EFFECT OF PYMARC WITH NPK 17-17-17 AND INTRA-ROW SPACING ON SOIL AND BUSH BEAN (*Phaseolus Vulgaris L.*) YIELD IN VOLCANIC HIGHLAND, RWANDA

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Abstract

Bush bean is the poor families' meat in Rwanda and grown in many corners of the country. However, unevenness application of organic and inorganic amendments brought soil degradation including soil toxicity or deficiency and low bush bean production. The objective of this study was to evaluate the effect of pymarc rates with NPK and spacing on Soil organic matter, physical parameters and bush bean yield parameters in volcanic highland. The design was RCBD with four replications and the experiment had two factors; Pymarc rates: P0(control), P1(250Kg ha^{-1}NPK), P2(10 tons ha^{-1}pymarc+250 Kg ha^{-1} NPK), P3(15 tons ha^{-1}pymarc+250Kg ha^{-1}NPK) and P4(20 tons ha^{-1}pymarc+250Kg ha^{-1}NPK) and spacing levels: S1(40cm x15cm), S2(40cm x 20cm) and S3(40cm x 30cm). Results showed that, highly significant difference ($p<0.01$) was in treatments and greatest improvements were brought out by P2S1 with lowest Bd(0.95 g cm^{-3}), highest WHC(38.34 %) and porosity(42.18 %) at harvesting with mean yield of 3.03 t/ha compared to P0S3 with least values of studied attributes. Highest SOM content was found out in P4S3 and P3S1 of 9.84 % and 9.75 % sequentially. The correlation analysis results between WHC, Porosity, SOM and yield varied from weak to strong ($0.4>r$, $r>0.7$), significant ($p<0.05$) and positive while the same relationship but negative existed between Bd and other parameters. Therefore, sowing the bush bean at the spacing of 40cm x15cm with application of 10t ha^{-1}pymarc+250 Kg ha^{-1} NPK 17-17-17 could be recommended to agronomists and farmers from volcanic highland in Rwanda for bush bean optimum yield.

Key words: Pymarc, spacing, Bush bean and NPK

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INTRODUCTION

Agriculture is generally known as the cornerstone of worldwide economy in a sense that it provides raw materials, food and employment as well (Ali *et al*. 2018). However, in Africa, especially in sub-Sahara, there is decrease of capacity to produce enough food and thus it has turned out to be a stumbling block as contrasted to human population increase (Partey & Thevathasan, 2013). In accordance to Borlaug & Dowswell, (1993) cited by Shand, (2007), who stated that, the most difficult problem is to feed a prolific population from unproductive soil in a frangible world. Soil productivity decrease is a hindrance to support crop yield and soil fertility in numerous countries (Roba, 2018). Among the constraints of sustainable soil fertility, it includes imbalance usage of mineral and organic fertilizers (Bhattacharyya *et al*., 2008). Nevertheless, organic wastes from different sources can be used as organic fertilizers to enhance sustainable agriculture (Marmo, 2008). The soil physical properties are of paramount importance in sustaining agricultural production (Lucas *et al*., 2018). Organic wastes (including industrial wastes) are the sources of soil organic matter, plants nutrients and enhancement of soil physical properties (Hernández *et al*., 2016) for they improve soil bulk density, soil porosity and water holding capacity (Li *et al*., 2018; Lucas *et al*., 2018). The application of either mineral fertilizers alone or only organic amendments can't achieve sustainable yields where high nutrients replenishment is required and thus, combination of both mineral and organic fertilizers improve bulk density, porosity and water holding capacity (Dhaliwal *et al*., 2019; Rasool *et al*., 2008; Tadesse *et al*., 2013). Nonetheless, projection of inorganic inputs use is anticipated to increment from 142 million tons in 2003 to 199 million tons in 2030 at worldwide level and the highest use of the expected inorganic fertilizer will be sub-Saharan Africa including Rwanda (Shand, 2007). This mineral fertilizers projection which doesn't plan for organic inputs is very perilous, for the excessive use of inorganic inputs impact negatively on soil physical and chemical properties (Pant & Ram, 2018). Additionally, use of mineral fertilizers alone reduces SOC which leads to poor porosity, decrease in WHC and increase in soil bulk density (Castro *et al*., 2002; Sarkar *et al*., 2003). To overcome the nefast effects of inorganic fertilizers, pyrethrum marc is an option when mixed with NPK 17-17-17, for it is an industrial waste obtained after the extraction of pyrethrins (Nyongesa *et al*., 2009). It is rich in NPK as contrasted to farm yard manure (Nyongesa *et al*., 2010; Shand, 2007). However the impact of pyrethrum marc on soil organic matter and soil physical properties is less known in Rwanda. Besides that, different plant densities affect physical properties (Yu *et al*., 2018) and influence soil organic matter (Duan *et al*., 2019). Nevertheless, less data is available in terms of bush bean spacing, in Rwanda (Musana *et al*., 2020) and its influence on soil organic matter (SOM), physical parameters and bush bean yield parameters as well. Bearing in mind these effects, the present study aims at availing data about the impact of applying pymarc with NPK 17-17-17 and plant spacing on soil organic matter (SOM), physical parameters and bush bean yield parameters in Volcanic highland. Specific objectives were: i) Determine the effect of Pyrethrum marc rates combined with NPK 17-17-17 on SOM, soil physical parameters and bush bean yield, ii) Determine the impact of bush bean spacing on SOM, soil physical properties and bush bean yield parameters and iii) Determine interaction effect of applying pymarc with NPK 17-17-17 and plant spacing on SOM, soil physical properties, bush bean yield and yield parameters.

