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K. Daoui [a], M. Karrou [b], R. Mrabet [a], Z. Fatemi [a], X. Draye [c] & J. F. Ledent [c]

[a] Department of Agronomy, Institut National de la Recherche Agronomique, Meknès, Morocco

[b] Integrated Water and Land Management Program, International Center for Agricultural Research in the Dry Areas, Allepo, Syria

[c] Laboratory of Crop Physiology and Plant Breeding, Université Catholique de Louvain, Louvain la Neuve, Belgium

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GENOTYPIC VARIATION OF PHOSPHORUS USE EFFICIENCY AMONG MOROCCAN FABA BEAN VARIETIES (*VICIA FABA* MAJOR) UNDER RAINFED CONDITIONS

K. Daoui,[1] M. Karrou,[2] R. Mrabet,[1] Z. Fatemi,[1] X. Draye,[3] and J. F. Ledent[3]

[1]*Department of Agronomy, Institut National de la Recherche Agronomique, Meknès, Morocco*
[2]*Integrated Water and Land Management Program, International Center for Agricultural Research in the Dry Areas, Allepo, Syria*
[3]*Laboratory of Crop Physiology and Plant Breeding, Université Catholique de Louvain, Louvain la Neuve, Belgium*

□ *Faba bean (*Vicia faba* L.) is one of the most important food legumes grown in Morocco under rainfed conditions. This crop requires phosphorus (P) fertilizers to produce higher yields. However, many farmers use low quantities of P because of its cost and the risk of drought. Consequently, the use of varieties with high P use efficiency (PUE) can improve productivity and farmers' income under erratic conditions where the application of high amounts of P is not economically justified. The genetic variation of PUE among Moroccan faba bean varieties was studied under different levels of available phosphorus to orientate the choice of adapted varieties. Two experiments were conducted, under rainfed conditions, at the experiment station of Douyet (Morroco) in 2000–2001 (year 1) and 2002–2003 (year 2). In both years, four P treatments 0, 40, 80 and 120 kg P_2O_5 ha^{-1} as fertilizer and four faba bean varieties (G) were tested. In year 1, the varieties tested were Aguadulce, Defês, Karabiga and Lobab. The same varieties were used in year 2 with the exception of Aguadulce, which was replaced by a determinate genotype with smaller straw production. Results showed that the G effect on PUE was significant in year 1, but not in year 2. In the conditions of the moderate P availability (year 1), the variety Defes had the highest PUE and grain yield. Where P availability was lower (year 2), the highest PUE was reached by Karabiga; however, the difference with Defes was not significant. Data showed also that PUE was positively correlated with harvest index (HI) and phosphorus harvest index (PHI). In year 1, genotypic variation for PUE was mainly explained by phosphorus utilization efficiency; but not by phosphorus uptake efficiency. From this study, we can conclude that for rainfed conditions, the breeding strategy is to develop genotypes like Defes with high HI and improved PUE.*

Keywords: *Vicia faba*, phosphorus, use efficiency, uptake efficiency, utilization efficiency

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Address correspondence to Khalid Daoui, Department of Agronomy, Institut National de la Recherche Agronomique, CRRA de Meknès. Km 10, Route Haj Kaddour B.P 578 (VN) Meknès, Morocco. E-mail: daoui_khalid@yahoo.fr

INTRODUCTION

Faba bean (*Vicia faba* L.) is the most important pulse crop in Morocco. It occupies, annually, an area varying between 120,000 and 200,000 ha representing in average 40% of the total food legumes area. It constitutes an important source of protein in human diet and animal nutrition. Due to its capacity to fix atmospheric nitrogen (N) (Diaz-Ambrona and Inés Minguez, 2001), enhance phosphorus (P) uptake by subsequently grown wheat (Nuruzzaman et al., 2005), and its beneficial effects of cultivation on soil structure (Rochester et al., 2001), the faba bean is utilized by farmers in rotation with cereals. In Morocco, however, this crop is mainly grown by small farmers and hence its productivity remains low and variable because of rainfall scarcity and variability and also due to traditional agricultural practices used, especially low fertilizer application. In general, only 50% of Moroccan exploitation uses fertilizers (FAO, 2006). Since in faba bean nitrogen can be provided by symbiotic fixation, and potassium is considered as sufficiently available in most soils in Morocco (Azzaoui et al., 1993), the application of optimal rates of P and the use of genotypes with high P use efficiency (grain yield per unit P added) is one of the strategies that the farmers can adopt to improve this crop productivity under the rainfed conditions of Morocco.

