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Effects of different irrigation volumes on the quantity and quality of forage harvested from Maralfalfa (Pennisetum sp.) at the experimental Station of IRED in N'Djamena (Chad)

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Abstract

This study, conducted at the experimental station of IRED in Farcha, N'Djamena/Chad, evaluated the effect of five irrigation water volumes (50%, 75%, 100%, 125%, and 150% of estimated requirements) on the quantity and quality of Maralfalfa forage (Pennisetum sp.) between November 2021 and May 2022. Water requirements were calculated by combining evapotranspiration (ETP), crop coefficient (Kc), and irrigation system efficiency. The results show that biomass production increases with the applied water volumes, but the growth rate diminishes beyond the plant's water needs. The water requirements of Maralfalfa (Pennisetum sp.) are lower than those of similar crops (alfalfa, maize). Furthermore, nutritional qualities (analyzed using near-infrared spectrometry, NIRS) varied slightly with water volumes. Lower water inputs produced forage with better nutritional quality but lower biomass yields. In conclusion, Maralfalfa (Pennisetum sp.) is a highly productive forage crop requiring moderate water volumes. Meeting the water requirements improves yields without significantly affecting forage quality.

Keywords: *Pennisetum sp., Maralfalfa, irrigation, nutritional quality, Chad.*

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Introduction

The Sahel, a transitional zone in Africa between the Sahara Desert and the southern savannahs, is characterized by predominantly pastoral, often nomadic, populations. In this region, livestock contributes 40% of the agricultural GDP and 15% of the total GDP of Sahelian countries (FAO, 2017). Pastoral systems provide 50% of meat production and 70% of milk production (De Haan et al., 1999). In Chad, natural pastures are the main feed resource for livestock.

These pastures cover an estimated area of 84 million hectares, equivalent to 65% of the country's total surface. They enable livestock to maintain good body condition, essential for achieving production and labor objectives for herders, particularly during the rainy season when natural forage is abundant. These vegetation resources offer high production potential for most tropical grasses, combined with the good nutritional quality of legumes and their drought resistance (Klein et al., 2014).

However, pastoral lean periods, particularly during the hot dry season (March to June), pose a significant challenge. During this period, the availability and quality of natural forages decline drastically, forcing herders to purchase supplemental feed. The collection and storage of crop and cereal residues, while crucial, remain insufficient to meet the dietary needs of livestock, particularly in terms of protein (Benard et al., 2021; Hiernaux et al., 2021).

Despite the strong potential for irrigated forage crops, their adoption remains limited in Chad. Producers prioritize staple food crops (millet, sorghum, rice, etc.), with crop residues serving as secondary feed for livestock. Logistical constraints, such as the need for fencing and secure storage, make the implementation of cultivated forage production challenging (Nianogo, 2000). However, the climatic conditions of the Sahel (sunlight, consistent heat, and localized water resources) offer a favorable environment for cultivating high-yielding C4 plants, such as sugarcane or elephant grass (Gosse, 1986).

In this context, exploring viable alternatives to enhance the resilience of livestock systems in the Sahel becomes increasingly relevant.

Materials and Methods Study Site

This study was conducted in N'Djamena, Chad, specifically at the experimental station of IRED, within the test plots of the ACCEPT project. The region's climate is characterized as tropical dry Sahelian, marked by two distinct seasons: a short rainy season, spanning from May-June to September (4 to 5 months), and a long dry season, lasting from October to May. Temperatures remain consistently high throughout the year, ranging from 20 to 45 °C.

Plant Material

The plant material consisted of Maralfalfa (Pennisetum sp.) cuttings obtained from a plot at the Institute of Livestock Research for Development (IRED).

