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Development of a model for estimating the biomass of pastures using normalized difference vegetation index (NDVI): the case of the Niassa pastoral zone in Burkina Faso

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Abstract

In Burkina Faso, livestock feeding is based on pasture productivity, which is a key factor in managing livestock productivity. As such, this management requires a good knowledge of pastures. However, the high cost of producing pasture data and the inaccessibility of pastures due to insecurity mean that there is a low availability or lack of data on pasture. This makes it difficult for stakeholders to take decisions to improve livestock feed in the event of a local food crisis. This is why this study aims to facilitate data production by developing a model for estimating herbaceous biomass in pastures using land observation tools. To this end, the study correlated biomass data collected on the ground with satellite imagery. A total of 24 the wooded, shrubby, and grassy savannahs and gallery forests vegetation units were used as ground observation stations. Simple multilinear regression was chosen for the correlation test. The model parameters gave an R^2 of 0.70, an RMSE of 236.7 kg DM/ha with a p-value of less than 0.0001 and an average production of 1,423 kg DM/ha. Based on these parameters, there is a strong relationship between vegetation indices and pasture biomass. The equation Y=45*Vav+9*Vmx-19*Rrg-2,256 derived from the model can be used to estimate pasture herbaceous biomass. This will improve the availability of data on pasture forage resources for better action planning in a context of insecurity.

Keywords: Pasture; Herbaceous biomass; NDVI; Estimation equation; Burkina Faso

1. Introduction

Agro-sylvo-pastoral activities are major contributor for the national economy in Sahel regions. These activities are based on the good performance of the land, which is an important resource for the national economy and food security. The livestock sector is one of the most important livelihoods components, where millions of people make at least part of their livelihoods [1]. In Burkina Faso, more than 80% of livestock-raising households practice extensive livestock system based on the mobility to ensure their animal feeding need [2]. Due to the sparse and fragile nature of natural vegetation, livestock mobility is the best way for pastoralists to take advantage of the diversity of ecological niches in Sahelian landscapes. It is described as a complex subsistence system seeking to maintain an optimal balance between pasture, livestock, and people in uncertain and variable environments [3]. Thus, the survival of this farming system depends on pasture productivity, which is mainly linked to rainfall, soil fertility and the effects of human activity [4].

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Droughts and population growth have led to shortages of the fodder and water resources needed for livestock production and have also led to increased competition between the different users of natural resources [5]. These factors, coupled with the poor availability of pasture production data, make it difficult to take decisions to anticipate and manage livestock feed crises, and for technical and financial partners to intervene to alleviate fodder shortages. This situation has been exacerbated by the inaccessibility of localities due to insecurity, which has made it difficult to collect field data, especially data on pasture production.

In this context, the availability of pasture fodder production data is necessary to direct livestock movements and improve the level of decision-making by both livestock farmers and policymakers with a view to managing pastoral food crises. It is for this reason that the use of monitoring and spatial observation methods based on remote sensing data is proving to be appropriate in these types of situations where the accessibility of areas has become critical. The aim of this study is to improve the provision of data on pasture production using remote sensing to facilitate decision-making for the management of the food situation of livestock in a context of insecurity.

2. Material and Method

2.1. Study area

Niassa pastoral area is created in 2000 under the terms of joint decree No. 2000-37/MRA/AGRI/MEE/MEF/MATS/MEM/MIHU of 21/7/2000. It is located to the east of Gogo Commune, Zoundwéogo District [6]. It lies between parallels 11°30'35' and 11°39'13'' north latitude; meridians 0°47'25'' and 0°52'54'' west longitude. This pastoral area is bounded on the east and north by Lake Bagré, on the south by the Koulwoko river and on the west by the villages of Samtenga, Yirpala, Kopelin and Nagrigré (Figure 1).

