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

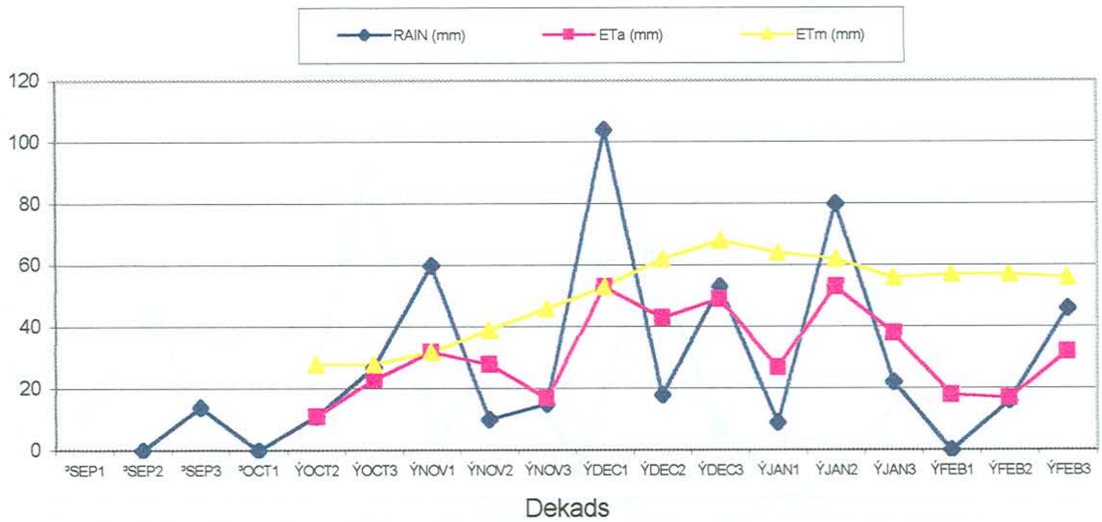


Fig. 4.1 Dekad Rainfall distribution and Simulated ETa & ETm 1986 season in Potchetstroom (Oct 2 planting)

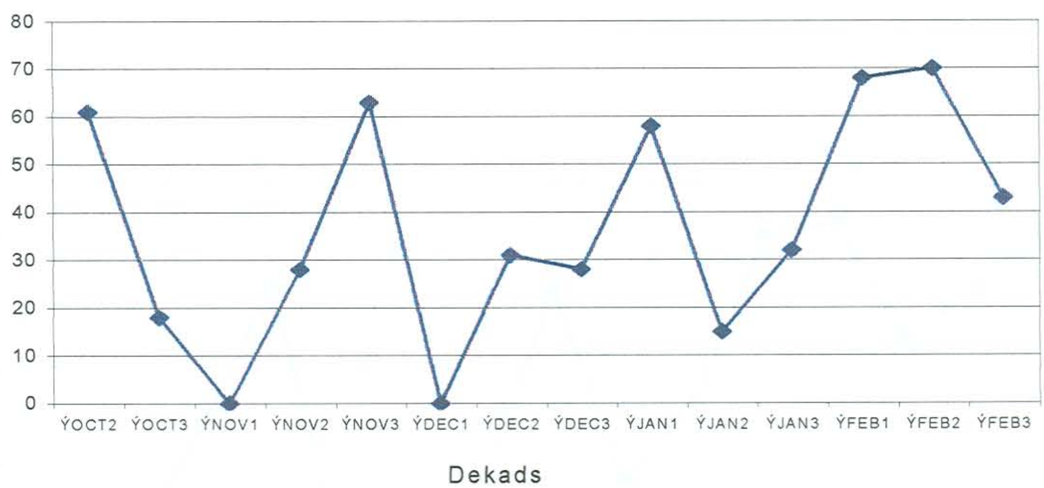


Fig 4.2 Simulated moisture stress (%) Oct2 planting in 1986 season in Potchefstroom

