Influence of sowing techniques and pesticide application on the emergence and the establishment of bean plants (Phaseolus vulgaris L.)

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Agronomie 24 (2004) 113–118

DOI: 10.1051/agro:2004007

Original article

Influence of sowing techniques and pesticide application on the emergence and the establishment of bean plants (*Phaseolus vulgaris* L.)

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(Received 10 March 2003; accepted 16 January 2004)

Abstract – The emergence and the establishment of beans are affected by bean seed fly attacks, soil fungi and crust formation. This work was carried out during 1998 and 1999 in the province of León (Spain). A split-split-plot design with three replications was used. The main plot was the bean cultivar (Riñón de León and Canela), the subplot was the application system of pesticides (untreated, treatment of seed before sowing and treatment of seed during sowing) and the sub-subplot was the sowing technique: sowing in raised beds, sowing in flat land without adding substratum, sowing in flat land adding sawdust and sowing in flat land adding vermiculite. The sowing in flat land, adding substrate to the sowing line, allowed the acceleration of the common bean emergence and the improvement of its establishment. Application of pesticides to the sowing line accelerated the bean emergence. Highly significant interaction between environment and sowing technique was obtained for all characters recorded.

bean seed fly / damping-off / root rot / crust / sowing techniques

1. INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is a major food crop in Spain, where it is consumed either as dry bean (pulse) or as snap bean (fresh vegetable), and sometimes as both types. The province of León is located in the Northwest of Spain and it is the main common bean-producing area in Spain, producing over 40% of total Spanish dry bean production.

The emergence and establishment of common bean depend on seed-related factors, but also on environmental factors. The main problems that appear during the sowing to emergence and establishment period are: bean seed fly attack, mycosis due to fungi (root rot) and the existence of a superficial crust that represents a physical barrier for the emergence of plants.

The bean seed fly (*Delia platura* [Meigen]) is a small dipterous insect of the *Anthomyiidae* family. It is polyphagous, affecting more than 40 different host plants, which it attacks during germination, reducing emergence and therefore causing serious economic losses [21]. It is a major pest in many countries of the world [40]. The most serious attack is that of first-generation larvae in spring [40]. It affects the buried seed or the cotyledons of the seedling before sprouting. The larvae penetrate the germinating seeds or the seedlings and mine the cotyledons, the small shoots and/or young roots before sprouting. When the plant is further developed, its tissues are harder and less vulnerable to attack. The period in which the plant is at greatest risk lasts 3–4 weeks. The attack weakens or kills nearly-emerged plants [45], sometimes necessitating re-sowing if treatment is not available. Plants thus attacked are also more susceptible to diseases caused by soil fungi [18]. The longer the lapse between seeding and the emergence of the cotyledons on the ground, the greater is the risk, attacks also being favoured by conditions of high moisture and low temperatures [21], and by a high content of organic matter in the soil. Since the attack affects buried seeds or cotyledons, the seeds are treated before sowing with insecticides [41]. These are preventive treatments, and by the time the damage is evident it is usually too late to do anything [21]. However, seed treatment can cause other problems such as premature germination (if sowing is delayed and the treatments are applied in a moist medium); hardening of the head, which makes germination difficult; impaired fluidity of seeds in seed drills, etc. Applying insecticides to the soil also gives good results, but, when the fly populations are large, then a combination of seed and soil treatment becomes necessary [21].

Root rot brings together the diseases caused by soil fungi; these diseases appear in all regions where common bean is cultivated [4]. They cause loss of plants, seriously limit establishment and can lead to a low development of the plants [42]. These fungi can appear in common bean individually or associated; antagonism and synergism phenomena may then be observed [9]. These diseases may be divided into three groups, based on the plant organ or growth stage they affect: damping-off, root rot and wilts. Damping-off causes seed rot, when the

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attack is in pregermination or in germination, or death of plants, when it occurs after germination. The main fungi responsible for damping-off are *Pythium* spp., *Rhizoctonia solani*, *Sclerotium rolfsii* and *Macrophomina phaseolina* [4, 27]. The main fungi responsible for root rot are *Pythium* spp., *Fusarium solani*, *Aphanomices eutiches*, *Sclerotium rolfsii*, *Macrophomina phaseolina* and *Rhizoctonia solani* [4, 20, 27]. They cause rot and/or destruction of roots, restricting the absorption of water and nutrients.Wilts appear after flowering, so they do not influence the establishment of common bean plants. Fast emergence can reduce root rot [26]. The use of fungicides increases germination and growth of plants, reduces damping-off, and improves emergence [13].

