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Responses of faba bean (*Vicia faba* L. cv Maris Bead) to different levels of plant available water. II. Yield, water use and water use efficiency

[Tindak balas kacang faba (*Vicia faba* L. cv Maris Bead) terhadap pelbagai aras kesediaan air tanaman. II. Hasil, kegunaan air dan kecekapan penggunaan air]

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Keywords: plant available water, yield, water use efficiency

Abstract

Seed yield and biomass of faba bean were highly dependent on the amount of water availability and its use efficiency. One glasshouse experiment was carried out to examine the water use, water use efficiency (WUE) and seed yield of faba bean cv Maris Bead under different levels of plant available water (PAW), i.e. 20, 40, 60, 80 and 100% (control). The higher values of seed yield was obtained from 100% PAW i.e. 40% to 76% higher than other treatments. Reduction in seed yield was mainly due to reduction in pod and seed number particularly at 20% and 40% PAW. Both of these yield components were strongly correlated with seed yield (r^2 = 0.92 and 0.94). Generally, seed yield increased as total water use increased, but WUE tended to increase as PAW decreased i.e. ranged from 0.8 to 1.5 g/plant/kg water use. The lowest PAW (20%) had significantly high WUE than higher PAW (100%) by approximately 46%.

Introduction

Faba bean (*Vicia faba* L.) is among the important annual grain legumes, grown in over 50 countries worldwide. Water availability and premature reproductive abscission (Hebblethwaite et al. 1984; Hardwick 1988) are two major factors causing yield variability of faba bean. It is generally accepted that water availability is a major yield determining factor in many crops. In faba bean, studies on the effects of water availability had shown that seed yield of faba bean was very sensitive to the level of water availability and found to be a major cause of its variability (De Costa et al. 1997; Ricciardi et al. 2001). Besides the amount of water availability, yield of faba bean was also determined by its use efficiency. Generally, biomass production and yield were increased with increasing in water use efficiency for constant water use (Loss et al. 1997; Mwanamwenge et al. 1998).

The amount of water use and water use efficiency vary with climatic, soil conditions and the ability of the crops to extract water stored in the soil (Ehdaie et al. 1991; Ebdon et al. 1998). It has been frequently reported that lack of water availability can reduce the amount and efficiency of water use (Ehdaie 1995; Massacci et al. 1996; Maman et al. 2003). However, several studies on different crops species showed contrasting results (Gomes and Carr 2003; Abbate et al. 2004; Goksoy et al. 2004) either decreased

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or increased. These results suggested that under water stress conditions, different crop species have different ability to extract water from the soil and adaptation to drought.

In faba bean, the amount of water use differs in different places and conditions. For example, the amount of water use ranged from 100 to 700 mm, 240 to 490 mm and 400 to 980 mm in Canada, Egypt and Sudan respectively (Farah et al. 1988), while in Western Australia, cumulative water use varied from 170 to 200 mm in dry year (Mwanamwenge et al. 1998). Dennett et al. (1993) found that total water use of faba bean was about 55% to 60% higher under irrigated compared to rainfed conditions.

As for amount of water use, the water use efficiency of faba bean also varies under different growth environments. It has been observed by Dennett et al. (1993) that it tends to increase with irrigation. Mwanamwenge et al. (1998) estimated the water use efficiency of dry matter and grain yield of faba bean in Western Australia during the dry growing season. For dry matter production, they obtained the value of 14 kg/ha/mm to 23 kg/ha/mm which is lower compared with other crops grown in similar environment like lupin (63), chick pea (35) and wheat (27) as reported by Anderson (1980), Siddique and Sedgley (1986) and Siddique et al. (1990) respectively, while water use efficiency for seed yield was up to 10 kg/ha/mm. Greater value of water use efficiency for dry matter and grain yield of faba bean of 36 kg/ha/mm and 14 kg/ha/mm was reported by Loss et al. (1997), when grown in the season with above average rainfall. Meanwhile, the lower value of water use efficiency of both dry matter (6.3) and grain yield (1.4) were obtained under limited amount of rainfall.

As water availability was found to be an important factor in determining the yield, water use and water use efficiency, therefore, the main objective of this study was to examine the water use, water use efficiency and seed yield of faba bean grown under different levels of plant available water.

