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Agronomic Performances of Compost Associated with Pollinating Insects on the Growth and Yield of *Glycine max* (L.) Merril under Field Conditions

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Abstract

Soybean is an oilseed crop legume cultivated for its benefits as a source of protein to human or animal food. The cultivation of soybean will promote the diversification of income sources for rural population. Like other crops, soybean flowers are visited by insects. It is expected that within the biodiversity conservation program, anthophilous insects including bees, generally increase fruit and seed yields of many plant species. Therefore, the effect of insect pollinators and compost on growth and yield parameters of *Glycine max* was assessed for two cropping seasons (2018 and 2019) in the field. The experiment was set up in a complete randomized block design with three treatments: subplots applied with compost; subplots applied with fertilizer-NPK; subplots applied neither with compost, nor with fertilizer-NPK. Two other treatments were designed by plants with flowers protected against insects or flowers pollination free. Results indicate that root nodules formed by soybean plants in plots that received compost were significantly higher ($P < 0.001$) than those from positive and negative controls. During the 2018 and 2019 cropping seasons, 948 and 593 visits from five insect species were recorded on *G. max* flowers respectively. *Lipotriches collaris* was the most insect species frequently observed in the field, with 44.20% and 43.34% visits yearly respectively. The synergistic effect of insects and compost increased the number of seeds per pod by 28.27% and the percentage of normal seeds by 24.47%. Hence, applying *Glycine max* seeds at sowing with compost and in an environment with hives close to field could be recommended in agricultural development programs of farmers for a sustainable improvement of pods and seed yield of this valuable crop.

Keywords

Soybean, *Lipotriches collaris,* Compost, Pollination, Yields

1. Introduction

Soybean (*Glycine max* L.) is an important source of vegetable oil and protein in the world [1]. In Africa, after groundnut and rapeseed-mustard, it is ranked as the third most important oilseed crop [2]. Soybean is a very important crop as rotation plant [3]. However, the drought tolerance and ability to produce yield in soils that are too poor are the agronomic values of this crop [4]. It enriches the soil with nitrogen for other crops through atmospheric nitrogen fixation, through the established symbiosis with *Rhizobium*, and is therefore beneficial in crop rotation and inter-cropping. In many African countries, Soybean is a highly versatile bean that can be processed into oil, flour and milk [2]. Nutritionally, it contains 20% oil and protein 40% with 6% - 7% total mineral, 5% - 6% crude fiber, 5% ash and 17% - 19% carbohydrates [2]. Soybean proteins contain a good amount of isoflavones which helps in preventing heart disease [2]. It is used for the production of various daily popular consumed products, such as soybeans sauce, cake, milk and for animal feed industries.

Poor management of soil fertility in most African countries due to massive population growth affects agricultural production by increasing demand for agricultural products, thus intensifying the pressure on natural resources, and consequently the continual depletion of soil fertility [5]. Yet the amount of nutrients present in the soil during the crop cycle determines the quality of plant mineral nutrition and largely the quantitative yields of crops [6]. Mineral fertilizers coupled with their low accessibility to growers are limiting factors for plant growth [7]. Hence, providing organic amendments to soil could be cheaper and more beneficial for maximizing crop yield in the context of the high cost of mineral fertilizers [8].

The production of soybean in Cameroon was estimated at 12,544 tonnes for a pressure-demand of over 15,260 tonnes in 2010 [9]. Therefore, it is important to investigate the possibilities of increasing the production of this valuable plant. In Cameroon, few pieces of research have been reported on the effects of different doses of cattle manure yield components of soybean as second crop organic production [1], on nutrient management practices for enhancing soybean production [10] and the residual effects of composted and fresh solid swine (*Sus scrofa* L.) manure on soybean growth and yield [4]. However, research on pollinating insects has been increased because of their vital importance in the pollination of food crops [11] [12]. In the world, the role of pollinators for many plant species is well known and their activities are essential for ecosystem functioning and agriculture [13] [14]. Up to date, no previous research has been reported in Adamawa Region on the relationships between compost, anthophilous insects and yield of soybean. This work was conducted to gather more data on the relationships between *G. max*, compost and flower-visiting insects for the optimal management of pollination services. The registration of the activity of insects on *G. max* flowers, the evaluation of the effect of flowers visiting insects on pollination, pods and seeds yields of this Fabaceae, the estimation of the impact of compost on *G. max* and the evaluation of the influence of the cumulative action of compost and flowers visiting insects are discussed.

2. Materials and Methods

2.1. Study Site, Experimental Plots and Biological Material

Investigations were carried out in the field from May to September 2018 and 2019 at Dang (latitude 7˚42.264'N, longitude 13˚53.945'E and altitude 1106 m above sea level) in Ngaoundere III Subdivision, Vina Division, Adamaoua Region in Cameroon. The site belongs to the high-altitude Guinean savannah agroecological zone. The climate is characterized by a rainy season (April to October) and dry season (November to March), with an annual rainfall of approximately 1500 mm. The mean annual temperature is 22˚C, while the mean annual relative humidity is 70% [15]. The animal material was mainly represented by insects naturally present in the environment and 35 colonies of *Apis mellifera* Linnaeus (Hymenoptera: Apidae) found close to the experimental field. The flora surrounding *G. max* field had various unmanaged and cultivated species. Compost was produced in the Composting Unit established and monitored at the Faculty of Science of the University of Ngaoundere. Approximately 1000 g of compost per hole were applied as a layer into sowing hole before sowing. *Glycine max* seeds (**Figure 1**) were provided by the Institute of Research for Agricultural Development (IRAD) at Wakwa-Ngaoundere (life cycle of 155 to 160 days). The fertilizer-NPK used was of the formula 20:10:10, purchased from a local phytosanitary store. It was applied 14 days after sowing, at a rate of 10g within the rhizosphere of each plantlet.

Figure 1. Soybean seeds of the TGX 1910-14F variety.

2.2. Land Preparation

On May 7, 2018 and May 15, 2019, experimental soil was plowed and divided into nine subplots of 3 m^2 each. Three subplots were applied with compost, three with chemical fertilizer-NPK and three others left unapplied neither with compost nor with fertilizer-NPK. Two seeds were sown per hole on three lines per subplot, for a total of 12 holes per line. Holes were separated 25 cm from each other, while lines were 30 cm apart. Weeding was performed manually as necessary to maintain subplots weed-free.

