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CROP PRODUCTION

Yield of creole corn under the residual effect of leguminous plants in the northeastern semi-arid region

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ABSTRACT. Agroecological production systems require profitable edaphic management strategies; therefore, the adoption of leguminous plants has become a strategy for improving nutrient cycling and straw input in the soil for subsequent crops. The objective of this study was to evaluate dry matter production and nutrient levels in leguminous plants grown alone and their effects on maize grown in succession in an agroecological production system. We conducted field experiments in two harvests under a randomized block design with eight treatments and three replicates. The treatments used were mulch, *Mucuna pruriens*, *Mucuna pruriens* (L.) DC., *Dolichos lablab*, *Cajanus cajan*, control (soil without vegetation cover), *Crotalaria juncea*, and *Canavalia ensiformis*. At the end of flowering, approximately 67 days after sowing (DAS), plants were collected and deposited in the soil as cover and fertilizer. The production of dry matter and nutritional content (nitrogen (N), phosphorus (P), and potassium (K)) in the agricultural fertilizers were analyzed, followed by the sowing of corn after this deposition as a form of residual fertilization. *C. juncea* produced the maximum amount of straw dry matter of 15,000 kg ha^{-1}, with a high N content (32.2 g kg^{-1}) but low K content (0.3 g kg^{-1}). Black velvet showed high K content (3.4 g kg^{-1}), and *M. pruriens* (MPL) showed high P content (3.0 g kg^{-1}). Production parameters were determined on a large scale using *C. juncea* and *C. ensiformis*, with average values of 3,380 kg ha^{-1}. The incorporation of green leguminous manures (sun hemp and jack bean) resulted in better yields in maize production components (ear length, ear diameter, number of rows, mass of 100 grains, and productivity) owing to the high accumulation of aerial phytomass and high N uptake under local conditions.

Keywords: *Zea mays* L.; nutrient cycling; peasant family farming; nutrient levels; edaphic management.

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Introduction

Corn (*Zea mays* L.) is one of the main cereals produced in recent years, with great economic importance, mainly owing to its chemical composition and nutritional value, and is used in human and animal food and industry (Silva Andrade et al., 2023). According to Companhia Nacional de Abastecimento (CONAB, 2023), this crop occupies 19.1 million hectares, with the production of 99.1 million tons of grain driven by market demand.

Corn production management is affected by phytosynthetic and nutritional aspects, with the latter being one of the main challenges, such as the availability of nutrients (mainly nitrogen (N)). However, the increase in fertilizer consumption, practices, and recommendations that promote the optimization and more efficient use of fertilizers to ensure the competitiveness of farmers, such as the use of legumes as green manure in organic systems, have been studied (Santos et al., 2021).

For organic production systems, this problem is more evident as the use of N obtained from renewable sources is not allowed; therefore, synthetic fertilizers with high solubility are used. Thus, interest in the use of green fertilizers has increased with the aim of incorporating atmospheric N into production systems. Nutrient recycling, considerable increase in organic matter content, and incorporation of N and other nutrients into the system through biological nitrogen fixation have previously been investigated (Oliveira et al., 2022).

In organic farming systems, the integration of N-fixing green-manure crops is essential to provide N to the cropping system. Martyniuk et al. (2019) highlighted the significance of incorporating such crops into each crop rotation cycle. Species, such as *Crotalaria* and jack beans, offer direct benefits to phytotechnical variables. The application of green manure is considered an edaphic soil management practice that influences the physical, chemical, and biological properties of the soil. Green manure, such as legumes, is incorporated into the soil to improve its fertility, structure, and microbiological activity, contributing to better plant growth and agricultural sustainability. This method enriches the soil with N, stimulates N mobilization, and enhances microbiological processes. Consequently, it improves N uptake by plants and significantly enhances the soil structure (Harindintwali et al., 2021; Guan et al., 2022).

Organic production systems integrate cultural, biological, and mechanical practices to promote resource recycling, ecological balancing, and biodiversity conservation. With rising environmental concerns and growing health awareness, there is greater consumer demand for fresh organic produce (Rodríguez-Espinosa et al., 2023). Sustainable organic agriculture has the potential to reduce the use of inorganic fertilizers and increase the use of organic waste as a source of N for plant nutrition. Agricultural management typically prioritizes nutrient cycling and supply for crop growth, whereas the mineralization of added biomass regulates plant nutrient availability and CO_2 emissions (Panday et al., 2024).