Materials and methods

Plant establishment

Faba bean was grown under glasshouse conditions at The School of Plant Sciences, University of Reading, for a period of approximately 220 days (12.9.2003 to 21.4.2004). At the beginning, three seeds were sown in 3-litre pots filled with 3 kg soil mixture of 50% loam and 50% sand, slow release fertilizer (Osmocote: 15% N, 11% P, 13% K, 2% MgO) and lime. Two weeks after germination, only one uniform plant was kept in each pot throughout the experiment and sprayed with Pirimor (Pirimicarb 50% w/w) at a rate of 0.5 g /litre against thrips and aphids.

Water stress treatment

Five levels of plant available water treatments i.e. 20, 40, 60, 80 and 100% (control) were imposed. The amount of water was replenished every 2 days until maturity. Detail calculation of plant available water and amount of water given for each treatment were presented by Mohamad Zabawi and Dennett (2010) in the first part of the paper.

Yield and yield component analysis

From the beginning of the flowering and podding, the number of flowering and podding nodes on each plant were counted. Yield components, namely total number of pods per plant, total seeds per plant, seeds per pod, seed size (individual seed weight) and seed dry weight were determined at final harvest. Harvest index was then computed as a ratio between seed yield and total above ground biomass. Contribution of yield components to seed yield was determined by correlation analysis.

Water use and water use efficiency

All treatment pots were weighed every alternate days to determine the amount of water use. Differences in weight between initial pot weight for each treatment and the weight on the day of measurement was considered as water use. Amount of water equivalent to weight loss was added for each treatment to maintain the level of plant available water. Total amount of water use then was calculated for the whole growing period by adding the amount of water given at each day of watering. Water use efficiency (WUE) refers to the efficiency between harvest, was calculated as a ratio of changes in total dry matter to changes in water use between harvest. Meanwhile, cumulative water use efficiency (CWUE) was calculated as the total above ground dry matter divided by total amount of water use from sowing to each harvest. Water use efficiency for total above ground dry matter and seed yield at final harvest were also determined by dividing total weight of above ground dry matter and seeds with the total amount of water use for the whole growing period.

Results

Yield and yield components

The effects of plant available water on seed yield and its components are shown in *Table 1*. There was a general trend for reduction in yield with reduced plant available water which showed significant differences between treatments. The highest seed yield recorded in control treatment (100% PAW) was 40% to 76% higher than obtained in other treatments.

Plant available water also showed a significant difference in pod and seed number. Average pod and seed number of 20% and 40% PAW were about 73% and 64% lower than control treatment respectively. The reduction in pod number and consequently seed number in low PAW was probably due to reduced flower production and also greater abortion of flowers. These were shown by the few numbers of flowering and podding nodes produced under these treatments. Meanwhile, there was no difference in seed number between 60, 80 and 100% PAW. On the other hand, the number of pod per node, seed per pod and individual seed weight were not significantly different between treatments.

The results of yield components showed that the decrease in seed yield in response to PAW arose due to reductions in pod and seed number. This was confirmed by correlation analysis between seed yield and various yield components (*Table 2*). It shows that podding node and pod number were the most strongly correlated with seed yield followed by flowering node and seed number, while pod per node, seed per pod and weight per seed were considerably less variable. The result also showed the importance of pod bearing nodes in determining the seed yield through it effects on the number of pods produced by the plant.

Water use and water use efficiency

Cumulative water use varied with the total amount of water applied under different plant available water regimes (*Figure 1*). Water use did not differ significantly

Table 1. Mean number of flowering nodes (FNo), podding nodes (PNo), percentage of flowering nodes which developed pods, pod number (PN), pods per node, seed number (SN), seeds per pod (SP), total seed weight (TSW) per plant and individual seed weight (ISW) at final harvest under various levels of plant available water (PAW)

