late sown crops and this undoubtedly contributed to the severe yield reduction. It may be that both cultivars are sensitive to reduced daylength.

Under rainfed conditions the yields of the early and late cultivars were not substantially different, indicating that there was no advantage to be gained from late genotypes when the water supply was limited to fallow storage and rainfall during crop growth. The earlier cultivars used the same total quantity of water as the late one (Dubbelde *et al.,* 1982) but, because of their shorter duration, there tended to be slightly more extractable water remaining in the profile at flowering (Figures 1 and 2). The yield potential demonstrated by the earlier cultivars under irrigation indicates they have the capacity to respond to seasons with better rainfall, and give yields comparable to those of late cultivars over a range of moisture conditions. It can be argued that this potential, coupled with the shorter duration, may lead to a reduced risk of yield loss with early cultivars in uncertain rainfall conditions.

If the shorter duration cultivars do use water more effectively in the development of yield, this should be reflected in better water use efficiency in the earlier cultivars under dryland conditions. A trend towards increased efficiency in the early and mid-season cultivars is suggested in the data (Table 1), but the variability in WUE was high. Evaluation over a wider range of seasonal rainfall conditions would be required to assess whether greater stability of production could be achieved with early cultivars.

CONCLUSION

This study was carried out in two seasons when the rainfall was well below the average for the area. The results for rainfed crops therefore can be expected to reflect the low end of a range of probable yields in the environment. The results relating to the effect of cultivar maturity type, while not conclusive, tend to suggest that earlier types may be more efficient in conditions of high rainfall variability. In order to test this, the results of this study will be used to further develop an existing simulation model of sunflower growth and development to allow the response of cultivars of different maturity types to be examined in a wide range of seasonal conditions.

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DETERMINATION OF REGIONAL STRATEGIES FOR SUNFLOWER PRODUCTION.

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ABSTRACT

Sunflower research by the Queensland Department of Primary Industries has been directed towards understanding crop adaptation via studies of the responses of growth and yield to climate and management variables. Results from these studies have been used to construct a dynamic crop simulation model which incorporates the interaction of climate with phenology, crop growth, leaf area development and water use.

To evaluate regional strategies, simulation studies using this model with historical weather records from sunflower production regions have been undertaken. This has enabled the determination of yield probabilities associated with the various strategies. A brief description of the model and an example of its use in determining the optimum time of planting and best cultivar type for a given region are presented.

INTRODUCTION

The development of oilseed sunflower production in Australia has been confronted with lack of knowledge on regional adaptation of the crop and on agronomic principles to guide husbandry practices. As climate is so variable, particularly in Queensland, no one agronomic practice is consistently superior to another. As a result, the optimum time of planting, plant population and most desirable cultivar vary from year to year and from site to site, depending on the conditions encountered during crop growth. Research by the Queensland Department of Primary Industries has therefore been directed towards understanding crop adaptation via studies of phenology, growth and yield responses to climate and management variables.

Traditional methods of conducting and analysing agronomic experiments lead to conclusions restricted to locations similar to the experimental sites and to a similar range of treatments. Little use is made of the data to extrapolate the findings to locations other than those in which the data were obtained. For crop adaptation studies this methodology requires long term experimentation at many sites. An alternative approach is to monitor relevant experimental variables and construct a comprehensive model of the crop system (Hammer, 1981).

To enable evaluation of regional strategies for dryland sunflower cropping this alternative approach was adopted. A dynamic crop model was developed to simulate crop phenology, growth and yield. Previously reported sunflower crop models (Hammer *et al.*, 1978, Smith *et al.*, 1978) were not adequate for this purpose as they were site specific in some aspects (eg. phenology), cultivar specific or too simplistic in their approach to moisture stress which was the major factor relevant to this study.

The dynamic model developed is suitable for application to most of the cultivars currently grown commercially in Australia. It has a more realistic approach to moisture stress and has overcome many of the problems associated with site specificity. This paper gives a brief description of the model and its application to the determination of regional strategies associated with planting time and cultivar choice.

