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Research article

Agronomic performance of forage corn for cattle feeding in Amazonas, Peru

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ABSTRACT

Corn (*Zea mays*) silage is an important and popular feed for dairy production in the Amazon region, so it is necessary to evaluate the agronomic performance of forage varieties of corn for cattle feeding in Amazonas. For this purpose, three corn varieties were evaluated (variety 1: Yellow Starchy Corn, variety 2: Chuska INIA 617, and variety 3: DOW 2B710), with two planting densities (density 1: 30 × 80 cm and density 2: 35 × 75 cm) and two fertilization conditions: with fertilization (F1) and without fertilization (F2). The parameters evaluated were plant height, number of leaves, leaf length and width, stem diameter, fresh forage, and dry matter. Student t-tests, correlation analysis of variables, and principal component analysis using R software version 4.1.3 were used for data analysis. The results indicated that variety 2 obtained the best values for the variables leaf width (12.33 cm) and stem diameter (3.25 cm), fresh forage (17.77 kg/m^2), and dry matter (4.8 kg/m^2), which would explain the directly proportional correlation found between leaf width and stem diameter with fresh forage and dry matter. The principal component analysis showed constant height and leaf length increases, and the best-evaluated parameters were associated with applying fertilizer. The variety that showed the best agronomic performance under Chachapoyas conditions was Chuska INIA 617, emerging as a potential feed for cattle.

1. Introduction

In the world, more than 60 % of the corn produced is yellow, destined mainly to manufacture balanced feed for animal feed. In Peru, corn is planted in the three natural regions, and approximately 56 % of the surface Nacional is planted with hard yellow corn, especially in the coastal and jungle regions, supporting cattle feeding [1]. In addition, for the last 25 years, corn-based silage has represented a critical and popular feed for dairy production [2].

Cattle play an important role for small farmers and are raised on native pastures and, to a lesser extent, improved pastures [3]. Cattle raising generates economic resources in meat and dairy systems [4]. The likely environmental impacts of milk production depend on the efficiency of livestock production and the land used for cultivation; China has been promoting an integrated system of

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corn silage cultivation for dairy production [5]. Cattle play an important role for small farmers and are raised on native pastures and, to a lesser extent, improved pastures [3]. Cattle raising generates economic resources in meat and dairy systems [4]. The likely environmental impacts of milk production depend on the efficiency of livestock production and the land used for cultivation; China has been promoting an integrated system of corn silage cultivation for dairy production [5].

Milk production in Peru has been growing over the years, reporting an annual increase of up to 5.77 % (Instituto Nacional de Estadística e Informática [6]). However, the scarce availability of good-quality forages produced under rainfed conditions and the low genetic potential of animals are considered the main limiting factors for livestock systems in the central Andes [7]. Studies such as those by Bernet et al. [8] and Holmann [9] identified improved forage management and higher-yielding forages among the development options for small Andean farming systems.

In the Amazon region, livestock production has been affected by the aforementioned limiting factors, reducing cattle production by 19.4 % in 2021, registering 1252 tons of live weight [10]. Forage corn production is carried out conventionally using manures and chemical fertilizers to meet the growing demand for fodder [11]. In that sense, corn silage is one of the sources for obtaining energy and fiber in diets for dairy cattle, and the options used, such as planting density and forage fertilization, will influence the yield and quality of silage [12].

In this sense, new varieties of forage corn for the region, such as Chuska INIA 617 and DOW 2B710, are proposed. According to some authors, this crop is known for its high demand for nitrogen fertilization, especially if the plant density is higher [13], and others indicate that there is no relationship between planting density and fertility [14,15]. Moreover, forage corn yield has been linked for years to an increase in plant spacing [16], which, according to some authors, is more significant than row spacing [17]. Considering that these are new varieties in the region, it is necessary to know the role that planting density and fertilization play in yielding forage corn.

Sánchez et al. [18] evaluated the agronomic parameters of 6 corn genotypes under three planting densities in Mexico. The results indicated that the main differences among genotypes are reported for plant height, cob length and diameter, and forage yield per hectare. On the other hand, the planting density that produced the highest forage yield was 83333 plants per hectare, with a value of 41.8 t/ha.

In the Peruvian context, authors such as Maguiña-Maza et al. [19] evaluated the agronomic, productive, nutritional, and economic potential of four forage corn genotypes from the Chancay Valley. Their results concluded that to make a good selection of forage corn,

