Table 2. Soil Moisture (% by mass) at the End of Sunflower Vegetation Period.

Irrigation Treatments	Year	soil depth, cm 0 — 10	10 — 20	20 — 40	40 — 60	60 — 80	80 — 100	100 — 120	120 — 140	140 — 160	160 — 180	180 — 200
Irrigated at 70% of FWC	1976	24.6	26.2	25.8	20.9	24.1	16.6	18.0	18.2	17.0	12.1	13.0
	1977	21.9	21.9	20.9	21.9	20.9	19.7	18.3	17.2	16.2	14.1	11.0
	1978	24.5	24.9	24.5	23.5	20.9	18.4	17.7	17.4	17.1	13.5	14.0
	Average	23.6	24.3	23.8	22.1	22.0	18.3	18.0	17.6	16.8	13.1	12.7
Irrigated at 60% of FWC	1976	21.9	24.8	24.4	21.1	22.5	17.6	18.0	17.7	18.1	14.3	10.5
	1977	20.8	20.8	19.9	21.6	18.5	15.8	16.7	17.9	14.9	14.7	15.7
	1978	24.4	24.8	24.7	22.9	19.6	16.7	16.5	16.3	16.4	12.4	12.5
	Average	22.4	23.5	22.9	21.7	20.2	16.7	17.1	17.3	16.5	13.8	12.9
Irrigated according to the Critical Phases	1976	17.6	25.7	23.6	15.4	14.3	20.0	13.2	15.4	13.0	12.7	10.1
	1977	19.5	19.5	23.7	23.8	24.5	22.7	19.4	17.4	16.9	14.8	12.5
	1978	23.7	24.4	22.7	19.3	19.0	18.0	17.9	16.7	17.4	17.4	12.9
	Average	20.0	23.2	23.3	19.4	19.3	20.3	16.6	16.4	15.8	15.0	12.0
Check — non Irrigated	1976	17.9	23.4	17.4	16.5	13.2	12.4	12.9	12.7	13.9	11.7	11.5
	1977	19.8	19.8	18.1	16.5	16.4	15.6	12.5	12.5	13.1	13.8	13.5
	1978	23.5	23.0	18.1	16.3	15.9	13.7	13.1	14.3	15.5	15.7	17.9
	Average	20.4	21.1	17.9	16.4	15.2	13.9	12.8	13.2	14.2	13.7	14.3
Field Water Capacity		26.7	26.7	26.7	26.2	24.8	24.8	24.8	23.1	23.1	23.1	20.7
Wilting Moisture		10.9	10.9	10.9	11.2	11.3	11.3	11.3	8.7	8.7	8.7	8.9
Lentocapillary Moist. (all % by mass)		15.6	15.6	15.6	16.8	17.1	17.1	17.1	12.0	12.0	12.0	12.7

CONCLUSION

Sunflower grown without irrigation takes up considerable quantities of reserve water from deeper soil layers. On calcareous chernozem on loess terrace in Yugoslavia, sunflower takes up 1,600 — 1,900 m^3 ha^{-1} of water from soil layers to the depth of two meters. This quantity amounts to one half of total water requirements of sunflower. The remaining portion is provided by rainfall during the growing season.

In conditions of irrigation, however, the sunflower root system is less active, taking only a half of the normally taken quantities of water (700 — 1,000 m^3 ha^{-1}, or even less than a half in some years.

This phenomenon bears both theoretical and practical importance because it affects the calculation of water balance and the irrigation practice. The phenomenon has been neglected until recently because the soil moisture extraction pattern of a certain crop had been considered immutable regardless of the variation in other factors.

T1982AGR25

INFLUENCE OF PLANT POPULATION ON PHASIC DEVELOPMENT, GROWTH, YIELD AND WATER USE OF IRRIGATED SUNFLOWER IN A SEMI-ARID ENVIRONMENT.