2.3. Determination of the Reproduction Mode of Soybean

On July 24, 2018, six subplots carrying 216 plants with 16,150 flowers at the bud stage were labeled. Three subplots carrying 108 plants with 8246 flowers were left open to be pollinated by insects (treatment 1) (**Figure 2**), while three others carrying 7904 flowers were protected with white gauze cages (1 mm^2 mesh) to prevent insect or other pollinating animals visits (treatment 2) (**Figure 3**). On July 27, 2019, the experiment was repeated. For treatment 3, there are three subplots carrying 108 plants with 10,130 flowers and for treatment 4, there are three subplots carrying 108 plants with 9873 flowers. Twenty days after shading of the last flower, the number of pods was assessed in each treatment. The fruiting index (P_i) was then calculated as described by [16]: $P_i = F_2/F_1$, where F_2 is the number of pods formed and F_1 the number of viable flowers initially set. The allogamy rate (Alr) from which derives the autogamy rate (Atr) was expressed as the difference in fruiting indexes between treatment X (unprotected flowers) and treatment Y (bagged flowers) as follows [17]: $Alr = [((P_iX - P_iY))/(P_iX)]*100$, Where P_iX and P_iY are respectively the podding average indexes of treatments X and Y $Atr = 100 - Alr$.

Figure 2. Soybean subplot showing unprotected plants.

Figure 3. Soybean subplot showing isolated plants.

2.4. Assessment of the Influence of Inoculation on Nodulation and Biomass of Soybean

For each uninoculated subplot (treatment a), subplot inoculated with compost (treatment b), and (subplot applied with fertilizer-NPK (treatment c), sampling for the assessment of plant biomass was done on 15 randomly selected plants per elementary plot at 60 days after planting (DAP), enumerated, sun dried, stored in envelopes, and weighed. Plants were dried in an oven at 72˚C for 12 hours and weighed [18]. Plant biomass and nodulation were evaluated on the same 45 individual plants of treatments a, b and c.

2.5. Determination of the Foraging Activity of Insects on Soybean Flowers

The frequency of insect visits on *G. max* flowers was evaluated based on observations scheduled on four daily time frames (09:00-10:00 am, 11:00-12.00 am, 13:00-14:00 pm and 15:00-16:00 pm) in all treatments. From July 27th to August 27th 2018 and from July 30th to August 31th 2019, flowers were entirely opened at 09:00 am and closed before 16:00 pm, corresponding to the period of insects activity. All insect visits were recorded on flowers of treatment 1. Specimens of all insect taxa (3 to 5 per species) caught with an insect net on flowers were conserved in 70% ethanol, except Lepidoptera that were kept in curls for subsequent taxonomy determination. All insects observed on flowers were noted, and the cumulated results were expressed in number of visits to determine the relative frequency of each insect species in the anthophilous entomofauna of *G. max* [19]. In addition to the determination of the floral insects' frequency, direct observations of the foraging activity on flowers were made on each insect species in the experimental field. Nectar or pollen harvested by insects during each floral visit was registered based on their foraging behavior [11].

In the morning of each sampling date, the number of opened flowers was counted, whereas the duration visits of each insect were recorded (using a stopwatch) for at least three times during each of the following daily time frames: 10:00 am-11:00 am, 12:00 am-13:00 pm and 14.00 am-15:00 pm. Moreover, the number of pollinating visits [19], the abundance of foragers [20] and the foraging speed referring to the number of flowers visited by an insect per minute [21] were determined.

Abundance of insects per flower was recorded following direct counts. For the abundance per 1000 flowers (A_{1000}), the number of foragers was counted at blooming flowers on the same dates and daily periods as for the registration of the duration of visits. (A_{1000}) was calculated by the formula: $A_{1000} = [(A_x/F_x)*1000]$, where F_x and A_x are the number of opened flowers and the number of insects effectively counted on these flowers at time x [19]. The foraging speed was calculated by the formula: $V_b = [(F_i/d_i)*60]$, where d_i is the time (sec) given by a stopwatch, and F_i, the number of flowers visited during d_i.

Around experimental plot, the disruption of the activity of each insect forager by competitors and the attractiveness exerted by other plant species on *G. max* insect foragers were assessed. Ambient temperature and relative humidity were recorded at each observation date after every 30 minutes, using a portable thermo-hygrometer (HT-9227).

2.6. Evaluation of the Relationship between the Flowering Rhythm of Soybean and the Rhythm of Pollinating Insects

From start of the flowering of the first flower to the wilting of the last flower, bloomed flowers of treatment 1 were counted. Data obtained were compared with the number of insect visits on the corresponding flowers.

2.7. Assessment of the Impact of Compost on Yield of Soybean

The estimation of this parameter was based on the effect of compost on *G. max* yield. The comparison of productivity (fruiting rate, mean number of seeds per pod and percentage of normal seeds) of treatments 2 (bagged flowers) and 5 (bagged flowers inoculates by compost) for the first year, 4 (bagged flowers) and 6 (bagged flowers inoculates by compost) for the second year were assessed as influenced by compost on soybean plants.

2.8. Assessment of the Cumulative Action of Insects and Compost on Soybean Yield

This evaluation was based on the impact of both compost and insects on *G. max* yield. The comparison of yields (fruiting rate, mean number of seed per pod and percentage of normal seeds) of treatment 9 and 10 with those of treatments 2 and 4 were assessed. The contribution of cumulative action of insects and compost on soybean fruiting rate, mean number of seeds per pod and the percentage of normal seeds was calculated using data of treatment 9 or 10 (inoculated flowers open to insects) and those of treatment 2 or 4 (bagged flowers).

2.9. Data Analysis

To analyze the data we used Microsoft Excel 2010 software and four test: Student's (t) for comparison of means of two samples, correlation coefficient (r) to determine the linear relationship between two variables, Chi-square (χ^2) to compare two percentages and Statgraghics Centurion for the comparison of means of more than two samples.

3. Results

3.1. Reproduction of the Breeding Mode of Soybean

Table 1 indicates that the allogamy rate was 14.01% and 12.73%, respectively in 2018 and 2019, whereas the autogamous rate was 85.99% and 87.28% respectively in 2018 and 2019. For the two cumulative years, the allogamy rate was 13.37% and the autogamy rate was 86.63%. Thus, soybean variety used in this experiment has a mixed autogamous allogamous reproduction mode with the predominance of autogamy.

Table 1. Allogamy and autogamy rates of soybean in years 2018 and 2019.

Years	Autogamous rate (%)	Allogamous rate (%)
2018	85.99	14.01
2019	87.28	12.73
Mean (2015/2016)	86.63	13.37

3.2. Influence of Compost on Numbers of Flowers, Nodulation and Biomass of Soybean

Plants inoculated with compost at sowing produced a significantly greater number of nodules, nodule dry weight and plant biomass compared to uninoculated plants in 2018 and 2019 (Table 2).