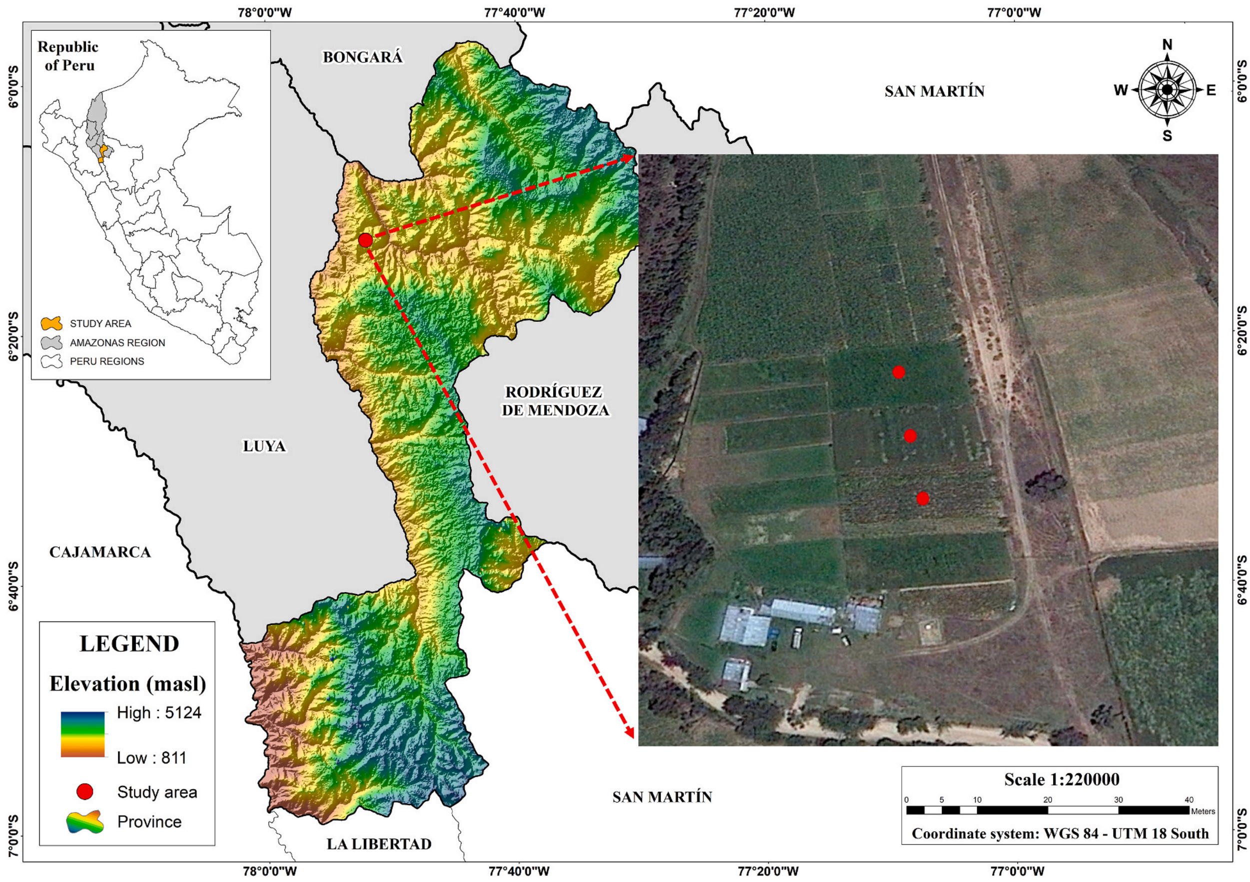

Fig. 1. Location of the study area.

its yield and nutritional contribution should be considered. From an agronomic point of view, the INIA 617 and M28T varieties showed greater plant height and higher yields of neutral detergent fiber and acid detergent fiber.

In the Amazon region, different species of forage corn are used for cattle feed; however, more information is needed on these corn varieties' agronomic performance, fertilization, and adequate planting density. In this context, the objective was to evaluate the agronomic performance of forage varieties of *Zea mays* for cattle feeding in Amazonas, Peru.

2. Materials and methods

2.1. Location of the study area

The research was conducted at the Estación Experimental Agraria Amazonas, ex Fundo San Juan Chachapoyas, Amazonas, Peru, located at 2400 m a.s.l. (Fig. 1). It presents climatic characteristics such as a maximum temperature of 21.56 °C and a minimum of 9.9 °C, a relative humidity of 74.95 %, and an average annual rainfall of 2489 mm [20].

Prior to the installation of the experiment, a soil fertility analysis study was conducted at the soil and water research laboratory of the UNTRM, finding chemical characteristics such as 8.42 soil pH, 0.10 dS/m of electrical conductivity, 11.49 ppm of phosphorus, 200.62 ppm of potassium, 1 % of carbon, 1.72 % of organic matter and 0.09 % of nitrogen.

2.2. Plant material

For the experimental setup, three corn varieties were established (Variety 1: Yellow Starchy Corn, Variety 2: Chuska INIA 617 and Variety 3: DOW 2B710).

Variety 1: Yellow Starchy Corn: This variety is adapted to the edaphoclimatic conditions of Chachapoyas and is planted from October to December; the seed was acquired from the agricultural experiment station Vista Florida – Lambayeque of INIA (National Institute of Agrarian Innovation), with registration number 06-2012-INIA. This variety tends to adapt to different types of soils but obtains better development in medium-textured, deep, and well-drained soils. The pH range is 6.1–7.8, and the optimum development temperature is 15 °C–25 °C [23].

