Foxtail Millet (*Setaria italica* L.) Performance under Irrigation. Sowing Dates and Cultivars in the Northern Oasis of Mendoza

Producción de moha (*Setaria italica* L.) bajo riego: evaluación de fechas de siembra y cultivares en el oasis norte de Mendoza

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Abstract

Foxtail millet is a short-season, summer annual forage crop primarily used for haymaking in Argentina. Valued for its efficient water use, it provides effective fiber for various milk and meat production systems. This trial evaluated two sowing dates (mid-November and mid-December) for the three commercially available foxtail millet cultivars in Argentina (Yaguané Plus INTA, Carapé Plus INTA, and Nará INTA) across two production cycles (2022/2023 and 2023/2024). The experiment was conducted at the Facultad de Ciencias Agrarias, Universidad Nacional de Cuyo, in Mendoza (33°00'38" S and 68°52'28" W). Yields of up to 14,000 kg DM/ha were obtained in the northern oasis of Mendoza. Significant differences in yield were observed between sowing dates, with December sowing yielding more than November. Additionally, Nará INTA was the highest-yielding cultivar.

Keywords
Setaria italica • forage • yield • arid zone

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Resumen

La moha es un forraje estival anual, cuyo principal destino en Argentina es la henificación. Este cultivo es valorado por su eficiente uso del recurso hídrico; es muy utilizado como heno en todos los sistemas productivos de leche y carne. En este ensayo se contrastan dos fechas de siembra (mediados de noviembre y mediados de diciembre) de los tres cultivares de moha disponibles en Argentina (Yaguané Plus INTA, Carapé Plus INTA y Nará INTA), en dos ciclos (2022/2023 y 2023/2024). El ensayo se realizó en la Facultad de Ciencias Agrarias de la Universidad Nacional de Cuyo, Mendoza (33°00'38" S y 68°52'28" O). Se obtuvieron rendimientos superiores a los 14.000 kg MS/ha de moha en el oasis norte de Mendoza, observándose diferencias significativas de rendimiento entre fechas de siembra (la siembra de diciembre rindió más que la de noviembre) y entre cultivares (Nará INTA rindió más que los otros cultivares).

Palabras clave
Setaria italica • forraje • rendimiento • zona árida

Introduction

Foxtail millet *Setaria italica* (L.) *P. Beauvois* is an annual summer forage crop primarily grown for haymaking in Argentina. Renewed interest in this crop is linked to climate change and the need for drought-tolerant varieties. Foxtail millet is known for its efficient use of resources, particularly water (Srikanya *et al.*, 2020). It also helps suppress weeds within agroecosystems. Furthermore, its short growing season (2-3 months), high photosynthetic efficiency as a C4 plant, and resistance to pests and diseases make it a suitable forage crop (Shanthi *et al.*, 2017; Yang *et al.*, 2016).

According to the Censo Nacional Agropecuario 2018 (INDEC, 2021), Argentina cultivates approximately 1.6 million hectares of annual summer forage grasses. Of this total, 60,000 hectares are dedicated to foxtail millet, primarily in the provinces of Córdoba, Buenos Aires, and Santa Fe, mostly under rainfed conditions. It ranks third among cultivated summer green crops after corn and sorghum. Previous trials in the northern Mendoza oasis have shown high yields of corn and sorghum silage. However, both species require over three months from sowing to harvest, while consuming over 550 mm of water per cycle (Ibarguren *et al.*, 2020; Rebora *et al.*, 2018). In contrast, foxtail millet requires less water and has a shorter cycle, making it potentially suitable as a preceding crop for alfalfa and winter greens (Sardiña and Diez, 2016). Additionally, foxtail millet is an energy-rich forage mainly providing effective fiber in milk and meat production systems. Additionally, given its short growing cycle and the consequent flexible sowing period, this crop also fits rotation plans. As a megathermic grass, soil temperatures should be approximately 18-20°C for rapid emergence, subjecting sowing times to regional climatic conditions (Curia, 2018). In Bordenave, southern Buenos Aires, the recommended sowing period is November to December (Bolletta *et al.*, 2009). INTA Pergamino suggest the second half of November as optimal, while Rafaela, in Santa Fe, might benefit from sowing in the first half of November (Mattera *et al.*, 2016). Therefore, thermal requirements dictate an environment-dependent sowing period to ensure optimal forage quality for haymaking.