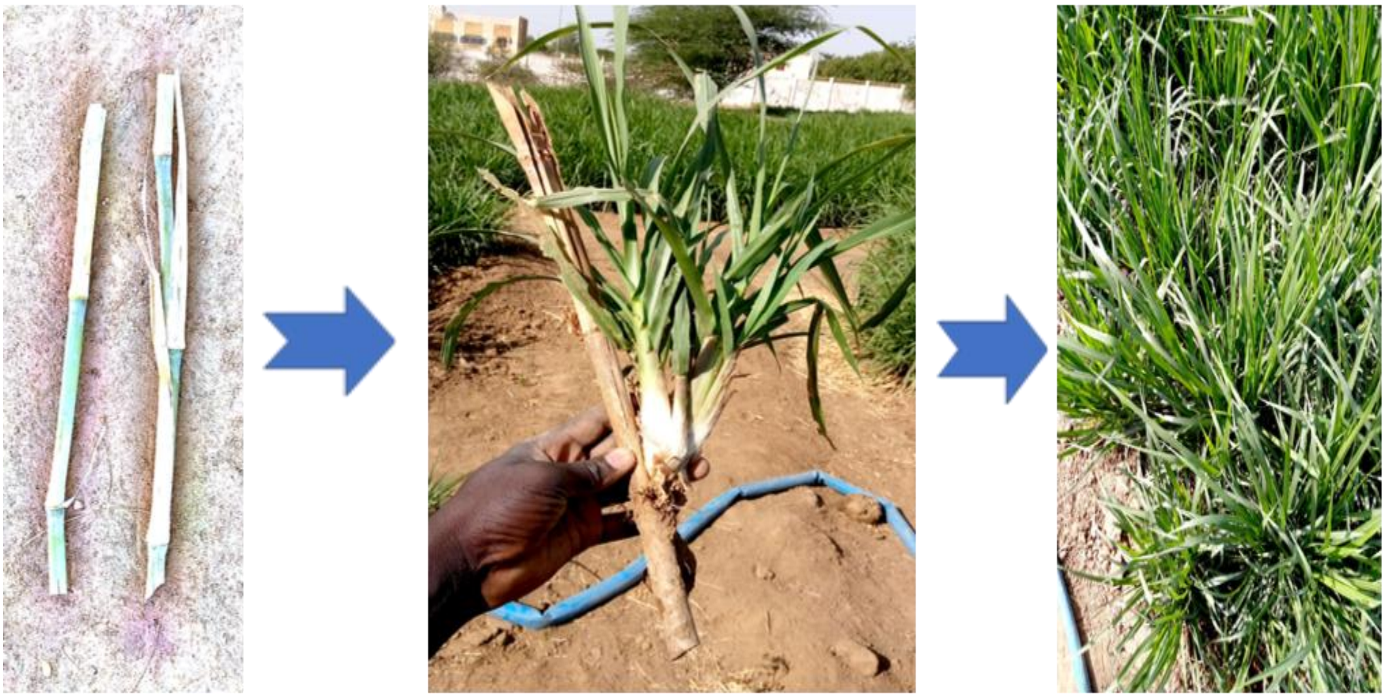

Figure 1: Sequentially, the cuttings, the first shoots, and the clumps of Maralfalfa.

Source**: Field data, 2022**

Experimental Design

The Fisher block design was implemented with 4 blocks, each comprising 5 plots (4 x 5). Each plot measured 6 m in length and 3 m in width, containing 6 ridges, each 6 m long, spaced 0.5 m apart, and 0.3 m in height. On each ridge, 12 Maralfalfa (Pennisetum sp.) cuttings were planted, with a spacing of 0.5 m between them, totaling 72 cuttings per plot.