However, basic information, such as the most suitable species for the respective edaphoclimatic parameters of the region, must be obtained. The objective of this study was to evaluate dry matter production and nutrient content of legumes as a function of maize cultivation in an agroecological production system.

Material and methods

The study was conducted during the harvests of 2018/2019 (1st year) and 2019/2020 (2nd year) in the municipality of Redenção, Ceará State, Brazil (4°13'35'' N; 38°43'53'' S). The soil in the experimental area is classified as Ultisols (Santos et al., 2018) and has a sandy loam texture (730 g kg^{-1} of sand, 120 g kg^{-1} of silt, and 150 g kg^{-1} of clay); the chemical characteristics from the soil before green manure application were: pH (H_2O), organic matter, and phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), and aluminum (Al) contents (Table 1). The organic matter content was determined using the Walkley and Black method. Ca, Mg, and Al were extracted with 1 N KCl and determined by atomic absorption (Ca and Mg) and titration with 0.025 M NaOH (Al); P and K were extracted with the $Mehlich^{-1}$ extractor and determined by flame ionization spectrophotometry (K) and the Mo blue method (P), as described in Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 1997).

Table 1. Soil attributes before the experiment.

Depth	pH	H + Al	Al^{3+}	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	CTC	COT	P	V
(m)	-	---------------------	------------	------------	$cmol_c$ kg^{-1}	------------	------------	------------	g kg^{-1}	mg kg^{-1}	%
0,00 – 0,20	6.5	2.31	0.0	3.0	2.60	0.22	0.42	8.53	8.08	21	72

The total area used for the experiment was 192 m^2, divided into three blocks of 64 m^2 and subdivided into eight plots of 8 m^2 (2 × 4 m). The experimental design involved randomized blocks with eight treatments and three replications, totaling 24 experimental units, wherein each experimental unit was contained. The treatments used were mulch, *Mucuna pruriens*, *Mucuna pruriens*, *Dolichos lablab*, *Cajanus cajan*, control (soil without vegetation cover), *Crotalaria juncea*, and *Canavalia ensiformis*.

The cover crops were sown manually on May 4, 2018 (1st year) and May 10, 2019 (2nd year). The cover crops were not irrigated or fertilized. Corn was grown in a rainfed regime under the effect of residual fertilizer from only the cover crops. The dry matter of the aerial parts of the cover crops was evaluated on September 10, 2018 (1st year) and September 15, 2019 (2nd year).

The period of four months until corn planting is the average time for legume decomposition, as reported by Mangaravite et al. (2023). One part of the straw from leguminous crops was deposited on the surfaces and the other was manually incorporated at a depth of 0.10 cm. For sampling, a wooden frame (0.5 × 0.5 m) was randomly placed three times in each experimental plot. Dry matter was quantified and the results were transformed into units of kg ha^{-1}. The N, P, and K contents in dry matter of the legumes were analyzed according to Silva (2009). The nutrient content (g kg^{-1}) was determined based on the dry matter and shoot production.

Corn (creole cultivar) used in this study had the characteristics of medium size (1.8 to 2.3 m) and high resistance to local pests and diseases; its complete cycle was approximately 120 to 140 days. Corn was sown on January 31, 2019 (1st harvest), with legumes planted on May 4, 2018, as well as January 29, 2020 (2nd harvest), with legumes planted on May 10, 2019. The spacing of rows in corn crops was 0.70 m, with a population of 47.619 plants ha^{-1}; the monthly averages of precipitation and relative humidity and maximum and minimum temperatures were recorded (Table 2).

Table 2. Maximum and minimum temperatures, relative humidity, and rainfall for the months during the first (2018/2019) and the second (2019/2020) experimental years.

Months	2018/2019 (1st harvest)				2019/2020 (2nd harvest)			
	Maximum temperature (°C)	Minimum temperature(°C)	Rainfall (mm)	RH (%)	Maximum temperature(°C)	Minimum temperature(°C)	Rainfall (mm)	RH (%)
May	31.1	23.4	182	72	37.1	23.5	160	62
June	35.5	21.1	65	70	36.2	22.1	78	64
July	34.9	21.8	60	66	32.2	22.5	42	58
August	39.2	22.5	20	60	37.1	23.2	14	58
September	38.2	22.6	0	59	28.6	23.4	4	57
January	33.1	23.1	216	80	32.2	22.9	273	80
February	32.4	23.4	248	83	32.1	23.2	243	83
March	33.0	23.3	229	85	31.4	23.4	260	85
April	32.9	22.9	215	76	32,4	21.3	215	76
May	31,9	23.5	118	61	31.9	23.1	115	61

*RH: Relative humidity.