PAW	FNo per plant	PNo per plant	Conversion of FNo to PNo (%)	PN per plant	Pods per node	SN per plant	SP	TSW (g/plant)	ISW (g/seed)
100%	40.3a	14.0a	35.2a	21.7a	1.5a	36.7a	1.7b	24.2a	0.67a
80%	31.3ab	8.0bc	24.8ab	13.3b	1.9a	28.0a	2.1ab	14.4b	0.57ab
60%	30.7ab	6.7c	21.7ab	9.7bc	1.8a	24.7ab	2.6a	14.6b	0.61a
40%	25.3bc	3.3c	13.7b	5.7c	1.9a	12.7b	2.3ab	8.0c	0.63a
20%	17.3c	4.7c	27.4ab	6.3c	1.4a	13.7b	2.1ab	5.7c	0.43b
$LSD_{0.05}$	11.7	4.9	14.5	4.4	1.2	13.4	0.8	5.4	0.15

Means followed by the same letters in column are not significantly different at $p < 0.05$

Table 2. Correlation coefficient between yield components per plant, i.e. flowering node (FNo), podding node (PNo), pod per node (P/N), pod number (PN), seed number (SN), seeds per pod (S/P), individual seed weight (ISW) and total seed weight (TSW)

	FNo	PNo	P/N	PN	SN	S/P	ISW
PNo	0.869*						
P/N	0.167	–0.303					
PN	0.896*	0.993**	–0.210				
SN	0.925*	0.955*	–0.084	0.961**			
S/P	–0.422	–0.699	0.434	–0.716	–0.511		
ISW	0.786	0.482	0.369	0.510	0.505	–0.133	
TSW	0.969*	0.957*	–0.076	0.961**	0.970**	–0.520	0.675

** and * showed significant at 1% and 5% probability level respectively

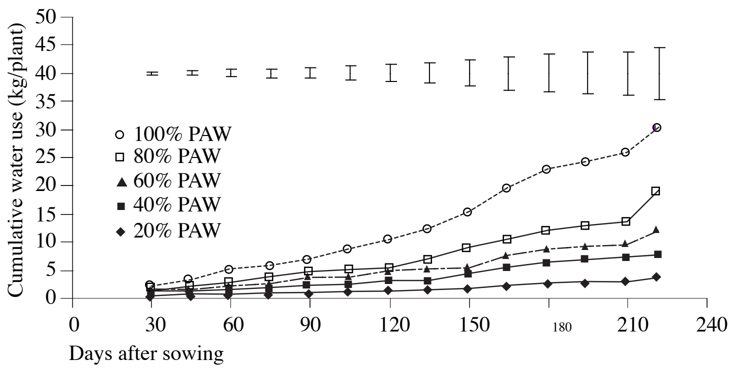

Figure 1. Cumulative water use (kg/plant) of faba bean at different days of sowing grown under various levels of plant available water (PAW). Vertical bars show standard error of means

among the treatments during the first 45 days after sowing (DAS), but the differences became apparent from 60 DAS onward, particularly at 100% PAW. The total water use during the growing season in 20, 40, 60, 80 and 100% PAW was 3.8, 7.6, 12.3, 19 and 30.1 kg respectively. The driest treatment (20% PAW) used approximately 50% to 88% less water than other treatments.

Daily water use efficiency fluctuates between the treatments because it depends on the difference in the amount of water use and change in total dry matter between two consecutive measurements (*Figure 2*). On average, daily WUE of 20% PAW was about 40% higher than 100% PAW and between 10–30% for other PAW level.

Meanwhile, in terms of cumulative water use efficiency (CWUE), there are no marked differences between treatments from 30 DAS until up to 60 DAS (*Figure 3*). Thereafter the differences can be observed with 100% PAW slightly higher, while 40% PAW was always the least efficient. At harvest, the pattern of efficiency totally changed, it decreased as PAW increased. This was mainly due to rapid change in water use but slower in total dry matter production at high PAW compared to low PAW.