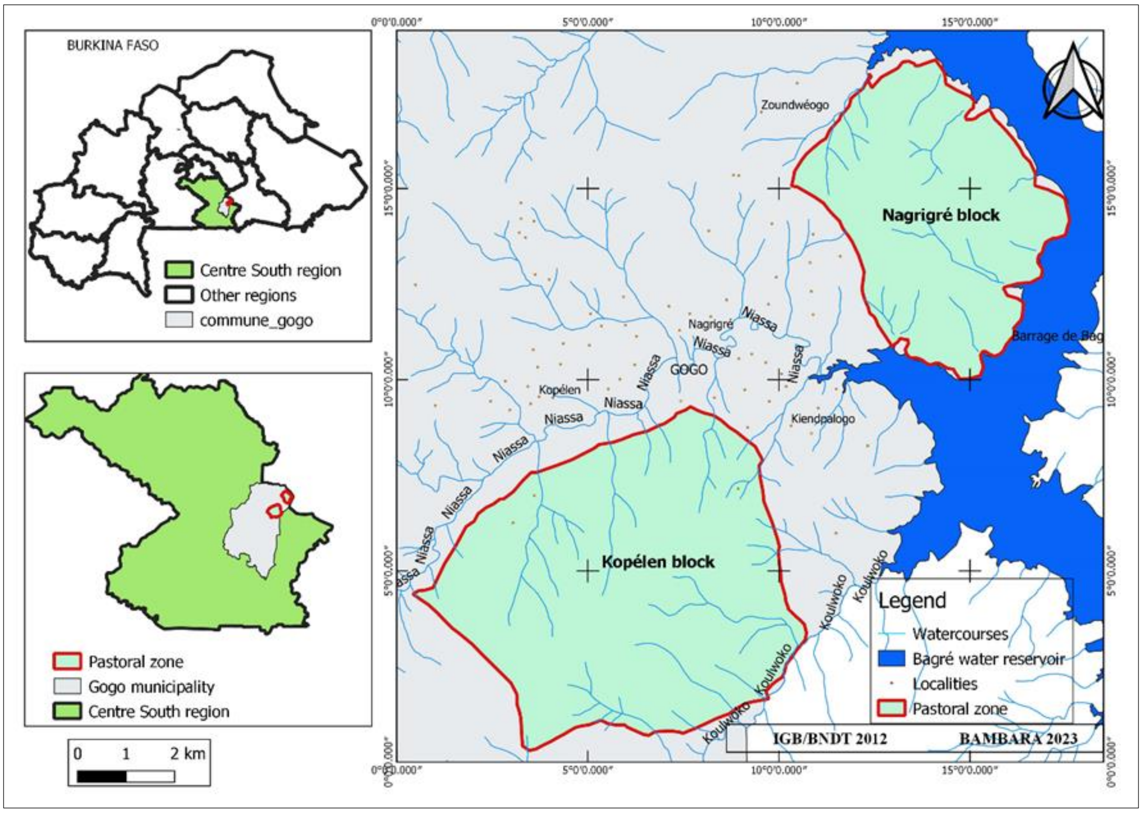

Figure 1 Map Niassa pastoral zone

It covers an area of 6, 386 ha divided into two (02) separate blocks separated by an agricultural front approximately 7 km wide. The first block covers an area of 4,374 ha (Kopelin block) and the second block, located to the north, covers an area of 2,012 ha (Nagrigré block). The pastoral area is divided into four (04) sectors not yet marked. These are Nagrigré, Kopelin, Mbouta and Tansablogo.

This zone was created by Burkina Faso government to support pastoralists in their search of quality and quantity pastoral resources. By creating this pastoral zone, the State aimed to rationalize access to pastoral resources, to promote the adaptation of pastoralists to the effects of climate change while promoting the peaceful coexistence of agriculture and livestock activities. However, it is under multiple pressures that compromise its original objectives.

2.2. Ground Data Collection

2.2.1. Choice of vegetation units

For the ecological characterisation of the study area, field trips were done for a better understanding of the physical organisation of the environment and the identification of the homogeneous vegetation units. Thus, the definition of vegetation units was based on the results of the land use survey. As a result, the work was carried out on four (04) vegetation units, namely herbaceous savannah, woody savannah, shrubs savannah and galleries forest. A reasoned choice of observation station was made based on the accessibility of vegetation units. Sampling of 24 observation stations was based on a repetition of 03 stations per vegetation unit in each block. Each observation station has a surface area of 50 m x 50 m, within which the various operations were carried out. All vegetation units were georeferenced using GPS.