Variety 2: Chuska INIA 617: This type of variety is a synthetic variety of forage corn with an average plant height of 260–280 cm, cob insertion height of 120 cm, cylindrical cob shape of 14–16 rows per ear, and number of ears per plant of 1. Three ears per plant, 204-grain weight per cob with a 1000-grain weight of 358 g, yellow-orange grain color, 55–60 days to flowering, vegetative period of 120–130 days, potential grain yield up to 8 t/ha, potential forage yield up to 95 t/ha. The seed of this variety was acquired from the agricultural experiment station Baños del Inca - Cajamarca of INIA, with registration number 04-2010-INIA. Its adaptation is nationwide and requires permanent irrigation throughout the vegetative cycle [21].

Variety 3: DOW 2B710: This variety is a hybrid with high yield and lodging potential, an average plant height of 230 cm, a cob insertion height of 110 cm, 48 days to flowering, and a potential forage yield of 35–45 t/ha of dry matter. The seed of this variety was acquired at the Vista Florida- Lambayeque Experimental Station, with registration number 07-2009-INIA. The soil requirement is sandy loam, pH 5.6 to 6.5, which develops between 24.4 °C and 35.6 °C at altitudes of 0–2500 m a. s. l. and requires permanent irrigation throughout the crop cycle [22].

2.3. Conducting the experiment

The land was prepared using an agricultural tractor, and then the experimental plots located in a randomized complete block design were demarcated.

Subsequently, soil sampling was carried out at a depth of 20 cm using the Scheweizer [24] methodology and then taken to the laboratory for fertility analysis.

Planting was carried out in November 2020, and harvesting was performed in May 2021 by manually applying the densities established by experimental units at a depth of 5 cm per 1 seed per stroke [25].

Favorable rainfall provided cultural tasks such as irrigation, and in some cases, flood irrigation was applied. Weeding was done mechanically, and fertilizer was applied twice (25 days and 35 days after planting), making holes 15 cm from the plant. Hilling was carried out together with the second application [25].

Phytosanitary control was carried out promptly to avoid damage caused by the most prevalent insects, such as codling moth (*Spodoptera frugiperda*), sugarcane cutworm (*Diatraea saccharalis*), and corn earworm (*Heliothis zea*) [25].

2.4. Variables evaluated

The height of the plant was measured in centimeters on the central axis where the leaves and various axillary complexes were inserted. From the roots' insertion point to the base of the spike, the leaf length was measured in centimeters.

From the point of union of the leaf lamina with the sheath (insertion of the ligule) to the apex of the same lamina, the leaf width was measured in centimeters from edge to edge in the central part of the leaf lamina, and the diameter of the stem was recorded with the help of a Vernier caliper. In addition, a leaf count was performed [26].

To determine the fresh forage yield per ha, 22 plants per plot were cut at a height of 7–10 cm above ground level and weighed, and the average weight per plant was obtained, which was multiplied by the density of plants per hectare to obtain the yield in t ha-1 of green matter for each treatment. 22 harvested plants were used to obtain the dry matter yield. These were cut into 3–5 cm pieces and mixed until a homogeneous sample was constituted. A subsample of 1 kg was taken and placed in a forced-air oven at 55 °C until it reached constant weight. Then, the dry matter content was weighed, and using the difference between the initial and final weight, the average dry matter per plant weight was determined and multiplied by the population of plants ha^{-1} [27]. With the data found for fresh weight and dry weight, the percentage of dry matter was determined for each experimental unit by applying the following formula:

$$\text{Percentage of dry matter} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} * 100$$

The fresh forage and dry matter percentages were evaluated at the end of the experiment (evaluation 4).

2.5. Experimental design

The design applied in the field was a completely randomized block design with three varieties and two conditions of fertilization with three replications, evaluated once every 30 days for a total of four evaluations (E1, E2, E3, and E4) until the cutting period. The varieties were Yellow Starchy Corn (variety 1), Chuska INIA 617 (variety 2), and DOW 2B710 (variety 3). Two fertilization conditions were used: F1 (240 kg N + 108 kg P + 108 kg K per hectare) and F2 (no fertilization). In addition, there were two densities: density 1 (30 × 80 cm) and density 2 (35 × 75 cm). These densities were chosen because producers generally use them for the Yellow Starchy Corn variety, adapted to the study area's conditions.

2.6. Data analysis

The assumptions of normality of data and homogeneity of variances were checked, followed by an analysis of the comparison of means using Student's t-test for independent samples with a significance level of 0.05. Pearson's correlation analysis was performed to determine the important variables of interest and multivariate analysis of principal components for the variables of growth and development of the crop, and the software used was R version 4.1.3.

