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Impact of *Solenopsis geminata* pest (Hymenoptera: Formicidae), the tropical fire ant on soybean (*Glycine max*) production in Littoral, Cameroon

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Abstract
In Ndog-bong and Mboppi, soybean was planted at three replication on three different plots: one of these plots was non-infested, while the other two were infested with 124 190 and 186 285 workers of *Solenopsis geminata* respectively. Comparison was done between the infested plots and the non-infested one on seed germination, plant density, nodule number and yield. The data collected showed that, the four studied parameters decreased with the increasing of *Solenopsis geminata* foragers in the infested plots. The germinating rate of soybean seeds was 48.82%, 28.77% and 22.41% in the non-infested, slightly infested and heavily infested plots respectively. Plant density was 40.04%, 33.07% and 26.89% in the non-infested, slightly infested and heavily infested plots respectively. Nodule number was 38.36%, 32.63% and 29.01% in the non-infested, slightly infested and heavily infested plots respectively. Yield was 1.36t/ha, 0.82t/ha and 0.60t/ha in the non-infested, slightly infested and heavily infested plots respectively. In conclusion, direct feeding of *Solenopsis geminata* on seeds, seedlings and plant root reduced plant density and caused an important reduction of soybean yield.

Keywords: Tropical fire ant, *Solenopsis geminata*, Soybean, production, Cameroon

1. Introduction

Invasive species represent a major threat to worldwide biodiversity [1, 2] and have dramatic effects on the economy and public health [3, 4]. Among invasive species in the world, ants are highly successful invaders. They can be ecologically and economically devastating and often outcompete native ant species [5, 6, 7]. Among these invader ants, tropical fire ant *Solenopsis geminata* is considered one of the worst invasive species, which causes damage to human health, plants, animals and artificial equipment [5]. These ants attack children and farmers, sometimes causing anaphylactic shock [8]. *Solenopsis geminata* is native of Central and South America, but has spread through human commerce to many parts of the world [9]. Like other fire ants, *Solenopsis geminata* has dramatic impact on many plants such as tomato, corn, sorghum and soybean particularly. This species spread over all the phenological stages of the plant. *Solenopsis* species affects the seed of soybean by removing and consuming them [10, 28]. Furthermore, fire ants feed on plant roots system and significantly reduce soybean root growth and inhibit nitrogen fixing nodule formation [12]. Soybean root feeding by these ant species reduces plant nodule number, and therefore their density, and yield [12]. However, the majority of the crop damage by fire ants is assumed to be the result of damage during early seedling establishment that reduced the crop density [13]. In addition, soybean loss caused by fire ants can be significant where this species is abundant [13]. In *Solenopsis geminata* colonies, monogyne and polygyne forms occur [14]. The number of workers in a nest can vary enormously, from 4000 to hundreds of thousands [15]. In a large nests, *Solenopsis geminata* workers can be estimated up to 100,000 workers. These workers generally forage within 15m of the nest [16] and mass recruit to a food source via trail pheromones [15]. In countries where it is introduced, the absence of natural enemies allow *Solenopsis geminata* to reach higher density than that of the native range. Although *Solenopsis geminata* is a soybean devastating in Cameroon, information about the impact of this tropical fire ant on plant production is not yet documented. Here, we reported the result of experiments designed to study the impact of *Solenopsis geminata* on soybean production in littoral Cameroon. Our specific objective in this study was to understand the impact of *Solenopsis geminata* on soybean production and possibly establish a link between *Solenopsis geminata* colony densities and soybean yield variation.

2. Material and methods

All tests were performed in three plots of each experimental area. The protocol was that used by Shatters and Vander Meer [12] and Adams *et al.* [13], with modifications. Each plot measured 15 by 20m and they were 20m separated from each other. Two of these plots were infested with 124 190 (slightly infested plot) and 186 285 (heavily infested plot) workers of *Solenopsis geminata* contained in the mounds, while the other plot (Non-infested plot) was maintained essentially ant-free by judicious use of cypercal insecticide. To test the tropical fire ant impact on soybean production, comparison was done between the two infested plots and the non-infested one on four parameters (seed germination, plant density, nodule number and yield). These parameters were evaluated both in the dry and the raining season, and the evaluation was repeated three time for each parameter. Furthermore, ant density for the infested plots was also evaluated both in the dry and the raining season to establish a link between *Solenopsis geminata* colonies increase and soybean crops damage, and this evaluation was repeated six time.

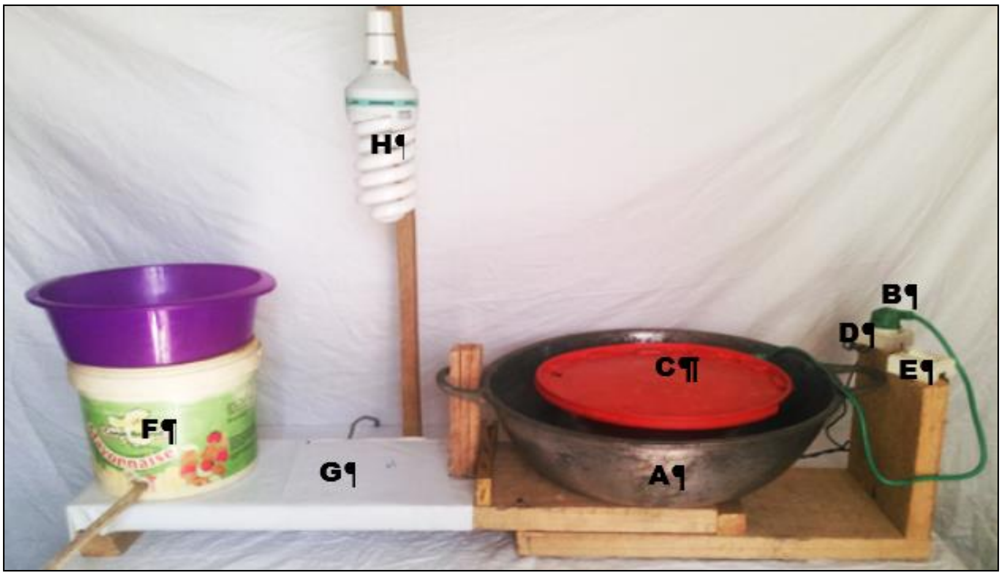
2.1. Study Sites

The study was carried out in Douala city, the littoral part of Cameroon. Two localities were selected as sampling sites: Mboppi (04º02.709’N; 009º42.958’E) and Ndog-bong (04º02.714’N; 009º42.947’E). Douala’s climate is hot and humid with temperature ranges between 24.8°C (February) and 27.6º (July), and annual precipitation are 3, 600mm [17].