INTA has developed three improved foxtail millet cultivars of national origin: a) Yaguané Plus INTA, well-suited for haymaking with high dry matter production and a plant structure with few tillers and wide blades. It performs best in high-productivity environments. b) Carapé Plus INTA offers greater potential and performance stability in less productive environments while maintaining high forage quality. Its good regrowth capacity makes it ideal for direct grazing. It is also well-suited for hay production due to its rapid dry matter accumulation, fine stems, and high leaf proportion. C) Nará INTA yields 20-30% more than the other Argentine cultivars, primarily due to its slightly longer growing cycle (10-15 days). This cultivar is tolerant to lodging and disease. Visually, Nará INTA is distinguished by reddish color in various plant parts and orange seeds (Carta *et al.*, 2017; Mich, 2020).

Considering absent scientific references regarding foxtail millet cultivation in irrigated oases in Mendoza, this study aims to generate information on suitable sowing dates for the northern oasis, performance of available cultivars, water requirements, and potential yields.

We hypothesized that yield and cycle duration would vary depending on cultivar and sowing dates under irrigated conditions. Our objectives were to evaluate dry matter (DM) yield per hectare for three foxtail millet cultivars across different sowing dates and under irrigated conditions, determine cycle duration for each cultivar and sowing date combination, quantify water needs, and determine forage quality during the cycle 2022/2023.

Materials and Methods

The experiment was conducted at the Facultad de Ciencias Agrarias, Universidad Nacional de Cuyo, in Luján de Cuyo, Mendoza, Argentina (33°00'38" S and 68°52'28" W). The site has alluvial soil with a silty loam texture and limited vertical development. Average annual temperature is 16.5°C, relative humidity is 50%, and precipitation averages 225 mm per year.

During the spring seasons of 2022 and 2023, three foxtail millet cultivars (Yaguané Plus INTA, Carapé Plus INTA, and Nará INTA) were sown on two dates: mid-November and mid-December. Each experimental plot was 5 m^2 and consisted of five 5-meter rows spaced 0.20 m. Sowing density was 700 viable seeds per m^2 (equivalent to 20 kg/ha). Urea was applied at a rate of 150 kg/ha at sowing time. The experiment used a completely randomized design (CRD), resulting in 18 experimental plots (3 cultivars x 2 sowing dates x 3 replicates).

The trial was irrigated using a center pivot sprinkler system, with an average daily sheet of approximately 5 mm.

Weeds were controlled manually. Harvest occurred at panicle stage, with a cutting height of 10 cm above the ground. The three central rows of each experimental plot were harvested, discarding 0.5 m from each end. Fresh weight of the harvested material was measured. Then, 200 g samples from each plot were oven-dried at 65°C until constant weight. Forage quality was evaluated in the first year of sowing (2022) for each treatment combination (cultivar * sowing date) by spectrophotometry at the FEEDLAB laboratory of Biofarma S.A. Total digestible nutrients, metabolizable energy, dry matter, crude protein, neutral detergent fiber, acid detergent fiber, and DM digestibility were determined. The analysis was performed on combined samples from the three replicates of each cultivar-sowing date combination in the 2022/2023 cycle.

Forage yield and kgDM/mm (rain + irrigation) data were subjected to ANOVA using Infostat software. The model included cultivars, sowing date, and crop cycle as fixed effects. Tukey's test was used for means comparison.

Results

An initial General Linear Model (GLM) was fitted, including second and third-order interactions. In this full model, only the cultivar × crop cycle interaction was significant ($p < 0.05$). A second model adjustment was performed, iteratively removing non-significant interactions. The cultivar × crop cycle interaction remained in the simplified model, showing a marginal significance level ($p=0.05$). Although this borderline value suggests a possible genotype × environment interaction over the cycles, its effect was weaker than the main effects. Significant differences ($p=0.0001$) were found among cultivars, with Nará INTA yielding more than Carapé Plus INTA and Yagané Plus INTA (figure 1, page 30). Likewise, significant differences ($p=0.0112$) were observed between sowing dates, with