MATERIALS AND METHODS

The crop model was developed and tested on data obtained from field studies in Queensland between 1972 and 1975 (Goyne *et al.*, 1977, 1978, 1979), controlled environment studies in the phytotron at Canberra and field studies on the Darling Downs and in Central Queensland between 1978 and 1981 (Goyne *et al.*, 1982, Goyne and Hammer, 1982). The model is structured into the four interacting components of crop phenology, soil water balance, crop growth and yield prediction.

Crop Phenology.

Serial plantings over a twelve month period at Toowoomba of cultivars commercially available in 1979 showed that most cultivars could be classified into two maturity groups — "quick" or "medium". These groups were represented by the cultivars Sunfola 68-2 and Hysun 30 respectively. The phytotron studies established the temperature and photoperiod responses of these two cultivars and hence of the maturity groups. From this information models to predict the daily rates of development for emergence (E) to head visible (HV) and HV to first anthesis (FA) were derived and tested on independent data (Hammer *et al.*, 1982). Time from planting (P) to emergence was determined via the model of Angus *et al.*, 1980 and time from first anthesis to physiological maturity (PM) via the data of Goyne *et al.*, (1979).

The equations were:

(i) P to E $\Delta D = 0.0130\ (T-7.9)$

(ii) E to HV $\Delta D = (0.00252\ (T-6.6) - 0.0000327\ (T-6.6)^2)\ PPM$

where PPM was photoperiod multiplier such that $PPM = 1.0$ for "quick" cultivars and $PPM = 1.0 - 0.24/(1.0 + e^{-42.33 + 3.12PP})$ for "medium" cultivars

(iii) HV to FA $\Delta D = 0.00291\ (T-3.9) - 0.00003275\ (T-3.9)^2$

(iv) HV to PM $\Delta D = 0.00140\ (T-0.0)$

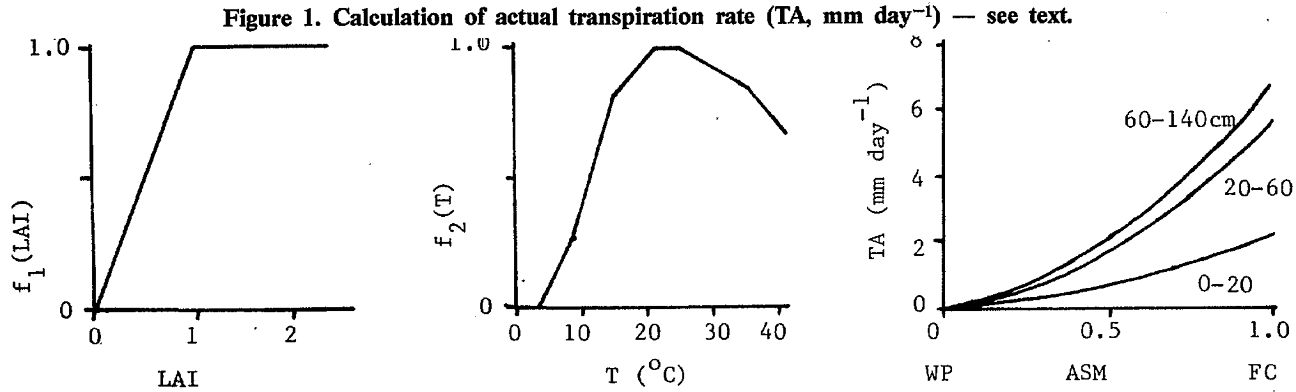
where ΔD was the daily rate of development ($days^{-1}$), T was daily mean temperature (°C) and PP was the photoperiod at emergence (hours). The relevant equation was evaluated each day and ΔD was accumulated until a value of one was reached. The crop was then switched to the next developmental state and the next equation was used.