3.3. Frequency of Each Insect in *Glycine max* Entomofauna

At Dang in 2018 and 2019, 948 and 593 visits of six insect species belonging to three orders were counted on 8246 and 10130 flowers respectively. Table 3 presents the list of the insects with their percentages of visits. This table shows that Hymenoptera was the most important order with 82.09% of 1265 visits. The most represented family was Halictidae, among which *Lipotriches collaris* ranked first with 43.87%; Diptera and Lepidoptera were poorly represented with 4.80% and 13.11% of visits each for all the treatment and the two years respectively.

A highly significant difference was obtained between flowers from the control and those from the compost plants ($P < 0.001$ in 2018 and 2019) and between the control and chemical fertilizer ($P < 0.001$ in 2018: 2019).

Table 2. Variation of nodulation and plant biomass of soybean as affected by compost application in 2018 and 2019.

Years	Treatments	Number of nodules per/plant	Weight of dry nodules (g/plant)	Plant biomass (g/plant)
2018	PC	(29.1 ± 0.82)a	(1.55 ± 0.03)a	(34.36 ± 1.21)a
	PE	(18.23 ± 0.82)b	(0.77 ± 0.03)b	(21.17 ± 1.21)b
	PN	(7.42 ± 0.82)c	(0.29 ± 0.03)c	(11.19 ± 1.21)c
	***P*-value**	<0.001	<0.001	<0.001
2019	PC	(32.55 ± 1.07)a	(1.67 ± 0.04)a	(36.84 ± 1.12)a
	PE	(21.33 ± 1.07)b	(0.88 ± 0.04)b	(25.71 ± 1.12)b
	PN	(8.11 ± 1.07)c	(0.31 ± 0.05)c	(14.77 ± 1.12)c
	***P*-value**	<0.001	<0.001	<0.001

In each column, the means followed by the same letter are not significantly different at 5% level.

Table 3. Diversity of insects visiting *Glycine max* flowers in 2018 and 2019 at Dang (number and percentage of insect visits).

		Insects	2018					2019					2018/2019	
			Subplot			Total		Subplot			Total		Total 2018/2019	
Order	Family	Genus, species	PC	PE	PN	n_1	P_1 (%)	PC	PE	PN	n_2	P_2 (%)	n_T	P_T (%)
Hymenoptera	Apidae	*Apis mellifera* (nectar)	69	43	31	143	15.08	41	25	21	87	14.67	230	14.92
	Halictidae	*Ceratina* sp. (nectar, pollen)	98	77	44	219	23.10	60	47	33	140	23.61	359	23.30
		Lipotriches collaris (nectar, pollen)	172	131	116	419	44.20	108	94	55	257	43.34	676	43.87
		Total Hymenoptera	**339**	**251**	**191**	**781**	**82.38**	**209**	**166**	**109**	**484**	**81.62**	**1265**	**82.09**
Diptera	Syrphidae	*Episyrphus* sp. (pollen)	32	25	17	74	7.81	-	-	-	-	-	74	4.80
		Total Diptera	**32**	**25**	**17**	**74**	**7.81**	**-**	**-**	**-**	**-**	**-**	**74**	**4.80**
Lepidoptera	Nymphalidae	*Precis* sp. (nectar)	-	-	-	-	-	26	18	5	49	8.26	49	3.18
	Pieridae	*Eurema* sp. (nectar)	53	28	12	93	9.81	30	19	11	60	10.12	153	9.93
		Total Lepidoptera	**53**	**28**	**12**	**93**	**9.81**	**56**	**37**	**16**	**109**	**18.38**	**202**	**13.11**
Total			**424**	**304**	**220**	**948**	**100**	**265**	**203**	**125**	**593**	**100**	**1541**	**100**
			5 species					**5 species**					**6 species**	

PC: subplot with compost; PE: subplot with fertilizer-NPK; PN: uninoculated subplot; n_1 and n_2: number of visits on 8246 and 10,130 flowers in 23 and 25 days respectively; sp.: undetermined species; P_1 and P_2: percentages of visits $P_1 = (n_1/929)*100$ and $P_2 = (n_2/593)*100$.

3.4. Activity of Insects on Soybean Flowers

The abundance, the foraging speed and the duration of insect visits were focused on the two major flowers insects visiting of *Lipotriches collaris* and *Ceratina* sp.

3.5. Relationships between Insect Visits and Flowering Stages of the Plant

The number of insect visits is proportional to the number of opened flowers on untreated, compost and chemical subplots of soybean (**Figure 4**). A positive and significant correlation was found between the numbers of opened flowers and the number of insect visits on flower of uninoculated plants ($r = 0.44$; $P < 0.05$) in 2018 and 2019 ($r = 0.42$; $P < 0.05$), compost affixed plants in 2018 ($r = 0.64$; $P < 0.05$) and 2019 ($r = 0.86$; $P < 0.05$), and fertilizer-NPK applied plants in 2018 ($r = 0.57$; $P < 0.05$), and 2019 ($r = 0.47$; $P < 0.05$).