2.2.2. Phytomass vegetation units' assessment

The herbaceous phytomass (primary production of herbaceous plants) was estimated using the full harvest method of Grouzis [7] and Fournier [8]. It took place from the third dekad of September 2022 to the first dekad of October 2022. To do this, 10 square plots measuring 1m x 1m ($1m^2$) were laid out at random in each observation station, and all the phytomass within the plot was mown and weighed. Thus, 60 square plots were assessed per vegetation unit. In addition, two (02) 250 g samples of phytomass were taken from each station and dried in the shade to constant weight to assess the quantity of dry matter.

2.2.3. Normalized Difference Vegetation Index (NDVI)

The NDVI images used are freely available data from the Copernicus Global Land Service (CGLS) website: https://land.copernicus.vgt.vito.be/ 11 November 2022. They were uploaded by File Transfer Protocol (FTP) with the Filezilla application. They come from the sensor of the Sentinel satellite 3, whose pixel resolution size is 300 m×300 m with a reference coordinate system expressed in Geodetic Parameter Dataset (EPGS: 4326) and projection in World Geodetic System (WGS 84). The decadal NDVI images have been uploaded for the rainy season period from the first decade of May to the third decade of October. They are given in digital accounts, that is, coded between 0 and 255 Digital Number (DN). The index is based on the reflectance property of the vegetation cover in the visible "red" spectrum (R) and in the "near infrared" (NIR). It is obtained by the following formula:

$$NDVI=(NIR-R)/(NIR+R)$$

2.2.4. Phenological metrics of vegetation

Table 1 Seasonal parameters

Order No.	Abbreviation	meaning
1	Vav	*Average value (or Mean)*
2	Vmn	*Minimum Value*
3	Vmx	*Maximum value*
4	Aup	*Largest increase (angle) between subsequent periods*
5	Adn	*Largest decrease (angle) between subsequent periods*
6	Rrg	*Relative Range (Maximum - Minimum)*
7	Rsd	*Relative Standard deviation (with N as denominator, not N-1)*
8	Dmn	*Relative date of first Vmn*
9	Dmx	*Relative date of last Vmx*
10	Dup	*Relative date of first Aup*
11	Ddn	*Relative date of last Adn*

The rate of vegetation growth can be captured from a change curve called a seasonal profile derived from NDVI values. The shape of the change curve given by the radiometric signal depends on the response of vegetation to precipitation over time. Representing the evolution curve in a two-dimensional plane allows you to identify specific points or regions that define 11 parameters called seasonal or phenological vegetation metrics. A short definition of these seasonal metrics is given in Table 1.

2.3. Data processing

QGIS version 3.4.12, SPIRITS, JUMP and Microsoft Office Excel were used to process the data.

The SPIRITS software is a software for processing and interpreting the time series of remote sensing images. The software was developed by the Flemish Institute for Technological Research (VITO) and the European Commission's Joint Research Centre (JRC) for monitoring vegetation conditions from medium and low-resolution satellite images. As part of this work, it was used to extract phenological metrics from vegetation. In addition, the QGIS software used to extract the seasonal NDVI metrics.

2.3.1. Observed stations phytomass assessment

The average yield of the phytomass of each plant is calculated on the basis of the average percentage of dry matter of the two (02) samples taken. This yield was expressed in kilograms (kg) of dry matter per hectare (ha). Then, using GIS environments, the average normalized vegetation index of each site is extracted. This index is correlated with the ground data collected for the regression equation. Finally, the integrated biomass estimate for each plant was generated.