MATERIALS AND METHODS

Study site description

This study was conducted in a field located in Cyuve sector, Musanze District one of 5 Districts which make Northern Province at 1º29'00.0" S latitude and 29º39'35.38" E longitude, during season A of 2022. The field is at 1875 m above sea level and the total rainfall received on the site from September to December, 2021 was 77.4.6 mm with effective rainfall of 519.68 mm. The area had an average annual rainfall which varied from 1400 m to 1800 m with the mean temperature of 20º C (Maniriho & Bizoza, 2018). The soil of the site was highland volcanic and its taxonomy was andosol (FAO, 2014).

Treatment, Design and Management

The experiment was factorial with five pyrethrum marc application rates P0(No pymarc and NPK), P1(0 t/ha of pymarc + 250 Kg ha^{-1} of NPK 17-17-17), P2(10 tons ha^{-1} of pymarc + 250 Kg ha^{-1} of NPK 17-17-17), P3(15 tons ha^{-1} of pymarc + 250 Kg ha^{-1} of NPK 17-17-17) and P4(20 tons ha^{-1} of pymarc + 250 Kg ha^{-1} of NPK 17-17-17) with three levels of spacing: S1(40 cm x 15 cm), S2(40 cm x 20 cm) and S3(40 cm x 30 cm). The experimental field was designed in complete randomized blocks with 4 replicates. Blocks were separated by 1 m while plots were spaced by 50 cm and the size of each experimental unit was 1.5 m x 1.8 cm. In terms of agronomic practices, pymarc was applied 3 days before sowing while NPK was incorporated twice, 3 weeks and 6 weeks after sowing. Additionally, thinning was done once and weeding was done twice, pests and diseases were treated accordingly, with respective pesticides and fungicides.

Data collected

Collected data were about: soil organic matter (SOM), Bulk density (Bd), water holding capacity (WHC) and soil porosity (ϕ) at blooming stage and post-harvest time. In light of yield attributes, number of beans per pod, number of pods per plant and bush bean yield data were recorded.

1.1. Collection and Laboratory analysis of soil samples and Pymarc

In order to analyze SOM, WHC and porosity (ϕ), soil samples were taken from 0-20 cm of depth with diagonal method by the help of soil Auger while for Bd core cylinders were used to gather samples of soil. Soil samples for SOM, WHC and porosity were collected from experimental field, mixed to make composite samples, air dried and sieved by 0.5 and 2 mm sieves. Soil organic matter was determined by loss on ignition method (Schulte & Hopkins, 1996) and pH was determined using glass electrode method (Jackson, 1958). Soil bulk density (Bd) was determined by core cylinder method (Blake & Hartge, 1986). The soil water holding capacity was determined by funnel method (Bernard, 1963). Soil porosity was determined by saturation method (Matko, 2004; Netto, 1993) while the soil texture was determined by hydrometer method (Bouyoucos, 1962). The organic fertilizer (Pymarc) used for this study was derived from pyrethrin extraction factory (SOPYRWA) located in Musanze District of Northern Province.