The same equations were suitable for both groups of cultivars except for E to HV where the "medium" maturity types showed a long day photoperiodic response whereas the "quick" maturity types were insensitive to photoperiod.

Soil Water Balance.

The soil was divided into three layers viz. 0-20, 20-60 and 60-140 cm. The top layer was used to determine soil evaporation using the model of Ritchie (1972) with the radiation interception function for sunflower reported by Hiroi and Monsi (1966). This layer was filled to field capacity during rain events before runoff and infiltration to deeper layers were calculated using the model of Boughton (1968). The third layer extended to the potential depth of water extraction. The actual depth of water extraction increased with the phenological stage of the crop, reaching the potential depth prior to anthesis.

Figure 1. Calculation of actual transpiration rate (TA, mm day⁻¹) — see text.



Potential transpiration (TP) was set at the class A pan evaporation rate less the amount of soil evaporation. Actual transpiration (TA) was then determined from this amount depending on leaf area index (LAI), temperature (T) and available soil moisture in the root zone (ASM) as follows (Fig. 1).

$TA\ (mm) = Min\ [TP*f_1\ (LAI);\ f_2(T)*f_3\ (ASM)]$

where f_1 and f_2 are dimensionless functions taking values between 0 and 1. The temperature function $f_2(T)$ was derived from that of van Keulen (1975) and used in a similar manner. The LAI and ASM functions (f_1 and f_3) were fitted via iterative optimization techniques (Galbraith, 1978) using sequential soil moisture measurements from the experiments referred to above.

The LAI function showed that sunflower was capable of high water use at low values of LAI. This observation was noted by Downes (1977) when comparing sunflower and sorghum. He found that at equivalent levels of leaf area per plant, sunflower used about 2½ times as much water as sorghum.

The ASM functions (one for each soil layer), once modified by the temperature effect, defined the actual amount of water uptake that was possible at any level of ASM. If this amount was greater than the modified potential (ie. $TP*f_1(LAI)$), then the potential was realized, otherwise actual transpiration was limited by ASM. This enabled the definition of an index of crop water stress (SI) similar to that of Nix and Fitzpatrick (1969).

That is $SI = 100\ (1 - TA/TP)$

so that $SI = 0$ when $TA = TP$

and $SI = 100$ when $TA = 0$

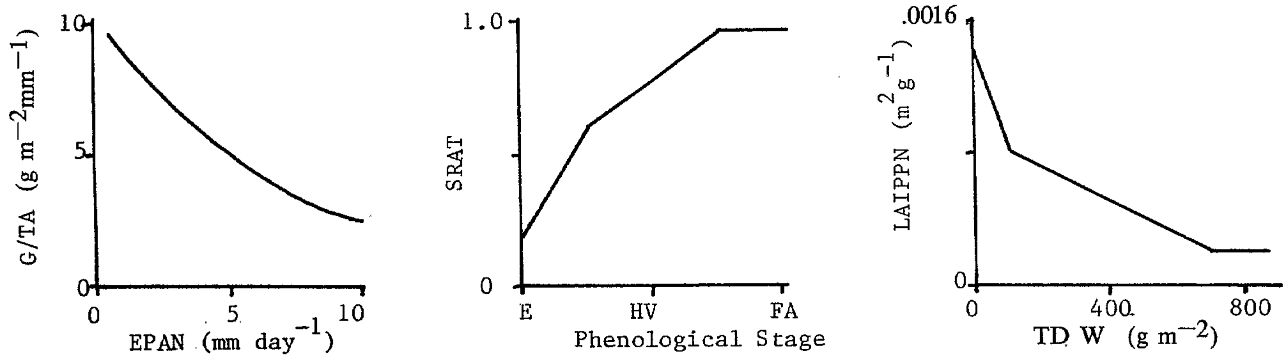
Crop Growth.

