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Differential response of pea (*Pisum sativum* L.) to plant density in relation to the growth and agronomic parameters

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Abstract - Pea (*Pisum sativum* L.) is known as a species that is not competitive with weeds, and certain agronomic levers such as increased seedling density allow peas to be more competitive. This work was conducted to study the response of a variety of field pea (Afila) to plant density. An experimental test on the INRAT site in Mornag-Tunisia, under rain conditions, consists in studying the effect of six seedling densities: 20, 60, 100, 140, 180 and 220 seeds/m^{-2} on the agronomic performance of *P. sativum*. Our objective is to evaluate the yield components of *P. sativum* in order to identify the planting density that generates optimum yield. The results indicate that the planting density significantly affects the production parameters (number of pods, number of seeds, harvest index..,) of *P. sativum*. Thus, plants with low planting densities produce more seeds than plants with high-density treatments. On the contrary, emergence rate and dry biomass increase with planting density. The increase in seedling density resulted in a significant increase in seed yield of 145 g/m^2 for the density of 140 seeds/m^2 to 273 g/m^2 for the density of 220 seeds/m^2. Thus, the average yield was 18 qx/ha against a yield having a ceiling of 30 qx/ha. However, field pea in association with cereals can also improve the agronomic performance of forage crops.

Mots clés : field pea, seedling density, seed yield, yield components

1. Introduction

Legumes (Fabaceae, syn. Leguminosae) comprise annual and perennial herbaceous plants, many of which are economically important grain, oilseed and forage crops, as well as shrubs and tropical or subtropical trees. They provide quality protein for humans and animals and enriching the soil by symbiosis with nitrogen-fixing bacteria (Singh et *al*., 2014). Among the most significant legumes is pea (*Pisum sativum* L.), a true multifunctional crop that may be used as green forage, forage dry matter, forage meal, silage, haylage, immature grain, mature grain, straw and green manure (Mihailović and Mikić, 2010).

Peas are grown for forage, grain (feed and food) and vegetable purposes. Consequently, peas have been differentiated in distinct types including for forage and grain (Cousin, 1997; Bilgil, 2010). Among legumes, the pea is the second most important grain legume crop in the world, which is widely used in human nutrition and as fodder (Cristou, 1997). In the past, plant breeding programs were focused mostly on developing high yielding cultivars. Recently the development of cultivars which are adapted to different environmental conditions is ultimate aim of a plant breeder in the crop improvement programs (Muhammad, et al., 2003; Mulusew, et *al*., 2009; Pratap and Kumar, 2011).

Field pea is grown in many countries and currently ranks fourth among the pulses in the world with cultivated area of 6.33 million ha (FAO, 2015). Field pea is known to be grown in Ethiopia since antiquity (Keneni et al., 2013). Currently, the crop is the fourth most important pulse crop in Ethiopia, preceded only by faba bean, haricot bean and chickpea in terms of both area coverage and total national production (CSA, 2011). The yield performance of plants is controlled by the genetic capacity of a plant, the environment and their interaction. High and stable seed yield performances are the main objectives in plant breeding programs (Cupina et *al*., 2004). The genotype must show good performance across a range of environments to be widely accepted. The genotypes respond to changes in the environmental conditions such as temperature, rainfall, soil type (Fehr, 1993; Mustafa, et al., 2012).

