

PROXIMAL AND GROWTH ANALYSIS OF FORAGE SOYBEAN (*Glycine max* (L.) Merr.) VARIETIES

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ABSTRACT

Due to their broad productivity and nutritional value, legumes are used in animal production systems. The aim of this study was to evaluate the productive behavior and the chemical quality of different varieties of forage soybean (*Glycine max* (L.) Merr.) using a growth analysis in the dry tropics of Mexico. The treatments included the following evaluated varieties: Salcer, Ojo de Tigre, Valente, and Albina. The variables determined were total dry matter (TDM), yield by component, plant height, intercepted radiation, plants per square meter, weight per stem, crude protein, acid detergent fiber, and neutral detergent fiber. The variety with the highest TDM yield was Ojo de Tigre, with 5562 kg ha⁻¹, whereas Salcer had the lowest, with 4626 kg ha⁻¹ ($p < 0.05$). The intercepted radiation increased with the age of the plant in all four varieties until day 61 after harvest, reaching an average of 96 %, a value that remained until day 68. The genotype with the best attributes in dry matter yields, structural characteristics, and plant height was Ojo de Tigre. The optimum moment for harvest was established at day 61, when an average of 95 % intercepted radiation and better quality were obtained, which defines the optimum cutting point for the conditions of the dry tropics of Mexico.

Keywords: legumes, yield, intercepted radiation, crude protein.

INTRODUCTION

In tropical regions of Mexico, prairies are mainly composed of forage grasses (Olivares-Pérez *et al.*, 2005) and some perennial legumes, planted in protein banks (Pamo *et al.*, 2007; Rojas-García *et al.*, 2021) or associated with grasses (Jiménez *et al.*, 2002; Benítez-Bahena *et al.*, 2010). However, they face prolonged droughts and management limitations in grazing areas. To mitigate this situation, improved grasses have been

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introduced (Torres-Salado *et al.*, 2020; Ventura-Ríos *et al.*, 2021; Rojas-García *et al.*, 2024). Nevertheless, the need to identify native or introduced forage legumes that provide higher nutritional value and dry matter (DM) yields persists (Maldonado-Peralta *et al.*, 2023). Traditional animal production has negative impacts on natural ecosystems (Benítez-Bahena *et al.*, 2010), and therefore, alternatives such as the use of annual legumes, including forage soybean, are considered (Rojas-García *et al.*, 2025; Maldonado-Peralta *et al.*, 2025).

Soybean is an annual legume that produces high nutritional quality forage (Pagano and Miransari, 2016), with green matter yields between 19 and 30 Mg ha⁻¹ and grain yields of up to 3500 kg ha⁻¹ (Tobía and Villalobos, 2004; Tobía, 2011; Hernández *et al.*, 2013). This forage is appealing to cattle, with a high crude protein content (16.4–17.3 %), total digestible nutrient levels of 58–68 %, and metabolizable energy between 2.2 and 2.5 Mcal kg⁻¹ of DM (Garay-Martínez *et al.*, 2021), which helps reduce the use of concentrates in the diets of the animals and improves profitability (Teixeira *et al.*, 2016). Ríos-Hilario *et al.* (2023), when evaluating the Salcer variety in the dry tropics in Guerrero, Mexico, found yields of 4462 kg ha⁻¹ of DM with high planting densities (250 000 plants ha⁻¹) and 2958 kg ha⁻¹ with lower densities (41 250 plants ha⁻¹).

Most available studies focus on soybean cultivars for the production of grain (Vega and Andrade, 2000; Enciso-Maldonado *et al.*, 2021) planted at different densities and harvest dates, where yield was affected by the planting season and the population density. In other legumes, such as chepil (*Crotalaria longirostrata* Hook. and Arn.), Maldonado-Peralta *et al.* (2023) reported 95 % of intercepted radiation 36 d after cutting, with crude protein, acid detergent fiber, and neutral detergent fiber of 22, 58, and 37 %, respectively; subsequently, the intercepted radiation dropped to 62 % on day 79.

