Colegio de Postgraduados

Biomass Incorporation into Degraded Soils and its Effect on the Productivity of Common Bean (*Phaseolus vulgaris* L.)

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ABSTRACT

Objective: to evaluate the effect of incorporating biomass in degraded soils, and fertilization, on yield of common bean plants grown in the semiarid highlands of northern México.

Design/Methodology/Approach: from 2019 to 2022, experiments were established in different soil conditions in Durango (México). Pinto Saltillo (PS) and Negro San Luis (NSL) common bean cultivars were planted in three fertilization treatments, 1: chemical, 2: organic and 3: foliar sprayings. Data were recorded for days to flowering and physiological maturity (days after sowing, DAS), reaction to diseases, yield, and weight of 100 seeds. The analysis of variance was performed in a completely randomized design, with a factorial arrangement, and a partial yield-stability analysis was also included.

Results: the PS cultivar showed precocious flowering (38 DAS) and intermediate maturity (91 DAS); while NSL showed late flowering (43 DAS) and maturity (101 DAS). In most of the conditions, the absence of anthracnose and rust was observed, as well as intermediate and generalized levels (5 and 6 on the CIAT scale) of common bacterial blight (CBB) with low influence on the results obtained. The biological cycle of NSL was longer than PS, influencing its response to the fertilization treatments evaluated. However, yield results were statistically similar among common bean cultivars and fertilization treatments.

Limitations/Implications of the study: leaf biomass incorporated into the soil is a natural and sustainable method for common bean production; although only two common bean cultivars were included in the study.

Findings/Conclusions: soil-incorporated biomass and foliar fertilizer sprayings could be considered as natural low-cost inputs, both related to increased common bean yield in Durango (México).

Keywords: yield, agronomic management, sustainability.

INTRODUCTION

In Durango and other states of the semi-arid highlands of México, physical and chemical degradation of agricultural soils is observed, which aggravates the production problems of common bean plants [1]. Soil degradation is expressed in the low content of organic matter

and limited availability of nutrients, such as potassium, iron and manganese, mainly due to the moderately high pH values (>7.9). The current condition of soils is combined with irregular rainfall, presence of pathogenic organisms, practices of subsistence agriculture and few use of agricultural inputs, which are present in the semi-arid highlands of México. All of this results in the low yield of common bean [2]. In this region, farmers apply chemical fertilizer (granulated and liquid) only when an acceptable amount of rainfall (>200 mm) is recorded from sowing until flowering of the common bean plants. This is due to the high risk of loss of investment in limited humidity conditions, which cause intermittent water stress in the plant.

The indiscriminate use of chemical fertilizers was related to the contamination of water tables, mainly due to the high mobility of some nutrients such as nitrogen that favors the formation of molecules such as nitrites (NO_2) and nitrates (NO_3) [3] that are carcinogenic [4-6]. These molecules are extracted during the pumping of well water and can cause health problems in the human population [7]. In addition, the transport of these molecules in water currents during heavy rains facilitates their accumulation in terrestrial water bodies and in the sea [8]. This causes health damage to macro- and microorganisms that inhabit water currents, river banks and dams; as well as on beaches and the open sea, which represents considerable ecological damage. The use of chemical fertilizer produces a momentary and costly increase in soil fertility, but shows inefficiency during its storage, application and use by plants.

The need to incorporate biomass has been established to increase grain yield in common bean plants for a long time, by reducing the problems caused by drought and low soil fertility. Biomass incorporation must be combined with the genetic improvement of common bean and other efficient and agroecological strategies to implement sustainable production of this legume in northern México.

The common bean varieties developed in Durango show high levels of potential yield, that is, the yield recorded when they are cultivated under irrigated conditions. Nevertheless, under rainfed conditions, the productive capacity of the common bean shows to be lower. Pinto Saltillo and Negro San Luis are the most popular common bean varieties for planting in the semi-arid highlands, due to their adaptation in most of the producing areas of the Mexican states of Durango and Zacatecas. The use of the Environmental Index is one of the techniques used to study the adaptability and stability of a variety yield under different evaluation conditions [9]. The technique consists of the linear regression of the yield of each variety at a specific site, in relation to the average of all varieties at that site. The objective was to evaluate the effect of biomass incorporation into degraded soils and fertilization on the yield of common bean plants grown in the semi-arid highlands of northern México.