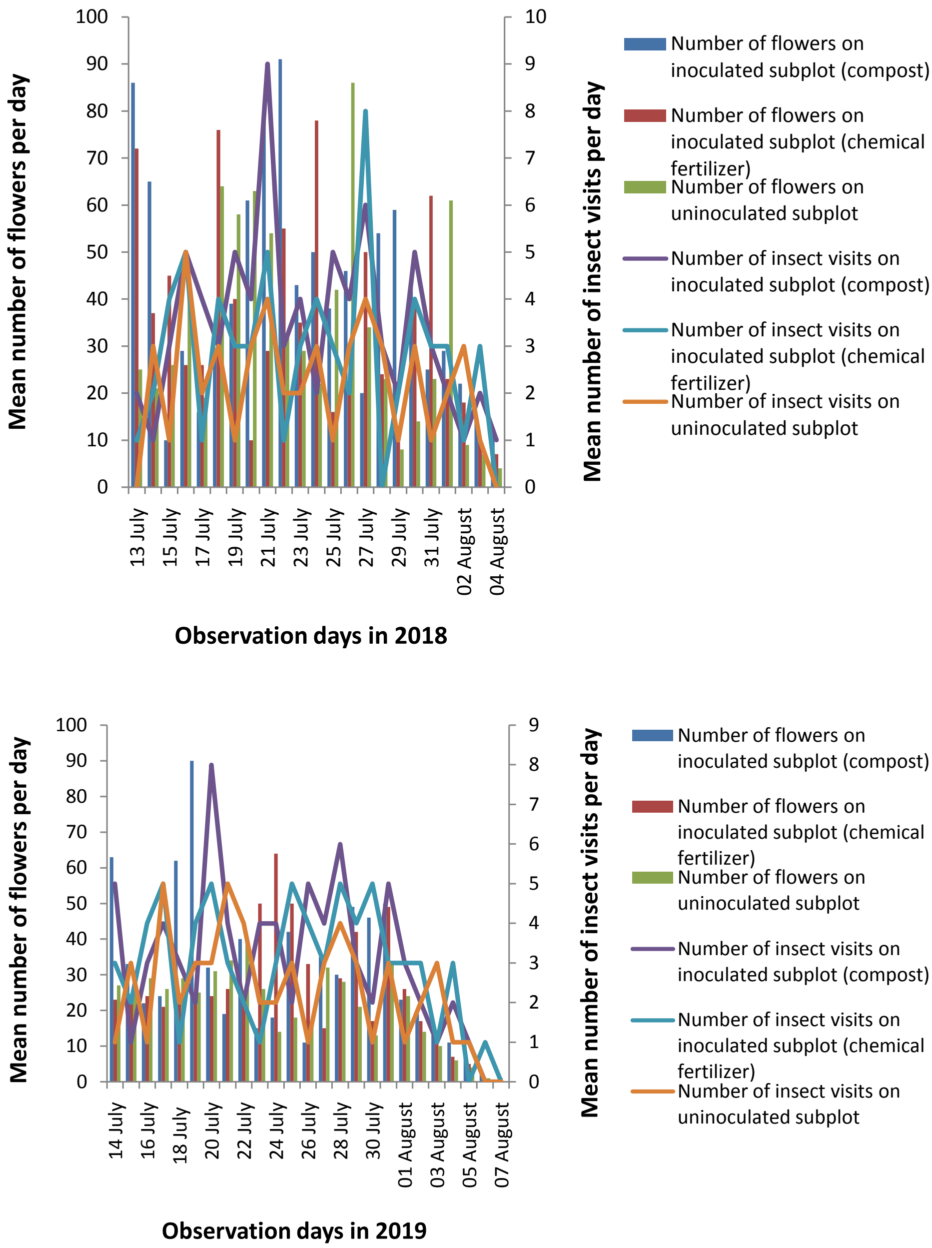

Figure 4. Variations of the number of *Glycine max* opened flowers and the number of visits of insects according to the observation days in 2018 and 2019 at Dang.

3.6. Differences in Rhythm of Visits According to Daily Time Frames

Insects foraged were abundant on soybean flowers in the afternoon, with a daily pic of activity situated between 01:00 pm and 02:00 pm (Table 4). This activity was influenced by ambient temperature, but not by hygrometry. The correlation between the number of insect visits and the temperature was positive and significant on untreated ($r = 0.89$; $P < 0.05$), applied compost ($r = 0.96$; $P < 0.05$), and fertilizer-NPK applied ($r = 0.88$; $P < 0.05$) plants for both years. As for the relative humidity, the correlation with the number of insect visits was negative and not significant on untreated ($r = -0.32$; $P > 0.05$), applied compost ($r = -0.43$; $P > 0.05$), and chemical fertilizer applied ($r = -0.40$; $P > 0.05$) subplots of this crop.

Table 4. Number and frequency of insect visits on *Glycine max* flowers according to daily observation period in 2018 and 2019 at Dang.

Insects	Subplot	Daily period days (hours)																	
		2018									2019								
		09 - 10		11 - 12		13 - 14		15 - 16		A	09 - 10		11 - 12		13 - 14		15 - 16		A
		n	*P* (%)	*n*	*P* (%)	*n*	*P* (%)	*n*	*P* (%)		*n*	*P* (%)	*n*	*P* (%)	*n*	*P* (%)	*n*	*P* (%)	
Apis mellifera	PC	1	1.56	29	45.31	32	50*	2	3.12	64	7	17.5	14	35	19	47.5*	0	0	40
	PE	0	0	26	50.98*	24	47.06	1	1.96	51	5	20.83	6	25	13	54.16*	0	0	24
	PN	0	0	12	38.71	19	61.29*	0	0	31	0	0	3	30	7	70*	0	0	10
Ceratina sp.	PC	15	19.73	23	30.26	31	40.781*	7	9.21	76	9	16.66	18	33.33	20	37.03*	7	12.96	54
	PE	8	18.18	14	31.81	17	38.641*	5	11.36	44	2	6.66	10	33.33	15	50*	3	10	30
	PN	4	13.33	12	40*	11	36.67	3	10	30	1	5	8	40	9	45*	2	10	20
Lipotriches collaris	PC	21	15.44	37	27.20	56	41.17*	22	16.17	136	15	15.46	24	24.74	47	48.45*	11	11.34	97
	PE	15	15.78	25	26.31	42	44.21*	13	13.68	95	4	5.07	33	41.77	36	45.57*	6	7.59	79
	PN	9	14.28	19	30.16	25	39.68*	10	15.87	63	3	7.32	10	24.39	25	73.13*	3	7.32	41
Episyrphus sp.	PC	20	24.69	31	38.27*	22	27.16	8	9.87	81	-	-	-	-	-	-	-	-	-
	PE	7	12.06	18	31.03	27	46.55*	6	10.34	58	-	-	-	-	-	-	-	-	-
	PN	4	15.38	6	23.07	13	50*	3	11.54	26	-	-	-	-	-	-	-	-	-
Eurema eximia	PC	12	16.43	17	23.28	32	43.83*	12	16.43	73	8	15.09	26	49.06*	14	26.41	5	9.43	53
	PE	8	10.81	29	39.18*	28	37.83	9	12.16	74	12	29.27	17	41.46*	9	21.95	3	7.32	41
	PN	12	26.08	17	36.95*	12	26.08	5	10.86	46	6	20.69	14	48.27*	7	24.14	2	6.90	29
Precis sp.	PC	-	-	-	-	-	-	-	-	-	2	5.40	15	40.54	16	43.24*	4	10.81	37
	PE	-	-	-	-	-	-	-	-	-	5	20.83	9	37.50*	8	33.33	2	8.33	24
	PN	-	-	-	-	-	-	-	-	-	3	21.43	4	28.57	6	42.86*	1	7.14	14
Total		136	14.34*	315	33.22	391	**41.24***	106	11.18	**948**	82	13.83	211	35.58	251	**42.33***	49	8.26	**593**

n: number of visits in 23 and 25 days; *p*: percentage of visits; $p = (n/A)*100$; A: total number of insect visits; *: daily peak of visit. PC: subplot with compost; PE: subplot with fertilizer-NPK; PN: uninoculated subplot.

