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Responses of faba bean (*Vicia faba*) to different levels of plant available water: I. Phenology, growth and biomass partitioning

[Tindak balas kacang faba (*Vicia faba*) terhadap pelbagai aras kesediaan air tanaman. I. Fenologi, pertumbuhan dan penghasilan biomassa]

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Keywords: plant available water, phenology, growth, biomass partitioning

Abstract

The present study was conducted under glasshouse condition to assess the effect of different levels of plant available water (PAW) on phenology, canopy development and biomass accumulation. Five levels of PAW were imposed on faba bean plant cultivar Maris Bead. Germination and flowering were significantly delayed under low PAW particularly 20% and 40% PAW i.e. 4–7 days and 23–33 days after sowing compared to the control (100% PAW). Low PAW has little effect on first pod development and maturity. Growth duration from germination to maturity was also reduced under low PAW (20%). In the absence of water stress i.e. 60, 80 and 100% PAW, longer duration from germination to maturity allowed the plant to develop a larger canopy resulting in high final total biomass i.e. 40, 60 and 90 g per plant while 20% and 40% PAW produced only 10 g and 25 g per plant respectively.

Introduction

Crop development, growth and production depend on the interaction between plant and its physical environment. Variability in plant available water is the most significant factor that causes growth and yield reduction in a wide range of crops (Boyer 1982). These reductions depend mainly on the amount of water available to the crops and the amount of water transpired by the crops.

The concept of plant available water (PAW) i.e. the amount of water in the soil that currently available to the plant is the most frequently used variable in assessing the plant responses to water deficit (Lecoeur and Sinclair 1996; Ray and Sinclair 1997; Soltani et al. 2000).

Basically, the growth and development of plant depends on continuing cell division, the initiation of tissue and organ, and cell enlargement. Growth and development processes are temporarily or permanently affected by water stress. However, under different levels of plant available water, the effects vary with duration, intensity of the stress and the ability of plant to adapt during the development of the stress (Jamieson et al. 1995; Sadras and Milroy 1996).

Biomass production is one of the most limiting factors for high seed yield. Loss and Siddique (1997) observed a strong relationship between seed yield and biomass production of faba bean in southern Australia, and biomass appeared to be

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restricted by lack of available soil water. Similar observations have also been made in other grain legumes (Siddique et. al. 1993).

Water stress can affect biomass production by affecting the rate of growth or its duration. The growth rate can be affected either by influences on leaf expansion and production, radiation interception or conversion efficiency (Giunta et al. 1995). Furthermore, reduction in dry matter production and crop yield due to water stress depend on the extent to which the photosynthesis processes are affected during the stress as well as after the stress was released (Ludlow et al. 1980). Decrease in dry matter production through photosynthesis is basically due to reduction in CO_2 exchange between air and leaves, and the limitation of energy supply for photosynthetic process which is reduced by water stress (Day and Legg 1983).

Faba bean is well known for its susceptibility in growth, flowering and pod set, and yield when suffering from limited water supply (Muller et al. 1986; Ricciardi et al. 2001). As in any other crops, water stress does decrease leaf expansion and production of faba bean (Dennett et al. 1979; Farah 1981). In the early growing stage, production of new leaves is more or less similar for both stressed and well-watered plants, but substantial decreases can be observed towards the later part of growth.

It is also reported that reduction in leaf expansion was the first indicator of water stress followed by leaf number and final biomass (De Costa et al. 1997). Besides the effects on leaf production and expansion, water stress also causes premature senescence of faba bean leaves (Finch-Savage and Elston 1982). A consequent of these responses normally can be observed on canopy size shown by lower leaf area index.

As well as reducing leaf area and production, water stress also decrease stem extension of faba bean (El-Far 1999; Sau and Minquez 2000) and consequently plant height (Hebblethwaite 1982; Grashoff 1990), resulted from fewer node numbers and shorter internodes. As a result of reduction in canopy development particularly leaf expansion and production (Grzesiak et al. 1989; Xia 1994), biomass production under water stress condition was substantially reduced.

Due to paramount important of water availability to crop growth, therefore, the objective of the present study was to assess the phenology, canopy development and biomass accumulation as affected by different levels of plant available water.

