Hindawi
International Journal of Agronomy
Volume 2023, Article ID 3034572, 8 pages
https://doi.org/10.1155/2023/3034572

Research Article

Implementation and Use of Green Manures for Weed Suppression in Sequential Maize Cropping

Amilcar Servín Niz, Modesto Osmar Da Silva Oviedo, Eulalio Morel López, Derlys López Ávalos, Hugo González Villalba, Alcides Fernández Sánchez, Pablo Fankhauser Solis, and Willian Insfrán

Facultad de Ciencias Agrarias, Universidad Nacional de Concepción, Concepción, Paraguay

Correspondence should be addressed to Amilcar Servín Niz; servinamilcar@gmail.com

Received 16 January 2023; Revised 11 August 2023; Accepted 23 August 2023; Published 31 August 2023

Academic Editor: David Clay

The ground cover produced by green manures has a direct influence on weed suppression and, in addition, the biomass produced by these same plants influences crop growth. This study was carried out to compare the effect of green manure species on the incidence of weeds, in sequence, in order to evaluate the effects of the use of green manure cover on the productive characteristics of maize plants. A completely randomised experimental design was used, with 11 treatments and 4 replications. The treatments were cover crops *Canavalia ensiformis* (T1), *Cajanus cajan* (T2), *Stizolobium pruriens* (T3), *Crotalaria juncea* (T4), *Phaseolus vulgaris* (T5), *Stizolobium trigre* (T6), *Stizolobium aterrimum* (T7), *Crotalaria retusa* (T8), *Crotalaria breviflora* (T9), *Dolichos lablab* (T10), and conventional system (T11). Ninety days after sowing, the green manures were cut, and 30 days after the green manures were cut, the hybrid maize Crop Top 520 was sown. The variables evaluated in relation to the planting of green manures were the green and dry biomass of green manures, alongside the green biomass of weeds and suppression of weeds. Concerning maize plants, the variables evaluated were plant height at 60 DAS, stalk diameter at 60 DAS, number of grain rows per ear, number of grains per grain row, and yield. The averages were subsequently analyzed using Tukey's test at 95% significance level. The use of green manure significantly reduces the green mass of weeds up to 90 days due to lack of access to light of the weeds, which reduces their appearance and growth. *Stizolobium aterrimum* showed the best results both as a dry mass producer and weed suppressor and also as a yield enhancer in maize crops.

1. Introduction

One of the requirements for the adoption of an integrated no tillage system is the use of cover crops which contributes to improving overall soil health, providing key ecosystem services through increased plant diversity [1], avoiding damage from raindrops, and promoting weed control and increasing organic matter. This in turn improves the physical and chemical properties of the soil [2, 3].

When adopting green manures before planting cash crops, the literature reports several benefits including increased crop yields, weed suppression, improved soil fertility, soil moisture, soil tilth, and erosion control [1–5]. Preference was shown for *Fabaceae* species because of the lower need for manual work, reduced need for chemical or manual weed removal, and the increased net benefits, mentioned above, when compared to conventional cultivation [4].

The integration of legumes as green manures into cereal farming is considered an alternative and sustainable approach to improving soil fertility, increasing crop productivity [6–8], and decreasing weed populations due to their function as cover crops, especially in developing countries with restricted access to nitrogen fertilizer [4, 9].

Green manure management is generally carried out before the reproductive stage in order to subsequently sow the main crop. In family farming systems in Paraguay, summer green manures are widely employed before planting maize (*Zea mays* L.), which is a cash crop, also used for human consumption and small livestock feed.

In Paraguay, maize represents a significant proportion of national agricultural income crops. Economically, maize contributes significantly to foreign currency availability in the country. The average crop yield nationwide was 4.148 kg·ha^{-1} in the 2021 cropping season and 5.016 kg·ha^{-1} in the 2022 cropping season [10].

Maize has high yield potential in South America, but only 50% of this potential is reached over a large area of Paraguay and other South American countries [11]. This is mainly due to the lack of technology adoption by farmers, such as soil tillage or conventional production system with low fertilizer and crop protection practices adoption. As such, it is necessary to adopt new production systems that maximize crop yields and increase farmers' profitability. One of the main consequences of soil tillage and a total absence of crop rotation is an excessive proliferation of weeds that compete with the maize crop.

These factors have led to a need for sustainable alternative methods of weed control. Crop rotation with green manure or cover crops, practiced mainly as part of conservation agriculture, is possibly the most effective and ecologically viable alternative or complementary measures [12, 13].

The hypothesis put forward in this study is that use of *Crotalaria juncea* will decrease weed populations and an increase in the productive parameters of the maize plants.

Therefore, the general aim of the present study was to compare the effect of green manure species on the incidence of weeds, in sequence, in order to evaluate the effects of the use of green manure cover on the productive characteristics of maize plants.

2. Materials and Methods

2.1. Experimental Site. The present study was carried out in the experimental field of the Agricultural School of Concepción at geographical coordinates latitude S 23° 25′ 40.3″ and longitude W 57° 20′ 00.2″, at an altitude of 242 m above sea level.