Dry weight of tops and leaf area at emergence were calculated from the seeding rate using the factor reported by Smith *et al.*, 1978. Crop growth was then determined via water use efficiency (de Wit 1958, van Keulen 1975) using the function reported by Fischer (1979) for wheat

$G/TA = 10.2 - 1.30*EPAN + 0.053*EPAN^2$ (see Fig. 2).

where G is daily crop growth ($g\ m^{-2}day^{-1}$) and TA and EPAN are actual transpiration and pan evaporation ($mm\ day^{-1}$) as defined in the soil water balance. This enabled calculation of G on a daily basis. The effects of moisture stress and temperature on growth were implicit in this relationship through their effects on TA as defined in the soil water balance. To determine above ground growth this amount was modified by a factor shoot/root ratio (Fig. 2) which accounted for the partitioning of growth to roots and shoots as the crop matured. Above ground growth was accumulated to give the total dry weight (TDW).

Figure 2. Calculation of crop growth ($gm^{-2}day^{-1}$) and LAI — see text.



LAI was incremented via a factor LAIPPN (Fig. 2) acting on the calculated amount of above ground growth. This factor was a composite of the proportion of growth going to leaves and the leaf area to weight ratio. It was related to TDW using field data. The effects of crop moisture stress on LAI were included in two ways. Firstly, as the moisture stress index increased from a value of 10 to 35 the potential LAI increase was reduced to zero. This simulated the cessation of leaf expansion due to moisture stress. Secondly, at high levels of moisture stress ($SI > 50$) leaf area loss was simulated by removing up to 10% of the existing LAI as SI increased from 50 to 100.

The functions defining the effect of moisture stress on LAI and the function for SRAT were fitted via iterative optimization techniques to sequential LAI measurements from the field experiments.

Yield Prediction.

Goyne *et al.,* (1978) found that moisture stress in the 30 day period around anthesis was the main factor associated with yield variation for dryland sunflower. The level of LAI and rust infestation at anthesis were also significant factors. The model described above was applied to the same data to generate stress indices, growth and transpiration for various periods of crop development. Regression analysis was undertaken and the yield prediction equation (Fig. 3) considered most suitable was

$$\ln(\text{Yield}) = 6.857 + 0.00114{*}TDWA - 0.0190{*}SIA$$
$$R^2 = 82.6\% \quad \text{kg ha}^{-1} \qquad (*) \quad (**)$$

where TDWA was total dry weight accumulated from E to FA and SIA was average daily SI in the 30 day period around anthesis. Significance levels for coefficients are indicated by *(5% level) or **(1% level). This equation combined goodness of fit and biological interpretation as yield was predicted to increase with increasing TDWA and decrease as SIA increased.

Oil quality, expressed as percentage of linoleic acid, was predicted using the equation reported by Goyne *et al.,* (1979). This equation related oil quality to mean daily temperature during grain fill. Oil content expressed as oil percentage could not be satisfactorily predicted.

Validation.

Forty-one sites (mainly commercial crops) were monitored to provide data to test the model. The data collected were soil moisture at planting and flowering, standing dry weight and leaf area index at flowering and grain yield. Soil samples were taken at each site for determination of maximum plant available soil water. At some sites this was determined using the equations reported by Shaw and Yule (1978).

Simulations Experiments.

Daily temperatures, evaporation and rainfall collected from a standard meteorological station over a 46 year period (1930 — 75) at Biloela, Central Queensland were used in the study. Simulated plantings of the two cultivars Sunfola 68-2 and Hysun 30, representing the two main maturity groups, were made at the beginning of each month for the 46 year period. The assumption was that a planting rain had occurred to enable such a planting. The antecendent plant available soil moisture was maintained at the same level (195 mm) for all simulated plantings. The soil type used was a deep (1.4 m) alluvial cracking clay with a maximum plant available water for 250 mm.

Yield probabilities associated with a given cultivar and planting time were generated from the output. Oil quality levels and dates of phenological events were also obtained.