Materials and methods

Plant establishment

The glasshouse experiment was conducted at the School of Plant Sciences, University of Reading. The pots (3 litre volume) were filled with 3 kg soil mixture of 50% loam and 50% sand. The soil mixtures also contain Osmocote (15% N, 11% P, 13% K, 2% MgO) i.e. slow release fertilizer and lime. Three faba bean (*Vicia faba* L. cv Maris Bead) seeds were sown in each pot and only one uniform plant was kept in each pot throughout the experiment. Two weeks after germination, all plants were sprayed against thrips and aphids using Pirimor (pirimicarb 50% w/w) at a rate of 0.5 g/litre.

Water stress treatment

At the beginning of the experiment, field capacity of each pot was determined by saturating the soil in the pot and left overnight and then weighed on the next day. Pot weight represents the weight at field capacity. Meanwhile, average pot weight at wilting point was measured separately by allowing the plant to wilt for three days at flowering before pots were weighed.

Five levels of plant available water treatments i.e. 20, 40, 60, 80 and 100% (control) were imposed. Initial pot weight for each treatment was calculated using the formula:

$$\text{Plant available water} = \frac{\text{Initial pot weight} - \text{Pot weight at wilting point}}{\text{Pot weight at field capacity} - \text{Pot weight at wilting point}}$$

This initial pot weight was maintained throughout the growing period by weighing the pots every two days. The amount of water replacement is the difference in initial pot weight at treatment levels and the pot weight on the day of watering. Due to the increase in the size of plants, the amount of water given was adjusted throughout the experiment to ensure the plant in each treatment received consistent amount of water.

Phenology

Plant development, namely germination (one true leaf appeared), start of flowering (at least one fully opened flower per plant), pod development (one visible pod about 2 cm long per plant) and maturity (50% of pods on each plant turned black) were regularly observed which was based on the scheme by Knott (1990). Each development stage was recorded as the number of days after sowing to reach respective stages.

Growth parameters and biomass accumulation

Growth parameters namely leaf area, number of green leaf, node number and plant height were measured approximately every 15 days commencing from 30 days after sowing until harvest. Due to the long growing period to reach maturity, sequential harvesting was made until 150 days after sowing and finally at harvest. Leaf area was measured using leaf area meter (AT Area Meter, Delta-T Devices, Cambridge). Plant height was measured from first visible node to the top node of fully expanded leaf.

Growth components data for all treatments at every harvest were pooled and related to the amount of water availability to determine the sensitivity of these components to plant available water. At every harvest, plant samples were partitioned into leaves and stem. Dry weight of each plant parts and total above ground biomass were obtained after 48–72 h drying in the oven at 80 °C. Crop growth rate was calculated per plant on daily basis. Specific leaf weight was also calculated as a ratio between leaf dry weight and leaf area.

Experimental design and statistical analysis

Experimental design of randomised complete block design was applied with three replications. Significance of treatment differences for all data were tested by analysis of variance (ANOVA) using the GENSTAT for Window 6.1 (Lawes Agricultural Trust, Rothamsted Experimental Station). Means were separated by using the least significant difference (LSD) at the 0.05 probability level.

Results

Phenology

The number of days from sowing to germination declined as the plant available water (PAW) increased with a range from 10 to 17 days (*Figure 1*). There is no significant delay in germination among the 60, 80 and 100 PAW treatments. However, under low PAW of 20% and 40%, germination takes about 4–7 days later than the control (100% PAW).

Time from sowing to flowering follows the same trend as for germination. The number of days for first flower to appear varied from 90 to 125 days. Plant at 80% PAW was the first to flower i.e. 2–32 days earlier than other treatments. Meanwhile, the longest time was taken by the driest treatment (20%) with a delay of about 4 weeks.

The amount of PAW shows little effect on the time from sowing to first podding and maturity. On average, podding commenced about 140 days after sowing and maturity was reached at 203 days after sowing regardless of the treatments. However, there is a tendency for these phenological stages to be accelerated by low PAW. For example, 20% PAW only take 20 days and 55 days from flowering to form first pod and reach