2.2. Soil Sampling and Characterization. The soil of the experimental site was classified as belonging to the order Alfisol and the Mollic Paleudalf subgroup [14]. Soil samples were air-dried, ground to pass a 2 mm sieve, and analyzed for soil pH in a 1 : 1 water suspension [15]. Soil organic carbon (SOC) was determined by the Walkley–Black method [15]. Soils P, K, Ca, and Mg were analyzed using the Mehlich-1 extractant [15]. Soil potential acidity (H + Al) was measured with the SMP buffer method [16]. Cation exchange capacity (CEC) at pH 7.0 was calculated by adding the exchangeable basic cations Ca^{+2}, Mg^{+2}, and K^{+} and the potential acidity (H + Al) [17]. Base saturation (V%) was calculated dividing the values of the basic cations by CEC and then multiplied by 100 [17].

Selected chemical characteristics of the soil at a depth of 0–20 cm were P (Mehlich^{-1}): 10.43 mg·dm^{-3}; O.C.: 0.520 g·dm^{-3}; pH ($CaCl_2$): 6.10; K: 0.05 cmol·dm^{-3}; Ca + Mg: 2.50 cmol·dm^{-3}; H + Al: 0.05 cmol·dm^{-3}; SB: 3.41 cmol·dm^{-3}; CIC: 5.56 cmol·dm^{-3}; and V%: 52.89.

2.3. Climatic Data at the Experimental Site. Data accumulated during the experiment on mean temperature and precipitation are shown in (Figure 1) [18].

2.4. Experimental Design and Treatments. The experimental design used was a completely randomised design (CRD) with 11 treatments and 4 replications, giving a total of 44 experimental units (EU). The control treatment (conventional system) was used for two of the variables evaluated (green mass and weed suppression) since the other parameters were related to the green manure crops used. The treatments were *Canavalia ensiformis* (T1), *Cajanus cajan* (T2), *Stizolobium pruriens* or *Mucuna pruriens* (T3), *Crotalaria juncea* (T4), *Phaseolus vulgaris* (T5), *Stizolobium trigre* or *Mucuna trigre* (T6), *Stizolobium aterrimum* or *Mucuna aterrimum* (T7), *Crotalaria retusa* L. (T8), *Crotalaria breviflora* DC (T9), *Dolichos lablab* L (T10), and the conventional system (T11), which consisted soil tillage with no cover crop adoption.

2.5. Installation Process. Each experimental unit was 3 m long and 2 m wide (6 m^2), with a distance of 0.5 m between rows and 0.5 m between plants, giving 6 plants per row and 4 rows. There were a total of 24 plants per experimental unit and 4 plants per linear meter. The plot was selected for the experiment weeks before sowing, taking into account the uniformity of the terrain, its incline and accessibility. As the chosen plot was pastureland, it was cleared with a rotary harrow. Afterwards, further clearing was carried out manually with a hoe. The hoe was also used to achieve uniformity of the terrain. Once the plot was cleared, measurements of the area were made; a stake was placed in each corner and a square was used for precision. The dimensions recorded were 59 m length and 18 m width, giving a total experimental area of 1062 m^2. Sowing of the green manures was carried out in October 2020. Sowing was carried out manually by opening furrows of approximately 2 cm depth for *C. ensiformis*, *C. cajan*, *S. pruriens, P. vulgaris, S. trigre*, *S. aterrimum*, and *D. lablab* with a density of 0.45 m between plants and 0.45 m between rows. Two seeds were placed in each hole for the aforementioned species. For the Crotalaria species, sowing was carried out using a continual flow of seeds with spacing between rows of 0.45 m [19] and a depth of 3 to 5 mm. For the conventional system, soil tillage was done manually using hoes at a depth of 0–20 cm [20]. Weed control was carried out manually using a hoe only on the walkways. At 90 DAS, during the flowering period of the green manures, the plants were cut [21]. This was done with a Husqvarna brand weed cutter with a double blade. 30 days after cutting the green manures (DACGM) [2], maize was sown. Crop Top 520 hybrid maize was planted with a planting density of 0.50 m between rows and 0.30 m between plants at a depth of 2 cm [22]. Two seeds were planted in each hole, and planting was carried out manually using a seed drill. Fertilization consisted of nitrogen (70 kg·ha^{-1}), phosphorus (110 kg·ha^{-1}), and potassium (150 kg·ha^{-1}), which were applied using urea (46% N), triple superphosphate (46% P_2O_5 and 14% Ca,) and potassium chloride (60%

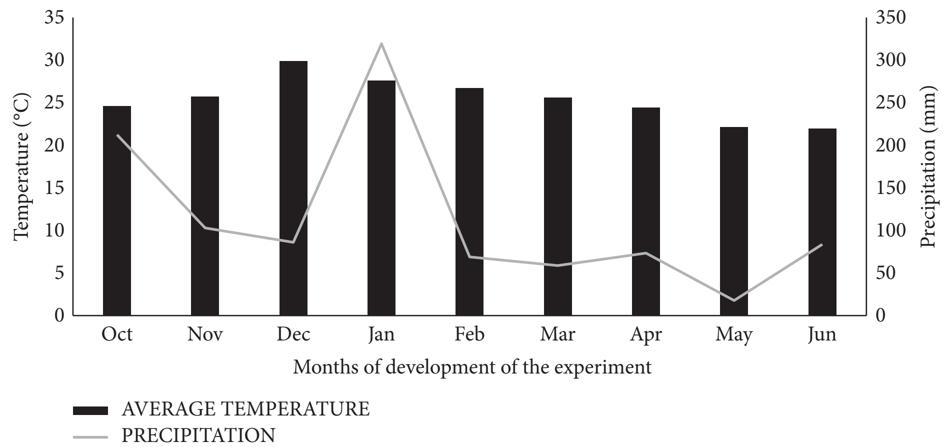

Figure 1: Mean temperature and cumulative precipitation data for October 2020 to June 2021.