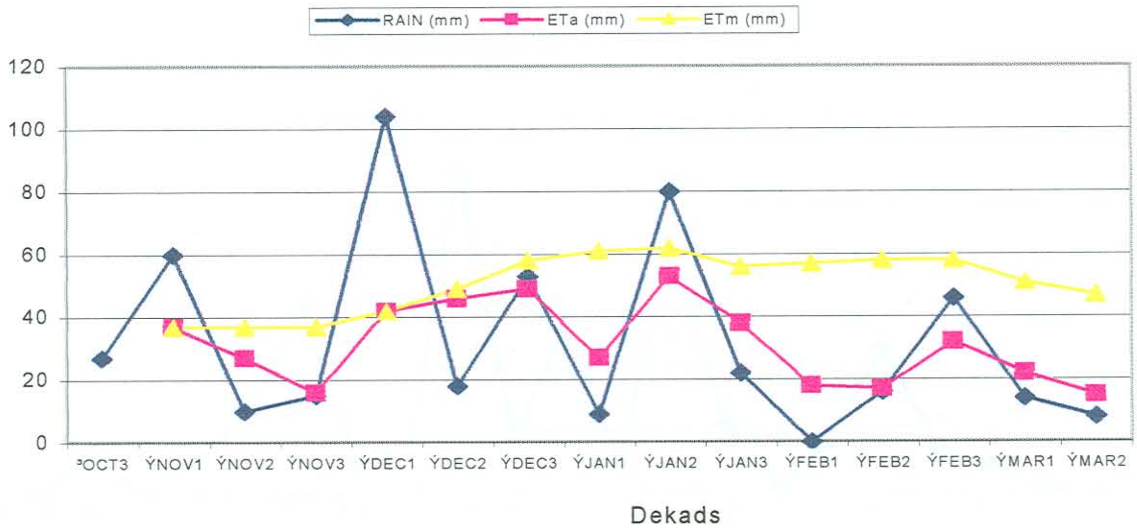


Fig 4.3 Dekad Rainfall Distribution Simulated ETa and ETm 1986 season in Potchefstroom (Nov1 planting)

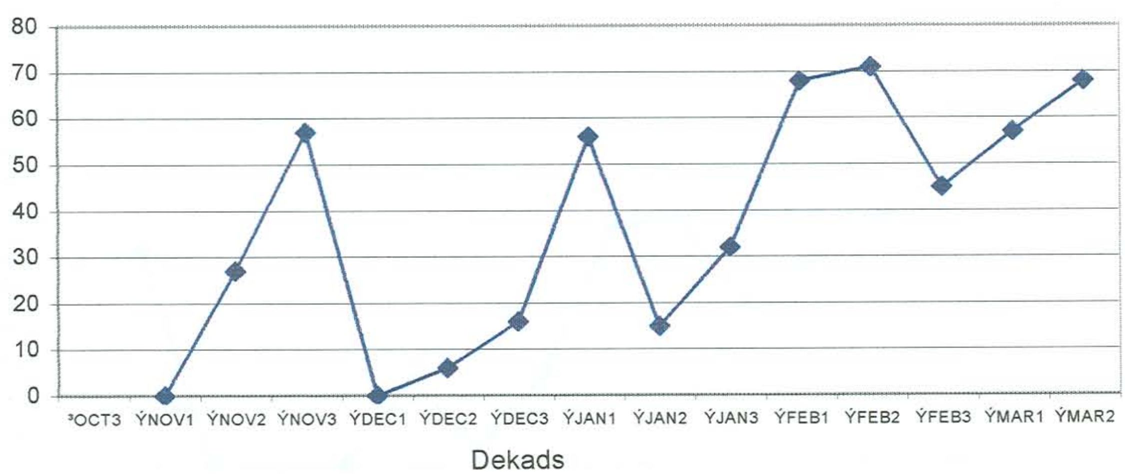


Fig 4.4 Simulated moisture stress (%) Nov 1 Planting 1986 season in Potchefstroom

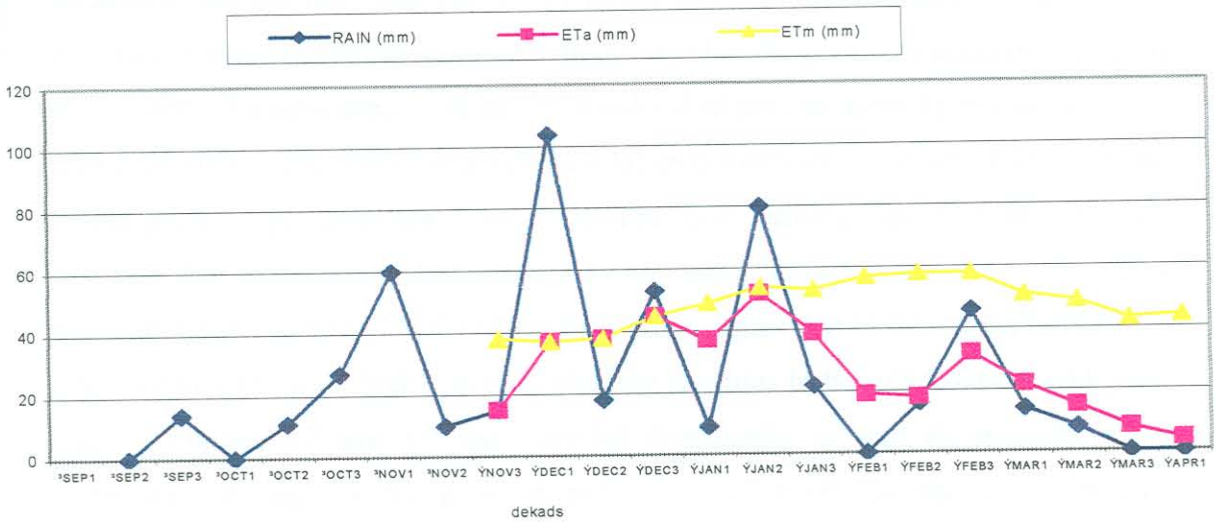


Fig 4.5 Dekad Rainfall Distribution Simulated ETa and ETm 1986 season in Potchefstroom (Nov3 planting)

