Using a model to quantify climatic risk to dryland sunflower production

H. Meinke[1], G.L. Hammer[1] and S.C. Chapman[2]

[1] QDPI/CSIRO Agricultural Production Systems Research Unit, PO Box 102, Toowoomba QLD 4350
[2] Present address: Maize Program, CIMMYT, Apartado Postal 6-641, 06600, Mexico D.F., Mexico

Summary. A crop simulation model for dryland sunflower (QSUN) was used to simulate production likelihood and, hence, quantify climatic risk to production for Dalby, Queensland. This was achieved by simulating fortnightly plantings throughout the year for one soil profile with a plant available water holding capacity of 180 mm either full or half full at planting and three maturity types. Median yield likelihoods differed little with time of planting. However, in the highest-yielding 25% of years, the higher yield potential associated with late summer plantings was expressed if a full profile of moisture was available at planting. Yields were lower and stable with planting time at the 25, 50 and 75% probability levels when a half-full profile of moisture was available at planting. There was no clear advantage for any maturity type. Both, early and late types outyielded the standard in some years and performed below the standard in other years. By extending this approach to other locations and soil conditions a database on production risk has been generated for use in a decision support system (5).

Introduction

To assist farmers in decision making, production risk has to be quantified. In highly variable environments, like those in north-east Australia, producers' experiences can be insufficient to adequately sample the climatic variability (7). Thus, in many instances, quantifying production risk can be achieved only through simulation studies using crop models in conjunction with long-term climatic records. In the mostly water-limited environments of north-east Australia, production likelihood depends on the amount of soil water stored in the profile at planting, total water holding capacity of that profile, rainfall during crop growth and maturity type chosen. Farmers can measure soil water, but are faced with uncertain future rainfall when deciding whether to plant, which crop to plant and which maturity type to choose. Knowing the production risk for alternative options will help farmers to make better informed decisions. In this study our aim was to quantify the production risk for dryland sunflower.

Methods

Model description and simulations

One soil profile (180 mm plant available water holding capacity), two starting conditions (full and half full at planting) and three maturity types (early, E; medium, M; and late, L) were considered in this study. We employed the dynamic sunflower model QSUN (1) to simulate sunflower yields for the 96 seasons of available daily climate data for Dalby.

The model requires daily inputs of solar radiation, maximum and minimum temperatures and rainfall. Yield is simulated *as* a function of total biomass and harvest index (9). Total aboveground biomass is calculated by accumulating daily crop growth increments. Daily growth is determined from radiation intercepted and the efficiency with which this radiation is converted into biomass or from water transpired and transpiration efficiency, depending on whether light or water is limiting crop growth. Total plant leaf area is described by a logistic function of thermal time from emergence to anthesis. Phenology routines, including parameter values for rate of development, are identical to those described by (3) for a photoperiod sensitive cultivar. At this stage the model does not account for pest and diseases or crop nutritional effects. Hence, in the simulation analysis it is assumed that these factors are non-limiting. Cultivars of type E, M and L differed in their time to reaching physiological maturity by four to nine days, depending upon planting date. This was achieved by increasing or decreasing the rate of development between emergence and head visible by 14% for type E and type L respectively.

The effect of frost at flowering is included in the phenology routine (6). If the daily minimum temperature drops to 0?C or below when stage of development is between 2.5 and 3.2 (i.e., immediately before and after 50% anthesis), then the model halts at that point. The importance of the function is to flag planting times at which frost risk is substantial, rather than to quantify the effect.

Data analysis

Simulated yields were sorted into ascending order, and the cumulative distribution functions (CDF) associated with each combination of location, maturity class, soil moisture condition and planting date calculated. These CDFs quantify production risk for each combination and are used to compare risk among these combinations. To simplify presentation, only the 25, 50 and 75 percentiles are presented.

Yield difference of the earlier or later cultivar relative to the standard were calculated for each year in order to examine the probability of a yield gain or loss due to differences in maturity type (8). The yield differences were ranked in ascending order, and CDFs calculated.

Results and discussion

At Dalby, a mid-February planting is recommended as an optimum planting date (2). The year- to-year variability in simulated yields for such a planting date reflects the high variability in rainfall (Fig. 1). Average yield for the 96 seasons was 129 g/m^2, and median yield 104 g/m2.

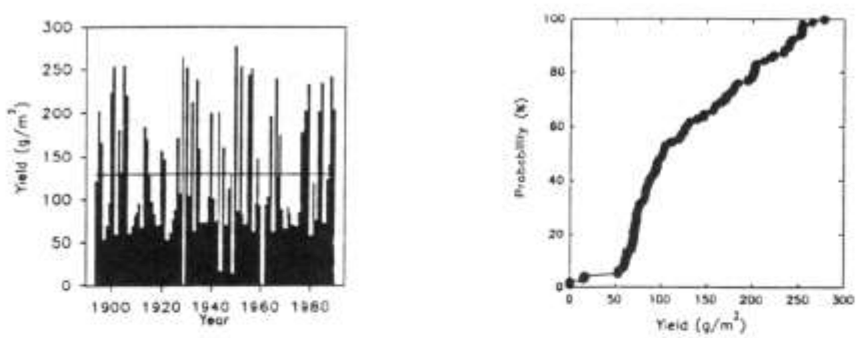

Figure 1. Simulated yields at Dalby (96 seasons) for a 15 February planting date (solid line represents the average yield) and the CDF calculated from this data.

