Research Article

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Productive potential of three *Urochloa* hybrids in low-fertility soils of the Peruvian Amazon

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Abstract: Tropical livestock production relies on the availability of adapted forages capable of sustaining productivity under limiting soil conditions. This study evaluated the performance of three *Urochloa* hybrids grown in low-fertility soils of a seasonally dry tropical forest in the Peruvian Amazon. The experiment was conducted at the Estación Experimental Agraria El Porvenir–INIA under a randomized complete block design with three replications and five consecutive harvests at 60-day intervals. Soil characteristics and Growth, yield, productive, and quality parameters were evaluated. Rotational harvesting improved soil properties, including organic matter and nutrient availability. During the initial harvests Cobra showed better growth and yield performance; however, Mavuno and Mulato II surpassed it at later stages, especially in fresh and dry matter yield. In the fourth and fifth harvests, Mavuno achieved the highest production (32.10 and 32.94 t ha^{-1} of fresh matter, and 7.65 and 7.18 t ha^{-1} of dry matter), followed by Mulato II (28.82 and 29.15 t ha^{-1} of fresh matter, and 6.73 and 6.70 t ha^{-1} of dry matter), both significantly better than Cobra (20.51 and 21.51 t ha^{-1} of fresh matter, and 5.00 and 5.16 t ha^{-1} of dry matter). Annual carrying capacity was highest for Mavuno (3.72 TLU ha^{-1}·year^{-1}), followed by Mulato II (3.41 TLU ha^{-1}·year^{-1}) and Cobra (2.97 TLU ha^{-1}·year^{-1}). The protein contents of Mavuno (9.61 g·kg^{-1}) and Mulato II (9.54 g·kg^{-1}) were significantly higher than that of Cobra (6.33 g·kg^{-1}). Mavuno and Mulato II hybrids have proven to be promising forage alternatives for sustainable livestock systems in seasonally dry tropical conditions.

Keywords: *Brachiaria* hybrids; tropical pastures; soil fertility; agroecological adaptation; forage production

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1 Introduction

Tropical livestock farming provides approximately 30 % of the animal based protein consumed worldwide and directly contributes to the well-being of more than 1.3 billion people [1]. In Peru, livestock farming is among the most important activities, especially in regions such as the Amazon and the High Jungle, where it represents one of the main sources of income, employment, and food security for thousands of rural families [2]. However, the sustainability and productivity of this activity largely depend on the availability and quality of forage, which are directly influenced by environmental conditions and pasture management [3]. Therefore, to ensure greater productivity and resilience in tropical livestock systems, it is essential to identify forage species with a high capacity for adaptation and tolerance to the conditions of these regions [4].

The selection and establishment of a forage species under tropical conditions must take into account its response to factors such as temperature, soil type, light availability, and rainfall [5]. These environmental factors not only influence plant growth and persistence but also determine the nutritive value of the herbage produced. Indeed, considerable differences in nutritive value have been reported among forage groups, as well as among species and even among cultivars within the same species [6]. Considering these agroecological requirements, forage species of the genus *Urochloa* (syn. *Brachiaria*) are well-recognized tropical grasses due to their high adaptability and widespread use in subtropical and tropical regions, including *Urochloa brizantha*, *Urochloa decumbens*, *Urochloa ruziziensis*, and *Urochloa humidicola* [7, 8]. These species are characterized by high biomass production, drought tolerance, adaptability to low-fertility soils, resilience to grazing pressure and good nutritional value [9–11]. In addition to these characteristics, these species can also be used as cover crops to reduce soil erosion, restore degraded lands, and control pests [12]. Furthermore, in many Peruvian Amazon regions, *Urochloa* species are widely used and recommended for the establishment of protein banks and the development of silvopastoral systems [13]. Previous reports [14–16] have highlighted the forage potential of *Urochloa* hybrids over other species. Their high adaptability to low-fertility, acidic soils with high aluminum saturation makes *Urochloa hybrids* particularly suitable for tropical conditions. Moreover, newly developed hybrids such as Mavuno, Mulato II, and Cobra can produce more dry matter than traditional cultivars such as *U. decumbens* and *Megathyrsus maximus* [17]. However, further evaluation under diverse agronomic conditions is necessary, due to the high variation observed in nutritional parameters such as protein content, fiber composition, and digestibility among cultivars and hybrids [6]. In Peru, some studies have already addressed the adaptability and yield of *Urochloa* under Amazonian climatic conditions; however, further research is needed to evaluate their performance across diverse environments and management practices. In particular, in areas such as seasonally dry tropical forests, information on the agronomic performance of these hybrids remains limited.

The aim of this study was to evaluate the adaptability of three *Urochloa* hybrids (Mavuno, Mulato II, and Cobra) in low-fertility soils located in a seasonally dry tropical forest in the San Martín region of Peru. Specifically, morphological traits such as plant height, leaf area, number of plants, and number of tillers per plant were recorded. In addition, productive and qualitative traits such as green forage yield, dry matter yield, carrying capacity, and protein content were evaluated.

2 Materials and methods

2.1 Study area

The experiment was carried out in the pasture area of the Estación Experimental Agraria El Porvenir of the Instituto Nacional de Innovación Agraria (INIA) (6°35’18’’ S and 76° 19′12″ W, at 232 m a.s.l.), located in the district of Juan Guerra, province and region of San Martín, Peru (Figure 1). The site is classified as a seasonally dry tropical forest [18] and has a semi-dry and warm climate of the C(r)A′ type [19]. Average maximum and minimum temperatures were 38.2 °C and 14.7 °C, respectively, with a mean relative humidity of 72.94 % and an average daily precipitation of 2.92 mm.