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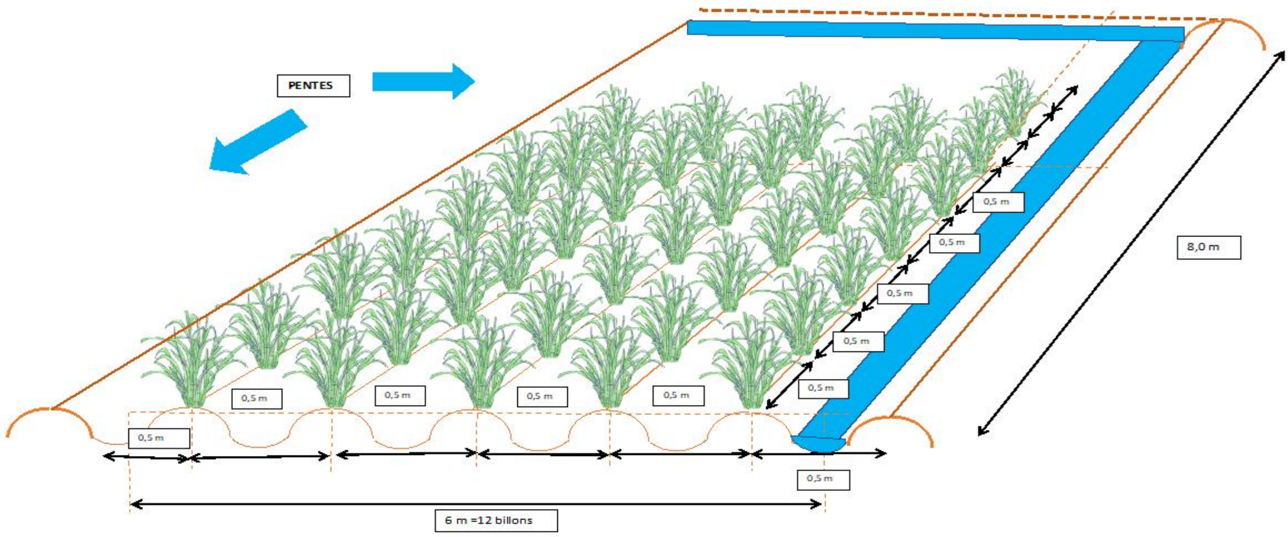

Figure 2: Diagram of the Experimental Design **(Source: Rémy Courcier, 2022)**

Planting of Cuttings

Twelve three-node cuttings were planted on each ridge, totaling 72 cuttings per plot. They were spaced 50 cm apart along the ridges, buried at the top of the ridges along the axis, and inclined such that only one node was visible above the ground.

Applied Treatments

A random draw of five letters was used to assign treatments to the different plots. Accordingly, the first block received the treatments BAEDC, the second block BCDEA, the third block EDBCA, and the fourth block CEABD. The five treatments applied were as follows: Treatment A corresponded to 50% of the plants' water requirements, Treatment B to 75%, Treatment C to 100%, Treatment D to 125%, and Treatment E to 150%.

Fertilization

Before planting the Maralfalfa (Pennisetum sp.) cuttings, 2 kg/m² of dried, powdered cattle manure (equivalent to 36 kg per plot) was applied as a base fertilizer to minimize heterogeneities observed across different parts of the plots. During the experiment, to compensate for the expected "exports" of NPK, fertilization was based on 16 tons of dried cattle manure per hectare per year (1.6 kg/m²/year) supplemented with nitrogen from urea at 1,100 kg/ha/year (0.11 kg/m²/year). Fertilization for 45 days was applied one week after each cut.

Irrigation

Gravity-fed irrigation (furrow irrigation) was used within the beds or plots (6 m × 3 m) by filling the furrows between the ridges (spaced 0.5 m apart) with water. Weekly irrigations (every Monday) were carried out from the first to the fourth decade. Due to increasing water requirements, irrigation was conducted twice a week (Monday and Friday) during the fifth decade. For each treatment, irrigation volumes were calculated based on the estimated water needs of the plants. These needs were calculated in mm of water per day by multiplying the estimated evapotranspiration (ETP in mm/day, based on the CROPWAT data for N'Djamena published by FAO) by the crop coefficient "Kc" (adjusted for the growth stage of the plants, using sorghum as a reference due to its similar growth rhythm) and by the system efficiency coefficient "Coeff" (estimated at 70% for short, closed furrows fed by pipes). The irrigation volumes for each treatment (50%, 75%, 100%, 125%, and 150% of the water needs) were then calculated.

