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Faba bean (*Vicia faba* L.) production under deficit irrigation with treated wastewater applied during vegetative stage

Abdelaziz Hirich*, Redouane Choukr-Allah

Agronomic and Veterinary Medicine Hassan II Institute, CHA 80150, Ait Melloul, Morocco
Tel. +212 673 53 09 63; email: hirich_aziz@yahoo.fr

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ABSTRACT

Recently, water crisis has become one of the most significant problems in the world especially in the Mediterranean region. A field research was carried out in the south of Morocco in order to evaluate the effect of deficit irrigation with treated wastewater applied during vegetative growth stage on biomass production and crop water productivity of faba bean (*Vicia faba* L.). Six deficit irrigation treatments were tested: 100, 75, 50, 25, and 0% of full irrigation and rainfed treatment. The effect of deficit irrigation on growth parameters, yield and its mean components and crop water productivity was evaluated. Deficit irrigation significantly affected crop growth and all yield components considered in this study. The finding of the research evidently indicated that under deficit irrigation applied during vegetative growth using half of required water supply, the yield production and water productivity were higher than where full irrigation was provided (+4% for yield and + 24% for crop water productivity), and nearly, 17% of whole volume of applied water has been saved.

Keywords: Leaf area; Yield; Crop water productivity; Water saving; Wastewater

1. Introduction

Recently, water crisis has become one of the most significant problems in the world especially in the Mediterranean region [1]. Thus, as countries confront the water crisis situation, there will be no doubt in increasing pressure to allocate water away from agricultural to industrial and municipal uses as well as to increase water efficiency within the agricultural sector [2]. Deficit irrigation (DI) is now widely been investigated as one of the solutions for this problem [3,4]. This practice of irrigation aims at obtaining maximum water use efficiency and at stabilizing yields [5–12]. Faba bean (*V. faba* L., broad bean, horse bean) is grown worldwide in cropping systems as a grain (pulse) and green-manure legume [13].

According to Sakr [14], faba bean is the most important food legume crop in Morocco, the cultivated area of faba bean in Morocco is about 186,000 ha or 118,000 Tons was the harvested production [15]. Water stress is a main factor limiting faba bean yields and, as for other crops [16–19]. Applying deficit irrigation strategy on faba bean was the key to improve water productivity and stabilize yield by avoiding sensitive growth stages to water stress, which could help in saving an ample amount of irrigation water [20,21].

*Corresponding author.

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The main objective of this research was to evaluate the effect of several deficit irrigation degrees applied during the vegetative growth stage on growth, yield, and water productivity.

2. Materials and methods

The research has been conducted in the experimental field of the Agronomic and Veterinary medicine Hassan II institute, Complex of Horticulture in Agadir in the south of Morocco cultivating faba bean (*V. faba* L. Var: Reina mora) between 30 December 2010 and 20 April 2011. The climate is arid, characterized by low precipitation (250 mm), rainfall is occurred from November to Marsh. Sunshine is more than 300 days a year, and average temperature is variable form 14 to 16℃ in January and from 19 to 22℃ in July. Soil type was loamy with a pH of 7.9 and EC 0.11 dS/m. The soil was moderately rich in organic matter (1.6%), field capacity humidity (FC_{RH}) was 30%, and the permanent wilting point humidity (PWP_{RH}) 15%.

The irrigation water used was treated domestic wastewater, very rich in nitrogen (22 mg l^{-1}) and organic matter (biological oxygen demand = 30 mg $O_2 l^{-1}$), with EC equal to 1.31 dS m^{-1} and pH 7.6. According to the nutrient content in this water, most of the fertilizer requirements of the crop can be covered since 1,000 m^3 can provide 22 kg of Nitrogen, 15 kg of Phosphorus and 19 kg of Potassium. In terms of microbiological analysis, the irrigation water remains within the standards of the World Health Organization [22]. Experimental units (18 m^2) were organized in a completely randomized design with 24 plots (Fig. 1). Buffer areas of 1 m between experimental units were sown to avoid border and interaction effects. Inside the plot, there were 5 sowing lines, a distance of 50 cm between lines and 20 cm between sowing holes.