2.2 Experimental design and treatments

Three *Urochloa* cultivars Mulato II (*Urochloa* hybrid CIAT 36087), Cobra (*Urochloa* hybrid CIAT BRO2/1794), and Mavuno (*U. brizantha* × *U. ruziziensis*) were selected for the experiment as treatments. These hybrids were selected for their superior agronomic and productive performance compared with common cultivars such as *U. brizantha* and *U. decumbens* [20, 21], and for their increasing adoption and seed availability among Peruvian farmers. The *Urochloa* cultivars were sown in July 2021. A leveling cut was performed 120 days after growth at 0.15 m above ground level to ensure uniform regrowth, after which harvest cuts were carried out at 60-day intervals until August 2022.

The experiment was laid out in a randomized complete block design with three replications. A total of nine plots, each measuring 128 m^2 (16 × 8 m), were used for the experiment. The hybrids were sown at a spacing of 0.25 × 0.25 m (between plants and rows), with six seeds per hole. A distance of 0.30 m was maintained between adjacent plots and between blocks.

2.3 Land preparation and management

The experimental field was plowed to a depth of 0.25 m and leveled to uniformize the terrain. It was then divided into three blocks, each of which was further split into three experimental plots. Treatment combinations were randomly assigned to the plots within each block. Before planting, the plots were irrigated, and fifteen days after plowing, glyphosate (3 $L \cdot ha^{-1}$) was applied for weed control, subsequent weed control was carried out manually when the growth of weeds was detected in each plot. The three hybrid seeds were obtained from AGP S.A. No fertilizers or pest control were applied, as no significant damage was observed during the growth of the hybrid grasses, and water was supplied only when necessary to meet crop requirements under rainfed conditions.

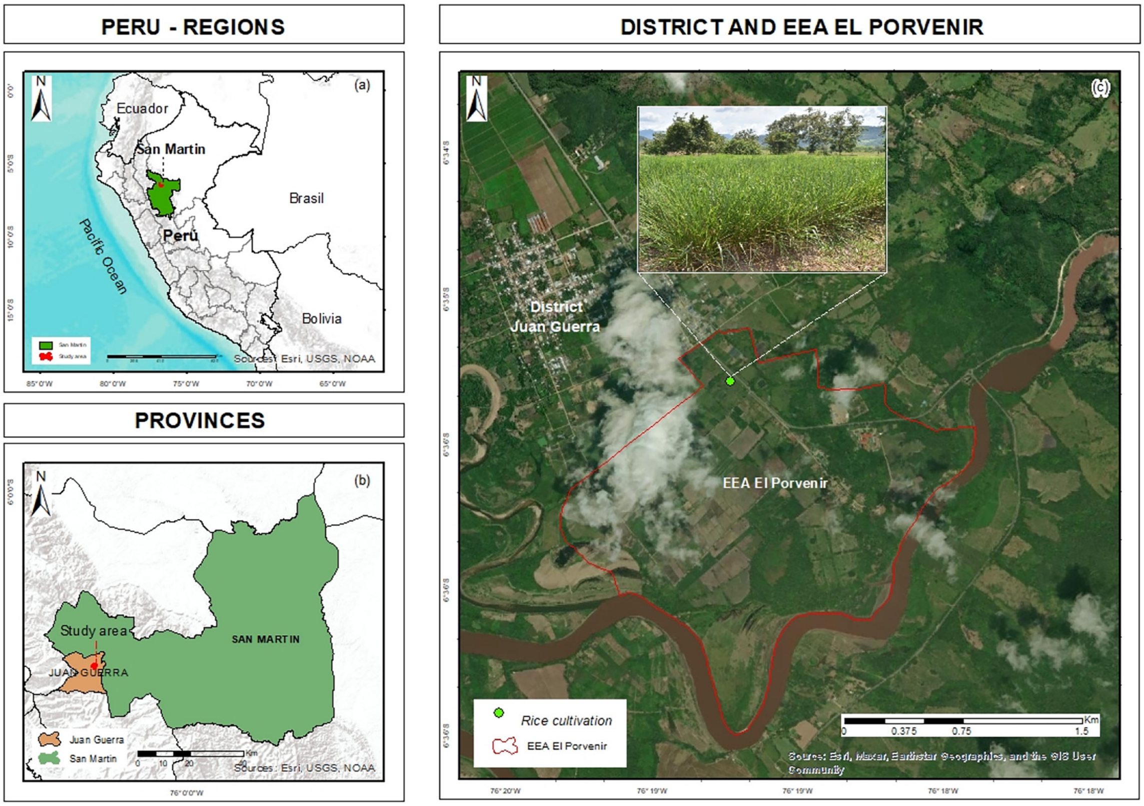

Figure 1: Geographical location of the study area. (a) San Martín region in Peru; (b) San martín province; (c) district of Juan Guerra showing the Estación experimental Agraria El Porvenir (INIA).

2.4 Soil characterization

A soil sample was taken before the start of the trial at a depth of 0.30 m; likewise, at the end of the experiment, soil samples from each plot at the same depth were collected and grouped by treatment.

The soil samples were analyzed at the Laboratorio de Suelos, Aguas, y Foliares at INIA, where the following parameters were measured: soil texture was measured via the Bouyoucos method [22]; soil pH (pH) was measured in a 1:1 soil-to-water suspension using an inoLab® pH 7310, electric conductivity (EC) was determined in a 1:5 soil-to-water suspension using an inoLab® Cond 7310, organic matter (OM) was determined by the Walkley Black method [23] and total nitrogen (N_{Tot}) was estimated using a conversion factor of 0.05 applied to the organic matter content [24]. Available phosphorus (P_{Av}) was determined using the Olsen method [25]. Available potassium (K_{Av}) and Cation exchange capacity (CEC_e) were determined following ammonium saturation, and quantified using microwave plasma atomic emission spectroscopy (MP-AES) (Agilent 4210, Agilent Technologies Inc., USA).

