bray-I)	:	23 (ppm)
When topsoil storage	:	0 (mm)	Available K (Undef.)	:	-9 (ppm)
And dekad rainfall	:	0 (mm)	Weighted average pH-H2O	:	6.6 (pH)
Weeding occurs after	:	30 days	Weighted average ECe	:	-9.0 (mS/cm)
Irrigation capacity	:	0 (mm/day)	Weighted average ESP	:	-9 (%)
Irrigation frequency	:	0.00(/dekad)	Weeds maximum evapotr. (%)	:	%-9.00 x ET0
Synoptic station	:	MADIBOGO	Weeds max. cover after	:	-9 days
Rainfall station	:	MADIBOGO	Range of rainfall years	:	1995/1995

(-9 = unknown / missing value)

SOIL MOISTURE BALANCE 1995/1996

DEK	ST.D	δST	RAIN	IRRI	MOIS	Eb	ETw	ETa	ST	MBRZ	Surpl	W.FR	ETm	STRESS
	(cm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(cm)	(mm)	(%)
^{3}JUL2	50								0	0		0		
^{3}JUL3	50		0		0	0			0	0	0	0		
^{3}AUG1	50		0		0	0			0	0	0	0		
^{3}AUG2	50		0		0	0			0	0	0	0		
^{3}AUG3	50		0		0	0			0	0	0	0		
^{3}SEP1	50		0		0	0			0	0	0	0		
^{3}SEP2	50		30		30	14			16	0	0	20		
^{3}SEP3	50		0		16	14			2	0	0	20		
^{3}OCT1	50		1		3	3			0	0	0	0		
^{3}OCT2	50		45		45	39			6	0	0	30		
^{3}OCT3	50		26		32	32			0	0	0	0		
^{3}NOV1	50		4		4	4			0	0	0	0		
ÝNOV2	19	0	20	0	20			19	1	0	0	14	35	46
ÝNOV3	39	0	4	0	5			4	1	0	0	14	36	89
ÝDEC1	58	0	70	0	71			34	37	0	0	48	34	0
ÝDEC2	77	0	94	0	131			36	95	0	0	76	36	0
ÝDEC3	97	0	0	0	95			41	54	0	0	76	41	0
ÝJAN1	116	0	30	0	84			37	47	0	0	76	44	16
ÝJAN2	135	0	22	0	69			27	42	0	0	76	42	36
ÝJAN3	154	0	53	0	95			33	62	0	0	76	39	15
ÝFEB1	174	0	0	0	62			19	43	0	0	76	38	50
ÝFEB2	193	0	16	0	59			17	42	0	0	76	38	55
ÝFEB3	210	0	37	0	79			21	58	0	0	76	38	45
ÝMAR1	210	0	72	0	130			33	97	0	0	88	35	6
ÝMAR2	210	0	0	0	97			25	72	0	0	88	33	24
ÝMAR3	210	0	17	0	89			22	67	0	0	88	29	24

DEK: dekad, ST.D: storage/rooting depth, δST: storage increase due to δST.D, RAIN: rainfall, IRRI: irrigation, MOIS: avail. Moisture, Eb: bare soil evap., ETw: weed evapotransp., ETa: crop evapotransp., ST: rest moisture up to ST.D, MBRZ: rest moisture below ST.D, Surpl: moisture surplus, W.FR: wetting front, ETm: maximum crop evapotransp., STRESS: crop moisture stress in current DEK.

CROP BIOMASS REDUCTION DUE TO MOISTURE STRESS: (planting at NOV2 of 1995)

Period (days after planting)	26-45	46- 70	71- 90	71-125	91-125	126-145
Crop biomass reduction	0%	5%	23%	-	17%	5%

Total Crop biomass reduction, multiplied for the 5 individual periods = **42%**
Total Crop biomass reduction for the whole growing period (day 1-145) = 38%

OVERALL RESULTS 1995 - 1996

CROP BIOMASS REDUCTION, DUE TO THE SOIL

Nutrient status:	0%	(NUTRI)
Salinity (ECe):	0%	(SALIN)
Sodicity (ESP):	0%	(SODIC)
Alkalinity (pH):	0%	(ALKAL)

CROP PRODUCTION FIGURES PER IDENTIFIED PLANTING OPPORTUNITY:

YR	DEK	P.NBP	IRRI	M.p	M.t	SURP	NBP.p	HI.p	YLD.p	NBP.t	HI.t	YLD.t
		(kg/ha)	(mm)	(%)	(%)	(%)	(kg/ha)	(%)	(kg/ha)	(kg/ha)	(%)	(kg/ha)
1995	Nov2,	13210	0	42	38	0	7660	50	4350	8190	50	4670

YR & DEK: date of planting; P.NBP: potential net biomass production; IRRI: irrigation; M.p/t: biomass reduction due to moisture stress, multiplied for all individual crop development periods (M.p), or estimated over the total crop growing period (M.t); SURP: biomass reduction due to moisture surplus; NBP.p/t: net biomass production, after correcting P.NBP for M.p/t, SURP, NUTRI, SALIN, SODIC and ALKAL; HI.p/t: harvest index for NBP.p/t; YLD.p/t: yield, harvested from NBP.p/t (moisture content of harvested produce is 12%).