3. Results and discussion

3.1. Plant height

At the variety level, there were significant differences, where the variety that reported the greatest plant height was variety 3 (Dow 2B710) during the last three evaluations (E2: 141.14 ± 31.64; E3: 218.05 ± 45.99 and E4: 311.98 ± 43.77) (Table 1). Lopez [20] found a plant height for the variety DOW2B710 at five months of 245.4 cm in conditions of Central Huallaga under a planting density of 75000 plants/ha. These results are lower than those in this research for the last evaluation, and this difference could be due to the edaphoclimatic conditions of each location [28].

Plant height in the plots where fertilizers were applied showed an increase during the four evaluations, with a final height of 253.95 cm (Table 2). Solís and Castaño [29] recorded corn height values of 233.63 cm with 120 kg/ha of nitrogen fertilizer application under Ecuadorian conditions.

Regarding planting density, significant differences were found only in the last evaluation, obtaining higher plant height values with

Table 1
Analysis of growth parameters for variety.

Evaluation (E)	Plant height (cm)	Number leaf	Leaf long (cm)	Leaf width (cm)	Stem diameter (cm)
Evaluation 1 (E1)	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**
Variety 1	35.89 ± 8.95 a	8.93 ± 1.31 a	43.08 ± 9.09 a	5.83 ± 1.24 a	2.55 ± 0.60 a
Variety 2	27.26 ± 7.49 c	8.49 ± 1.28 b	35.58 ± 7.41 c	5.53 ± 1.38 b	2.23 ± 0.54 b
Variety 3	33.90 ± 10.19 b	8.11 ± 0.92 c	40.56 ± 10.56 b	3.71 ± 1.16 c	1.99 ± 0.43 c
Evaluation 2 (E2)	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**
Variety 1	99.57 ± 26.71 b	11.92 ± 1.50 a	79.43 ± 19.14 b	9.40 ± 2.13 b	3.41 ± 0.75 a
Variety 2	78.16 ± 19.16 c	12.03 ± 1.54 a	69.45 ± 12.11 c	10.60 ± 1.98 a	3.51 ± 0.60 a
Variety 3	141.14 ± 31.64 a	11.18 ± 1.81 b	87.51 ± 13.68 a	7.69 ± 1.57 c	2.93 ± 0.50 b
Evaluation 3 (E3)	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**
Variety 1	175.69 ± 33.11 b	15.08 ± 1.27 a	90.53 ± 13.55 b	10.21 ± 1.89 b	3.31 ± 0.55 b
Variety 2	137.16 ± 22.58 c	14.86 ± 1.35 a	81.72 ± 10.63 c	12.92 ± 1.70 a	3.81 ± 0.75 a
Variety 3	218.05 ± 45.99 a	13.29 ± 1.18 b	93.80 ± 12.23 a	9.26 ± 1.44 c	2.86 ± 0.49 c
Evaluation 4 (E4)	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**	**(p= <0.0001)**
Variety 1	238.57 ± 37.05 b	13.72 ± 1.30 a	93.09 ± 12.25 b	10.44 ± 1.69 b	2.97 ± 0.62 b
Variety 2	174.48 ± 34.18 c	13.28 ± 1.26 b	84.34 ± 10.55 c	12.33 ± 1.63 a	3.25 ± 0.70 a
Variety 3	311.98 ± 43.77 a	12.51 ± 1.12 c	99.59 ± 10.23 a	8.77 ± 1.27 c	2.65 ± 0.57 c

Different letters vertically indicate significant differences by Student's t-test ($p < 0.05$). Variety 1: Yellow Starchy Corn, variety 2: Chuska INIA 617, and variety 3: DOW 2B710.

Table 2
Analysis of growth parameters for fertilization.

Evaluation (E)	Plant height (cm)	Number leaf	Leaf long (cm)	Leaf width (cm)	Stem diameter (cm)
Evaluation 1 (E1)	**(p= <0.0001)**	**(p= 0.53)**	**(p=0.008)**	**(p=0.034)**	**(p=0.001)**
With fertilization (F1)	33.55 ± 9.90 a	8.51 ± 1.22 a	40.92 ± 9.93 a	5.21 ± 1.53 a	2.32 ± 0.56 a
Without fertilization (F2)	28.75 ± 7.92 b	8.52 ± 1.24 a	36.21 ± 7.57 b	4.47 ± 1.58 b	2.07 ± 0.58 b
Evaluation 2 (E2)	**(p= <0.0001)**	**(p= 0.061)**	**(p=0.006)**	**(p=0.027)**	**(p=0.026)**
With fertilization (F1)	113.09 ± 37.54 a	11.93 ± 1.66 a	81.10 ± 16.32 a	9.48 ± 2.16 a	3.35 ± 0.61 a
Without fertilization (F2)	85.91 ± 26.99 b	11.05 ± 1.50 b	71.89 ± 16.98 b	8.48 ± 2.35 b	3.10 ± 0.80 b
Evaluation 3 (E3)	**(p= <0.0001)**	**(p= 0.049)**	**(p=0.003)**	**(p=0.008)**	**(p=0.003)**
With fertilization (F1)	187.54 ± 46.18 a	14.44 ± 1.46 a	91.52 ± 11.31 a	11.02 ± 2.24 a	3.45 ± 0.70 a
Without fertilization (F2)	145.25 ± 39.83 b	14.33 ± 1.61 a	80.17 ± 14.76 b	10.12 ± 2.31 b	2.95 ± 0.66 b
Evaluation 4 (E4)	**(p= <0.0001)**	**(p= 0.072)**	**(p=0.0039)**	**(p=0.001)**	**(p=0.001)**
With fertilization (F1)	253.95 ± 65.42 a	13.17 ± 1.36 a	94.18 ± 12.00 a	10.66 ± 2.14 a	3.14 ± 0.60 a
Without fertilization (F2)	204.86 ± 62.84 b	13.17 ± 1.22 a	86.82 ± 13.08 b	10.06 ± 2.01 b	2.42 ± 0.62 b