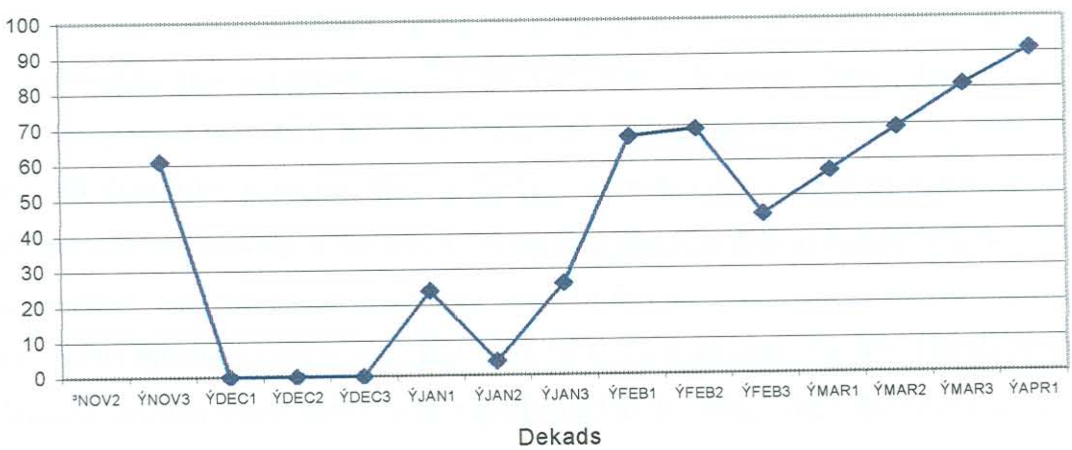


Fig 4.6 Simulated moisture stress (%) Nov 3 Planting 1986 season in Potchefstroom

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.

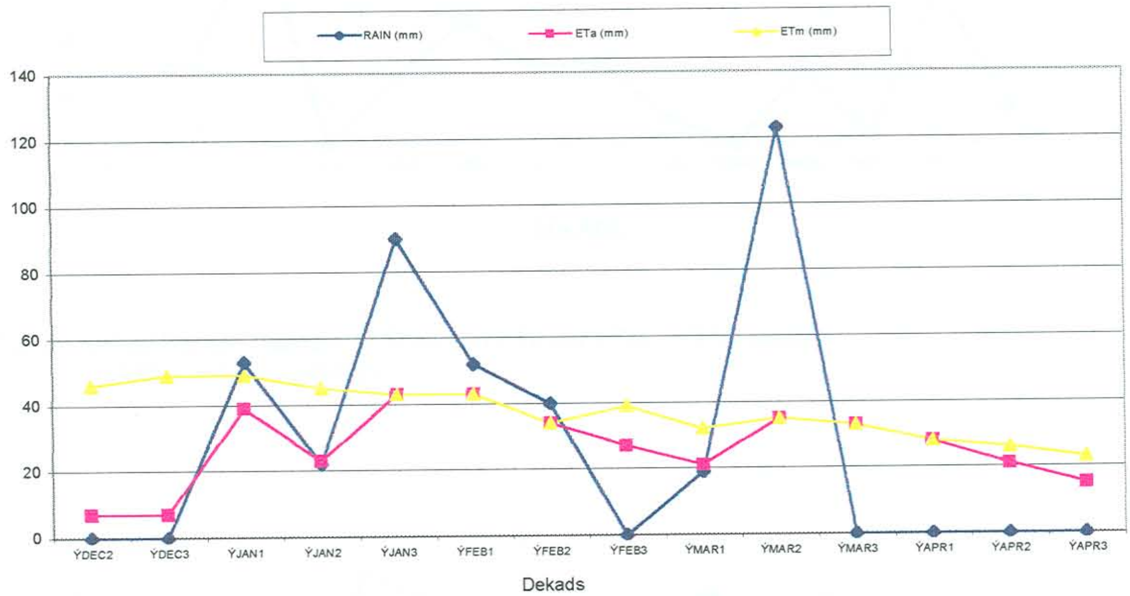


Fig 4.7 Dekad Rainfall Distribution Simulated ETa and ETm 1990/91 season in Ottosdal (Dec2 planting)