Many studies showed that phosphorus application increases grain yields and its components (El Kalla et al., 1999; Bolland et al., 2000). It also improves grain quality (Parashar et al., 1999). However, excessive P application could negatively affect yields due to its antagonist effect with zinc (Barea et al., 1988) or due to excessive vegetative growth that causes grain yield reduction (Castillon, 1994). Providing farmers with genotypes adapted to specific conditions of phosphorus availability in the soil and having good phosphorus use efficiency (PUE) should improve yields, without excessively increasing production cost or damaging the environment. PUE has been studied in many species: *Vicia faba* (Stelling et al., 1996), *Triticum aestivum* (Manske et al., 2001), *Solanum tubersosum* (Trehan and Sharma, 2005), *Manihot esculenta* (El-Sharkawy et al., 1998), *Cajanus cajan* (Subbarao et al., 1997) and *Phaseolus vulgaris* (Yan et al., 1995). In those studies, genetic variation for PUE was found and explanations were given on the basis of root architecture and physiology and/or on biomass translocation and phosphorus partitioning. According to Ortiz-Monasterio et al. (2001), nutrient use efficiency can be divided into two components: uptake or the ability of the plant to extract the nutrient from the soil and utilization efficiency, or the ability of the plant to convert the absorbed nutrient into grain yield. In faba bean pot experiments, Stelling et al. (1996) found that under conditions of high phosphorus supply, P efficiency depended mostly on high P uptake efficiency (PUPE) (Total P in plant per unit of added P); whereas, under conditions of low P supply, the internal P utilization (PUZE) played the major role. For wheat, Manske et al. (2001) found that in acid Andisol with no aluminium

(Al) toxicity, uptake was more important than utilization in explaining P use efficiency. However, in the same group of genotype, P utilization efficiency was more important when evaluated in alkaline Vertisol.

Taking into consideration the constraints described above and the lack of information on genotypic variation of PUE in faba been in Morocco, the aims of this work were 1) to evaluate the genotype variability for PUE in a sub-set of Moroccan faba bean varieties under different P levels in the soil and 2) to determine the relationships that exist between plant characteristics easily measurable and PUE to facilitate the identification and choice of P efficient genotypes.

MATERIALS AND METHODS

A field experiment was conducted in 2000–2001 and 2002–2003 in the Douyet Experiment station of the National Institute of Agronomic research of Morocco (INRA-Morocco) (latitude: 34°2, longitude: 5°, altitude 416 m). Soil characteristics of this site are presented in Table 1. According to the P norms developed by Soltanpour et al. (1987) for the soil conditions of Morocco and by Matar et al. (1987) for Syria, we can consider that the phosphorus level was sufficient for faba production in year 1 and low in year 2.

In year 1, the four faba bean varieties (*Vicia faba major*) Aguadulce, Defès, Karabiga and Lobab and four levels of phosphorus application as fertilizer (0, 40, 80 et 120 P_2O_5 kgha^{-1}) were tested. The varieties used are the main ones grown by farmers in Morocco. The variety Aguadulce with larger seeds and longer pods is preferred by consumers for human nutrition. The other varieties are less appreciated due to their small seeds but are used in feeding the livestock. In year 2, the same combination of treatments was used, but Aguadulce was replaced by a determinate variety (D88010-6-4-2) with less vegetative growth to diversify the tested material and hence evaluate the effect of the lower straw production of this variety on PUE. The experiment design was a split plot with four replications and P level as the main plot and variety as the sub-plot.

Phosphorus was incorporated in rows as triple super phosphate [$Ca(H_2PO_4)_2H_2O$] and nitrogen (N) and potassium were added,

TABLE 1 Physical and chemical soil characteristics

	Soil (%) (clay-silt-sand)	Calcium carbonate (%)	pH water	Organic matter (%)	P (Olsen) (mg/kg)	K_2O (mg/kg) (ammonium acetate)	Zn (mg/kg) (DTPA)
Year 1	38-48-13	21.08	8.3	1.08	11.35	531	2.6
Year 2	38-50-11	Not determined	8	1.86	5	394	2.4

respectively, as ammonium sulfate (20 kg N ha^{-1}) (only in year 1) and potassium sulfate (40 kg K_2O ha^{-1}). In year 2, no N fertilizer was used in the objective to test if the total biomass reduction due to low nitrogen availability can increase PUE.

Sowing was hand-done on 14 November (year 1) and 25 November (year 2). Each subplot was 4*2 m^2, consisting of 4 rows that were 4 m long and 0.50 m apart. Plant density was 12 plants m^{-2}.