The superficial crust is a physical barrier for plant emergence [3, 10, 29, 38] and for crop establishment. Its formation depends on the soil characteristics, the soil management conditions and the environment [7]. The crust is a hard superficial layer with little porosity and low permeability [3, 7]. It is caused by rainwater drops' impact on soil [38], by the movement, the accumulation and the deposition of fine particles of soil at the end of a shower of rain [2], by chemical dispersion, or by a combination of these factors [7], when the soil dries off. The crust can develop in all soils except sandy soils, but its formation is easier in soils with a high content of thin sands and slime. Its hardness depends on physical and chemical factors, such as the texture and structure of the soil, aggregate stability, organic matter content and water content [3, 6]. Crust formation before plant emergence leads to a small establishment because it prevents emergence [10]. When its formation occurs during emergence, it causes broken plants. It may also cause strangulation problems if the formation occurs after emergence [3]. The organic material on the soil surface reduces crust formation [7, 15]. The addition of several substrates over the seed zone [15] prevents superficial crust formation, improving emergence.

This study evaluates different sowing techniques and different methods of bean seed protection in order to assess their influence on the emergence and the establishment of bean cultivars.

2. MATERIALS AND METHODS

2.1. Site characteristics

Four experimental plots were established in the province of León (Spain), two in 1998 and two in 1999, using two traditional bean cultivars (Canela and Riñón de León) and different sowing methods. The site characteristics are shown in Table I.

The 1998 plots were located in Ribas de la Valduerna and San Pedro Bercianos and, respectively, had an organic matter content of 2.8% and 2.2%, and a loamy and sandy loam texture. The previous crops in both had been sugar beet. The 1999 plots were located in Ribas de la Valduerna and Bercianos del Páramo, and had an organic matter content of 2.5% and 1.1%, respectively, and a loamy texture. The previous crop at Ribas de la Valduerna had been wheat and at Bercianos del Páramo, maize.

Table I. Climatic conditions and site characteristics of locality where the experimental plots were established during the experimental period.

	Locality			
	Ribas de la Valduerna[a]		San Pedro Bercianos[b]	Bercianos del Páramo[b]
Year	1998	1999	1998	1999
Average rainfall (mm)				
May	70.3	48.9	78.1	105.9
June	49.0	22.5	52.2	24.5
Number of days of rain				
May	7	10	10	8
June	1	2	3	2
Average temperature (°C)				
May	9.4	10.4	13.0	13.4
June	14.3	12.8	17.2	17.1
Longitude	5°57.1 W		5°42.2 W	5°42.2 W
Latitude	42°18.5 N		42°23.6 N	42°22.8 N
Altitude	799 m		828 m	824 m

[a] Source: Meteorological Station of Astorga, Spain.
[b] Source: Meteorological Station of Laguna Dalga, Spain.

Table II. Characteristics of bean cultivars used in this experiment.

	Bean cultivars	
	Canela	Riñón de León
Seed colour	Cinnamon (light brown)	White
Weight 1000 seeds	525 g	450 g
Growth habit	Type I (Determinated bush)	Type I (Determinated bush)
Cycle	Long (115–120 days)	Medium (100–105 days)

2.2. Experimental design

Sowing was carried out following a statistical pattern of subdivided plots (split-split-plots) with three replicates and three factors.

The main factor was the bean cultivars, Riñón de León and Canela, whose characteristics appear in Table II.

The secondary factor was the use or non-use of insecticides, those used being himexazol and diazinon. The doses were those recommended by the manufacturers (0.001 m^3/m^3 for himexazol and 0.002 m^3/m^3 for diazinon), with three different application methods: zero application (untreated seeds), treatment of seeds before sowing and treatment in the sowing line directly on the soil during sowing, after placing the seed on the soil but before burying it.

