Impact of water regime and harvest management on the quantity and quality of herbaceous forage in the Sahelian ecosystem of Senegal

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Summary

Background: The climate and harvest management practices influence forage production in the Sahel. However, the combined effect of these parameters has not been assessed. *Aim*: This study aims to measure the joint effect of rainfall and harvesting practices on the quantity and quality of forage. *Methods*: Aboveground biomass samples were collected during (July and August) and at the end (October) of the 2021 rainy season by full cutting on 68 harvest plots: 20 plots with different water regimes (varying water quantities and duration of inputs), and 48 plots with different quantities of water combined with different cutting heights (0 or 5 cm above ground) and harvest periods (early or late). *Results*: The aboveground biomass ranged from 2,932.2 ± 1,672.1 to 6,383.6 ± 2,962.6 kg/ha for water regime treatments, and 2,397.7 ± 6,263.4 kg/ha to 15,059.2 ± 9,782.9 kg/ha for cumulated harvest aboveground biomass. The crude fiber rate (as % of dry matter) was between 5.5 ± 0.9% and 6.4 ± 1.2%. Digestible crude protein varied between 21.8 ± 67.96% and 67.2 ± 15.8%. Regardless of the quantity of water received, equivalent quantities and qualities of forage ($p > 0.05$) were produced by the plots that were not harvested until the end of the season and those harvested at the beginning of the development cycle of the forage species. The amount of aboveground biomass produced was the same, independent of the cutting heights (3,535.8 ± 2,953.5 for 0 cm and 4,503.4 ± 3,068.6 kg/ha for 5 cm). On the other hand, the plots harvested at the fruiting stage of the species produced forage composed of young plants in smaller quantities and of good quality. *Conclusions*: The quantity and quality of herbaceous forage yield at the end of the rainy season were mainly influenced by the phenological stage. Forage resource management programs should favor cutting times and heights that allow optimal ground coverage to reduce the risk of erosion.

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■ INTRODUCTION

In arid and semiarid areas, forage production - mainly based on rangeland vegetation - is dictated by two principal factors. Rainfall variability is the primary factor (Behnke, 2000), but the management of grazing intensity and the timing and distribution of harvesting also can impact the quantity and quality of forage production (Derry et Boone, 2010). It is important to predict the paradigm in which management measures will facilitate improved forage production.

Forage production from Sahelian pastures takes place entirely during the rainy season, from June to October (Nicholson, 2000; Nicholson et al. 2018a; Nicholson et al., 2018b). Studies have been conducted in Sahelian pastoral tropical ecosystems (Cisse, 1986; Son et al., 2011;

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Ndiaye, 2015; Diawara et al., 2020) to determine the responses of grass cover to rainfall variations. Without considering certain rainfall events (annual maximum rainfall), these studies reveal the sensitivity of Sahelian ecosystems to variations in the quantity and distribution of rainfall. Water deficit is one of the factors limiting agricultural production in the Sahelian zone (Son et al., 2011). The total amount of rain is positively correlated with the production of aboveground biomass (Cisse, 1986; Taugourdeau et al., 2018). In addition to climatic conditions, the quantity and quality of forage production can be limited by the species composition of pastures (Cisse, 1986). Reduced forage production also can be induced by poor rangeland management.

In the Sahel, the main sources of forage are spontaneous vegetation (herbaceous and woody), cultivated forage crops, and residues of cereal, groundnut and cowpea crops (Assouma et al., 2019; FAO, 2020). These resources are used for direct grazing (permanent or in rotation), harvested to produce forage for the dry season, and marketed (Faustine et al., 2016; Sakatai et al., 2021). An adequate quantity and quality of forage resources are required to meet the needs of animals and generate income for producers. The quantity can be evaluated by the dry aboveground biomass produced, an essential parameter in the determination of the livestock carrying capacity (Richard et al., 2019). The quality can be assessed by considering the chemical composition [dry matter rate (rt_DM), crude fiber (CF), crude protein (CP), etc.] and the nutritional value of the forage (digestibility of the DM, etc.). The chemical composition of plants in grasslands is an important factor influencing herbivore consumption and material cycling, and is an important parameter in determining the state of degradation and restoration of grassland ecosystems (Xu and Wang, 2007). Near Infrared Spectrometry (NIRS) combined with laboratory reference analyses makes it possible to give reliable estimates of the chemical composition of the samples (Andueza et al., 2011; Bastianelli et al., 2019). The nutritive value is related to several factors, including: (i) the energy value expressed in feed units, (ii) the nitrogenous value including the measurement of the quantity of digestible protein in the intestine and/or of the digestible nitrogenous matter, (iii) the fill value relative to the ingestibility of the feed, and (iv) the mineral content (Jarrige, 1988; Boudet, 1991; Baumont et al., 2009; Inra, 2010; Richard et al., 2019). The nutritive value of forage then makes it possible to estimate the potential production of milk and/or meat by ruminants.

Forage production in the Sahelian zone is therefore influenced both by environmental conditions (climate) and by the management methods implemented (Klein et al., 2013). However, the impact of practices, strongly modulated by climate, and the consequences of interactions (practices x climate) on herbaceous communities are still poorly understood. We studied the impact of the interaction between water regimes and harvest management practices (timing of harvests and cutting height) on the quantity and quality of forage grass. We hypothesized that the interaction between the water regime and harvest management would have a different effect on the quantity and quality of forage grass than the effect of the water regime alone. To test this, we investigated the effect of different water regimes (rain with or without supplementary irrigation), and then the combined effect of water regimes and the timing of cuts and cutting height on the quantity and quality of forage grass.

■ MATERIAL AND METHODS

Study zone

The trial was conducted on a 0.35 ha plot at the Zootechnical Research Centre (CRZ: Centre de Recherche Zootechnique) in Dahra (15°21' N, 15°26' W). Located in the silvopastoral zone of Senegal, the centre has an average cumulative rainfall per year of 431 ± 148 mm (period 1981-2021; NASA, 2021). The rainy season extends from the end of June to the beginning of October with most of the precipitation from August to September (Figure 1; Delon et al., 2017Senegal). The average temperature was 27.4 ± 0.4°C, with a maximum of 44.4 ± 0.8°C in May and a minimum of 12.3 ± 1.5°C in January, over the period 1981-2021 (NASA, 2021). The soil is sandy luvic arenosol with negligible amounts of organic material and low clay content (clay = 0.35%, silt = 4.61%, and sand = 95.04%) or haplic lixisol type (Tagesson et al., 2015). The herbaceous species *Diodella sarmentosa*, *Zornia glochidiata*, *Alysicarpus ovalifolius* and several Poacea species (*Aristida*

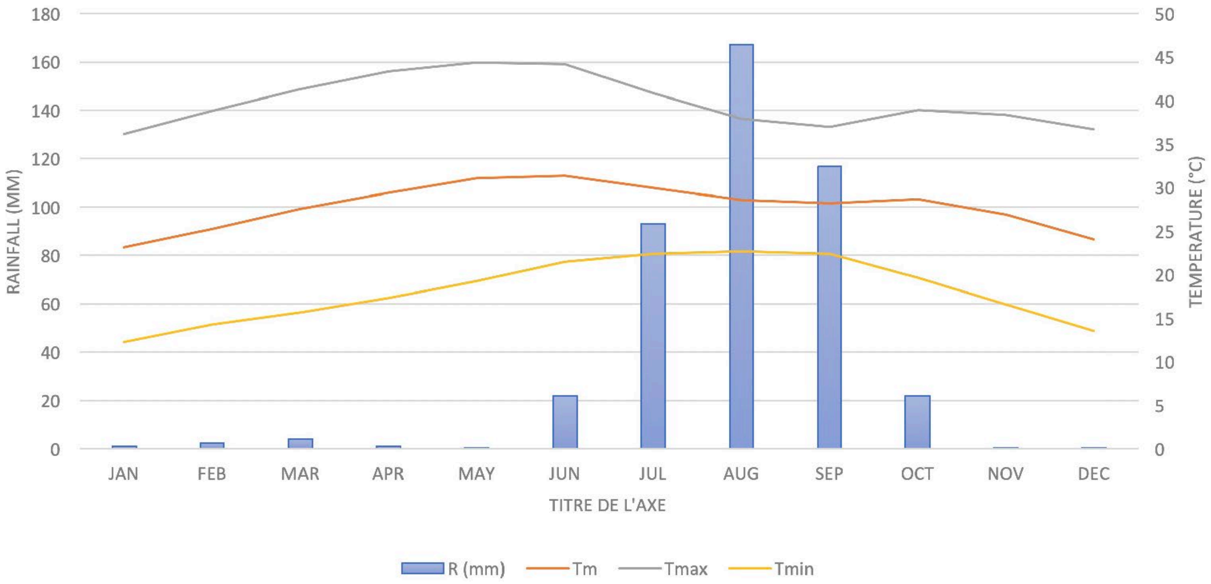


Figure 1: Temperatures (average, maximum and minimum) and the amount of rain (rainfall) from 1981 to 2021. R_1981-2021: Rainfall from 1981 to 2021; R_2021: Rainfall in 2021 Tm: Mean temperature; Tmax: Maximum temperature; Tmin: Minimum temperature; Jan: January; Feb: February; Mar: March; Apr: April; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October; Dec: December /// *Températures (moyennes, maximales et minimales) et quantité de pluie (précipitations) de 1981 à 2021. R_1981-2021 : Pluies de 1981 à 2021 ; R_2021 : Pluies en 2021 Tm : Température moyenne ; Tmax : Température maximale ; Tmin : Température minimale ; Jan : janvier ; fév : février ; Mar : mars ; avr : Avril ; Jun : juin ; juil : juillet ; août : août ; sep ; septembre ; oct : octobre ; déc : décembre*