2.2. Plot Infestation

2.2.1. Estimation of *Solenopsis geminata* mounds

Firstly, a fragment of nest was placed in a bucket of 5 liter and weighed. Another fragment of nest was introduced in a plastic tube 10cm wide and 6cm high and then weighed. The 5 liter bucket container was therefore evaluated using the plastic tube. Thus, the plastic tube containing a nest fragment was carried to a laboratory and put on a disk over a cooking pot containing hot water. The tube cover was then opened and his container was throw on the disk to allow *Solenopsis geminata* workers jumping in the hot water pot (Figure 1). After getting all ants of this tube in the hot water pot, these workers were collected and conserved in 70% alcohol. After this, the disk ground was progressively carried out with a spoon and thrown on a white portion to count *Solenopsis geminata* workers which didn’t jump in the hot pot of water. All workers of *Solenopsis geminata* coming from the plastic tube were then counted. This experiment was repeated 8 times. The mean number of *Solenopsis geminata* that can be contained in a 5 liter bucket has been estimated via that of the plastic tube, and the bucket was therefore used as mounds measure (Figure 1).



A= circular pot containing hot water, B= water heater soaked used to raise the temperature of the water, C= disc, D= socket to the water heater connection, E= switch conditioning the water heater operation, F= sieve used to extract dead ants from the pot water, G= white portion used to count ants, H= electric lamp used to facilitate ant counting.

Fig 1: Experimental device used for mound quantification

2.2.2. Infestation

Large nests where dug down near experimental areas in a 20m far field. Ant colony fragments were collected in the five liter bucket and carried from the two experimental plots to their infestation. The slightly infested plot received 10 mounds, while the heavily infested plot received 15 mounds. Each mound contained approximately 12 419 workers of *Solenopsis geminata*. The infestation of these plots was carried out 30 days before soybean sowing and repeated 2 days after sowing.

2.3. Ant Density

Forager density of *Solenopsis geminata* for each infested plot was evaluated 18, 39 and 88 days after sowing to establish a link between *Solenopsis geminata* colonies increase and soybean crops damage. This density evaluation was performed with the bait method [18], using fish and honey as a bait. So, 50g of this bait was located at the center of twenty covered arenas of 10cm large and 6cm size. A plastic tube ended with a cover was connected on each arena to allow *Solenopsis geminata* foragers getting in the arena. Ten arenas 1m separated from each other were hazard placed in each infested plot at 7am and 5pm. The plastic tube covers were opened and the arenas were maintained in different plots for one hour. After this time, plastic tube for all arenas were covered and arenas for the two infested plots were carried out to the laboratory where *Solenopsis geminata* workers were identified and counted. The mean number of *Solenopsis geminata* workers for the two infested plots, counted at the different periods (days 18, 39 and 88 after sowing) was then compared both in the raining and the dry season. The experiment took place in 06 seasons (03 dry seasons and 03 raining seasons), at the frequency of two trials per season for each experimental period (days 18, 39 and 88 after sowing). Furthermore, ant density of the raining season was compared with that of the dry season at the same period, to establish a link between the season and *Solenopsis geminata* colonies variation.

2.4. Soybean Germination
Germination studies of soybean in association with tropical fire ant *Solenopsis geminata* were performed in three plots of each experimental area. A total of 3600 soybean seeds were planted at a depth of 4cm in 900 holes of each plot, at the rate of 4 seeds per hole. Seeds were 30cm apart in two rows that were 40cm apart, at the rate of 120 seeds per row. Germinating seeds were observed and counted 7 days after sowing in each plot. Comparison was made between the mean number of germinated seeds for the tow infested plots and the non-infested one, both in the raining and the dry season, to establish a link between *Solenopsis geminata* colonies variation and seed germination. In addition, the mean number of germinated seeds counted for each plot in the raining season was compared with that counted for the same plot in the dry season, to establish a link between the season and seed germination.

2.5. Plant Density
The effect of tropical fire ants on plant development was determined in experiments terminated 88 days after sowing. For this experiments, 300 plants of germinating seeds were sampled. Plant density counts (plants number per unit) were initiated 11 days after sowing and conducted once weekly in 10 units of each plot, each unit contained 30 plants. So during the different development stages of these plants, the number of plants contained in each unit was counted. A final plant density count was made 88 days after sowing. In addition, the mean number of plants for the non-infested plot, counted 18, 39 and 88 days after sowing was compared with that for the slightly infested plot and the heavily infested one counted at the same periods, both in the raining and the dry season. This comparison was done to establish a link between *Solenopsis geminata* colonies variation and plants density. Furthermore, the mean number of plants counted for each plot in the raining season was compared with that counted for the same plot in the dry season, to establish a link between the season and plant density.

2.6. Root Nodule Development
A total of 270 soybean seeds were planted in 90 pots of each plot, at the rate of 3 seeds per pot. After germination of these seeds, only one plant was maintained in each pot. 18 days after sowing, 30 of the 90 plants were dug up and the number of root nodules were visually observed and recorded for each plant. In addition, 30 other plants were dug up 39 days after sowing, while the last 30 plants were dug up 88 days after sowing. The number of root nodules for these plants were also visually observed and recorded. Comparison was made between the mean root nodule number for the two infested plots and that for the non-infested one, both in the raining and the dry season, to establish a link between *Solenopsis geminata* colonies variation and plant root nodule development. On the other hand, the mean number of root nodule counted in each plot in the raining season was compared with that counted in the same plot in the dry season, to establish a link between the season and root nodule development.