3.7. Abundance of Foraging Insects between Treatments

In 2018 and 2019, the largest number of individuals simultaneously active on a flower was 1 for all the treatments. For both years, the mean abundance per 1000 flowers (MATF) ranged from 35.87, 51.57 and 30 for *Ceratina* sp. to 37.09, 41.46 and 33.71 for *Lipotriches collaris* respectively on negative control, compost and fertilizer-NPK applied plants (Table 5).

3.8. Duration of Insect Visits Per Flower in Treatments

In 2018 and 2019, the mean duration of insect's visit varies from 2.19, 1.75 and 3.15 with *Ceratina* sp. to 2.99, 2.70 and 2.58 with *Lipotriches collaris* on untreated, compost and chemical fertilizer subplots respectively (Table 6).

3.9. Foraging Speed of Insects on Soybean Flowers as Influenced by Treatments

The foraging speed's mean of insects on soybean flowers was 10.21, 10.49 and 6.18 with *Ceratina* sp. to 57.35, 8.81 and 24.73 with *Lipotriches collaris* on untreated, compost and fertilizer-NPK subplots respectively (Table 7).

Table 5. Differences in abundances of *Ceratina* sp. and *Lipotriches collaris* on soybean flowers in 2018 and 2019 as influenced by treatments.

Insects	Subplot	Year	*n*	Abundance per 1000 flowers (AMMF)		
				m	*s*	Comparison of means
Ceratina sp.	PC	2018	64	31.02	18.84	$F = 168.42$ ($df1 = 5$; $df2 = 453$; $P < 0.001$; THS)
		2019	115	72.12	50.25	
		$T_{2018/2019}$	**182**	**51.57**	**34.54**	
	PE	2018	56	31.51	17.30	
		2019	64	28.49	17.75	
		$T_{2018/2019}$	**120**	**30**	**17.52**	
	PN	2018	28	49.78	16.04	
		2019	35	21.97	10.34	
		$T_{2018/2019}$	**63**	**35.87**	**13.19**	
Lipotriches collaris	PC	2018	176	37.39	27.11	$F = 413.81$ ($df1 = 5$; $df2 = 812$; $P < 0.001$; THS)
		2019	183	45.54	27.72	
		$T_{2018/2019}$	**359**	**41.46**	**27.41**	
	PE	2018	116	27.92	14.41	
		2019	137	39.50	21.40	
		$T_{2018/2019}$	**253**	**33.71**	**17.90**	
	PN	2018	99	29.21	14.70	
		2019	107	44.98	20.64	
		$T_{2018/2019}$	**206**	**37.09**	**17.67**	

PC: subplot with compost; PE: subplot with fertilizer-NPK; PN: uninoculated subplot; *m*: average; *s*: standard deviation; *n*: sample size.

Table 6. Duration of *Ceratina* sp. and *Lipotriches collaris* on soybean flower as influenced by treatments in 2018 and 2019.

Insects	Subplot	Year	n	Duration of insects visits per flower		
				m	s	Comparison of means
Ceratina sp.	PC	2018	142	1.10	0.30	$F = 44.08$ ($df1 = 5$; $df2 = 209$; $P < 0.001$; THS)
		2019	165	2.41	1.49	
		$T_{2018/2019}$	**307**	**1.75**	**0.89**	
	PE	2018	92	2.45	1.07	
		2019	162	3.85	2.98	
		$T_{2018/2019}$	**254**	**3.15**	**2.02**	
	PN	2018	54	2.18	0.98	
		2019	100	2.21	0.85	
		$T_{2018/2019}$	**154**	**2.19**	**0.91**	
Lipotriches collaris	PC	2018	142	2.66	1.49	$F = 396.2$ ($df1 = 5$; $df2 = 768$; $P < 0.001$; THS)
		2019	206	2.74	1.89	
		$T_{2018/2019}$	**348**	**2.70**	**1.69**	
	PE	2018	140	2.46	1.30	
		2019	198	2.70	1.80	
		$T_{2018/2019}$	**338**	**2.58**	**1.55**	
	PN	2018	119	2.93	1.99	
		2019	167	3.06	2.12	
		$T_{2018/2019}$	**286**	**2.99**	**2.05**	

PC: subplot with compost; PE: subplot with fertilizer-NPK; PN: uninoculated subplot; *m*: average; *s*: standard deviation; *n*: sample size.

Table 7. Foraging speed between treatments of *Ceratina* sp. and *Lipotriches collaris* on soybean flowers at Dang in 2018 and 2019.

Insects	Subplot	Year	Mean speed of insects visits on flowers			
			n	m	s	Comparison of means
Ceratina sp.	PC	2018	117	8.10	7.15	$F = 241.5$ ($df1 = 5$; $df2 = 742$; $P < 0.001$; THS)
		2019	190	12.88	5.36	
		$T_{2018/2019}$	**307**	**10.49**	**6.25**	
	PE	2018	93	9.96	4.39	
		2019	157	2.40	1.93	
		$T_{2018/2019}$	**250**	**6.18**	**3.16**	
	PN	2018	68	7.85	6.17	
		2019	111	12.58	7.44	
		$T_{2018/2019}$	**179**	**10.21**	**6.80**	
Lipotriches collaris	PC	2018	106	7.97	4.89	$F = 506,57$ ($df1 = 5$; $df2 = 974$; $P < 0.001$; THS)
		2019	164	9.66	4.35	
		$T_{2018/2019}$	**270**	**8.81**	**4.62**	
	PE	2018	111	21.13	12.07	
		2019	122	28.34	21.29	
		$T_{2018/2019}$	**233**	**24.73**	**16.57**	
	PN	2018	75	52.03	34.63	
		2019	96	62.67	40.87	
		$T_{2018/2019}$	**171**	**57.35**	**37.75**	

PC: subplot with compost; PE: subplot with fertilizer-NPK; PN: uninoculated subplot; *m*: average; *s*: standard deviation; *n*: sample size.

3.10. Apicultural Value of Soybean

During anthesis of soybean, there was low nectar harvesting activity of *A. mellifera* workers on flowers. This result reveals the low attractiveness of soybean nectar to *A. mellifera* workers and consequently allows the classification of this plant species among the low bee plant species.

3.11. Impact of Insects on Pollination, Pod and Seed Yields of Soybean

During nectar harvest on soybean, foraging insects always shook flowers and were regularly in contact with anthers and stigma, thus, increasing cross-pollination possibility of *G. max* fruiting rate, number of seeds per pod and percentage of normal seeds in different treatments (Table 8).