At physiological maturity, the 2 central rows of each sub-plot plants were harvested from a spot of 3 m length. The harvest took place on 11 May and 27 April in the two years, respectively. Total biomass per unit area (TB), grain yield per unit area (GY), straw yield per unit area (SY) and harvest index (HI), 100 grain weight expressed as hundred grains weight [HGW (g)] after drying at 70°C during 48h were determined.

Representative samples of dry matter (approximately 100 g) of straw and grain were analyzed for P concentration in grain (PGr) and straw (PS) at the laboratory of INRA-Settat in Morocco using the digestive method with sulfuric acid and P was determined colorimetrically in year 1. In year 2, the analyses were undertaken at the Catholic University of Louvain (Belgium) by inductively coupled plasma (ICP)- atomic emission spectroscopy (AES). Phosphorus harvest index was determinate as: $PHI(\%) : \frac{100*PGr*GY}{PTB}$;

Where PTB represents total phosphorus in the plant at the final harvest and $PTB = PGr * GY + PS * SY$.

PUE was calculated using the equation from Moll et al. (1982). This equation was presented initially for nitrogen but we adopted it for available phosphorus from soil supply and applied fertilizer: $PUE = \frac{GY}{P_{available}}$ Where $P_{available} = P_{sol} + P_{added\ as\ fertilizer}$.

$P_{sol:}$ represents P supply from the soil itself estimated as indicated below:

$$P_{sol} = d * S * Z * P(sol)$$

d: dry bulk density (1,2 g/cm^3),
S: total area (1 ha),
Z: estimated rooting zone for mineral nutrition (30 cm)
and P (sol) represents phosphorus content as indicated by Olsen method (mg P kg^{-1} sol).

We estimated soil supply by 40.8 kg P ha^{-1} and 18 kg P ha^{-1} in years 1 and 2, respectively.

PUE is decomposed into two components as: $PUE = (\frac{GY}{P_{available}}) = (\frac{GY}{PTB}) \times (\frac{PTB}{P_{available}})$

Where $(\frac{GY}{PTB})$ corresponds to grain yield per unit of P absorbed or phosphorus utilization efficiency (PUZE) And $(\frac{PTB}{P_{available}})$ is P absorbed per unit of available phosphorus or phosphorus uptake efficiency (PUPE). The relative contribution of genotypic variation of PUZE and PUPE in PUE can be analyzed as described by Moll et al. (1982). So, this relationship was changed from a multiplicative to an additive equation by taking the log of all components. Consequently, we have: $Y = X_1 + X_2$ where $X_1 = \log(PUZE)$ and $X_2 = \log(PUPE)$. The sum of cross-products of each term, divided by the sum of squares of PUE_i estimates the kth component's contribution (C) to variation of PUE : $C_i = (\frac{\sum X_i Z}{\sum Z})$

Analyses of variance were performed using the SAS general linear models (GLM) procedure for each variable (SAS Institute, Cary, NC, USA). When the F-test indicated statistical significance, treatments means were separated by Newman-Keuls test. An alpha level of $P = 0.05$ was used. Correlations were calculated using as data the means per subplot thus they are based on n = 64 observations.

RESULTS

Climatic Conditions

Figure 1 shows that rainfall received from September to May was 364 mm and 507 mm during year 1 and year 2, respectively. In year 1, rainfall was limited during flowering – pod feeling phase (March–April) which is the most sensitive period for faba bean to water stress (Xia, 1997). On the other hand, this situation was unfavorable to pathogenic attacks. For trial 2 rainfall was more important and frequent, and this might have been responsible for the repeated parasite attacks that season which explain more control interventions.