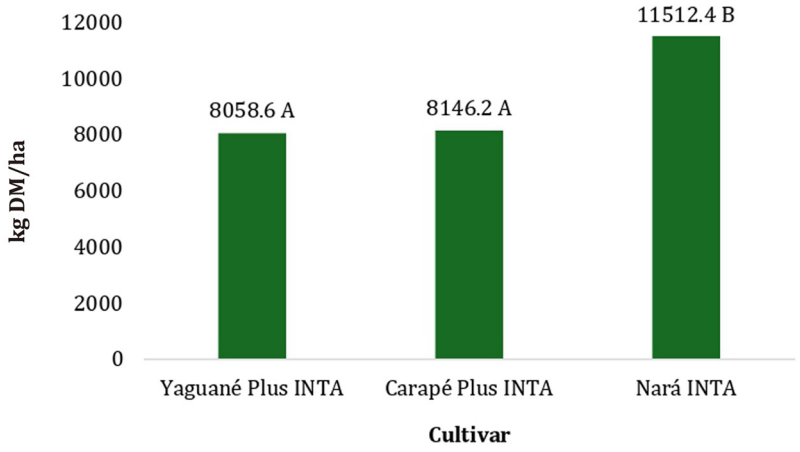

Figure 1. Average dry matter of foxtail millet cultivars across two growing cycles and two sowing dates.

Figura 1. Rendimiento de materia seca de cultivares de moha, promedio de dos ciclos de cultivo y dos fechas de siembra.

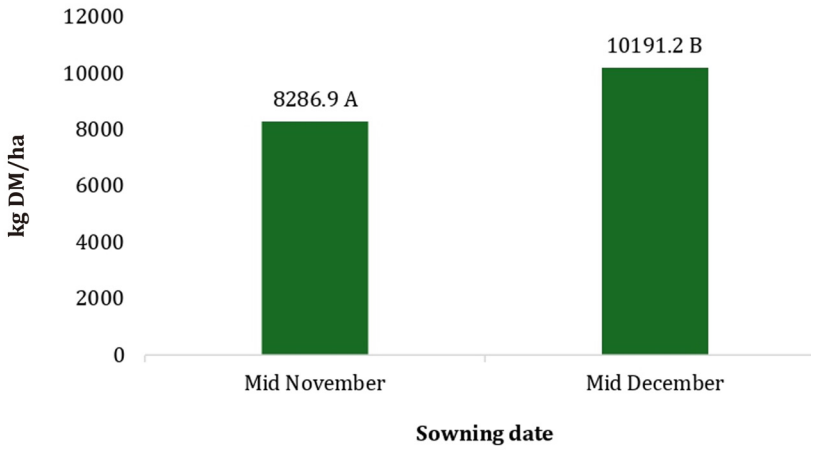

Figure 2. Average dry matter of foxtail millet considering two productive cycles and three cultivars at different sowing dates.

Figura 2. Rendimiento de materia seca de moha, en distintas fechas de siembra, promedio de dos ciclos productivos y tres cultivares.

mid-December showing a higher yield than mid-November (figure 2, page 30).

Tables 1 and 2 (page 31), show yield information for the two crop cycles (2022/2023 and 2023/2024).

Yields in our oasis exceeded those obtained in some dryland environments in Argentina. Narà standed as the most productive cultivar across these contrasting environments. Trials in various sites of the Argentine Pampas region (Bolivar, Pergamino, Concepción del Uruguay, Rafaela, Manfredi) indicated Narà INTA yields the highest values, from 7.92 to 10.97 T DM/ha. Yaguané Plus INTA yielded between 6.05 and 8.25 T DM/ha, ranking second in Bolivar, Pergamino, and Rafaela. Carapé Plus INTA yielded between 6.38 and 8.10 T DM/ha in the mentioned places, but exceeded Yaguané Plus INTA in Concepción del Uruguay and Manfredi

Table 1. Sowing date, harvest date, days from sowing to harvest, forage production (kg DM/ha), rainwater and irrigation during the cycle, DM production per mm of water (rain plus irrigation) for each cultivar and sowing date combination in the 2022/2023 crop cycle, Luján de Cuyo, Mendoza, Argentina.

Tabla 1. Fecha de siembra, fecha de cosecha, días desde siembra hasta cosecha, producción de forraje (kg MS/ha), mm de agua de lluvia y mm de agua aplicada por riego durante el ciclo, producción de MS por mm de agua (lluvia más riego), para cada combinación de cultivar de moha y fecha de siembra, ciclo productivo 2022/2023, Luján de Cuyo, Mendoza, Argentina.

Cultivar	Sowing date	Harvest date	Days from sowing to harvest	kg DM/ha	Rain (mm)	Irrigation (mm)	*Kg DM/ mm
Yaguané Plus INTA	15/11/22	26/01/23	72	7983	30	398.2	18.64
Carapé Plus INTA	15/11/22	26/01/23	72	7605	30	398.2	17.76
Nará INTA	15/11/22	13/02/23	90	12123	40.75	451.8	24.61
Yaguané Plus INTA	15/12/22	22/02/23	69	9297	38.5	334.2	24.94
Carapé Plus INTA	15/12/22	22/02/23	69	8991	38.5	334.2	24.12
Nará INTA	15/12/22	09/03/23	84	14098	40.5	385.2	33.11

* kg DM/mm (rain + irrigation).
* kg MS/mm (lluvia + riego).