There was a highly significant between fruiting rate of free opened flowers (treatment 1) and that of bagged flowers (treatment 2), the first year ($P < 0.001$) and the second year ($P < 0.001$). The fruiting rate of treatment 1 (unprotected flowers) was higher than treatment 2 (protected flowers) in 2018 and in 2019. The fruiting rate due to the action of insects was 19.09 and 18.54% in 2018 and 2019 respectively. For the two cumulated years, the fructification rate due to the influence of insects was 18.81%.

The mean number of seeds per pod was highly significant between treatments 1 and 2 ($P < 0.001$). Consequently, a high mean number of seeds per pod in treatment 1 (unprotected flowers) was noticed compared to treatments 2 (bagged flowers). The number of seeds per pod attributed to the activity of insects was 19.27% in 2018 and 21.77% in 2019, giving an overall mean of 20.52%.

There was a highly significant difference between the percentage of normal seed of treatment 1 and that of treatment 2 in the first year ($P < 0.001$), as well as the second year ($P < 0.001$). Thus, the percentage of normal seeds in opened flowers was higher than that of protected flowers in 2018 and 2019. The percentage of the normal seeds due to the action of insects was 14.09% in 2018 and 17.58% in 2019. For all the flowers studied, the percentage of the normal seeds due to flowering insects was 15.83%.

Table 8. Yield components of treatments as influenced by protection of soybean flowers from insects in 2018 and 2019.

Years	Traitements	NF	NFP	FrR (%)	Seeds/Pod		TNS	NS	% NS
					m	*s*			
2018	1 (Unprotected flowers)	8246	6388	77.46	3.27	0.91	11,560	9427	81.54
	2 (Bagged flowers)	7904	4954	62.67	2.64	0.62	8735	6119	70.05
2019	3 (Unprotected flowers)	10,130	8145	80.40	3.95	1.27	14,215	11,990	84.34
	4 (Bagged flowers)	9873	6466	65.49	3.09	0.86	10,094	7017	69.51

NF: Number of flowers; NFP: Number of formed pod; FrR: Fruiting rate; TNS: Total number of seeds; NS: Normal seeds; % NS: Percentage of normal seeds; *m*: Mean; *s*: Standard deviation.

3.12. Impact of Compost on Pod and Seed Yields of Soybean

The comparison of the fruiting rate (Table 9) showed that the differences observed were highly significant between treatments 2 and 5 ($P < 0.001$) and treatments 4 and 6 ($P < 0.001$). The fruiting rate due to compost was 26.86% in 2018, 24.57% in 2019 and 25.71% for the two cumulated years.

The comparison of the mean number of seeds per pod revealed that differences observed were highly significant between treatments 2 and 5 ($P < 0.001$) and between treatments 4 and 6 ($P < 0.001$). The mean number of seeds per pod due to compost was 31.07% in 2018, 33.83% in 2019 and 32.45% for the two cumulated years.

Hence, in 2018 and 2019, the percentage of the normal seeds from flowers of plants protected and applied with compost (treatments 5 and 6) was higher than that of Bagged flowers and uninoculated (treatments 2 and 4). The percentage of the normal seeds due to compost was 19.40% in 2018, 21.60% in 2019 and 20.50% for the two cumulated years.

Table 9. Yield components of soybean in different treatments as influenced by compost in 2018 and 2019.

Years	Traitements	NF	NFP	FrR (%)	Seeds/Pod		TNS	NS	% NS
					m	*s*			
2018	5 (Bagged flowers inoculates by compost)	9298	7968	85.69	3.83	1.21	14,070	12,229	86.91
	2 (Bagged flowers)	7904	4954	62.67	2.64	0.62	8735	6119	70.05
2019	6 (Bagged flowers inoculates by compost)	10,576	9183	86.82	4.67	1.38	16,086	14,263	88.66
	4 (Bagged flowers)	9873	6466	65.49	3.09	0.86	10,094	7017	69.51

NF: Number of flowers; NFP: Number of formed pod; FrR: Fruiting rate; TNS: Total number of seeds; NS: Normal seeds; % NS: Percentage of normal seeds; *m*: Mean; *s*: Standard deviation.

3.13. Impact of Fertilizer-NPK on Pod and Seed Yields of Soybean

The comparison of the fruiting rate (Table 10) showed that the differences were highly significant between treatments 7 and 2 ($P < 0.001$) as well as 8 and 4 ($P < 0.001$). the fruiting rate from flowers of plants protected and applied with fertilizer-NPK (treatment 7 in 2018; treatment 8 in 2019) was higher than that from flowers of plants protected and uninoculated (treatment 2 in 2018; treatment 4 in 2019). The fruiting rate due to fertilizer chemical was 20.36% in 2018, 21.73% in 2019 and 21.04% for the both years of study.

The comparison of the mean number of seeds per pod (Table 10) showed highly significant differences between treatments 7 and 2 ($P < 0.001$), as well as 8 and 4 ($P < 0.001$). Pod and seed yields from flowers of plants protected and applied with fertilizer-NPK (treatment 7 in 2018; treatment 8 in 2019) were higher than that from flowers of plants protected and uninoculated (treatment 2 in 2018; treatment 4 in 2019). The mean number of seeds per pod due to fertilizer chemical was 22.58% in 2018, 34.95% in 2019 and 28.76% for both years of study.

The comparison of the percentages of normal seeds shows that the differences were highly significant between treatments 7 and 2 ($P < 0.001$), and treatments 8 and 4 ($P < 0.001$). The percentage of normal seeds from flowers of plants protected and applied with fertilizer-NPK (treatment 7 in 2018; treatment 8 in 2019) was higher than those protected and uninoculated (treatment 2 in 2018; treatment 4 in 2019). The percentage of the normal seeds due to fertilizer chemical was 13.25% in 2018, 16.55% in 2019 and 14.90% for both years of study.

Table 10. Yield components of soybean in different treatments as influenced by fertilizer-NPK in 2018 and 2019.

Years	Traitements	NF	NFP	FrR (%)	Seeds/Pod		TNS	NS	% NS
					m	*s*			
2018	7 (Bagged flowers inoculates by chemical fertilizer)	8763	6896	78.69	3.41	1.83	12,912	10,427	80.75
	2 (Bagged flowers)	7904	4954	62.67	2.64	0.62	8735	6119	70.05
2019	8 (Bagged flowers inoculates by chemical fertilizer)	10,312	8629	83.67	4.75	1.64	15,843	13,198	83.30
	4 (Bagged flowers)	9873	6466	65.49	3.09	0.86	10,094	7017	69.51

NF: Number of flowers; NFP: Number of formed pod; FrR: Fruiting rate; TNS: Total number of seeds; NS: Normal seeds; % NS: Percentage of normal seeds; *m*: Mean; *s*: Standard deviation.