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ABSTRACT

Sunflowers are an established irrigated crop in Australia but recommendations for optimum plant population are widely divergent. To assist in clarification, populations of 50, 80, 110 and 140 thousand plants ha^{-1} were grown in hilled rows 75 cm apart. Soil type was a heavy grey clay (60% clay). Furrow irrigation was applied at an interval of 70 mm of estimated evapotranspiration. Irrigation water was metered onto the plots and a water balance approach was used to calculate water use. Crop development, ground cover and plant height development with time, seed yield, yield components, total dry matter production and oil content were also measured. Population had no effect on phasic development with bud appearance, peak flowering and physiological maturity occurring 35, 55 and 89 days after emergence, respectively. There was a significant difference in percent ground cover at 19 and 26 days after emergence but all populations achieved a similar ground cover by day 35 (80%). Seed yield was significantly highest from 50 and 80 thousand plants ha^{-1} but differences between populations would be of little practical significance. The data presented indicate the ability of the sunflower plant to compensate for large differences in plant numbers. Water use at 695 mm was not greatly influenced by population, and represented 85% of pan evaporation.

INTRODUCTION

Sunflowers (*Helianthus annuus*) are an established irrigated summer crop in Australia but recommendations for optimum plant population under irrigation are widely divergent. Schuppan and Thomas (1976) recommend a plant population of 100,000 plants ha^{-1} for northern Victoria, while 60,000 plants ha^{-1} (Matheson, 1976) and 100 — 110,000 plants ha^{-1} (Anon. 1972) are both recommended for New South Wales.

This paper reports an experiment conducted to examine the influence of plant population on phasic development, growth, yield and water use of sunflowers in the semi-arid environment of southern New South Wales.

MATERIALS AND METHODS

The experimental site was on the Leeton Agricultural Research Station (lat. 34°28'S, long. 146°25'E) in the Murrumbidgee Irrigation Area. The soil type was a grey, texturally undifferentiated heavy clay soil (van Dijk, 1961) with an available water content of the top 120 cm of 185 mm. As hydraulic conductivity of the subsoil is low, drainage beyond the root zone would have been minimal. There was no effective water table.

During the period of growth, rainfall was 133 mm, evaporation (U.S. Class A pan) averaged 8.5 mm per day, mean maximum temperature was 31°C and mean minimum temperature was 17°C. All components were average except minimum temperature which was 1.6°C above the long-term mean.

The experiment was set out in a randomised block design with four replications. The cultivar VNIIMK 6540 was grown in hilled rows 75 cm apart and plant populations of 50, 80, 110 and 140 thousand plants ha^{-1} were achieved by sowing excess seed and hand-thinning the seedlings. Plot size was 6 m x 15 m with each plot being surrounded by a bank and isolated from neighbouring plots by a border ditch.

Prior to sowing, fertilizer was banded at the base of the hill at rates of 45 kg ha^{-1} of P as superphosphate, 150 kg ha^{-1} of N as sulphate of ammonia and 30 kg ha^{-1} of K as potassium chloride. Weeds were controlled with trifluralin and insect pests were not a problem.

Germination was initiated with an irrigation on November 20, 1975 and an irrigation interval of 70 mm of estimated evapotranspiration was employed from emergence to physiological maturity. Physiological maturity was determined by the floret abscission method of Browne (1978). With three exceptions, at any particular irrigation all plots received the same quantity of water; the amount applied was judged by previous experience so as to produce no significant ponding after 24 hours. For the irrigations 42, 72 and 82 days after emergence the two highest populations received an additional 4 mm of water. It was necessary to allow some short-term ponding because of the low infiltration rate of the soil. Irrigation water was applied via a pipeline and measured to each plot through a flow meter. There was no surface drainage.

To estimate evapotranspiration, daily evaporation (on — site U.S. Class A pan) was mutiplied by a crop coefficient. A crop coefficient of 0.5 was used from emergence to the attainment of 50% ground cover and then 1.0 until the cessation of irrigation (ground cover reached 50% 27 days after emergence).