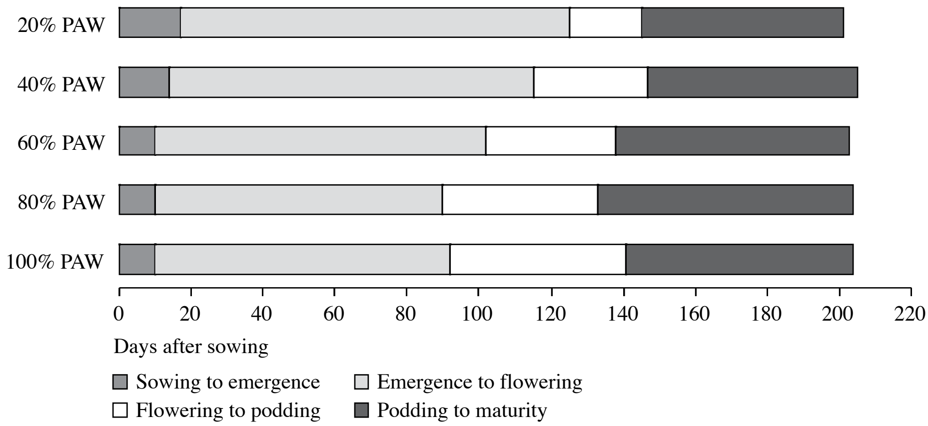

Figure 1. Duration of phenological stages (days after sowing) of faba bean resulting from five levels of plant available water (PAW). LSDs for the time from sowing to emergence, to flowering, to podding and to maturity were 2, 16, 17 and 10 days respectively

maturity, while 100% PAW required 49 days and 63 days to reach both stages although the flowers were produced early.

Canopy development

Plant available water has substantially reduced leaf area growth (*Figure 2*). The patterns of increases were similar for all treatments and the values between 20% and 40% PAW are very close. Maximum leaf area was attained by the plant in each treatment at 150 DAS and thereafter leaf area decreased rapidly especially at 100% PAW. In dry treatment (20% PAW) average leaf area from 30–150 DAS was reduced by 87% compared to control (100% PAW) and a range of 47–78% with other treatments with a maximum area was only 443 cm^2.

The number of leaflets showed a similar pattern and significant differences as leaf area (*Figure 2*), but the differences between treatments at each sampling were much closer. From day 30 to day 45, the rate of leaflet production was slower, i.e. approximately 0.58 leaf per day. This was changed to a relatively faster rate of about 1.25 leaves per day at day 60 until reaching a maximum number at day 150. Maximum leaflet numbers are in a range between 91 and 203. As the plant developed towards maturity, leaf number then declined rapidly with average decreasing rate of 1.8 leaflets per day, mainly due to leaf senescence and abscission.

The mean number of nodes produced per plant was greater for wettest treatment throughout the growing season (*Figure 2*). Total number of nodes per plant markedly increased for all treatments until 150 DAS and continued at a slower rate until reaching maximum at harvest (222 DAS). Nodes appeared at a constant rate from germination to 120 DAS for 60, 80 and 100% PAW at an average rate of one node every three days. Plant at 20% PAW had fewer nodes compared to other treatments throughout the growing period followed by 40% PAW.

The differences in stem height was not clearly seen until 75 DAS (*Figure 2*), but then increased significantly ($p < 0.05$) over time. Until this particular time, all treatments had almost similar height; thereafter plant at 100% PAW continued to increase rapidly until its maximum height was 15–50% longer than other treatments. Although the differences among the treatments in terms of node number per plant were not very obvious, especially among treatment 60, 80 and 100% PAW, the 100% PAW treatment seemed to have longest internodes which accounted for the higher plant height.