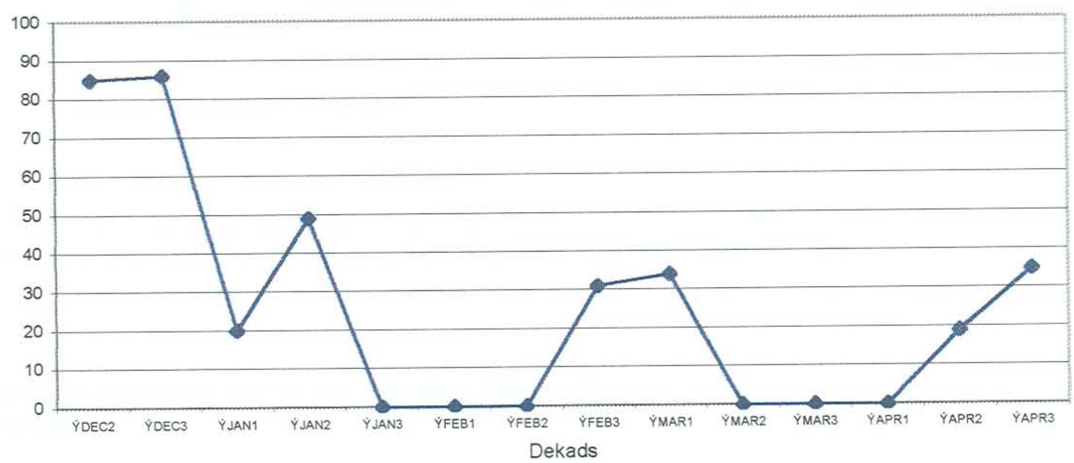


Fig 4.8 Simulated moisture stress (%) Dec2 Planting 1990/91 season in Ottosdal

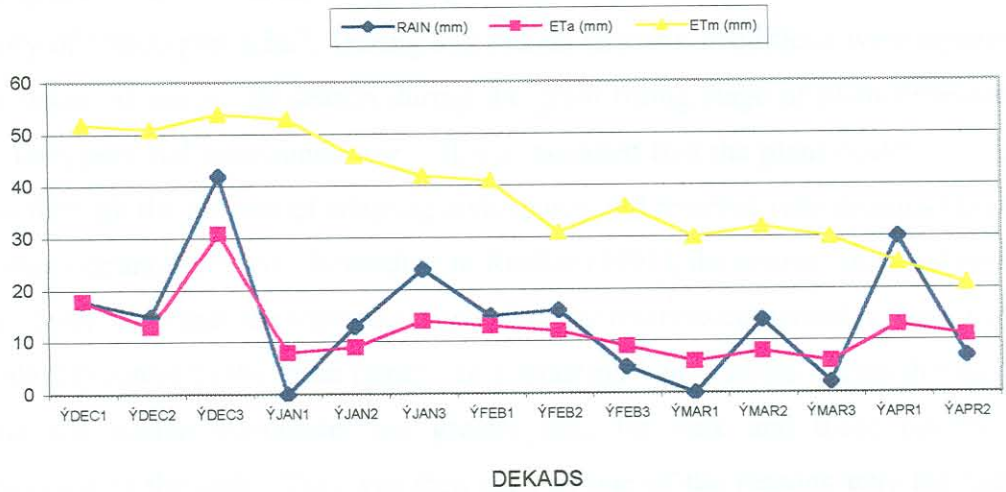


Fig 4.9 Dekad Rainfall Distribution Simulated ETa and ETm 1991/92 season in Ottosda (Dec1 planting)

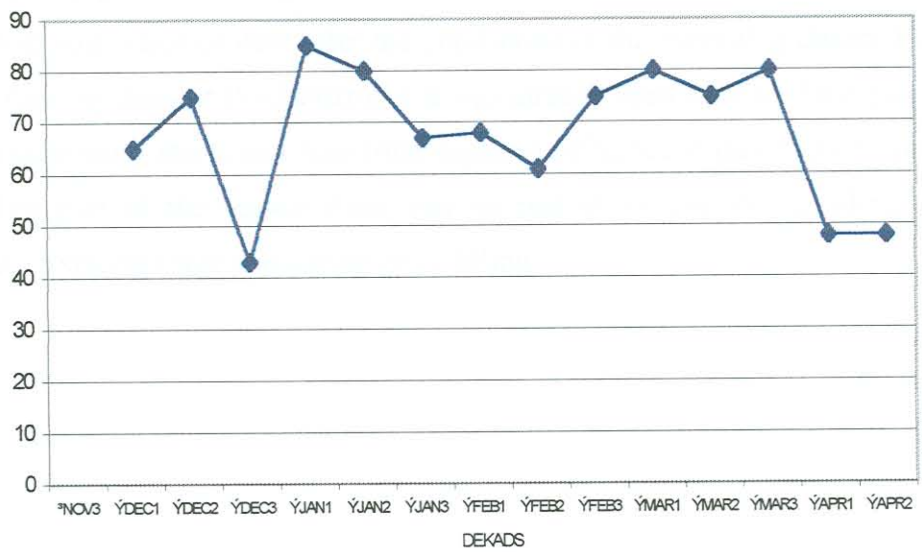


Fig 4.10 Simulated moisture stress (%) Dec 1 Planting 1991/92 season in Ottosdal

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.