Corn was harvested manually on May 1, 2019 (1st harvest) and May 3, 2020 (2nd harvest). After harvesting and correcting the grain moisture to 13%, the central plants of each treatment (10 plants) were chosen. The ear length (EC) was determined using a graduated ruler; ear diameter (ED) was determined using a digital caliper in the central part of the cob; number of rows (NR) was determined through manual counting; number of grains per ear (NGE) was determined through manual counting; grain mass per plot (GMP) was determined using an analytical scale; mass of 100 grains (M100) was determined using an analytical scale; and final productivity (PROD) was determined by extrapolating the number of plants per area × average number of ears per plant × average mass of grains per ear 60 kg^{-1} (weight of a bag of corn).

The data were subjected to the Shapiro Wilk normality test, using the "shapiro.test" command and when the normal distribution of residuals was verified, the data were subjected to analysis of variance (ANOVA) at the 0.05 probability level. Flat legumes were compared using the Scott-Knott test with a significance level of 0.05. Data analyses were conducted using the R software, version 3.6.1. To observe the influence of green manures on corn productivity, a multivariate analysis was conducted using the principal component analysis (PCA) technique, presented through biplot graphs, using the packages "ggcorrplot", "ggplot2", "factoMineR", and "factextra," using cos2 in the analysis. The biplot graphs were prepared considering the first two principal components with greater variances and eigenvalues greater than 1.0. They were also subjected to Cluster_Analysis by the complete method using Euclidean distance, with the packages "dendextend: Cluster_Analysis," "hclustFactoMineR: clustering" based on the Ward D2 method".

Results and discussion

The production of dry matter varied according to the leguminous plants used in the first and second years of cultivation. *C. juncea* showed superiority in relation to the other plants, which generated an increase of approximately 400% in relation to the fallow (control treatment), as presented in Table 3. The high production of phytomass of the legume in a short period of time indicated that this species adapted to the environmental conditions of the experiment. According to Parenti et al. (2021), *C. juncea* is a fast-growing legume species, especially under high-temperature conditions, which enables the high production of dry mass. Additionally, it has low C/N ratios, which enables the ability to rapidly add N and organic matter to the soil.

Considering the primary macronutrient content, in the first and second years of cultivation, *C. juncea*, *C. ensiformis*, and *C. cajan* showed higher values for N, approximately 500 and 85% higher than those of the control treatment and other plants, respectively. The main reason for the disparity in the N content is the biological N fixation capacity (BNF). The aforementioned plants belong to the legume family, which establish symbiosis with bacteria of the genus Rhizobium in the roots. These bacteria fix atmospheric N in their nodes, making it available to the plants. Considering P, the amount of P absorption owing to the use of velvet bean was 500 and 25% higher than those of the control treatment and other leguminous plants, respectively. The absorption of K showed the same trend, with a high difference of approximately 400 to 600% from other leguminous plants and control treatments, respectively.

Table 3. Dry matter and macronutrient contents (N, P, and K) in leguminous plants in the two cropping cycles in the northeastern semi-arid region.

	Parameters of leguminous plants (1st harvest)				Parameters of leguminous plants (2nd harvest)			
	Dry mass	N contents	P contents	K contents	Dry mass	N contentes	P contentes	K contents
	(kg ha^{-1})		(g kg^{-1})		(kg ha^{-1})		(g kg^{-1})	
Mulch	2,080 ± 4,1 d*	18.5 ± 0.9 d	0.5 ± 0.01 c	1.02 ± 0,03 c	2,840 ± 4.4 e	17.90 ± 0.08 d	0.4 ± 0.01 c	1.0 ± 0,02 c
M. pruriens	6,210 ± 6.2 b	25.6 ± 0,1b	2.9 ± 0.07 b	3.66 ± 0.06 a	7,100 ± 5.9 b	24.8 ± 1.6 b	3.1 ± 0.03 a	3.2 ± 0.05 a
M. pruriens L.	6,950 ± 7.1 b	22.4 ± 0,9 c	2.9 ± 0.08 b	1.16 ± 0.09 c	6,950 ± 6.8 b	21.6 ± 1.7 c	2.7 ± 0.04 b	1.4 ± 0.02 c
D. lablab	3,640 ± 4.3 c	26.1 ± 1.2 b	2.9 ± 0.06 b	2.57 ± 0.07 b	3,770 ± 4,5	26.0 ± 1.5 b	2.7 ± 0.06 b	2.2 ± 0.04 b
C. cajan	7,080 ± 7.5 b	35.5 ± 1.4 a	2.9 ± 0.07 b	0.27 ± 0.02 d	7,430 ± 7.2 b	32.1 ± 2.2 a	3.0 ± 0.07b	0.4 ± 0.01 d
Control	3,090 ± 4.5 d	5.8 ± 1,1 d	0.4 ± 0.01 d	0.3 ± 0.02 d	3,990 ± 4.0 d	5.9 ± 1.9 e	0.1 ± 0.001 d	0.3 ± 0.01 d
C. juncea	15,000 ± 10.6 a	33.7 ± 1.8 a	3.6 ± 0.06 a	0.3 ± 0.02d	14,920 ± 9.8 a	30.8 ± 1.8 a	2.6 ± 0.04 b	0.4 ± 0.01 d
C. ensiformis	8,220 ± 9.7 b	33.5 ± 1.6 a	2.8 ± 0.04 b	0.4 ± 0.03 d	7,280 ± 9.1 b	31.3 ± 1.6 a	2.2 ± 0.03 b	0.6 ± 0.02 d
CV (%)	12.4	9.1	16.8	18.1	19.3	14.6	13.1	12.9