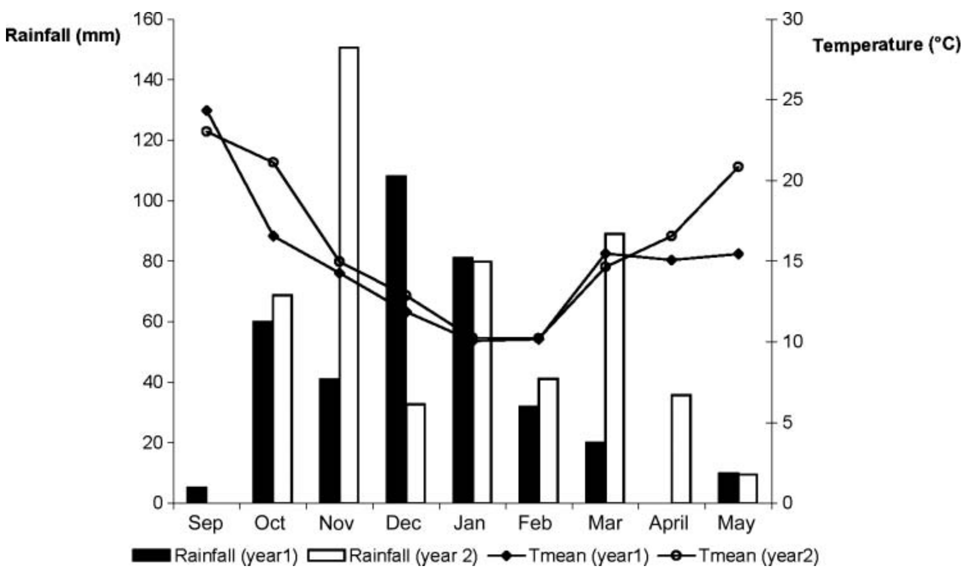

FIGURE 1 Growing season rainfall and temperature for trials 1 and 2.

TABLE 2 Phosphorus use efficiency PUE (kg grain/kg $P_{available}$)

	0	40	80	120	Mean G
			Year 1		
Aguadulce	52.78 (9.9)	25.12 (5.9)	22.29 (5.7)	23.87 (3.2)	31.02 (4.4) b
Defes	65.14 (5.6)	45.09 (6.7)	32.73 (4.4)	30.6 (1.5)	43.39 (4.1) a
Karabiga	50.14 (6.4)	34.91 (3.7)	27.81 (2.8)	22.48 (2.1)	33.84 (3.2) b
Lobab	55.74 (2.8)	38.42 (7.6)	29.94 (7.0)	24.17 (3.2)	37.07 (3.9) ab
Mean P	55.95 (3.3) a	35.89 (3.3) b	28.19 (2.5) c	25.28 (1.4) c	36.33 (2.0)
			Year 2		
Determinate	104.37 (17.1)	74.51 (10.9)	38.89 (4.1)	29.12 (3.1)	61.72 (9.02)
Defes	118.54 (11.7)	78.59 (10.7)	46.09 (6.1)	37.12 (2.6)	70.09 (9.1)
Karabiga	141.94 (7.7)	81.69 (9.5)	41.47 (6.6)	39.15 (3.3)	76.06 (11.2)
Lobab	114.1 (4.6)	73.09 (6.5)	52.42 (9.7)	28.6 (5.2)	67.05 (8.6)
Mean P	119.74 (6.18) a	76.97 (4.37) b	44.72 (3.4) c	33.50 (2.0) d	68.73 (4.7)

P: significant effect at 1/1000. G: significant effect at 1% (year 1). Interaction: P $*$ G not significant. For varieties: means on the last column followed by the same letters are not statistically different at 5% probability level. For phosphorus, means on the last lines followed by the same letter are not statistically different. Numbers between brackets are standard errors.

Genotypic Variation of PUE in Moroccan Faba Bean

Table 2 shows that the genotype effect on PUE was significant ($P <$ 5%) in year 2000–2001. In year 2002–2003, this effect was significant at only $P < 0.10$. In the first year, Defes was the most efficient variety in using P (highest PUE); while in year 2, Karabiga was ranked number 1 (Table 2). In both years, the interaction genotype $*$ phosphorus (G $*$ P) for PUE was not significant indicating that the differences of PUE between varieties were not affected by the application of P fertilizer.

PUE was positively correlated with harvest index ($r = 0{,}62^{***}$ in year 1 and $r = 0{,}30^{*}$ in year 2) and phosphorus harvest index (PHI) with $r = 0{,}59^{**}$ and $r = 0{,}34^{**}$ in year 1 and year 2, respectively. In year 1, PUE was also positively correlated with total biomass (TB) ($r = 0.33^{**}$), total straw phosphorus ($r = 0.62^{***}$). In the following year, none of these correlations were significant. However, a low, but significant negative correlation between PUE and plant height ($r = -0.26^{*}$) was registered; in year 2 but not in year 1.

Phosphorus Uptake Efficiency (PUPE)

In both years, phosphorus uptake efficiency (PUPE) was highly affected by the application of phosphorus fertilizer but neither genotype nor G $*$ P interaction effects on this character were significant (Table 3). In the check (without phosphorus application), PUPE was higher in year 2 (0.84 kg total absorbed P kg^{-1} available P in the soil) than in year 1 (0.46 Kg total absorbed P kg^{-1} available P in the soil). This increase from the first year to the following was accompanied by a reduction of total phosphorus absorbed which varied

TABLE 3 PUPE (kg total P absorbed/kg P available)

