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Biological Yield and Harvest Index of Faba Bean (V*icia faba L.*) as Affected by Different Agro-ecological Environments

Amna A. Abdalla[1], Ahmed M. El Naim[2,*], Mahmud F. Ahmed[3], Musa B. Taha[1]

[1]Agricultural Research Corporation, P. O. Box 126 Wad Medani, Sudan
[2]Department of Crops Sciences, Faculty of Natural Resources and Environmental Studies, University of Kordofan, Elobeid, Sudan
[3]Department of Agronomy, Faculty of Agriculture, University of Khartoum, 13314 Shambat, Sudan
*Corresponding author: naim17amn@yahoo.com

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Abstract The crop biological yield refers to the total dry matter accumulation of a plant system. Improved harvest index of the represents increased physiological capacity to mobilize photosynthates and translocate them into organs having economic yield. The economic yield is a fraction of dry matter produced; the harvest index forms a useful measure of crop yield potential. Accordingly, multi agro-ecological field experiments were conducted for three consecutive seasons (2005/06, 2006/07 and 2007/08), to investigate the effect of five agro-ecological environments on the biological yield and harvest index of Faba bean (*Vicia faba* L.). The selection based on different soil types and different climatic growing conditions. Six Faba bean lines were used; namely: H.72/7/1, Daba.1/1, Z B F.1/1, C.86, Triple White and Turki. The treatments were arranged in a Randomized Complete Block Design (RCBD) with three replications. The results showed that the environments had significant effect on the biological yield. The highest biological yield of faba bean crop was obtained from the lower terrace soil, Riverian (Al Salama location). However, the high terrace soils in Almatara location attained the lowest biological yield compared to other environments. The highest harvest index of faba bean crop was observed in the middle and lower terrace soils in Hudeiba and Al Salama environment. In all production environments tested in this study the line C.86 scored the highest biological yield and harvest index.

Keywords: *climate change, production environments, pulses crop, broad bean*

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1. Introduction

Faba bean requires a cool season for best development. It is grown as a winter annual in warm temperate and subtropical areas; hardier cultivars in the Mediterranean region tolerate winter temperatures of -10° C without serious injury whereas the hardiest European cultivars can tolerate up to -15°C [1]. "It can be grown anywhere and does not winterkill. Tolerates nearly any soil type; grows best on rich loams. Moderate moisture supply is necessary" [2,14]. They are considered to be the least drought resistant of legume crops; however, cultivars with high water use efficiency have been developed at ICARDA [2]. "Moisture requirement is highest about 9-12 weeks after establishment. Faba bean is more tolerant to acid soil conditions than most legumes. Growing seasons should have little or no excessive heat, optimum temperatures for production range from 18 to 27°C (65-85°F)" [2]. Rainfall of 650-1000 mm per annum evenly distributed is ideal [3]. The maturity period ranges from 90-220 days depending upon the cultivars and climatic conditions [4].

Faba bean is the most important food legume in the Sudan [17,18]. It is the main staple food and the main source of protein for millions of people. Its nutritional importance is even greater as many people have limited access to animal food protein. Its consumption increased among the middle and low income strata of the population, being the traditional dish for breakfast and supper. Further demand has, however, increased over time in the whole country to magnitudes that increasing productivity would be essential to satisfy the local needs.

Faba beans are traditionally grown in the fertile (Gureir) soils, those are silty loams deposited in a narrow strip along the banks of the Nile and on isolated islands. Due to the scarcity of fertile soil and the high demand for Faba bean coupled with the ever increasing prices, new land of inferior quality such as 'karu' and 'high terrace' soils are coming up into production.

The main objective of this study is to investigate the effect of five environments on biological yield and harvest index in six faba bean genotypes.

2. Materials and Methods

A field experiment was conducted for three consecutive seasons (2005/06, 2006/07 and 2007/08), at five environments to investigate the effect of these environments on biological yield and harvest index of Faba bean (*Vicia faba L.*) in Sudan. The environments selected mainly to represent different soil types. In addition, temperature and relative humidity during the growing seasons were also considered. The environments where: Environment 1 (E_1): *Al Salama* location: an island 17 kilometers from Atbara city, longitude 33° 99` E, latitude 17° 84` N and altitude 348 meters above sea level to represent lower terrace soil (Riverian).

Environment 2 (E_2): *Hudeiba* Research Station Farm, longitude 33° 92` E, latitude 17° 56` N and altitude 350 meters above sea level to represent middle terrace soil (Karu).

Environment 3 (E_3): *Almatara* location 1.5 kilometers from *Hudieba* Research Station, longitude 33° 95` E, latitude 17° 56` N and altitude 351 meters above sea level to represent high terrace soil.