*In each year, the means grouped by the same letter in the column did not differ according to the Scott-Knott test at a significance of p<0.05%. CV: coefficient of variation; ±: standard error; Mulch (ML), *Mucuna pruriens* (MP), *Mucuna pruriens* (MPL), *Dolichos lablab* (DL), *Cajanus cajan* (CC), control (soil without vegetation cover), *Crotalaria juncea* (CJ), and *Canavalia ensiformis* (CE).

These plants develop an extensive and deep root system that allows them to access greater amounts of nutrients, including P and K, present in the deeper layers of the soil. Additionally, the ability of velvet bean roots to exude organic acids may facilitate the solubilization and release of these nutrients into the soil, making them more readily available for plant uptake. Another important factor was that the ratio of leguminous plant levels followed the order N>P>K, depending on the characteristics of the chosen plants.

The probable answer in relation to N values lies in the transformation of atmospheric N into inorganic N owing to the biological fixation of these plants, resulting in high accumulation of N during flowering and high deposition of N during decomposition in the soil. In a similar study, Naz et al. (2023) reported that leguminous plants are a sustainable alternative source of nutrients to crops and that green manure is the best strategy to increase N in organic systems owing to the high levels of N accumulated during growth.

Considering the absorption of P by leguminous plants, the morphological characteristics and greater biomass are related to the high absorption of nutrients, as observed in *Mucuna pruriens* in a similar study with green manures in dry matter content. The absorption of P by mass flow, which occurs in the roots, directly influences the transport of P to the aerial part of the crops. Moreover, another important factor would be that legumes can mobilize P, in relation to their growth period, as P-solubilizing compounds are secreted in the rhizosphere (Solangi et al., 2019).

Considering K, *M. pruriens* had an important impact on its absorption, which is related to the amount of dry mass, owing to the indeterminate growth morphology and root system of the strong impact that cycles K from the subsurface to the aerial part of the crop. In a previous study (Dahal & Ghosh Bag, 2023), during their growth period, legume crops had an important impact on K availability at the legume plant level, which may be associated with the extensive root systems of leguminous crops.

Considering the components of corn production, the use of different leguminous plants resulted in statistical differences. The ear length of corn with the use of C. *juncea* and *C. ensiformis* was 85% higher than that of the other green manures in the first and second years. A similar trend was observed for ear diameter, wherein the same types of green manure increased the ear diameter by approximately 35% compared with other plants and the control treatment (Table 4).

These legumes may have been more responsive with the presence of greater phytomass production and accumulation of primary nutrients associated with biological nitrogen fixation, as observed by Lyu et al. (2024). They found that the morphological characteristics of corn, plant height, number of leaves, ear size, and number of grains could be attributed to the availability of primary macronutrients; however, the grain yield could be explained as a function of biomass incorporation of green manures.

The use of sunn hemp and jack bean increased the numbers of rows and grains per row by 70 and 95% higher, respectively. Such high increases compared are influenced by the deposition of materials with a high accumulation of nutrients, such as N, which results in benefits related to productive parameters owing to crop germination in the field. In an experiment with green manure for winter cultivation, Liu et al. (2022) observed that the accumulation of residues in soil improved the growth process of corn owing to the residual mineralization of nutrients, which enhanced the corn production parameters. Another important factor is the increase in N in the organic system, as observed in previous studies (Deguchi et al., 2022). The use of green manures in tropical and temperate environments in Asian regions can help reduce the amount of N applied to crops subsequent to their cultivation owing to the high accumulation, large amount of dry matter, and rapid release due to the low C/N ratio, which reduces the expenses related to N fertilizers in organic or conservationist systems.