K_2O) respectively. Nitrogen application was divided into two sessions: on sowing (30%) and when the plant had eight true leaves (70%) [23]. Phosphorus and potassium were applied in a single application (20 DAS); they were applied by hand at locally recommended dosages [24]. No weeding was carried out. The cover provided by the green manures minimized the development of weeds. Thinning was carried out because two seeds had been planted per hole. Applications of phytosanitary products were carried out at an interval of 15 days to prevent insect and fungal infestation. The insecticide used was phenylpyrazole 80 at a dosage of 10 g per 20 l tank. The fungicide used was benzimidazole at a dosage of 1 l·ha^{-1}. The harvesting process began 150 DAS, with two harvest sessions carried out. The ears of maize were collected manually [25]. The variables of the summer green manures were evaluated 60 and 90 days into the crop cycle. The following parameters were evaluated.

2.6. Parameters Evaluated. Green mass of green manure (Mg·ha^{-1}): green mass was measured at 60 and 90 days into the crop cycle. A polyvinyl chloride (PVC) frame with dimensions of 1 m^2 was used; it was randomly thrown in the areas used for each treatment. The green manure plants inside the frame were harvested and weighed on scales of 0.005 grams precision [21]. The percentage (%) increase from 60 to 90 DAS was calculated using the values obtained. Dry mass of green manure (Mg·ha^{-1}): to measure the dry mass, the green manure plants used to measure green mass were placed in a forced-circulation oven at 65°C for 72 hours [26, 27]. Percentage (%) increase between 60 and 90 DAS was calculated using the data obtained. Green mass of weeds (Mg·ha^{-1}): to measure the green mass of weeds present in the treatments, collection was carried out manually at ground level [28]. A PVC frame of 1 m^2 dimensions was used; the frame was randomly thrown for each treatment and repetition. A different area of the experimental unit was chosen at random for evaluation at 90 days. The weeds located within the frame were collected and weighed using scales with 0.005 g precision [29]. Weed suppression (Mg·ha^{-1}): the control treatment (T11: conventional system) [30] was used as a reference for the determination of the green mass of weeds and weed suppression. Formula (1) was used to obtain the values of weed reduction at 60 and 90 days after the planting of green manures.

$$WS = CT - TGM, \quad (1)$$

where WS is the weed suppression Mg·ha^{-1}, CT is the control treatment, and TGM is the treatment with green manure crops used.

The following parameters were measured in relation to the maize plants. Plant height (cm): a tape measure was used to measure the height of the plant between its base and the collar of the highest leaf; 10 plants were selected for measurement from the plot of each experimental unit at 60 DAS [31]. Stem diameter (mm) was determined using a Vernier caliper, using the first internode in base-apex direction at 60 DAS. Number of grain rows per ear: 20 ears were selected per experimental unit and the number of grain rows of each of the ears was counted and averaged. The number of grains per grain row was counted in 20 ears gathered from plants selected randomly; an average was obtained for each treatment [32]. Grain yield (Mg·ha^{-1}): ears were harvested on the center rows at the end of the crop cycle, and the weight of grain production was determined using precision scales when the grains reached 13% humidity [33, 34].

2.7. Data Analysis. The data obtained from each treatment were evaluated statistically; variance analysis (5% F-test) was used to verify whether there were significant differences between treatments; the averages were subsequently analyzed using Tukey's test at 95% significance level [35]. A free statistical software called AgroEstat [36] was used.

3. Results

3.1. Green Mass of Weeds and Weed Suppression. Table 1 displays the comparison of averages for the values of green mass of weeds (GMW) and suppression of weeds (SW) at 60 and 90 DAS, respectively. It can be observed that for GMW at 60 DAS, there were significant differences, with coverage from *S. aterrimum* and *P. vulgaris* achieving the best results. At 90 DAS, statistical differences were also found between the control and the green manures in question. For WS, significant differences were also found between the green manures used as cover crops at both 60 and 90 days, evidencing that green manures are excellent weed suppressors (Table 1).

3.2. Dry Mass and Green Mass (DMGM) of Green Manure. Green and dry mass production at 60 and 90 days, respectively, shows differences between treatments. Green manure species also showed different green mass production, varying from 3.39 to 4.66 Mg·ha^{-1} and 4.92 to 6.33 Mg·ha^{-1} at 60 and 90 DAS, respectively (Table 2). The same trend was observed with DMGM, varying from 1.26 to 1.66 Mg·ha^{-1} and 1.52 to 2.17 Mg·ha^{-1} at 60 and 90 DAS, respectively (Table 2).

3.3. Plant Height, Stalk Diameter, Number of Grains per Row, Number of Rows per Ear, and Yield. Table 3 shows the impact of green manure cover on maize traits. High significance is seen between the values studied in relation to the green manure covers used.

Table 1: Comparison of averages for green mass of weeds (GMW) and weed suppression (WS) (Mg·ha^{-1}) at 60 and 90 days after sowing (DAS) of green manure.

