

Physiological Determinants of Potential Yield of Sunflower

Michael BANGE, Greame HAMMER and Ken RICKERT
Cotton Research Unit, Locked Bag 59 Narrabri NSW 2390 (Australia)

Abstract

Three field experiments were conducted from 1991-1994 in Queensland Australia to investigate effects of temperature, applied nitrogen, and incident radiation on the components of potential yield.

Low temperature reduced harvest index (HI) grain yield, biomass assimilation, and translocation. Biomass accumulation was affected by the pattern of leaf area development through effects on light interception. Leaf area index (LAI) changed with duration of phenological phases, but the phyllochron interval was stable across experiments. Temperature, radiation, and nitrogen levels did not affect the light extinction coefficient.

Increasing nitrogen supply increased final biomass, grain yield, LAI, and radiation use efficiency (RUE), but not HI. Differences in RUE were related to the level of specific leaf nitrogen (SLN g N/m²), and were explained by the effects of SLN on potential photosynthesis. Relating RUE to SLN was confounded by distribution of nitrogen in the canopy, and by the ability of the crop to compensate for low nitrogen conditions by reducing LAI.

Lower incident radiation levels (15% less) increased RUE but not LAI and final total biomass. This demonstrated that a relatively small decrease in direct radiation, coupled with an increase in the diffuse proportion of radiation, enabled the crop to utilise radiation more efficiently.

Key Words: Growth, Development, Harvest-Index, Radiation-Use-Efficiency

Introduction

Yield of sunflower is highly dependant on environmental conditions during the life of the crop. The physiological determinants of yield (Equation 1) provide a useful framework to investigate and understand environmental effects on yield. This framework defines yield using five key variables:

$$YIELD = \left(\sum_{i=1}^n Q_i \cdot I_i \cdot \epsilon_i \right) \cdot HI \quad (1)$$

where n is the crop duration in days, Q_i is the incident radiation on day i , I_i is the proportion of radiation intercepted on day i , which is dependant on leaf area index and the canopy extinction coefficient, ϵ_i is the efficiency of conversion of radiation into biomass on day i , and HI is the harvest index.

Many studies have investigated these physiological determinants for sunflower and there have been attempts to integrate this physiological understanding into crop simulation models (Chapman et al., 1993a; Steer et al., 1993). While they have been relatively successful, and have provided tools

suitable for use in crop management decision making (Meinke et al., 1993), they have also exposed some deficiencies in understanding. These deficiencies relate particularly to environmental effects on biomass accumulation and its partitioning to grain. The aim of this study was to enhance understanding of biomass accumulation and partitioning by quantifying the physiological determinants of crop growth and yield of sunflower in different environments generated by changing planting dates, nitrogen and incident radiation regimes.

Materials and Methods

Three field experiments were conducted from 1991-94 in south-east Queensland Australia (27° 33' S; 152° 17' E) a sub-tropical region, on an alluvial-prairie soil (USDA Soil Taxonomy: Fluventic Haplustoll). The first experiment (Exp 1) had Ag Seed genotype Suncross 41 ® (Sun 41) sown on 13 September 1991 (S1) and 5 March 1992 (S2). A second experiment (Exp 2), sown 15 January 1993 again with Sun 41 incorporated five nitrogen treatments (Table 1). The third experiment (Exp 3) sown 3 December 1993 with Sun 41 incorporated three radiation treatments where treatment 1 was a control treatment which was exposed to full incident radiation, while treatments 2 and 3 were shaded treatments receiving 86.0% and 79.7% of incident radiation respectively.

A population of 70 000 plants per hectare in all experiments was established using conventional row crop seed bed preparation. Fertilisers were applied immediately after planting, and irrigation was applied with overhead sprinklers weekly in amounts ensuring water was non-limiting. Plots were maintained so that weed and pest influences were minimal.

Daily maximum and minimum temperatures, and solar radiation were measured throughout the experimental periods at a fully serviced climate station adjacent to the site, and are summarised in Table 2. Further cultural and experimental details are reported in Bange (1995).

Results and Discussion

Phasic Development

In this study, temperature was the major influence on rate of crop development, while, the level of applied nitrogen, and possibly, photoperiod had smaller influences. The changed radiation environment had no effect on development (Table 3).