Environment 4 (E_4): *Wad Medani* location, Gezira Research Station Farm, longitude 33° 29` E, latitude 14° 24` N and altitude 410 meters above sea level to represent the Central clay plain soil.

Environment 5 (E_5): *Ed Damer* Food Security Scheme location 2.5 kilometers from *Almatara* location, longitude 33° 97` E, latitude 17° 54` N and altitude 355 meters above sea level to present high terrace soil (this environment was added in the second and third seasons to study another location of the high terrace soil).

The soil physical and chemical properties for all sites were described by Abdalla *et al*. [5]. The monthly mean maximum and minimum temperatures and relative humidity during the experimental period were recorded [5].

Sex Faba bean lines were used in this study:

Small-medium seeded (*H.72/7/1*, *Daba.1/1*, *Z B F.1/1*, *C.86* and *Triple White*); and large seeded *Turki*. The treatments were arranged in Randomized Complete Block Design (RCBD) with three replications in the three seasons. The land was pre-irrigated and then prepared by disc ploughing, harrowing and ridging at 60 cm apart. Spacing between plants was 10 cm in all seasons. The size of the individual plot was 6 x 3.6 meters consisting of six ridges. The two outer ridges on each plot were left as guard while the inner ridges were used for yield determination. Sowing was done manually on the shoulder of the ridges on the first half of November in River Nile locations. While, Wad Medani location it was sown on the first week of December. The lines were planted at a rate of 3 – 4 seeds per hole and then three weeks later were thinned to 2 plants per hole to gain the recommended plant population (33 plants /m^2). Weeds were controlled three times by hand. Crops were irrigated at 8 – 10 days intervals.

Characters studied included biological yield (ton/ha) and harvest index (%), determined according to method described by El Naim *et al* [16].

$$Harvest\ Index = \frac{Economical\ Yield\ (seed\ yield\ /\ plant)}{Biological\ Yeild\ (shoot\ dry\ weight)} \times 100$$

The data were statistically analyzed using IRRSTAT software computer packages.

3. Results and Discussion

3.1. Biological Yield

In the three seasons, the biological yield was affected by all treatments (Tables 1a-c). Statistical analysis showed that environment, line and their interaction had a highly significant effect on mean biological yield in the three seasons. The overall mean biological yield was relatively higher in the second season (4982 kg/ha) compared to the first and third seasons (3383 and 4036 kg/ha), respectively (Tables 1a-c). Toker [15] found that the biological yield of faba bean was the most strongly affected by environmental conditions.

Table 1(a). Effect of environment, line and their interaction on biological yield (kg/ha) of faba bean grown during season 2005/06.

Environment (Location)	Lines						Mean
	H.72/7/ 1	Daba.1/1	Z B F.1/1	C.86	Turki	T. W	
E_1 *Al Salama*	4960	5356	5968	6166	5830	4788	5511
E_2- *Hudeiba*	5545	6047	5256	6028	5335	3998	5368
E_3 Al Matara	239	355	123	194	236	80	205
E_4- *Wad Medan*	2732	2773	2719	2861	2283	1319	2448
Mean	3369	3633	3516	3812	3421	2546	3383
SE	Environment±21.2***; Lines ± 10.6***; E x L interaction ± 52.0***						
CV%	2.7						

*** = Significant at 0.1% probability level.

Table 1(b). Effect of environment, line and their interaction on biological yield (kg/ha) of faba bean grown during season 2006/07.

Environment (Location)	Lines						Mean
	H.72/ 7/ 1	Daba.1/ 1	Z B F.1/ 1	C.86	Turki	T. W	
E_1 *Al Salama*	10321	9576	10547	10841	9794	8335	9902
E_2- *Hudeiba*	7699	7449	6607	7999	6370	5883	7001
E_3 Al Matara	3862	2596	3313	2947	3806	3153	3280
E_4- *Wad Medan*	3642	3580	3951	4074	3642	3395	3714
E_5- *Ed Damer* F.S.S	1206	1065	950	906	1434	500	1010
	SE±41.6***						SE±17.0***
Mean	5346	4853	5074	5353	5009	4253	4982
SE	Environment±17.0***; Lines±18.6***; E x L interaction±41.6***						

CV% = 1.4 *** = Significant at 0.1% probability level.

Table 1(c). Effect of environment, line and their interaction on biological yield (kg/ha) of faba bean grown during season 2007/08.