Treatments	GMW (Mg·ha^{-1})		WS (Mg·ha^{-1})	
	60 DAS	90 DAS	60 DAS	90 DAS
T1 *Canavalia ensiformis*	2.58 b	4.57 b	1.94 b	4.57 b
T2 *Cajanus cajan*	2.58 b	4.53 b	1.94 b	4.61 b
T3 *Stizolobium pruriens*	2.63 b	4.42 b	1.89 b	4.72 b
T4 *Crotalaria juncea*	2.69 b	4.03 ab	1.83 b	5.11 ab
T5 *Phaseolus vulgaris*	2.18 ab	3.36 a	2.33 ab	5.79 a
T6 *Stizolobium trigre*	2.50 b	3.64 ab	2.01 b	5.50 ab
T7 *Stizolobium aterrimum*	1.59 a	3.34 a	2.93 a	5.80 a
T8 *Crotalaria retusa*	2.40 b	3.70 ab	2.12 b	5.44 ab
T9 *Crotalaria breviflora*	2.36 b	4.45 b	2.15 ab	4.69 b
T10 *Dolichos lablab*	2.65 b	3.82 ab	1.87 b	5.32 ab
T11 Conventional system	4.52 c	9.15 b		
OA:	2.61	4.45	2.10	5.16
CV (%):	11.47	8.82	15.49	8.31
LSD (5%):	0.73	0.96	0.78	1.03

*Unequal letters differ from each other statistically by Tukey's test at 5%. OA: overall average; CV (%): coefficient of variation; LSD (%): least significant difference.

4. Discussion

4.1. Green Mass of Weeds (GMW) and Weed Suppression (WS) (Mg·ha^{-1}). Table 1 shows that there are significant differences at 60 DAS between the control and the treatments in which green fertilizers were used. Significant differences are also seen at 90 days with the conventional system in which no cover crop was sown. This shows that the use of green manures greatly reduces the GMW because they have less access to light; as the incidence of weeds is lower, there will be less economically significant competition. With the use of *S. aterrimum*, *P. vulgaris*, *C. breviflora*, *C. retusa*, *S. trigre*, *C. ensiformis*, *C. cajan*, *C. juncea*, *S. pruriens*, and *C. juncea* reductions of 64.82, 51.55, 47.57, 46.90, 44.47, 42.92, 42.92, 41.81, 41.37, and 40.49%, respectively, of green mass of weeds were recorded at 60 days compared to the conventional system. At 90 DAS, they already displayed uniform behavior in relation to the incidence of weeds, with *S. aterrimum*, *P. vulgaris*, *S. trigre*, *C. retusa*, *D. lablab*, *C. juncea*, *S. pruriens*, *C. breviflora*, *C. cajan*, and *C. ensiformis* showing respective reductions of 63.39, 63.28, 60.11, 59.45, 58.14, 55.85, 51.58, 51.26, 50.38 and 49.95% compared to the control. According to Sodré Filho et al. [37], the absence of cover crops before planting the cash crop could increase weed infestation during the crop's development, that is, to say that the incidence of weeds is higher when using bare soil. Similar results were observed in this experiment. The occurrence of weeds is greater, reducing the productive and reproductive variables of the cash crop [26]. As such, soil cover from the cover crop residues acts as a physical barrier, preventing the emergence of weeds, reducing competition and producing better conditions for the subsequent crop [6].

In the same way, Marasca et al. [38] reported that an increase in weed control was observed when using vegetation cover in comparison to the conventional system; similar results were observed in this study.

The higher efficiency of *Stizolobium aterrimum* in weed reduction can be explained by its rapid growth and its ability to produce large amounts of biomass covering the entire soil surface [39].

The inclusion of green manures in crop rotation is of utmost importance for the production of abundant biomass in order to reduce the presence of weeds. As can be seen in Table 1, all the green manures used are effective at suppressing weeds, and it is evident that the appearance of weeds was mitigated through the use of green manures, producing favorable results. The main weed species found in the course of the experiment were *Digitaria insularis* L., *Digitaria bicornis* (Lam.) Roem. & Schult., *Commelina erecta* L., *Cenchrus echinatus* L., *Conyza bonariensis* (L.) Cronquist var. Bonariensis, *Gamochaeta calviceps* (Fernald) Cabrera, *Amaranthus blitum* L., *Sida rhombifolia* L., *Tridax procumbens* L., *Cleome aculeata* L., *Ipomoea grandifolia* (Dammer) O´Donnell, *Boerhavia diffusa* L., and *Cucurbitella asperata* (Gillies ex Hook. and Arn.) Walp.

4.2. Green Mass and Dry Mass (DMGM) of Green Manure (Mg·ha^{-1}). Green mass levels of 4.66 Mg·ha^{-1} and 3.59 Mg·ha^{-1} are observed (Table 2) for *S. aterrimum* and *C. cajan*, respectively (60 DAS). However, in relation to the increase in mass between 60 and 90 DAS, higher growth is observed in *S. pruriens* (66.02%), followed by *C. ensiformis* (51.55%) and *C. cajan* (44.13%).

According to de Jesús et al. [19], dry matter production of 4.43 Mg·ha^{-1} was seen with *Crotalaria* spp.; these values are higher than those found in this experiment. Likewise, a study on the phytomass of green manures found different

Table 2: Comparison of averages of green mass (GMGM) and dry mass (DMGM) of green manure (Mg·ha^{-1}) at 60 and 90 DAS green manures.