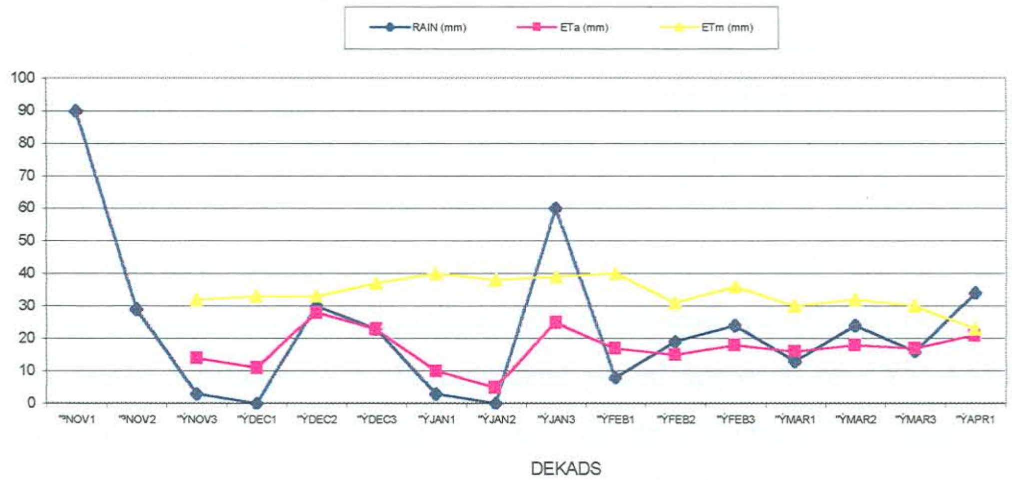


Fig 4.11 Dekad Rainfall Distribution Simulated ETa and ETm 1992/93 season in Ottosdal (Nov3 planting)

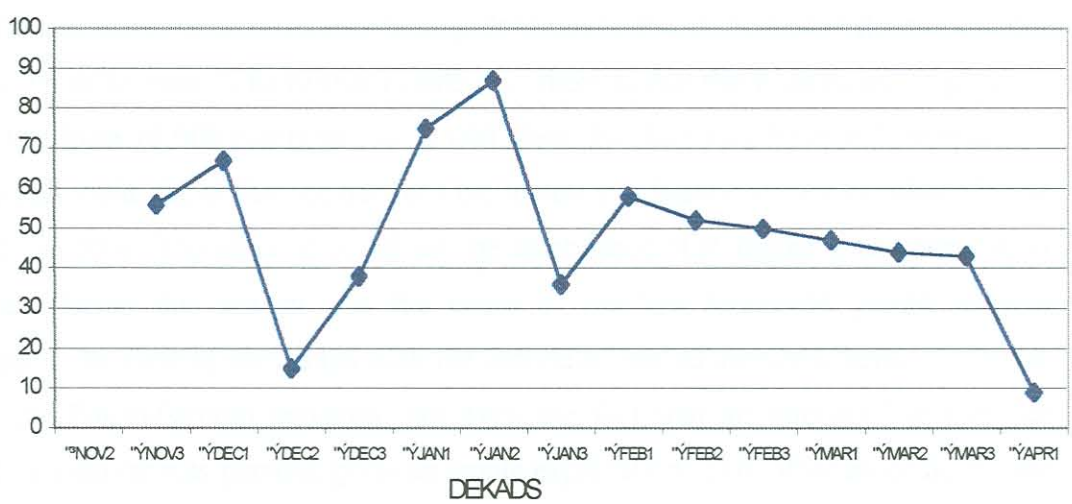


Fig 4.12 Simulated moisture stress (%) Nov3 Planting 1992/923season in Ottosdal

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.

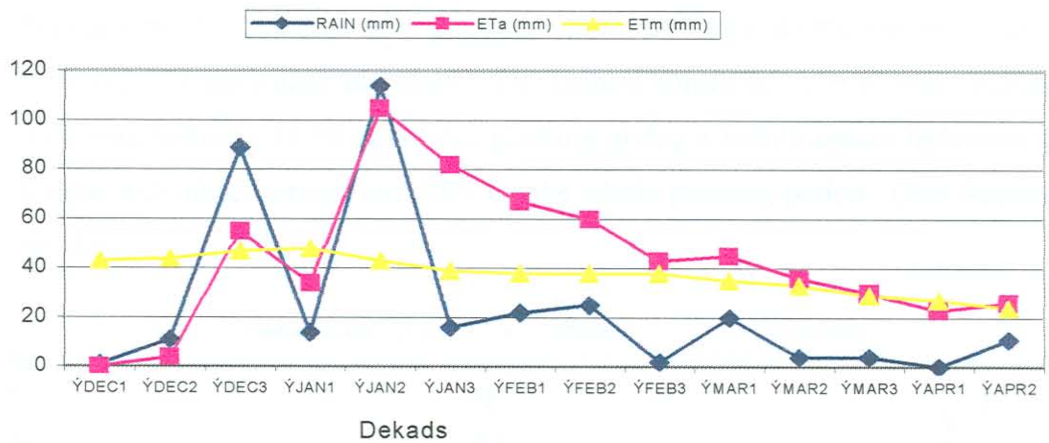


Fig 4.13 Dekad Rainfall Distribution Simulated ETa and ETm 1993/94 season in Setlagole (Dec1 planting)

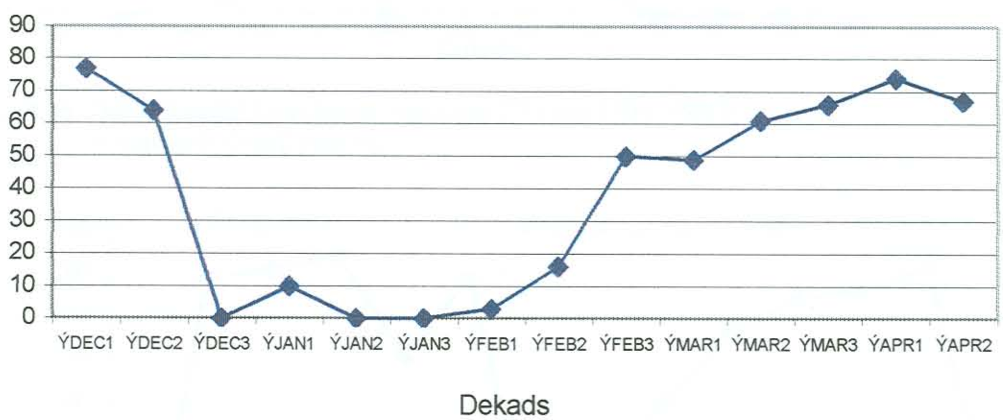


Fig 4.14 Simulated moisture stress (%) Dec 1 Planting 1993/94 season in Setlagole

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.)