2.3.2. Extraction of phenological metrics from vegetation

The 11 phenological vegetation metrics or seasonal parameters were extracted using SPIRITS software (Software for the Processing and Interpretation of Remotely sensed Image Time Series), which is freely available at http://spirits.jrc.ec.europa.eu/. It has been designed and recommended for monitoring and evaluating agropastoral campaigns using satellite data. Its use during processing was marked by the creation of import, smoothing and extraction scenarios for seasonal parameters or metrics. Smoothing is an operation that reduces the effect of clouds on images and improves product quality. The filter used for smoothing is the SWEPS filter. The polygons of 24 sampled observation stations were generated using QGIs. This was used to extract the 11 seasonal parameters for the different stations. This made it possible to reconstitute the database for the development of the forage yield estimation model with JUMP. The main steps of image processing with SPIRITS and Qgis software are given in Figure 2.

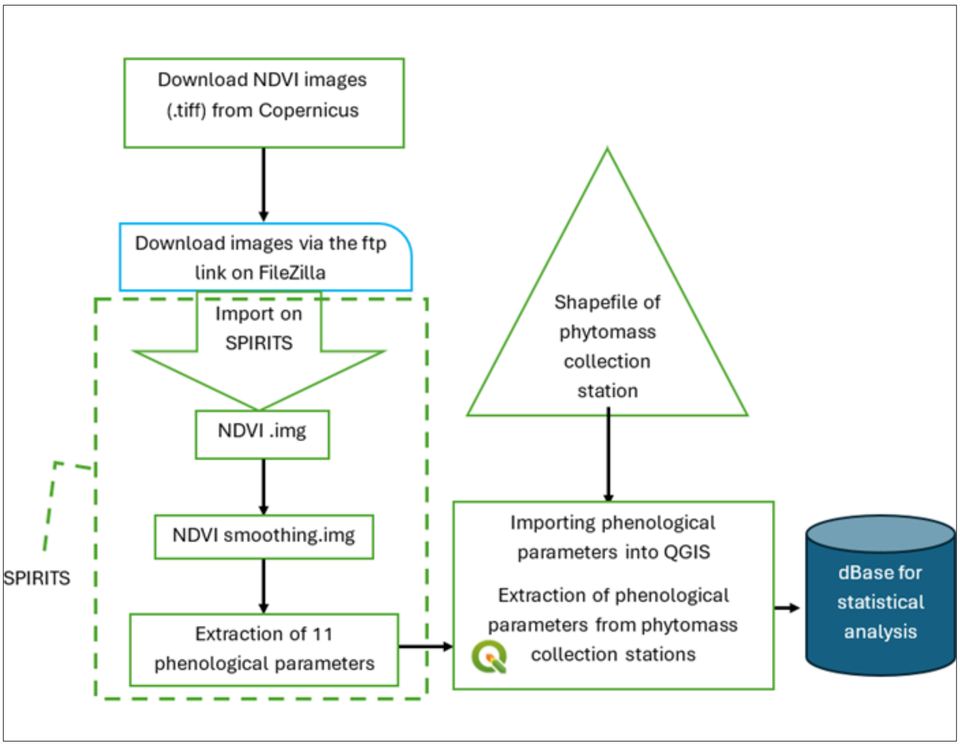

Figure 2 Main steps for extracting seasonal parameters

2.3.3. Choice of multilinear regression model

The correlation consists coupling NDVI metrics extracted from satellite images with biomass measurements in the field. From this correlation, a model has been established so that, from a given satellite image, it is possible to assess the biomass yield of a plot at a defined time 't'. An estimated model using ground data and satellite products is used to quantify the biomass on a given entity on the ground. Statistical regression is only possible if there is a strong correlation between phytomass collected on the ground and seasonal NDVI metrics. For the construction of the model, the multivariate correlation test was used to select the seasonal NDVI parameters that correlate well with the phytomass at the observation stations. The terms used to assess the model's performance are the correlation coefficient R^2, the adjusted R and the errors, including the root mean square error (RMSE).

3. Results

3.1. Biomass production

The table 2 shows the phytomass production of the different vegetation units as well as the values of their phenological metrics for the season. This data was used to test the correlation between ground-based phytomass and the observation station season metrics. Biomass production varies from one vegetation unit to another and within the same plant. As a result, it varies from 890 kgDM/ha to 2293 kgDM/ha.