MATERIALS AND METHODS

During the spring-summer cycles from 2019 to 2022, six experimental and commercial plots were established in different locations in the common bean-producing area of the state of Durango, México. Thus, six soil conditions which define growth environments were established at the planting sites, Durango 2020, Durango 2021, Durango 2022, La

Soledad (Canatlán) 2022, Poanas 2022 and La Purísima (Cuencamé) 2022. Two varieties of common bean (Pinto Saltillo and Negro San Luis) were planted and treatments 1: chemical fertilization, 2: organic fertilizer and 3: foliar application were evaluated. The experimental plot, for each variety, consisted of 20 rows of 100 m in length and 0.81 m of separation (1600 m^2), for a total area of about 1 ha. Chemical fertilization was based on technical recommendations for irrigated common bean cultivation in Durango [10], which include the 35-50-00 dose for nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O). The dose was obtained by mixing 109 kg of diammonium phosphate (DAP: 18-46-00) and 37 kg of urea (46-00-00); as well as with the calibration of the fertilizer canisters. The application was mainly carried out at the time of the first cultural work (weeding), which was made in stage V_3, related to the deployment of the first leaflet.

The application of biomass and compost (organic treatment) consisted of the incorporation of 6 Mg ha^{-1} of crushed maralfalfa (*Pennisetum* sp.) biomass and other experiments, established at a commercial level, in which compost mechanically incorporated into the soil was used. In the foliar fertilization treatment, a combination of liquid products (6 L ha^{-1} UAN 32®+5 L ha^{-1} FertigroP® or 1.1 L ha^{-1} of Bayfolán®) was applied during the pre-flowering stage (R_5), which was carried out by means of manual spraying equipment. Insecticide (dimethoate or spinetoram) was applied up to four times, to control the mexican bean beetle (*Epilachna varivestis*) and the pod weevil (*Apion* sp.). The weed control was achieved through two mechanized weedings, an application of herbicide (Fomesafén=Flex®) and two manual weedings made with a hoe. In Durango (2020, 2021 and 2022) and in La Soledad, of Canatlán municipality, a gravity supplemental irrigation was applied to avoid water stress in the common bean plants in order to obtain a greater expression of the genetic yield potential.

The number of days to flowering, reaction to diseases, days to physiological maturity, yield and weight of 100 seeds were evaluated. Days to flowering and physiological maturity [11] were counted in days after sowing (DAS). When the common bean varieties reached the phenological stage of grain filling (R_8), the reaction to the diseases with the highest incidence in Durango was evaluated; anthracnose (*Colletotrichum lindemuthianum*), rust (*Uromyces appendiculatus* var. *appendiculatus*) and common bacterial blight [*Xanthomonas axonopodis* (syn. *campestris*) pv. *phaseoli*]. The evaluation used the scale ranging from 1 to 9, proposed by the International Center for Tropical Agriculture-CIAT [11]. On this scale,

Table 1. Soil Characteristics in six conditions of evaluation of the effect of biomass incorporation on the yield of two common bean varieties in Durango, México.

Environment	Soil Type	[1]O. M.	N	P	K	pH
Durango, 2020	Clay Loam	Medium	High	[2]M. L.	Very High	8.2
Durango, 2021	Clay Loam	Very High	Low	Low	Very High	8.3
Durango, 2022	Clay Loam	High	Medium	M. L.	Very High	8.4
La Purísima, 2022	Sandy Loam	M. L.	Low	M. H.	M. H.	8.1
La Soledad, 2022	Loamy Sand	M. L.	Very Low	M. L.	High	8.3
Poanas, 2022	Sandy Loam	M. L.	Low	M. H.	High	8.6

[1]O.M.: organic matter content, N: nitrogen, P: phosphorus, K: potassium; [2]M. L.: moderately low content, M. H.: moderately high content.

common bean varieties classified in categories 1 to 3 are considered as resistant; 4 to 6, intermediate; and between 7 and 9 are susceptible to pathogenic microorganisms.