In contrast, studies on forage soybean varieties in tropical regions of Mexico are scarce; therefore, agronomic studies and proximal chemical analyses are needed. In this work, the proposed hypothesis is that, over time, soybean yield increases while its chemical quality decreases, making the optimal cutting time between days 61 and 68, depending on the genotype. Accordingly, the aim of this study was to evaluate total dry matter yield and yield by component, plant height, intercepted radiation, population density, stem weight per stem, crude protein, and acid and neutral detergent fiber of different forage soybean varieties through growth analysis in the dry tropics of Mexico.

MATERIALS AND METHODS

Study area

The evaluation of productive behavior was carried out in the town of El Pitahayo, Cuajinicuilapa, Guerrero, Mexico (16° 32' 5.49" N and 98° 30' 28.87" W), from September 1, 2020, to February 28, 2021, at an altitude of 50 m (INEGI, 2010). Weather data were obtained from the station located in Cuajinicuilapa, Guerrero, 10 km from

the experimental site (CONAGUA, 2022). The area has a warm, subhumid climate, with the highest rainfall during the study period recorded in September, October, November, and December, 2020, accumulating 832 mm, and a mean temperature of 26 °C (Figure 1).

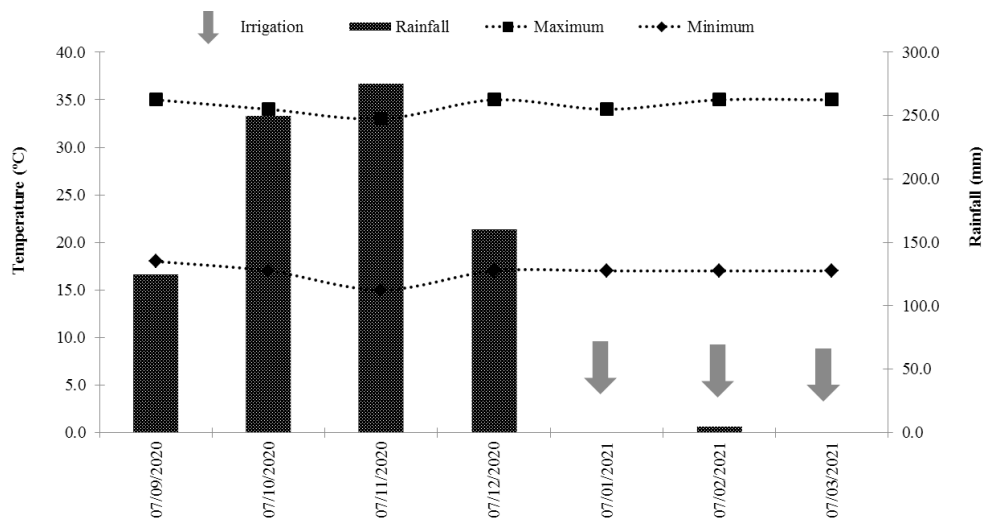


Figure 1. Rainfall (mm) and maximum and minimum temperatures (°C) during the study period in the municipal area of Cuajinicuilapa, Guerrero, Mexico.

Experimental plots

The Salcer variety of forage soybean (*Glycine max* (L.) Merr.) was evaluated, along with three genotypes: Ojo de Tigre, Valente, and Albina, developed by the Center for Professional Studies of the Higher Agricultural College of the State of Guerrero (CEP-CSAEGro) through different selection processes. Salcer is the only variety registered within the National Seed Inspection and Certification Service (SNICS); the remaining genotypes are in the evaluation process.

The experiment was established under a completely randomized block design with three repetitions. Every genotype was planted in a 10 × 10 m plot, corresponding to each treatment. The soil had a silty-sandy texture, a 15 % slope, a slightly alkaline pH (7–8), and low organic matter content (0.2 %). The land was prepared using conventional tillage: plowing once, harrowing twice, furrowing, and layout marking. Planting was carried out on September 7, 2020, during the rainy season, with a density of 230 000 seeds ha⁻¹. Each seed was placed at the top of the furrow, in a double row, with a topological arrangement of 80 cm between furrows, 10 cm between rows, and 12 cm between seeds.