Table 2 Station efficiency and phenological metrics

Order No.	Unit	Station Code	Yield (kg DM/ha)	NDVI seasonal metrics										
				Dna	Aup	Ddn	Dmn	Dmx	Dup	Rrg	Rsd	Vav	Vmn	Vmx
1	Foret Gallery	FGS1BN	890	90	90	186	5	152	98	74	27	76	30	117
2	Foret Gallery	FGS3BN	1,018	90	90	150	5	135	90	80	28	87	33	127
3	Foret Gallery	FGS2BN	1,127	90	90	190	5	145	100	90	33	87	31	137
4	Foret Gallery	FGS2BS	2,080	90	91	190	5	145	110	103	38	98	38	160
5	Foret Gallery	FGS3BS	2,079	90	90	190	5	145	110	104	38	101	37	160
6	Foret Gallery	FGS1BS	2,293	90	90	190	5	145	100	111	39	110	36	167
7	Tree Savannah	SABS1BN	979	90	90	190	5	145	90	81	30	77	25	120
8	Tree Savannah	SABS2BN	1,279	90	90	170	5	145	100	105	39	88	29	153
9	Tree Savannah	SABS1BS	1,382	90	90	190	5	145	110	102	37	98	36	156
10	Tree Savannah	SABS2BS	1,700	90	90	190	5	145	110	108	39	101	35	163
11	Tree Savannah	SABS3BN	1,731	90	90	190	5	155	110	108	40	96	35	163
12	Tree Savannah	SABS3BS	1,905	90	91	160	5	135	95	116	42	102	32	168
13	Shrub Savannah	SarbS2BN	1,095	90	90	190	5	145	110	96	35	86	31	144
14	Shrub Savannah	SarbS1BN	1,187	90	90	177	5	145	97	101	37	88	29	149
15	Shrub Savannah	SarbS3BN	1,331	90	91	160	5	144	109	109	38	96	32	161
16	Shrub Savannah	SarbS1BS	1,360	90	91	190	5	135	110	109	38	101	35	164
17	Shrub Savannah	SabrS2BS	1,538	90	91	190	5	135	110	109	39	102	36	165
18	Shrub Savannah	SarbS3BS	1,677	90	91	190	5	145	100	115	43	100	34	170
19	Grass Savannah	SHS3BS	1,063	90	90	190	5	155	110	99	38	91	35	152
20	Grass Savannah	SHS2BN	1,079	90	91	190	5	145	110	109	42	92	27	156
21	Grass Savannah	SHS3BN	1,054	90	91	170	5	145	104	109	41	91	28	157
22	Grass Savannah	SHS1BN	1,188	90	90	190	5	135	90	108	39	93	30	158

23	Grass Savannah	SHS1BS	1,208	90	91	190	5	145	110	106	40	98	36	161
24	Grass Savannah	SHS2BS	1,911	90	91	190	5	145	110	122	45	109	35	179

Adn : Largest decrease (angle) between subsequent periods; Aup: Largest increase (angle) between subsequent periods; Ddn: Relative date of last And; Dmn: Relative date of first Vmn; Dmx: Relative date of last Vmx; Dup: Relative date of first Aup; Rrg: Relative Range (Maximum - Minimum) ; Rsd: Relative Standard deviation (with N as denominator, not N-1; Vav: Average value (or Mean); Vmn: Minimum value ; Vmx: Maximum value

3.2. Template

The table 3 shows the correlation between the different variables. Thus, the variables which have a strong correlation with the yield of the biomass of the stations (Y) are Rrg (60%), Rsd (52%), Vav (82%), Vmn (68%) and Vmx (69%).