RESULTS AND DISCUSSION

Model Validation.

Of the 41 sites used for model validation 15 showed an unacceptable level of error in yield prediction. In all of these 15 cases the predicted yield underestimated the actual yield indicating that too much moisture stress was predicted. In most cases this could be associated with one or more of the following factors

(i) underestimating the maximum plant available water for the given soil type
(ii) underestimating the infiltration rate
(iii) underestimating the potential depth of water extraction

All of these factors were associated with soil characteristics although the second involves an interaction with rainfall intensity and the third an interaction with root growth. Whilst all sites were on soils that could be generally described as heavy uniform cracking clays there was a range of types giving different cracking and water-holding characteristics.

Hence, although the model had been made less site specific with respect to crop factors better understanding of soil water characteristics (particularly plant available water-holding capacity and infiltration) and root growth dynamics (particularly root depth) are necessary to fully generalize the applicability of the model.

Simulation Experiments.

Acting within the limitations due to soil characteristics it was still feasible to use simulation experiments to evaluate management strategies. The analysis was restricted to those soils where the characteristics listed above were known and the model had performed adequately on the independent validation data. This was predominantly the case for the soils in the Central Queensland region.

Figure 4a gives the 20, 50 and 80% simulated yield probability lines for Sunfola 68-2 ("quick" maturing type) as planting time was varied throughout the year at Biloela, Central Queensland. The probability is interpreted as the chance of obtaining at least the specified yield for the given time of planting. The results for Hysun 30 ("medium" maturing type) are presented similarly in figure 4b. Both cultivars gave higher yields for plantings between December and May with peak yields for April and January plantings. These results reflected the pattern of rainfall and evaporation at the site and its interaction with crop growth and development.

Sunfola 68-2 performed slightly better than Hysun 30 at the 50% probability level but this was reversed at the 20% level. This indicated that 20% of years had sufficiently favourable moisture regimes to enable dry weight at anthesis of the longer maturing type (Hysun 30) to be reflected in higher grain yields. However, at the 50% level the moisture saved by the quicker maturing type (Sunfola 68-2) was more important than the additional dry weight, giving those types the slight yield advantage.

It was also necessary to consider the likelihood of frost at flowering and any constraints on oil quality as these represent important factors in time of planting and cultivar choice decisions. Figure 5 shows the simulated number of days from planting to the major phenological events for both maturity types. The lines indicating the dates of first and last frosts at the 10% risk level are also included. Depending on the cultivar chosen, planting in mid February to early March was the latest feasible at this risk level. Figure 6 shows the simulated oil quality for both cultivars. Higher oil quality was found for plantings between February and May for both cultivars.

Figure 3. Yield prediction equation.

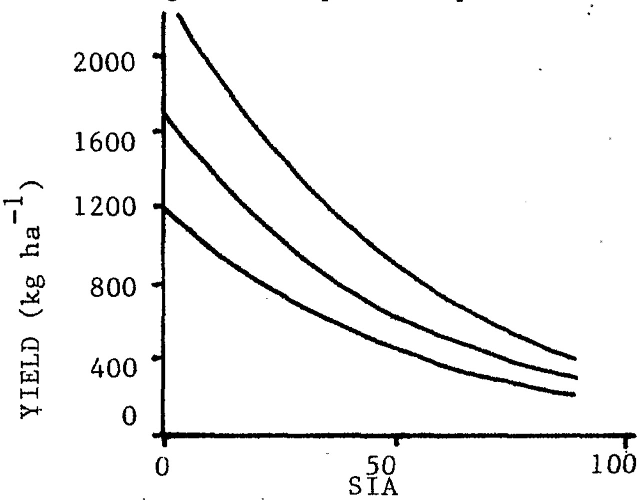


Figure 4. Simulated yield probabilities for Sunfola 68-2((a) — solid line) and Hysun 30 ((b) — broken line) for various planting times.