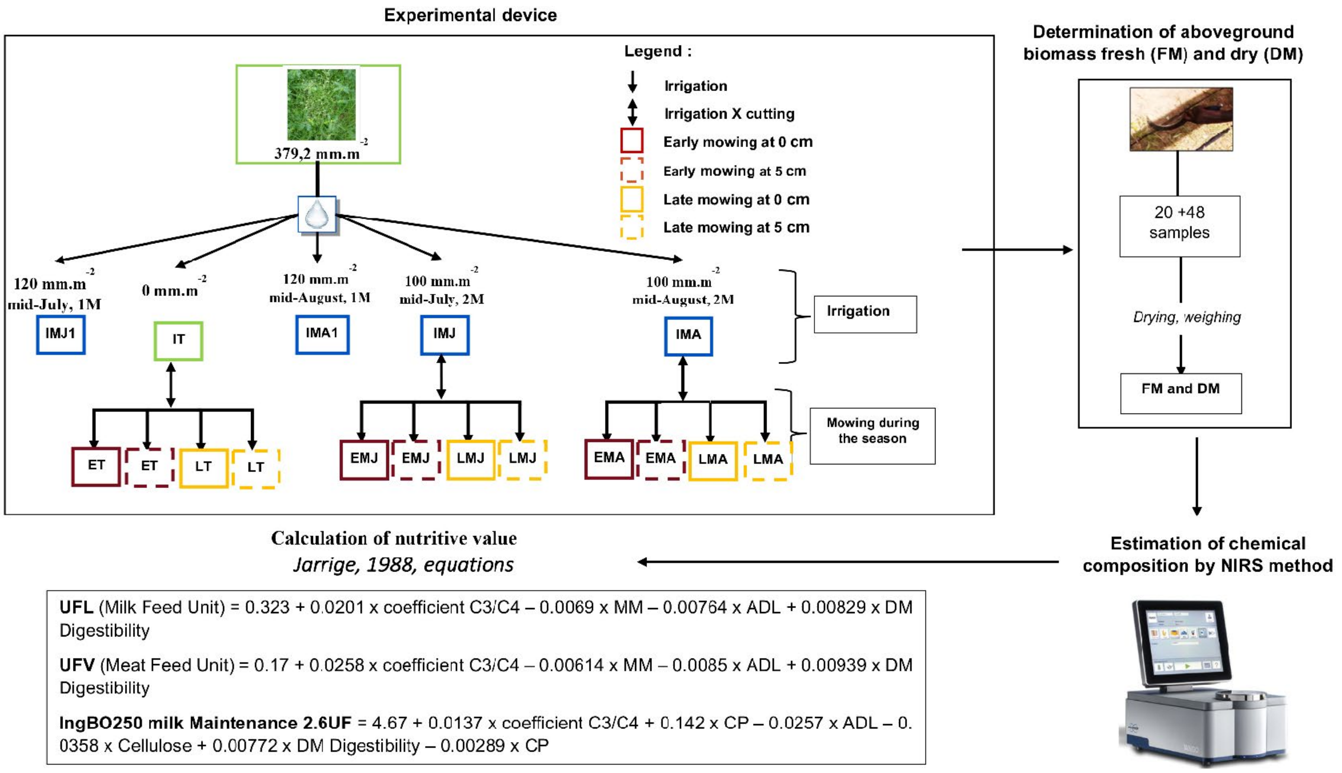
mutabilis, *Cenchrus biflorus*, *Enteropogon prieurii*, etc.) are the most common in pastures (Diatta, 2021).

Experimental device

In March 2021, on the 0.35 ha plot, we delimited 68 subplots, each covering 1.0 m^2 and spaced 1.5 m apart. During the rainy season from June to mid-October, four water regime treatments and 12 harvest management treatments were randomly assigned to the plots and repeated four times (Figure 2). During the experimental phase, all plots including the control plots (four without irrigation and harvest) received 379.2 mm of water from June to mid-October 2021, with 50 mm precipitation less compared to the long-term precipitation for the same period. The water regime treatments consisted of supplementing rainfall with drip irrigation, which supplied plots with 100 to 120 mm of water for one or two months. The water regimes also varied in terms of the amount of the initial supplementary water input provided. The IMJ1 and IMJ treatments, lasting one and two months respectively, began in mid-July with initial supplementary inputs of 10 $mm.m^{-2}$ and 5.6 $mm.m^{-2}$, accumulating to 499.2 mm and 479.2 mm, respectively. Similarly, the IMA1 and IMA treatments, also lasting one and two months respectively, started in mid-July with initial supplementary inputs of 33.3 $mm.m^{-2}$ and 18.8 $mm.m^{-2}$. After mid-July, the IMA1 and IMA plots did not receive additional water supplements until mid-August. From then on, water supplements were provided every three days. IMA1 plots received inputs of 10 $mm.m^{-2}$ to reach a total input of 499.2 $mm.m^{-2}$, while IMA plots received 5.6 $mm.m^{-2}$ to reach a total input of 479.2 $mm.m^{-2}$. We then implemented different harvest regimes on 48 plots of 1 m^2, some with and some without irrigation, to test the combined effects of water regime and harvest management practices (Figure 2). Two harvest variables were tested on the 1 m^2 plots: (i) harvest height, including cutting the grass at 0 (ground level) or 5 cm above the ground, and (ii) harvest period, carried out by a cut at the early flowering stage of fast-growing species or at the fruiting stage in the majority of species (Figure 2). In total, four of the twelve treatments received only rain, with no irrigation, and cuts at ground level or 5 cm above the ground and/or at the beginning of flowering of fast-growing species or at fruiting in most species per plot (treatment ET: E for early harvest and T for ground level harvest height; LT: L for late harvest and T for ground level harvest height). The other plots received an additional 100 mm of water at a rate of 5.6 mm per injection, every three days, for two months, starting in mid-July (EMJ: combine treatment of early harvest and IMJ water regime, LMJ: combine treatment of late harvest period and IMJ water regime) or mid-August (EMA: combine treatment of early harvest and IMA water regime, LMA: combine treatment of late harvest period and IMA water regime). It should be noted that the LMA on one plot received more water than the other plots due to a one-off failure of the irrigation system.

Collection of aboveground biomass

Aboveground biomass were sampled using a 1 m^2 quadrat according to the method described by Levang and Grouzis (1980). Twenty samples (5 treatments × 4 repetitions) of aboveground biomass were collected from the water regime plots and the control plots at the end of the season. For the different harvest treatments, 48 samples were collected during the season, including 24 at the early stage (on 27/07/2021, Figure 3) and 24 at the fruiting stage (on 04/09/2021, Figure 3), and a further 48 samples were collected at the end of the season (on 12/10/2021). The 116 samples collected (20+24+24+48) were dried in an oven at 65°C until a constant weight was obtained for the determination of the dry aboveground biomass. Two quantities of aboveground biomass were collected for the presentation of the results regarding the different harvest regimes: the dry aboveground



UFL (Milk Feed Unit) = 0.323 + 0.0201 x coefficient C3/C4 – 0.0069 x MM – 0.00764 x ADL + 0.00829 x DM Digestibility

UFV (Meat Feed Unit) = 0.17 + 0.0258 x coefficient C3/C4 – 0.00614 x MM – 0.0085 x ADL + 0.00939 x DM Digestibility

IngBO250 milk Maintenance 2.6UF = 4.67 + 0.0137 x coefficient C3/C4 + 0.142 x CP – 0.0257 x ADL – 0.0358 x Cellulose + 0.00772 x DM Digestibility – 0.00289 x CP

Figure 2: Methodology steps: experimental device, phytomass, estimation of chemical composition by Near Infrared Spectrometry (NIRS) Method and calculation of nutritive value of forage /// *Étapes méthodologiques : dispositif expérimental, phytomasse, estimation de la composition chimique par la méthode de la spectrométrie proche infrarouge (SPIR) et calcul de la valeur nutritive du fourrage*

Figure 3: Flowering of fast-growing species stage (left, 27/07/2021) and fructification of most species (right, 04/09/2021) /// *Stade de floraison des espèces à croissance rapide (à gauche, 27/07/2021) et fructification de la plupart des espèces (à droite, 04/09/2021)*

biomass of the end-season cut and the cumulated dry aboveground biomass collected during the season and at the end of the season.

Chemical composition of forage

The 116 samples were ground to 1 mm, then scanned for the acquisition of their spectral signature using the Bruker TANGO FT-NIR Spectrometer, measured in absorbance mode at wavelengths from 800 to 2,500 nm.

Subsequently, different chemical parameters of the samples were estimated (Supplementary material I): residual DM (at 103°C), cumulated mineral matter (ash, MM), crude protein (N × 6.25, CP), crude fiber (Weende method, CF), neutral detergent fiber (Van Soest method, NDF), acid detergent fiber (Van Soest method, ADF), acid detergent lignin (Van Soest method, ADL), organic matter digestibility (enzymatic method Pepsin-Cellulase, OMD), and digestibility of dry matter (enzymatic method Pepsin-Cellulase, DMD). These estimates are based on models developed by the animal feed laboratory of the Mediterranean Research Unit, SELMET, at the Centre for International Cooperation in Agricultural Research for Development (CIRAD), in Montpellier. These models were established with reference values from aboveground biomass samples collected across the sylvopastoral zone of Senegal. The values were then used to estimate the nutritive value of the forage.