Water Meter and Outlet Valves

Weighing of a Forage Sheaf

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Figure 3: Measurement Systems

Tableau 1 Average ETP and Rainfall in N'Djamena (mm)

	Nov.	Dec.	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
ETP	5.99	5.54	5.88	7.60	8.05	7.53	7.59	6.63	4.97	4.08	4.57	5.64
Pluies	0.1	0	0	0	0.3	10.1	24.7	46.3	70.8	125.7	72.9	19.5

Source: Crop Coefficient (Kc) for Sorghum

Tableau 2: Crop Coefficient (Kc) for Sorghum

Décade	1	2	3	4	5
Kc	0.3	0.4	0.6	0.8	1.0

Source: FAO

Harvests

The forage harvest was carried out every 45 days. During each harvest, all the plants in the plot were cut 5-10 cm above the ground and bundled for weighing.

Measurement of fresh forage (biomass): The total biomass (Fresh Matter or FM) produced in each plot was measured using a hanging scale attached to a tripod after each cut, performed every month and a half (see Figure N°3).

Forage quality analysis: During harvests, a 1000 g sample of the plants (leaves and stems), representative of the entire plot's yield, was collected, cut into pieces of 5-10 cm, and stored in a numbered plastic bag for analysis. The forage samples were oven-dried at 55°C for 48 hours. Each dried sample was then finely ground to particles smaller than 1 mm using a mill and analyzed with an NIRS spectrometer to generate spectral data (electronic files). These were analyzed at CIRAD (Montpellier) to predict the nutritional values (CP, UFL, OM digestibility, MS, ADL).

Results and Discussion

Biomass Production

Across the three successive harvests, the quantity of biomass produced (kg of fresh forage harvested per test plot) increased significantly with higher volumes of water applied. The increase in biomass yield when irrigation rose from 50% to 75% and then to 100% of water needs was highly significant. The yield with only 50% of water requirements was very low (less than 50% of the yield obtained with full irrigation). However, when irrigation volumes increased from 100% to 150% of water needs, the yield continued to rise but only slightly (by 4 to 8%). This clearly indicates that, for the three periods, the water requirements of the plants were accurately estimated (average ETP values close to reality, Kc accounting for variations in needs according to developmental stages, and irrigation system efficiency closely reflecting field conditions).