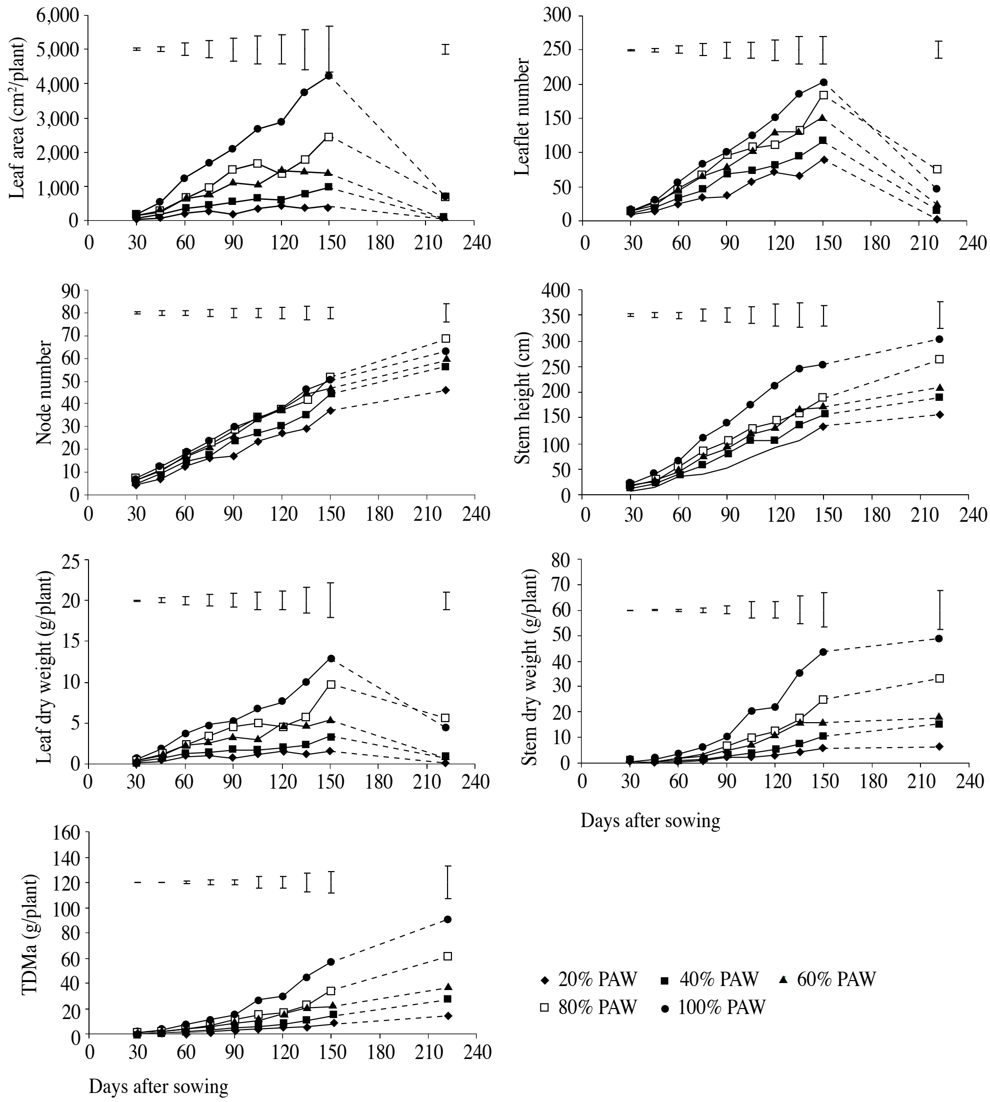

Figure 2. Seasonal variation of various parameters under different levels of plant available water (PAW). Vertical bars show standard error of mean. The dashed lines indicated the changes from 150 DAS to final harvest

Biomass accumulation

There was a consistent increase in the dry weight of leaves from the beginning of the growing season to about 120 DAS (*Figure 2*). Generally, leaf dry weight increased more slowly for all levels of PAW and this was particularly so in 20% and 40% PAW treatment and reached a maximum at 150 DAS. Plants in the control treatment (100% PAW) had significantly (p <0.05) higher leaf dry weight of 13 g per plant. The leaf dry weight then decreased until harvest with 80% and 100% PAW remained greater compared to other treatments.

The differences in stem dry weight between treatments can be observed at about 90 DAS onward (*Figure 2*). It rapid increase was observed in 100% PAW resulting in highest stem dry weight of 49 g per plant at harvest. In 20% and 40% PAW, stem dry weight was about 12–42% and 4–35% less compared to other treatments respectively.

Total above ground dry matter which comprises leaves, stem, pod and seed dry weight, exhibited a steady increase in all treatments (*Figure 2*). The control treatment (100% PAW) produced more total above dry matter at any time throughout the growing period followed by 80, 60, 40 and 20% PAW. Maximum values ranged from 13.8 g to 89.7 g per plant at final harvest.