Different letters vertically indicate significant differences by Student's t-test ($p < 0.05$). F1: 240 kg N + 108 kg P + 108 kg K per hectare and F2: 0 kg N + 0 kg P + 0 kg K.

density 1 (Table 3). Paitán and Paitán [30] reported higher planting heights for the cusqueado forage corn variety, with average heights of 3.01 m for a planting spacing of 25 cm. The differences found in this research could be associated with the variety or hybrid under study [27].

3.2. *Number of leaves*

Significant differences were reported for varieties, where variety 1 (Yellow Starchy Corn) showed the highest number of leaves during the last two evaluations (E3: 15.08 ± 1.27 and E4: 13.72 ± 1.30) (Table 1). Similar results were presented with the data reported by Collazos et al. [31], with 13.08 leaves for the same variety under conditions in Molinopampa, Peru. These similarities are due to the edaphoclimatic conditions shared by these locations, showing the adaptability of this crop to maintain characteristics such as the number of leaves per plant [32].

The number of leaves did not show significant differences with and without fertilizer application, reaching an average of 13 leaves per plant in the last evaluation (Table 2). Ayvar-Serna et al. [33] also reported that there were no significant differences with the hybrids evaluated (P4082 W, DK357, and H565), where the hybrid DHH357 obtained the highest number of leaves with an average of 14.33. Xiu [34] mentioned that some maize hybrids to which 100 % chemical fertilization was applied produced more leaves than plants with lower fertilizer applications.

Planting density also did not show significant differences in any of the evaluations for the leaf number variable (Table 3). In contrast, Chuntong et al. [35] observed that different planting densities and nitrogen application rates affect corn's leaf number and yield under Chinese conditions.

3.3. *Leaf length and width*

These two variables showed significant differences, where variety 3 (Dow 2B710) from the second evaluation reported the highest values for leaf length (E2: 87.51 ± 13.68; E3: 93.80 ± 12.23 and E4: 99.59 ± 10.23). For leaf width, the highest averages were presented with variety 2 (Chuska INIA 617) from evaluation 2 (E2: 10.60 ± 1.98; E3: 12.92 ± 1.70 and 12.33 ± 1.63) (Table 1). Perez [36] obtained similar values of 104.04 cm for leaf length and 12.38 cm for leaf width with the varieties INIA 605 and INIA 612. In this research, the hybrids showed higher values than the local variety.

Leaf length and width showed significant differences in relation to fertilizer application, presenting the highest values with

Table 3
Analysis of growth parameters for density.

Evaluation (E)	Plant height (cm)	Number leaf	Leaf long (cm)	Leaf width (cm)	Stem diameter (cm)
Evaluation 1 (E1)	**(p=0.048)**	**(p=0.097)**	**(p=0.44)**	**(p=0.051)**	**(p=0.071)**
Density 1	32.53 ± 9.87 a	8.61 ± 1.31 a	39.70 ± 9.64 a	5.03 ± 1.53 a	2.25 ± 0.58 a
Density 2	32.17 ± 9.47 a	8.41 ± 1.13 a	39.78 ± 9.60 a	5.01 ± 1.61 a	2.26 ± 0.57 a
Evaluation 2 (E2)	**(p=0.063)**	**(p=0.071)**	**(p=0.54)**	**(p=0.068)**	**(p=0.084)**
Density 1	107.62 ± 39.47 a	11.68 ± 1.65 a	78.65 ± 15.94 a	9.10 ± 2.35 a	3.25 ± 0.74 a
Density 2	104.97 ± 34.59 a	11.74 ± 1.68 a	78.93 ± 17.92 a	9.36 ± 2.14 a	3.32 ± 0.60 a
Evaluation 3 (E3)	**(p=0.071)**	**(p=0.068)**	**(p=0.070)**	**(p=0.087)**	**(p=0.057)**
Density 1	179.08 ± 50.49 a	14.39 ± 1.52 a	88.89 ± 13.36 a	10.61 ± 2.37 a	3.26 ± 0.74 b
Density 2	174.85 ± 45.92 a	14.43 ± 1.49 a	88.48 ± 13.06 a	10.98 ± 2.19 a	3.40 ± 0.70 a
Evaluation 4 (E4)	**(p=0.095)**	**(p=0.072)**	**(p=0.74)**	**(p=0.097)**	**(p=0.043)**
Density 1	244.59 ± 69.28 a	13.14 ± 1.37 a	92.39 ± 12.13 a	10.40 ± 2.19 a	2.91 ± 0.69 a
Density 2	238.76 ± 66.97 b	13.20 ± 1.27 a	92.29 ± 13.22 a	10.63 ± 2.05 a	3.01 ± 0.67 a