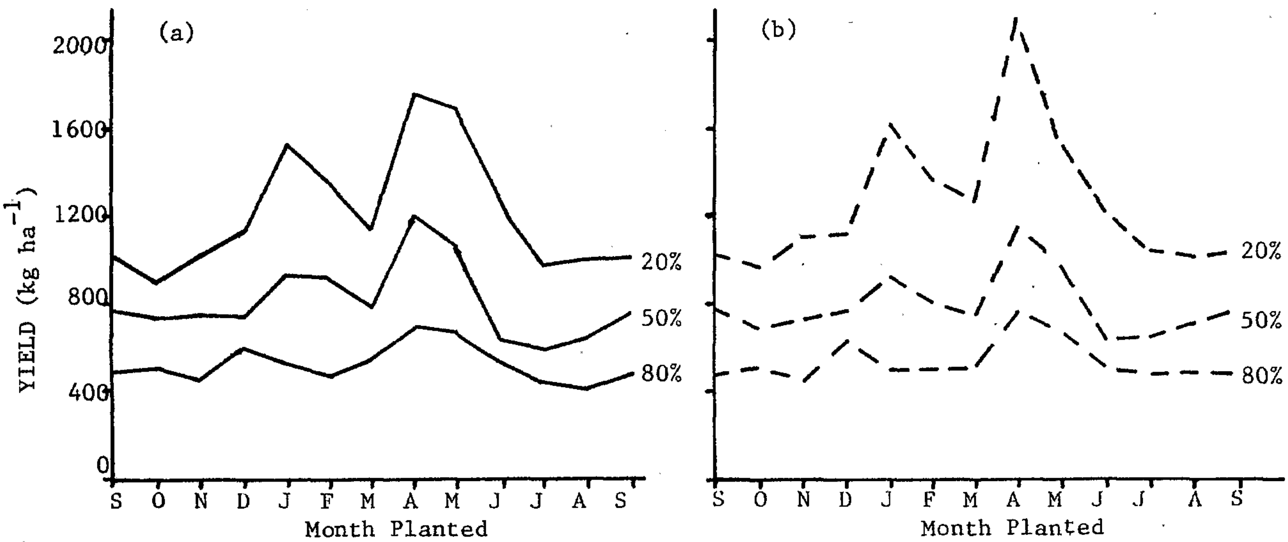


Figure 5. Number of days to major phenological events from various planting times.

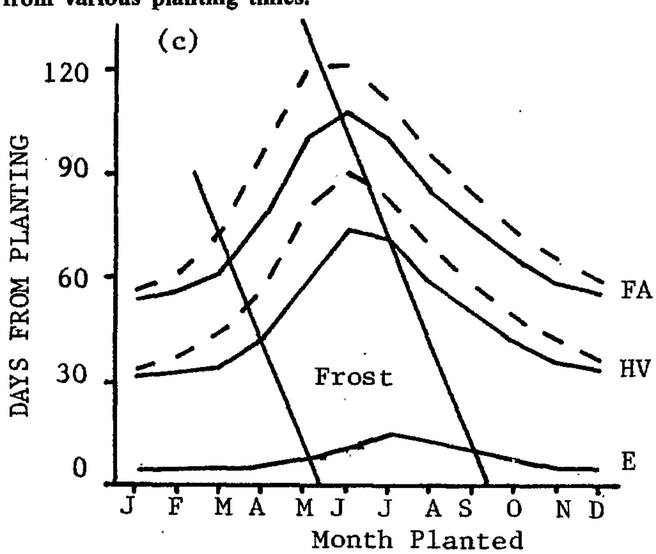
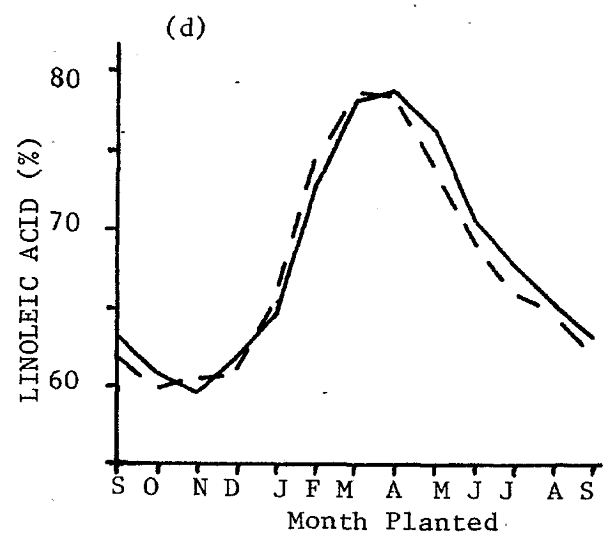