	0	40	80	120	Mean G
			Year 1		
Aguadulce	0.47 (0.06)	0.24 (0.04)	0.21 (0.04)	0.20 (0.02)	0.28 (0.03)
Defes	0.49 (0.03)	0.34 (0.05)	0.25 (0.03)	0.23 (0.01)	0.33 (0.03)
Karabiga	0.43 (0.04)	0.30 (0.02)	0.24 (0.02)	0.20 (0.01)	0.29 (0.02)
Lobab	0.46 (0.02)	0.32 (0.04)	0.25 (0.04)	0.20 (0.02)	0.31 (0.03)
Mean P	0.46 (0.02) a	0.30 (0.02) b	0.24 (0.01) c	0.21 (0.01) c	0.30 (0.01)
			Year 2		
Determinate	0.79 (0.5)	0.43 (0.06)	0.29 (0.02)	0.23 (0.03)	0.44 (0.06)
Defes	0.85 (0.01)	0.51 (0.04)	0.34 (0.01)	0.27 (0.02)	0.49 (0.06)
Karabiga	0.90 (0.09)	0.56 (0.07)	0.34 (0.03)	0.26 (0.01)	0.52 (0.07)
Lobab	0.83 (0.11)	0.46 (0.06)	0.38 (0.03)	0.18 (0.01)	0.46 (0.07)
Mean P	0.84 (0.04) a	0.49 (0.03) b	0.34 (0.01) c	0.23 (0.02) d	0.48 (0.03)

P: effect significant at 1/1000. G: effect not significant. P ∗ G: not significant. For P: means on the last lines followed by the same letters are not statistically different at 5% probability level.

from 18.9 kg P ha^{-1} (year 1) to 15.2 kg P ha^{-1} (year 2). This reduction was associated with less total biomass production in year 2. PUPE was positively correlated with grain yield (r = 0.51***), total biomass (r = 0.34**), harvest index (r = 0.45***), phosphorus harvest index (r = 0.45***), total grain phosphorus (r = 0.52***), total phosphorus (r = 0.52***) only in year 1. The absence, in year 2, of significant correlations between PUPE and these different characters was consistent with the absence of significant effects on PUPE of G, P and interaction G ∗ P.

Phosphorus Utilization Efficiency (PUZE)

Table 4 shows that the only significant effect on PUZE was that of variety in year 1 with Defès having the highest value (131,91 kg grain kg^{-1} P absorbed). PUZE of Karabiga and Lobab did not differ significantly and amounted 116,75 kg grain kg^{-1} P absorbed. The lowest value of PUZE (105,63 kg grain kg^{-1} P absorbed) was obtained with the variety Aguadulce.

In both years, PUZE was positively correlated with PUE, PHI, HI, GY, total grain phosphorus (PGr ∗ GY). PUZE was, also, positively related to total biomass; but only in year 1 the correlation was low (r = 0.29*). PUZE was also positively correlated to total phosphorus (r = 0.79***) in year 1; but this relation was negative and lower (r = −0.31*) in the following year. This can be explained by better total biomass produced and the significant variety effect in year 1 comparatively to year 2. This higher amount in total phosphorus absorbed in year 1 was accompanied by better yields. In both years, PUZE was negatively correlated with straw yield (r = −0.27* and r = −0.40* in both years, respectively) and with straw total phosphorus (r = −0.41*** and; r = −0,83***) indicating that straw reduction may increase

TABLE 4 Phosphorus utilization efficiency PUZE (kg grain/kg P absorbed)

	0	40	80	120	Mean G
			Year 1		
Aguadulce	110.3 (6.25)	99.5 (6.72)	98.7 (10.87)	114.0 (5.14)	105.6 (3.80) c
Defes	132.1 (4.30)	133.1 (1.73)	129.7 (3.03)	132.7 (1.32)	131.9 (1.31) a
Karabiga	114.5 (6.13)	114.9 (3.06)	115.7 (3.66)	113.9 (4.53)	114.7 (2.02) b
Lobab	121.5 (2.63)	117.6 (7.83)	114.6 (15.18)	121.2 (4.82)	118.7 (4.08) b
Mean P	119.6 (3.1)	116.3 (3.9)	114.7 (5.2)	120.5 (2.7)	117.8 (1.90)
			Year 2		
Determinate	128.71 (15.27)	171.32 (6.07)	131.82 (11.23)	128.45 (14.43)	140.07 (7.21)
Defes	139.76 (9.39)	156.9 (24.1)	134.21 (17.25)	140.06 (19.39)	142.73 (8.48)
Karabiga	161.08 (14.05)	144.24 (6.07)	121.08 (11.37)	150.57 (14.9)	144.24 (6.62)
Lobab	146.97 (24.44)	162.14 (6.24)	138.82 (25.76)	155.33 (25.67)	150.81 (10.73)
Mean P	144.13 (8.06)	158.65 (7.29)	131.48 (7.98)	143.60 (8.97)	144.47 (4.13)

P: effect not significant. G: effect significant at 1/1000 (only in year 1). Interaction: P ∗ G not significant. For genotypes: mean on the last column followed by the same letters are not statistically different at 5% probability level.