Chemical fertilization was carried out on days 20 and 30 after planting (DAP), using the formula 60-40-00 (N-P-K). Ammonium sulfate served as the nitrogen source (FertiQuim, Mexico). For phosphorus, diammonium phosphate (18-46; FertiQuim, Mexico) was applied by squirting it 5 cm from the stem. For foliar fertilization, Gro Green Campbell 20-30-10 (Gor Green, Mexico) and Supra Fe (Arvensis, Mexico, as a source of iron) were sprayed using a motorized backpack sprayer (Honda, Japan) at 20, 30, and 40 DAP.

For pest control, cypermethrin was applied three times (CIMA, Química Sagal S.A., Mexico) at a dose of 1 mL L⁻¹ of water, aimed at the black cutworm (*Agrotis ipsilon* Hufnagel, 1766), using a motorized backpack sprayer (Honda, Japan). Weed control was carried out twice, chemically and manually. The chemical control consisted of the targeted application of a non-selective contact herbicide (paraquat) at a dose of 1 mL L⁻¹ of water, using a manual spray with a hooded nozzle. Manual control was carried out using a hoe.

Agronomic samplings were carried out at 26, 33, 40, 47, 54, 61, 68, 75, 82, and 89 DAP. The proximal chemical analyses were performed at 26, 40, 54, 68, and 82 DAP. In the months of minimum rainfall (January, February, and March 2021), underground water was used to irrigate every 8 d, with a sheet of approximately 32 mm per irrigation.

Variables evaluated

Total yield and yield by component

One day before each cut, two samples were taken from each plot, considering 1 m per furrow. The plants were separated by components (leaf, stem, and pod) and weighed on a digital precision scale (METALTEX, VE-200RT, Switzerland). Subsequently, they were dried at 55 °C until they reached a constant weight in a forced-air oven (Faithful, WGLL-230BE, China). Later, they were weighed once again to determine the content of dry matter and to estimate the yield of dry matter per hectare.

Plant height

The readings of 20 plants were taken at random in each experimental plot one day before every cut, using a measuring tape (Truper, Mexico) 3 m in length. The measurement was carried out at ground level until the last morphological component.

Intercepted radiation

Five readings were taken for every experiment. A 100-cm wooden ruler was placed under the canopy, pointing south-north, and the centimeters with shade were counted, which represented the percentage of radiation intercepted by the plant's canopy.

Population density (plants per m²)

At the beginning of the experiment, 1 m² areas were traced at random in each plot using wooden stakes. In each sampling, the number of plants in the area was counted to determine the population density and evaluate the persistence of each genotype.

Weight by stem

Five stems were cut at random from each plot, at ground level and with leaves, which were dried in a forced-air oven until their weight was constant. Subsequently, the dry weight of every stem was registered.

Proximal chemical analysis

The proximal chemical analysis was carried out in the animal nutrition laboratory of the School of Veterinary Medicine and Animal Husbandry No. 2 of the Autonomous University of Guerrero, located in the municipal seat of Cuajinicuilapa. The determinations were carried out on days 26, 40, 54, 68, and 82. The samples used to estimate the dry matter yield were used to determine the crude protein (CP) content using the method described by the AOAC (2005). All analyses were carried out in triplicate. The neutral detergent fiber (NDF) and the acid detergent fiber were determined following the method proposed by van Soest *et al.* (1991).