Six treatments and four replications for each treatment have been adopted as shown in the Table 1. Several water stress degrees (75, 50, 25, and 0% of full irrigation (FI)) have been applied only during the vegetative growth stage in addition to fully irrigated treatment (control T1) and rainfed treatment (T0). All treatments have received the same quantity of irrigation water (treated wastewater) during the initial stage (20 days after sowing), this irrigation supply during this stage was necessary for crop to start its growth and to be able after to resist to deficit irrigation supply. Irrigation treatments were applied every day except during rainy days.

Differences between response variables to deficit irrigation treatments were assessed with a general linear model in the StatSoft STATISTICA 8.0.550. All statistical differences were significant at $\alpha = 0.05$ or lower. Tukey's HSD test was used to reveal homogeneous groups.

3. Results

3.1. Growth parameters

Since 53 days after sowing (DAS), a significant difference was obtained in terms of plant height until the end of growing period. Treatment receiving full irrigation (T1) showed in all dates the highest plant height followed by treatment T2 (75% of full irrigation during vegetative growth), rainfed treatments recorded the lowed plant height (Fig. 2(a)).

During treatments application, biomass partitioning measurements were carried out every week, then every 15 days until the end of growing period. Deficit irrigation during vegetative growth stage was evaluated in terms of root weight (Fig. 2 (b)). Three weeks after starting treatments application, a significant difference has been revealed (46 DAS), rainfed treatment (T0) and treatment receiving 0% of full irrigation during vegetative growth stage showed in all dates the lowest root weight, while the treatment receiving 50% of full irrigation (T3) showed almost the highest root weight after treatments application (95 and 111 DAS).

According to Fig. 2(c), rainfed treatment (T0) showed always the lowest shoot weight, followed by treatment T5 receiving 0% of full irrigation during vegetative growth stage. Here, again treatment receiving 50% of full irrigation (T3) showed almost the highest root weight after treatments application (95 and 111 DAS). Significant difference was revealed in most of cases in the end and after treatments application.

Treatment fully irrigated (T1) showed the highest leaf area in all dates (Fig. 2 (d)), followed by treatment receiving 75% (T2) and 50% of full irrigation (T3). Treatment receiving 0% of full irrigation (T0 and T5) showed both the lowest leaf area in all dates. During grain-filling stage (80 to 111 DAS), treatments fully irrigated (T1), receiving 75% (T2) and 50% of full irrigation (T3) during vegetative growth stage formed one statically homogenous group and recorded statistically an equal value.

3.2. Yield components and crop water productivity

Table 2 shows the obtained yield and its components, water supply, and crop water productivity. Statistical analysis has not revealed any significant difference between treatments in terms of fresh pod yield and number of grains per pod. While for grain yield, number of pods per plant and 1,000 grains weight, there was a very highly significant difference, treatment receiving 50% of full irrigation during

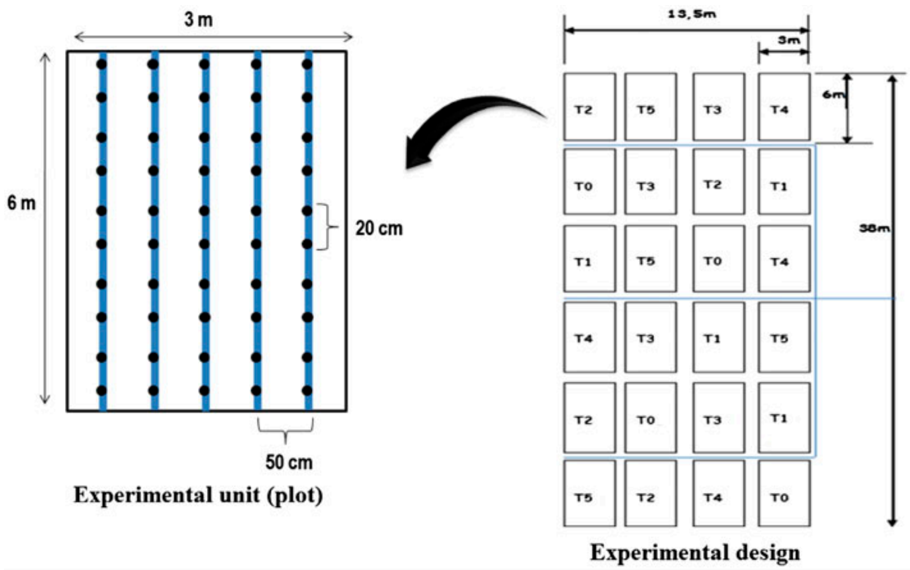

Fig. 1. Experimental design and experimental unit (plot) dimensions.