The duration from sowing to emergence in well prepared seedbeds was similar across experiments (Table 3). While the duration from emergence to bud visible phase was not affected by the level of applied nitrogen in Exp 2, nor by radiation in Exp 3, it was affected by sowing time in Exp 1. However, across experiments there appeared to be no consistent pattern to thermal duration for Sun 41 (Table 3), suggesting that development may have been affected by photoperiod, or by photoperiod temperature interactions (Goynes and Hammer, 1982). Similarly, there was no consistent response for thermal duration across experiments for bud visible to anthesis, a phase that may also respond to photoperiod, temperature, and nitrogen deficiencies (Connor and Sadras, 1992).

Duration of anthesis to physiological maturity was slightly delayed in low nitrogen treatments, and there was no consistent relationship across experiments (Table 3). In sowing 2 Exp 1, the effect of minimum temperature may have caused the cessation of grain-filling by limiting both biomass assimilation and translocation (Paul et al., 1990; Kursanov, 1984) reflected in the lower grain size and final harvest index (Table 4). While physiological maturity is influenced by temperature, it may also be dependant on source/sink relationships, which dominate the normal effects of temperature on phenology. Further research is needed to support these hypotheses.

Grain Yield and Components

Over all experiments, grain yield ranged from 6.02 to 2.16 t/ha (Table 4), and was affected by time of sowing, application of N fertiliser, and incident radiation. Grain yield was dependent on grain number per inflorescence in Exp 2, grain size in Exp 3, and both grain number and size in Exp 1.

Another major factor in the determination of economic yield, is the concentration of oil in the grain, which is affected by a number of complex factors. Across experiments, oil to protein ratios decreased as average temperature during grain-filling increased (with the exception of Exp S1) in a similar way to that found by Canvin (1965). The higher oil to protein ratio in this sowing was because of a lower crude protein level, which may have resulted from the increased demand for nitrogen, driven by the large grain number.

Leaf Area

LAI across experiments at anthesis ranged from 7.2 to 2.4, and varied in response to N applications and sowing time (Table 5). In general, higher LAI was associated with higher biomass accumulation and final grain yield, but this was not always the case. For example, in sowing 2 of Exp 1, low biomass accumulation, caused by cold temperatures and low radiation levels during grain-filling, was not compensated by the relatively high LAI compared with other treatments and experiments.

Differences in LAI across experiments were not due to differences in leaf number, but to differences in the individual sizes of leaves, which was related to how quickly a leaf was initiated, and the duration of leaf expansion. Phyllochron interval (Thermal units for the E-BV phase divided by the final leaf number) was relatively constant across experiments, and similar to that recorded by Chapman et al., 1993b) (Table 5).

Duration of the phenological phase (BV-A) was inversely related to average temperature during BV-A. Cooler conditions during this phase in S1 of Exp 1 allowed more time for leaf expansion, which contributed to this sowing's greater LAI.

Light Interception

The canopy light extinction coefficient (k) varied by 0.05 across experiments but did not change with level of applied nitrogen, or radiation environment (Mean Exp

1 0.84; Exp 2 0.88; and Exp 3 0.89). Also, the relationships between instantaneous extinction coefficient (k') and LAI were similar across experiments, but different to the coefficients derived by Zaffaroni and Schneiter (1989). Rawson et al. (1984) found differences in this relationship and proposed that these differences were associated with the radiation environment at the time of growth. Nevertheless, the association between k' and LAI demonstrated that as LAI increased, canopy geometry changed to allow better penetration of light into the canopy. However, even at high LAI, k' remained high indicating that the majority of light was probably intercepted at the top of the crop canopy. A generalised relationship for Sun 41 was derived (Equation 2):

$$k' = 3.78 \cdot LAI^{-0.83} \quad (2) \quad (R^2 = 0.97)$$

Radiation Use Efficiency

Radiation Use Efficiency (RUE) was a major determinant of biomass accumulation and crop yield. Contrary to earlier work by Monteith (1977), who claimed that RUE was constant across environments, this study showed that RUE varied with, temperature, level of applied nitrogen and radiation environment. Crop RUE varied from 1.25 to 1.62 g/MJ across experiments, being greater than the RUE of 1.05 g/MJ (Kiniry et al., 1989; Zaffaroni and Schneiter, 1989; Whitfield et al., 1989) (Table 4).