Statistical analysis

The data gathered was analyzed under a completely randomized block design with three repetitions and a divided plot arrangement, in which the large plot corresponded to the cuts (days after planting) and the small plot, to the soybean genotype evaluation. The analysis was carried out with the PROC GLM procedure by SAS (SAS Institute, 2011), where the effects of harvest time were considered fixed. The multiple comparison of means was carried out with Tukey's test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

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total yield and yield by component

The total dry matter yield of the four soybean varieties at different cutting ages during the rainy season (Figure 2) increased with plant age until day 75 after planting, reaching an average of 9422 kg ha⁻¹. Subsequently, it decreased until day 89, with 7033 kg ha⁻¹ ($p < 0.05$). The variety with the highest yield was Ojo de Tigre, with 5562 kg ha⁻¹, whereas the one with the lowest yield was Salcer, with 4626 kg ha⁻¹ ($p < 0.05$). However, Albina displayed the highest yield on day 75, with 12 542 kg ha⁻¹ ($p < 0.05$). The four varieties displayed a similar component pattern. The leaf component predominated with more than 60 % of the yield until day 40 after planting; thereafter, the stem became dominant until day 89. The pod component appeared on day 61, with a greater proportion in the Albina variety and a lower one in Salcer ($p < 0.05$) (Figure 2). Aponte *et al.* (2015) reported similar values in 10 forage lines in Puerto Rico, with DM yields of 5300 and 6573 kg ha⁻¹ on days 54 and 68, respectively. Tobía *et al.* (2006), in evaluations performed in Venezuela and Costa Rica, recorded yields between 5000 and 13 000 kg ha⁻¹ on day 75, comparable to those obtained in this study. In turn, Ríos-Hilario *et al.* (2023) reported values similar to those found in this study on day 60 of