PUZE since competition between vegetative and reproductive development may been reduced.

On this basis, we can consider that in the conditions of P availability in the soil above the minimum value reached in year 1, but not in year 2, genotypic variation of PUE can be mainly explained by genotypic variation of PUZE and not by that of PUPE. This result was confirmed by the methodology proposed by Moll et al. (1982) (Table 5).

PUZE and PUPE were significantly and positively correlated in year 1 ($r = 0.44^{***}$). In this case, the improvement of PUZE was accompanied by the increase of PUPE; but this relation was not significant in year 2 where the genotype effects on yield and PUE were also not significant.

Grain Yield, HI and Biomass

The genotype variation had a high significant effect on grain yield in year 1 ($P < 0.01$); but this effect was significant in year 2 only at $P < 0.1$. In both years, neither P nor $G * P$ did significantly affect this parameter.

TABLE 5 Relative contribution of PUZE and PUPE into variation of PUE (year 1) according to P fertilization

P_2O_5 (kg/ha)	Contribution of PUZE	Contribution of PUPE
0	1.19	−0.19
40	1.34	−0.34
80	1.43	−0.43
120	1.49	−0.49

The mean grain yield recorded in year 1 was 2216 kg ha^{-1}. Defes gave the highest grain yield (2654 kg ha^{-1} (Table 6). In year 2, Defes came in the second position behind Karabiga, which gave the best grain yield (2601 kg ha^{-1}) (Table 6); but the differences were not significant.

In both years, genotype had a significant effect on total biomass (Table 7). In year 1, Defes that produced the highest grain yield, produced the least total biomass with an average (across P treatments) of 8512 kg/ha (Table 7). In year 2, Karabiga produced the highest total biomass with an average (across P treatments) of 6756 kg/ha (Table 7). The highest straw production was reached by Karabiga followed by Lobaba in both yields and the lowest one was produced by Defes.

In year 1, which was characterized by low annual rainfall (364 mm), mean total biomass production was 8590 kg ha^{-1}; while in year 2 (507 mm), mean total biomass was only 6201 kg ha^{-1}. This difference could be explained by repetitive pest attack due to wet climatic conditions and by the absence of added mineral nitrogen in year 2. The limitation of total biomass production in this year, could explain the absence of significant difference between the determinate and the indeterminate varieties. However, the mean HI recorded in year 1 was 27% while it was 39% in year 2. The number of pods and the number of grains per plant were higher in year 2 comparatively to year 1, probably due to higher water availability during the flowering phase in year 2. In fact, cumulative rainfall till flowering stage was about 286 mm (year 1) and 394 mm (year 2). However, the seed weight was lower probably due to less photoassimilates availability per grain following increased competition between grains and *Botrytis* attacks. The 100-seed weight of the three same varieties tested in both years decreased from 118 g in year 1 to 90 g in year 2. Also, the lack of mineral nitrogen in year 2 may explain those differences since no N fertilizer was added.

The genotype effect on HI was highly significant in year 1 (Table 8) while in year 2 (Table 8) this effect was not significant (significance only with $P = 10\%$). In year 1, HI explained 83% of yield variation while in year 2 it explained only 55%. Total biomass production explained 45% of grain yield variation (year 1) against 32% (year 2). In both seasons, Defes, a variety combining lower straw production and highest HI translocated the highest amounts of photoassimilates to grain, so that HI was 31% and 42% in the two years, respectively. The climatic conditions during year 1 permitted a higher grain yield than in year 2.

DISCUSSION

Data showed the genotypic differences in grain yield and total biomass in the Moroccan faba bean material tested. In fact, the varieties Defes and Karabiga produced the lowest and highest total biomass, respectively. However,