Table 2. Sowing date, harvest date, days from sowing to harvest, forage production (kg DM/ha), rainwater and irrigation during the cycle, DM production per mm of water (rain plus irrigation) for each cultivar and sowing date combination in 2023/2024, Luján de Cuyo, Mendoza, Argentina.

Tabla 2. Fecha de siembra, fecha de cosecha, días desde siembra hasta cosecha, producción de forraje (kg MS/ha), mm de agua de lluvia y mm de agua aplicada por riego durante el ciclo, producción de MS por mm de agua (lluvia más riego) para cada combinación de cultivar de moha y fecha de siembra, ciclo productivo 2023/2024, Luján de Cuyo, Mendoza, Argentina.

Cultivar	Sowing date	Harvest date	Days from sowing to harvest	kg DM/ha	Rain (mm)	Irrigation (mm)	*Kg DM/ mm
Yaguané Plus INTA	16/11/23	29/01/24	74	6631	39.25	369	16.24
Carapé Plus INTA	16/11/23	29/01/24	74	7173	39.25	369	17.57
Nará INTA	16/11/23	08/02/24	84	8256	51	396	18.47
Yaguané Plus INTA	13/12/23	20/02/24	69	8305	31.5	356	21.43
Carapé Plus INTA	13/12/23	20/02/24	69	8815	31.5	356	22.75
Nará INTA	13/12/23	04/03/24	82	11608	35.5	388	27.44

* kg DM/mm (rain + irrigation).
* kg MS/mm (lluvia + riego).

(Velazco, 2020).

Table 3 (page 32), shows quality data for each cultivar by sowing date combination, during the 2022-2023 cycle.

Foxtail millet is a highly palatable crop with good nutritional value. The literature reports crude protein (CP) values of 10-12% and digestibility exceeding 60% for cuts made

Table 3. Forage quality variables for each cultivar combination by sowing date (1=mid-November and 2=mid-December) in the 2022/2023 cycle.

Tabla 3. Variables de calidad de forraje para cada combinación de cultivar y fecha de siembra (1=mediados de noviembre y 2=mediados de diciembre) en el ciclo 2022/2023.

Cultivar / Sowing date	TDN (%)	Energy (Mcal/kg)	DM (%)	Crude protein (%)	NDF (%)	ADF (%)	Dig. (%)
Yaguané Plus INTA 1	50.4	1.82	22.4	8.24	62.7	45.94	53.11
Carapé Plus INTA 1	42.89	1.54	20.93	7.16	73.17	53.18	47.47
Nará INTA 1	56.17	2.02	22	6.21	S/D	40.28	57.52
Yaguané Plus INTA 2	57.17	2.06	25.51	8.95	66.3	39.56	58.08
Carapé Plus INTA 2	56.22	2.03	23.76	10.03	69.59	40.46	57.38
Nará INTA 2	53.66	1.93	25.7	5.15	68.33	42.91	55.47

Total digestible nutrients (TDN), metabolizable energy (Energy), dry matter (DM), crude protein, neutral detergent fiber (NDF), acid detergent fiber (ADF), and DM digestibility (%)= 88.9 - (%FDA * 0.779).

Nutrientes digestibles totales (NDT), energía metabolizable (Energía), materia seca (MS), proteína cruda, fibra detergente neutro (FDN), fibra detergente ácido (FDA) y digestibilidad de MS (digestibilidad (%) = 88,9 - (%FDA * 0,779).

between flowering and milky/pasty grain stages (Fernández Mayer *et al.,* 2009).

Field trials across several locations and cycles found average digestibility of 65.2% for Carapé Plus INTA, 64.8% for Nará INTA, and 63.5% for Yaguané Plus INTA (Velazco, 2020). In our study, however, CP values ranged from 5.15 to 10.03% and digestibility fell between 47% and 58%. These lower values could be explained by the phenological state at the time of cutting, which in our case occurred at panicle stage. Anticipating harvest could improve forage quality.

Conclusions

High yields of foxtail millet were obtained in the northern oasis of Mendoza. Sowing in December produced more forage than in November for three cultivars tested. Nará INTA was the most productive cultivar on both sowing dates. Additionally, December sowing resulted in the highest water use efficiency (yield *vs.* water). Therefore, sowing foxtail millet in mid-December is recommended for the study area.

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