Environment (Location)	Lines						Mean
	H.72/ 7/ 1	Daba.1/ 1	Z B F.1/ 1	C.86	Turki	T. W	
E_1 *Al Salama*	8286	7951	7906	8617	7762	7860	8064
E_2- *Hudeiba*	4761	4687	4754	5011	4536	3681	4572
E_3 Al Matara	3177	3443	3643	3501	3202	2301	3212
E_4- *Wad Medan*	2924	3441	3250	3274	3514	2619	3170
E_5- *Ed Damer* F.S.S	1128	913	1250	954	1860	880	1164
	SE±38.0 ***						SE±15.5 ***
Mean	4055	4087	4161	4271	4175	3469	4036
SE	Environment±15.5***; Lines±17.0***; E x L interaction±38.0***						

CV% = 1.6 *** = Significant at 0.1% probability level.

Average over lines, plants grown at E_1 (*Al Salama* location) produced significantly the highest biological yield (5511, 9902 and 8064 kg/ha) in seasons 1, 2 and 3 respectively, followed by E_2 (*Hudeiba), E_4 (Wad Madeni), E_3 (Almatara)* and E_5 (*Ed Damer)* in the three seasons (Tables 1a-c). The variation in biological yield could be attributed to variations in the growing environments. These results agree with the observations of Dantuma and Thompson [6] who stated that soil conditions markedly affect total dry matter productivity.

Average over environments, line *C.86* had significantly the highest mean biological yield (3812, 5353 and 4271 kg/ha) in the three seasons, respectively (Table 1a-c). However, the lowest mean biological yield was produced by *Triple White* (2546, 4253 and 3469 kg/ha) in the three seasons respectively (Tables 1 a-c). Similar variations in biological yield were reported by Toynbee-Clarke [7] when he compared whole-plant yields in some major and minor beans. Yield of dry matter ranged from 4900 to 8700 kg/ha, and the spring beans had lower yields than winter cultivars.

The results showed positive correlation between biological yield and seed yield (Tables 1a-c). Almost a similar finding was reported by Agung, *et al.* [8] who pointed out that yield was related to biomass accumulation. Also, Loss and Siddique [9] found that faba bean can produce impressive biomass and seed yield in a range of dry land Mediterranean-type environments.

The high biological yield observed in E_1 was attributed to the favourable conditions in this location. Interesting supportive evidence is the finding of Dantuma and Thompson [6] that, with potentially high levels of total dry-matter productivity; the proportion devoted to seed production is important. It seems, however, that a high allocation of assimilate to reproductive growth is obstructed by highly fertile growing conditions. However, Thompason and Taylor [10] compared crops grown under normal conditions with crops with high cultural inputs to ensure, that resources for growth were available in non-limiting amounts. Their results indicated that non-limiting treatment produced higher yield of total dry matter.

3.2. Harvest index

Harvest index of Faba bean lines at different environments in the three seasons is presented in Tables 2a-c. Analysis of variance showed that environment, line and their interaction had a highly significant effect on mean harvest index in the three seasons. The overall mean harvest index was significantly higher in the second season compared to the first and third seasons (Tables 2a-c).

Averaging over lines, plants grown at E_1 (*Al Salama)* and E_2 (*Hudeiba)* had slightly higher harvest index in the three seasons. However, the lowest mean harvest index was found at E_4 (*Wad Madeni)* in the first season and at E_3 (*Almatara)* in the second and third seasons (Tables 2a-c). The results indicated that high harvest index is recorded under good environmental conditions (E_1 and E_2). Contrasting results were reported by Thompson and Taylor [10] who said that crops grown at a lower level of inputs always produced a higher harvest index (HI) than plants grown with minimal constraints to growth.

Table 2(a). Effect of environment, line and their interaction on harvest index % of faba bean grown during season 2005/06.

Environment (Location)	Lines						Mean
	H.72/ 7/ 1	Daba.1/ 1	Z B F.1/ 1	C.86	Turki	T. W	
E1 Al Salama	34.9	34.5	32.0	32.6	31.9	30.7	32.7
E2- Hudeiba	29.2	42.5	22.7	49.0	32.4	20.5	32.7
E3 Al Matara	33.9	29.9	30.3	34.8	32.2	26.2	31.2
E4- Wad Medan	10.1	11.3	18.5	13.1	10.7	9.7	12.2
Mean	27.0	29.5	25.9	32.4	26.8	21.8	27.2
SE	Environment + 0.80***; Lines + 1.1***; E x L interaction + 2.1***						

CV% = 13.5 *** = Significant at 0.1% probability level.

Table 2(b). Effect of l environment, line and their interaction on harvest index % of faba bean grown during season 2006/07.