Data analysis

Genstart 14th edition helped to analyze variance and means were compared by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$. Correlation analysis with Pearson correlation method ($p \leq 0.05$) was carried out by Stata 13(64-bits).

RESULTS AND DISCUSSION

Pre-sowing characteristics of soil and pymarc

The soil texture was fine sandy loam for the soil contained 19.80 % of clay, 0.10 % of silt and 80.10 % of sand. This texture is preferred by the bush bean, however optimum yield is attained in well-drained sandy loam soils (Leap *et al.*, 2017).The bulk density was 1.16 g/cm^3 and according to the findings of Castro *et al*., (2002); Shein, (2004); Shober, (2009) and Tirado-Corbala & Slater, (2010), it is ideal for bush bean farming. Water holding capacity was 29.2 % and is good for sandy loam soils as they give optimum yields of bush bean by allowing free movement of water beneath them (Haqiqi *et al*., 2020; Revell *et al*., 2012; Elsas *et al*., 2000). The soil porosity was 37.2 % (Table 1), and it was also falling within the limits of sandy loam soil (33% to 47 %) and favorable for optimum bush bean growth and yield as found out by Alhammadi & Al-Shrouf, (2013) and Hartmann & Lesturgez, (2005). The soil was moderately acidic with pH of 5.59 (Horneck *et al*., 2011). According to Duarah *et al*., (2011), the optimum pH range for bush bean varies from 5.5 to 6.8. The soil organic matter before sowing was 7.25 % and according to Kalisa & Nshimyumukiza, (2007), the organic matter was high. The organic fertilizer used (pyrethrum marc) contained organic matter content of 67.20% and with reference of Kalisa & Nshimyumukiza, (2007) it was too high while the pH was 7.1 and as rated by Ransom, (2004), it was slightly alkaline.

Effect of pymarc on SOM, selected physical parameters and yield parameters

The results from Table 3, indicated that a highly significant difference was reigning among treatments ($p<0.01$) at flowering stage whereby the highest organic matter content (8.83 %) was in pymarc treatment P2 which had 10 t/ha of pymarc together with 250 kg/ha of NPK while P0 (No fertilizer added) and P1 (250 kg/ ha) contained less organic matter with 7.17 and 7.73 % in 0-20 cm depth. At harvesting time organic matter was great in P3 with 9.52 % as opposed still to P0 and P1. The amount of OM had increased as compared to initial soil organic matter. This was attributed to the highest content of organic matter in pyrethrum marc (67.20 %). These results were found out by Lin *et al*., (2019) and Zhang *et al*., (2019), who argued that decomposion of organic fertilizers add on organic matter in soil . Still from the flowering to harvesting time, the gradual decomposition of pymarc (Ogutu, 2013), increased its content at harvesting time by releasing humic acids, hymatomelanic acids, fulvic acids and humin through humification and same findings were also reported by Hadas & Rosenberg, (1992); Senesi, (1989) and Shaji *et al*., (2021).

Taking into consideration selected physical parameters, P2 was very outstanding at flowering stage with Bd (0.96 g/cm^3), and WHC (37.22 %) and ϕ (41.2 %) contrasted to P0 with greater bulk density of 1.02 g / cm^3, WHC (28.38 %) and 37.94 %. In terms of NPK treatment the treatment P1 had high Bd, less WHC and porosity. At harvesting time, still the same trend was magnified with P2 which had less Bd (0.954 g/cm^3), WHC (38.34 %) and porosity of 42 .18 %. As opposed to P0 (Bd: 1.007 g/cm^3, WHC: 31.39 % and Porosity: 37.95 %) and P1 (Bd: 0.966 g/cm^3, WHC: 33.58 % and Porosity: 38.83 %) with least values but about Bd, P3 (15 tons ha^{-1} of pymarc + 250 Kg ha^{-1} of NPK) had same effect as P2. The increase in water holding capacity (WHC) and porosity was attributed to the increase in pores space and decreased bulk density in depth of 0-20 cm. These results are in same line with findings of Li *et al.*, (2018); Papini et al., (2011); Prabakaran, (2006) and Rasool *et al.*, (2008) who found out that the dispersal of pore-size is refashioned and the relative number of micro and macro pores escalates and in this study, pymarc instigated soil particles sticking together thus making favorable conditions for plant roots and micro-organisms for sandy loam soils. All in all, soil WHC is dictated by: i) the distribution of total pores and ii) Soil particles surface area and these factors were impacted by addition of pymarc, reason why WHC of the soil greatly waxed as it was reported by Verma *et al*., (2010).