TABLE 6 Effect of genotype and phosphorus on grain yield according to year

	0	40	80	120	Mean G
			Year 1		
Aguadulce	2153.33 (407.28)	1464.00 (342.95)	1688.33 (435.511)	2225.00 (302.83)	1882.67 (186.99) b
Defes	2657.50 (228.05)	2627.50 (392.82)	2479.17 (366.12)	2852.50 (144.36)	2654.17 (134.85) a
Karabiga	2045.83 (260.84)	2034.17 (213.86)	2106.67 (209.87)	2095.83 (197.7)	2070.63 (99.55) b
Lobab	2274.17 (114.8)	2239.17 (441.62)	2268.34 (530.9)	2253.34 (297.59)	2258.76 (170.13) b
Mean P	2282.71 (136.06)	2091.21 (193.39)	2135.63 (192.45)	2356.67 (133.07)	2216.55 (82.28)
			Year 2		
Determinate	1878.75 (307.73)	2642.5 (386.56)	2058.75 (216.69)	2050 (220.44)	2157.50 (150.18)
Defes	2133.75 (210.24)	2787.5 (379.69)	2440 (325.15)	2613.75 (181.89)	2493.75 (142.28)
Karabiga	2555 (138.7)	2897.5 (336.73)	2195 (349.93)	2756.25 (233.86)	2600.94 (141.91)
Lobab	2053.75 (82.64)	2592.5 (232.15)	2775 (511.42)	2013 (366.58)	2358.56 (173.68)
Mean P	2155.31 (83.30)	2730.00 (154.00)	2367.19 (174.00)	2358.25 (130.00)	2402.69 (77.31)

P: not significant. G: effect significant at 5% probability level (only in year 1). P ∗ G: not significant. For genotypes: mean on the last column followed by the same letters are not statistically different at 5% probability level.

TABLE 7 Effect of genotype and phosphorus on total biomass according to year

	0	40	80	120	Mean G
			Year 1		
Aguadulce	9083.33 (587.76)	7716.67 (824.79)	8416.67 (1157.7)	8850.00 (596.52)	8516.67 (392.59) b
Defes	8466.67 (303.07)	8166.67 (841.62)	8333.33 (593.17)	9083.34 (315.49)	8512.50 (265.65) b
Karabiga	8816.67 (87.66)	8866.67 (396.46)	9000.00 (222.78)	9383.33 (197.7)	9016.67 (158.52) ab
Lobab	9483.33 (354.21)	9566.67 (526.7)	9566.67 (646.64)	9216.67 (420.21)	9458.34 (226.39) a
Mean P	8962.50 (194.27)	8579.17 (352.00)	8829.17 (352.82)	9133.34 (213.00)	8876.04 (142.77)
			Year 2		
Determinate	5412.4 (312.5)	6162.5 (717.16)	5975 (388.64)	5537.5 (449.25)	5771.85 (233.54) b
Defes	5162.5 (503.89)	6350 (395.28)	5975 (260.21)	6162.5 (482.78)	5912.50 (221.85) b
Karabiga	6475 (680.84)	7162.5 (482.78)	6787.5 (471.86)	6600 (204.12)	6756.25 (229.21) a
Lobab	5912.5 (471.86)	6475.2 (515.39)	7287.5 (623.96)	5787.5 (571.68)	6365.67 (289.10) ab
Mean P	5740.6 (268.22)	6537.55 (262.27)	6506.25 (286.61)	6021.875 (198.51)	6201.57 (129.11)

P: not significant. G: effect significant at 5% probability level. P $*$ G: not significant. For genotypes: mean on the last column followed by the same letters are not statistically different at 5% probability level.

TABLE 8 Effect of genotype and phosphorus on harvest index according to year

	0	40	80	120	Mean G
			Year 1		
Aguadulce	23.27(3.25)	18.22(2.62)	18.62(3.47)	25.16(2.97)	21.32(1.58) b
Defes	31.70(3.65)	31.74(1.43)	29.39(2.15)	31.38(0.9)	31.05(1.05) a
Karabiga	23.16(2.87)	22.80(1.61)	23.36(2.09)	22.50(2.34)	22.96(1.02) b
Lobab	24.07(1.44)	23.09(3.71)	23.79(5.52)	24.34(2.79)	23.82(1.65) b
Mean P	25.55(1.60)	23.96(1.69)	23.79(1.88)	25.85(1.37)	24.79(0.81)
			Year 2		
Determinate	34.1(4.45)	42.55(1.56)	34.53(3.31)	37.34(4.1)	37.13(1.80)
Defes	41.68(3.62)	43.77(4.66)	40.54(4.57)	43.25(4.59)	42.31(1.99)
Karabiga	40.77(4.52)	40.1(2.29)	32.07(3.77)	41.99(4.11)	38.73(1.96)
Lobab	35.45(3.16)	40.04(1.84)	37.51(5.32)	34.13(3.68)	36.78(1.76)
Mean P	38.00(1.72)	41.61(1.38)	36.16(1.78)	39.18(2.10)	38.74(0.96)

P: not significant. G: effect significant at 5% probability level (only in year 1). P ∗ G: not significant. For genotypes: mean on the last column followed by the same letters are not statistically different at 5% probability level.

harvest index was the highest in the case of Defes, but the other genotypes with high biomass yield had their HI reduced. Results obtained in year 1 supported the idea that varieties with an indeterminate growth habit characterized by a greater biomass production could reduce the harvest index. This result confirms those reported by De Costa et al. (1997) and Sau and Minguez (2000). However, in year 2, it was observed that the determinate variety did not have a higher HI than the indeterminate ones and its grain yield was clearly lower. Duc (1997) reported that, the ti gene inducing a determinate stem growth has been used in many breeding programs; but it did never result in significant yield improvement.