During the vegetative period i.e. 30–105 DAS, total above ground dry matter only consisted of stem and leaves. Among these two vegetative parts, plants had more biomass in stem than leaves. On average across the growing period and treatments, 58% of total above ground dry matter was from stem. Meanwhile, total above ground dry matter at harvest also including the weight of seeds and pod wall. At harvest, seeds comprised 41, 30, 37, 24 and 27% of the total above ground dry matter in 20, 40, 60, 80 and 100% PAW respectively. As during the vegetative stages, stem and leaves were also the main plant parts contributing to total above ground dry matter at harvest ranging from 44–55% and 3–9% respectively.

Discussion

It is well established that the success of the crop growth depends on the amount of water available and its use during the growing cycles from germination until maturity. Plant available water can alter the phenological development of the plant. Germination, which is important for plant establishment, was delayed under low water availability. This observation was in agreement with the studies by Singh and Afria (1985) and Singh (1990). It was observed that the time for germination was delayed under dry soil (20% and 40% PAW) i.e. 4–7 days. As a result of delay in germination, plants at both 20 and 40% PAW were also delayed in flowering and pod development.

The growth duration was also affected by water stress, being shorter under low plant available water and longer under wet regimes. However, the extent of the effect depends on the amount of available water to the plant and also varies with different crops and species (Muchow 1985). In the present study, although the flowering and podding were delayed, which is attributed by delayed germination, the duration of both stages was shortened under dry conditions (20% PAW).

Faster development was also reported for other crops like lentil (Siddique et al. 1998) and wheat (Giunta and Motzo 2004) when grown under low rainfall condition. Similar observations were found on faba bean (Dennett et al. 1993; De Costa et al. 1997).

Low plant available water reduced all the growth components. Under low PAW (20%) the leaf area was sharply reduced due to a combination of low leaf expansion, leaf production and senescence. Leaf growth (expansion and production) is affected by water stress through a reduction in stomata conductance and photosynthesis which decrease the amount of assimilates for these processes (Squire et al. 1983; Ong et al. 1985). Between these two processes, leaf expansion normally contributes more to the final leaf area than leaf number (Sau and Minquez 2000). Similar response was found in this experiment. This result is also supported by other studies on faba bean (Xia 1994; De Costa et al. 1997).

Although leaf number is less important to leaf area development particularly during the vegetative phase and known to be almost unaffected by water stress (Karamanos 1978), but it gave a significant effect towards the maturity as observed in this experiment. Decline in leaflet number with an average rate of 1.8 leaves per day indicate that the loss of leaf during this period was enhanced by the process of senescence and abscission. This phenomenon was also found in other studies on faba bean (Farah 1981; Finch-Savage and Elston 1982) and in chickpea (Davies et al. 1999).

Apart from the effect on leaf area, plant available water also affects the stem growth. The trend of increase in stem height as plant available water increased was observed in the present study. Taller plant under high water level normally resulted from longer internodes rather than the node number (Husain et al. 1988; Dwapanyin 1995).

The decline in growth of leaf and stem under low plant available water also showed as a decline in total biomass. In early stage, i.e. until about 75 DAS, regardless the level of plant available water; leaves contributed more dry weight than stem. After that, plants produced relatively higher stem dry weight. Similar results were observed by Loss et al. (1997) and Mwanamwenge et al. (1998). They found that leaf dry weight was higher than stem dry weight during the first 60 to 100 days after sowing. This suggested that during this period plant mobilised more assimilate to leaf than stem.

Conclusion

Phenological development canopy growth and biomass production were significantly affected by the amount of water availability. Germination and flowering were delayed under low plant available water i.e. 20% and 40% PAW, while, larger canopy and high total biomass was produced between 60% and 100% PAW.

References

Boyer, J.S. (1982). Plant productivity and environment. *Science* 218: 543–548

Davies, S., Turner, N.C., Siddique, K.H.M., Leport, L. and Plummer, J. (1999). Seed growth of desi and kabuli chickpea (*Cicer arietinum*) in a short season Mediterranean-type environment. *Australian Journal of Experimental Agriculture* 39: 181–188

Day, W. and Legg, B.J. (1983). Water relation and irrigation response. In: *The faba bean* (Hebblethwaithe, P.D., ed.), p. 217–231. London: Butterworth

De Costa, W.A.J.M., Dennett, M.D., Ratnaweera, U. and Nyalemegbe, K. (1997). Effects of different water regimes on field-grown determinate and indeterminate faba bean (*Vicia faba* L.). I. Canopy growth and biomass production. *Field Crops Research* 49: 83–93