Changes in the level of specific leaf nitrogen (SLN g N/m² of green leaf area) explained changes in RUE as crop development proceeded, but this was confounded by the distribution of SLN within the canopy and by the ability of the crop to compensate for low nitrogen conditions by reducing LAI. Also, RUE increased as direct radiation decreased and diffuse radiation increased. Similar findings have been found and shown theoretically for peanuts (Hammer and Wright, 1994).

Conclusion

A major outcome of this study shows that relatively few determinants of potential sunflower yield are stable across environments. It is therefore necessary that in developing crop simulation models that these determinants be derived for a range of environments, and caution taken when using these models in other environments from which they are developed.

References

- Bange, M.P. (1995). Ph.D. Thesis, The University of Queensland, Brisbane.
 Canvin, D.T., 1965. *Can. J. Bot.*, **43**: 63-69.
 Chapman, S.C., Hammer, G.L., and Meinke, H., 1993a. *Agron. J.*, **85**: 725-735.
 Chapman, S.C., Hammer, G.L., and Palta-Paz, J., 1993b. *Field Crop Res.*, **20**: 251-263.
 Connor, D.J. and Sadras, V.O., 1992. *Field Crops Res.*, **30**: 333-389.
 Goyne, P.J. and Hammer, G.L., 1982. *Aust. J. Agric. Res.*, **33**: 251-261.
 Hammer, G.L. and Wright, G.C., 1994. *Aust. J. Agric. Res.*, **45**: 575-589.
 Kiniry, J.R., Jones, C.A., O'Toole, J.C., Blanchet, R., Cabelguenne, M., and

Spanel, D.A., 1989. *Field Crops Res.*, 20: 51-64.
 Kursanov, A.L., 1984. *Assimilate Transport in Plants*. Elsevier, Amsterdam.
 Meinke, H., Hammer, G.L., and Chapman, S.C., 1993. *Agron. J.*, 85: 735-742.
 Monteith, J.L., 1977. *Phil. Trans. Royal. Soc., Series B*, 281: 277-294.
 Paul, M.J., Lawlor, D.W. and Driscoll, S.P., 1990. *J. Exper. Bot.*, 41: 547-555.
 Rawson, H.M., Dunstone, R.L., Long, M.J., and Begg, J.E., 1984. *Aust. J. Plant. Physiol.*, 11: 255-265.
 Steer, B.T., Milroy, S.P. and Kamona, R.M., 1993. *Field Crops Res.* 32: 83-99.
 Whitfield, D.M., Connor, D.J., and Hall, A.J., 1989. *Field Crops Res.*, 20: 65-80.
 Zaffaroni, E. and Schneiter, A.A., 1989. *Agron. J.*, 81: 831-836.

Table 1. Timing (days after sowing - DAS) and amount of nitrogen applied (kg/ha) for the five treatments in Exp 2.

| DAS | Treatment and Nitrogen Applied (kg/ha) | | | | |
|-----|--|----|----|-----|-----|
| | 1 | 2 | 3 | 4 | 5 |
| 0 | 10 | 10 | 40 | 120 | 180 |
| 30 | - | - | - | - | 60 |
| 50 | - | - | - | - | 60 |
| 70 | - | 60 | - | - | 60 |

Table 2. Average temperature and incident radiation values for all experiment/treatment combinations (S - sowing date and R - incident radiation level (MJ/m²/day)). S-E is sowing to emergence; E-BV is emergence to bud visible; BV-A is bud visible to anthesis; and A-PM is anthesis to physiological maturity.

| | S-E | | E-BV | | BV-A | | A-PM | |
|----------|------|------|------|------|------|------|------|------|
| | °C | R | °C | R | °C | R | °C | R |
| Exp 1/S1 | 17.9 | 18.1 | 21.7 | 18.4 | 24.1 | 22.1 | 24.8 | 21.6 |
| Exp/S2 | 22.6 | 20.8 | 22.9 | 18.4 | 19.4 | 14.2 | 14.6 | 13.8 |
| Exp 2 | 25.3 | 26.8 | 26.8 | 20.9 | 26.1 | 19 | 22.7 | 16.1 |
| Exp 3/R1 | 25.6 | 18.9 | 24.5 | 23.2 | 28.2 | 19.7 | 24.1 | 16.5 |
| Exp/R2 | 25.6 | 16.2 | 24.5 | 19.9 | 28.2 | 16.9 | 24.1 | 14.2 |
| Exp 3/R3 | 25.6 | 15.1 | 24.5 | 18.5 | 28.2 | 15.7 | 24.1 | 13.2 |