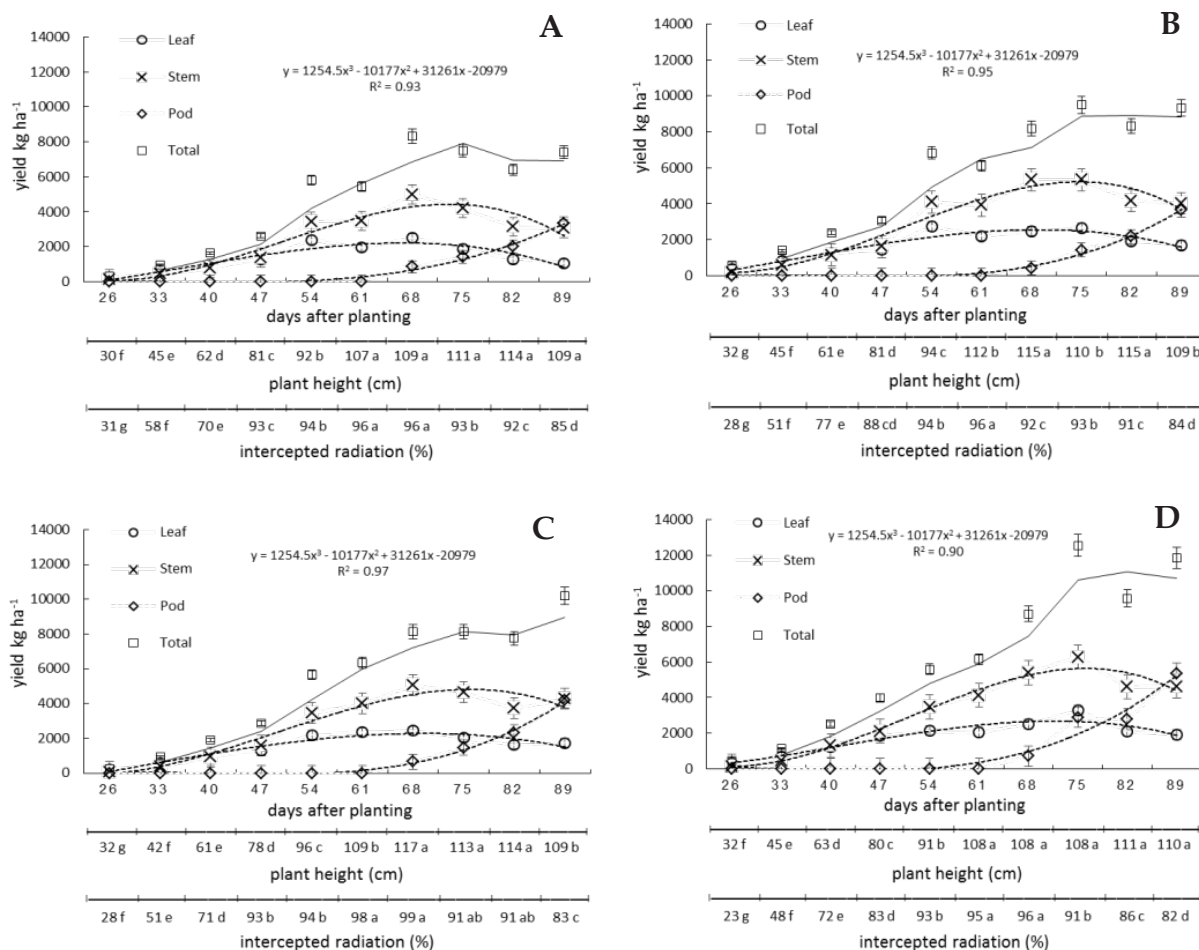


Figure 2. Total dry matter (DM) and yield by component (kg ha⁻¹ of DM), plant height (cm), and intercepted radiation (%) of different forage soybean (*Glycine max* (L.) Merr.) genotypes in the dry tropics of Mexico. A: Salcer; B: Ojo de tigre; C: Valente; D: Albina.

plant growth, with 5500 kg ha⁻¹ at a population density of 250 000 plants ha⁻¹ in the Salcer variety.

In Brazil, Wilson-Cortez *et al.* (2011) evaluated the Monsoy 5942 variety at different population densities and fertilization depths and reported an average DM yield of 5634 kg ha⁻¹ on day 68, lower than that obtained in this study on the same day after planting. In Turkey, Acikgoz *et al.* (2007) evaluated three forage soybean varieties on days 54, 68, and 82, with yields of 8467, 11 356, and 14 225 kg ha⁻¹, respectively, which were higher than those recorded in this study, possibly due to more favorable weather conditions, since plant growth varies depending on temperature and nutrient availability in the soil. Altogether, these results show that yield in forage soybean varies depending on the genotype, cutting date, geographic location, and soil fertility.

Plant height

The plant height of the four forage soybean varieties at different cutting ages during the rainy season (Figure 2) increased as plant age advanced, regardless of the genotype. The maximum height was recorded on day 82, with 114 cm, and later decreased to 109 cm on day 89. The lowest values were observed between days 26 and 54 ($p < 0.05$). On average, the tallest genotypes were Valente and Ojo de Tigre (87 cm), whereas Salcer and Albina presented the lowest values (86 cm).

Tosquy-Valle *et al.* (2009) reported lower heights in two soybean varieties evaluated in the Mexican tropics at different planting densities, which depend on the variety and regional temperature. After day 61, they recorded heights ranging from 44 to 54 cm. In Cuba, Romero-Arias *et al.* (2013) evaluated seven varieties and reported 49 cm on day 60 after planting. In Venezuela, Hernández *et al.* (2013) found average heights of 67 cm on day 75 in nine forage soybean varieties, which were also lower than those found in this study. Ríos-Hilario *et al.* (2023) reported an average height of 58 cm for the Salcer variety when evaluating different population densities and cutting ages. In this study, Valente and Ojo de Tigre displayed the greatest average height (87 cm), surpassing Salcer and Albina, which showed lower growth.