2.7. Soybean Yield
Soybean plants were hand cut above soil level and all pods of these plants were collected, drying under ambient light and temperature conditions for 4 days and threshed. Soybeans from each plot were bagged separately and returned to the laboratory, where all debris were removed before they were weighed. The mean yield of each infested plots was compared with that of the non-infested one, both in the raining and the dry season, to establish a link between the infestation level and soybean yield. Furthermore, the yield of each plot in the raining season was compared with that of the same plot in the dry season, to establish a link between the season and soybean yield.

2.8. Statistical Analysis:
ANOVA in SPSS software was used and Duncan test to separate the mean at $p \leq 0.0001$.

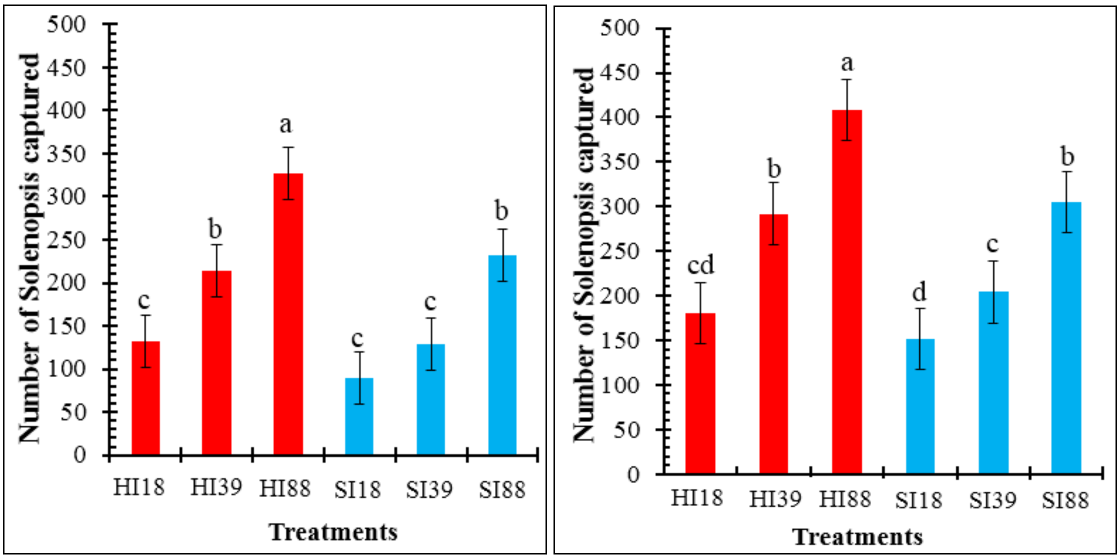
3. Results
3.1. Evolution of ant density with time
The mean number of *Solenopsis geminata* foragers captured in each infested plot increased with time in Ndog-bong and Mboppi, both in the raining and the dry season. Indeed, the mean number of foragers captured in the two infested plots 88 days after sowing was significantly higher than that of foragers captured 18 and 39 days after sowing in the same plots, both in the dry and the raining season ($p \leq 0.0001$). 18 days after sowing, there were no a significant difference between the mean number of foragers captured in the slightly infested plot and the heavily infested one, both in the raining and the dry season. Although the mean number of *Solenopsis geminata* foragers increased with time, there were no significant difference in the dry season between foragers captured in the slightly infested plot 18 and 39 days after sowing, while the mean number of foragers captured 39 days after sowing in the same plot in the raining season was significantly higher than that of the foragers captured 18 days after sowing ($p \leq 0.0001$). However, the mean number of foragers captured in the heavily infested plot for the day 39 after sowing was significantly higher than that of the foragers captured in the same plot 18 days after sowing, both in the raining and the drying season. In addition, the mean numbers of foragers captured in the heavily infested plot 39 and 88 days after sowing were significantly higher than those of foragers captured at the same periods in the slightly infested plot, both in the dry and the raining seasons ($p \leq 0.0001$). Although our data did not globally showed the significant difference between the mean number of *S. geminata* workers

in the dry and the raining seasons, the value of this mean number of *S. geminata* workers was higher in the dry season than the raining one (Table 1; figure 2).

Table 1: Mean number of *Solenopsis geminata* workers captured related with time and treatments

	Number of ***Solenopsis geminata*** workers	
	Dry season	**Raining season**
SIJ18	90.00±8.92^{c}	151.38±25.55^{d}
HIJ18	132.62±39.45^{c}	180.60±12.14^{cd}
SIJ39	128.47±22.75^{c}	204.13±32.54^{c}
HIJ39	213.30±41.35^{b}	291.90±58.50^{b}
SIJ88	232.47±27.49^{b}	305.33±50.92^{b}
HIJ88	327.63±58.10^{a}	408.17±49.10^{a}

a, b, c, for the number of Solenopsis geminata worker captured, means affected with the same letter are not significantly different at p≤0.0001. HI18= heavily infested plot for the day 18 after sowing, HI39= heavily infested plot for the day 39 after sowing, HI88= heavily infested plot for the day 88 after sowing, SI18= slightly infested plot for the day 18 after sowing, SI39= slightly infested plot for the day 39 after sowing, SI88= slightly infested plot for the day 88 after sowing.



A **B**

Fig 2: Number of *Solenopsis geminata* workers captured, related with treatment and time (A: dry season, B: raining season).

a, b, c, for the number of Solenopsis geminata worker captured, means affected with the same letter are not significantly different at p≤0.0001. HI18= heavily infested plot for the day 18 after sowing, HI39= heavily infested plot for the day 39 after sowing, HI88= heavily infested plot for the day 88 after sowing, SI18= slightly infested plot for the day 18 after sowing, SI39= slightly infested plot for the day 39 after sowing, SI88= slightly infested plot for the day 88 after sowing.