Furthermore, soil water is held by adhesive forces (between soil particle and water molecule) and cohesive (between water molecules themselves) and the increase of 1% of OM boosted WHC by 3.7 %. Bhadha *et al*., (2017) and Nath, (2014), noted same effect organic matter on the increase of WHC. Amid yield and yield parameters, a significant difference was found in pods per bean plant, beans per pod and yield whilst no significant difference was revealed in 100-seeds weight ($p<0.05$). The treatment P4 had great mean number of pods per plant with 8.3 as opposed to the rest of treatments while P2 had high mean number of beans per plant (5.2) and high yield of 2.47 t/ha compared to P0 and P1. Note that the treatment P3 had same effect as P2 in regard of mean yield. Organic fertilizers incorporated in soil at 10 tons ha^{-1} in conjunction with mineral fertilizers were reported to give highest yields and yield parameters (Ahmadi & Arain, 2021; Sharma *et al.*, 2009).

Effect of plant spacing on OM, physical parameters, yield and yield attributes

In response to the impact of plant spacing on soil organic matter, table 3 results revealed that a highly significant difference was ruling among treatments ($p<0.01$). At both stages, the spacing treatment S3 (40 cm x 15 cm) with wide spacing contained highest amount of OM equal to 8.67 and 8.37 % respectively compared to the rest of treatments. The consumption of OM became high in narrow plant spacing due to the increase of competition between plants and this was in accordance with the findings of Duan *et al.*, (2019). Especially at harvesting time the soil OM decreased due to excessive use of OM and other nutrients to reach maturity stage. Jia *et al*., (2018), reported that 40 % of all required nutrients for its whole cycle are needed at maturity stage. Regarding selected physical parameters, Bd, WHC and porosity, the highly significant difference was outliving between the treatments ($p<0.01$). Furthermore, S1(40 cm x 10 cm) showed tremendous improvements in Bd, WHC and porosity with respective values, 0.96 g/cm^3, 34.8 % and 40.81 at blooming period while at harvesting time it had 0.95 g/cm^3, 37.38 %

and 41.12 sequentially as opposed to S3 (40 cm x 30 cm) which had least values of WHC (32.00 %) and Porosity (38.08 %) with high bulk density of 0.99 g/cm^3 at lowering while at harvesting it showed poor improvements in Bd (0.98), WHC(34.26 %) and Porosity (38.58 %) (Table 3). The awesome changes in physical properties of narrow spacing S1 could be attributed to the expansion of root system, break and interlacing in soil resulted in making gentle and porous root-soil fusion which progressively ameliorated physical properties. Yu *et al.*, (2018) found out that the increase in plant density led to increased pores in soil. Furthermore, the increase in soil micro and macro-pores led to the decrease in bulk density (Rasool *et al.*, 2008). High number of plants per unit area generated high number of roots (root density) in soil and thus, more soil pores were created (Yu *et al.*, 2018; Zhou *et al.*, 2007). There was a closer link between Bd, porosity and WCH, for the increase in soil porosity led to increment of soil WHC (Mohamed *et al.*, 2016). Water is stored in soil under adhesion and cohesion forces, the increase in pores resulted also in increase of adhesion and cohesion forces and attracted huge molecules of water. Additionally, Rasool *et al.*, (2008) reported same effect. About the influence of spacing on the yield and yield parameters, the only significant difference was found out in bush bean yield ($p<0.05$). No significant difference was found out in number of beans per pod, number of pods per bush bean plant and weight of 100-seeds weight between treatments. The highest yield was recorded in S1 (40 cm x 15 cm) with 2.38 t/ha as opposed to the rest of spacing treatments. Findings of Hadiayompamungkas *et al.*, (2019) and Muchira *et al.*, (2018) also showed that same spacing resulted in high yield.