Increasing plant density in field pea is used to improve the crop's competitive ability and as well as to increase yields (Townley-Smith and Wright, 1994). In Australia, when the plant density of field pea increased from 10 to 60 plants m^{-2} the losses in yield from annual ryegrass competition were reduced from 70 to 80% to 5 to 50%, respectively (Lemerle et *al*., 2006). Likewise, a study conducted between 1998 and 2001 in Lacombe, Alberta showed a reduction in weed biomass in 2 of 4 years in both barley and field pea crops when crop target densities were increased (Blackshaw et *al*., 2005). However, it is critical to choose a field pea planting density that provides better competitive ability with weeds (interspecific competition) without allowing field pea plants to compete with each other for limited resources (intraspecific competition). The optimal plant density usually differs according to the environmental conditions and availability of resources. For example, the recommended field pea plant density is 75 plants m^{-2} in Alberta (Alberta Agriculture and Rural Development, 2010). However, in Saskatchewan it is 88 plants m^{-2} (Saskatchewan Pulse Growers, 2000), while in south Australia the optimal plant densities range from 60 to 100 plants m^{-2} depending on growing season rainfall (McMurray, 2003). Grevsen (2003) found that the recommended density of 120 plants m^{-2} for organic pea production minimum seeding rate, and that seeding rates should be as high as is economically feasible. The objectives of this study were to determine the influence of plant density on the grain productivity and growth of forage pea considering a number of agronomic factors and profitability.

2. Materials and methods

2.1. Site and experiment set up

A field experiment was performed during 2017-2018 at the INRAT experimental station of Mornag situated in the north of Tunisia (36°37'20" N; 10°17'29" E) under rain fed conditions. The average precipitation was 450 mm (Figure 1). The texture of soil is clay-loam.

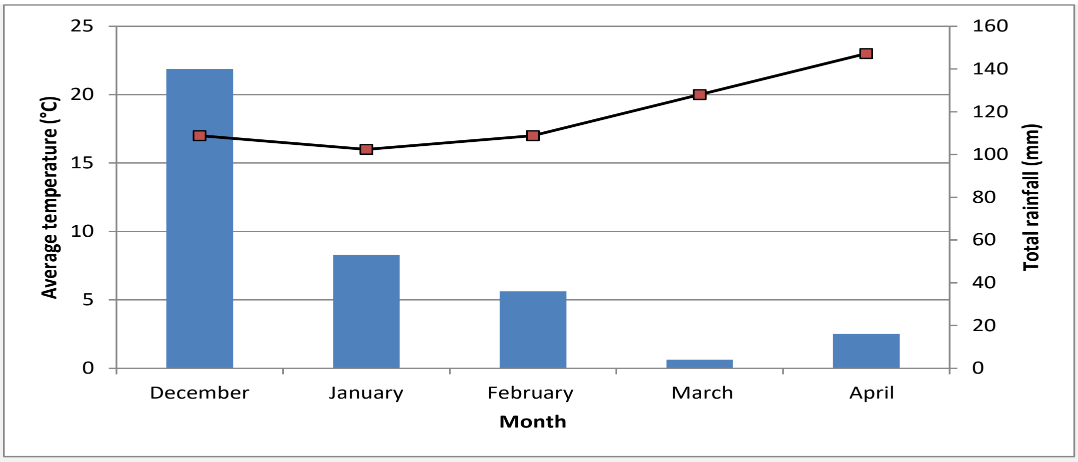

Figure 1. Monthly data of the mean temperature (°C) and precipitation (mm) during the experimental period (data recorded at the INRAT experimental station in Mornag 2017-2018).

2.2. Agronomic and yield measurements

The experimental design was a randomized complete block (RCB) design with 6 treatments with five replications. The experimental plots consisted of six rows, 1.6 x 3 m and with 0.4 m spacing between rows. Blocks were separated by 0.5 m buffer zone. Grain yield (kg ha^{-1}): The grain yield was determined at harvest. Grain yield per hectare was recorded and expressed in kilogram using the formula:

Grain yield (kg) x 10,000 m^2 / net plot size (m^2)

Total dry matter (kg ha^{-1}) was determined at harvest by cutting the entire plants in each net plot from ground level after they had been dried and weighed. The weights per plot were recorded. Total dry matter per hectare was recorded and expressed in kilogram using the formula:

Total dry matter in (kg) x 10,000 m^2 / net plot size in (m^2)

Therefore, harvest index was determined and calculated using the formula:

Harvest index (HI) = Grain yield (kg ha^{-1}) x Total dry matter (kg ha^{-1})

2.3. Data Analysis

All data were processed with Satistica (Stat Soft) version 6. The analysis of variance and the least significant difference (LSD) were used to compare the differences between different data sets ($P < 0.05$). All results are given as means ± SE.