Different letters vertically indicate significant differences by Student's t-test ($p < 0.05$).

fertilizer application; for the fourth evaluation, leaf length and width were 94.18 and 10.66 cm, respectively. Castro [37] reported similar values for leaf length and width, reporting the highest leaf length for the Advanta corn hybrid (103.5 cm) and the highest leaf width for the Azor variety (11.75 cm), with the application of Yaramila and Yarabela fertilizer under Ecuadorian conditions.

Concerning density, no significant differences were found for these two variables evaluated (Table 3), coinciding with what was reported by Huancco [38], who mentions that there are no significant differences in planting density about leaf length and width at 60 days of evaluation for three varieties evaluated (PVM-580, SHS-5070, and INIA-617 in conditions of Arequipa, Peru. However, density 2 (35 × 70 cm) showed the highest values to density 1 (30 × 80 cm) for the first two evaluations, contrary to what can be observed with the later evaluations in the case of leaf length and leaf width, D2 reported the highest values during the four evaluations (Table 3).

3.4. Stem diameter

The varieties evaluated showed significant differences, where variety 2 (Chuska INIA 617) reported the best values for stem diameter during the last three evaluations (E2: 3.51 ± 0.60; E3: 3.81 ± 0.75 and E4: 3.25 ± 0.70) (Table 1). Vasquez [39] reported lower values of 2.6 cm with a density of 88889 plants/ha for the same variety under conditions of the central coast of Peru and those of Rivas-Jacobo et al. [40], who reported 2.82 cm for the hybrid HT-6 from an evaluation of 14 varieties of forage corn in the evaluation of productivity and morphological characteristics under conditions in Mexico. These differences are related to the varieties used and the environmental and nutritional conditions of the soil [41].

Significant differences in the variable stem diameter were presented during the four evaluations, with the highest values obtained by applying fertilizer with a final value of 3.14 cm (Table 2). This is explained by the fact that the fertilized plants receive absent or unavailable nutrients for the plants [42].

For sowing density, there were no significant differences; however, density 2 (35 × 70 cm) showed the best results (Table 3). This is related to the number of plants per hectare because having a greater planting distance allows adequate development since there will be no competition between plants for light, with weeds that are factors that cause elongation of the stems and reduce their thickness [43].

3.5. Fresh forage and dry matter

Variety 2 (Chuska INIA 617) showed significant differences between fresh forage and dry matter, with values of 17.77 ± 7.05 and 4.8 ± 1.90 kg/m^2, respectively. These results are lower than those obtained by Vásquez et al. [44], who reported green forage values of 47 t/ha and 13 t/ha of dry matter for the same variety in Huambo, Peru.

The highest averages were obtained for green forage 14. 49 ± 6.21 kg/m^2) and dry matter (3.91 ± 1.60 kg/m^2), using fertilizer.