Table 1
Irrigation treatments (% of full irrigation)

Treatment	Germination	Vegetative growth	Flowering	Seed filling	Senescence
T0 (Rainfed)	100	0	0	0	0
T1	100	100	100	100	0
T2	100	75	100	100	0
T3	100	50	100	100	0
T4	100	25	100	100	0
T5	100	0	100	100	0

vegetative growth (T3) recorded the highest dry grain yield, number of pods per plant and the 1,000 grains weight, and rainfed treatment (T0) showed the lowest value of all measured parameters.

Treatment fully irrigated (T1) showed statistically dry grain yield equal to treatment receiving 75% of full irrigation (T2) during vegetative growth stage, while for the number of pods per plant, treatment T1 produced less pods per plant compared with treatment T2 even there is no significant difference between T1 and T2 in terms of grain yield, this can be explained by the difference in number of grain per pod in where T1 produced 4.8 grains per pod more than T2 which produced 4.9 grains per pod.

Crop water productivity (CWP) was calculated by dividing the dry grain yield on the consumed water quantity by each treatment. Statistical analysis showed significant difference ($p = 0.01$) between treatments in terms of CWP (Table 2). Rainfed treatment (T0) recorded the highest CWP, and this was due to less water consumption, followed by treatment receiving 50% of full irrigation during vegetative growth stage (T3) which recorded 3.6 kg m^{-3}, this high value is due to high yield obtained by this treatment. Treatment fully irrigated (T1) and treatment receiving 0% of full irrigation during vegetative growth stage (T5) recorded the same CWP (2.9 kg m^{-3}), for T1 was mainly due to higher consumed water quantity (354 mm consumed by T1 compared to 233 consumed by T5) and for T5 was mainly due to low obtained yield (66.6 g $plant^{-1}$ harvested for T5 compared with 101.6 g $plant^{-1}$ harvested for T1).

Applying deficit irrigation using 50% of full irrigation during vegetative growth stage (T3), 17% of water quantity could be saved compared with full irrigation, which give about 600 m^3 ha^{-1} that can be saved.

4. Discussion

Deficit irrigation has negatively affected plant height of faba bean [18,23,24], it was increased as water supply was increased. During treatment, application root weight decreased as water deficit degree increased [18,23–25], after treatment application,