Table 4. Components of corn grain yield as a function of leguminous plants during the harvests in 2018/2019 and 2019/2020 in Redenção, Ceará State, Brazil.

Treatments	Corn production components							
	1st harvest				2nd harvest			
	EC	ED	NR	NGE	EC	ED	NR	NGE
	cm				Cm			
Mulch	7.1 ± 0.2 c*	2.1 ± 0.03 c	6.6 ± 0.3d	9.2 ± 0.9 d	7.5 ± 0.3c*	1.9 ± 0.02c	6.1 ± 0.5 c	8.3 ± 0,9 d
M. pruriens	8.9 ± 0.3 b	2.6 ± 0.04 b	8.2 ± 0.4 b	28.6 ± 1.1 b	8.1 ± 0.4 b	2.5 ± 0.03 b	8.3 ± 0.6 b	22.3 ± 0,3 b
M.pruriens L.	9.3 ± 0.4 b	2.4 ± 0.06 b	8.2 ± 0.5 b	25,8 ± 1.2 b	9.0 ± 0.4 b	2.6 ± 0.02 b	8.4 ± 0.4 b	24.1 ± 0.3 b
D. lablab	9.1 ± 0.2 b	2.4 ± 0.02 b	9.3 ± 0.2 b	29.9 ± 1.7 b	9.6 ± 0.6 b	2.5 ± 0.01 b	8.6 ± 0.6 b	26.9 ± 1,2 b
C. cajan	9.3 ± 0.3 b	2.6 ± 0.03 b	8.6 ± 0.5 c	26.8 ± 1.3 b	9.0 ± 0.5 b	2.4 ± 0.04 b	8.1 ± 0.5 b	27.3 ± 1.4 b
Control	8.1 ± 0.4 c	2.0 ± 0.01 c	5.1 ± 0.3 d	16.2 ± 0.9 c	7.9 ± 0.3 c	2.1 ± 0.09 c	6.9 ± 0.6 c	14.1 ± 0,9 c
C. juncea	15.1 ± 0.9 a	3.0 ± 0.04 a	12.8 ± 0.9 a	58.7 ± 1.5 a	14.9 ± 1.1 a	2.9 ± 0.05 a	12.4 ± 0.4 a	54.3 ± 2,3 a
C. ensiformis	15.2 ± 1.2 a	2.9 ± 0.03 a	12.8 ± 0.8 a	63.4 ± 2,9 a	15.1 ± 1.2 a	2.9 ± 0.06 a	12.2 ± 0.3 a	56.1 ± 2,4 a
CV (%)	12.3	12.8	9.4	9.1	9.9	10.6	14.9	13.6

*In each year, the means grouped by the same letter in the column did not differ according to the Scott-Knott test at a significance of p < 0.05%. CV: coefficient of variation. ±: standard error; Mulch (ML), *Mucuna pruriens* (MP), *Mucuna pruriens* L. (MPC), *Dolichos lablab* (DL), *Cajanus cajan* (CC), control (soil without vegetation cover), *Crotalaria juncea* (CJ), and *Canavalia ensiformis* (CE).

The grain mass per plot and mass of 100 grains were higher with the use of *C. juncea* and *C. ensiformis*, and in both cases, the grain productivity ratio showed satisfactory levels that benefit corn productivity. The use of these two types of legumes increased the mass of grains per plot and mass of 100 grains by more than 100 and 35%, respectively, and helped stimulate the relationship between dry matter deposition and the residual fertilization process by leguminous plants (Table 5).

Table 5. Corn grain yield components as a function of leguminous plants during the harvests in 2018/2019 and 2019/2020 in Redenção, Ceará State, Brazil.