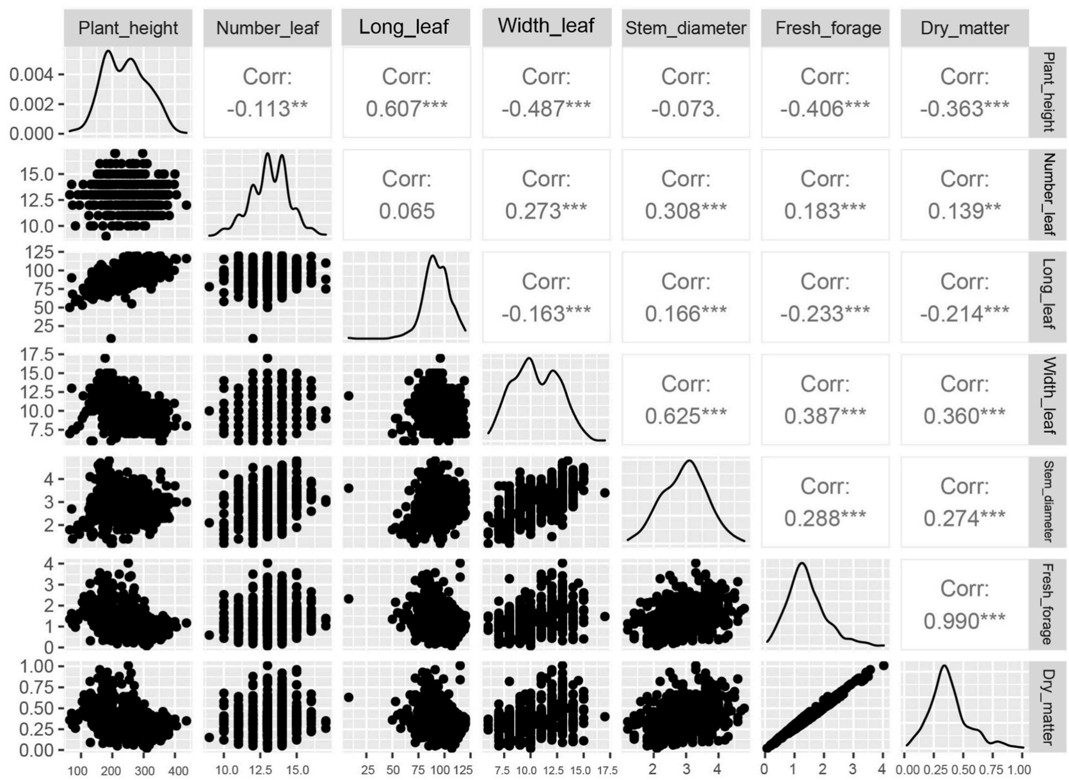

Fig. 2. Multiple R Pearson correlation analysis, with scatter and density plots for the variables evaluated during the fourth evaluation.

Velasco et al. [45] reported lower values than this research, with a green forage yield of 6.44 kg/m^2 for the hybrid Santa Lucía1 in the High Valleys of Mexico with a planting density of 55000 plants/ha. Garcia et al. [46] recorded lower dry matter values than this research, with an average of 1.38 kg/m^2 for the forage corn hybrid Pioner P3966 W under Mexican soil and climatic conditions with a conventional urea application at 240 kg/ha.

Density 2 (35 × 75 cm) showed the best values for these variables, with 14.67 ± 5.97 kg/m^2 for green matter and 3.96 ± 1.53 kg/m^2 for dry matter. These results contradict other researchers, such as Shi et al. [47] and Agnew et al. [48], who argue that higher plant density increases forage production. The variables that could influence these differences are the varieties of forage corn and the edaphoclimatic conditions of each evaluation zone.

It was possible to demonstrate that using planting densities managed by local producers for forage corn maximized production and improved resource use and crop resilience to adverse conditions; in addition, the data obtained show that increasing planting density is not always the best option to increase productive yields of forage corn [49].

3.6. Pearson's correlation between evaluated variables

The plant height and leaf length variables are inversely proportional to green forage and dry matter, i.e., the higher the plant height is, the lower the values for green forage and dry matter in this research (Fig. 2), contrary to what was reported by Gutiérrez et al. [50], who found a positive association between plant height and green forage and dry matter yield for 20 commercial hybrids under Cuban conditions. This contrary behavior could be due to other factors not considered in this work, such as fiber concentration and the degree of leaf lignification [51].

The variables leaf number, leaf width, and stem diameter are directly proportional to green forage and dry matter, i.e., the greater the number of leaves, leaf width, and stem diameter, the greater the amount of green forage and dry matter (Fig. 2). These results are in agreement with those reported by Rivas-Jacobo et al. [40], who found a positive correlation between stem diameter and green forage and dry matter, and Rivas et al. [52], who observed a positive correlation between stem diameter and dry matter. The stalk represents 50 % or more of the total biomass of the corn plant; for this reason, it is the plant structure that is most identified as having potential for the genetic improvement of forage corn since stalk height and diameter are closely related to dry matter yield [53].

3.7. Principal component analysis (PCA) of the evaluated variables

The PCA was able to explain 86.9 % of the variance with the first two dimensions (Dim) (Dim1 69.3 % and Dim2 17.6 %) (Fig. 3). This explains a clear increase in the variables evaluated during the four evaluations, with plant height and leaf length growing and increasing constantly compared to the other variables. Dittel-Pérez et al. [54] observed similar behavior to the plant height variable for all the corn materials evaluated, showing a constant growth pattern, with more excellent development between 45 and 75 days, compared to the beginning and end of the period evaluated.

Fig. 4 shows that the PCA explains 64.6 % of the variance in its first two dimensions (Dim 1: 42.4 % and Dim 2: 22.2 %). The fertilization factor shows less dispersion, indicating less variability in the variables evaluated, such as plant height, leaf length, number of leaves, stem diameter, fresh weight, and dry matter, demonstrating that applying fertilizers contributes to homogeneity in crop