Water use efficiency for total above ground biomass (WUEb) and seed yield (WUEy) at final harvest were presented in *Table 3*. WUEb corresponds to the final harvest value of CWUE. There was no significant difference between treatments in water use efficiency for total above ground biomass (WUEb) at final harvest, but it tended to be higher as PAW decreased. However, WUEy was significantly different between treatments and ranged from 0.8 to

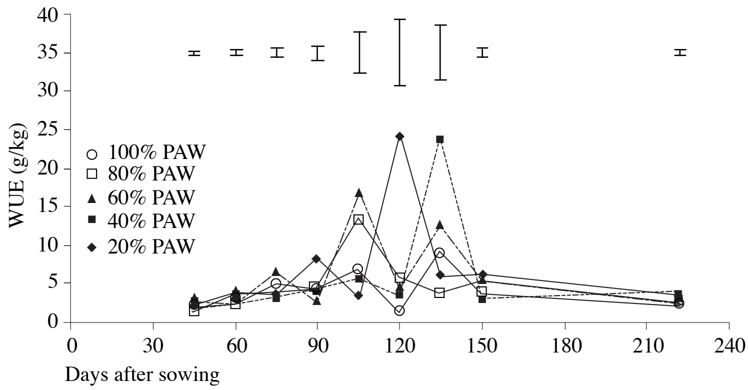

Figure 2. Water use efficiency (WUE) of faba bean as affected by different plant available water (PAW). Vertical bars show standard error of means

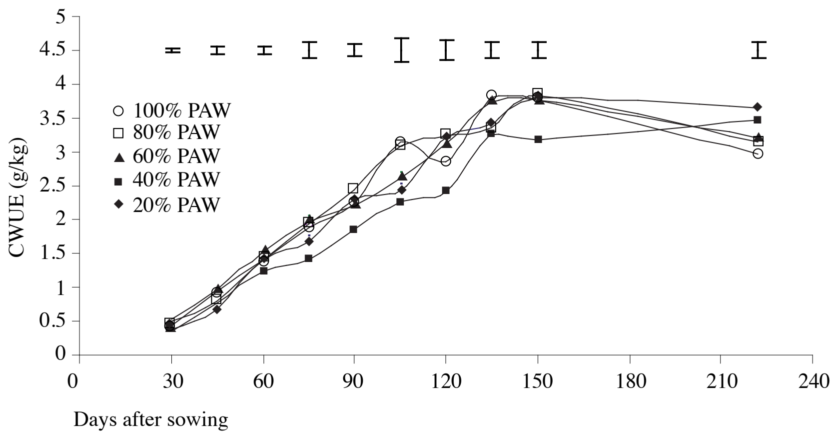

Figure 3. Cumulative water use efficiency (CWUE) of faba bean as affected by different levels of plant available water (PAW). Vertical bars show standard error of means

1.5 g/kg. The lowest PAW (20%) treatment had significantly high WUEy than the control (100% PAW) by approximately 46%. The differences between WUEb and WUEy are explained by significant differences in harvest index between treatments. Harvest index (*Table 3*) in high plant available water (100% PAW) was significantly lower compared to low available water (20% PAW).

Discussion

In terms of production, the highest seed yield was obtained from plant under high available water (100% PAW) and lowest at 20% PAW. Reduction in yield with decreased in PAW was probably due to adverse effect of water stress on biomass production (Loss et al. 1997), canopy photosynthesis (Singh et al. 1987) and yield attributes (Loss and Siddique 1997).

Among the yield components, pod and seed number are the most sensitive to the amount of water use. In faba bean, the number of podding nodes and pods per node determine the number of pods per plant as well as seed number. In this experiment, as the pods per podding node did not differ between the treatments (*Table 1*), podding node is the main determinant of pod and seed number. As a result from higher podding nodes, pods and seed number also showed a strong relationship ($r^2 = 0.92$ and 0.94) with seed yield (*Table 2*). This

Table 3. Total above ground dry matter (TDMa), total water use (WU), total seed weight (TSW), harvest index (HI), water use efficiency of biomass (WUEb) and water use efficiency of seed yield (WUEy) at final harvest as affected by different levels of plant available water (PAW)

PAW	WU (kg/plant)	TDMa (g/plant)	TSW (g/plant)	HI	WUEb (g/kg)	WUEy (g/kg)
100%	30.1a	89.7a	24.2a	0.27c	3.0a	0.8c
80%	19.0b	60.1b	14.4b	0.24c	3.2a	0.8c
60%	12.3c	39.5c	14.6b	0.37ab	3.2a	1.2ab
40%	7.6d	26.4d	8.0c	0.30bc	3.5a	1.1bc
20%	3.8e	13.8e	5.7c	0.42a	3.6a	1.5a
$LSD_{0.05}$	3.7	7.3	5.4	0.10	3.0	0.4

Means followed by the same letters in column are not significantly different at $p < 0.05$

observation was agreeable with findings by Husain et al. (1988) on faba bean.