3. Results and Discussion

When the pea crop reached physiological maturity, an area of approximately 0.25 m² corresponding to 6 seeding rate on all plots was chosen in order to determine the components of the yield. Emergence rate, dry matter, harvest index, number of pods, number of seeds and weight of 100 seeds were also determined.

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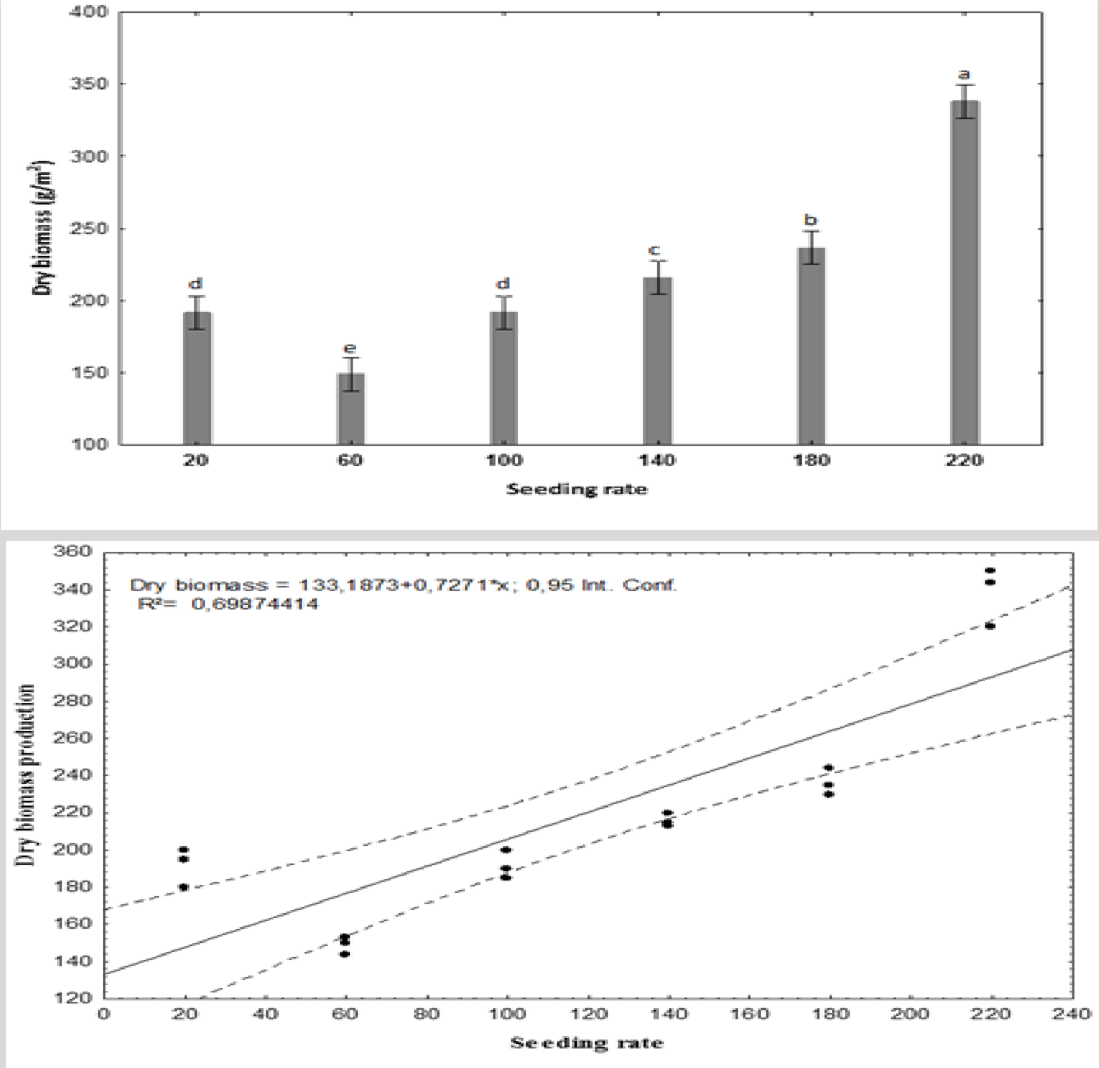
3.1. Effect of seeding density on dry biomass production