Percent ground cover was recorded three times during the period of vegetative growth using the line quadrat method described by Cackett (1964). Plant height was recorded on two occasions including flowering when height would have been maximal. A count of the number of harvestable plants was made at physiological maturity.

Phasic development was measured three times a week at bud appearance, flowering and physiological maturity. At each recording the same 20 consecutive plants from one of the middle rows were recorded and the result expressed on a percentage basis. In this way the time of peak and/or 50% development could be determined.

Core samples to determine soil stored moisture were taken at emergence and again at physiological maturity to a depth of 200 cm. A thin-walled sampling tube was used to take one core per plot. Total water use (W) was estimated using the water balance equation:

$$W = 1 + R + (S1 - S2).$$

Irrigation (I) and rainfall (R) were measured directly and S1 and S2 represent soil stored moisture at emergence and physiological maturity, respectively.

Seed yield was determined by hand-harvesting the central 20 m^2 of each plot. The heads were individually threshed and seed samples were cleaned of trash and unfilled seeds using a small commercial seed cleaner. Individual seed weight (g 1000^{-1}) was determined from these samples and this allowed seed number per head and the number of harvestable seeds m^{-2} to be calculated. Prior to threshing the diameters of all heads were measured. Dry matter production at physiological maturity was assessed by separating 10 plants per plot into leaf, stem and head. Seed samples from each plot were analysed for oil content by wide-line nuclear magnetic resonance using a method similar to that of Collins *et al.*, (1967).

All data are expressed on a dry weight basis.

RESULTS

Actual plant populations at havest time were 50, 78, 109 and 133 thousand plants ha^{-1} indicating only slight plant mortality during the growing season.

Per cent ground cover increased rapidly with all plant populations achieving maximum cover by bud appearance (35 days after emergence). Plant population had a significant ($P < 0.05$) effect when measured 19 and 26 days after emergence but not at 35 days. At this time ground cover had reached 80% and represented a leaf area index of approximately 4.0 (J.A. Thompson, unpublished data).

Table 1. The effect of plant population on seed yield, yield components and oil content.

Population (plants ha^{-1})	Seed yield	Individual seed weight	Seeds/ head	No. harvestable seeds	Head area/ plant	Oil content
	t ha^{-1}	g 1000^{-1}	no.	no. m^{-2}	cm^2	%
50,000	3650	61.0	1200	6000	188	46.6
80,000	3430	48.3	888	7090	125	46.9
110,000	3210	40.2	727	8010	93	45.7
140,000	3290	40.1	586	8220	79	47.3
P	<0.01	<0.001	<0.01	<0.01	<0.001	n.s.

Table 2. The effect of plant population on dry matter production, harvest index and head area index.

Population (plants ha^{-1})	Total dry matter	Leaf dry matter	Stem dry matter	Head dry matter	Harvest index	Head area index
	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}		
50,000	10.2	1.95	3.04	5.2	0.35	0.097
80,000	10.8	1.76	3.56	5.5	0.32	0.099
110,000	13.8	1.66	4.57	7.5	0.23	0.102
140,000	14.4	1.55	5.17	7.5	0.23	0.110
P	<0.01	n.s.	<0.001	<0.001	<0.001	<0.001

There was no difference in plant height 26 days after emergence when mean plant height had reached 60 cm. At flowering, plants at 80 and 110,000 plants ha^{-1} were significantly ($P < 0.05$) taller than plants at either 50 or 140,000 plants ha^{-1} — 198 and 200 cm vs 185 and 188 cm.

Thrice weekly monitoring of phasic development did not disclose any significant effect of plant population on time of bud appearance, flowering or physiological maturity. These events occurred 35, 55 and 89 days after emergence, respectively.

Total dry matter production increased significantly with increase in plant populations (Table 2). Leaf weight varied little but stem weight and head weight both increased significantly ($P < 0.001$) as plant population increased.