The physicochemical properties of the soil before the trial were as follows: pH 6.30, EC 3.10 mS m^{-1}, OM 19.0 g kg^{-1}, N_{Tot} 0.9 g kg^{-1}, P_{Av} 7.40 mg kg^{-1}, K_{Av} 124.34 mg kg^{-1}, and CEC_e 15.88 cmol kg^{-1}.

2.5 Data collection

Following the pre-experimental cut, the trial plots were evaluated every 60 days (180, 240, 300, 360 and 420 days of growth) to record morphological and productive variables.

Plant height was measured from the soil surface to the tip of the highest leaf without extending it. Leaf area was calculated using the formula developed by Bianco et al. [26], applying a factor of 0.9810 for for Mulato II and 0.7468 for Mavuno and Cobra. Leaf length was measured from the base to the apex, and leaf width was measured at one-third of the distance from the leaf base. Number of tillers per plant was assessed by direct counting using a 1 m^2 quadrat.

Representative field conditions and the general appearance of *Urochloa* hybrids during the experimental period are shown in Figure 2.

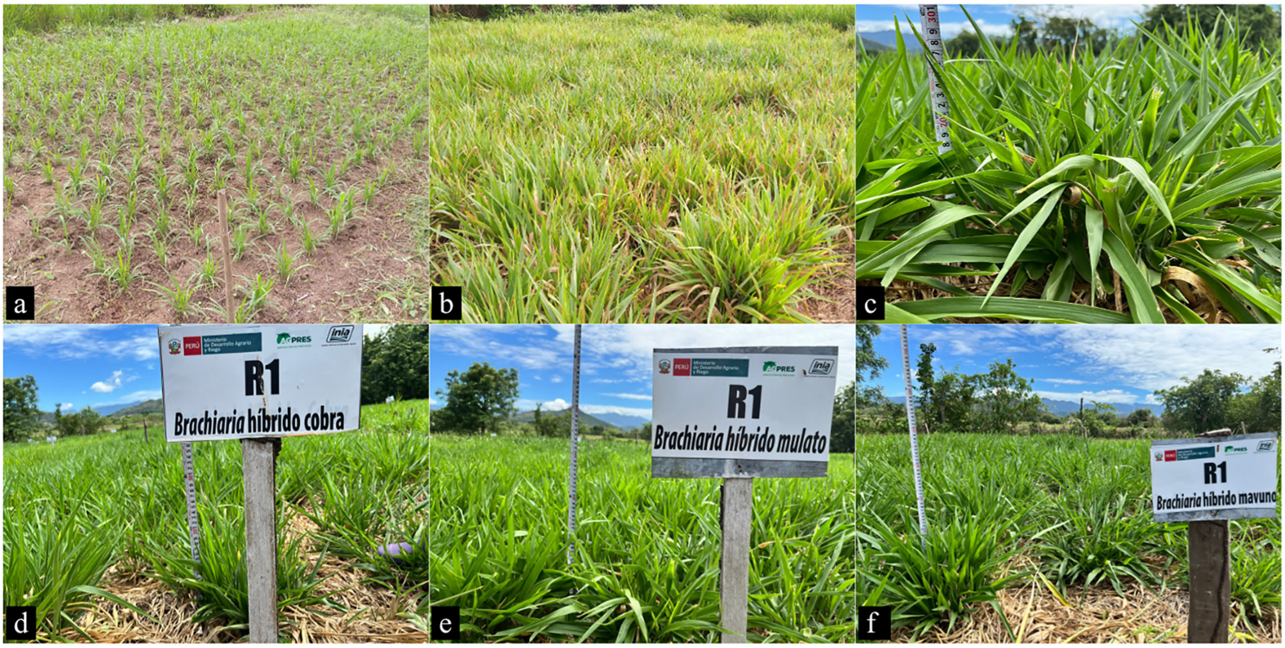

Figure 2: Field performance of *Urochloa* hybrids at representative growth stages. (a) Plot of *Urochloa* seedlings during early establishment. (b) Plot of *Urochloa* seedlings before the pre-experimental cut. (c) Regrowth of *Urochloa* plants a few days after the pre-experimental cut. (d–f) experimental plots of *Urochloa* hybrids cobra, Mulato II and Mavuno, respectively.

Green forage yield was calculated from the fresh weight of forage collected at ground level within three randomly placed 1 m^2 quadrats inside each plot. Dry matter yield was calculated by multiplying the green forage yield by the dry matter conversion factor, which was obtained from drying a 250 g fresh forage subsample in an oven at 70 °C until a constant weight was reached.

Carrying capacity was calculated according to Saleem et al. [27], using the formula

$$\mathrm{CC} = \frac{F}{I \times D}$$

Where:

Carrying capacity (CC), is the maximum number of cattle that a given rangeland can support for a specific period without causing ecosystem degradation, expressed in total living units per hectare and year (TLU ha^{-1}·$year^{-1}$).

Usable forage (F), is the portion of total forage produced by the rangeland that is actually available and consumable by grazing animals, expressed in kilograms of dry matter per hectare (kg DM·ha^{-1}). In this study, a utilization factor of 70 % was assumed.

Forage intake (I), is the daily amount of dry matter consumed by one animal unit, expressed in kilograms of dry matter per day (kg DM·day^{-1}). In this study, forage intake was calculated based on a 450 kg live weight and a daily dry matter intake equivalent to 3.0 % of live weight.

Grazing period (D): The total number of days in the year during which the rangeland is available for grazing, expressed in days.

The total protein content was determined according to the methodology described by Baerlocher [28]. At each harvesting time, a composite sample was prepared by combining representative subsamples from the evaluated hybrids, which was then sent to the Laboratorio de Suelos, Aguas y Foliares at INIA for protein analysis.