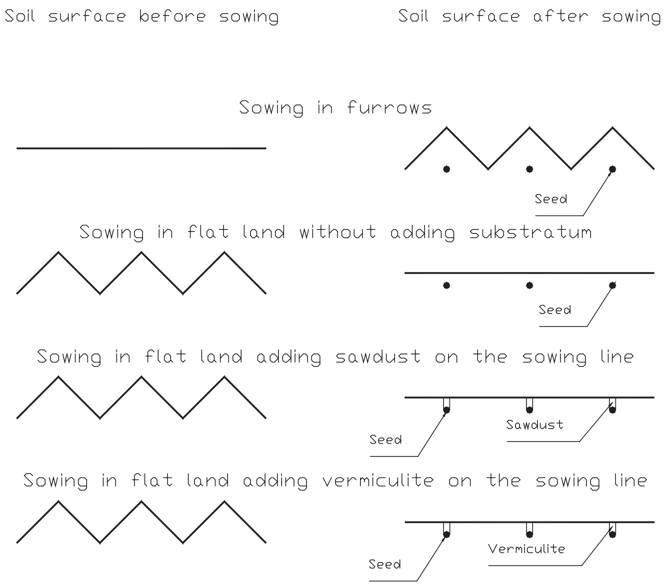

Figure 1. Sketch of different types of sowing used.

The tertiary factor was the sowing technique. Four techniques were tried (Fig. 1):

– Sowing in furrows or raised beds: the sowing was done on flat land, earthing up on the sowing line, over the seed; leaving the post-sowing surface furrowed and the seed buried more than 0.1 m deep, because the sowing train ends in two earthing-up ploughshares. For this reason, the plot was smoothed down 8–10 days after sowing.
– Sowing on flat land without adding substrate: the surface of the plot was furrowed as a result of the last preparatory work. This was carried out well in advance (two weeks) to preserve moisture. The seed was then sown in these furrows. The seed drill broke the raised beds, leaving the post-sowing surface flat, with the seed buried 0.02–0.03 m deep.
– Sowing on flat land with sawdust added to the sowing line: this mode of sowing is similar to the previous one, but a narrow band of dry, clean, sieved sawdust was put over the seed up to the surface level. About 10 m^3/ha of sawdust were used at a cost of 0 €/ha, as the sawdust was free.
– Sowing on flat land with vermiculite in the sowing line: this mode of sowing is similar to the previous one but with the addition of vermiculite. About 10 m^3/ha of vermiculite was used at a cost of around 500 €/ha.

The experimental plot was 16.5 m^2, with lines 0.55 m apart and a space between plants of 0.15 m, for a total of 200 plants per plot. One seed was dropped in every blow.

The sowing was carried out with an adapted, single-seed, pneumatic seed drill. A seed drill prototype with a distributor-dose meter system for substrate was developed to avoid the formation of crust on the sowing line.

In 1998, sowing was carried out in the 3rd week of May, and in 1999 in the 4th week of the same month. The plots were kept free from weeds by applying Ethalfluralin prior to sowing (doses: 0.0025 m^3/ha).

2.3. Data collected

The following traits were recorded in plots on the basis of sub-sub-plot averaged value:

- Emergence: number of days from sowing until 50% of the expected plants show the cotyledons at soil level.
- Number of plants emerged: total number of emerged plants from sowing to 30 days after the sowing, independent of sanitary state.
- Number of plants established: total number of existing plants (good plants) at the end of the establishment period (30 days after the sowing).

2.4. Data analyses

Analysis of variance appropriate to a split-split-plot design was performed using the general linear models (GLM) procedure of the SAS statistical package [33]. Cultivars, insecticide application and sowing technique were considered to be fixed effects. The least significant difference (LSD) method ($P < 0.05$) was used to evaluate differences between treatments when they were observed to be significant.

3. RESULTS

The results of the analysis of variance for the obtained data are shown in Table III.

3.1. Emergence

The analysis of variance showed highly significant differences for the sowing techniques. The sowing in flat land adding substrate (sawdust or vermiculite) on the sowing line was the most favourable technique for emergence; on the other hand, the sowing in furrows technique resulted in a longer emergence (Tab. IV).

Significant differences between pesticide applications were found. The treatment on the seeds in the sowing line directly on the soil during sowing, after placing the seed on the soil but before burying it, allowed a reduction in the emergence time (Tab. V).

The analysis of variance also showed significant differences for the environment.

Moreover, there were highly significant interactions between environment and sowing techniques and significant interactions between application of pesticides and sowing techniques.