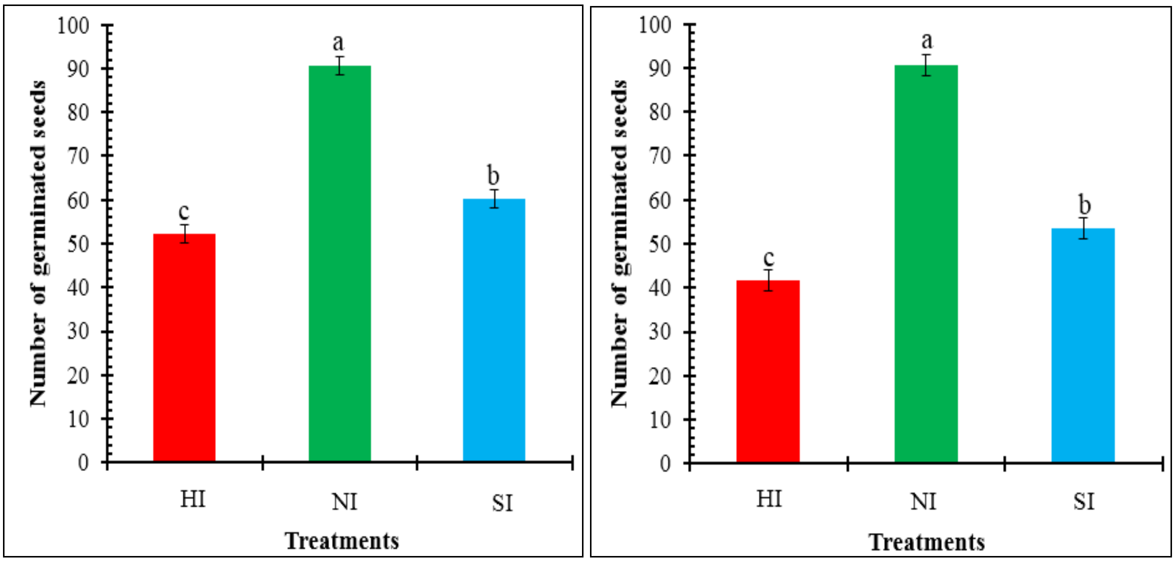
3.2. Soybean Germination related with Treatment and Seasons

Seeds were observed cracking the ground 4 days after sowing and *Solenopsis geminata* foragers were observed feeding on the cotyledons of germinating seeds. Seed germination was observed in all plots of the two studied sites. However, germinating rate varied among the plots. Both in the dry and the raining season, the mean number of germinated seeds for the non-infested plot was significantly higher than that for the two infested plots (p≤0.0001). Moreover, the mean number of germinated seeds for the slightly infested plot was significantly higher than that for the heavily infested plot, both in the dry and the raining season (p≤0.0001). There were not no significant difference between the mean number of germinated seeds in the dry and the raining season but the mean number of germinated seeds in value was higher in the dry season than the raining one, particularly in the two infested plots (Table 2; figure 3).

Table 2: Mean number of germinated seeds and yield, related with treatments and seasons

	Germinating seeds		**Yield (t/ha)**	
	Dry season	**Raining season**	**Dry season**	**Raining season**
NI	90.57±2.99^{a}	90.68±3.11^{a}	1.40±0.082^{a}	1.36±0.08^{a}
SI	60.12±2.94^{b}	53.43±3.17^{b}	1±0.15^{b}	0.82±0.12^{b}
HI	52.21±0.43^{c}	41.62±1.95^{c}	0.78±0.13^{c}	0.60±0.11^{c}

a, b, c for the number of germinated seeds, means affected with the same letter are not significantly different at *p≤0.0001. HI= heavily infested plot, SI= slightly infested plot, NI= non infested plot.*



A B

Fig 3: Number of germinated seeds, related with treatments and seasons (A: dry season, B: raining season).

a, b, c for the number of germinated seeds, means affected with the same letter are not significantly different at *p≤0.0001. HI= heavily infested plot, SI= slightly infested plot, NI= non infested plot.*

3.3. Plant Density related with treatments and seasons

The mean number of plants was identical (30) in the infested plots and the non-infested one 11 days after sowing, both in the dry and the raining season. Subsequently, plant density varied with time, both in the dry and the raining season. Particularly, plants density decreased with time in the two infested plots. Indeed, plants density recorded 18 days after sowing in the non-infested plot was not significantly different of that recorded 39 and 88 days after sowing in the same plot, both in the dry and the raining season. However, plants density recorded 18 days after sowing in the two infested plots was significantly higher than that recorded 39 and 88 days after sowing in the same plots, both in the dry and the raining season (p≤0.0001). Furthermore, there were no significant difference between plants density of the two infested plots and the non-infested one 18 days after sowing, while plants density of the two infested plots was significantly lesser than that of the non-infested one 39 and 88 days after sowing, both in the dry and the raining season (p≤0.0001). Plants density recorded 39 and 88 days after sowing in the slightly infested plot were significantly higher than those recorded in the heavily infested one at the same periods, both in the dry and the raining season (p≤0.0001). Although plants density recorded in the three plots 18 days after sowing in the dry season was not significantly different than that recorded in the raining season at the same period, plant densities recorded in the two infested plots 39 and 88 days after sowing in the dry season were significantly higher than those recorded in the raining season at the same periods (p≤0.0001) (Table 3; figure 4).