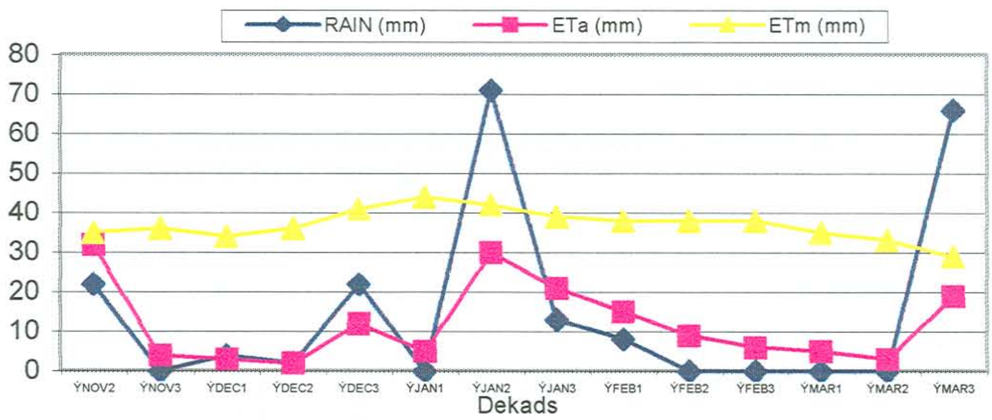


Fig 4.15 Dekad Rainfall Distribution Simulated ETa and ETm 1994/95 season in Setlagole (Nov2 planting)

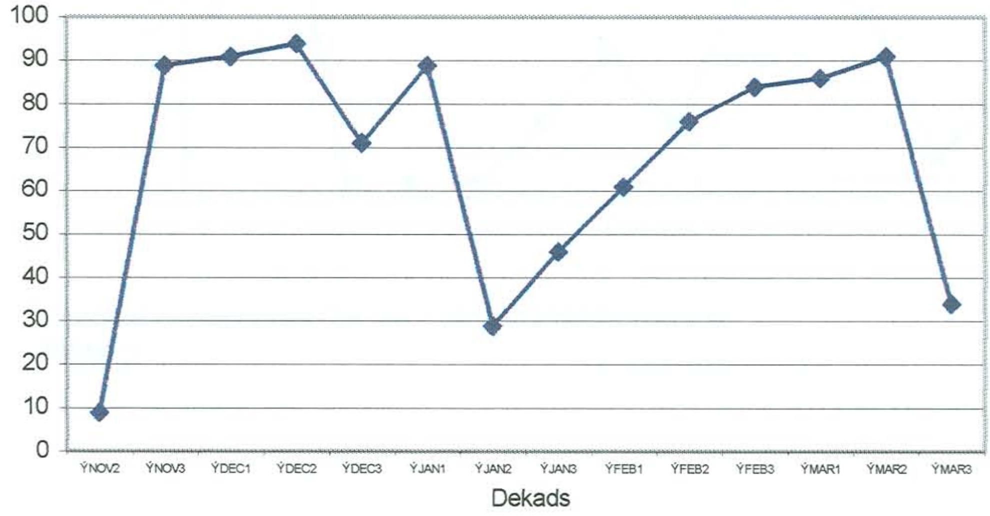


Fig 4.16 Simulated moisture stress (%) Nov2 Planting 1994/95 season in Setlagole

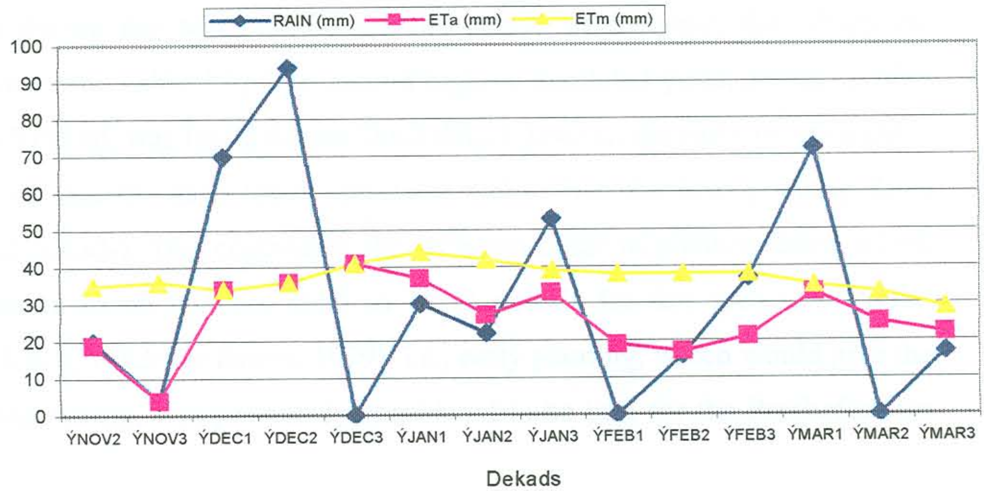


Fig 4.17 Dekad Rainfall Distribution, Simulated ETa and ETm 1995/96 season in Setlagole (Nov2 planting)