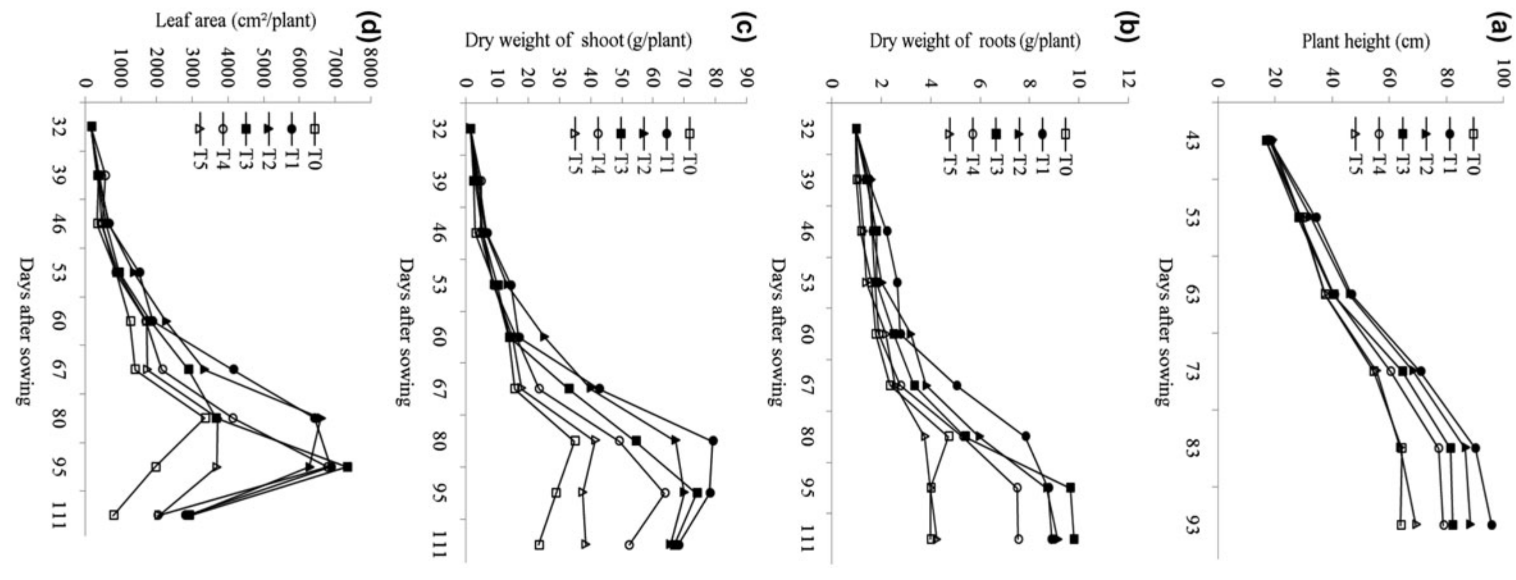

Fig. 2. Plant height (a), dry weight of roots (b), dry weight of shoots (c) and leaf area (d) evolution during growing period of faba bean. Biomass portioning measurement was destructive, one plant from each plot has been taken to laboratory to be weighted and dried. The average value was formed by 4 values corresponding to each taken plant.

Table 2
Dry grain yield, fresh pod yield, number of grains per pod, number of pods per plant and the 1,000 grains weight at faba bean harvest. The fresh pod yield has been measured when crop reached maturity. While the dry grain yield has been measured in the end of cropping period after drying under field conditions

Treatments	Dry grain yield (g/plant)	Fresh pod yield (g/plant)	Number of grains/pod	Number of pods/plant	1,000 grains weight (g)	Water supply + rain (mm)	CWP (kg/m^3)
p^*	<0.001	0.67	0.5	<0.001	<0.001		
T0	44 ± 19c	290 ± 150	4.9 ± 1.5	9 ± 4c	1,023 ± 22c	105	4.2 ± 1.9a
T1	101 ± 42a	339 ± 202	4.8 ± 1.8	15 ± 5ab	1,456 ± 125a	354	2.9 ± 1.2b
T2	101 ± 25a	316 ± 123	4.9 ± 1.5	14 ± 4ab	1,338 ± 51ab	324	3.1 ± 0.8ab
T3	105 ± 38a	342 ± 142	4.7 ± 1.5	15 ± 5a	1,463 ± 9a	294	3.6 ± 1.3ab
T4	86 ± 38ab	272 ± 151	4.8 ± 1.7	13 ± 5abc	1,393 ± 17ab	264	3.3 ± 1.5ab
T5	66 ± 23bc	316 ± 136	4.9 ± 1.6	10 ± 3bc	1,280 ± 18b	233	2.9 ± 1.0b

*Significant difference was obtained when $p < 0.05$.