After maturity, the yield and weight of 100 seeds were determined in each of the varieties and treatments under study. The useful plot (8.1 m^2) consisted of two 5 m furrows 0.81 m apart, with five replications. The manually harvested plants were sun-dried, mechanically threshed and then the grain was cleaned with a sieve and electric blower for the removal of impurities. The cleaned grain was weighed on a digital scale with an accuracy of 0.1 g, for the estimation of the yield (kg ha^{-1}). The weight of 100 seeds (g) was determined in each of the samples obtained in the field, by collecting a random sub-sample of 100 whole and well-developed grains.

Field data were used in the analysis of variance to identify the outstanding variety or fertilization treatment. The yield and weight of 100 seeds were analyzed based on a completely randomized design, with factorial arrangement (varieties×fertilization treatments) and five replications. The comparison of means was performed with Tukey's test ($p \leq 0.05$). SAS© version 9.4 was used to perform both, the analysis of variance and multiple comparison of means, as well as the analysis of adaptability and yield stability.

RESULTS Y DISCUSSION

The Pinto Saltillo common bean variety showed precocity to flowering, with an average of 38 days after sowing (DAS) ranging from 31 to 48 DAS. The maturity of this variety was intermediate (91, 86-96 DAS) [12], through the environmental conditions defined by the study; when compared with Negro San Luis, which showed late flowering (43, 35-52 DAS) and maturity (101, 91-112 DAS) (Table 2). In most years there was an absence of symptoms of anthracnose and rust; and only in 2022, in the sites of La Purísima and

Table 2. Variables evaluated in two common bean varieties grown under six production conditions and three fertilization treatments in Durango, México.

Environment	Variety	[1]DF	A	R	B	DPM
Durango, 2020	Pinto Saltillo	41	1	1	5	96
Durango, 2021	Pinto Saltillo	39	1	1	6	90
Durango, 2022	Pinto Saltillo	48	1	1	6	95
La Purísima, 2022	Pinto Saltillo	31	2	1	6	90
La Soledad, 2022	Pinto Saltillo	36	1	1	6	86
Poanas, 2022	Pinto Saltillo	34	2	1	6	90
	Average	38				91
Durango, 2020	Negro San Luis	48	1	1	5	106
Durango, 2021	Negro San Luis	46	1	1	5	112
Durango, 2022	Negro San Luis	52	1	1	5	108
La Purísima, 2022	Negro San Luis	35	1	1	6	95
La Soledad, 2022	Negro San Luis	42	2	1	6	91
Poanas, 2022	Negro San Luis	38	1	1	5	94
	Average	43				101

[1]DF=days to flowering, A=anthracnose, R=rust, B=common bacterial blight, DPM=days to physiological maturity.

Poanas, very light symptoms (2, in CIAT scale) of anthracnose were recorded in the case of Pinto Saltillo (Table 1). In the case of Negro San Luis, similar levels of anthracnose symptoms were observed in La Soledad, Durango. In the case of common bacterial blight, intermediate (5, in CIAT scale) to generalized (6, in CIAT scale) levels of the disease were recorded [11], for both varieties under all environmental conditions under study.

The results showed that the prolonged duration of the biological cycle of the Negro San Luis variety influenced the use of each of the fertilization treatments included in the study. The influence of pathogenic microorganisms was low and, in the case of common bacterial blight, it presented similarity in both varieties through environments, so the effect on the results obtained was reduced.