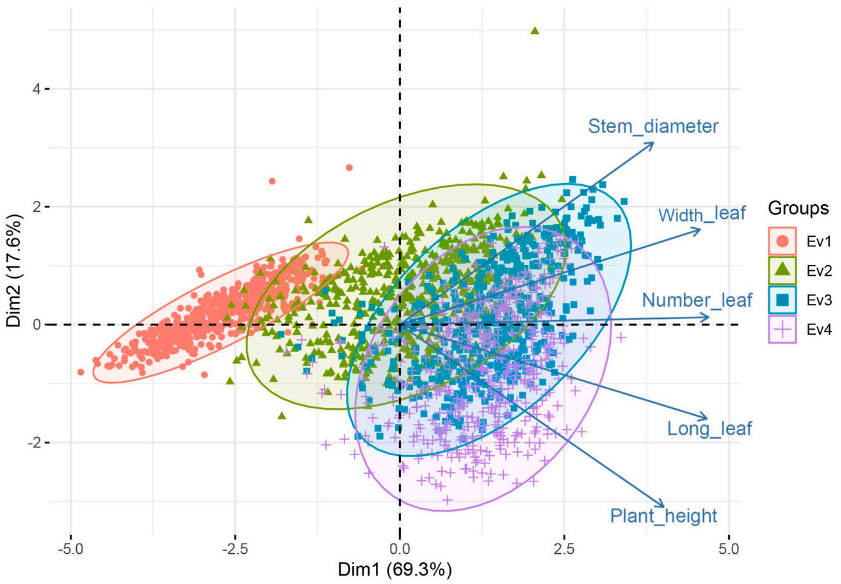

Fig. 3. Biplot principal component analysis for the biometric variables (stem diameter, leaf width, leaf length, number of leaves, and plant height) evaluated at four points in time.

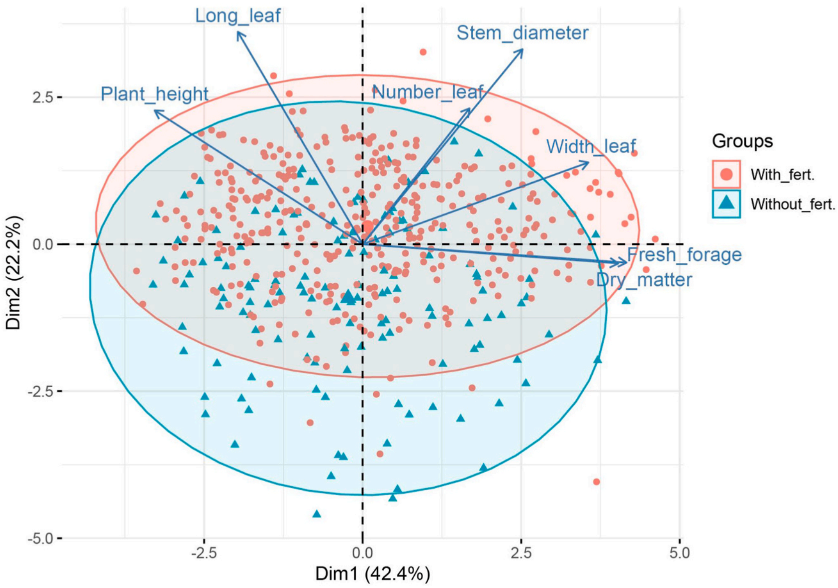

Fig. 4. Biplot principal component analysis (PCA) for the biometric variables (stem diameter, leaf width, leaf length, number of leaves and plant height, fresh forage, and dry matter) in the fourth evaluation with fertilizer clustering.

development. This is corroborated in the study by Sánchez et al. [55], who mentions that the variability of growth and yield of corn crops in Colombia responds to better soil fertility conditions.

4. Conclusions

Chuska INIA 617 (variety 2) showed the best leaf width, stem diameter, green forage and dry matter reports. In addition, leaf number, leaf width, and stalk diameter positively influence the amount of fresh forage and dry matter. Fertilizer application is an important factor in the development of the forage corn crop as it contributes to its homogeneity; however, it should be considered that an increase in planting density implies a more significant requirement of nitrogen fertilizer if high yields are to be obtained. A proportional correlation was found between the variables leaf number, leaf width, and stem diameter with green forage and dry matter. The variables that showed the greatest increase during the four evaluations were plant height and leaf length. Under the conditions of the Chachapoyas district, the variety Chuska INIA 617 represents an alternative for the production of silage for cattle; however, it is recommended that a bromatological analysis of the forage obtained be carried out. In addition, it is recommended that these varieties of fodder corn be tested in other livestock microbasins in the Amazon region. One of the main limitations was the limited timeframe to complete the research, which meant that the nutritional analysis of the forage corn could not be carried out. This research will provide livestock producers with specific management practices to maximize forage production and the best use of resources in the soil and climatic conditions of the Chachapoyas district and similar places in the Amazon region.

Data availability statement

The data will be available as supplementary material and are referenced in the article.

CRediT authorship contribution statement

Héctor V. Vásquez: Writing – original draft, Investigation, Conceptualization. **Carmen N. Vigo:** Writing – original draft, Formal analysis, Data curation. **David Saravia:** Writing – original draft, Software, Formal analysis. **Leandro Valqui:** Writing – original draft, Resources, Investigation. **Leidy G. Bobadilla:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30790.

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