The highest aboveground biomass of 325 g/m^2 was observed with the highest crop density respectively. The yields of pea in dry biomass for the first five densities are not significantly different except at full density of 220 seeds/m^2 (Fig. 2). The quantity of dry biomass harvested significantly increased just with the density of 220 seeds/m^2. The average amounts of dry matter collected varied between a maximum of 210 g/m^2 and a minimum of 150 g/m^2.

Field pea yield increases sharply as crop density is increased to about 54 plants m^{-2} (Lawson 1982). Knott and Belcher (1998) found that as the population density increased from 75 to 90 plants m-2, the increase in yield was slight. At extremely high densities, the final yield is actually depressed (Heath and Hebblethwaite, 1987). Based on this research, optimal economic plant density is the point on the yield curve where increases in yield are not sufficient to cover the cost of the seed required to increase the yield.



(A)

(B)

Figure 2. The effect of seeding rate on the dry biomass of field pea. Different letters indicate a significant difference at P ≤ 0.05, and bars represent + 1 SEM (A). Curves are based on the equation dry biomass = (slope * density) + y-intercept where slope is the rate of dry biomass increase with increased plant density and the y-intercept is the minimum potential biomass production for a field pea (B).

3.2. Effect of seeding density on emergence rate

The ANOVA for plant emergence of field pea across the targeted plant densities differed significantly. The emergence rate in each plot of the trial was determined 2 months after sowing (December 07, 2017) by carrying out counts eight times of 1 square meter, representative of the 6 densities taken into account. For each density, the number of plants raised increases significantly, going from the density of 20 to that of 220 seeds/m^2 (Table 1). Thus, the rate of emergence varies from 6 to 44 plants/m^2 and shows significant differences between the different sowing densities. Johnston et al. (2002) documented that the proportion of seedlings that emerged at lower seeding rates was greater when compared with higher seeding rates for all pea cultivars. The emergence rates relative to the corresponding target seeding rates progressively decreased as seeding rate increased (Johnston et al. 2001). At lower sowing densities (60 and 100 seeds/m^2), the number of established plants per square meter was more similar than higher sowing densities (Sobko et al, 2019). A reason might be that competition between plants increases with increasing sowing density, thus not all seeds and seedlings developed into a plant at higher sowing densities. At higher seeding rates, the number of surviving plants was also reduced as the growth of the plants progressed (Kruger 1977). Seedling mortality in pea increased dramatically with planting rates above 50 seeds m^{-2} (Johnston et al. 2002).

Table 1. Variation in the number of plants raised as a function of 6 sowing densities (20, 60, 100, 140, 180 and 220 seeds/m^2). Values followed by different letters are significantly different at the 5% level.

Seeding rate (seeds/m^2)	Number of sprouted plants
20	5,62 d
60	18,75 c
100	20,50 c
140	33,88 b
180	35,13 b
220	44,13 a

3.3. Effect of sowing density on the number of seeds

The maximum number of seeds per plant was obtained with the lowest sowing density 20 seeds/m^2. Increasing the sowing density resulted in a significant increase in the number of seeds from 1250 to 1700 seeds/m^2. Under lower sowing densities (20, 60, 100 and 140 seeds/m^2), the number of seeds/m^2 was statistically similar, and significantly less than under 180 and 220 seeds/m^{-2} of density seedlings. During the final harvest made after 20 weeks from the sowing date, the seed yield parameters did not show significant differences ($P > 0.05$) (fig 3).The increased sowing density resulted in an increase in seed yield from 145 g/m^{-2} for the density 140 seeds/m^{-2} to 273 g/m^{-2} for the density 220 seeds/m^{-2}. Thus, the average seed yield was 18 qx/ha against a yield that had capped at 30 qx/ha (fig 3).