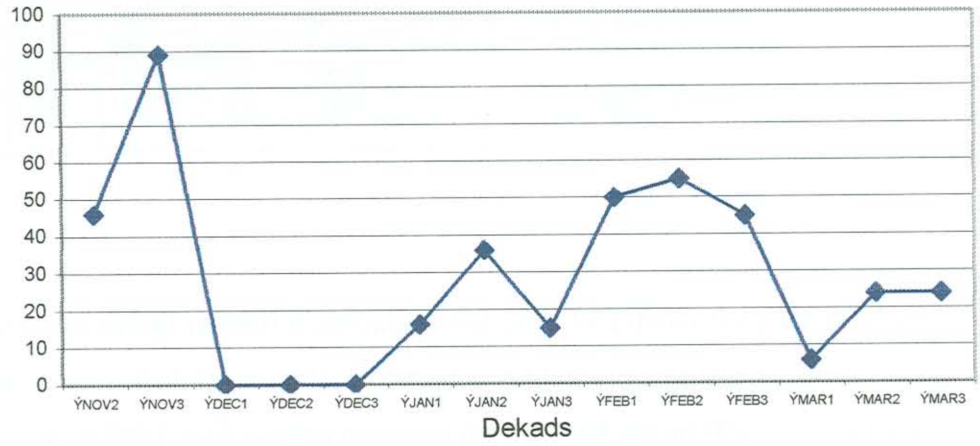


Fig 4.18 Simulated moisture stress (%) Nov 2 planting 1995/96 season in Setlagole

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		
7	Dec-02	1150	1980	1470	3160		AWC 100mm/m

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.