Treatments	GMGM (Mg·ha^{-1})		Increase (60–90 DAS) (%)	DMGM (Mg·ha^{-1})		Increase (60–90 DAS) (%)
	60 DAS	90 DAS		60 DAS	90 DAS	
T1 *Canavalia ensiformis*	3.84 bc	4.94 c	51.55	1.41 abc	1.84 ab	22.28
T2 *Cajanus cajan*	3.39 c	4.92 c	44.13	1.39 abc	1.80 ab	22.23
T3 *Stizolobium pruriens*	3.52 bc	5.50 bc	66.02	1.49 abc	1.80 ab	17.23
T4 *Crotalaria juncea*	3.55 bc	5.58 bc	38.96	1.36 abc	1.92 ab	28.90
T5 *Phaseolus vulgaris*	3.98 b	6.33 ab	22.88	1.61 ab	2.11 a	22.00
T6 *Stizolobium trigre*	3.84 bc	5.54 bc	31.1	1.38 abc	1.57 b	11.78
T7 *Stizolobium aterrimum*	4.66 a	7.15 a	34.59	1.66 a	2.17 a	21.76
T8 *Crotalaria retusa*	3.74 bc	5.72 bc	34.47	1.47 abc	1.71 ab	13.67
T9 *Crotalaria breviflora*	3.83 bc	5.42 bc	29.17	1.33 bc	1.62 b	18.62
T10 *Dolichos lablab*	3.51 bc	5.54 bc	36.49	1.26 c	1.52 b	16.51
OA:	3.79	5.66		1.44	1.80	
C.V (%):	5.30	7.74		8.85	11.07	
LSD (5%):	0.48	1.05		0.30	0.48	

*Unequal letters differ from each other statistically by Tukey's test at 5%. OA: overall average; C.V(%): coefficient of variation; LSD (%): least significant difference (LSD).

Table 3: Comparison of averages of maize plant height (PH) (cm), stalk diameter (SD) (cm), number of grains per row (N°GR), number of rows per ear (N°RE), and yield (Y) (Mg·ha^{-1}) by green manure cover.

Treatments	PH (cm)	SD (cm)	N°GR	N°RE	Y (Mg·ha^{-1})
T1 *Canavalia ensiformis*	91.68 ab	1.50 c	28.28 b	15.20 c	5.98 c
T2 *Cajanus cajan*	83.80 ab	1.49 c	27.95 b	15.15 c	5.73 c
T3 *Stizolobium pruriens*	82.35 ab	1.52 c	29.75 ab	15.24 bc	5.75 c
T4 *Crotalaria juncea*	83.30 ab	1.50 c	27.96 b	15.16 c	5.68 c
T5 *Phaseolus vulgaris*	102.10 a	1.96 b	30.57 ab	15.97 b	7.22 ab
T6 *Stizolobium trigre*	94.37 ab	1.54 c	29.27 ab	15.43 bc	6.56 bc
T7 *Stizolobium aterrimum*	84.95 ab	2.30 a	32.12 a	16.77 a	7.66 a
T8 *Crotalaria retusa*	78.90 ab	1.86 b	28.60 b	15.79 bc	6.06 c
T9 *Crotalaria breviflora*	78.95 ab	1.54 c	29.63 ab	15.55 bc	6.06 c
T10 *Dolichos lablab*	98.35 a	1.63 c	28.58 b	15.26 bc	5.98 c
T11 Conventional system	72.35 b	1.43 c	24.47 c	13.82 d	3.82 d
OA:	86.46	1.66	28.83	15.39	6.04
CV (%):	11.22	5.68	4.34	1.96	6.33
LSD (5%):	23.69	0.23	3.06	0.73	0.93

*Unequal letters differ from each other statistically by Tukey's test at 5%. OA: overall average; C.V(%): coefficient of variation; LSD (%): least significant difference (LSD).

results for green biomass [40] than those found in this study. In an investigation carried out by Teodoro et al. [41], the highest averages for green biomass were obtained with *C. breviflora* followed by *C. ensiformis*. Different results were observed in the current experiment; the highest averages were recorded with *S. aterrimum* and *P. vulgaris*.

For DMGM, it can be seen that *S. aterrimum* produced the best result with 1.66 and 2.17 Mg·ha^{-1} at 60 and 90 DAS, respectively, an increase of 21.76%. This result was obtained because of the rapid adaptability of this green manure; the longer the green manure crop is left in the field, the higher the production of dry matter. This can be seen in the present study, which lasted 90 days, by the fact that the species had begun their flowering processes. All the green manure species showed an increase in dry mass from 60 to 90 DAS.

According to Amilcar et al. [42], in a study evaluating the behavior of green manure species in conventionally used soil, dry mass increased progressively; the present study produced similar results.

4.3. Plant Height, Stalk Diameter, Number of Grains per Row, Number of Rows per Ear, and Yield. As can be seen in Table 3, the vegetative cover crop *S. aterrimum* produced an increase for the variables PH, N°GR, N° RE, and Y, but not for SD. This increase in maize yield coincides with the higher biomass production of the green manures used and the decrease in weed incidence, as such the increase in yield is due to the suppression of weeds through higher vegetative cover.

According to Gomes et al. [43], in a study of two soil management systems for maize production, an increase in the number of grain rows per ear was seen when using green manures; compared to the conventional system, similar results were observed in this study.