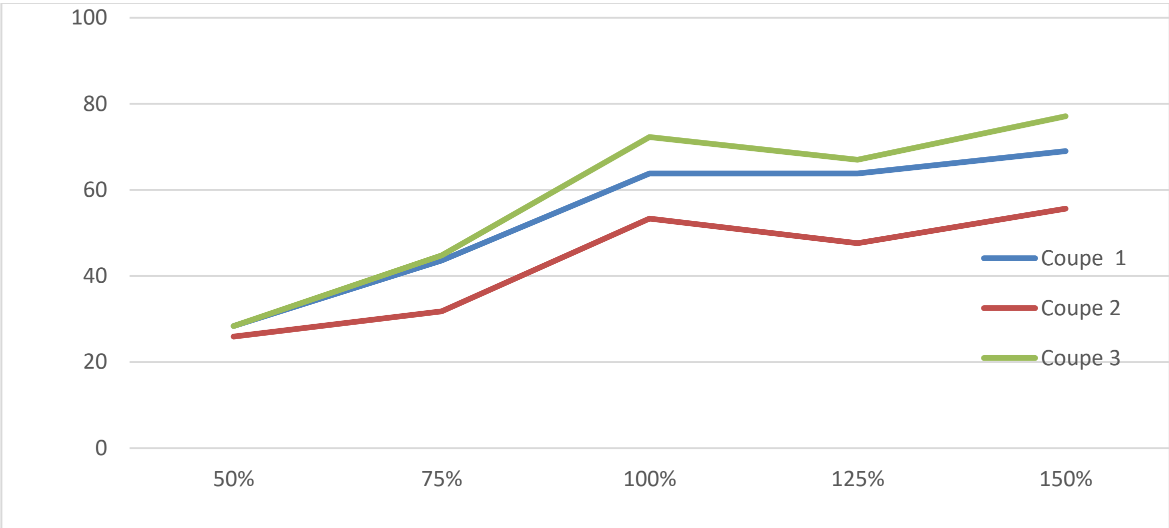

Figure 4: Biomass Harvests (FM) produced every 45 days (kg per 18 m² plot)

Tableau 3: Harvests of Biomass (FM) Produced every 45 Days (kg per 18 m² plot)

Harvests of Biomass (FM) Produced every 45 days (kg per 18 m² plot)					
Cut Number	Harvest for 50% Irrigation Needs	Harvest for 75% Irrigation Needs	Harvest for 100% Irrigation Needs	Harvest for 125% Irrigation Needs	Harvest for 150% Irrigation Needs
Cut No. 1	28.4	43.6	63.8	63.8	69.0

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Cut No. 2	25.9	31.8	53.3	47.6	55.6
Cut No. 3	28.4	44.8	72.3	67.0	77.1
Average	27.6	40.1	63.1	59.5	67.2

Fresh Biomass Production (kg)

(Source: Field Data, 2022)

The average yield per plot of biomass produced in 45 days varied according to the treatment: from 27.6 kg of fresh matter (FM) when the irrigation volume was 50% of the water requirements to 67.2 kg of FM when 150% of the water requirements were applied. The production when the water needs were covered at 100% averaged 63.8 kg/plot. Estimating annual production based on these measurements during the period, the average fresh matter yield would be 283.5 tonnes per hectare per year (FM/ha/year), which can be estimated at 62.4 t/ha/year of dry matter (DM/ha/year). These yields are very high and closely align with those obtained during other trials under the ACCEPT project for Maralfalfa production (Comparison of 5 irrigated forages, H.A. Djefil et al., 2021).

The different irrigation water volumes applied

The period with the largest water volumes applied was during the third harvest, which was at the end of the cool dry season. The volumes distributed per 18 m² plot during this third period to cover 100% of the needs over 45 days were 2,770.1 liters. During this period, the average evapotranspiration (ETP) given by CROPWATT reached 8 mm/day, significantly higher than the 6 mm/day recorded during the first period at the beginning of the cool dry season. Water volumes applied during the first period were 1,790.5 liters to cover 100% of the needs over 45 days. During the second period, the irrigation water volumes were intermediate (1,433.2 liters to cover 100% of the needs).

The average irrigation water volume corresponding to the needs (100%) over the three successive periods was 1,618 liters per plot, equivalent to 90 liters per m² over 45 days or 2 liters/day/m² (2.0 mm/day).

Biomass production

The average fresh matter (biomass) production was 63.1 kg FM/plot/45 days, or 3.5 kg FM/m²/45 days. Based on the average of previous ACCEPT trials (DM/FM ratio of 22%), the dry matter (DM) production can be estimated at 13.9 kg DM/plot/45 days, or 0.77 kg DM/m²/45 days. It can be concluded that, on average, to produce 1 kg of DM during the dry season, 116.4 liters of irrigation water are required (1,618 liters of irrigation water / 13.9 kg of DM).