Environment (Location)	Lines						Mean
	H.72/ 7/ 1	Daba.1/ 1	Z B F.1/ 1	C.86	Turki	T. W	
E1 Al Salama	44.9	37.9	38.4	42.4	39.9	40.6	40.7
E2- Hudeiba	47.8	45.9	46.1	45.9	50.2	51.7	47.9
E3 Al Matara	22.1	35.4	36.4	44.6	35.9	31.1	34.3
E4- Wad Medan	44.2	35	37.9	34.1	35.3	31.6	36.4
E5- Ed Damer F.S.S	32.6	42.9	38.4	50.4	40.7	31.4	39.4
Mean	38.3	39.4	39.5	43.4	40.4	37.3	39.7
SE	Environment + 0.24***; Lines + 0.26***; E x L interaction + 0.58***						

CV% = 2.5 *** = Significant at 0.1% probability level.

Table 2(c). Effect of environment, line and their interaction on harvest index % of faba bean grown during season 2007/08.

Environment (Location)	Lines						Mean
	H.72/ 7/ 1	Daba.1/ 1	Z B F.1/ 1	C.86	Turki	T. W	
E1 Al Salama	34.9	33.9	41.1	38.6	29.8	34.6	35.5
E2- Hudeiba	44.2	38.0	38.8	41.8	37.6	33.4	39.0
E3 Al Matara	19.6	14.0	20.1	33.6	20.3	12.9	20.1
E4- Wad Medan	33.0	34.9	37.1	36.1	35.7	30.5	34.6
E5- Ed Damer F.S.S	21.3	17.9	20.9	28.7	18.1	17.3	20.7
Mean	30.6	27.7	31.6	35.8	28.3	25.7	30
SE	Environment + 0.69***; Lines + 0.76***; E x L interaction + 1.71***						

CV% = 9.9 *** = Significant at 0.1% probability level.

Irrespective of environments, line *C.86* had higher harvest index (32.4, 43.4 and 35.8) in the three seasons, respectively. However, *Triple White* line had the lowest mean harvest index (21.2, 37.3 and 25.7) in the three seasons respectively. These results showed considerable variations in harvest index among lines. Contrasting results were reported by Agung, *et al*. [8] who stated that harvest index differed little between genotypes. While, Loss and Siddique [9] stated that faba bean had consistently high harvest indices (37-62%).

Table 3. Correlation (r) between grain yield of Faba bean lines and biological yield and harvest index measured in each experimental site of the trial, 2005/2008 seasons.

Season	Environment	Biological yield	Harvest index
2005/06	E1- AlSalama	0.90**	0.21 NS
	E2- Hudeiba	0.95**	0.92**
	E3- AlMatara	0.95**	0.76*
	E4- Wad Medani	0.62 NS	-0.04 NS
	Mean	0.96***	0.42*
2006/07	E1- AlSalama	0.83*	0.71*
	E2- Hudeiba	0.93**	-0.58 NS
	E3- AlMatara	0.92**	0.79*
	E4- Wad Medani	0.75*	0.96**
	E5- Ed Damer F.S.S	0.99***	0.55 NS
	Mean	0.99***	0.66***
2007/08	E1- AlSalama	0.54 NS	0.82*
	E2- Hudeiba	0.91**	0.92 **
	E3- AlMatara	0.91**	0.77*
	E4- Wad Medani	0.59NS	0.66 NS
	E5- Ed Damer F.S.S	0.97**	0.78*
	Mean	0.97***	0.77***

Notice: *, **, *** = Significant at 5%, 1%, and 0.1% probability level, respectively. NS = Not significant

In this study, the moderately good soil and cool temperature seem to have some effect on the high harvest index observed in E_1 and E_2. A contrasting result was reported by Thompson and Taylor [10] who showed that high proportion of total dry matter is utilized for seed production. Harvest index was consistently lower from the plants grown at moderately good soil. However, Fasheun and Dennett [11] gave examples of apparently good growing conditions leading to high levels of total dry matter, but relatively low yields of seed. Conversely Ishag [12] found that limited vegetative growth was associated with high seed yield and high harvest index. Moreover, Keller and Burkhard [13] concluded that the harvest index does not significant from location to location.

4. Conclusion

The results indicated that agro-ecological environment plays considerable role in productivity of faba bean crop. The highest biological yield was produced in low terrace soil Riverian land; *Al Salama* location. However, low biological yields of faba bean were obtained from the high terrace soil in *Almatara* location. The highest harvest index of faba bean crop were recorded from the middle and lower terrace soil Environments. The highest biological yield and harvest index were obtained by line *C.86* in all production environments tested.

The new production environment, heavy clay soil of *Wad Madeni* location (central Sudan) produced moderate biological yield of faba bean; thus more further research is needed to come up with appropriate cultural practices to increase the yield of faba bean crop.

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