Coverage with *S. aterrimum*, *Phaseolus vulgaris*, and *S. trigre* produced an increase of 100.52, 89, and 71.72%, respectively, in comparison to the conventional system; this indicates a significant increase in yield, as productivity was doubled. According to Cazetta et al. [44], in a study on the effects of plant cover and nitrogen fertilization on maize production in a no-tillage system, the use of *Fabaceae* led to an increase in productivity compared to the conventional system. Similar results were observed in the present study. Nunes et al. [22] planted maize after cover crops in no-tillage conditions. They observed that when dry matter of the soil cover increased, maize yield also increased. The same behavior was observed in this experiment. Likewise, Krenchinski et al. [45] found that a greater amount of plant cover dry matter provides a higher percentage of soil cover, maximizing soybean productivity in contrast to plant cover producing less dry matter. Isah et al. [46] evaluated the yield of tomato varieties in relation to quantities of green manures. They found that maximum productivity was achieved through the highest amount of plant cover; similar results were observed in this study. Elsewhere, Lang et al. [47] were able to increase carrot productivity through the use of vegetative cover on the soil surface.

These results do not coincide with those found by Moura et al. [20] who, studying the effect of cover crop and soil preparation on maize growth and productivity, found that yields were higher in tillage systems compared to systems employing a cover crop. González Villalba et al. [4], however, showed great increase in maize grain yield when using winter cover crops as previous crops to maize and quantified the amount of N provided by them, with up to 53 $kg \cdot ha^{-1}$ N when using a legume, explaining the great response in maize grain yield.

5. Conclusions

The adoption of green manures significantly reduces the green mass of weeds up to 90 days compared to the conventional system. Thus, weeds impact on the subsequent planted corn is significantly reduced. Weed suppression is greater when incorporating green manures into a crop rotation system before maize planting. This is very important especially for small farms.

The results of this study show that any of the cover crops used in this study are recommended as previous crops to maize in order to improve small farm agriculture sustainability, as they reduce weeds presence, increases crop residues, and increase maize grain yield in succession.

We encourage long-term trials looking at the adoption of summer and winter cover crops, mixtures, and evaluation of soil properties changes, as options to increase overall soil health parameters and small farms profitability, in subtropical conditions.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Authors' Contributions

EML and DFLA designed the experiments; PF, AFS, and WI carried out the field and laboratory experiments; MODO, HGV, and AISN contributed to the data analysis; and AISN and HGV wrote the article. The translation was carried out by HGV. All authors reviewed the final version of the manuscript.

Acknowledgments

The authors thank the Consejo Nacional de Ciencia y Tecnología (CONACYT), specifically the Programa Nacional de Incentivo al investigador (PRONII), for funding this study.

References

[1] D. M. Finney, C. M. White, and J. P. Kaye, "Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures," *Agronomy Journal*, vol. 108, no. 1, pp. 39–52, 2016.

[2] A. I. Servín Niz, M. O. D. S. Ovkdo, E. Morel López et al., "Cobertura de abonos verdes de verano como supresor de malezas en un sistema de rotación de cultivos utilizando Pennisetum glaucum," *Idesia*, vol. 40, no. 2, pp. 123–128, 2022.

[3] M. V. Correia, L. C. Pereira, L. De Almeida et al., "Maize-mucuna (Mucuna pruriens (L.) DC) relay intercropping in the lowland tropics of Timor-Leste," *Field Crops Research*, vol. 156, pp. 272–280, 2014.

[4] H. A. González Villalba, D. Ruiz Diaz, E. L. Schoninger, and C. A. Leguizamón Rojas, "Winter cover crops influence weed establishment and nitrogen supply to maize," *Investigación Agraria*, vol. 20, no. 2, pp. 100–109, 2018.

[5] A. Scavo, S. Fontanazza, A. Restuccia, G. R. Pesce, C. Abbate, and G. Mauromicale, "The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review," *Agronomy for Sustainable Development*, vol. 42, no. 5, p. 93, 2022.

[6] G. Agegnehu, B. Lakew, and P. N. Nelson, "Cropping sequence and nitrogen fertilizer effects on the productivity and quality of malting barley and soil fertility in the Ethiopian highlands," *Archives of Agronomy and Soil Science*, vol. 60, no. 9, pp. 1261–1275, 2014.

[7] B. L. Meena, R. K. Fagodiya, K. Prajapat et al., "Legume green manuring: an option for soil sustainability," in *Legumes for Soil Health and Sustainable Management*, pp. 387–408, Springer, Singapore, 2018.

[8] T. Amede, G. Legesse, G. Agegnehu et al., "Short term fallow and partitioning effects of green manures on wheat systems in East African highlands," *Field Crops Research*, vol. 269, Article ID 108175, 2021.

[9] J. K. Norsworthy, L. Brandenberger, N. R. Burgos, and M. Riley, "Weed suppression in Vigna unguiculata with a spring-seeded Brassicaceae green manure," *Crop Protection*, vol. 24, no. 5, pp. 441–447, 2005.

[10] Capeco, "Cámara paraguaya de Exportadores y comercializadores de Cereales y oleaginosas," 2021, https://www.capeco.org.py.

[11] R. de Souza Nóia Júnior and P. C. Sentelhas, "Yield gap of the double-crop system of main-season soybean with off-season

maize in Brazil," *Crop and Pasture Science*, vol. 71, no. 5, pp. 445–458, 2020.

[12] O. A. Abdin, X. M. Zhou, D. Cloutier, D. C. Coulman, M. A. Faris, and D. L. Smith, "Cover crops and interrow tillage for weed control in short season maize (Zea mays)," *European Journal of Agronomy*, vol. 12, no. 2, pp. 93–102, 2000.