Table 3. Thermal durations ($^{\circ}\text{C d}$) of phenological phases for Sun 41 over all experiments and treatments (base temperatures from Chapman et al. (1993a)). Months in which treatments were sown are shown in brackets.

| Period | Experiment 1 Sowings | | Experiment 2 Treatment | | | | | Experiment 3 Treatment | | |
|--------|----------------------|---------|------------------------|--------|--------|---------|--------|------------------------|-------|-------|
| | 1 (Sep) | 2 (Mar) | 1 | 2 | 3 | 4 (Jan) | 5 | 1 (Dec) | 2 | 3 |
| S-E | 89.6 | 88.3 | 91.3 | 91.3 | 91.3 | 91.3 | 91.3 | 88.3 | 88.3 | 88.3 |
| E-BV | 553.1 | 489.4 | 524.7 | 524.7 | 524.7 | 524.7 | 524.7 | 466.6 | 466.6 | 466.6 |
| BV-A | 604.7 | 525.4 | 543.7 | 543.7 | 507.3 | 507.3 | 507.3 | 557.9 | 557.9 | 557.9 |
| A-PM | 1064.7 | 533.6 | 1034.6 | 1034.6 | 1004.2 | 1004.2 | 1004.2 | 938.3 | 938.3 | 938.3 |

Table 4. Grain yield and components for all experiments.

| Experiment | Grain Yield (t/ha) | Total Biomass (t/ha)* | RUE* (g/MJ) | Oil (%) | HI** | Crude Protein (%) | Grains per head | 1000 Grain Mass (g) |
|------------|--------------------|-----------------------|-------------|---------|------|-------------------|-----------------|---------------------|
| Exp 1 S1 | 6.02 | 24 | 1.47 | 50 | 0.4 | 15.7 | 2006 | 43.2 |
| Exp 1 S2 | 2.17 | 13 | 1.47 | 43 | 0.25 | 22.9 | 1265 | 24.3 |
| Exp 2 T1 | 2.71 | 10 | 1.20 | 27 | 0.4 | 11.7 | 1168 | 43.8 |
| Exp 2 T2 | 2.53 | 10 | 1.19 | 27 | 0.4 | 17.3 | 1301 | 43.8 |
| Exp 2 T3 | 3.45 | 11 | 1.24 | 27 | 0.4 | 13.5 | 1379 | 43.8 |
| Exp 2 T4 | 4.57 | 14 | 1.47 | 27 | 0.4 | 17.9 | 1850 | 43.8 |
| Exp 2 T5 | 3.34 | 12 | 1.25 | 27 | 0.4 | 20.8 | 1442 | 43.8 |
| Exp 3 T1 | 2.86 | 10 | 1.18 | 25 | 0.4 | 23.3 | 1108 | 39.0 |
| Exp 3 T2 | 2.16 | 10 | 1.34 | 25 | 0.29 | 23.3 | 1108 | 28.6 |
| Exp 3 T3 | 2.34 | 10 | 1.32 | 25 | 0.33 | 23.3 | 1108 | 29.8 |

* (RUE) Radiation Use Efficiency

* (HI) Harvest Index corrected for oil in grain.

Table 5. LAI, leaf number, phyllochron interval and duration of BV-A.

| Variable | Experiment 1 Sowings | | Experiment 2 Treatment | | | | | Experiment 3 Treatment | | |
|--------------------------------------|----------------------|------|------------------------|------|------|------|------|------------------------|------|------|
| | 1 | 2 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 |
| LAI at Anthesis | 7.2 | 5.6 | 2.4 | 2.07 | 3.41 | 5.03 | 3.96 | 4.41 | 4.41 | 4.41 |
| Leaf Number | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 32 | 32 | 32 |
| Phyllochron ($^{\circ}\text{C d}$) | 15.8 | 14.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 14.9 | 14.9 | 14.9 |
| Duration BV-A (days) | 29 | 33 | - | - | - | 23 | - | 23 | - | - |