2.6 Data analysis

The collected data was analyzed using the general linear model. A significant probability level of $p < 0.05$ was used. The model used for the study was:

$$Y_{\mathrm{ijk}} = \mu + H_i + C_j + (H \times C)_{\mathrm{ij}} + B_k + P_{k(i)} + \varepsilon_{\mathrm{ijk}}$$

Where:

Y_{ijk}. is the observed value of the response variable for the i$^{\mathrm{th}}$ hybrid, j$^{\mathrm{th}}$ cut and k$^{\mathrm{th}}$ block.

μ is the overall mean.

H_i is the effect of i$^{\mathrm{th}}$ hybrid.

C_j is the effect of j$^{\mathrm{th}}$ cut.

$(H \times C)_{\mathrm{ij}}$ is the i$^{\mathrm{th}}$ hybrid by j$^{\mathrm{th}}$ cut interaction.

B_k is the random effect of the k$^{\mathrm{th}}$ block.

P_{ik} is the random effect of the plot within the ith hybrid and kth block.

ε_{kij} is the residual error for the ith hybrid, jth cut and kth block.

3 Results

3.1 Soil characterization

The physicochemical properties of the soil before and after the trial with *Urochloa* hybrids are presented in Table 1. Soil textural analysis showed that the field has a clay-loam texture. Post-trial soil analysis showed an increase in pH to near-neutral values, ranging from 6.80 to 6.97. A similar trend was observed for soil EC (5.57–8.03 mS·m^{-1}), OM (30.7–32.3 g·kg^{-1}), N_{tot} (1.5–1.6 g·kg^{-1}), P_{av} (26.57–50.13 mg·kg^{-1}), K_{av} (362.63–560.10 mg·kg^{-1}) and CEC$_e$ (20.53–22.30 cmol·kg^{-1}).

3.2 Growth and yield performances

Plant height showed significant differences between hybrids, harvesting stages and interaction (Table 2). In the first harvest, Cobra exhibited a significantly greater estimated mean height (94.67 cm) compared to Mavuno (65.93 cm) and Mulato II (65.53 cm). During the second harvest, no significant differences were observed among the estimated mean heights; however, the trend remained similar, with Cobra showing the highest value (92.93 cm), followed by Mulato II (92.80 cm) and Mavuno (84.67 cm). In the third harvest, significant differences were found, with Mavuno (95.27 cm) and Cobra (90.13 cm) presenting higher estimated mean heights than Mulato II (76.60 cm). In the fourth and fifth harvests, no significant differences were detected among estimated mean heights; however, the trend indicated a higher estimated mean height for Mavuno (97.68 cm in the fourth harvest and 94.93 cm in the fifth), followed by Mulato II (92.80 cm in the fourth and 94.00 cm in the fifth) and Cobra (92.67 cm in the fourth and 93.87 cm in the fifth).

Leaf area showed significant differences between hybrids, harvesting stages and interaction (Table 2). In the first harvest, the estimated mean leaf area of Cobra (91.63 cm^2·plant^{-1}) was significantly greater than that of Mavuno (66.24 cm^2·plant^{-1}) and Mulato II (45.70 cm^2·plant^{-1}). During the second harvest, Cobra exhibited a significantly greater estimated mean leaf area (82.02 cm^2·plant^{-1}) compared with Mavuno (35.37 cm^2·plant^{-1}) and Mulato II (36.23 cm^2·plant^{-1}). In the third harvest, significant differences were observed among all hybrids. Mavuno exhibited the greatest estimated mean leaf area (87.64 cm^2·plant^{-1}), followed by Cobra (59.01 cm^2·plant^{-1}) and Mulato II (42.75 cm^2·plant^{-1}). In the fourth and fifth harvest significant differences were observed between Mavuno (83.19 cm^2·plant^{-1} in the fourth and 79.38 cm^2·plant^{-1} in the fifth) and Mulato II (71.44 19 cm^2·plant^{-1} in the fourth and 69.18 cm^2·plant^{-1} in the fifth), and Cobra (52.87 19 cm^2·plant^{-1} in the fourth and 53.38 cm^2·plant^{-1} in the fifth).

The number of plants showed significant differences only between harvesting stages (Table 2). In the first harvest, Cobra recorded the highest estimated mean number of plants (18.00), followed by Mavuno (16.33) and Mulato II (14.67). In the second harvest, Cobra had the highest mean (14.33), followed by Mulato II (12.00) and Mavuno (11.33). In the third harvest, Mavuno recorded the highest mean (12.33), followed by Cobra (11.33) and Mulato II (10.33). In the fourth and fifth harvests, the highest estimated mean number of plants was recorded by Mavuno (11.33 in the fourth harvest and 12.33 in the fifth harvest), followed by Mulato II (11.00 in the fourth harvest and 11.33 in the fifth harvest) and Cobra (10.33 in the fourth harvest and 10.67 in the fifth harvest).

The number of tillers per plant only showed significant differences between harvesting stages (Table 2). In the first harvest, Cobra recorded the highest estimated mean number of tillers per plant (20.67), followed by Mavuno (20.00) and Mulato II (17.22). In the second harvest, Cobra had the highest estimated mean number of tillers per plant (30.78), followed by Mulato II (26.00) and Mavuno (21.00). In the third harvest, Mavuno recorded the highest estimated mean number of tillers per plant (40.00), followed by Cobra (34.78) and Mulato II (32.00). In the fourth and fifth harvests, the highest estimated mean number of tillers per plant was recorded by

Table 1: Soil physicochemical properties before and after the trial with three *Urochloa* hybrids.