3.14. Cumulative Impact of Insect Pollinators and Compost on the Pollination, Pod and Seed Yields of Soybean

The comparison of the podding rate (Table 11) showed that the differences observed were highly significant between treatments 9 and 2 ($P < 0.001$) and treatments 10 and 4 ($P < 0.001$). Therefore, in 2018 and 2019, the podding rate from plants applied compost and opened to insects (treatments 9 and 10 respectively) was higher than that of flowers protected during their flowering period (treatments 2 and 4 respectively). The cumulative effect of flowering insects and compost on the podding rate was 29.95% in 2018, 26.59% in 2019 and 28.27% for the two years of study.

As far as the mean number of seeds per pod is concerned, there were highly significant between treatments 9 and 2 ($P < 0.001$) and treatments 10 and 4 ($P < 0.001$). As a matter of fact, in 2018 and 2019, the mean number of seeds per pod from flowers of applied compost subplot and opened to insect pollinators (treatment 9 in 2018, treatment 10 in 2019) was higher than that of flowers bagged (treatment 2 in 2018, treatment 4 in 2019) during their flowering period. The combined effect of flowering insects and compost activity on the number of seeds per pod was 44.42 % in 2015, 36.42 % in 2016 and 40.42 % for the two cumulative years. For the percentage of normal seeds, the differences observed were highly significant between treatments 9 and 2 ($P < 0.001$) and treatments 10 and 4 ($P < 0.001$). Hence, in 2018, as well as 2019, the percentage of normal seeds from flowers opened to insects on applied compost plants (treatment 9 in 2018, treatment 10 in 2019) was higher than that of flowers protected from insect visits (treatment 2 in 2018, treatment 4 in 2019). The percentage of normal seeds due to cumulative effects of flowering insects and compost activity was 23.99 % in 2018, 24.95 % in 2019 and 24.47 % for the two years of study.

Table 11. Yield components of soybean in different treatments as influenced by compost and insect pollinators in 2018 and 2019.

Years	Traitements	NF	NFP	FrR (%)	Seeds/Pod		TNS	NS	% NS
					m	*s*			
2018	9 (Inoculated flowers open to insects)	9786	8756	89.47	4.75	2.13	14,558	13,417	92.16
	2 (Bagged flowers)	7904	4954	62.67	2.64	0.62	8735	6119	70.05
2019	10 (Inoculated flowers open to insects)	11,064	9871	89.21	4.86	1.61	16,574	15,351	92.62
	4 (Bagged flowers)	9873	6466	65.49	3.09	0.86	10,094	7017	69.51

NF: Number of flowers; NFP: Number of formed pod; FrR: Fruiting rate; TNS: Total number of seeds; NS: Normal seeds; % NS: Percentage of normal seeds; *m*: Mean; *s*: Standard deviation.

3.15. Combined Impact of Insect Pollinators and Fertilizer-NPK on the Pollination, Pod and Seed Yields of Soybean

The podding rates were 87.30%, 62.67%, 88.37% and 65.49% in treatments 11, 2, 12 and 4 respectively (Table 12). When treatments were compared two by two, the difference observed was highly significant between treatments 11 and 2 ($P < 0.001$) and between treatments 12 and 4 ($P < 0.001$). Hence, in 2018 and 2019, the podding rate from plants applied with fertilizer-NPK and opened to insects (treatments 11 and 12) was higher than that from flowers of plants protected (treatments 2 and 4).

The mean numbers of seeds per pod were 3.73, 2.64, 3.69 and 3.09, 2.96 in treatments 11, 2, 12 and 4 respectively (Table 12). The difference observed was significant between treatments 11 and 2 ($P < 0.001$) as well as between treatments 12 and 4 ($P < 0.001$). Thus, in 2018 and 2019, the mean number of seeds per pod from plants applied with fertilizer-NPK and opened to insects was higher than that from flowers of plants protected.

The percentages of normal seeds were 90.88%, 70.05%, 72.36%, 91.89% and 69.51% in treatments 11, 2, 12 and 4 respectively (Table 12). Pairwise comparisons showed that the difference observed was highly significant between treatments 11 and 2 ($P < 0.001$) as well as between treatments 12 and 4 ($P < 0.001$). For both cropping seasons, the percentage of normal seeds from plants applied with chemical fertilizer and opened to insects was higher than that from flowers of plants protected.

In 2018, the contribution of cumulative effects of flowering insects and fertilizer-NPK in the podding rate, the mean number of seeds per pod and the percentage of normal seeds were 28.21%, 29.22% and 22.92% respectively. In 2019, the corresponding figures were 25.89%, 16.26% and 24.35%. For the two cumulated years, the numeric contribution of combined effects of flowering insects and chemical fertilizer were 27.05%, 22.74% and 23.63% for the podding rate, the mean number of seeds per pod and the percentage of normal seeds respectively.

Table 12. Yield components of soybean in different treatments as influenced by fertilizer-NPK and insect pollinators in 2018 and 2019.

Years	Traitements	NF	NFP	FrR (%)	Seeds/Pod		TNS	NS	% NS
					m	*s*			
2018	11 (Inoculated flowers open to insects)	9421	8225	87.30	3.73	1.52	14,312	13,007	90.88
	2 (Bagged flowers)	7904	4954	62.67	2.64	0.62	8735	6119	70.05
2019	12 (Inoculated flowers open to insects)	10,764	9512	88.37	3.69	1.88	16,183	14,871	91.89
	4 (Bagged flowers)	9873	6466	65.49	3.09	0.86	10,094	7017	69.51

NF: Number of flowers; NFP: Number of formed pod; FrR: Fruiting rate; TNS: Total number of seeds; NS: Normal seeds; % NS: Percentage of normal seeds; *m*: Mean; *s*: Standard deviation.

4. Discussion

4.1. Effect of Compost on Soybean Growth Parameters

Analysis of the results of the effect of organic manure enrichment on soybean growth parameters showed a significant correlation between the number of nodules, weight of dry nodules and biomass of plants enriched with compost, as compared to those enriched with chemical fertilizer or untreated. Successful nodulation of leguminous crops largely depends on compost, which helps improve the soil's ability to hold water, an essential factor in the nodulation process [22]. Compost also created a favorable environment for root development, improve the accessibility of plant roots to phosphorus by making the nutrient available, and reduce crop stress related to factors such as soil acidity [23]. This result is in line with that of [24], who reported an increase in the number and weight of nodules obtained with the addition of organic fertilizer in the form of chicken droppings.