APPENDIX 3

FARM RECORDS CHECKLIST FOR NW PROVINCE

Long-term farm data on:

- Total farm arable area allocated for maize (optional)
- Long term average crop yield per soil type
- Farm management:
  - -Rainfed/ Irrigated
  - -Maize variety
  - -Plant density (highest, normal, lowest)
  - -Ploughing and planting dates (earliest, normal, latest)
  - -Duration of the ploughing and planting period (No. of weeks)
  - -Weed occurrence and control techniques
  - -Plant disease occurrence and control techniques
  - -Soil fertilization and fertilization timing
- Soils: -Types of soils occurring in the farm
  - -Soil depth
  - -Water holding capacity
  - -Textural and drainage class of different soils

2. FARMER'S PERSONAL EXPERIENCE:

2.1 About crop production (maize) in the region

2.1.1 Maize varieties that they use, why and how long have they been using it.
2.1.2 Production opportunities offered by the particular cultivars
2.1.3 Constraints imposed by those cultivars and how do they deal with those?
2.1.4 Have they been successful over the years? To what extent?
2.1.5 how much yield (t.ha^{-1} or no. of bags) do they regard to be the best, better or bad?
2.1.6 How often to they normally get each of the above?
2.1.7 At which stage is their crop more sensitive to stressful conditions and how do they manage that?

2.2 About climate in the region

2.2.1 How has it been affecting their production over the years
2.2.2 Opportunities and constraints imposed by climatic conditions in the region.
2.2.3 Strategies adopted to counteract the constraints
2.2.4 How do they differentiate between climatic good and bad years

2.3 About the soils in his farm

2.3.1 Which type of fertilizer do they normally apply, why, how and when?
2.3.2 Productivity of soils in each farm as compared to the neighbors, why?
2.3.3 General performance of different soils and their unique qualities.

APPENDIX 4

SIMULATED MAIZE YIELD AT DIFFERENT PLANT POPULATIONS OBTAINABLE AT DIFFERENT PLANTING DATES IN POTCHEFSTROOM AND MMABATHO

Table 11 simulated maize yield at different plant populations, during Nov3, Dec1 and Dec2 dekads. 1942-1997, Potchefstroom

Nov3, 1942-1997,											
Run	Pl.dens.	YLD.p (kg/ha) probability					YLD.t (kg/ha) probability				
	(/ha)	Max.	75%	50%	25%	Min.	Max.	75%	50%	25%	Min.
1	10000	920	2430	5000	6150	6760	320	3380	5000	5540	6480
2	12000	960	2460	5160	6350	6980	320	3490	5160	5730	6700
3	14000	970	2540	5340	6560	7210	330	3610	5340	5910	6920
4	16000	710	2330	4760	6320	7440	0	2770	5350	5950	7140
5	18000	260	1100	2250	3150	6970	0	1580	3380	4440	7050
6	20000	270	1130	2320	3250	7170	0	1620	3470	4570	7250
7	22000	270	1170	2380	3340	7380	0	1660	3570	4600	7450
8	24000	280	1200	2440	3420	7570	0	1670	3670	4730	7650
9	26000	280	1230	2510	3510	7760	0	1720	3760	4850	7850
10	28000	290	1260	2570	3600	7950	0	1760	3850	4970	8040
11	30000	290	1260	2630	3690	8140	0	1810	3950	5090	8230

Dec2, 1942-1997											
Run	Pl.dens.	YLD.p (kg/ha) probability					YLD.t (kg/ha) probability				
	(/ha)	Max.	75%	50%	25%	Min.	Max.	75%	50%	25%	Min.
1	10000	310	2640	4490	5950	6610	1160	3040	4690	5420	6150
2	12000	310	2730	4640	6150	6830	1200	3140	4850	5600	6350
3	14000	320	2760	4800	6350	7050	1240	3240	5010	5780	6560
4	16000	180	1850	4070	6550	7270	840	2850	5020	6110	7060
5	18000	0	1150	1980	3310	7190	0	1470	3160	4420	7270
6	20000	0	1180	2040	3400	7400	0	1510	3250	4550	7480
7	22000	0	1220	2090	3490	7600	0	1520	3340	4580	7680
8	24000	0	1250	2150	3590	7810	0	1560	3420	4700	7890
9	26000	0	1280	2210	3680	8010	0	1600	3510	4820	8090
10	28000	0	1310	2260	3770	8200	0	1640	3600	4940	8290
11	30000	0	1340	2320	3860	8400	0	1680	3690	5060	8490