Intercepted radiation

The intercepted radiation of the four forage soybean varieties at different cutting ages during the rainy season (Figure 2) increased as phenological development progressed, reaching an average of 96 % on day 61 in the four genotypes, which remained until day 68. Subsequently, it decreased until day 89, with an average of 84 %, regardless of the variety. Albina reached 99 % on day 68 ($p < 0.05$), although, on average, it presented the lowest intercepted radiation (77 %). The recommended intercepted radiation is 95 % (Rojas-García *et al.*, 2018), as it represents the best ratio between dry matter yield and chemical quality at that point. In this study, that average was reached on day 54. Giayetto *et al.* (2011) pointed out that intercepted radiation in maize and soybean has a direct influence on plant components and yield. Leguizamón and Verdelli (2011) evaluated intercepted radiation in soybean-maize under intercropping and monoculture systems and obtained a maximum average of 45 %, different from the averages reported in this study, possibly due to differences in plant density and weather conditions. Díaz *et al.* (2003), in a maize-soybean intercrop in Argentina, reported 95 % intercepted radiation on day 54, which coincides with the 94 % registered in this study at the same age. In turn, Ríos-Hilario *et al.* (2023) reported the highest intercepted radiation, 86 %, at a population density of 250 000 plants ha⁻¹ in the Salcer variety on day 60 after planting.

Population density

The population density of the four forage soybean genotypes at different physiological ages during the rainy season (Figure 3) showed, on average, a decrease as phenological growth advanced, with similar behavior among the four genotypes, declining from 24