Statistically equal results were recorded for grain yield between fertilization treatments and common bean cultivars (Figure 1). Only slight (non-significant) differences were observed between common bean cultivars for grain yield among plant nutrition systems and higher values (1929 to 2156 kg ha^{-1}) were recorded for Negro San Luis. This was mainly due to biomass incorporation into the soil combined with a late maturity (115 DAS), which allowed this variety to take advantage of the benefits of the organic matter incorporated. Among the benefits of incorporating organic matter are the increased fertility and nutrient availability; as well as the improvement of soil structure, moisture retention capacity and microbial activity [13].

In the case of Pinto Saltillo cultivar, it showed a shorter range of grain yield with values between 1853 and 1917 kg ha^{-1} related to intermediate maturity (96 DAS). The response of this variety was lower in the organic treatment, due to the shorter biological cycle and this makes it necessary to recommend biomass incorporation before planting, so that all the benefits from the organic matter activity can be obtained.

In each Environmental Index (EI), larger, although not significant, increases in yield were recorded in soils treated with biomass incorporation, mainly in the late-season variety (Negro San Luis) (Figure 2). The highest yield values in Negro San Luis were observed in the organic treatment with values ranging from 915 kg ha^{-1} in the least productive environment, up to 3498 kg ha^{-1} in the site with the highest level of productivity. Foliar application of liquid fertilizer caused low yields in Negro San Luis

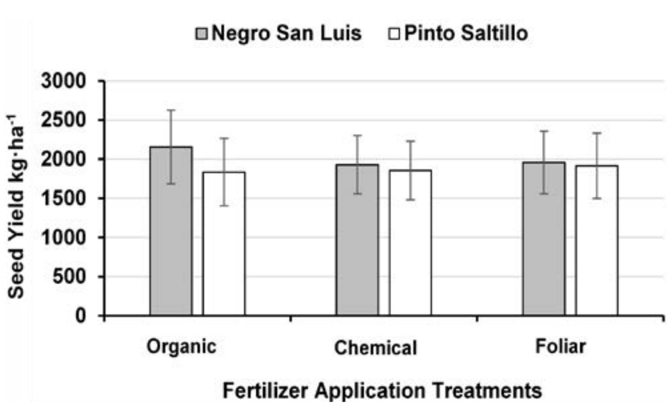

Figure 1. Effect of fertilization treatments on the average yield of two varieties of common bean, grown in six soil conditions (environments) in the state of Durango, México.

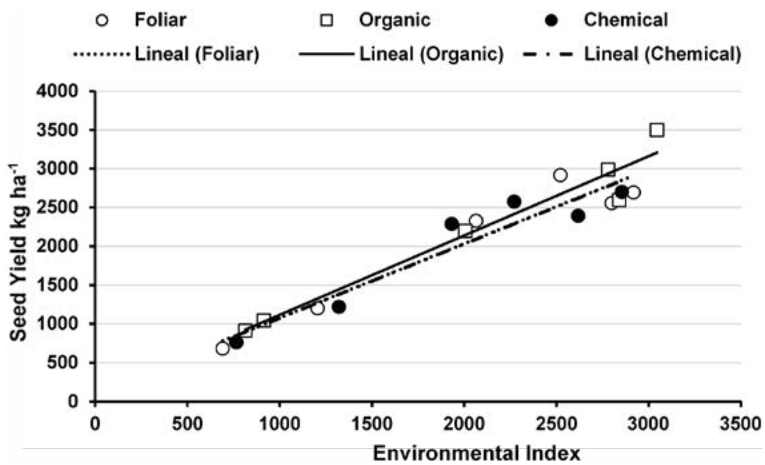

Figure 2. Effect of fertilization treatments on the yield of the Negro San Luis variety (NSL) of common bean, grown at six soil conditions (environments) in the state of Durango, México.

(687 to 2695 kg ha^{-1}); however, it was statistically equal to that obtained with the use of granulated chemical fertilizer (766 to 2700 kg ha^{-1}). Soil-incorporated biomass should be considered as a low-cost and sustainable system related to increased yield in the semi-arid highlands of México.