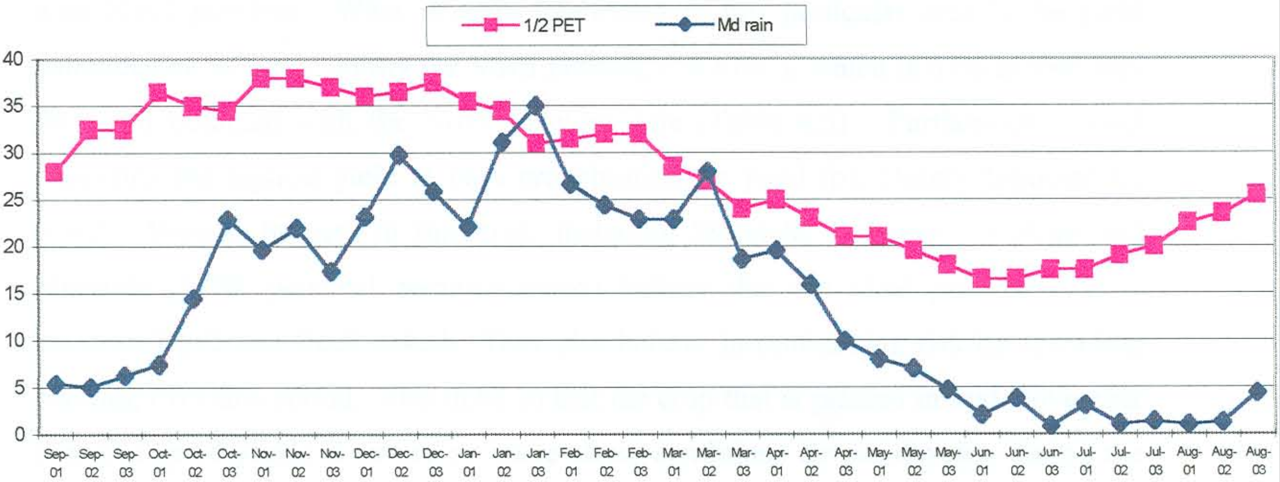


Fig. 4.19 Mean Dekad rainfall (mm) and ½ PET for 56 years in Potchefstroom

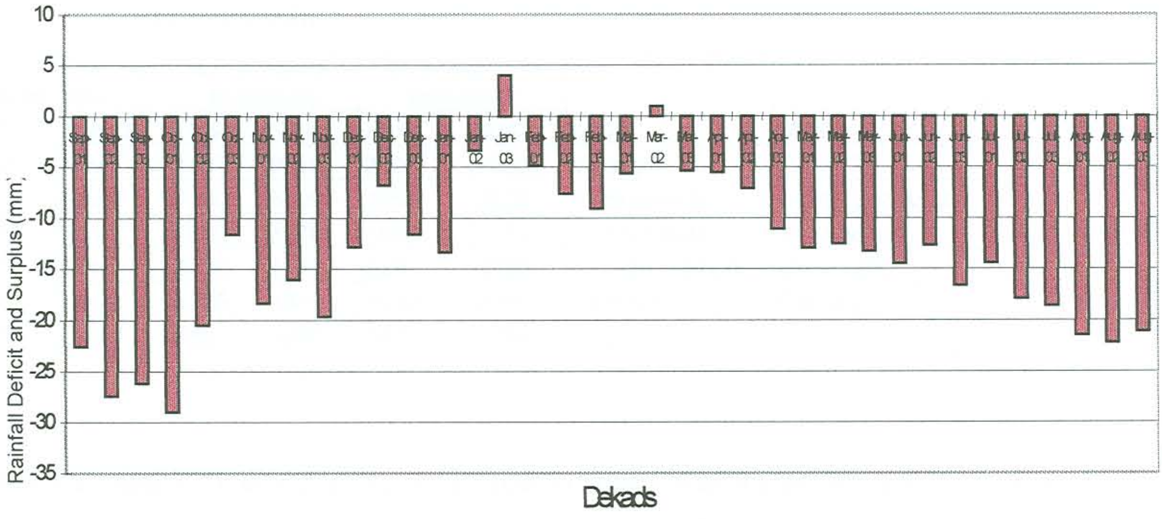


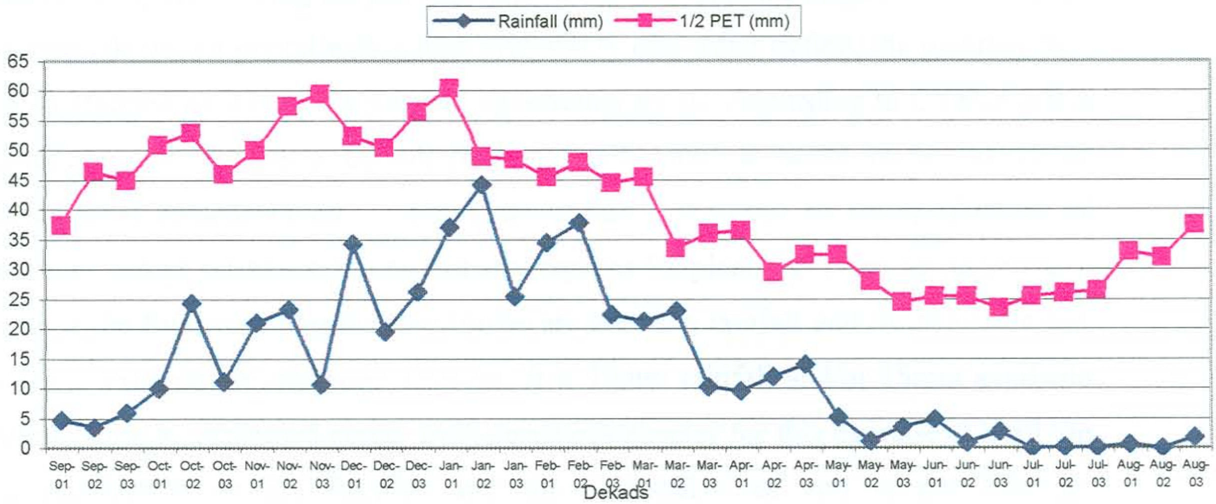
Fig. 4.20 Distribution of Mean Dekad Rainfall surplus and Deficit (56 years in Potchefstroom)

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).

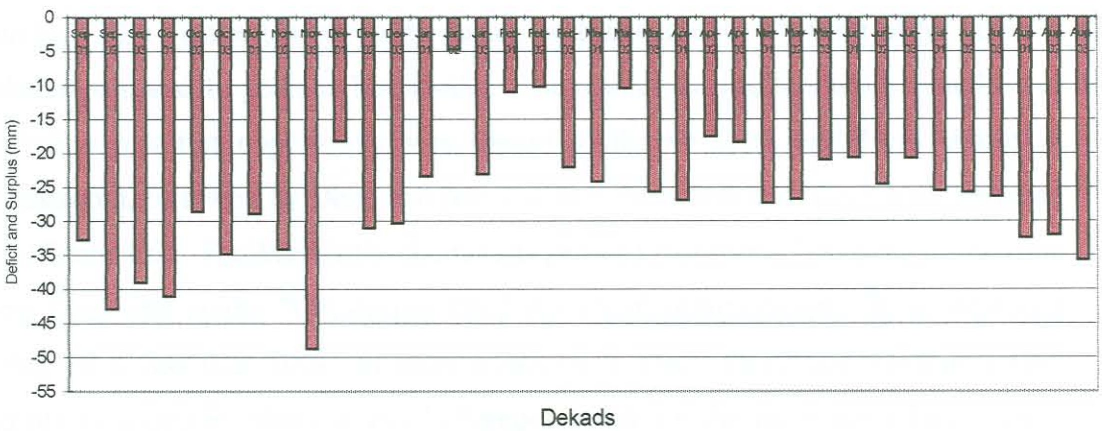
Table 4.5. Yield potential of different planting dates at different probabilities in Mmabatho

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.