Time of sowing and soil moisture stored at sowing affected yield likelihoods (Fig. 2). For the full soil profile the highest median yield was 108 g/m^2 for a 15 January sowing, and the lowest median yield 91 g/m^2 for a 1 February sowing. Median yields throughout the year (excluding frost periods) were fairly constant, but the variability (i.e., the differences between the 25 and the 75 percentile) changed substantially with time of sowing. For winter sowings (1 June to 15 August) the model predicted a 25% chance of exceeding a yield of 150 g/m^2 and, although the median yields remained similar, the 25% exceedence levels dropped sharply with spring sowings (1 September to 15 November). Mid to late summer sowings resulted in a strong increase in the 25% exceedence levels, until the time of potential frost damage was reached. For a 15 February sowing, 25% of years exceeded a yield of 190 g/m^2 (Figs 1 and 2). This coincides with the period of high yield potential when water is not limiting (data not presented). At this time, there is a favourable balance between temperature and radiation. Lower temperature extends crop duration and, although radiation levels are decreasing, the greater duration has the dominating effect. Hence, yield potential is high in those years with adequate moisture to allow its expression.

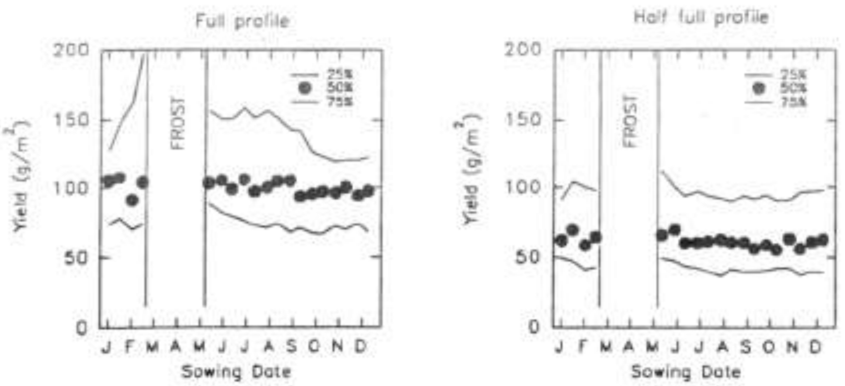

Figure 2. 25%, 50% and 75% probability of exceedence levels for all sowing dates and two starting soil moisture conditions (full and half full) at planting.

Reduced soil moisture at sowing changed those seasonal patterns (Fig. 2). Median yields for the half full profile were around 60 to 70 g/m^2, 75% probability levels at around 50 g/m^2 and 25% levels at around 100 g/m^2 throughout the year. This shows, that unless good soil moisture conditions prevail at planting, high yields cannot be expected even when planting at the times of high yield potential. Soil moisture at planting can only be manipulated to a small extent by management practises but can easily be monitored. Thus, without any prior knowledge of future rainfalls, the decision on whether or not to plant on a given amount of stored soil moisture will depend on the manager's attitude to risk.

To compare yield performance of different maturity types, cumulative probability functions of the yield difference each year between maturity types must be calculated (8). We only considered differences if they were greater than 5 g/m^2. For a 15 February sowing on a full profile, maturity type E yielded lower (i.e., positive yield difference) than the standard in 48% of years and higher than the standard in 30% of years (Fig. 3). Type L yielded lower in 30% and higher in 45% of years. There was an increase in frost risk with type L, which resulted in some highly positive yield differences with the standard. This effect removed most of the potential advantage associated with later maturity.

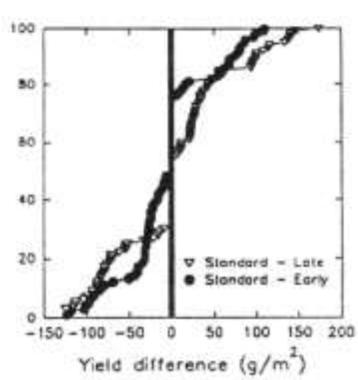

Figure 3. Cumulative probability distributions of yearly yield difference between early and late cultivars compared to the standard cultivar.

We found no clear advantage or disadvantage in all years from a given phenology type. However, the choice of maturity type, although on average of little importance for the soil profile types evaluated, could be a most valuable strategic tool if some degree of prior knowledge about future rainfall probabilities was available. Latest research on climatic indicators for long-term rainfall forecasting, such as the southern oscillation index (SOI), suggests that improved predictions will become available for some regions in the near future (10). The economic value of such forecasting tools in strategic decision making has been demonstrated for other crops (4).

By extending this approach of quantifying production risk to other locations and soil conditions, a database on production risk has been generated. This database is used in a decision support system aimed at assisting decisions on crop and cultivar choice at a given planting opportunity (5).

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