In New Zealand, Bussel et *al*. (1983) recommended 90-120 seeds m^{-2} suggested 80-140 plants m^{-2} was suitable for high seed yield of horticultural pea. Townley-Smith and Wright (1994) suggested that in Saskatchewan, field pea should be seeded at the rate of 100 seeds m^{-2}. More recently, the estimated optimum seeding rate for seed yield was 108 (range 82-112 among individual sites) plants m^{-2}, although yield increases were minimal at targeted seeding rates above 50 plants m^{-2} (Johnston et *al*. 2002). This average yield can be compared to the potential yield of the Rahma variety in Tunisia (Srarfi and Kharrat, 2007).

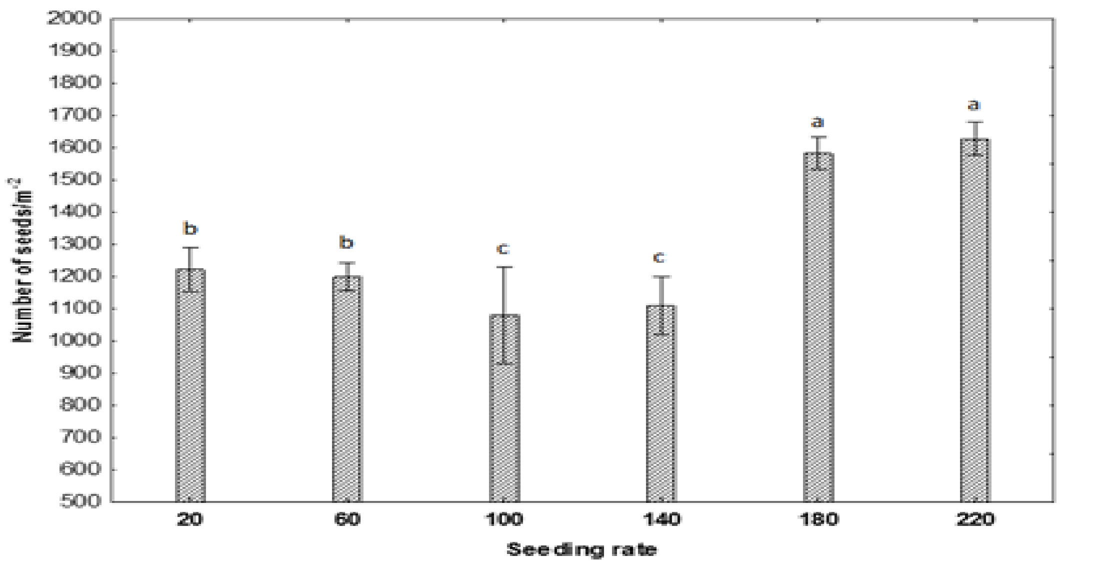


Figure 3. The effect of seeding rate on the number of seeds of field pea. Different letters indicate a significant difference at $P \leq 0.05$, and bars represent + 1 SEM (standard error of the mean).

3.4. Effect of sowing density on the harvest index

The analysis of the effect of planting density on the harvest index which represents the proportion of seeds in the total above-ground biomass produced (fig 4). Significant difference was noted between plants of different densities for the harvest index. The results also show that the average values for the harvest indices vary between 35 and 45% with the different planting densities. Harvest index was maximized at planting densities of 60 and 180 plants/m^2, respectively, while grain yield was maximized at 180 plants/m^2 and 200/m^2. Liang et al, 2019 found a decrease in harvest index due to increased planting density for different planting