Treatments	Corn production components					
	1st harvest			2nd harvest		
	GMP	M100	PROD	GMP	M100	PROD
	(g)		(kg ha^{-1})	(g)		(kg ha^{-1})
Mulch	64.4 ± 7.9 c*	7.7 ± 2.3 d	860 ± 56 c	60.1 ± 8.1 c	7.7 ± 2.1 d	793 ± 85 c
M. pruriens	132.5 ± 6.6 b	28.2 ± 2.9 b	1,281 ± 42 b	119.8 ± 9.3 b	25.4 ± 3.3 b	1,069 ± 109 b
M. pruriens L.	133.4 ± 10.9 b	27.2 ± 2.4 b	1,450 ± 102 b	127.3 ± 11.1 b	26.2 ± 3.5 b	1,255 ± 128 b
D.lablab	114.3 ± 9.5 b	24.7 ± 4.1 b	1,318 ± 104 b	130.3 ± 10.4 b	24.9 ± 3.2 b	1,267 ± 109 b
C.cajan	109.9 ± 9.9 b	29.4 ± 3.8 a	1,196 ± 110 b	123.4 ± 10.1 b	26.1 ± 3.1 b	1,185 ± 112 b
Control	74.3 ± 13.4 c	12.8 ± 3.3 c	619 ± 81 c	70.8 ± 12.7 c	12.8 ± 2.9 c	597 ± 78 c
C. juncea	421.7 ± 23.4 a	33.2 ± 3.1 a	3,598 ± 189 a	401.4 ± 25.4 a	30.6 ± 3.2 a	3,203 ± 205 a
C. ensiformis	349.5 ± 23.4 a	33.3 ± 3.2 a	3,420 ± 193 a	332.1 ± 21.2 a	29.8 ± 3.4 a	3,310 ± 210 a
CV (%)	10.9	11.5	18.5	13.1	12.6	15.1

*In each year, the means grouped by the same letter in the column did not differ according to the Scott-Knott test at a significance of p < 0.05%. CV: coefficient of variation; ±: standard error; Mulch (ML), *Mucuna pruriens* (MP), *Mucuna pruriens* (MPC), *Dolichos lablab* (DL), *Cajanus cajan* (CC), control (soil without vegetation cover), *Crotalaria juncea* (CJ), and *Canavalia ensiformis* (CE).

These results may be ascribed to the fact that the decomposition of green manure reduces N losses, retains residual N, replaces N in inorganic fertilizers, and improves its availability and utilization. Furthermore, continuous addition of green manure can additionally provide approximately 100 kg N ha^{-1}. These results may be attributed to the favorable soil environment, which is related to increases in soil organic matter, total organic carbon values, and soil microbiome diversity, leading to healthier plants with better photosynthesis and assimilation and formation and translocation of ears and grains (Bihari et al., 2022).

Corn productivity was responsive to the use of *C. junce* and *C. ensiformis* owing to the greater increase in nutrients and dry matter deposition compared with other plants. The productivity values in both years were higher by more than 100%, indicating that these two legumes exhibit an organic alternative for agroecological production systems (Table 6). These legumes not only contribute to corn productivity but also promote system sustainability by reducing the dependence on external inputs and improving soil health. The benefits of crop succession using legumes include greater soil coverage, weed suppression, forage, and supply of food and firewood, among others (Souza et al., 2022). Similarly, in a previous study (Madembo et al., 2020), the use of legumes as green fertilizers was found to benefit the soil physics generated by different rooting patterns, enabling the greater exploration of larger volumes of soil and greater nutrient cycling.

Table 6. Correlation, representation quality (cos2), and contribution (%) of original variables and the main components of the parameters evaluated in corn under the application of different mulches.

Parameters	PC1	cos2	PC2	cos2
Dry mass	0.815**	0.664	-0.189	0.036
N contents	0.821**	0.675	0.258	0.067
P contents	0.717**	0.515	0.669**	0.488
K contents	-0.055	0.003	0.848**	0.719
EC	0.877**	0.769	-0.435	0.189
ED	0.974**	0.949	0.274	0.002
NR	0.952**	0.907	0.049	0.062
NGE	0.950**	0.902	-0.250	0.075
GMP	0.902**	0.814	-0.389	0.151
M100	0.938**	0.880	0.288	0.083
PROD	0.769**	0.917	0.203	0.102
lEigenvalues	7.630	-	2.030	-
Accumulated variance (%)	70.574	-	19.003	-

Note: **Significant at 1% probability.

PCA explained 70.57% of the total variation in the data, with 89.57 and 15.19% in principal components 1 (PC1) and 2 (PC2). A high percentage of variance indicated that the main components captured a large part of the variability in the original dataset. From this perspective, we suggested that certain plant species, particularly legumes, have a positive impact on the growth and productivity of corn owing to their high capacity to fix atmospheric N in the soil, thus increasing soil fertility and nutrient availability. Furthermore, high biomass production contributes to soil organic matter, which improves soil health and productivity (Figure 1).