Interaction effect of pyrethrum marc and spacing on OM, physical properties, yield and yield parameters

A perusal of results of interaction effect of pyrethrum marc and bush bean spacing on soil OM, pointed out that highly significant difference was found out in treatments ($p<0.01$) and at flowering stage three treatments contained high amounts of OM notably P3S3(9.40 %) with 15 tons ha^{-1} of pymarc + 250 Kg ha^{-1} of NPK and spacing of 40 cm x 30 cm; P4S3 (9.37 %) with 20 tons ha^{-1} of pymarc + 250 Kg ha^{-1} of NPK coupled with spacing of 40 cm x 30 cm and P2S3 (9.32 %) with 10 tons ha^{-1} of pymarc + 250 kg ha^{-1} of NPK and spacing of 40 cm x 30 cm as contrasted to P0S1 (No fertilizer added and 40 cm x 15 cm) with least amount of OM (6.84 %) while at harvesting stage two treatments, P4S3 and P3S1(15 t/ha of pymarc + 250 kg/ha and 40 cm x 15 cm) contained great amount of OM with 9.84 % and 9.75 % respectively compared to P0S1 with 6.55 % of OM (Table 4). The increase in organic matter for treatments which received high rates of pymarc laid behind pyrethrum marc decomposition which was induced by light absorption and incited the breakdown to free radical products, percolation, decomposition of non-mineral substances into inorganic ones by soil microflora and micro-organisms (Comminution). Similar findings about organic matter decomposing process and release of mineral compounds was reported by Antil & Singh, (2007) and Menšík *et al.*, (2018).

In regard of interaction influence of spacing and pymarc on selected physical parameters, still the highly significant difference was reigning amid treatments ($p<0.01$). The treatment P2S1 had exhibited enormous changed in owning least bulk density at both stages with 0.940 g/cm^3 and 0.935 g/cm^{3}at flowering and harvesting times respectively compared to P0S3 and P0S2 with Bd of 1.045 and 1.036 g/cm^3 at flowering and both treatments had Bd of 1.03 g/cm^3 at harvesting time. However at blooming stage, P3S1 and P0S1 exerted same effect as P2S1 whereas at harvesting P3S1 and P4S1 had same impact as P2S1. In regard of WHC, the interaction effect was highly significant ($p<0.01$) and P2S1 retained more water 39.43 % sequentially as compared to P0S3 and P0S2 at blooming stage. At harvesting the trend in WCH was that P2S1, P3S1 and P4S1 held much water with 40.6 %, 40.2 % and 39.6 % respectively whilst P0S3 retained least water (Table 4). Concerning the interaction effect of pymarc and spacing on porosity, the very significant difference was shown amid treatments ($p<0.01$). Globally, at both blooming and harvesting stages P2S1 had high porosity of 42.8 % and 44.1 % correspondingly and P4S3 had low porosity of 37.1 % while at harvesting P0S3 indicated low porosity with 37.5 %. The use of only inorganic amendment led to the slight increase of bulk density. This negative effect (soil degradation) from using only mineral fertilizers on soil was also reported by Kibunja *et al.*, (2012). Generally in NPK treatments, the pymarc treatment P1 (250 kg/ha of NPK) with either spacing S1, or S2 or S3 had little changes in OM and physical properties when compared to the rest of treatments. The best performance of P2S1 in selected physical properties, proved that pyrethrum marc combined with NPK, ascertained to ameliorate soil physical parameters through increased soil aggregation, upgraded consistency of aggregates and climaxed to decrease in Bd, waxing of WHC and improved soil porosity for sustainable soil productivity (Bhatt *et al.*, 2017; Pant *et al.*, 2017; Rasool *et al.*, 2008). Additionally, high root density helped in improving soil physical conditions as well, as they pushed soil aggregates for their expansion (Yu *et al.*, 2018). About yield and yield parameters, no significant difference was highlighted out in regard of interaction effect of pyrethrum marc and spacing on pods number per plant, beans number per pod, weight of 100-seeds and only Bush bean yield remarked significant difference amid treatments ($p<0.05$). Evidently, P2S1 gave highest yield of 3.03

t/ha as contrasted to P4S1 which had lowest yield of 1.72 tons ha^{-1}. The least yield of P4S1 which received highest application rate of pymarc (20 t/ha) could be attributed to the toxicity caused by excess fertilizer application. Shand, (2007), also reported that the excess of soil nutrients can lead to hidden or visible toxicity.