3.2. Number of plants emerged

The analysis of variance showed highly significant differences for the sowing techniques. The sowing in flat land was the most favourable technique for the number of plants emerged. There were no significant differences between sowing in flat land without substratum or adding substratum (Tab. IV).

Furthermore, there were highly significant interactions between environment and cultivar and between environment and sowing techniques.

Table III. Mean squares of the combined analyses of variance for emergence, plants emerged and plants established per plot.

Source of variation	DF	Emergence		Number of plants emerged per plot		Number of plants established per plot	
Analysis of the environment							
L (Environment)	3	287.33	*	6489.69		6839.42	
R (Repetition)	8	57.73	**	1258.75		1464.55	*
Analysis of the main plot							
A (Bean cultivar)	1	0.78		2520.50		245.68	
L × A	3	11.81		4502.01	**	6246.73	**
R × A (L)	8	3.76		442.97		354.18	
Analysis of the sub-plot							
B (Use of pesticide)	2	42.71	*	459.69		3139.71	
L × B	6	5.04		313.14		693.07	
A × B	2	2.84		44.82		74.84	
L × A × B	6	1.48		181.25		244.77	
Analysis of the sub-sub-plot							
C (Sowing technique)	3	245.35	**	18450.62	**	36645.43	**
L × C	9	18.98	**	1392.66	**	884.23	**
A × C	3	2.54		378.58		414.50	
B × C	6	3.67	*	220.25		454.26	
A × B × C	6	1.16		156.56		203.67	
L × A × B × C	45	1.41		153.61		215.34	
Error	176	1.25		170.29		182.23	
Total	287						

DF: degree of freedom.
* Significant at 5%.
** Significant at 1%.

Table IV. Means for emergence, plants emerged and plants established per plot for sowing techniques.

	Emergence (days)		Number of plants emerged per plot		Number of plants established per plot	
Raised beds sowing	14.31	a	148.50	b	129.67	c
Flat land sowing without adding substrate	12.03	b	170.76	a	153.69	b
Flat land sowing adding sawdust	10.53	bc	181.08	a	175.92	a
Flat land sowing adding vermiculite	10.29	c	183.68	a	177.72	a
Least significant difference (0.05)	1.64		14.07		11.21	

Different letters in the same column indicate statistically significant differences (0.05).

Table V. Means for emergence, plants emerged and plants established per plot for the application of pesticides.

	Emergence (days)		Plants emerged per plot	Plants established per plot
Untreated	12.23	a	168.64	152.70
Treatment on the seed	12.11	a	171.44	161.55
Treatment on the sowing line	11.02	b	172.95	163.54
Least significant difference (0.05)	0.79			

Different letters in the same column indicate statistically significant differences (0.05).

3.3. Number of plants established

The analysis of variance showed highly significant differences for the sowing techniques. The sowing in flat land adding substrate (sawdust or vermiculite) on the sowing line provided the greatest number of plants established. There were no significant differences between substrata. The smallest number of plants established was obtained with the sowing in raised beds (Tab. IV).

Similarly to the number of plants emerged, there were highly significant interactions between environment and cultivar and also between environment and sowing techniques.

4. DISCUSSION

Significant differences were detected for the environment in emergence, and highly significant interaction between environment and sowing technique and between environment and bean cultivars. This shows the strong environmental influence on the bean cultivars' performance, which has also been recorded by other authors [32].

4.1. Emergence

The literature shows differences in emergence between cultivars with respect to seed colour [11, 28], but there were no differences between the cultivars used in this work.

The pesticide treatment on the seeds in the sowing line, directly on the soil during sowing, provided the best results. This method allows seed protection, as well as improving germination, possibly due to the moisture increase around the seed [29], thereby reducing the emergence time [11]. The worst results were obtained with untreated seeds or seeds treated before sowing, and there were no significant differences between them. The treatment of the seeds before sowing provides a protective layer on the seeds that increases the possibility of germination [17, 43], but this modifies the germination and seed emergence characteristics [44]. This protective layer does not inhibit germination [41]; although germination is not accelerated, it can even be delayed [44], since this protective layer makes up a temporary barrier for the exchange between seeds and environment and may cause phytotoxicity.