Table 3 Results of the multivariate correlation test between the different variables

	Y	**Dna**	**Aup**	**Ddn**	**Dmn**	**Dmx**	**Dup**	**Rrg**	**Rsd**	**Vav**	**Vmn**	**Vmx**
Y	1.0000	0.2810	0.1949	0.1772	-0.2691	-0.0635	0.2782	0.6020	0.5277	0.8205	0.6805	0.6915
Dna	0.2810	1.0000	0.1762	-0.0477	-0.0225	-0.3179	0.1588	0.5335	0.5263	0.4622	0.1838	0.5187
Aup	0.1949	0.1762	1.0000	-0.1047	-0.1782	-0.3238	0.3322	0.5652	0.5653	0.4397	0.1464	0.5389
Ddn	0.1772	-0.0477	-0.1047	1.0000	0.4231	0.3487	0.4195	0.1125	0.1696	0.1556	0.2636	0.1594
Dmn	-0.2691	-0.0225	-0.1782	0.4231	1.0000	0.3204	0.2779	-0.1712	-0.1415	-0.1633	0.0439	-0.1409
Dmx	-0.0635	-0.3179	-0.3238	0.3487	0.3204	1.0000	0.3331	-0.1800	-0.0620	-0.2566	-0.0080	-0.1639
Dup	0.2782	0.1588	0.3322	0.4195	0.2779	0.3331	1.0000	0.4287	0.4422	0.4465	0.5543	0.5082
Rrg	0.6020	0.5335	0.5652	0.1125	-0.1712	-0.1800	0.4287	1.0000	0.9748	0.8412	0.3671	0.9781
Rsd	0.5277	0.5263	0.5653	0.1696	-0.1415	-0.0620	0.4422	0.9748	1.0000	0.7544	0.2875	0.9376
Vav	0.8205	0.4622	0.4397	0.1556	-0.1633	-0.2566	0.4465	0.8412	0.7544	1.0000	0.7226	0.9136
Vmn	0.6805	0.1838	0.1464	0.2636	0.0439	-0.0080	0.5543	0.3671	0.2875	0.7226	1.0000	0.5521
Vmx	0.6915	0.5187	0.5389	0.1594	-0.1409	-0.1639	0.5082	0.9781	0.9376	0.9136	0.5521	1.0000

For the construction of the model, three (03) variables were selected because of their good correlation with the stations' biomass production. These are Vav (Value of the mean), Vmx (Value of the Maximum) and Rsd (Standard deviation of the Range expressed as a percentage). The test performed yielded the results presented in Table 4, which gives an R2 of 0.70 and an RMSE of 236.7 kg DM/ha for an average production of 1 423 kg DM/ha.

Table 4 Test Settings

Parameters	**Values**
Square R	0.70
Adjusted Square R	0.67
Root of Mean Square Error	236.7
Average Response	1,423
Observations (or weighted sums)	24

The Table 5 presents the different parameters of the model, which allows to establish the equation of herbaceous biomasses yield production for the vegetation units of the pastoral zone of Niassa.

Table 5 Template Settings

Term	Estimate	Standard Error	t ratio	Prob. > |t|
Constant	-2256	546	-4.13	0.0005*
Rrg	-19	26	-0.73	0.4766
Vav	45	18	2.54	0.0197*
Vmx	9	26	0.34	0.7389

The model produced the following estimation equation:

$$Y = 45*Vav+9*Vmx-19*Rrg-2256$$

Where Y = Yield in Kg of DM/ha; DM = Dry matter; Vav = Value of the mean; Vmx = Value of the Maximum and Rrg = Relative value of the range given by the difference between the Maximum and the Minimum

From the analysis in Figure 3, the Pearson correlation coefficient r is significant with a very low p-value below 0.0001. This indicates that there is a strong relationship between biomass yield and NDVI metrics used for this purpose.

From the analysis of Figure 3, the Pearson correlation coefficient R^2 is significant with a very low p-value of less than 0.0001. This indicates that there is a strong relationship between the yield of biomass collected on the ground and the NDVI metrics used for this purpose.