Correlation analysis between selected pa rameters

The results from table 2 about the relationship analysis, showed that at flowering stage the Bd had a significant, weak and negative correlation with porosity and soil OM ($r<0.4$ and $p<0.05$) while the highly significant, moderate and negative relationship was among Bd and WHC ($0.4<r<0.7$ and $p<0.01$). Additionally, the relationship between WHC and porosity was highly significant, strong whereas a weak, positive and insignificant correlation was among porosity and soil organic matter at blooming stage. At harvesting time, the negative, weak and significant relationship was found out between Bd and porosity and same relationship but not significant between Bd and soil OM. The Bd had still negative but moderate and highly significant relationship with WHC and yield ($0.4<r<0.7$ and $p > 0.01$). Furthermore, the correlation analysis between WHC and porosity was positive, highly significant and strong while amidst it had positive, moderate and highly significant relationship with SOM and bean yield. The porosity exhibited positive, weak and very significant correlation with SOM and same relationship but moderate existed between porosity and yield at harvesting time. Eventually, the correlation between SOM and yield was positive, weak and highly significant ($r<0.4$ and $p<0.01$). The Pearson's correlation coefficient (r) indicated that at both stages, the decrease of Bd resulted in increase of the rest of the correlated parameters for the addition of pymarc into the soil increased OM and it incited soil aggregation, more pores were formed and more water stored in soil pores. In the research conducted by Ahn *et al*., (2008) and Khater (2015), they found out that the decrease of soil bulk density resulted in increase of soil porosity and water holding capacity due to soil aggregation brought out by organic amendments applications. The decrease in Bd created favorable conditions for bush bean growth and yield and similar findings were previously reported by Masood *et al*., (2014) and Tadesse *et al*., (2013).

CONCLUSION

The application of pyrethrum marc combi ned with constant dose of NPK 17-17-17, significantly had interaction effect with intra-row spacing and this resulted in decreased bulk density and increased porosity and water holding capacity at both stages (flowering and harvesting stages). At harvesting, the lowest bulk density of 0.935 g cm^{-3} but favorable to bush bean was found in the treatment P2S1 and still this same treatment had highest soil porosity (39.43 %) and highest water holding capacity (44.1 %) as compared to the remaining treatments. Moreover, the interaction effect of P2 and S1 resulted in highest mean yield of 3.03 tons per ha. From this study, the combined fertilizer application of P2(10 tons ha^{-1} of pymarc + 250 Kg ha^{-1}) together with bush bean spacing S1(40 cm x 15 cm) could be recommended to boost bush bean yield and for optimum use of fertilizers, so as to protect soil against degradation in volcanic highland of Rwanda.

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APPENDICES

Table 1: Initial soil and pymarc characteristics

Parameters	**Initial soil Characteristics**	**Organic Fertilizer (Pymarc) characteristics**
Bd	1.16 g cm^{-3}	-
WHC	29.2 %	-
Soil porosity	37.2 %	-
Texture		
- Sand	80.10 %	-
- Silt	0.10 %	-
- Clay	19.80 %	-
Textural class	Fine Sandy loam soil	-
pH_{water}	5.59	7.1
Organic Matter	7.25 %	67.20 %

Table 2: Correlation analysis among selected parameters

Parameters		**At flowering**				**At harvesting**				
		Bd	**WHC**	**ϕ**	**SOM**	**Bd**	**WHC**	**ϕ**	**SOM**	**Yield**
Bd	r	1.00				1.00				
WHC	r	-0.44	1.00			-0.45	1.00			
	p	0.00				0.00				
ϕ	r	-0.28	0.83	1.00		-0.37	0.81	1.00		
	p	0.03	0.00			0.00	0.00			
SOM	r	-0.33	0.44	0.06	1.00	-0.24	0.61	0.38	1.00	
	p	0.01	0.00	0.63		0.07	0.00	0.00		
YIELD	r	-	-	-	-	-0.69	0.62	0.61	0.31	1.00
	p	-	-	-	-	0.00	0.00	0.00	0.02	

r: Pearson's correlation Coefficient, p: Calculated probability, Bd: Bulk density, WHC: Water Holding Capacity, ϕ: Porosity and SOM: Soil organic Matter