Dec3, 1947-97											
Run	Pl.dens.	YLD.p (kg/ha planted) probability					YLD.t (kg/ha planted) probability				
	(/ha)	Max.	75%	50%	25%	Min.	Max.	75%	50%	25%	Min.
1	10000	50	1730	4190	6340	6540	0	2120	4580	5630	6150
2	12000	40	1790	4330	6560	6760	0	2190	4730	5810	6360
3	14000	40	1850	4470	6770	6980	0	2260	4890	6010	6560
4	16000	40	1620	3740	6630	7200	0	2040	4390	6410	7060
5	18000	0	770	1960	2980	6380	0	700	2690	4380	6820
6	20000	0	790	2020	3070	6560	0	720	2770	4410	7020
7	22000	0	810	2080	3150	6740	0	740	2850	4530	7220
8	24000	0	830	2130	3240	6930	0	760	2920	4660	7410
9	26000	0	850	2180	3320	7100	0	760	3000	4770	7600
10	28000	0	880	2240	3400	7280	0	780	3070	4890	7780
11	30000	0	880	2290	3480	7450	0	800	3140	5010	7970

Table 12 simulated maize yield at different plant populations, during Nov1, Nov2 and Nov3 dekads. 1985-91997 Mmabatho

Nov1,											
Run	Pl.dens.	YLD.p (kg/ha) probability					YLD.t (kg/ha) probability				
	(/ha)	Max	75%	50%	25%	Min	Max	75%	50%	25%	Min
1	10000	890	1020	2780	3970	4250	600	2050	2510	3550	4180
2	12000	920	1060	2880	4110	4390	620	2120	2540	3680	4320
3	13000	920	1070	2870	4180	4470	630	2150	2580	3730	4390
4	14000	930	1100	2920	4240	4540	640	2190	2630	3800	4470
5	15000	730	800	2150	3030	3780	200	1630	2000	3630	3780
6	16000	740	810	2180	3080	3840	200	1650	2030	3680	3840
7	17000	750	820	2220	3130	3900	200	1680	2060	3660	3900
8	18000	360	360	910	1390	2320	0	200	430	1550	2400
9	19000	360	360	920	1410	2360	0	200	440	1570	2430
10	20000	360	360	940	1410	2390	0	200	440	1590	2470
Nov2,											
Run	Pl.dens	YLD.p (kg/ha) probability					YLD.t (kg/ha) probability				
	(/ha)	Max.	75%	50%	25%	Min.	Max.	75%	50%	25%	Min.
1	10000	750	1090	3180	4840	6290	530	1560	2700	4150	5670
2	12000	750	1120	3290	5010	6510	550	1610	2790	4290	5860
3	13000	770	1140	3340	5090	6610	540	1640	2780	4360	5960
4	14000	780	1160	3400	5160	6720	560	1660	2820	4430	6050
5	15000	570	790	2350	4800	5320	200	1080	2280	4050	5690
6	16000	570	800	2390	4880	5400	190	1100	2310	4110	5780
7	17000	580	820	2420	4940	5490	200	1110	2350	4170	5880
8	18000	270	350	1050	2230	2460	0	0	830	2460	3690
9	19000	270	360	1070	2260	2490	0	0	840	2490	3740
10	20000	280	360	1090	2290	2530	0	0	830	2530	3800
Nov3,											
Run	Pl.dens.	YLD.p (kg/ha) probability					YLD.t (kg/ha) probability				
	(/ha)	Max.	75%	50%	25%	Min.	Max.	75%	50%	25%	Min.
1	10000	1540	1540	3350	4230	6350	1740	1740	4100	4160	5810
2	12000	1590	1590	3460	4380	6570	1800	1800	4240	4310	6010
3	13000	1620	1620	3520	4450	6680	1830	1830	4310	4380	6100
4	14000	1640	1640	3570	4520	6780	1860	1860	4380	4450	6200
5	15000	1380	1380	2390	2980	5480	1310	1310	3560	3560	6000
6	16000	1400	1400	2430	3020	5570	1330	1330	3540	3540	6090
7	17000	1420	1420	2470	3070	5650	1350	1350	3590	3590	6190
8	18000	660	660	890	1270	3190	0	0	1440	1520	4110
9	19000	660	660	910	1280	3240	0	0	1460	1540	4080
10	20000	670	670	920	1300	3280	0	0	1490	1560	4140