Nutritive value of forage

The quality of the forage was evaluated by estimating the energy value and the nitrogen value of the forage collected from plots under each treatment (water regime with or without harvest). To consider the forage fill value, the potential ingestibility of the forage was estimated. All the calculation formulas were developed by Jarrige (1988).

The net energy value is expressed in feed unit for meat production (UFV) and in feed unit for lactation (UFL) forage units and calculated according to the following formulas:

$UFL = 0.323 + 0.0201 \times \text{coefficient } C3/C4 - 0.0069 \times MM - 0.00764 \times ADL + 0.00829 \times DMD$ (Equation 1)

where C3/C4 corresponds to the ratio of C3 plants to C4 plants here equal to 0.90,

$UFV = 0.17 + 0.0258 \times \text{coefficient } C3/C4 - 0.00614 \times MM - 0.0085 \times ADL + 0.00939 \times DMD$ (Equation 2)

where C3/C4 corresponds to the ratio of C3 plants to C4 plants here equal to 0.90.

The nitrogen value corresponds to the quantity of protein absorbed in the small intestine (PDI) according to the INRA feed evaluation method (2010) and to the digestible crude protein (DCP) according to Boudet (1991) and Jarrige (1988). Two PDI values are considered for each sample: PDIN, corresponding to the PDI in conditions where nitrogen is the limiting factor of microbial protein synthesis, and PDIE, corresponding to the PDI in conditions where energy is limiting. The following formulas were used:

$DCP = 9.16 \times CP - 28.9$ (Equation 3)

Where CP corresponds to the rate of crude protein per percentage of dry matter.

$PDIA\ (g/kg\ DM) = 9.1 - 8.18 \times \text{coefficient } C3/C4 + 2.92 \times CP + 0.0461 \times NDF$ (Equation 4)

where C3/C4 corresponds to the ratio of C3 plants to C4 plants here equal to 0.90.

$PDIN\ (g/kg\ DM) = 0.807 - 0.726 \times \text{coefficient } C3/C4 + 6.34 \times CP + 0.00409 \times NDF$ (Equation 5)

where C3/C4 corresponds to the ratio of C3 plants to C4 plants here equal to 0.90.

$PDIE\ (g/kg\ DM) = 84.7 - 8.01 \times \text{coefficient } C3/C4 - 0.58 \times MM + 3.15 \times CP - 0.71 \times CF$ (Equation 6)

where C3/C4 corresponds to the ratio of plants in C3 to plants in C4 here equal to 0.90.

Forage fill value is correlated with ingestibility (INRA, 2010). According to the formula of Jarrige (1988), the potential ingestibility of forage for cattle with a live weight of 250 kg (IngBO250) is equal to:

$IngBO250\ (kg\ DM.d = 4.67 + 0.0137 \times \text{coefficient } C3/C4 + 0.142 \times ay^{-1})\ CP - 0.0257 \times ADL - 0.0358 \times CF + 0.00772 \times DMD - 0.00289 \times CP^2$ (Equation 7)

where C3/C4 corresponds to the ratio of plants in C3 to plants in C4 here equal to 0.90.

The potential ingestibility of forage for dairy cows with a live weight of 600 kg (IngVL600) is equal to:

IngVL600 (kg DM.day^{-1}) = 14.8 + 0.0218 × coefficient C3/C4 + 0.234 × CP- 0.0422 × ADL – 0.0589 × CF + 0.0128 × DMD – 0.00474 × CP^2 (Equation 8)

where C3/C4 corresponds to the ratio of plants in C3 to plants in C4 here equal to 0.90.

Milk and meat potential production associated with the forages were calculated from the following formulas:

Milk (l.day^{-1}) = ((UFL × IngBO250) – 2.6)/0.4 (Equation 9)

Meat (kg.day^{-1}) = (((UFV × IngBO250) – 2.3)/0.25) × 100/1000 (Equation 10)

Statistical analysis of data

The Kruskal-Wallis test at the 5% threshold and the Dunn.test function were used to compare the treatments. The comparison was carried out on the dry aboveground biomass and cumulated aboveground biomass data collected according to the water regime (quantity of water and duration of the inputs) and harvest (cutting height and period). Models of interaction between dry aboveground biomass and water regime parameters were produced by a two-factor analysis of variance (harvest period and amount of water) at the 5% threshold to assess the effect of the interaction between harvest practice and water regime. When the analysis of the interaction models did not show any effect, we carried out comparison tests using the Kruskal-Wallis test at the 5% threshold and the Dunn.test function to determine which of the variables explain the observed differences. Finally, a principal component analysis (PCA) was carried out to assess the effect of harvest height and harvest period modalities, in interaction with the water regime, on the chemical composition and nutritive value of forage. All analyses were performed using R Statistical Software, version 4.1.2.

■ RESULTS

Dry aboveground biomass at the end of the season (DM) of the plots according to the water regime

The mean values of dry aboveground biomass, from water regime treatments (IT, IMA1, IMA, IMJ1, IMJ), presented in Supplementary material II, ranged from 2,932 ± 1,672 to 6,384 ± 2,963 kg/ha. No statistical difference ($p = 0.5$) was found between the water regime treatments (Figure 4). However, the non-statistically significant result showed that the lowest quantities of dry aboveground biomass were observed on plots that received only rainwater (IT).

Dry season aboveground biomass of the plots according to the harvest height combined with the water regime

The mean values of dry aboveground biomass from the harvest of 12/10/2021 varied between 1,503 ± 746 and 7,059 ± 2,023 kg/ha (Supplementary material II). The mean cumulated aboveground biomass, the sum of the aboveground biomass harvested during the season (on 27/07/21 or 04/09/2024) and at the end of the season (on 12/10/2021), varied between 2,398 ± 6,263.4 kg/ha and 15,0592 ± 9,7839 kg/ha. Whatever the quantity of water supplied, the dry aboveground biomass ($p = 0.92$) and the cumulated aboveground biomass ($p = 0.15$) from plots harvested at 0 cm (respectively 3,844 ± 3,417 and 6,763 ± 2,763 for 100 mm of supplementary water input) were not statistically different from those harvested at 5 cm (respectively 4,051 ± 2,505 and 6,509 ± 2,262 for 100 mm of supplementary water) (Figure 5).

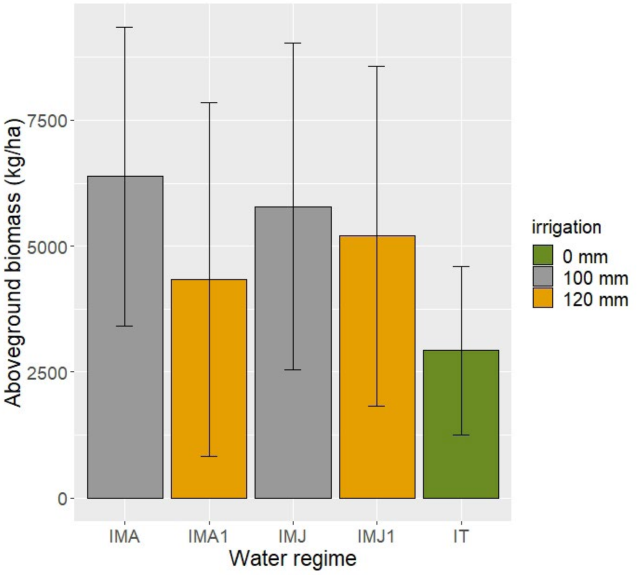


Figure 4: Dry aboveground biomass DM in kg/ha of herbaceous forage collected on 12/10/2021 on the water regime plots at the CRZ of Dahra according to the quantity of water supplied and the start dates of water supply: IMA1= addition of 120 mm in mid-August during 1 month, IMA= addition of 100 mm in mid-August during 2 months, IMJ1= addition of 120 mm in mid-July during 1 month, IMJ = addition of 100 mm in mid-July during 2 months, IT= no addition of water, no harvest /// *Phytomasse sèche aérienne DM en kg/ha des fourrages herbacés récoltés le 12/10/2021 sur les parcelles à régime hydrique de la CRZ de Dahra en fonction de la quantité d'eau apportée et des dates de début d'apport d'eau : IMA1= apport de 120 mm à la mi-août pendant 1 mois, IMA= apport de 100 mm à la mi-août pendant 2 mois, IMJ1= apport de 120 mm à la mi-juillet pendant 1 mois, IMJ = apport de 100 mm à la mi-juillet pendant 2 mois, IT= pas d'apport d'eau, pas de récolte.*

Dry aboveground biomass of the plots according to the harvest period combined with the water regime

Whatever the quantity of water received, the dry aboveground biomass taken on 12/10/2021 on the early harvest plots (on 27/07/2021, treatments EMA, EMJ, ET) was not statistically different from the water regime plots where the water supply was lower or equal to 100 mm.m^{-2} (treatments IMA, IMJ, IT), and higher ($p < 0.001$) than that of late harvest plots (on 04/09/2021, treatments LMJ, LT), except those where the water supply was mainly added after mid-August (LMA) (Figure 6.a).The dry aboveground biomass of this treatment LMA was highly variable, with a standard deviation above the mean.