[13] J. T. Rugare, P. J. Pieterse, and S. Mabasa, "Allelopathic potential of green manure cover crops on germination and early seedling development of goose grass [eleusine indica (L.) gaertn] and blackjack (bidens pilosa L.)," *International Journal of Agronomy*, vol. 2021, Article ID 6552928, 13 pages, 2021.

[14] O. E. López, E. González, P. A. De Llamas et al., "Estudio de reconocimiento de suelos, capacidad de uso de la tierra y propuesta de ordenamiento territorial preliminar de la Región Oriental del Paraguay", Asunción, MAG/Dirección de Ordenamiento Ambiental/Banco Mundial. Proyecto de Racionalización de Uso de la Tierra. Convenio 3445. P. Banco Mundial," 1995, https://www.geologiadelparaguay.com/Estudio-de-Reconocimiento-de-Suelos-Regi%C3%B3n-Oriental-Paraguay.pdf.

[15] M. J. Tedesco, C. Gianello, C. A. Bissani, H. Bohnen, and S. J. Volkweiss, *Análises de solo, plantas e outros materiais*, Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, BR, USA, 1995.

[16] H. E. Shoemaker, E. O. McLean, and P. F. Pratt, "Buffer methods for determining lime requirement of soils with appreciable amounts of extractable Aluminum," *Soil Science Society of America Journal*, vol. 25, no. 4, pp. 274–277, 1961.

[17] B. van Raij, *Fertilidade do solo e manejo de nutrientes*, International Plant Nutrition Institute (IPNI), Piracicaba, BR, USA, 2013.

[18] Dmh Dirección de Meteorología e Hidrología de la and Dinac Dirección Nacional de Aeronáutica Civil, "Datos de los parámetros meteorológicos," 2021, https://www.meteorologia.gov.py/index.php.

[19] R. P. de Jesus, G. Corcioli, A. D. Didonet, J. D. Borges, J. A. A. Moreira, and N. F. da Silva, "Plantas de cobertura de solo e seus efeitos no desenvolvimento da cultura do arroz de terras altas em cultivo orgánico," *Pesquisa Agropecuária Tropical*, vol. 37, no. 4, pp. 214–220, 2007.

[20] E. G. D. Moura, J. M. Albuquerque, and A. D. C. F. Aguiar, "Growth and productivity of corn as affected by mulching and tillage in alley cropping systems," *Scientia Agricola*, vol. 65, no. 2, pp. 204–208, 2008.

[21] M. E. D. Sá, H. M. Simidu, L. C. D. D. Souza, F. D. L. Abrantes, M. P. D. Silva, and O. Arf, "Efeito do adubo verde e época de semeadura sobre a produtividade do feijão, em plantio direto em região de cerrado," *Acta Scientiarum. Agronomy*, vol. 32, no. 2, pp. 309–315, 2010.

[22] D. O. Nunes, J. H. D. S. Favaro, H. C. D. O. Charlo, A. Loss, A. C. Barreto, and J. L. R. Torres, "Green and sweet corn grown under different cover crops and phases of the no-tillage system," *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 26, no. 3, pp. 173–179, 2022.

[23] A. F. Almeida, L. C. Grangeiro, N. M. Ferreira, V. E. D. V. Gomes, S. A. Silva, and R. R. D. A. Lacerda, "Phosphorus use efficiency by maize cultivars for the production of green ears," *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 24, no. 8, pp. 547–553, 2020.

[24] J. D'Amours, D. E. Pelster, G. Gagné et al., "Combining reduced tillage and green manures minimized N2O emissions from organic cropping systems in a cool humid climate," *Agriculture, Ecosystems & Environment*, vol. 341, Article ID 108205, p. 2023, 2023.

[25] F. Panison, L. Sangoi, D. F. Kolling, C. M. M. Coelho, and M. M. Durli, "Harvest time and agronomic performance of maize hybrids with contrasting growth cycles," *Acta Scientiarum. Agronomy*, vol. 38, no. 2, pp. 219–226, 2016.

[26] P. H. R. Cabral, A. Jakelaitis, I. S. Cardoso, V. T. D. Araújo, and E. C. F. Pedrini, "Interferência de plantas daninhas na cultura do sorgo cultivado em safrinha," *Pesquisa Agropecuária Tropical*, vol. 43, no. 3, pp. 308–314, 2013.

[27] J. C. Martins, R. S. Menezes, E. V. Sampaio, A. F. D. Santos, and M. A. Nagai, "Produtividade de biomassa em sistemas agroflorestais e tradicionais no Cariri Paraibano," *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 17, no. 6, pp. 581–587, 2013.

[28] Ú. R. Zaidan, R. C. Campos, R. M. Faria et al., "Productivity and grain size of coffee grown in different weed management systems," *Acta Scientiarum. Agronomy*, vol. 44, Article ID e55692, 2022.

[29] C. M. Maszura, S. M. R. Karim, M. Z. Norhafizah, F. Kayat, and M. Arifullah, "Distribution, density, and abundance of parthenium weed (Parthenium hysterophorus L.) at Kuala Muda, Malaysia," *International Journal of Agronomy*, vol. 2018, Article ID 1046214, 8 pages, 2018.