Parameter	Unit	Pre-trial soil analysis	Post-trial soil analysis		
			Cobra	Mavuno	Mulato II
pH	–	6.30	6.97	6.80	6.83
Electric conductivity	mS·m^{-1}	3.10	80.3	55.7	73.3
Organic matter	g·kg^{-1}	19.0	30.7	32.3	31.3
Total nitrogen Tot	g·kg^{-1}	0.9	1.5	1.6	1.5
Available phosphorus	mg·kg^{-1}	7.40	32.47	50.13	26.57
Available potassium	mg·kg^{-1}	124.34	449.13	560.10	362.63
Cation exchange capacity	cmol·kg^{-1}	15.88	22.30	20.53	21.53
Texture	–	Clay-loam	Clay-loam	Clay-loam	Clay-loam

Table 2: Morpho agronomic traits of three *Urochloa* hybrids at different harvesting stages. Data are expressed as adjusted means. Values followed by different letters within the same column are significantly different according to Tukey's test (p < 0.05).

Harvesting stage	Hybrid	Plant height (cm)	Leaf area ($cm^2 \cdot plant^{-1}$)	Number of plants	Number of tillers ($Tillers \cdot plant^{-1}$)	Fresh weight ($t \cdot ha^{-1}$)	Dry weight ($t \cdot ha^{-1}$)
180 days of growth	Cobra	94.67[a]	91.63[a]	18.00 [a]	20.67[a]	10.90[a]	2.18[a]
	Mavuno	65.93[b]	66.24[b]	16.33[a]	20.00[a]	9.13[a]	1.77[a]
	Mulato II	65.53[b]	45.70[c]	14.67[a]	17.22[a]	8.14[a]	1.72[a]
240 days of growth	Cobra	92.93[a]	82.02[a]	14.33[a]	30.78[a]	11.93[a]	2.15[a]
	Mavuno	84.67[a]	35.37[b]	11.33[a]	21.00[a]	11.18[a]	2.08[a]
	Mulato II	92.80[a]	36.23[b]	12.00[a]	26.00[a]	11.45[a]	2.13[a]
300 days of growth	Cobra	90.13[a]	59.01[b]	11.33[a]	34.78[a]	13.35[a]	2.70[a]
	Mavuno	95.27[a]	87.64[a]	12.33[a]	40.00[a]	13.36[a]	2.85[a]
	Mulato II	76.60[b]	42.75[c]	10.33[a]	32.00[a]	11.70[a]	2.44[a]
360 days of growth	Cobra	92.67[a]	52.87[b]	10.33[a]	51.00[a]	20.51[b]	5.00[b]
	Mavuno	97.68[a]	83.19[a]	11.33[a]	75.67[a]	32.10[a]	7.65[a]
	Mulato II	92.80[a]	71.44[a]	11.00[a]	67.67[a]	28.82[a]	6.73[a]
420 days of growth	Cobra	93.87[a]	53.38[b]	10.67[a]	51.67[a]	21.51[b]	5.16[b]
	Mavuno	94.93[a]	79.38[a]	12.33[a]	76.67[a]	32.94[a]	7.18[a]
	Mulato II	94.00[a]	69.18[a]	11.33[a]	67.33[a]	29.15[a]	6.70[a]
***P*-Value**							
Hybrid		0.0,021	0.0,003	0.5,576	0.2,239	0.0,442	0.0,143
Harvesting stage		<0.0,001	<0.0,001	0.0,009	<0.0,001	<0.0,001	<0.0,001
Hybrid: Harvesting stage		<0.0,001	<0.0,001	0.8,527	0.2,298	0.0,004	<0.0,001

Data are expressed as adjusted means. Values followed by different letters within the same column are significantly different according to Tukey's test ($p < 0.05$).

Mavuno (75.67 in the fourth harvest and 76.67 in the fifth harvest), followed by Mulato II (67.67 in the fourth harvest and 67.33 in the fifth harvest) and Cobra (51.00 in the fourth harvest and 51.67 in the fifth harvest).

Fresh weight showed significant differences among hybrids, harvesting stages, and their interaction (Table 2). In the first harvest, no significant differences were observed in the estimated mean fresh weight among hybrids; however, a higher value was recorded for Cobra (10.90 $t \cdot ha^{-1}$), followed by Mavuno (9.13 $t \cdot ha^{-1}$) and Mulato II (8.14 $t \cdot ha^{-1}$). In the second harvest, no significant differences were observed either, although Cobra again had the highest value (11.93 $t \cdot ha^{-1}$), followed by Mulato II (11.45 $t \cdot ha^{-1}$) and Mavuno (11.18 $t \cdot ha^{-1}$). In the third harvest, a similar trend to that of the first and second harvests was observed, with no significant differences; Mavuno recorded the highest estimated mean fresh weight (13.36 $t \cdot ha^{-1}$), followed by Cobra (13.35 $t \cdot ha^{-1}$) and Mulato II (11.70 $t \cdot ha^{-1}$). In the fourth and fifth harvests, significant differences were observed between Mavuno and Mulato II, and Cobra. Mavuno showed the highest estimated mean fresh weight (32.10 $t \cdot ha^{-1}$ in the fourth harvest and 32.94 $t \cdot ha^{-1}$ in the fifth), followed by Mulato II (28.82 $t \cdot ha^{-1}$ in the fourth and 29.15 $t \cdot ha^{-1}$ in the fifth) and Cobra (20.51 $t \cdot ha^{-1}$ in the fourth and 21.51 $t \cdot ha^{-1}$ in the fifth).