Table 3: Effect of pymarc and spacing on SOM, physical parameters and yield parameters

	At flowering				At harvesting				Yield parameters			
Pymarc treatments	**Bd (g cm^{-3})**	**WHC (%)**	**ϕ (%)**	**SOM (%)**	**Bd (g cm^{-3})**	**WHC (%)**	**ϕ (%)**	**SOM (%)**	**Pods**	**Beans n^{o}**	**100- seeds (g)**	**Yield (t ha^{-1})**
P0	1.02^{a}	28.38^{e}	37.94^{e}	7.17^{e}	1.007^{a}	31.39^{d}	37.95^{e}	6.74^{e}	6.7^{b}	4.8^{c}	59.4^{a}	1.46^{c}
P1	0.99^{b}	29.48^{d}	38.44^{d}	7.73^{d}	0.966^{b}	33.58^{c}	38.83^{d}	7.31^{d}	7.0^{b}	4.9^{bc}	53.0^{a}	2.07^{b}
P2	0.96^{c}	37.22^{a}	41.20^{a}	8.83^{a}	0.954^{c}	38.34^{a}	42.18^{a}	8.12^{c}	6.9^{b}	5.2^{a}	60.4^{a}	2.47^{a}
P3	0.97^{c}	36.02^{b}	40.42^{b}	8.50^{b}	0.954^{c}	36.87^{b}	40.92^{b}	9.52^{a}	7.4^{b}	5.2^{ab}	59.6^{a}	2.36^{a}
P4	0.98^{bc}	35.43^{c}	39.27^{c}	8.27^{c}	0.967^{b}	37.08^{b}	39.81^{c}	9.15^{b}	8.3^{a}	5.1^{ab}	60.0^{a}	2.07^{b}
p-Value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.001	0.025	0.131	< 0.001
Spacing treatments												
S1	0.96^{b}	34.86^{a}	40.81^{a}	7.64^{c}	0.95^{b}	37.38^{a}	41.12^{a}	8.03^{c}	7.4^{a}	5.1^{a}	61.1^{a}	2.38^{a}
S2	0.99^{a}	33.05^{b}	39.48^{b}	7.99^{b}	0.98^{a}	34.73^{b}	40.11^{b}	8.11^{b}	7.1^{a}	5.0^{a}	55.3^{a}	2.00^{b}
S3	0.99^{a}	32.00^{c}	38.08^{c}	8.67^{a}	0.98^{a}	34.26^{c}	38.58^{c}	8.36^{a}	7.3^{a}	5.1^{a}	59.0^{a}	1.88^{b}
p-Value	< 0.001	< 0.001	< 0.001	<0.001	< 0.001	< 0.001	< 0.001	<0.001	0.427	0.862	0.073	< 0.001
CV (%)	2	1.9	1.2	1.5	1.3	2	1.4	0.9	12.3	7.4	13.3	14.3

Values with similar superscript letter in each column do not differ significantly ($p<0.05$), SOM: Soil organic matter, Bd: Bulk density, ***ϕ:*** *Porosity and WHC: Water Holding Capacity*

Table 4: Interaction effect of pymarc and plant spacing on SOM, physical parameters and yield parameters