[30] C. Buchling, G. B. P. Braz, S. D. O. Procópio, C. J. B. Ferreira, A. G. D. Silva, and J. Coradin, "Pre-emergence control and interference of voluntary maize plants on a soybean crop in Brazilian Cerrado," *Acta Scientiarum. Agronomy*, vol. 44, Article ID e54544, 2022.

[31] T. W. Steusloff, G. Singh, K. A. Nelson, and P. P. Motavalli, "Enhanced efficiency liquid nitrogen fertilizer management for corn production," *International Journal of Agronomy*, vol. 2019, Article ID 9879273, 12 pages, 2019.

[32] E. Lorenzetti, J. Tartaro, J. R. Stangarlin, O. J. Kuhn, R. L. Portz, and A. J. Alves "Neto, "Agronomic characteristics and management of diseases in maize with chelate-based products containing calcium, copper, manganese, and zinc," *Acta Scientiarum. Agronomy*, vol. 43, Article ID e48432, 10 pages, 2020.

[33] T. W. Janak and W. J. Grichar, "Weed control in corn (Zea mays L.) as influenced by preemergence herbicides," *International Journal of Agronomy*, vol. 2016, Article ID 2607671, 9 pages, 2016.

[34] E. Trogello, A. J. Modolo, M. Scarsi, C. L. D. Silva, P. F. Adami, and R. Dallacort, "Manejos de cobertura vegetal e velocidades de operação em condições de semeadura e produtividade de milho," *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 17, no. 7, pp. 796–802, 2013.

[35] M. V. Wagner, S. O. Jadoski, M. F. Maggi, L. R. Saito, and A. D. S. Lima, "Estimativa da produtividade do milho em função da disponibilidade hídrica em Guarapuava, PR, Brasil," *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 17, no. 2, pp. 170–179, 2013.

[36] J. C. Barbosa and W. J. Maldonado, *Experimentação Agronômica & AgroEstat – Sistema para análises estatísticas de ensaios agronômicos, Brasil*, Springer, Berlin, Germany, 2015.

[37] J. Sodré Filho, R. Carmona, R. L. Marchão, and A. M. D. Carvalho, "Weed infestations in soybean grown in succession to cropping systems with sorghum and cover plants," *Pesquisa Agropecuária Brasileira*, vol. 55, p. 11, 2020.

[38] I. Marasca, E. D. S. D. Jesus, S. V. D. Paiva filho, and R. L. M. Tavares, "Eficiência das plantas de cobertura na densidade de plantas daninhas e como descompactadoras de solo," *Agrarian*, vol. 14, no. 53, pp. 295–303, 2021.

[39] F. D. O. Alvino-Rayol, L. D. S. Rosa, and B. P. Rayol, "Efeito do espaçamento e do uso de leguminosas de cobertura no manejo de plantas invasoras em reflorestamento de Schizolobium amazonicum Huber Ex. Ducke (Paricá)," *Revista Árvore*, vol. 35, no. 3, pp. 391–399, 2011.

[40] L. E. S. G. Alves, L. F. Fontana, and C. R. Dias-Arieira, "Green manure and Pochonia chlamydosporia for *Meloidogyne javanica* control in soybean," *Revista Caatinga*, vol. 35, no. 3, pp. 625–632, 2022.

[41] M. S. Teodoro, K. N. D. C. Castro, and J. A. Magalhaes, "Assessment of legumes with potential use as green manure in the coastal tablelands of Piauí State, Brazil," *Revista Caatinga*, vol. 31, no. 3, pp. 584–592, 2018.

[42] I. S. N. Amilcar, D. L. P. Wilfrido, F. L. A. Derlys, S. M. P. Alexis, O. D. S. O. Modesto, and M. L. Eulalio, "Performance of varieties of green manure in conventionally used soil," *African Journal of Agricultural Research*, vol. 13, no. 36, pp. 1874–1879, 2018.

[43] P. R. Gomes, A. W. de Albuquerque, M. Cavalcante, S. L. Paixão, and P. B. Maracajá, "Influência dos sistemas de manejo do solo sobre os componentes de produção do milho e Brachiaria decumbens," *Revista Caatinga*, vol. 22, no. 1, pp. 64–71, 2009.

[44] D. A. Cazetta, D. Fornasieri Filho, and F. Girotto, "Efeitos da cobertura vegetal e da adubação nitrogenada sobre os componentes de produção do milho em sistema de semeadura direta," *Acta Scientiarum. Agronomy*, vol. 27, no. 4, pp. 567–572, 2005.

[45] F. H. Krenchinski, V. J. S. Cesco, D. M. Rodrigues, L. P. Albrecht, K. S. Wobeto, and A. J. P. Albrecht, "Agronomic performance of soybean grown in succession to winter cover crops," *Pesquisa Agropecuária Brasileira*, vol. 53, no. 8, pp. 909–917, 2018.

[46] A. S. Isah, E. B. Amans, E. C. Odion, and A. A. Yusuf, "Growth rate and yield of two tomato varieties (Lycopersicon esculentum Mill) under green manure and NPK fertilizer rate Samaru Northern Guinea Savanna," *International Journal of Agronomy*, vol. 2014, Article ID 932759, 8 pages, 2014.

[47] M. C. Lang, J. D. A. Barbosa, S. D. Ferreira, A. R. G. Baptistão, and N. V. D. Costa, "Periods of coexistence of weeds with carrot grown with and without black oat straw," *Pesquisa Agropecuária Brasileira*, vol. 57, p. 7, 2022.