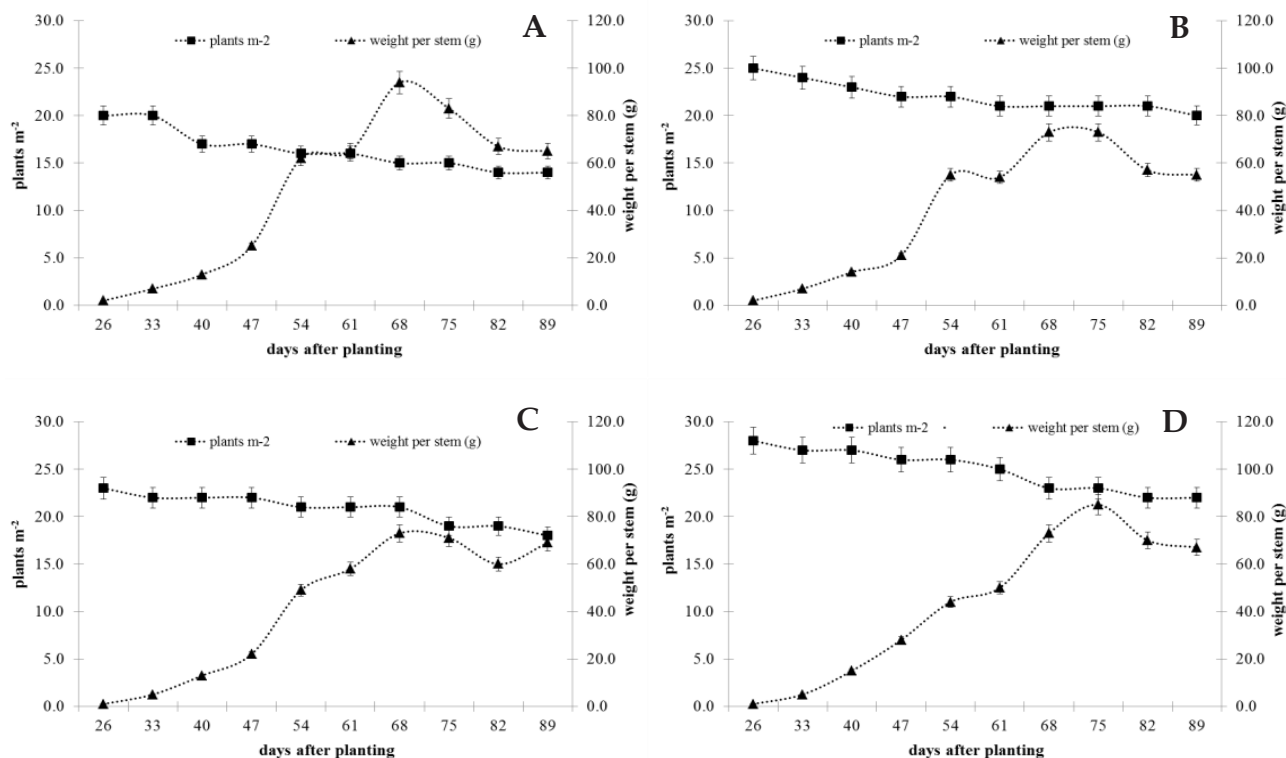


Figure 3. Population density (plants m⁻²) and weight per stem (g) of different forage soybean (*Glycine max* (L.) Merr.) genotypes in the dry tropics of Mexico. A: Salcer; B: Ojo de tigre; C: Valente; D: Albina.

plants m⁻² on day 26 to 19 plants m⁻² on day 89. Albina displayed the highest average density during the cycle (25 plants m⁻²; $p < 0.05$), whereas Salcer presented the lowest value (16 plants m⁻²). Ojo de Tigre and Valente registered intermediate and similar values, with 22 and 21 plants m⁻², respectively. These differences depend on the adaptive capacity of each genotype to produce under the site's weather conditions, which influence forage yield.

Roche *et al.* (1990) evaluated 74 varieties with 20 plants m⁻² and reported DM yields of 4360 kg ha⁻¹ on day 65 and 7880 kg ha⁻¹ on day 78. These values are lower than those obtained in this study, in which 9422 and 8006 kg ha⁻¹ of DM were reached with similar densities on days 68 and 75, respectively. Hintz *et al.* (1992) evaluated three varieties with 28 and 89 plants m⁻² in the United States and obtained similar yields on day 75, with 7500 and 7300 kg ha⁻¹ of DM. Tobía and Villalobos (2004) used 19 plants m⁻² in Costa Rica and reported 4800 kg ha⁻¹ of DM on day 61, lower than the values recorded in this study at the same age. Tosquy-Valle *et al.* (2009) evaluated densities of 20, 30, and 40 plants m⁻² and found better agronomic characteristics with 20 plants m⁻². Gaso (2018) evaluated densities from 10 to 60 plants m⁻² and found a higher final

yield with 30 plants m^{-2} , whereas the highest yield in this study was obtained with 20 plants m^{-2} on day 75.

Stem weight

The stem weight of the four forage soybean genotypes at different cutting ages (Figure 3) increased as plant age advanced, reaching an average of 78 g across the four varieties on days 68 and 75 after planting ($p < 0.05$). Subsequently, it decreased on days 82 and 89, regardless of the genotype, with an average of 64 g. The genotype with the highest average stem weight was Salcer, with 48 g, whereas the lowest was found in Ojo de Tigre, with 41 g. Likewise, Salcer recorded the highest weight on day 68, with 94 g ($p < 0.05$).

Maqueira *et al.* (2016) studied the growth and yield of four soybean varieties and reported stem weights of 9 g on day 89, lower than the values observed in this study. Díaz *et al.* (2003) recorded average weights of up to 77 g on day 90 in Cuba, similar to the 64 g obtained on day 89 in this study. Tobía and Villalobos (2004), under adverse tropical conditions, reported weights of up to 100 g on day 89, which are higher than the values found in this study. Hernández *et al.* (2013) recorded average weights of 82 g on day 89 and pointed out that stem weight later decreases due to the translocation of nutrients to the production of senescent pods and leaves, a behavior that coincides with the results obtained in this study.