Considering the cumulated aboveground biomass collected during the season, no difference ($p = 0.26$) was observed and the trend showed that the lowest quantities of dry aboveground biomass were observed on plots that received only rainwater (IT, Figure 6.b).

Chemical composition and nutritive value of forage

DM ranged from 92.7 ± 0.5% to 93.3 ± 0.3% (Supplementary material III). CP (%DM) was between 6.7 ± 1.0% and 7.7 ± 1.6%. CF (%DM) was between 5.5 ± 0.9% and 6.4 ± 1.2%. ADL (%DM) was between 8.5 ± 3.5% and 8.9 ± 0.3%. UFL and UFV varied respectively between 0.44 ± 0.03 and 0.53 ± 0.05 and between 0.31 ± 0.03 and 0.42 ± 0.03. DCP varied between 21.8 ± 68.0 and 67.2 ± 15.8 (Supplementary material IV).

Axis 1 of the principal component analysis (PCA) explained more than 62% of the difference between the variables. Two groups of individuals were plotted along axis 1. Group 1 consisted of forage collected on 12/10/2021 from early and late harvest plots and those of water regime (with positive coordinates). It was negatively correlated with group 2, which was composed of forage collected during the season (on 04/09/2021) from late harvest plots (Figure 7). Regarding the variables related to DM rate (rt_DM), aboveground biomass (DM and PT), crude fiber (CF) and lignin (NDF, ADF, ADL), and energy value of meat and milk production (UFV and UFL), formed a group mainly represented by forage of group 1 (Figure 7). These variables were negatively

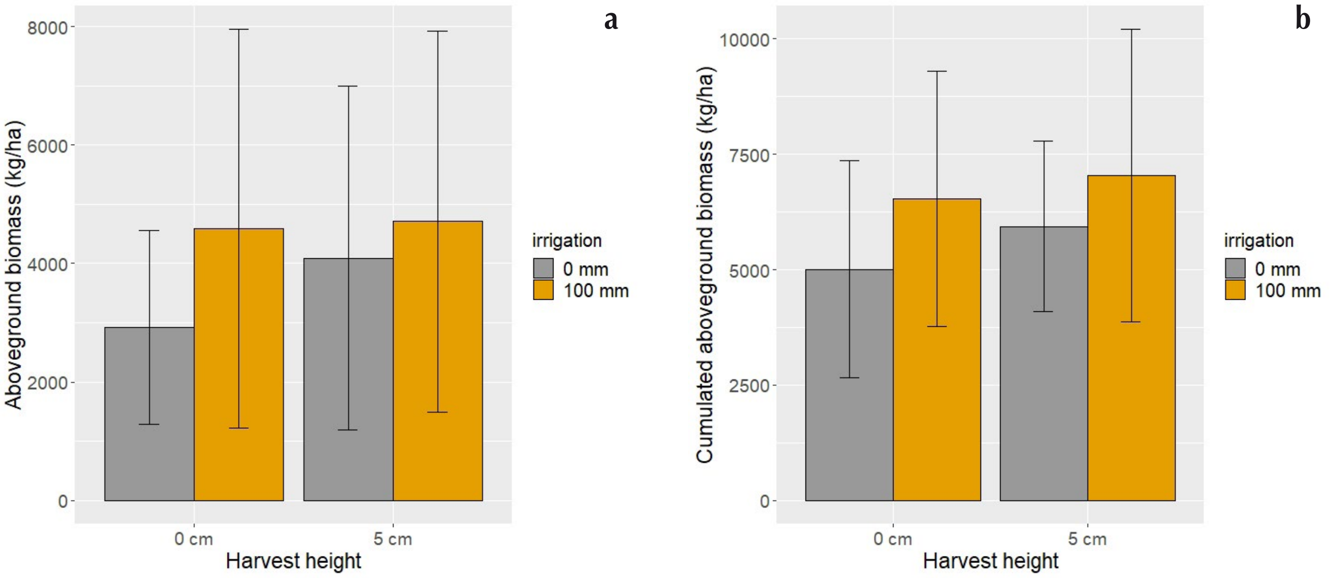


Figure 5: Dry aboveground biomass in kg/ha (a) of herbaceous forage collected on 12/10/2021 and the cumulated dry aboveground biomass in kg/ha (b) collected during the season (27/07/2023 or 04/ 09/2021) and on 12/10/2021 at the CRZ of Dahra at the CRZ of Dahra in function of the interaction between the amount of water supplied (0 and 100 mm) and the harvesting height (0 and 5 cm above the ground) /// *Phytomasse sèche aérienne en kg/ha (a) des fourrages herbacés récoltés le 12/10/2021 et le cumul de la phytomasse sèche aérienne en kg/ha (b) récoltés au cours de la campagne (27/07/2023 ou 04/ 09/2021) et le 12/10/2021 à la CRZ de Dahra en fonction de l'interaction entre la quantité d'eau apportée (0 et 100 mm) et la hauteur de récolte (0 et 5 cm au-dessus du sol).*

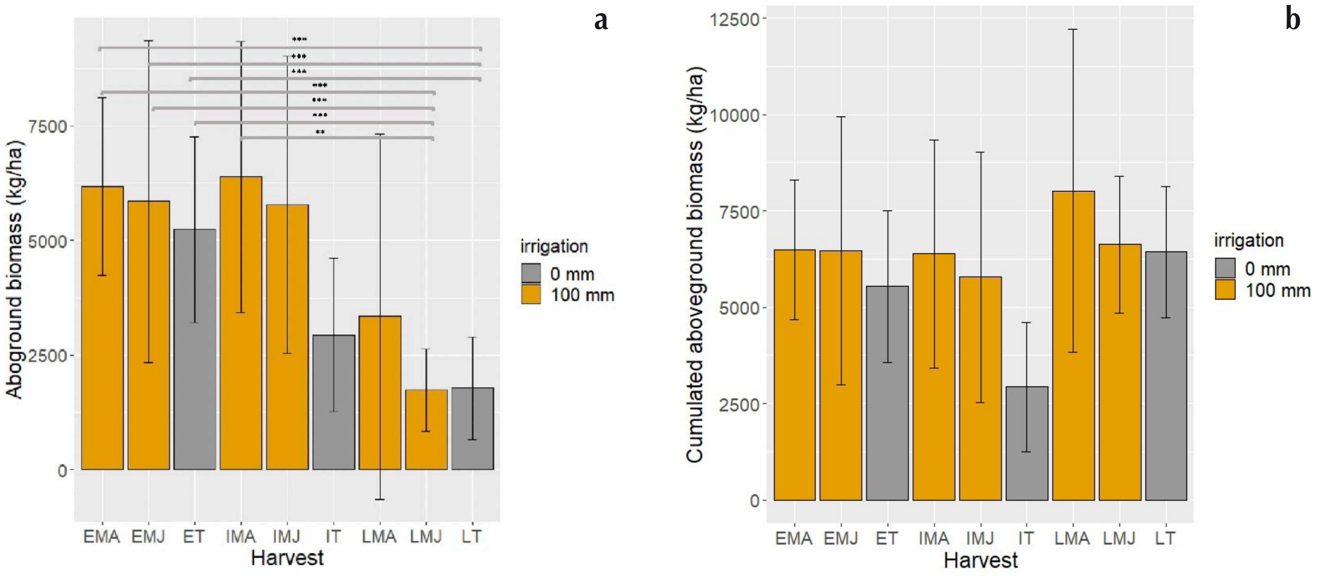


Figure 6: Dry aboveground biomass in kg/ha (a) of herbaceous forage collected on 12/10/2021 and the cumulated of dry aboveground biomass in kg/ha (b) collected during the season (27/07/2023 or 04/ 09/2021) and on 12/10/2021 at the CRZ of Dahra depending on the quantity of water supplied (T = 0 mm, 100 mm), the start dates of the water supplies and the harvest period: EMA = early harvest and addition of 100 mm in mid-August, EMJ = early harvest and addition of 100 mm in mid-July, ET = early harvest without addition of water, IMA = addition of 100 mm in mid-August, IMJ = add of 100 mm or 120 mm in mid-July, IT = no irrigation and no harvest, LMA = late harvest and addition of 100 mm, LMJ = late harvest and addition of 100 mm in mid-July, LT = late harvest without addition of water. The asterisk (*) represent a comparative statistically significant difference between treatments after post-hoc Bonferroni test : ***, $p < 0.001$; **, $p < 0.01$ /// *Phytomasse sèche aérienne en kg/ha (a) des fourrages herbacés récoltés le 12/10/2021 et le cumul de la phytomasse sèche aérienne en kg/ha (b) récoltée en cours de campagne (27/07/2023 ou 04/ 09/2021) et le 12/10/2021 à la CRZ de Dahra en fonction de la quantité d'eau apportée (T = 0 mm, 100 mm), des dates de début des apports d'eau et de la période de récolte : EMA = récolte précoce et apport de 100 mm à la mi-août, EMJ = récolte précoce et apport de 100 mm à la mi-juillet, ET = récolte précoce sans apport d'eau, IMA = apport de 100 mm à la mi-août, IMJ = apport de 100 mm ou 120 mm à la mi-juillet, IT = pas d'irrigation et pas de récolte, LMA = récolte tardive et apport de 100 mm, LMJ = récolte tardive et apport de 100 mm à la mi-juillet, LT = récolte tardive sans apport d'eau. L'astérisque (*) représente une différence statistiquement significative entre les traitements après le test post-hoc de Bonferroni : ***, $p < 0,001$; **, $p < 0,01$*

correlated with digestibility variables (DMD, OMD), nitrogenous and mineral matter (DCP, MM) and forage protein content (PDIE and PDIN) represented by the forage of group 2 (Figure 7).