Table 3: Plants density and the mean number of root nodule, related with treatments and seasons

	Plants density		**Nodule number**	
	Dry season	**Raining season**	**Dry season**	**Raining season**
NIJ18	29.87±0.39^{a}	29.88±1.45^{a}	30.75±0.67^{e}	30.93±0.86^{e}
SIJ18	29.45±0.53^{a}	29.30±0.23^{ab}	29.17±0.89^{e}	28.63±1.22^{e}
HIJ18	29.45±0.53^{a}	29.37±0.19^{a}	28.14±0.94^{e}	28.03±0.92^{e}
NIJ39	29.67±0.51^{a}	29.43±0.15^{a}	139.43±8.12^{b}	139.37±8.17^{b}
SIJ39	28.25±0.89^{b}	27.62±0.33^{c}	125.76±1.63^{c}	125.51±1.51^{c}
HIJ39	27.27±0.94^{c}	26.57±0.52^{d}	116.73±2.24^{d}	116.11±2.19^{d}
NIJ88	28.97±1.02^{ab}	28.48±0.40^{a}	164.26±7.51^{a}	164.45±7.29^{a}
SIJ88	24.28±1.80^{d}	23.52±1.67^{e}	140.59±0.89^{b}	139.84±8.75^{b}
HIJ88	20.10±1.72^{e}	19.13±1.03^{f}	125.28±8.32^{c}	124.37±8.36^{c}

a, b, c, for plant density, means affected with the same letter are not significantly differ at *p≤0.0001. HI18= heavily infested plot for the day 18 after sowing, HI39= heavily infested plot for the day 39 after sowing, HI88= heavily infested plot for the day 88 after sowing, SI18= slightly infested plot for the day 18 after sowing, SI39= slightly infested plot for the day 39 after sowing, SI88= slightly infested plot for the day 88 after sowing. NI18= non-infested plot for the day 18 after sowing, NI39= non-infested plot for the day 39 after sowing, NI88= non-infested plot for the day 88 after sowing.*

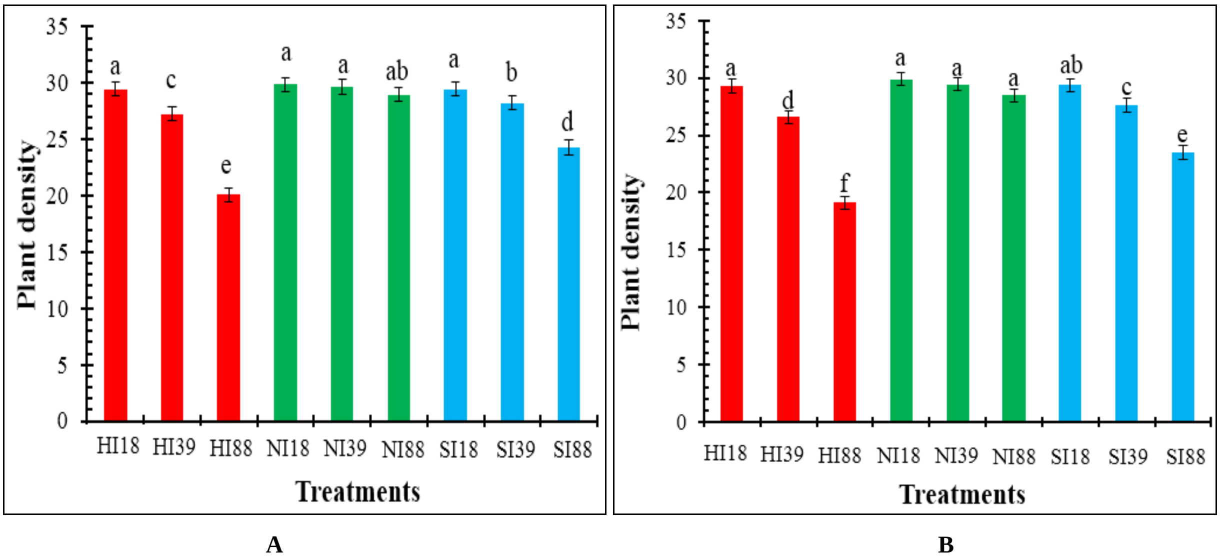


Fig 4: Plant density, related with treatments and time (A: dry season, B: raining season).

a, b, c, for plant density, means affected with the same letter are not significantly differ at *p≤0.0001. HI18= heavily infested plot for the day 18 after sowing, HI39= heavily infested plot for the day 39 after sowing, HI88= heavily infested plot for the day 88 after sowing, SI18= slightly infested plot for the day 18 after sowing, SI39= slightly infested plot for the day 39 after sowing, SI88= slightly infested plot for the day 88 after sowing. NI18= non-infested plot for the day 18 after sowing, NI39= non-infested plot for the day 39 after sowing, NI88= non-infested plot for the day 88 after sowing.*

3.4. Root Nodule Development related with treatment and seasons

Ants were observed digging soil around the base of the plants. The nodules that were visible on the plants root for the infested plots were smaller than those observed on the non-infested plants (Figure 5). Furthermore, the nodule number counted on plant root in Ndog-bong and Mboppi increased with time, both in the dry and the raining season. Indeed, root nodule number recorded 39 and 88 days after sowing in the two infested plots and the non-infested one were significantly higher than those recorded 18 days after sowing in the same plots (p≤0.0001). Moreover, the mean number of nodule recorded 18 day after sowing in the non-infested plot was not significantly different for that recorded at the same period in the two infested plots, while the mean numbers of nodule recorded 39 and 88 days after sowing in the non-infested plot were significantly higher than those recorded at the same period in the two infested plots, both in the dry and the raining season (p≤0.0001) (Table 3; figure 6). The nodule number recorded 39 and 88 days after sowing in the slightly infested plot were significantly higher than those recorded in the heavily infested one at the same periods, both in the dry and the raining seasons (p≤0.0001) (Table 3). There were no significant difference between the mean number of nodule in the dry and the raining season but the mean number of nodule in value was higher in the dry season than the raining one, particularly in the two infested plots.