The plots sown using the sowing in flat land adding substrate in the sowing line technique were the plots that emerged in less time. On the other hand, the emergence time in the plots with the sowing in raised beds was longer. This sowing technique favours superficial crust formation and delays the plant emergence [34, 36]. Furthermore, the sowing depth is greater, and this delays emergence, reduces the possibility of emergence [3, 39], and favours the attack of damping-off fungi [26].

Significant interaction between application of pesticides and sowing techniques was detected. This can be explained by the high influence of these factors on pathogen incidence [21, 23], and particularly the sowing [25, 26] during the first crop stage. When the conditions for the crop development are improved, the pathogen incidence decreases [23]; furthermore, the compaction and/or structure loss of the soil is related to the increase in root rot [8].

A highly significant difference between environment and sowing technique was also detected. This could be due to the high influence of the environment on the germination and emergence velocity [16], and to the influence of soil characteristics [6, 38] and climate characteristics [1, 12] on the superficial crust formation.

4.2. Number of plants emerged

The trial soils had a loamy and sandy loam texture; the crust develops very easily on this plots [31] restricting the growth [34] due to mechanical resistance. The plants can exhaust the energy supply of the seed before they can defeat this resistance [35].

According to Demir [11], the emergence in coloured seed is greater but a significant difference was not detected for the bean cultivars in this experiment.

The damage of pathogens can cause faults in the crops' emergence [14] so differences ought to exist between pesticide applications, as fungicide applications reduce damping-off [13] and insecticide applications protect the seed against bean seed fly attack [21, 22]. However, in this work no differences were found for the number of plants emerged between pesticide applications. These results agree with the results obtained by Debicki [10]. According to him, the reduction in emergence in the crusting soils is mainly caused by crusting, whereas in the non-crusting soils the reduction in emergence is caused by other factors.

The sowing techniques influenced the number of bean plants emerged [25]. The sowing in flat land adding substrate provided the best results, as long as these techniques do not allow for superficial crust formation that prevents the plants' emergence; the same result has been indicated by other authors [30, 39]. These techniques also allow the improvement of the germination conditions [17] and a faster development of the plants [36]. The emergence of common bean is very sensitive to soil crusting [3, 10], and superficial crust formation is easier in the plots with sowing in furrows or sowing in flat land without substrate. This could explain why their emergence was less and this led to a worse establishment [10]. Furthermore, as the depth of sowing was greater in sowing in furrows, this had a negative effect on plant emergence, as previously indicated by other authors [24, 39]. These results contrast with the results of Henning and Wiebe [15]. They did not find improvement in plant emergence when sawdust or other materials were incorporated onto the soil surface by the seeder during sowing; they did not find it when the sowing line was covered, either. However, Takenaka [37] managed to minimise the negative effect of a superficial crust on the plants' emergence by covering the seeds with materials that did not form a crust; and he did not find differences between substrates, independent of their origin, obtaining an increase in plant emergence, which is in agreement with our results.

The highly significant interaction that was detected between environment and sowing techniques may be due to the influence of the soil characteristics [6, 38] and the climate characteristics [1, 12] on the crust formation, mainly on the hardness.

4.3. Number of plants established

Initial stages in plant development are the most susceptible to adverse environmental conditions [19]. The treatments that had more negative results for emergence were the treatments that provided a lower number of plants established and a less uniform establishment [24].

Significant differences were not detected for the use of pesticides in this experiment, although according to Mote [22] and Trotus et al. [41], the application of pesticides improves the number of plants established, since the number of healthy plants increases [17], due to the reduction in bean seed fly attack and the reduction in the loss of plants to soil mycosis [13, 21].

The sowing in flat land adding substrate in the sowing line increased the number of plants established, because the plant emergence was better, improving both the number of plants emerged and the number of unbroken plants. So, adding substrate in the sowing line prevents crust formation, which improves the establishment of plants [5, 39].

5. CONCLUSIONS

Obtaining some conditions that favour a fast emergence, and reducing the resistance of the soil to emergence had a greater influence on common bean establishment than the phytosanitary treatment carried out for its protection.

The addition of substrate in the sowing line to prevent crusting, when the sowing was carried out in flat land, allowed an acceleration of common bean emergence and an improvement of its establishment.

Acknowledgements: This work was financed by the Diputación Provincial of León.

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