4.2. Foraging Activity of Insects on Soybean Flowers

At Dang, during the two cropping season, Hymenoptera were the most important order with 82.09% of 1541 visits. They were mainly represented by Halictidae family, the most important being *Lipotriches collaris* (43.87%). Diptera and Lepidoptera were poorly represented with 4.80% and 13.11% of visits each. These results are similar to those recently obtained by [25] indicating that at Maroua, among soybean entomofauna, Hymenoptera were the most important Order (with 52.59% of visits in 2015 and 24.62% in 2018), among which, Halictidae ranked first (23.58% in 2015 and 5.86% in 2018).

The high frequency of Halictidae on soybean flowers could be explained by the good attractiveness of its nectar and/or its pollen vis-à-vis of these insects, by its accessibility, its availability and also by the presence of their nests in the experimental field. In addition, the fact that at the flower level, Halictidae only harvests nectar and/or pollen suggests that the floral products of this plant may have stimuli responsible for the attractiveness exerted on them. These are mainly olfactory and taste stimuli. Indeed, for a given plant, the attractiveness of the nectar depends in part on the average concentration of total sugars it has at the level of the flowers, whereas the pollen has its own clean odor [26], which can be detected by insects, using antennae and palps [27] [28]. [29] further indicated that the smell of pollen was involved precisely in its localization by the insect, its regular harvest being mainly under the influence of taste stimuli. These results confirm those already reported by [25], who revealed *L. collaris* as the most frequent insect on flowers of the same plant in Maroua. On the other hand, [30] and [31] reported that *Apis mellifera* was the main floral visitor of this Fabaceae, and was able to collect nectar exclusively on *G. max* in USA and Brazil respectively. This finding shows on one hand that plants have specific food resources available to insects through flowers, and on the other hand that the diversity of soybean insects may vary in time and space.

The abundance of insect visits on flowers was higher on subplots enriched with compost than on uninoculated subplot. This could be explained by higher number of flowers on subplot enriched with compost. The peak activity of insects on soybean flowers was between 01:00 pm and 02:00 pm, which corresponds probably to the period of higher availability of nectar and/or pollen on this crop. Between 7:00 am and 8:00 am time slot, no insect visits were recorded. This period could correspond to the time when flowers of this Fabaceae are not yet well bloomed. The reduction of insects activity observed on flowers after 4 pm could be linked to the low quantity and/or quality of their respective floral products and to the drop in ambient temperature in the experimental field, thus causing the closure of flowers. In fact, several foraging prefer hot periods for their activity on flowers [32]. As in all legumes [33], the leaflets of soybean are arranged vertically in broad daylight, this facilitating the exposure of flowers to insects. Such flowers can therefore receive a higher number of visits. This is true, as the localization of a flower by an insect depends more or less on the visual stimuli emanating from this organ [26] [29]. Similar observations were reported by [25] on soybean by foraging insects in Maroua. In fact, these insect species does not visit *G. max* flowers when they are poor in nectar after 03:00 pm. Moreover, according to [34], a higher temperature along with a very weak relative humidity has a negative influence on the activity of pollinators on flowers.

4.3. Impact of Insect Activity on Pollination and Yields of Soybean

When harvesting pollen and/or nectar on soybean flowers, most insects were frequently in contact with the anthers and the stigma of visited flowers. They could therefore be directly involved in self-pollination, by putting pollen of one flower on to the stigma of the same flower. The fruiting rate, the percentage of seeds per pod and the percentage of normal seeds due to the influence of flowering insects were 25.71%, 32.45% and 20.50% respectively. These results indicate that flowering insects are not only important in the improvement of pod and seed yields of this plant, but they also play an important role in the production of seeds of good quality. According to [35], the more a flower receives pollen grains, the more it has the potential to turn into a bulky fruit containing many seeds. For this purpose, [11] pointed out that pollination by insects increases the fruiting rate, the percentage of the number of seeds per pod and the percentage of normal seeds of soybean by 35.87%, 73.09%, 31.1%, respectively. These percentages are high compared to those obtained in this study and could be explained by the presence of more pollinating species in their experimental plots.

4.4. Impact of Compost on Pod and Seed Yields of Soybean

The positive and significant contribution of compost in fruit and seed yields of soybean could be justified by its richness in nutrients such as phosphorus, nitrogen and potassium. In fact, these nutrients are involved in the correction of nutrient deficiencies, ensuring adequate nutrition and maintaining optimal soil fertility conditions, while improving the quality of crops [36]. Similarly, it could also be attributed to reduction of certain plant disease symptoms that have been reported to field application of compost and derived products [37].

4.5. Impact of Fertilizer-NPK on Pod and Seed Yields of Soybean

The yields of the subplots that received chemical fertilizer exceeded those of the control plots. This suggests that the fertilizer applied under the crop had positive effects on yields. Indeed, this increase would be due to the improvement of the properties of the soil (in mineral elements), leading to a good development of the roots and a good assimilation of the nutrients released by them [38]. Similarly, it could also be explained by a difference between the nutrient balances provided by each treatment [39].

4.6. Cumulative Impact of Insect Pollinators and Compost on the Pollination, Pod and Seed Yields of Soybean

In our experience, compost and pollinating insects greatly increased the fruiting rate, number of seeds per pod and number of normal seeds by 28.27%, 40.42% and 24.47% respectively. Indeed, compost improves plant growth and the diffusion of nutrients to plants through microbiological processes [40]. Thus, legumes will satisfy, under the right conditions of symbiosis, most of their needs to ensure their growth, flowering and increase their production [41]. Moreover, to increase the possibilities of pollination, insects facilitate the release of pollen from the anthers for occupation of the stigma [42].

5. Conclusion

The results of this study have revealed that soybean benefits enormously from pollinating insects, among which *Lipotriches collaris* is the most important. The comparison of pod and seed sets of unprotected flowers with those of flowers visited by insects sustains the value of these insects in increasing pod, seed yields and quality. Furthermore, the comparison of pod and seeds set of uninoculated and bagged flowers with those of plants inoculated with compost and visited by insects indicates the value of cumulative activity of insects and compost in increasing pod and seeds yields. It is suggested that sowing soybean with compost and the preservation of pollinating insects near flowering plants would be a better way of valuing the benefits of pollinators and wastes in agriculture in order to reduce the nutritional needs of population through sustainable intensification of soybean production.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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