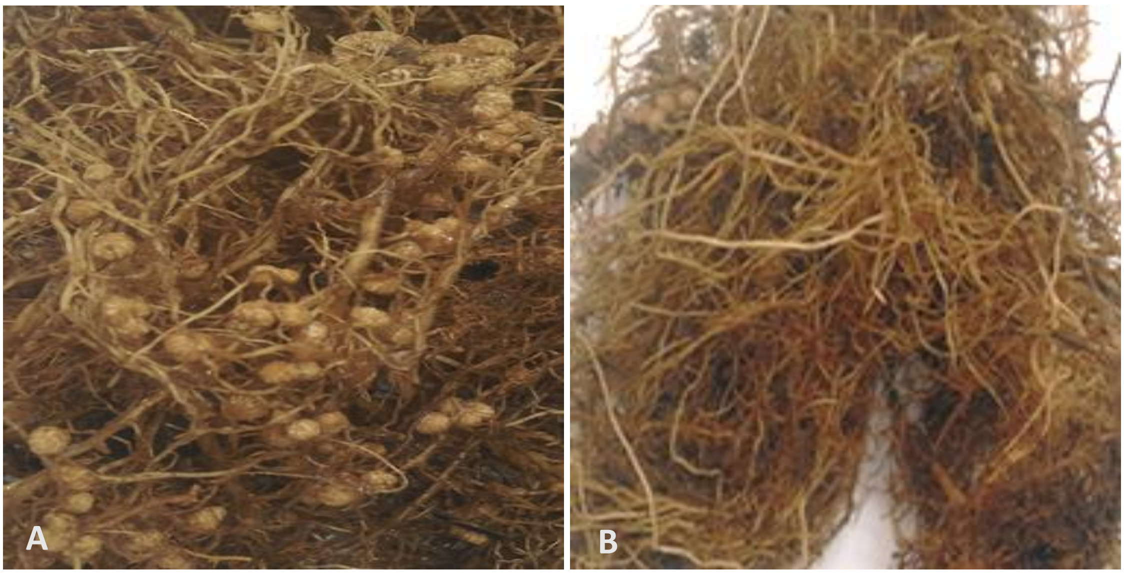
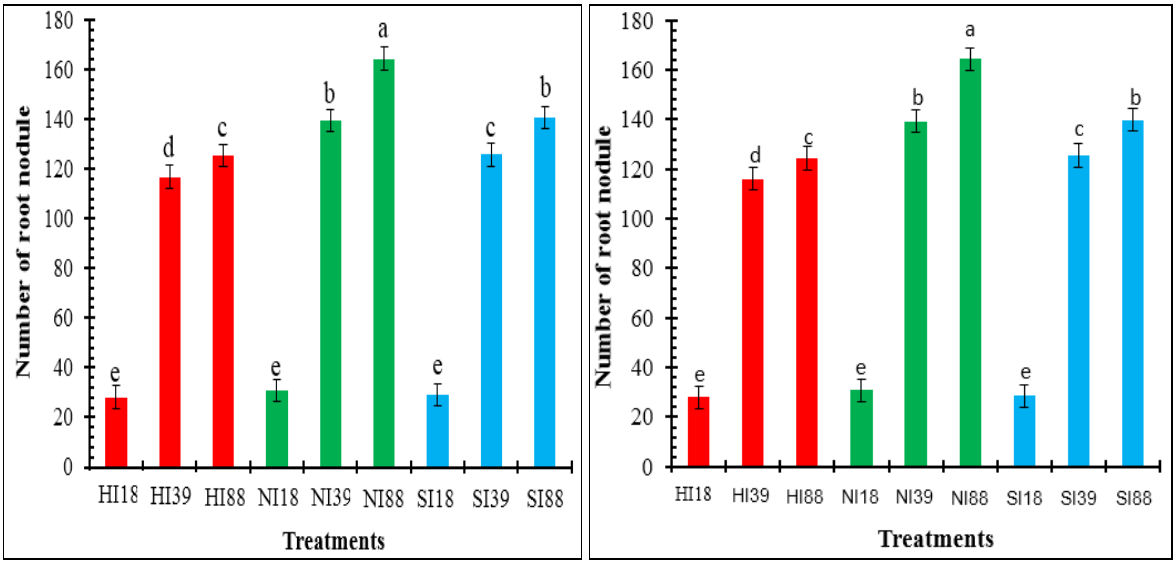


Fig 5: Root from plants dogged up 88 days after sowing in the non-infested plot (A) and the heavily infested one (B).



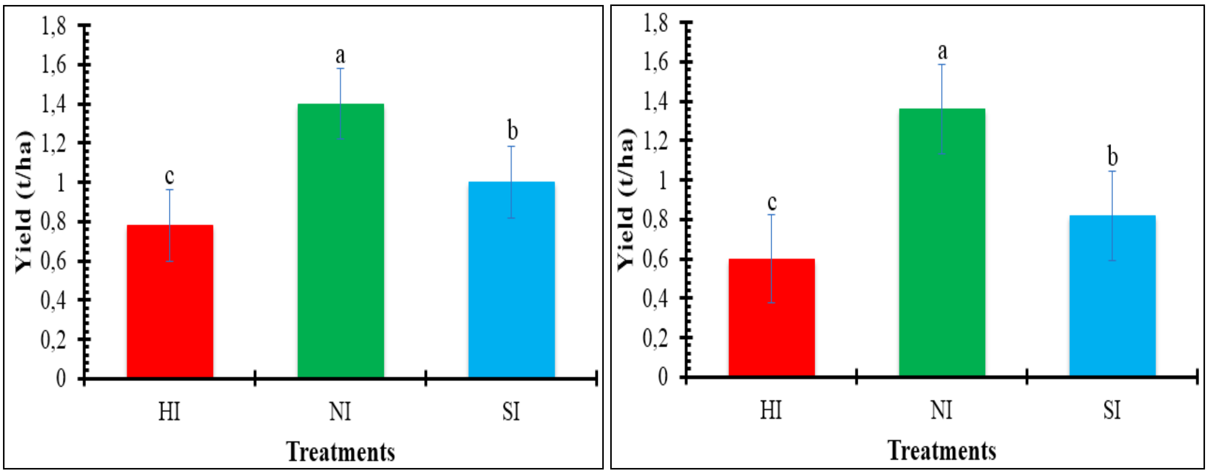
A **B**

Fig 6: Root nodule number, related with treatments and time (A: dry season, B: raining season).