Treatments	At Flowering				At harvesting				Yield parameters			
	Bd (g cm^{-3})	WHC (%)	ϕ (%)	SOM (%)	Bd (g cm^{-3})	WHC (%)	ϕ (%)	SOM (%)	Pods	Beans No	100-seeds (g)	Yield (t ha^{-1})
P0xS1	0.965^{bcd}	28.72^{gh}	38.4^{fg}	6.84^{h}	0.96^{bc}	28.72^{gh}	38.5^{fgh}	6.55^{l}	6.8^{a}	60.5^{a}	60.5^{a}	1.77^{e}
P0xS2	1.036^{a}	28.40^{h}	37.7^{gh}	7.26^{g}	1.03^{a}	28.40^{h}	37.8^{hi}	6.74^{k}	6.1^{a}	59.1^{a}	59.1^{a}	1.32^{f}
P0xS3	1.045^{a}	28.02^{h}	37.7^{gh}	7.39^{fg}	1.03^{a}	28.02^{h}	37.5^{i}	6.94^{j}	7.3^{a}	58.7^{a}	58.7^{a}	1.30^{f}
P1xS1	0.980^{bc}	28.90^{gh}	38.9^{ef}	7.52^{f}	0.97^{bc}	28.90^{gh}	38.9^{fg}	7.16^{i}	7.2^{a}	58.0^{a}	58.0^{a}	2.15^{bcde}
P1xS2	0.991^{b}	29.40^{fg}	38.7^{ef}	7.80^{e}	0.96^{bcd}	29.40^{fg}	39.3^{ef}	7.36^{h}	6.9^{a}	42.6^{a}	42.6^{a}	2.16^{bcde}
P1xS3	0.993^{b}	30.12^{f}	37.6^{gh}	7.86^{e}	0.97^{b}	30.12^{f}	38.2^{ghi}	7.43^{h}	7.0^{a}	58.4^{a}	58.4^{a}	1.89^{de}
P2xS1	0.940^{d}	39.43^{a}	42.8^{a}	8.39^{c}	0.935^{f}	39.43^{a}	44.1^{a}	7.98^{g}	7.3^{a}	63.2^{a}	63.2^{a}	3.03^{a}
P2xS2	0.974^{bc}	37.23^{c}	41.2^{cd}	8.78^{b}	0.96^{bc}	37.23^{c}	42.4^{b}	7.97^{g}	7.1^{a}	57.2^{a}	57.2^{a}	2.38^{bcd}
P2xS3	0.974^{bc}	35.00^{d}	39.5^{e}	9.32^{a}	0.96^{bc}	35.00^{d}	40.0^{e}	8.40^{f}	6.5^{a}	60.7^{a}	60.7^{a}	2.00^{cde}
P3xS1	0.950^{cd}	39.02^{ab}	42.1^{b}	7.98^{de}	0.94^{df}	39.02^{ab}	42.7^{b}	9.75^{a}	7.3^{a}	62.0^{a}	62.0^{a}	2.61^{ab}
P3xS2	0.975^{bc}	35.40^{d}	40.7^{d}	8.13^{d}	0.96^{bcde}	35.40^{d}	40.9^{cd}	9.60^{b}	7.2^{a}	58.1^{a}	58.1^{a}	1.97^{de}
P3xS3	0.979^{bc}	33.62^{e}	38.4^{fg}	9.40^{a}	0.96^{bcde}	33.62^{e}	39.1^{f}	9.20^{c}	7.8^{a}	58.7^{a}	58.7^{a}	2.49^{bc}
P4xS1	0.979^{bc}	38.22^{b}	41.7^{bc}	7.48^{f}	0.95^{cdef}	38.22^{b}	41.2^{c}	8.71^{e}	8.8^{a}	61.7^{a}	61.7^{a}	2.32^{bcd}
P4xS2	0.981^{bc}	34.85^{d}	38.9^{ef}	7.96^{de}	0.97^{b}	34.85^{d}	40.1^{de}	8.90^{d}	8.1^{a}	59.7^{a}	59.7^{a}	2.17^{bcde}
P4xS3	0.975^{bc}	33.22^{e}	37.1^{h}	9.37^{a}	0.98^{b}	33.22^{e}	38.0^{hi}	9.84^{a}	8.0^{a}	58.8^{a}	58.8^{a}	1.72^{ef}
p-Value	0.011	< 0.001	< 0.001	<0.001	< 0.001	< 0.001	< 0.001	<0.001	0.544	0.681	0.519	0.016
CV (%)	2	1.9	1.2	1.5	1.3	2	1.4	0.9	12.3	7.4	13.3	14.3

Means which have similar letter in column do not differ significantly (P<0.05), SOM: Soil Organic Matter, WHC: Water Holding Capacity, ϕ: Porosity and Bd: Bulk density