It is necessary to evaluate the date of early application of the biomass (before planting) to favor the efficient use of organic matter by common bean plants, whose varieties present different number of days to physiological maturity. The biological cycle of common bean is relatively short (86 to 120 days), which limits the use of nutrients from decomposing the natural biomass, such as that obtained from Maralfalfa grass (*Pennisetum* sp.).

The highest yield values in Negro San Luis were observed for the organic treatment, with values ranging from 915 kg ha^{-1} in the least productive environment, up to 3498 kg ha^{-1} in the site with high productivity. Foliar application of liquid fertilizer caused low yields in Negro San Luis (687 to 2695 kg ha^{-1}); however, it was statistically similar to those obtained by using chemical fertilizer (766 to 2700 kg ha^{-1}). It is necessary to evaluate the date for early application of the biomass (before planting) to achieve the efficient use of organic matter by common bean plants that present different number of days to physiological maturity.

In Pinto Saltillo, the same yield response was observed between fertilization treatments, with values ranging from 691 kg ha^{-1} in the least productive environment, up to 3138 kg ha^{-1} in the site with high productivity, which was achieved with foliar application of liquid fertilizer (Figure 3). It was observed that the biomass incorporated into the soil favored Pinto Saltillo at a lower level, compared to Negro San Luis. This is mainly due to the late moment of application, and the intermediate biological cycle that limited the benefits of the incorporation of organic matter into the soil. Similar results were obtained in previous studies with common bean, in which the application of organic matter reached yields (1.82 to 1.98 Mg ha^{-1}) statistically equal to the treatment with chemical fertilization [14]. In other studies, increased biomass accumulation was observed in broccoli plants with distinct types of organic fertilization [15].

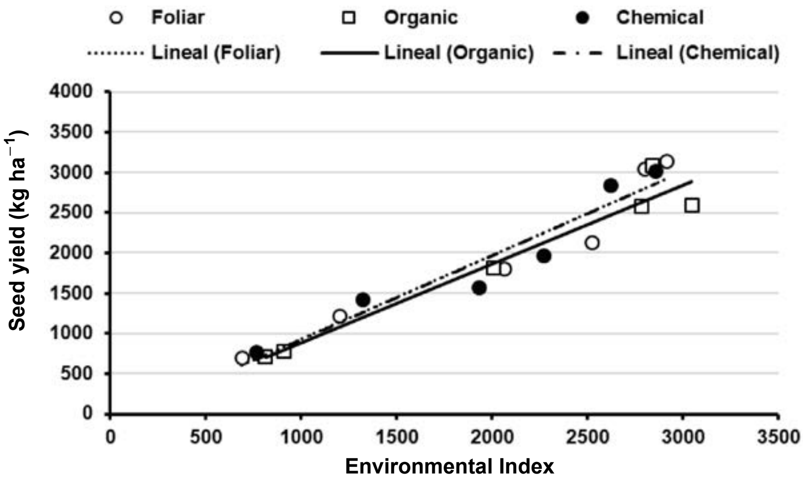

Figure 3. Effect of soil biomass application on the yield of the Pinto Saltillo variety of common bean, grown under six soil conditions (environments), in Durango, México.

CONCLUSIONS

Biomass incorporation into degraded soils, during the post-emergence of seedlings, had a positive effect statistically equal to that obtained with chemical fertilization, on the grain yield of common bean, mainly in the late-maturing variety (Negro San Luis). Liquid fertilizer favored the yield of the improved variety of intermediate maturity (Pinto Saltillo), although the influence was statistically equal to the use of granular chemical fertilizer and the use of organic fertilizer.

Common bean varieties responded differently to fertilization treatments; which is derived from their geographical and genetic origin, as well as from duration of their biological cycle. That is why it is necessary to adjust the timing, and methods of application of biomass and organic fertilizer before sowing, to optimize their positive effect on common bean yield. The goal is to strengthen sustainability in the cultivation of common bean plants, under the soil conditions of the semi-arid highlands of México.

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