The variables of ingestibility (IngBO250, IngVL600), energy production (UFV, UFL), and digestible protein content (PDIE, PDIN, DCP) were negatively correlated with DM and the dry aboveground biomass according to axis 2. Two groups of individuals were also observed along this same axis: one composed of forage collected on 12/10/2021 from the late harvest plots, and the other of forage from all of the other plots.

By specifically analyzing the organic matter, no difference was observed on the organic matter content of the cumulated forage collected during and at the end of the season (Figure 8.a). On the other hand, the analysis of the digestibility of organic matter showed that the cumulated forage from 27/07/2021 and 12/10/2021 had a significantly higher digestibility than that of the cumulated forage from 04/09/2021 and 12/10/2021 and that of irrigated plots not harvested during the season (Figure 8.b). Similarly, the cumulated forage from 04/09/2021 and 12/10/2021 had a significantly higher digestibility than that of irrigated forage not harvested during the season.

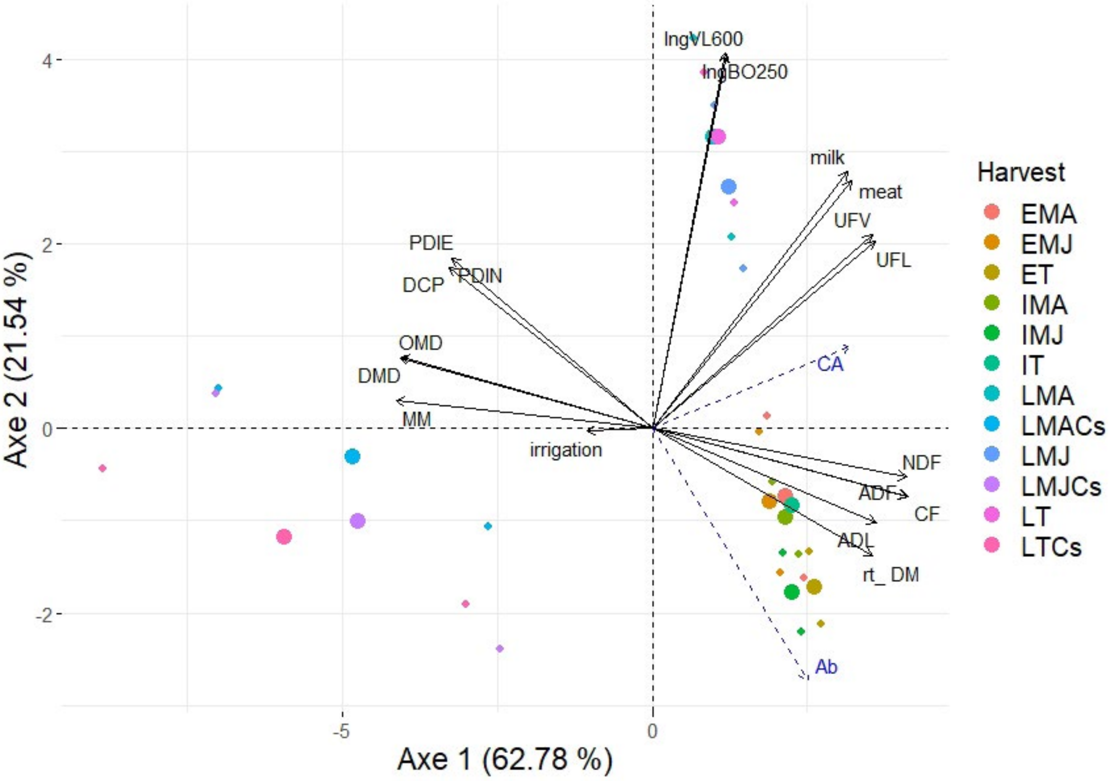


Figure 7: Principal component analysis of the quality of fodder collected at the CRZ of Dahra at the end of the 2021 rainy season following water regime treatments (IMA = addition of 100 mm in mid-August, IMJ = add of 100 mm or 120 mm in mid-July, IT = no irrigation and no harvest), of the harvest period (EMA = early harvest and addition of 100 mm in mid-August, EMJ = early harvest and addition of 100 mm in mid-July, ET = early harvest without addition of water, LMA = late harvest and addition of 100 mm, LMJ = late harvest and addition of 100 mm in mid-July, LT = late harvest without addition of water), and according to quality parameters: feed unit for lactation (UFL), feed unit for meat production (UFV), the ingestibility of fodder for cattle of 250 kg live weight (IngBo250, kg DM/day), the potential ingestibility of fodder for dairy cow of 600 kg live weight (IngVL600, kg DM/day), digestible crude protein (DCP, g), quantity of protein absorbed in the small intestine in conditions where nitrogen is the limiting factor of microbial protein synthesis (PDIN, g/kg MS), quantity of protein absorbed in the small intestine in conditions where energy is limiting factor of microbial protein synthesis (PDIE, g/kg MS), total mineral matter (MM, %DM), crude protein matter (CP, %DM), crude fiber (CF, %DM), neutral detergent fibers (NDF, %DM), acid detergent fibers (ADF, %DM), acid detergent lignin detergent fibres (ADL, %DM), organic matter digestibility (OMD, %DM), dry matter digestibility (DMD, %DM), dry matter rate (rt_DM), dry aboveground biomass (Ab, kg/ha), dry cumulated aboveground biomass (CA, kg/ha), meat production (meat, kg/day) and milk production (l/day), amount of water received (irrigation). Groups of individuals along axe 1 in solid circle and along axe 2 in dashed circle /// *Analyse en composantes principales de la qualité des fourrages collectés dans la CRZ de Dahra à la fin de la saison des pluies 2021 selon les traitements du régime hydrique (IMA = ajout de 100 mm à la mi-août, IMJ = ajout de 100 mm ou 120 mm à la mi-juillet, IT = pas d'irrigation et pas de récolte,), de la période de récolte (EMA = récolte précoce et ajout de 100 mm à la mi-août, EMJ = récolte précoce et ajout de 100 mm à la mi-juillet, ET = récolte précoce sans ajout d'eau, LMA = récolte tardive et ajout de 100 mm, LMJ = récolte tardive et ajout de 100 mm à la mi-juillet, LT = récolte tardive sans ajout d'eau), et en fonction des paramètres de qualité : unité d'alimentation pour la lactation (UFL), unité d'alimentation pour la production de viande (UFV), ingestibilité des fourrages pour les bovins de 250 kg de poids vif (IngBo250, kg MS/jour), ingestibilité potentielle des fourrages pour les vaches laitières de 600 kg de poids vif (IngVL600, kg MS/jour), protéines brutes digestibles (DCP, g), quantité de protéines absorbées dans l'intestin grêle dans des conditions où l'azote est le facteur limitant de la synthèse microbienne des protéines (PDIN, g/kg MS), quantité de protéines absorbées dans l'intestin grêle dans des conditions où l'énergie est le facteur limitant de la synthèse microbienne des protéines (PDIE, g/kg MS), matière minérale totale (MM, %DM), matière protéique brute (CP, %DM), fibres brutes (CF, %DM), fibres détergentes neutres (NDF, %DM), fibres détergentes acides (ADF, %DM), fibres détergentes acides et lignine (ADL, %DM), digestibilité de la matière organique (OMD, %DM), digestibilité de la matière sèche (DMD, %DM), taux de matière sèche (rt_DM), phytomasse aérienne sèche (Ab, kg/ha), phytomasse aérienne cumulée sèche (CA, kg/ha), production de viande (viande, kg/jour) et production de lait (l/jour), quantité d'eau reçue (irrigation). Groupes d'individus le long de l'axe 1 en cercle plein et le long de l'axe 2 en cercle pointillé*