Dry weight showed significant differences among hybrids, harvesting stages, and their interaction (Table 2). In the first harvest, no significant differences were observed in the estimated mean dry weight among hybrids; however, a higher value was recorded for Cobra (2.18 $t \cdot ha^{-1}$), followed by Mavuno (1.77 $t \cdot ha^{-1}$) and Mulato II (1.72 $t \cdot ha^{-1}$). In the second harvest, no significant differences were observed either, although Cobra had the highest value (2.15 $t \cdot ha^{-1}$), followed by Mulato II (2.13 $t \cdot ha^{-1}$) and Mavuno (2.08 $t \cdot ha^{-1}$). In the third harvest, a similar trend to that of the first and second harvests was observed, with no significant differences; Mavuno recorded the highest estimated mean dry weight (2.85 $t \cdot ha^{-1}$), followed by Cobra (2.70 $t \cdot ha^{-1}$) and Mulato II (2.44 $t \cdot ha^{-1}$). In the fourth and fifth harvests, significant differences were observed between Mavuno and Mulato II, and Cobra. Mavuno showed the highest estimated mean dry weight (7.65 $t \cdot ha^{-1}$ in the fourth harvest and 7.18 $t \cdot ha^{-1}$ in the fifth), followed by Mulato II (6.73 $t \cdot ha^{-1}$ in the fourth and 6.70 $t \cdot ha^{-1}$ in the fifth) and Cobra (5.00 $t \cdot ha^{-1}$ in the fourth and 5.16 $t \cdot ha^{-1}$ in the fifth).

The average yield values obtained across all harvesting stages are summarized in Table 3. Among the hybrids, Mavuno exhibited the highest mean dry-matter yield (4.71 t·ha^{-1}), followed by Mulato II (3.94 t·ha^{-1}) and Cobra (3.44 t·ha^{-1}).

In Figure 3, the temporal variation of morpho-agronomic traits among the three *Urochloa* hybrids is presented. Cobra showed better performance in all morpho agronomical traits during early stages over Mulato II and Mavuno. However, at later stages, Mavuno and Mulato II were better than Cobra, particularly in tillering capacity and fresh and dry biomass accumulation.

3.3 Carrying capacity

Carrying capacity (Table 4) was calculated for a year considering a utilization factor of 70 % and a dry matter intake equivalent to 3.00 % of the live weight of a 450 kg cow, showed significant differences among hybrids, harvesting stage and interaction. Mavuno recorded the highest carrying capacity (3.72 TLU·ha^{-1}·year^{-1}), followed by Mulato II (3.41 TLU ha^{-1}·year^{-1}) and Cobra (2.97 TLU·ha^{-1}·year^{-1}), with significant differences observed between Mavuno y Cobra.

Table 3: Comparative dry-matter yield of *Urochloa* hybrids and related species evaluated under tropical environments in Latin America and Africa.

Species/Hybrid	Dry-matter yield (t·ha^{-1})	Reference	Region/ Country
Urochloa hybrid cv. Cobra	3.44	This study	San Martín, Peru
Urochloa hybrid cv. Mavuno	4.71	This study	San Martín, Peru
Urochloa hybrid cv. Mulato II	3.94	This study	San Martín, Peru
Urochloa hybrid cv. Mulato II	2.35	[29]	Kenya
Urochloa hybrid cv. Cobra	3.06	[29]	Kenya
Urochloa hybrid cv. Cobra	5.87	[30]	Tamaulipas, Mexico
Urochloa hybrid cv. Mulato II	5.78	[30]	Tamaulipas, Mexico
Urochloa hybrid cv. Mavuno	7.69	[31]	Mexico
Urochloa decumbens	6.27	[32]	Coruripe, Brazil
Urochloa brizantha	5.00	[32]	Coruripe, Brazil

3.4 Protein analysis

Protein content showed significant difference among hybrids (Figure 4). Mavuno (9.61 g·kg^{-1}) and Mulato II (9.54 g·kg^{-1}) showed significantly higher protein content than Cobra (6.33 g·kg^{-1})

4 Discussion

Low soil fertility is one of the main challenges affecting agricultural productivity, as it limits the potential yield of forage crops. This constraint, reported in tropical countries [33], may also have similar effects in places with similar characteristics such as Peruvian Amazon, where poor soil fertility, characterized in our study by low soil OM, N_{Tot} and P_{Av} may be influencing the performance of the evaluated *Urochloa* hybrids. In our study, rotational grazing with a 60-day rest period was implemented, and this management strategy resulted in improvements in soil properties, including pH, EC, OM, N_{Tot}, P_{Av}, K_{Av}, and CEC_e. These changes are consistent with previous studies [34], which mention that *Urochloa* grasses can establish in nutrient poor and degraded soils while progressively enhancing soil health. Moreover, Byrnes et al. [35] have shown that rotational grazing increases soil organic carbon compared to continuous grazing, with levels comparable to those observed under no-grazing conditions. This improvement is attributed to the nutrient recycling effect of grazing cattle, as they return the nitrogen, phosphorus and potassium they consume back to the soil through feces and urine.

Although some species such as *Pennisetum*, *Panicum*, *Paspalum*, or *Cynodon* may outperform *Urochloa* in specific nutritive parameters such as crude protein content, digestibility, or metabolizable energy; however, *Urochloa* combines good forage quality with greater adaptability, persistence, and productivity under tropical conditions [6]. Moreover, *Pennisetum* or *Paspalum* species present some limitations, such as limited tolerance to shade, poor performance in poorly drained or cold environments, low persistence under intensive management and in some cases can become invasive species [36]. Also, there is substantial evidence indicating that *Urochloa* can achieve high forage yields under favorable climatic conditions and appropriate management with yields that range from 5 to 36 t DM·ha^{-1}·year^{-1}, depending on soil fertility, moisture availability, and fertilizer application [37]. Within the genus