a, b, c, for root nodule number, means affected with the same letter are not significantly different at p≤0.0001. HI18= heavily infested plot for the day 18 after sowing, HI39= heavily infested plot for the day 39 after sowing, HI88= heavily infested plot for the day 88 after sowing, SI18= slightly infested plot for the day 18 after sowing, SI39= slightly infested plot for the day 39 after sowing, SI88= slightly infested plot for the day 88 after sowing. NI18= non-infested plot for the day 18 after sowing, NI39= non-infested plot for the day 39 after sowing, NI88= non-infested plot for the day 88 after sowing,

3.5. Soybean Yield related with treatments and seasons

Both in Ndog-bong and Mboppi, soybean yield varied among plots with season and the level of plot infestation, as observed in table 2 and figure 7. So, the mean yield for the non-infested plot was significantly higher than that for the two infested plots, both in the raining and the dry seasons (p≤0.0001). The mean yield of the slightly infested plot was significantly higher than that for the heavily infested one, both in the dry and the raining season (p≤0.0001). There were no significant difference between the mean yield in the dry and the raining season but the mean yield in value was higher in the dry season than the raining one, particularly in the two infested plots.



A **B**

Fig 7: Yield, related with treatments (A: dry season, B: raining season).

a, b, c for the yield, means affected with the same letter are not significantly different at p≤0,0001. HI= heavily infested plot, SI= slightly infested plot, NI= non infested plot.

4. Discussion

The data clearly revealed a difference in studied parameters (germination rate, yield, root nodule number and density), for the two infested plots and the non-infested one, in Ndog-bong and Mboppi, both in the raining and the dry season. This difference was correlated with *Solenopsis geminata* foragers increase and the level of plot infestation. Globally, the four studied parameters were lower in the two infested plots than the non-infested one. The low yield in the infested plots can be attributed primarily to a low number of plants per plot, caused by a low number of germinated seeds. Direct feeding by *Solenopsis geminata* on germinating seeds and seedlings reduced plant density and is therefore the main cause of yield reduction. Several studies revealed that fire ants feed on germinating seeds. These studies also established a link between yield and plant density, suggesting that yield loss may be attributed to decrease in plant density. Seed damage by fire ant has been well characterized in a number of crops including soybean [28]. Previous studies also suggested that fire ant association with seeds/seedling germinated in soil reduced seedling vigor [12]. Studies in Florida and Mississippi showed that the read imported fire ant feeding on the germinating seed reduced the plant stand with an ultimate reduction of up to 600kg/ha in soybean yield [13, 19]. Furthermore, our data also showed the root nodule reduction in the two infested plots comparing with the non-infested one, related with the increasing of *Solenopsis geminata* foragers. Although the number of root nodules was low in the two infested plots than the non-infested one, fire ant association with plants did not significantly influence root nodule number 18 days after sowing. This result indicates that root nodule reduction 18 days after sowing could not be a major cause of soybean yield reduction. However, 39 and the day 88 days after sowing, fire ant in association with plants significantly reduced nodule number in the infested plots. Particularly, this reduction was more important in the heavily infested plot and may be due to the *Solenopsis geminata* colonies increase. The increasing of *Solenopsis geminata* foragers caused root nodule reduction by direct feeding on the root and can be secondary the cause of soybean yield reduction. Indeed, this root feeding inhibits nitrogen fixing formation, reduced soil mineral nutrient absorption and therefore caused plants density and yield reduction [12]. However, the negative impact of this fire ant on root nodules may depend to their colonies size. Previous studies also showed that increased numbers of read imported fire ant (IFA) correlated positively with reduced soybean yield in North Carolina [20]. It was also reported that soybean loss varied with level of infestation by imported fire ants [13, 19, 21].

Plant density recorded in the dry season 39 days after sowing in the two infested plots was significantly higher than that recorded in the raining season at the same period. Although our data did not globally showed the significant difference between certain parameters (mean number of germinated seeds, mean nodule number and yield) in the dry and the raining season, these parameters values were higher in the dry than the raining season, particularly in the two infested plots. The higher value of studied parameters in the dry season than the raining one may be due to the colony size increase of *Solenopsis geminata* during the raining season. Indeed, because of the link between season and temperature, global warming during the drying season add soil temperature, and therefore reduce the activity of fire ant foragers and their impact on the crops. Several studies also revealed the impact of temperature and season on the ant activities including *Solenopsis geminata*. Globally temperature is a key determinant of ant diversity, but precipitation also influences ant richness and it can strongly interact with temperature [22]. Previous studies on daily foraging pattern and proteinaceous food preferences of *Solenopsis geminata* revealed that foraging activity of this fire ant was reported maximum at midnight [23]. It was also revealed that temperature plays an important role in forage and thus determines the seasons and hours activity [24; 25, 26, 27].

5. Conclusion

Our specific objective in this study was to understand the impact of *Solenopsis geminata* on soybean crop and possibly establish a link between the *Solenopsis geminata* colony densities and soybean yield variation. This study clearly showed that *Solenopsis geminata* caused important soybean yield reduction. Firstly, this reduction was caused by direct feeding of *Solenopsis geminata* on germinating seeds and seedlings, which reduced plants density and therefore the soybean yield. Secondary, direct feeding of *Solenopsis geminata* on plant root inhibits nitrogen fixing formation, reduced soil mineral nutrient absorption by plants, and therefore caused yield reduction. Furthermore the soybean yield reduction may be important when *Solenopsis geminata* colony densities increase.