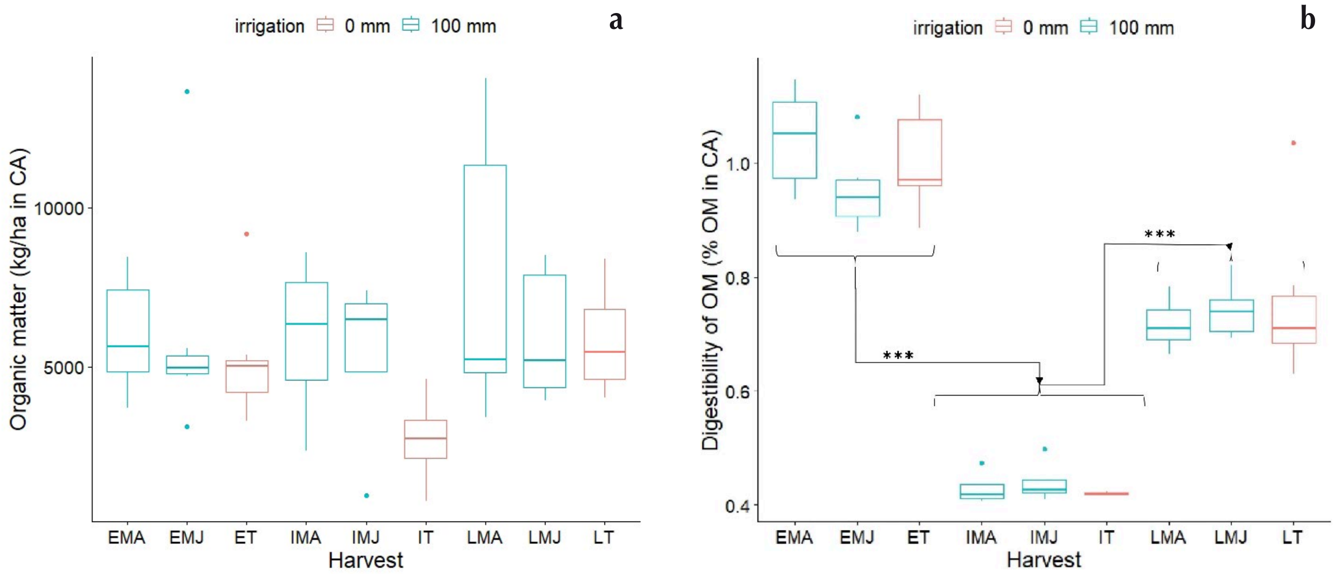


Figure 8: Organic matter in kg/ha (a), and rate of digestible organic matter in % organic matter (b) contained in the cumulated dry aboveground biomass (CA in kg/ha) collected during the season (27/07/2021 or 04/09/2021) and 12/10/2021 at the CRZ of Dahra depending to the quantity of water supplied and the start dates of water supply: IMA1 = addition of 120 mm in mid-August during 1 month, IMA = addition of 100 mm in mid-August during 2 months, IMJ1 = addition of 120 mm in mid-July during 1 month, IMJ = addition of 100 mm in mid-July during 2 months, IT = no addition of water, no harvest. The asterisk (*) represents a comparative statistically significant difference between treatments after post-hoc Bonferroni test : ***, $p < 0.001$ /// *Matière organique en kg/ha (a), et taux de matière organique digestible en % de matière organique (b) contenus dans les cumuls de phytomasse aérienne sèche (CA en kg/ha) collectés au cours de la campagne (27/07/2021 ou 04/09/2021) et le 12/10/2021 à la CRZ de Dahra en fonction de la quantité d'eau apportée et des dates de début d'apport d'eau : IMA1 = apport de 120 mm à la mi-août pendant 1 mois, IMA = apport de 100 mm à la mi-août pendant 2 mois, IMJ1 = apport de 120 mm à la mi-juillet pendant 1 mois, IMJ = apport de 100 mm à la mi-juillet pendant 2 mois, IT = pas d'apport d'eau, pas de récolte. L'astérisque (*) représente une différence statistiquement significative entre les traitements après le test post-hoc de Bonferroni : ***, $p < 0.001$*

■ DISCUSSION

The mean of the dry aboveground biomass of the control plot (2,932 kg ha^{-1}) was of the same order of magnitude as those measured by Diatta et al. (2021) at the CRZ in Dahra (2,500 to 3,000 kg ha^{-1}), Boudet (1991) in the so-called “Sahel type” zone (1,000 to 3,000 kg ha^{-1}), and Akpo (1998) in the Ferlo (2,310 to 4,360 kg ha^{-1}). The average quantities of dry aboveground biomass of the water regime treatments were of the same order of magnitude as those of the Sahelo-Sudanian border zone, where rainfall varies between 400 and 600 mm (1,300 to 5,000 kg ha^{-1} (Boudet, 1991)).

Effect of water regime on the amount of aboveground biomass at the end of the season

The water regime factor had no effect on the dry aboveground biomass produced at the end of the season. In other words, the plots that received 380 mm.m^{-2} of rainwater produced the same quantity of aboveground biomass as the irrigated plots with an additional supply of at least 100 mm for one or two months, applied from mid-July or mid-August. The mid-July irrigation started three days after a rain of 21.4 mm (13/07/2021) and an accumulation of 45.6 mm already received by the plots (Supplementary material V). The mid-August irrigation was carried out during the rainiest month with a cumulative rainfall of 237.0 mm.m^{-2} against 380.0 mm.m^{-2} during the full 2021 rainy season. This could have been due to an infiltration of a large part of the additional water brought by the irrigation on the sandy soil in mid-July or mid-August for one or two months. Sandy soils are quite permeable and have low water retention capacity. Indeed, the cumulated biomass produced during plant growth is mainly determined by soil fertility and rainfall (Penning de Vries, 1982). In addition, the quantities of rainwater received were sufficient to meet the plants’ needs. Similar results were observed by Boudet and Cheick (1986) in Mauritania. They suggest adding additional water at the start of the rainy season to allow more efficient water use by herbaceous plants.

Effect of harvest on the quantity of aboveground biomass according to harvest height

It was not statistically significative that plots harvested at 5 cm produced more aboveground biomass than plots harvested at 0 cm above ground level (Supplementary material II). This result could be explained by the presence of species with vital organs (at soil level or in the subsoil) and a stratum of basal plants below 5 cm. This hypothesis was also put forward by Boudet (1991), Fournier (1994) and Dieng and Buldgen (1997) and needs to be verified in a specific study. Based on this observation, we propose harvesting at 5.0 cm above the ground in order to preserve ground cover, avoid the risk of soil erosion and its consequences on soil fertility, and reduce greenhouse gas emissions. As shown by Klein et al. (2013), reducing the risk of erosion by covering the soil leads to the preservation of soil organic matter, which represents an important carbon sink. According to this suggestion, Yang et al. (2020) tested seven harvest heights (14 cm, 12 cm, 10 cm, 8 cm, 6 cm and less than 0.3 cm) at the Inner Mongolia University of China. They concluded that the optimum stubble height for sustainable harvests was 6–12 cm.

Effect of harvest on the quantity of aboveground biomass according to harvest period

The plots harvested on 04/09/2021 with additional water inputs from mid-August produced end-of-season aboveground biomass statistically equal to those of the other plots. This result could be partly explained by a maximum aboveground biomass value observed on one of the eight plots considered for the late harvest treatment for which the water supply started in mid-August. This plot received more water than the others because of a field management mistake. When this value is excluded, the results show that the aboveground biomass of early harvested plots was higher than that of late harvested plots.

The plots previously harvested on 27/07/2021 produced more aboveground biomass at the end of the experiment (12/10/2021) than those previously harvested on 04/09/2021 which did not receive water or where additional water supplies started in mid-July. This difference could be explained by the fact that the plots harvested at the end of July, at the beginning of the season when the rains are still sufficient and regular, were able to complete their vegetative cycle. Meanwhile the plots harvested at the beginning of September had to start their cycle again one month before the end of the rainy season and try to complete it with an accumulation of rain between 50 $mm.m^{-2}$ and 110 $mm.m^{-2}$ (Supplementary material V). A positive correlation exists between rainfall and the amount of aboveground biomass produced during the rainy season (Cisse, 1986; Boudet, 1991; Taugourdeau et al., 2018; Diatta et al., 2021) because of the devastating effects of the droughts during the last 15 years. For this purpose description and evaluation of the species composition of the herbage vegetation is needed, which is especially difficult because the predominance of annuals contributes to large differences from year and from place to place.The present thesis concerns research on the interaction between the properties of species, rainfall, substrate and way of exploitation, as reflected in the dynamics of the rangeland vegetation. This research was executed in Niono in Mali in the South of the Sahel at an average rainfall of 600 mm per year. Experiments were done on sand, loam and clay soils. Natural rainfall was varied by shielding against rain and additional sprinkling. The main annual species were studied throughout the growing season from germination to seed production. Auto-ecological experiments in the field and under controlled conditions provided additional information about the species response to environmental differences. The observed changes in the absolute and relative contribution of the species in terms of number and biomass clarified the role of various plant properties in conjunction with rainfall amount and distribution, substrate properties and management. Important properties of the species that govern the dynamics of the vegetation are germination rate, drought resistance of the young seedlings, type of photosynthesis (C 3 or C 4) . However, the cumulated aboveground biomass collected on the early harvest plots (27/07/2021 + 12/10/2021) was not statistically different from that of late harvest plots (04/09/2021 + 12/10/2021). This result showed that if we cut the grass to feed the animals or let them graze different plots on two different dates (one during the rainy season and one at the end of the season), the cumulated amount of forage provided to the animal would be the same on both types of plots. The production of herbaceous aboveground biomass is mainly linked to rainfall and frequency of rain in the Sahel (Hiernaux et Fernandez-Rivera, 1999).