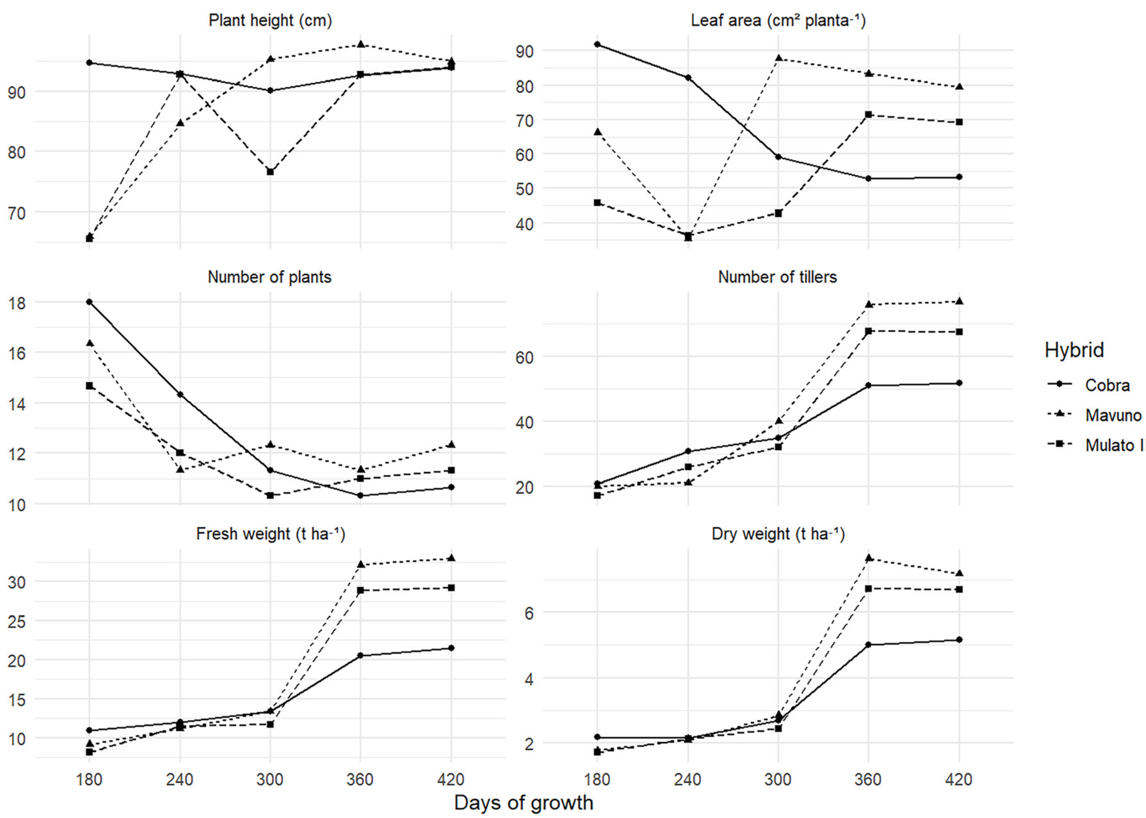

Figure 3: Temporal changes in morpho-agronomic traits of three *Urochloa* hybrids during the growth cycle.

Table 4: Carrying capacity of three *Urochloa* hybrids. Data are expressed as adjusted means. Values followed by different letters within the same column are significantly different according to Tukey's test (p < 0.05).

Hybrid	Carrying capacity ($TLU \cdot ha^{-1} \cdot year^{-1}$)
Cobra	2.97^{b}
Mavuno	3.72^{a}
Mulato II	3.41^{ab}
***P*-value**	
Hybrid	0.0,142
Harvesting stage	<0.0,001
Hybrid: Harvesting stage	<0.0,001

Data are expressed as adjusted means. Values followed by different letters within the same column are significantly different according to Tukey's test (*p* < 0.05).

Urochloa, Mulato II is the most popular cultivar [6] and according to Argel et al. [38], Mulato II has yields between 10 and 27 t $DM \cdot ha^{-1} \cdot year^{-1}$, with crude protein contents from 8 to 6 %, and is characterized by its high productivity, forage quality, drought tolerance, adaptation to acidic soils, and rapid regrowth after grazing, which makes it suitable for intensive rotational systems. Cobra on the other hand, yields on average 10.28 t $DM \cdot ha^{-1}$ during the rainy season and 2.78 t $DM \cdot ha^{-1}$ in the dry season, with crude protein contents from 11 to 13 % at 30 days of regrowth, and it is tolerant to drought and fire [39]. For Mavuno, yields of up to 7.69 t $DM \cdot ha^{-1}$ have been reported at nine weeks of regrowth under warm subhumid environment conditions [40]. Furthermore, annual herbage accumulation of about 11 $t \cdot ha^{-1}$ has also been reported, reinforcing its potential as a promising forage hybrid for subtropical regions [41].

Our findings indicate that, under a 60-day harvest interval, both Mavuno and Mulato II improved progressively in most productive parameters as the number of cuts increased. Moreover, Mulato II and Mavuno achieved higher yields than Cobra, while behaving similarly between them. Comparable patterns have been reported in other studies [41–43], suggesting that repeated defoliation at this interval may enhance plant performance. Mwendia et al. [44], showed that cutting intervals of 4, 6, 8, and 12 weeks increased cumulative dry matter yields; however, the 12-week interval led to a decline in forage quality.