Meanwhile, the high correlation between podding and flowering nodes with seed yield suggested the importance of these particular growth parameters in relation to seed development. One of the aspects of growth component which is necessary for seed development is node number. Generally, plant under high water level had more nodes compared to plants under low water level. This will affect the number of reproductive sites i.e. flowering and podding nodes. In this experiment, plants under 100% PAW were taller than other treatments and had more nodes. Therefore, the potential site for reproduction development (flowering and podding) is greater. As a result, more pods per plant and seed number were obtained (*Table 1*).

The decline of the number of pods with decreased plant available water was opposed by an increase in seeds per pod. But this was not sufficient to compensate for decline in pod number to increase seed yield due to low individual seed weight. Although seeds per pod tended to increase as plant available water decreased, it was considerably less variable than pod and seed number as observed by Husain et al. (1988).

An increase in plant available water decreased both WUEb and WUEy (*Table 3*). Difference in crop water use between water treatments was probably the main factor that affects the efficiency. Under high water level, total water use was higher due to larger canopy size coupled with high stomata conductance. In the current study, the amount of water use at 100% PAW was 88% more than at 20% PAW, while differences in biomass and seed yield only 85% and 76% respectively. This means, under low PAW, faba bean use water more efficient than at high PAW, resulted in high WUEb and WUEy. Similar conclusions were reported by Nerkar et al. (1981) for five different genotypes of faba bean. Increase in WUE under low PAW is also in accordance with other species grown under reduced soil moisture such as cowpea (Ismail and Hall 1992) and wheat (Zhang et al. 1998). The result also revealed that WUEb was less responsive than WUEy to PAW although there is tendency to increase under low PAW. This finding was in agreement with Muchow (1985), who found that WUEb of mungbean was not affected by different soil water regimes. Meanwhile, in terms of harvest index, plant under high available water had lower value despite producing higher biomass and seed yield. The results also showed that plant with high biomass also produced high seed yield. This suggested that high biomass is required to produce high seed yield in faba bean as indicated by other authors (Grashoff 1990; Silim and Saxena 1993) and in other pulses (Siddique et al. 1993).

Conclusion

In summary, yield was significantly reduced as plant available water reduced. Greater reduction was obtained by lower plant available water i.e. at 20% and 40%

PAW with seed yield 76% and 67% less respectively. However, despite reduction in growth and production, plants under low water regime can utilise water efficiently as shown by high water use efficiency for both biomass and seed yield. It showed that faba bean had greater ability to utilise and adapt at low water availability by changing its physiological processes.

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Abstrak

Hasil bijian dan biomass bagi kacang faba sangat bergantung kepada jumlah air yang tersedia dan juga kecekapan penggunaannya. Satu kajian di dalam rumah kaca telah dijalankan untuk meneliti penggunaan dan kecekapan penggunaan air, serta hasil kacang faba cv Maris Bead di bawah aras kesediaan air tanaman yang berbeza iaitu 20, 40, 60, 80 dan 100%. Hasil yang paling tinggi telah diperoleh pada aras kesediaan air tanaman 100% iaitu 40% hingga 76% lebih tinggi berbanding dengan aras air lain. Pengurangan hasil terutamanya pada aras 20% dan 40% kesediaan air adalah berpunca daripada pengurangan bilangan pod dan bijian. Kedua-dua komponen ini mempunyai kaitan yang rapat dengan hasil bijian secara keseluruhannya (r^2 = 0.92 dan 0.94). Pada dasarnya, hasil meningkat apabila jumlah penggunaan air meningkat, tetapi kecekapan penggunaan air pula menunjukkan peningkatan apabila kesediaan air tanaman berkurangan iaitu antara 0.8 hingga 1.5 g/pokok/kg air yang digunakan. Aras kesediaan air yang paling rendah (20%) menunjukkan kecekapan penggunaan air yang paling tinggi dibandingkan dengan aras kesediaan air yang paling tinggi (100%) iaitu kira-kira 46%.

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