Figure 6. Simulated oil quality for various planting times.



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EFFECTS OF EARLY SPRING PLANTING OF SUNFLOWER ON YIELD IN IRAQ.

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ABSTRACT

Six fortnightly plantings of sunflower (cv. Peredovik), commencing from the first February were done in northern Iraq under rainfed and irrigated conditions, and in central Iraq under irrigation. In all the three situations the earliest planting gave the highest yield, and the last planting the lowest. The decline in yield was the most drastic in central Iraq under irrigation. Cultivation of sunflower in the north with supplementary irrigation and early February planting is recommended. Association between seed yield and other yield-determining traits was studied through correlation and path coefficient analyses. Yield was found to be differently structured under the three situations. Seed number per head, 100 seed weight and degree of empty seededness were the predominant yield determinants respectively in the north-irrigated, central-irrigated and north-rainfed situations. Based on these relationships certain crop management practices to optimize yield are suggested.

INTRODUCTION

To augment domestic supply of vegetable oils sunflower cultivation has recently been introduced in Iraq. Because of high summer temperatures and low winter rains, spring planting is considered the most feasible. This study was undertaken to find out the optimum spring planting time as an irrigated crop in central Iraq and rainfed crop in the north with and without supplementary irrigation.

MATERIALS AND METHODS

Sunflower cv. Peredovik was planted at 15 day intervals commencing from 1st February, at two locations, Baghdad (Central Iraq-irrigated, hereinafter referred to as CIR), Nineveh (North Iraq-irrigated, NIR) and also rainfed (NRF), in randomized block layouts with 4 replications. The net plot size was 13.3 m^2, the plants were spaced 0.25 m within rows which were 10 m long and 0.7 m apart. In CIR and NIR irrigation was *ad libitum.* Seed yields were estimated on plot mean basis, and single plant seed yield and other traits on the means of five randomly selected plants. The data were subjected to conventional analyses of variance, covariance leading to regression —, correlation — and path correlation coefficient estimates. The data on extent of empty seededness (ESN) were estimated as percentages and subjected to angular transformation before analysis.

RESULTS

In Table 1 are presented some climatological features of the two experimental locations that could be considered typical for their respective regions. The mean seed yields obtained at the different planting dates, under the three situations are given in Table 2. The overall mean yields recorded, viz. 1.8, 2.3 and 1.0 tonnes ha^{-1} respectively for CIR, NIR and NRF, indicate the relative potential for sunflower production in Iraq. Considering the individual planting dates, the first planting on 1st February failed in NIR and NRF due to slow and poor germination and stand, probably due to low temperatures and also to bird damage. There was a decline in seed yield with later plantings in February, March and April in all the three situations. The highest yields were obtained from the first planting in CIR and from the second NIR and NRF, and the lowest from the last planting in all of them. The steepness of this decline could be assessed by the regression equations given at the bottom of Table 2. The linear and quadratic components of the regression were all negative in sign, only the linear ones being significant. Planting on 15 April brought about 72% reduction in yield over the first planting in CIR,while in NRF it was 61%. The corresponding figure for the NIR was only 44%.