Effect of water regime and harvest on the chemical composition of dry aboveground biomass

Forage from plots that tested different water regimes had a similar chemical composition. DM rates (between 92.7 ± 0.5 and 93.3 ± 0.3%) were similar to those found in the literature (Cisse, 1986; Boudet, 1991; Diatta, 2021 because of the devastating effects of the droughts during the last 15 years. For this purpose description and evaluation of the species composition of the herbage vegetation is needed, which is especially difficult because the predominance of annuals contributes to large differences from year and from place to place. The present thesis concerns research on the interaction between the properties of species, rainfall, substrate and way of exploitation, as reflected in the dynamics of the rangeland vegetation. This research was executed in Niono in Mali in the South of the Sahel at an average rainfall of 600 mm per year. Experiments were done on sand, loam and clay soils. Natural rainfall was varied by shielding against rain and additional sprinkling. The main annual species were studied throughout the growing season from germination to seed production. Auto-ecological experiments in the field and under controlled conditions provided additional information about the species response to environmental differences. The observed changes in the absolute and relative contribution of the species in terms of number and biomass clarified the role of various plant properties in conjunction with rainfall amount and distribution, substrate properties and management. Important properties of the species that govern the dynamics of the vegetation are germination rate, drought resistance of the young seedlings, type of photosynthesis (C 3 or C 4). According to Boudet's classification (1991), we can classify the quality of forage from mediocre (less than 0.45 UF and 25 g of DCP) to good (more than 0.50 UF and 34 g of DCP).

The principal component analysis (PCA) showed a negative correlation between CP and NDF (Figure 7). This result corroborates that of Archimède et al. (2009) in their study on the nutritive value of tropical forage. The older the forage, the greater the content of DCP, PDIE and PDIN decreases and the greater the content of fiber and cell wall constituents increases (Jarrige, 1988; Inra, 2010; Klein et al., 2013). The results of the PCA also showed that the forage from the plots studied could be classified into two groups according to the correlations between the variables of chemical and nutrient composition. Group 1 was composed of forage from plots with water regimes and harvested early during the season, while group 2 consisted of forage from plots that were harvested late. Group 1 forages were of lower quality because they had a chemical composition rich in crude fiber and lignin. Group 2 forages were of a better quality with a chemical composition (DCP, OMD, DMD, MM) and richer protein nutritional value (DCP, PDIE, PDIN), and likely to meet the nutritional needs of animals and allow the production of milk and meat. Group 2 plots underwent a late harvest at the fruiting stage of most species in a square during the season, while group 1 plots were composed of species at the end of their growth cycle. Group 2 forage was therefore composed of regrowth of herbaceous plants (legumes and grasses). Forage composed of green grasses and legumes, at young stages, make it possible to simultaneously achieve high energy density and high digestible protein intake (Baumont et al., 2009). In addition, the analysis of organic matter digestibility rates of the cumulated forage collected during the season and the digestible protein content of the intestine on the different plots, showed that these were higher in forage composed of two harvests when the organic matter content of the forage was equal. This result suggests that the harvesting practice carried out resulted in better forage digestibility. In other words, a forage composed of grass from the beginning or middle of the season and grass from the end of the season will be more digestible for the animal than forage consisting of grass collected only at the end of the season. Grazing pastures during the rainy season rather than only at the end of the season also allows ruminants to consume more digestible feed and thus contributes to reducing the levels of methane produced during enteric fermentation.

Limitations of the study

These results are based on data collected over one year with a few repeated measurements. However, they show the crucial importance of considering the correct height and period of forage harvest in sustainable pasture management in the Sahel.

■ CONCLUSION

Our analysis of the effects of water regime and harvest interactions reveals that the timing of harvests during the season is the crucial factor determining the quality and quantity of aboveground biomass produced at the end of the season. The quantity and quality of forage collected at the end of the rainy season varies depending on the periodicity of harvests carried out over the entire season. Plots that were harvested at the beginning of the rainy season (mid-July) produced forage that was similar to that of plots that were irrigated and harvested only at the end of the season. The lower amounts of forage from the late harvested plots showed better quality. These results confirm the influence of the phenological parameter on vegetative production. The establishment of forage resource management processes should therefore identify the period of use of pastures and consider the phenological stage of the plants that compose them. At the same time, the harvest height should be taken into account by favoring harvesting at 5 cm rather than at ground level to allow a reduction in the risk of erosion and conservation of organic matter in the soil to mitigate greenhouse gas emissions. This last option could be the subject of a more in-depth study to verify the long-term effect of a 5 cm cut on the quantity and quality of the forage produced and the impact on soil organic matter content.

Supplementary materials

Supplementary materials for this article can be viewed at the link https://doi.org/10.19182/remvt.37286

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Conflicts of interest

The authors declare that there is no conflict of interest.

Author contributions

AJAN, ST, PS, DN, SD, OD, and OD contributed to the study design, supervision of data collection, data analysis and interpretation, writing the original draft of the manuscript, and the critical review of the manuscript. HH and CF contributed to all of these activities except the design of the study and the drafting of the first version of the document. LB and DB contributed to the acquisition of spectral data and the critical review of the document.

Ethics approval and informed consent

As this study did not use data obtained from animals or people, ethics approval was not required for this study.

Data Availability

The data were not deposited in an official repository. The data that support the study findings are available from the authors upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors did not use any artificial intelligence-assisted technologies in the writing process.

REFERENCES

Akpo L.E., 1998. Effet de l'arbre sur la végétation herbacée dans quelques phytocénoses au Sénégal. Variation selon un gradient climatique. Thèse Doct. d'Etat en sciences naturelles, Université Cheikh Anta Diop, Dakar, Senégal, 142 p.

Andueza D., Picard F., Jestin M., Andrieu J., Baumont R., 2011. NIRS prediction of the feed value of temperate forages: efficacy of four calibration strategies. *Animal*, **5** (7): 1002-1013, doi: 10.1017/S1751731110002697

Archimède H., Sauvant D., Assoumaya C., Fanchone A., Boval M., 2009. Fourrages tropicaux: Valeur alimentaire comparée aux fourrages tempérés et évaluation au pâturage. In: 16^{éme} Renc. Rech. Ruminants, INRA, France, pp. 16-24

Assouma M.H., Hiernaux P., Lecomte P., Ickowicz A., Bernoux M., Vayssières J., 2019. Contrasted seasonal balances in a Sahelian pastoral ecosystem result in a neutral annual carbon balance. *J. Arid Environ.*, **162**: 62-73, doi: 10.1016/j.jaridenv.2018.11.013

Bastianelli D., Bonnal L., Barre P., Nabeneza S., Salgado P., Andueza D., 2019. La spectrométrie dans le proche infrarouge pour la caractérisation des ressources alimentaires. *INRA Prod. Anim.*, **31** (3): 237-254, doi: 10.20870/productions-animales.2018.31.2.2330

Baumont R., Aufrere J., Meschy F., 2009. La valeur alimentaire des fourrages : rôle des pratiques de culture, de récolte et de conservation. *Fourrages*, **198**: 153-173

Behnke R.H., 2000. Equilibrium and non-equilibrium models of livestock population dynamics in pastoral Africa: their relevance to Arctic grazing systems. *Rangifer*, **20** (2-3): 141-152, doi: 10.7557/2.20.2-3.1509

Boudet G., 1991. Manuel sur les pâturages tropicaux et les cultures fourragères. Orstom. Ministère des relations extérieures, France, 255 p.

Boudet G., Cheick A.W.O., 1986. Recherches sur les pâturages et leur conservation en Mauritanie., ACCT, Paris, France, pp. 79-87

Cisse A.M., 1986. Dynamique de la strate herbacee des paturages de la zone sud-sahelienne. Landbouwhogeschool Wageningen, Pays-bas, 211 p.

Delon C., Galy-Lacaux C., Serça D., Loubet B., Camara N., Gardrat E., Saneh I., et al., 2017. Soil and vegetation-atmosphere exchange of NO, NH3, and N2O from field measurements in a semi arid grazed ecosystem in Senegal. *Atmospheric Environment*, **156**: 36-51, doi: 10.1016/j.atmosenv.2017.02.024

Derry J.F., Boone R.B., 2010. Grazing systems are a result of equilibrium and non-equilibrium dynamics. *J Arid Environ*, **74** (2): 307-309, doi: 10.1016/j.jaridenv.2009.07.010

Diatta O., 2021. Suivi saisonnier et interannuel de la strate herbacée des parcours sahéliens du Sénégal (CRZ Dahra, Nord Sénégal). Thèse Doct. en Biologie, Productions et Pathologies Animales, Université Cheikh Anta Diop de Dakar, Sénégal, 112 p.

Diatta O., Ndiaye O., Ngom D., Diatta S., Fensholt R., Tagesson T., Taugourdeau S., 2021. Réponses de la phytomasse herbacée aux fluctuations de la pluviométrie en milieu pâturé sahélien du Ferlo. *Fourrages*, **246**: 97-105

Diawara M.O., Hiernaux P., Sissoko S., Mougin E., Ba A., Soumaguel N., Diakité H.S., 2020. Sensibilité de la production herbacée aux aléas de la distribution des pluies au Sahel (Agoufou, Mali): une approche par modélisation. *Int. J. Biol. Chem. Sci.*, **14** (4): 1341-1353, doi: 10.4314/ijbcs.v14i4.14

Dieng A., Buldgen A., 1997. Andropogon gayanus var bisquamulatus, une culture fourragère pour les régions tropicales. Les presses agronomiques de Gembloux, Belgique, 174 p.

FAO, 2020. Estimation des bilans fourragers dans la région du Sahel d'Afrique de l'Ouest et Centrale. FAO, Rome, Italie, 64 p.