	Quantity of water (liters/45 days/plot)					
Cutting	Period	50%	75%	100%	125%	150%
1st	06/11/2021 to 20/12/2021	895.1	1.342.9	1.790.5	2.238.1	2.685.7
2nd	21/12/2021 to 03/02/2022	955.4	1.433.2	1.911.0	2,388.8	2.866.7
3rd	04/02/2022 to 20/03/2022	1.385.0	2.077.5	2.770.16	3.462.6	4.161.7

Tableau 4: Distribution by treatment of irrigation water volumes supplied for each production period (number of liters/18 m² plot)

Quality Analysis

The analyses of NIRS spectra show that total nitrogenous matter (TNM) ranges from 18.4% to 13.4% of DM depending on the treatment (which are excellent protein levels for a grass species). The energy value in forage units (UFL) is between 0.6 and 0.7 per kg of DM, digestibility (DMD and OMD) ranges from 52% to 75%, and lignin (ADL) is between 1% and 2% of DM. These results indicate that plants subjected to lower irrigation tend to resemble younger plants (with lower lignin content and higher nitrogenous matter, hence higher protein levels). Conversely, the more irrigated plants developed further and exhibit higher lignin content, lower nitrogenous matter, slightly lower energy values, and reduced digestibility (Table V). However, the differences are not significant, and overall, irrigation water volumes do not appear to have a significant impact on forage quality.

Tableau 5: Forage Quality Analysis (MAT, UFL, SMS, SMO, ADL) for the 1st, 2nd, and 3rd Harvests

In % of DM						
Cut	Treatment	MAT	UFL	SMS	SMO	ADL
IRRIGATION AND HARVEST OF DECEMBER 2021						
1st	50%	16,04	0,7	58,13	55,44	1,89
	75%	18 ,50	0,72	59,95	57,53	2,53
	100%	16,6	0,71	59,84	57,19	2,28
	125%	15,91	0,7	56,63	53,24	2 ,69
	150%	13,4	0,67	54,92	52,45	2,78
IRRIGATION AND HARVEST OF FEBRUARY 2022						

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2nd	50%	18,82	0,78	66,5	62,68	1,12
	75%	18,64	0,74	61,92	58,27	2,26
	100%	19,9	0,77	64,52	60,58	2,07
	125%	20,47	0,78	65,03	61,36	1,95
	150%	18,55	0,76	63,46	59,99	1,79
IRRIGATION AND HARVEST OF MARCH 2022						
3rd	50%	21,62	0,86	73,52	74,91	1,55
	75%	21,63	0,85	73,76	75,03	1,39
	100%	0	0	0	0	0
	125%	18,82	0,78	68,91	68,52	1,57
	150%	13,76	0,69	60,53	59,19	2,58

Discussion

During the second period, yields were significantly lower than those recorded in the first and third periods, regardless of the amount of irrigation water applied. This decrease in production may be attributed to under-irrigation across all treatments. The average ETP published by the FAO, commonly used to estimate plant water requirements, may have been lower than the actual ETP. The period at the end of 2021 and the beginning of 2022 may have been hotter than the FAO's reported average, whereas for the other periods, the FAO estimate likely provided a more accurate representation of the actual conditions during the 2021/2022 season.

The water requirement of Maralfalfa (*Pennisetum sp.*) to produce 1 kg of dry matter (DM) averaged 116.4 liters over the 4.5-month study period in the dry season. This value is considerably lower than the estimates reported by Birouk et al. (1997), which indicate that 1,000 liters of water are required to produce 1 kg of lucerne DM and 4,500 liters for 1 kg of rice DM. However, it is closer to the 228 liters needed to produce 1 kg of maize forage DM. These results confirm that, due to its high productivity, Maralfalfa is a water-efficient forage crop.

Similarly, Hammani et al. (2009) reported that producing 1 kg of lucerne DM requires 1,666 liters of water, while 526 liters are needed for 1 kg of maize forage DM

Conclusion

At the end of this study, which covered three harvests over a total of 4.5 months during the dry season, it is clear that different water volumes had very significant effects on yield but very little impact on the quality of Maralfalfa (Pennisetum sp.) forage. The three consecutive trials at the station with varying irrigation water volumes showed consistent results that validated water requirement estimates (ETP x Kc x Coefficient) and demonstrated that Maralfalfa (Pennisetum sp.), despite its rapid and robust growth, requires very little water to produce large quantities of quality forage, provided that the irrigation water volume is at least close to its needs.

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