Seed yield from 50 and 80,000 plants ha^{-1} was marginally but significantly ($P < 0.05$) higher than from 110 and 140,000 plants ha^{-1} (Table 1). As plant population increased individual seed weight, number of seeds per head and head area per plant decreased ($P < 0.001$) and the number of harvestable seeds per m^2 increased (Table 1).

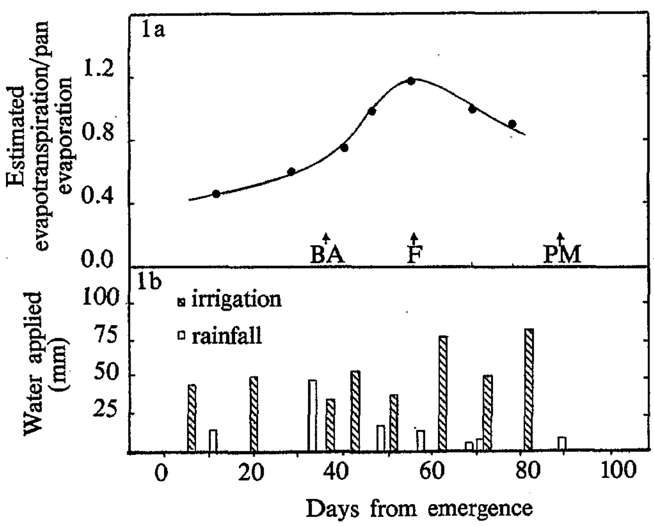
Harvest index fell with increased population ($P < 0.001$) and at plant populations of 110 and 140,000 plants ha^{-1} was reduced to 0.23 (Table 2). Values for head area index (the area of sunflower face per unit area of ground surface area also shown in Table 2. All treatments had a head area index of approximately 0.1.

Oil content of the seed was not effected by plant population (Table 1).

Quantities of water applied as irrigation or as effective rainfall (>5 mm) are shown in figure 1b. Water use from emergence to physiological maturity averaged 695 mm, was not effected by plant population and represented 85% of Class A pan evaporation for the same period.

An estimate of evapotranspiration during a period can be made by measuring the amount of water required to bring the soil back to its initial moisture content (Downey, 1971). When this is plotted as a fraction of the Class A pan evaporation, the curve shown in Figure 1a is obtained. Peak demand coincided with the flowering period.

Figure 1a. Ratio of estimated evapotranspiration over pan evaporation. BA = bud appearance, F = peak flowering, PM physiological maturity. 1b. Time and quantity of water applied.



DISCUSSION

In this experiment seed yield varied only marginally over the wide range of populations studied. The data presented indicate that the ability of the sunflower plant to compensat allowed it to adjust to differing plant populations. Individual seed weight (g $1,000^{-1}$), seed number per head, number of harvestable seeds per m^2 and head area all adjusted with change in plant population to produce practically identical seed yields. The highest value for harvest index was 0.35. A harvest index as high as 0.53 has been recorded with other species grown under similar conditions (maize, grain sorghum, J.A. Thompson, unpublished data). Even within currently available cultivars of sunflowers there is variation in harvest index which may be useful to plant breeders. Donald and Hamblin (1977) discuss several ways that harvest index could be used in cereal plant breeding, and these could well be applied to sunflowers.

That oil content was not influenced by plant population can probably be ascribed to adequate irrigation which prevented any significant moisture stress during seed development.

Under the well irrigated conditions of this experiment plant population had little effect on yield. However, where significant moisture stress is allowed to develop seed yield at high populations can be substantially reduced (J.A. Thompson, unpublished data). This response is also evident in many commercial crops.

Values for the ratio of estimated evapotranspiration over pan evaporation reached 1.2 (Figure 1a). This is higher than reported for most crop species but Anderson (1979) and Rollier (1975) have obtained similar values for sunflowers. This high ratio together with the sensitivity of sunflower to moisture stress during flowering (Rollier, 1975) highlights the importance of good irrigation management during this period.

ACKNOWLEDGEMENTS

I would like to thank Mr. R. Wandel for technical assistance and Mr. A. Gunn for providing oil analyses.

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