Faustine K.A., Francis T.B. boli, Jean K.K., 2016. Etude Socio-Économique De L'exploitation Des Plantes Fourragères Dans Le District d'Abidjan (Côte d'Ivoire). *Europ. Sci. J.*, **12** (34): 357-357, doi: 10.19044/esj.2016.v12n34p357

Fournier A., 1994. Cycle saisonnier de la phytomasse et de la production herbacée dans les savanes soudaniennes de Nazinga (Burkina Faso) : comparaison avec d'autres savanes ouest-africaines. *Ecologie*, **25** (3): 173-188

Hiernaux P., Fernandez-Rivera S., 1999. Grazing rotation in the annual-dominated rangelands of the Sahel. In: People and Rangelands Building the Future VIth International Rangeland Congress. Aitkenvale, Qld, Australia, pp. 513-514

Inra, 2010. Tables d'alimentation des bovins, ovins, caprins. Besoins des animaux - Valeurs des aliments.. Editions Quae, Versailles, France, 315 p.

Jarrige R., 1988. Alimentation des bovins, ovins et caprins. INRA Editions, Paris, France, 471 p.

Klein H.D., Rippstein G., Huguenin J., Toutain B., Guerin H., Louppe D. 2013. Les cultures fourragères. Editions Quae, Versailles, France, 264 p., doi: 10.35690/978-2-7592-2169-1

Levang P., Grouzis M., 1980. Méthodes d'études de la biomasse herbacée de formations sahéliennes: application à la Mare d'Oursi, Haute-V. *Acta oecologica. Série Oecologia plantarum Montreuil*, **1** (3): 231-244

NASA P., 2021. POWER | Data Access Viewer https://power.larc.nasa.gov/data-access-viewer/ (consulté le 21 novembre 2023)

Ndiaye O., 2015. Déterminants de la dynamique de la végétation d'un milieu pâture en région sahélienne du Sénégal. Thèse Doct.unique en Biologie, Productions et Pathologies Animales, Université Cheikh Anta Diop de Dakar, Sénégal, 130 p.

Nicholson S.E., Fink A.H., Funk C., 2018a. Assessing recovery and change in West Africa's rainfall regime from a 161-year record. *Int. J. Climatol.*, **38** (10): 3770-3786, doi: 10.1002/joc.5530

Nicholson S.E., Funk C., Fink A.H., 2018b. Rainfall over the African continent from the 19th through the 21st century. *Glob. Planet. Change*, **165**: 114-127, doi: 10.1016/j.gloplacha.2017.12.014

Nicholson S.E., Some B., Kone B., 2000. An Analysis of Recent Rainfall Conditions in West Africa, Including the Rainy Seasons of the 1997 El Niño and the 1998 La Niña Years. *J.. Clim.*, **13** (14): 2628-2640, doi: 10.1175/1520-0442(2000)013<2628:AAORRC>2.0.CO;2

Penning de Vries F.W.T. (Ed.), 1982. La productivité des pâturages sahéliens : une étude des sols, des végétations et de l'exploitation de cette ressource naturelle. PUDOC, Wageningen, Pays Bas, 525 p.

Richard D., Alary V., Corniaux C., Duteurtre G., Lhoste P., 2019. Dynamique des élevages pastoraux et agropastoraux en Afrique intertropicale. Collection Agricultures tropicales en poche, Quae. CTA, Presses agronomiques de Gembloux, 250 p., doi: 10.35690/978-2-7592-2895-9

Sakatai D.P., Folefack D.P., Balna J., Tize K.J., 2021. Vers une crise des plantes fourragères marchandes en zone soudano-sahélienne du Cameroun. *JEMED*, **4** (1): 27-43

Son D., Compaoré E., Bonkoungou S., Sangaré S., 2011. Effet du stress hydrique sur la croissance et la production du sésame (Sesamum indicum). *J. Applied Biosci.*, **37**: 2460-2467

Tagesson T., Fensholt R., Guiro I., Rasmussen M.O., Huber S., Mbow C., Garcia M., et al., 2015. Ecosystem properties of semiarid savanna grassland in West Africa and its relationship with environmental variability. *Glob. Change Biol.*, **21** (1): 250-264, doi: 10.1111/gcb.12734

Taugourdeau S., Ndiaye O., Diatta O., Assouma M.H., 2018. Dynamic of herbaceous biomass during the wet season in the Sahel. In: Sustainable meat and milk production from grasslands. Wageningen Academic Publishers, (Grassland science in Europe, 23) European Grassland Federation General Meeting. 27, Cork, Irlande, 17-21 Juin 2018, pp. 676-678

Xu D., Wang K., 2007. [Application of near-infrared spectroscopy to management of vegetation for natural grassland]. *Guang Pu Xue Yu Guang Pu Fen Xi*, **27** (10): 2013-2016

Yang Z., Minggagud H., Baoyin T., Li F.Y., 2020. Plant production decreases whereas nutrients concentration increases in response to the decrease of mowing stubble height. *J. Env. Manag.*, **253**: 109745, doi: 10.1016/j.jenvman.2019.109745

Résumé

N'Goran A.A.J., Ndiaye O., Diatta O., Ngom D., Diatta S., Haftay H., Fassinou C., Bonnal L., Bastianelli D., Salgado P., Taugourdeau S. Impact du régime hydrique et de la gestion des récoltes sur la quantité et la qualité du fourrage herbacé dans l'écosystème sahélien au Sénégal

Le climat et la fauche influencent la production fourragère au Sahel. Cependant, l'effet combiné de ces paramètres reste à évaluer. Cette étude vise à évaluer l'effet conjoint de la pluviométrie et des pratiques de fauche sur la quantité et la qualité des fourrages. Des échantillons de phytomasse ont été prélevés au cours et à la fin de la saison des pluies 2021 par coupe intégrale sur 68 parcelles : 20 parcelles avec différents régimes hydriques et 48 parcelles avec différentes quantités d'eau combinées à différentes hauteurs et périodes de fauche. Les valeurs de la phytomasse sèche étaient respectivement comprise entre 2 932,2 ± 1 672,1 et 6 383,6 ± 2 962,6 kg/ha, 2 397,7 ± 6 263,4 et 15 059,2 ± 9 782,9 kg/ha pour les traitements de régime hydrique et du cumul de phytomasse fauchée. Le taux de cellulose brute (en % de Matière sèche) était compris entre 5,5 ± 0,9 % et 6,4 ± 1,2 %. La matière azotée digestible a varié entre 21,8 ± 67,96 et 67,2 ± 15,8 %. Quelle que soit la quantité d'eau reçue, des quantités et qualités équivalentes de fourrages ont été produites par les parcelles non fauchées et celles fauchées au début du cycle de développement des espèces. Pour une fauche à 0 ou 5 cm au-dessus du sol, la quantité de phytomasse était la même. Les parcelles fauchées au stade de fructification des espèces ont produit des fourrages composés de jeunes plantes en quantités plus faibles et de bonne qualité. La quantité et la qualité de fourrage herbacé en fin de saison des pluies ont surtout été influencées par le stade phénologique. Les programmes de gestion des ressources fourragères devront privilégier des périodes et hauteurs de coupe permettant une couverture optimale du sol afin de réduire les risques d'érosion.

Mots-clés : Fourrage, production de biomasse, composition chimique, valeur nutritive, Sahel

Resumen

N'Goran A.A.J., Ndiaye O., Diatta O., Ngom D., Diatta S., Haftay H., Fassinou C., Bonnal L., Bastianelli D., Salgado P., Taugourdeau S. Impacto del régimen hídrico y de la gestión de los cultivos en la cantidad y calidad del forraje herbáceo en el ecosistema saheliano de Senegal

El clima y la siega influyen en la producción forrajera del Sahel. Sin embargo, falta evaluar el efecto combinado de estos parámetros. Este estudio tiene como objetivo evaluar el efecto conjunto de la pluviometría y de las prácticas de siega en la cantidad y calidad de los forrajes. Se recogieron muestras de fitomasa durante y al final de la estación lluviosa del 2021 mediante corte integral en 68 parcelas: 20 parcelas con diferentes regímenes hídricos y 48 parcelas con diferentes cantidades de agua combinadas con diferentes alturas y períodos de siega. Los valores de la fitomasa seca estaban comprendidos, respectivamente entre 2 932,2 ± 1 672,1 y 6 383,6 ± 2 962,6 kg/ha, 2 397,7 ± 6 263,4 y 15 059,2 ± 9 782,9 kg/ha para los tratamientos del régimen hídrico y de la acumulación de fitomasa segada. La tasa de celulosa bruta (en % de materia seca) estaba comprendida entre 5,5 ± 0,9 % y 6,4 ± 1,2 %. La materia nitrogenada digerible varió entre 21,8 ± 67,96 y 67,2 ± 15,8 %. Fuese cual fuese la cantidad de agua recibida, se produjeron cantidades y calidades equivalentes de forraje en las parcelas no segadas y las segadas al principio del ciclo de desarrollo de las especies. Para una siega a 0 o 5 cm por encima del suelo, la cantidad de fitomasa fue la misma. Las parcelas segadas en el estadio de fructificación de las especies produjeron forrajes compuestos por plantas jóvenes en cantidades menores y de buena calidad. La cantidad y la calidad de forraje herbáceo al final de la estación lluviosa estuvieron especialmente influidas por el estadio fenológico. Los programas de gestión de recursos forrajeros deberían dar mayor importancia a los períodos y alturas de corte que permitan una cobertura óptima del suelo para reducir los riesgos de erosión.

Palabras clave: Forrajes, producción de biomasa, composición quimica, valor nutritive, Sahel