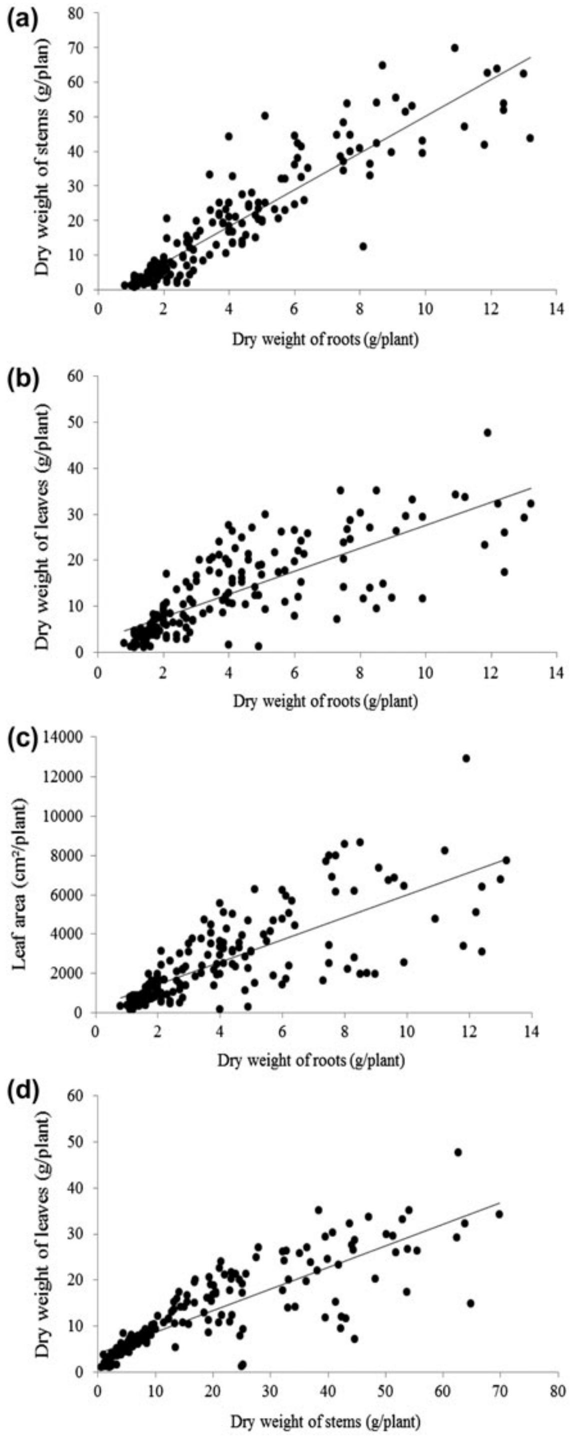

Fig. 3. (a): Relationship between dry weight of roots and dry weight of stems ($R^2 = 0.84$), (b): relationship between dry weight of roots and dry weight of leaves ($R^2 = 0.61$), (c) relationship between dry weight of roots and leaf area ($R^2 = 0.57$) and (d): relationship between dry weight of stems and dry weight of leaves ($R^2 = 0.71$).

treatment receiving 50% of full irrigation during vegetative growth stage (T3) recorded increasing in root weight induced by water stress applied earlier, while other stressed treatment during vegetative growth remained affected by water stress.

As water stress degree increased more than 50% of full irrigation (T4, T5, T0) during vegetative growth stage, shoots production and development was negatively affected by water deficit [18,23–25]. Supplying 50% of full irrigation during vegetative growth stage (T3) has increased significantly shoots weight and induced their development sometimes even more when 75% of full irrigation (T2) was provided.

Leaf area decreased as water stress degree during vegetative growth stage increased [26], when applying water deficit degree of 50% of full irrigation, leaf area was increasing significantly to respond to significant roots and shoots increase and development.

Fig. 3 shows relationship between dry weight of roots and dry weight of stems (a), between dry weight of roots and dry weight of leaves (b), between dry weight of roots and leaf area (c) and between dry weight of stems and dry weight of leaves (d). Those good linear relationships give evidence that deficit irrigation has affected root weight as well as stem and leaves weight and leaf area.

Deficit irrigation applied during vegetative growth stage was affecting yield and its components, when water deficit degree was less than 50% of full irrigation yield and its components, yield, number of pods per plant and grain weight, were affected negatively, those parameters decreased as water stress increased [18,19,24–26]. The difference in terms of grain yield can be explained by the same difference in terms of number of pods per plant and grain weight. When crop was subjected to hard water deficit (25, 0% of full irrigation during vegetative growth and rainfed treatment), yield has been affected severely by producing less pods per plant and slight grains.

Applying half required water supply for crop has improved crop productivity [25] by inducing its root system development, full irrigation during flowering and grain filling gave chance to plant to uptake more water and nutrients through its developed root system, as result crop produced more shoots and flowers intercepting more radiations by its large leaf area and producing higher yield. Those results indicated that throw deficit irrigation strategy using a water stress of 50% of full irrigation during vegetative growth stage can lead to double benefice, in terms of water saving and in terms of marketable yield.

5. Conclusion

The mean objective of this work mainly was focusing on bringing a reasonable answer to the question:

can we have satisfactory yield production with less water following the deficit irrigation technique? Deficit irrigation is a viable option that can be used by farmers in the Mediterranean region to increase and stabilize their rainfed faba bean production. Furthermore, deficit irrigation can effectively boost water use efficiency. This is particularly important in water-scarce areas, where the saved water as a result of this practice can be used to irrigate additional land, thus, allowing farmers to achieve higher levels of production.

The finding of the research evidently indicates that under deficit irrigation applied during vegetative growth using half of required water supply, we can have a yield production and water productivity higher than where full irrigation is provided (+4% for yield and +24% for crop water productivity). Under deficit irrigation during the vegetative growth, applying 50% of full irrigation nearly 17% of whole volume of applied water could be saved.

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