6. References

1. Sanu PV, Newport JK. Invasive alien species dispersal: the millennium biodiversity disaster. *Disaster Prevention and Management*. 2010;19:291-297.
2. Simberloff D, Martin JL, Genovesi P, Maris V, Wardle DA, Aronson J *et al*. Impacts of biological invasions: what's what and the way forward? Trends in *Ecology and Evolution*. 2013;28:58-66.
3. Everett RA. Patterns and pathways of biological invasions. Trends in Ecology and Evolution. 2000;15:177-178.
4. Pimentel D, Lach L, Zuniga R, Morrison D. Environmental and economic costs of nonindigenous species in the United States. *BioScience*. 2000;50:53-65.
5. Byeon Dh, Jung JM, Park Y, Lee HS, Lee JH, Jung S, et al. Model-based assessment of changes in the potential distribution of *Solenopsis geminata* (Hymenoptera: Formicidae) according to climate change scenarios. *J. Asia Pac. Biodivers*. 2020;13:331-338.
6. Suarez AV, Tsutsui ND. The evolutionary consequences of biological invasions. *Molecular Ecology*. 2008;17:351-360.
7. LeBrun EG, Abbott J, Gilbert LE. Imported crazy ant displaces imported fire ant, reduces and homogenizes grassland ant and arthropod assemblages. *Biological Invasions*. 2013;15:2429-2442.
8. Sukprasert S, Uawonggul N, Jamjanya T, Thammasirirak S, Daduang J, Daduang S. Characterization of the allergen sol gem 2 from the fire ant venom, *Solenopsis geminata*. *Journal of Venomos Animals and Toxins including Tropical Diseases*. 2012;18:325-334.
9. Wetterer JK. Worldwide spread of the tropical fire ant, *Solenopsis geminata* (Hymenoptera: Formicidae). *Myrmecological News*. 2011;14:21-35.
10. Horvitz CC. Analysis of how ant behaviours affect germination in a tropical myrmecochore Calathea microcephala (P. and E.) Koernickle (Marantaceae): Microsite selection and aril removal by Neotropical ants, *Odontomachus*, *Pachcondyla*, and *Solenopsis* (Formicidae). Oecologia. 1981;51:47-52.
11. Laércio Zambolim, Fernando C Juliatti, Wanderlei Guerra. How to cope with the vulnerability of site specific fungicides on the control of Asian soybean rust. Int. J Res. Agron. 2021;4(1):14-25. DOI: 10.33545/2618060X.2021.v4.i1a.44
12. Shatters RG, Vander Meer RK. Characterizing the Interaction between Fire Ants (Hymenoptera: Formicidae) and Developing Soybean Plants. *J. Econ. Entomol.* 2000;93:1680-1687.
13. Adams CT, Banks WA, Lofgren CS, Smittle BJ, Harlan DP. Impact of the red imported fire ant, *Solenopsis*

invicta (Hymenoptera: Formicidae), on the growth and yield of soybeans. *J. Econ. Entomol*. 1983;76:1129-1132.
14. Ross KG, Krieger MJB, Shoemaker DD. Alternative genetic foundations for a key social polymorphism in fire ants. *Genetics*. 2003;165:1853-1867.
15. Taber SW. *Fire ants*. College Station, Texas, *Texas A and M University Press*. 2000, 308.
16. Perfecto I, Vander Meer J. Microclimatic changes and the indirect loss of ant diversity in a tropical agroecosystem. *Oecologia*. 1996;108:577-582.
17. Feumba R, Ngounou Ngatcha B, Tabué Youmbi JG, Ekodeck GE. Relationship between Climate and Groundwater Recharge in the Besseke Watershed (Douala-Cameroon). *Journal of Water Resource and Protection*. 2011;10:607-619.
18. Nageleisen LM et Bouget C. L'étude des insectes en forêt: méthodes et techniques, éléments essentiels pour une standardisation. Synthèse des réflexions menées par le groupe de travail « Inventaires Entomologiques en Forêt » (Inv.Ent.For.). Les Dossiers Forestiers n°19, Office National des Forêts. 2009, 44-45.
19. Lofgren CS, Adams CT. Reduced yield of soybeans in fields infested with the red imported fire ant. *Solenopsis invicta*. *Fla. Entomol*. 1981;64:199-202.
20. Apperson CS, Powell EE. Correlation of the red imported fire ant (Hymenoptera: Formicidae) with reduced soybean yields in North Carolina. *J. Econ. Entomol*. 1983;76:1129-1132.
21. Banks WA, Adams CT, Lofgren CS, Wojcik DP. Imported Fire ant Infestation of soybean fields in the Southern United States. *Florida Entomologist*. 1990;73:503-504.
22. Jenkins CN, Sanders NJ, Andersen AN, Arnan X, Brühl CA, Cerda X, *et al.* Global diversity in light of climate change: the case of ants. *Diversity and Distributions*. 2011;17(4):652-662.
23. Norasmah B, Abu Hassan A, Che Salmah MR, Nurita AT, Nur Aida H. Daily foraging pattern and proteinaceous food preferences of *Solenopsis geminata* (Fabricius) (Hymenoptera: Formicidae). *Trop. Biomed*. 2006;23:134-139.
24. Vogt JT, Smith WA, Grantham RA, Wright RE. Effects of temperature and season on foraging activity of red imported fire ants (Hymenoptera: Formicidae) in Oklahoma. *Environ. Entomol*. 2003;32(3):447-451.
25. Drees BM, Summerlin B, Vinson SB. Foraging activity and temperature relationship for the red imported fire ant. *Southwest. Entomol*. 2007;32:149-155.
26. Amor F, Ortega P, Cerdá X, Boulay R. Solar elevation triggers foraging activity in a thermophilic ant. *Ethology*. 2011;117:1031-1039.
27. Jayatilaka P, Narendra A, Reid SF, Cooper P, Zeil J. Different effects of temperature on foraging activity schedules in sympatric *Myrmecia* ants. The Journal of experimental biology. 2011;214:2730-2738.
28. Morrison JE, Williams DF, Oi DH, Potter KN. Damage to dry crop seed by red imported fire ant (Hymenoptera: Formicidae). J Econ. Entomol. 1997;90:218-222.