The reduction of vegetative growth was also reduced when nitrogen available in the soil was low. Therefore controlling biomass production, through genetic improvement toward small plants or agronomic practices like limiting N fertilization to reduce growth, may reduce excessive vegetation that permits an efficient use of nutrient mainly in limited rainfall conditions. In species, like manioc (*Manihot esculenta*) (El-Sharkawy et al., 1998) and wheat (Batten, 1992; Jones et al., 1989) it was shown that genotypes with the lowest plant height have the better mineral use efficiencies. Moreover, under rainfed conditions where production is limited by precipitations, N fertilizer application as starter may not be economically justified. In such conditions, biological nitrogen fixation may be sufficient to achieve high biomass production. Scientific research on this way will be useful.

Harvest index was also affected by rainfall conditions. It was shown that for high yielding variety Defes, harvest index varied from 31% in year 1 to 42% in year 2. These values are lower than the ones obtained by Loss et al. (1997) in Australia on faba bean. These authors showed that in dry year, HI varied from 33 to 53%; however in relatively wet season it was between 53 and 62%. This affected PUE since this latter was positively correlated with HI. In fact, according to Janssen (1998), factors affecting HI affect also utilization efficiencies of all nutrients. Calderini et al. (1995) found that the characters most correlated to the improvement of N and P yields (total amounts in the plant) were their harvest indexes (NHI and PHI). Wissuwa and Ae (2001) found that it was possible to more than triple the rice yield by combining high P uptake variety that was P deficiency-tolerant with high harvest index characteristics of modern varieties.

Our data showed also that phosphorus concentration in the grain and in the straw were positively related to the total amount of phosphorus in the straw with $r = 0.25^{*}$ and $r = 0.91^{***}$, respectively. Also, phosphorus concentration in the straw was negatively correlated with PUE ($r = -0.30^{*}$) and with grain yield ($r = -0.40^{***}$). While, HI was negatively correlated with phosphorus concentration in the grain ($r = -0.25^{*}$) and in the straw ($r = -0.49^{***}$), phosphorus concentration in the grain was not significantly correlated with neither PUE nor grain yield. Consequently, these findings showed that although the improvement of HI by a better translocation of photoassimilates from vegetative biomass to grain should have enhanced phosphorus migration to the grain, the dilution effect might have caused a decrease of phosphorus concentration in the grain. In fact, no significant correlation was found between phosphorus concentration in the grains and the total amount of P in the grains. These results are similar to those found in wheat by Calderini et al. (1995). Batten (1992) suggested that increased HI, PHI and low P concentration in grain may improve PUE.

Our results showed that in the two years of study, the genotype and $G * P$ effects on phosphorus uptake efficiency were not significant. However, for phosphorus utilization efficiency, Defes and Aguadulce gave the highest and lowest values, respectively. Nevertheless, in both years, PUZE was positively correlated with PUE, PHI, HI and grain yield. Our data showed also that when P availability was moderate which was the case in year 1, genotypic variation for PUE was mainly explained by phosphorus utilization efficiency. These results are consistent with the findings of Manske et al. (2001) in wheat. However, they disagree with those of Stelling et al. (1996) for faba bean under pot conditions. According to these authors, under conditions of high phosphorus supply, P efficiency in faba bean depended mostly on high P uptake efficiency (PUPE); whereas, under conditions of low P supply, the internal P utilization (PUZE) played the major role.

From this study, we can conclude that under the conditions of moderately P availability (case of year 1) characterized by an application of N and lower rainfall, Defes was the most efficient variety due to its higher HI and PHI. PUE, in this case, was conditioned by a better assimilates translocation from vegetative part to reproductive ones. While in conditions of very low P, possibly N limitations and higher precipitation (year 2), PUE was conditioned by the importance of total biomass production. In this case, Karabiga was the most efficient variety in using P. For rainfed conditions, we recommend Defes variety because of its lowest biomass production and its higher HI. Karabiga should be interesting under irrigated conditions.

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