The annual DM yields observed in this study were approximately 20.9 t ha^{-1} for Cobra, 26.2 t $ha^{-1} \cdot year^{-1}$ for Mavuno, and 24.0 t $ha^{-1} \cdot year^{-1}$ for Mulato II. Previous studies conducted under similar environmental conditions have reported yields of up to 36.53 t $ha^{-1} \cdot year^{-1}$ in *U. decumbens*/ILRI-14720 and 19.1 t $ha^{-1} \cdot year^{-1}$ in *U. ruziziensis*/

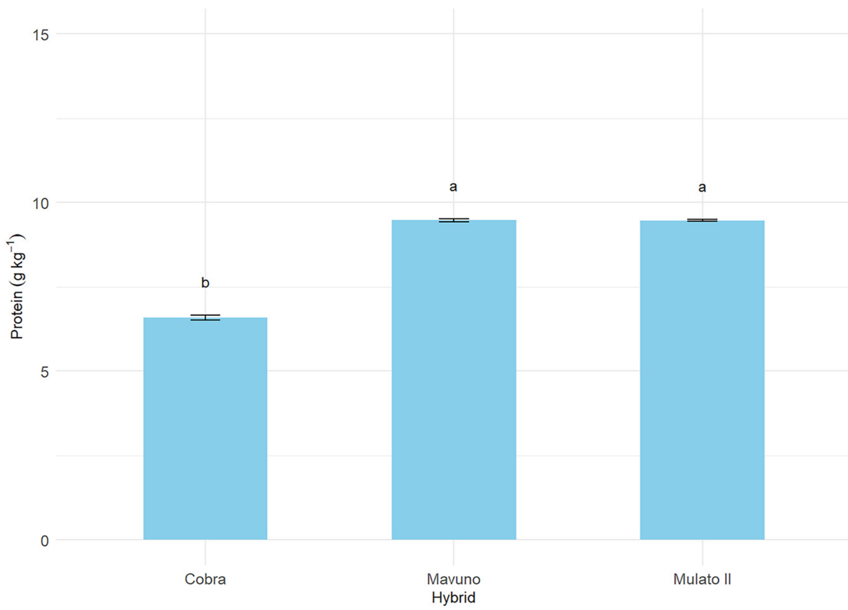

Figure 4: Protein content of three *Urochloa* hybrids. Bars represent the mean value and standard error (μ ± SE). Different letters above the bars indicate statistically significant differences among hybrids according to Tukey's test ($p < 0.05$).

ILRI-14813; however, these higher yields were obtained under fertilized conditions [45], while in crop rotation or intercropping systems, yields of up to 16 t ha^{-1}·$year^{-1}$ have been reported for *Urochloa* cultivars [17]. Moreover, studies conducted on the degradation of pasture productivity and silvopastoral systems in very humid tropical premontane forest areas of livestock farms in the Huánuco region of Peru have reported lower yields than those obtained with the hybrids evaluated in this study [46]. In those systems, annual dry matter production ranged from 4.5 t ha^{-1}·$year^{-1}$ in traditional pastures to 19.5 t ha^{-1}·$year^{-1}$ in intensive silvopastoral systems with tree and shrub components. These results highlight the potential of *Urochloa* hybrids, particularly Mavuno and Mulato II, to enhance forage productivity under humid tropical conditions, contributing to the sustainable intensification of livestock systems in degraded Amazonian pastures.

Our dry matter yields at 60 days of regrowth (approximately 8 weeks) increased over time, with the highest production observed around the fourth and fifth harvests, reaching up to 5.16, 7.65, and 6.73 t ha^{-1} for the hybrids Cobra, Mavuno, and Mulato II, respectively. These values are higher than those reported in Mexico under semiarid conditions after 8 weeks of regrowth [47], where Cobra and Mulato II produced 2.99 and 5.54 t ha^{-1}, respectively. Likewise, our results are consistent with those reported under rainy tropical conditions, where Mavuno reached DM yields of around 5 to 7 t ha^{-1} meanwhile Cobra reached DM yields between 3 and 5 t ha^{-1} during the eighth to tenth week of regrowth [40].

According to Paul et al. [48], improved forages can produce up to 2.65 times more herbage than local controls, especially in grasses. In this study, the performance of the three hybrid cultivars Cobra, Mavuno, and Mulato II under low-fertility tropical soil conditions demonstrates their potential to enhance the feed resource base for livestock with carrying capacities exceeding 2.97 TLU·ha^{-1}·$year^{-1}$, surpassing previous reports for the San Martín region of 1.8 TLU·ha^{-1}·$year^{-1}$ [13].

In our study, crude protein analysis in forage showed a higher protein content in the hybrids Mavuno and Mulato II compared to Cobra. Muñoz et al. [49] reported higher protein levels for the hybrids Cobra and Mulato II; however, those results were obtained from fertilized field trials. Also, Balseca et al. [50], indicated that crude protein content in various species of the genus *Urochloa*, ranges between 7.7 % and 9.1 %. Overall, these findings suggest that, although there are genetic differences among cultivars, protein content is strongly influenced by factors such as soil fertility, and management practices.

Since 2018, the Peruvian Government has promoted low-carbon agricultural technologies through national policies [13]. The findings of this study contribute to these national efforts by providing technical evidence on the performance of *Urochloa* hybrids in the San Martín region, where dry tropical forest conditions and low soil fertility prevail. These results support the potential rehabilitation of approximately 119,000 hectares of degraded pastures through the implementation of silvopastoral systems using selected hybrids in the Peruvian Amazon, thereby promoting sustainable livestock intensification in alignment with the objectives of the Peruvian National Livestock Development Plan. Nevertheless, it is important to emphasize that the productive response of *Urochloa* hybrids may vary significantly depending on local edaphoclimatic conditions; therefore, their evaluation under the specific environmental conditions of each area is recommended before making definitive conclusions about their efficiency under low-input systems.

5 Conclusions

This study demonstrated that, under the conditions where the experiment was conducted, *Urochloa* hybrids exhibited strong adaptability and productive potential in low-fertility soils, making them suitable options for sustainable forage production and pasture rehabilitation in tropical livestock systems. Integrating these hybrids, particularly Mavuno and Mulato II, into silvopastoral or rotational grazing systems can enhance livestock productivity, stabilize forage supply and improve soil fertility, contributing to the sustainable intensification of livestock production in the Peruvian Amazon.

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Conflict of interest: Authors state no conflict of interest

Data availability statements: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request

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