Proximal chemical analysis

The crude protein (CP) content of the four forage soybean genotypes in the growth analysis during the rainy season (Table 1) showed that, regardless of the variety, the highest value was recorded on day 26, with 20 %, and the lowest on day 82, with 13 %. On average, Salcer presented the highest content (18 %), whereas Albina had the lowest (16 %) ($p < 0.05$). Hernández *et al.* (2013) reported an average CP content of 15.7 % for leaf, stem, and pod on day 75, similar to the values obtained in this study. Díaz *et al.* (2003) reported 21.7 % CP on day 54 in the whole plant, comparable to the value observed on day 26 in this study. Tobía and Villalobos (2004) reported 20 % CP on day 68. Maldonado-Peralta *et al.* (2023), when evaluating *Crotalaria longirostrata* Hook. and Arn. at different planting densities, found that CP content decreased as the physiological stage advanced ($p < 0.05$).

On average, the highest neutral detergent fiber (NDF) content was recorded on day 82, with 60 %, and the lowest on day 26, with 52 % ($p < 0.05$) (Table 1). The Valente genotype presented the lowest average NDF content (55 %), whereas Albina and Ojo de Tigre presented the highest values (57 %). Acid detergent fiber (ADF) was 31 % on day 26 and reached its peak on day 54, with 39 %; Albina presented the highest value on day 54 (40 %) ($p < 0.05$).

Tobía and Villalobos (2004) reported an average NDF content of 40 % when evaluating a soybean variety under adverse conditions. Aponte *et al.* (2015) reported 42.6 % NDF on day 82 in 10 forage soybean lines in Puerto Rico, with values lower than those

Table 1. Crude protein and neutral and acid detergent fiber (%) of four forage soybean (*Glycine max* (L.) Merr.) varieties in a growth analysis in the dry tropics of Mexico.

Plant age (days)	Varieties Crude protein (%)				
	Salcer	Ojo de tigre	Valente	Albina	Promedio
26	21 Aa	20 Aa	19 Aa	20 Aa	20 A
40	20 Aa	17 ABa	17 Aa	16 Aa	18 B
54	15 B Cab	16 Ba	15 ABab	11 Bb	14 C
68	16 Ba	15 BCa	18 Aa	18 Aa	17 B
82	13 Ca	11 Ca	12 Ba	11 Ba	13 C
Average	18 a	16 b	16 b	16 b	
	Neutral detergent fiber (%)				
26	55 Ba	53 Ba	53 Ca	56 Ba	55 B
40	53 Ba	55 ABa	54 BCa	54 Ba	54 B
54	60 Aa	60 ABa	59 ABa	61 Aa	60 AB
68	58 ABa	63Aa	57 ABCa	63 ABa	60 AB
82	65 Aa	63 Aa	61 Aa	61 ABa	63 A
Average	58 b	59 a	57 c	59 a	
	Acid detergent fiber (%)				
26	35 Ba	30 Cc	30 Cbc	34 Bab	33 D
40	35 Ba	36 Ba	37 ABa	36 Ba	36 B
54	38 Aa	39 Aa	38 Aa	40 Aa	39 A
68	33 Bb	38 ABa	35 ABab	37 Bab	36 B
82	36 Ba	34 Ba	34 BCa	35 Ba	35 C
Average	35 b	35 b	35 b	36 a	

Means with the same lowercase letter in the same row (a, b, c) and column (A, B, C) are not statistically different (Tukey; $\alpha = 0.05$).

found in this study. Díaz *et al.* (2003) reported 58.3 % NDF in four varieties evaluated in Cuba, similar to the results obtained in this study. Hernández *et al.* (2013) found average NDF contents of 47 % in pods, 38.5 % in leaves, and 66.4 % in stems in 10 forage soybean varieties. In the Comarca Lagunera region of Mexico, average ADF values of up to 38 % have been reported on day 82 (Reta-Sánchez *et al.*, 2013), which coincides with the observations made in this study.

CONCLUSIONS

The forage soybean genotype with the best attributes in dry matter yield, structural characteristics, and plant height was Ojo de Tigre. The optimum harvesting time was established on day 61, when an average intercepted radiation of 95 % was obtained and before pod production began in the four genotypes, while maintaining acceptable quality levels. The proximal chemical analysis showed variation depending on the genotype; therefore, further research on forage soybean is necessary.

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