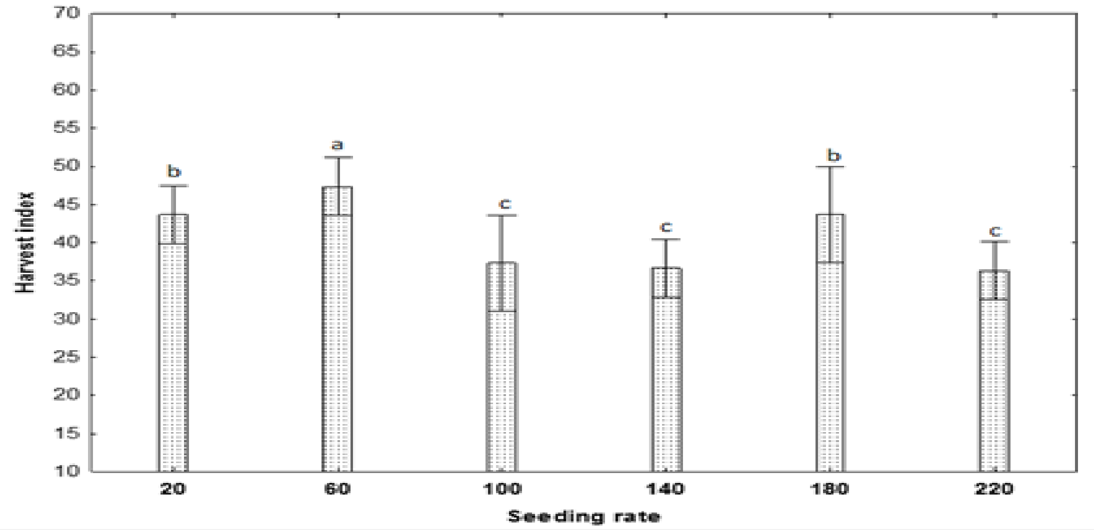


Figure 4. The effect of seeding rate on the harvest index of field pea. Different letters indicate a significant difference at P ≤ 0.05, and bars represent + 1 SEM (standard error of the mean).

3.5. Correlation between seed yield parameters

The correlation matrix between seed yield/m^2 and the main components of seed yield was calculated (Table 2). The seed yield was positively correlated with the number of pods per m², the number of seeds per m² and the weight of 100 seeds. Our results agree with those of French (1990) who mentioned that through multi-local and multi-year pea trials in South Australia, seed yield is most strongly related to the number of pods per m². In more favorable growing conditions, on the other hand, it is the weight of the seeds and the number of seeds per pod that contribute the most to the yield (Poggio et *al*. 2005; Spies, 2011). However, the calculation of the correlations shows a strong correlation between the number of seeds per plant and the number of pods per plant (r = 0.99 *). On the contrary, these two parameters are negatively correlated with the seed yield (Table 2).

4. Conclusion

Our work represents a first step towards the constitution of an appropriate technical package for the cultivation of field peas from local genetic material, under local rain conditions. The effect of six seeding densities 20, 60, 100, 140, 180 and 220 seeds/m^2 on growth and seed productivity of field pea (Afila) have been investigated under rainfed conditions in a semi-arid bioclimatic stage site. Results proved that the increase in seedling density resulted in a significant increase in seed yield of 145 for the density of 140 seeds/m^2 to 273 g/m^2 for the density of 220 seeds/m^2. Thus, the average yield was 18 qx/ha against a yield having a ceiling of 30 qx/ha. A seeding density of around 200 plants/m^2 could be considered suitable for producing optimal yields of seed of field pea.

Table 2. Matrix of correlations between seed yield / m^{-2} and seed yield parameters (number of pods per plant, number of pods per m^{-2}, number of seeds per m^{-2}, number of seeds per plant and weight of 100 seeds).

	Seed yield /m^{-2}	**Weight of 100 seeds**	**Nber pods/plt**	**Nber pods/m^{-2}**	**Nber seeds/m^{-2}**	**Nber seeds/plt**
Seed yield /m^{-2}	1	0,45*	0,04 ns	0,47*	0,57*	0,06 ns
Weight of 100 seeds		1	0,42*	-0,30 ns	-0,26 ns	-0,40 ns
Nber pods/plant			1	-0,10 ns	-0,25 ns	0,99*
Nber pods/m^{-2}				1	0,55*	-0,17 ns
Nber seed/m^{-2}					1	-0,19 ns
Nber seed/plte						1

*: Significant at the 5% threshold, ns: Not significant.

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