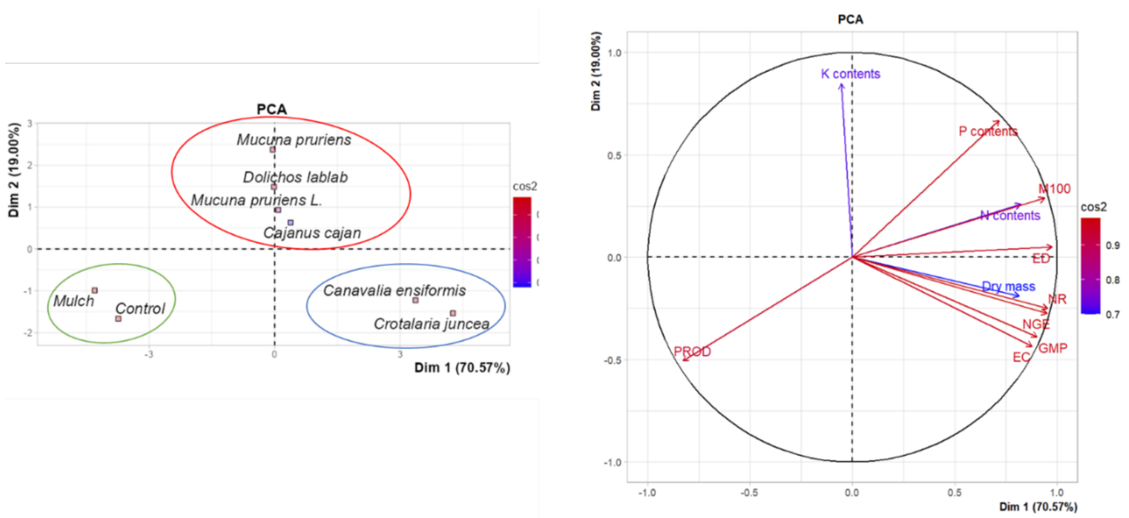

Figure 1. Principal component analysis (PCA) for the effect of different green manures on the components of corn yield in Redenção, Ceará, Brazil. Abbreviations: ear length (EC), ear diameter (ED), number of rows (NR), number of grains per ear (NGE), grain mass per plot (GMP), mass of 100 grains (M100), productivity (PROD), potassium (K), phosphorus (P), and nitrogen (N).

We observed that among the variables analyzed, only K did not directly influence the other productive and nutritional parameters. This indicated that through its high mobility in plant structures, K increased growth and development, reducing the need for high levels of K accumulation in any tissue and consequently contributing to soil health. Another factor is the correlation between P, N, M100, and ED, indicating that N and P influence grain mass and corn ear growth, and are actively transported to the developing grains to support processes, such as cell division and the increase and accumulation of starch (Figure 1).

These results indicate that crop residues in agroecological cultivation systems benefit from the production of straw from predecessor crops and the accumulation of N and other nutrients derived from legumes. These results are consistent with those of Lai et al. (2021), who studied legume rotation and intercropping systems and found a complex interaction between different nutrients and their effects on corn growth and development. Thus, understanding how each nutrient uniquely contributes to plant physiology and productivity as well as its implications for soil health and agricultural practices is essential.

Cluster analysis for the analyzed factors (green manures) helped us divide the factors into three groups, which corresponded to the use of mulch and the control. Thus, we identified soil management practices with the lowest biometric and nutritional response in corn, with low accumulation of primary macronutrients, and consequently low productivity per area. GII corresponded to *Mucuna pruriens* L. (MPL), *M. pruriens* (MP), *Cajanus cajan* (CC), and *Dolichos lablab* (DL), which are treatments showing a satisfactory increase in the accumulation of biomass and nutrients in corn; thus, they can be used by producers. GIII corresponded to the use of C. *juncea* and C. *ensiformis*, indicating that the two fertilizers had similar responses and high increases in the biomass, accumulation of macronutrients, and productive responses of corn in a semi-arid environment (Table 7).

Table 7. Mean cluster values for parameters evaluated in corn under the application of different green manures.