Dennett, M.D., Elston, J. and Milford, J.R. (1979). The effect of temperature on the growth of individual leaves of *Vicia faba* L. in field. *Annals of Botany* 43: 197–208

Dennett, M.D., Nyalemegbe, K. and de Costa, W.A.J.M. (1993). Growth, water use and nitrogen fixation of determinate and indeterminate cultivars of *Vicia faba* L. under contrasting soil moisture regimes. *Aspects oj'Applied Biology* 34: 269–277

Dwapanyin, O.A. (1995). The growth, yield and nitrogen fixation of *Vicia faba* L. under shade and irrigation. PhD Thesis, 76 p., University of Reading

El-Far, I.A. (1999). Response of some faba bean cultivars *(Vicia faba* L.) to skip one irrigation at different growth stages in a sandy calcareous soil. *Assiut Journal of Agricultural Science* 30: 49–62

Farah, S.M. (1981). An examination of the effects of water stress on leaf growth of crops of field beans *(Vicia faba* L.): I. Crop growth and yield. *Journal of Agricultural Science Cambridge* 96: 327–336

Finch-Savage, W.E. and Elston, J. (1982). The effect of temperature and water stress on the timing of leaf death in *Vicia faba*. *Annals of Applied Biology* 100: 567–579

Giunta, F. and Motzo, R. (2004). Sowing rate and cultivar affect total biomass and grain yield of spring triticale (x Triticosecale Wittmack) grown in a Mediterranean type environment. *Field Crops Research* 87: 179–193

Giunta, F., Motzo, R. and Deidda, M. (1995). Effects of drought on leaf area development, biomass production and nitrogen uptake of Durum wheat grown in a Mediterranean environment. *Australian Journal of Agricultural Research* 49: 99–111

Grashoff, C. (1990). Effect of pattern of water supply on *Vicia faba* L. 1. Dry matter partitioning and yield variability. *Netherlands Journal of Agricultural Science* 38: 21–44

Grzesiak, S., Filek, W. and Koscielniak, J. (1989). Influence of different soil moistures during the vegetative phase of development of field bean (*Vicia faba* L. var. minor) on leaf water status, photosynthesis rate and plant growth. *Journal of Agronomy and Crop Science* 162: 192–200

Hebblethwaite, P. (1982). The effects of water stress on the growth, development and yield of *Vicia faba* L. In: *Faba bean improvement,* (Hawtin, G. and Webb, C., eds.), p. 165–176. Kluwer Academic Publishers and ICARDA

Husain, M.M., Hill, G.D. and Gallagher, J.N. (1988). The response of field beans (*Vicia faba* L.) to irrigation and sowing date. 2. Growth and development in relation to yield.