Treatments	Groups	Dry mass	N contents	P contents	K contents	EC	ED	NR	NGE	GMP	M100	PROD
		kg ha^{-1}		g kg^{-1}		cm		-	-	g		kg ha^{-1}
Mulch	GI	2,460	18.2	0.4	0.3	7.3	2.0	6.3	8.5	62.5	7.7	810
Control		3,540	5.8	0.2	0.2	8	2.0	6.0	15.1	72.5	12.8	608
M. pruriens	GII	9,760	25.2	3.0	3.2	8.5	2.2	8.2	25.5	126.1	26.8	1,175
M. pruriens L.		6,950	22.0	2.8	1.7	9.2	2.0	8.2	24.9	130.1	26.7	1,352
D. lablab		3,705	26.0	2.8	2.6	9.3	2.5	8.8	28.4	122.3	24.8	634
C. cajan		7,200	33.1	3.0	1.6	9.2	2.5	8.3	27.0	116.6	27.7	1,190
C. juncea	GIII	14,960	32.1	3.1	1.6	15	3.0	12.6	56.5	412.5	31.6	3,400
C. ensiformis		8,000	ab32.5	2.6	1.5	15	3.0	12.4	59.7	340.5	31.5	3,365

GI: mulch and control treatments; GII: *Mucuna pruriens*, *Mucuna pruriens* L., *Dolichos lablab*, and *Cajanus cajan*; GIII: grouping of treatments of *Crotalaria juncea* and *Canavalia ensiformis*.

Cluster analysis of the analyzed factors (green manures) helped us divide the factors into three groups, wherein similarities were observed between cover crops. GI was significant for mulch and the control, indicating that treatments were similar owing to slight increases in biomass and mineralization of nutrients, suggesting low productivity in corn. In relation to GII, we obtained two species that responded similarly: *D. lablaband* and *C. cajan* showed slight incorporation of biomass into the soil and low amounts of nutrients, indicating that they are not viable choices for organic corn production. In GIII, *C. juncea*, *M. pruriens*, *M. pruriens L.*, and *C. ensiformis* showed high similarity, indicating that the production of dry matter, nutritional content, and productivity were promoted by these leguminous plants compared with other treatments (Figure 2).

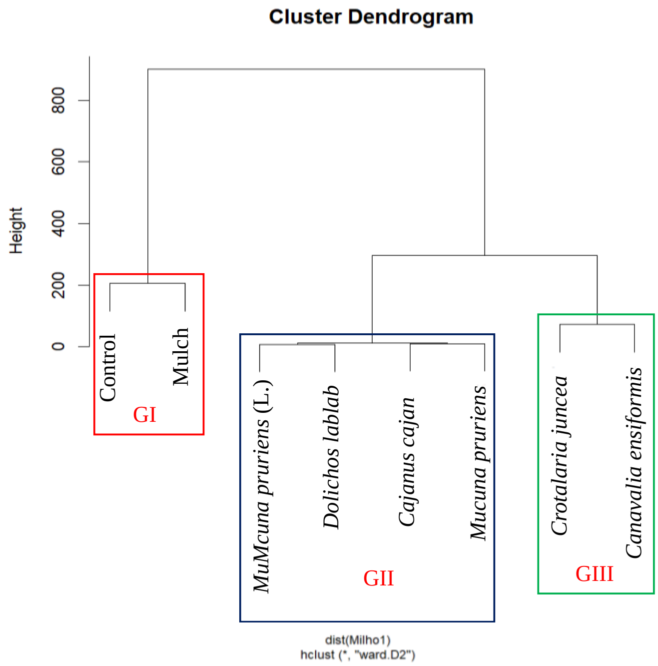

Figure 2. Dendrogram based on the Ward method by considering the leguminous plants used as fertilizers to evaluate the productive parameters of corn.

The division of green manure into three groups follows previous experimental studies, such as Silva et al. (2020) and Nunes et al. (2020). In these studies, green manure was graded based on the greater availability of nutrients released by green manuring, derived from the release of the residual form of aerial biomass, highlighting the C/N ratios of the materials used; this ratio is linked to the rate of decomposition of organic residues and in turn, the release of nutrients.

Furthermore, Ambrosano et al. (2018) suggested that the composition of the aboveground biomass of green manures also plays a significant role in nutrient release. This finding highlights the complexity of agricultural systems and the importance of considering not only the C/N ratio but also other factors, such as the specific composition of the applied organic matter.

Conclusion

The incorporation of green leguminous manures (sun hemp and jack bean) provided better yields in maize production components (ear length, ear diameter, number of rows, mass of 100 grains, and productivity) owing to the high accumulation of aerial phytomass and high N uptake under local conditions. The additional incorporation of these leguminous cover crops in the soil allows the nutrients retained in the green manures to be released and made available for subsequent crops. This method is an alternative for family farming and is a form of fertilization in agroecological production systems.

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