Journal of Agricultural Science Cambridge 111: 233–254
Jamieson, P.D., Francis, G.S., Wilson, D.R., Martin, R.J. (1995). Effects of water deficits on evapotranspiration from barley. *Agricultural and Forest Meteorology* 76: 41–58
Karamanos, A.J. (1978). Water stress and leaf growth of field beans (*Vicia faba* L.) in the field: Leaf number and total leaf area. *Annals of Botany* 42: 1393–1402
Knott, C.M. (1990). A key for stages of development of faba bean (*Vicia faba*). *Annals of Applied Biology* 116: 391–404
Lecoeur, J. and Sinclair, T.R. (1996). Field pea transpiration and leaf growth in response to soil water deficits. *Crop Science* 36: 331–335
Loss, S.P. and Siddique, K.H.M. (1997). Adaptation of faba bean (*Vicia faba* L.) to dryland Mediterranean-type environments. I. Seed yield and yield components. *Field Crops Research* 52: 17–28
Loss, S.P., Siddique, K.H.M. and Martin, L.P. (1997). Adaptation of faba bean (*Vicia faba* L.) to dryland Mediterranean-type environments. II: Phenology, canopy development, radiation absorbtion and biomass partitioning. *Field Crops Research* 52: 29–41
Ludlow, M.M., Ng, T.T. and Ford, C.W. (1980). Recovery after water stress of leaf gas exchange in *Panicum maximum* var. trichoglume. *Australian Journal of Plant Physiology* 7: 299–313
Muchow, R.C. (1985). Phenology, seed yield and water use of grain legumes grown under different soil water regimes in a semi-arid tropical environment. *Field Crops Research* 11: 81–97
Muller, U., Grimme, K., Meyer, C. and Ehlers, W. (1986). Leaf water potential and stomatal conductance of field-grown faba bean (*Vicia faba* L.) and oats (*Avena sativa* L.). *Plant and Soil* 93: 17–33
Mwanamwenge, J., Loss, S.P., Siddique, K.H.M. and Cocks, P.S. (1998). Growth, seed yield and water use of faba bean (*Vicia faba* L.) in a short-season Mediterranean-type environment. *Australian Journal of Experimental Agriculture* 38: 171–180
Ong, C.K., Black, C.R., Simmonds, L.P. and Saffell, R.A. (1985). Influence of saturation deficit on leaf production and expansion in stands of groundnut (*Arachis hypogaea* L.) growth without irrigation. *Annals of Botany* 56: 528–536
Ray, J.D. and Sinclair, T.R. (1997). Stomatal closure of maize hybrids in response to drying soil. *Crop Science* 37: 803–807
Ricciardi, L., Polignano, G.B. and De Giovanni, C. (2001). Genotypic response of faba bean to water stress. *Euphytica* 118: 39–46
Sadras, V.O. and Milroy, S.P. (1996). Soil-water thresholds for the responses of leaf expansion and gas exchanges: A review. *Field Crops Research* 47: 253–266
Sau, F. and Minquez, M.I. (2000). Adaptation of indeterminate faba beans to weather and management under a Mediterranean climate. *Field Crops Research* 66: 81–99
Siddique, K.H.M., Loss, S.P., Regan, K.L. and Pritchard, D.L. (1998). Adaptation of lentil (*Lens culinaris* Medik) to short season Mediterranean type environments: Response to sowing rates. *Australian Journal of Agricultural Research* 49: 1057–1066
Siddique, K.H.M., Walton, G.H. and Seymour, M. (1993). A comparison of seed yields of winter grain legumes in Western Australia. *Australian Journal of Experimental Agriculture* 33: 915–922
Singh, K.P. (1990). Seed germination and seedling growth of *Vigna* L. cultivars under simulated moisture stress. *Annual Plant Physiology* 4: 102–105
Singh, K.P. and Afria, B.S. (1985). Seed germination and seedling growth of chickpea (*Cicer arietinum*) under water stress. *Seed Research* 13: 1–9
Soltani, A., Khooie, F.R., Ghassemi-Golezani, K. and Moghaddam, M. (2000). Thresholds for chickpea leaf expansion and transpiration response to soil water deficits. *Field Crops Research* 68: 205–210
Squire, G.R., Black, C.R. and Ong, C.K. (1983). Response to saturation deficit of leaf extension in a stand of pearl millet (*Pennisetum typhoides* S&H): II. Dependence of leaf water status and irrigation. *Journal of Experimental Botany* 34: 856–865
Xia, M.Z. (1994). Effects of soil drought during the generative development phase faba bean (*Vicia faba*) on photosynthetic characters and biomass production. *Journal of Agricultural Science Cambridge* 122: 67–72

Abstrak
Kajian ini dijalankan di dalam rumah kaca untuk menilai kesan aras kesediaan air tanaman (PAW) yang berbeza terhadap fenologi, pembentukan kanopi dan penghasilan biomassa. Lima aras air tanaman yang berbeza telah diaplikasikan ke atas tanaman kacang faba kultivar Maris Bead. Percambahan dan pembungaan telah dilambatkan dengan ketara pada PAW tanaman yang rendah terutamanya 20% dan 40% PAW iaitu 4–7 hari dan 23–33 hari selepas menyemai. Aras PAW yang rendah hanya memberi kesan yang kecil kepada pembentukan pod dan kematangan. Jangka masa pertumbuhan dari percambahan hingga kematangan juga dipercepat di bawah aras kesediaan air tanaman yang rendah (20%). Dalam keadaan tanpa ketegasan air iaitu 60, 80 dan 100% PAW, jangka masa pertumbuhan yang panjang dari percambahan hingga peringkat matang membolehkan tanaman membentuk kanopi yang besar dan menghasilkan biomassa yang tinggi iaitu 40, 60 and 90 g sepokok, manakala aras 20% dan 40% PAW hanya menghasilkan 10 g dan 25 g sepokok.

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