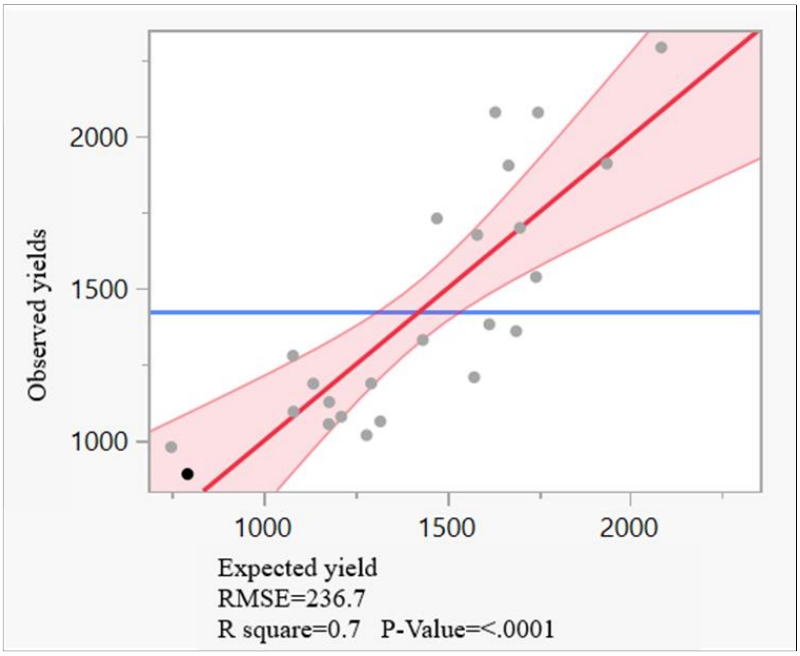

Figure 3 Observed values based on expected values

4. Discussion

Niassa pastoral area biomass productions varies widely within vegetation units and from one unit to another. Pasture biomass availability is influenced by the frequency of livestock graze in the unit at the time of assessment, because depending on the season; and pastoralists have preferences for the vegetation unit in which their livestock graze. They prefer to frequent grassy and shrub savannahs more than treed savannahs and gallery forests in the rainy season. In this case, these vegetation units could be overgrazed.

The value of fodder production from pastures varies widely within different vegetation units and from one unit to another. Pasture biomass availability is influenced by the grazing of animals at the time of assessment because the observation stations are open to grazing. Indeed, several authors who have worked on pastures have shown that the availability of herbaceous biomass in pastures is influenced by grazing intensity, the floristic composition and/or structure of herbaceous plants, rainfall, soil water stock and the nature of the soil substrate [9, 10, 11, 12, 13].

The R^2 found is higher than the founding of Diouf et al. [14] on Senegalese pastures. Those authors' R^2 varies from 0.21 to 0.52 depending on the year from the linear regression model. In Niger, the national assessment of pasture yielded an R^2 of 0.56 and an RMSE of 367 kg DM/ha [15]. In Burkina Faso, Bambara et al. [16] found an R^2 of 0.73 and an RMSE of 550 Kg MS/ha. On the *Brachiaria brizantha* plots in the Western Middle of Madagascar, the exponential correlation model between NDVI and the biomass collected on the ground gave an R^2 of 0.64 without giving the RMSE, which makes it possible to evaluate the estimation error [13]. The NDVI and biomass relationship model vary from one species to another and according to grazing practices. Thus, Alexandre [17] obtained very low correlation coefficients ($r^2 < 0.31$) to establish a relationship between tropical and temperate grazing biomass with NDVI. This could be explained by the heterogeneity of the grazing because livestock consume the most appetized grasses leaving the plot in a form of total heterogeneity between low palatable species and high unpalatable ones.

Several factors may influence the validity of biomass prediction models related to remote sensing. These factors are related to vegetation conditions and environmental factors. Indeed, the quality of remote-sensing products is often confronted with atmospheric conditions such as clouds, dust, haze, rain, and other aerosols which reduce the quality of the images including that of the product [18, 19]. It is also correlated by the response of plants to soil and climate conditions [15]. When vegetation cover is low, the signal measured by the sensor integrates both soil and vegetation reflectance. Grazing and mowing of the plots before images are taken have an impact on canopy reflectance and therefore on model calibration [14, 17, 20, 15, 13].

This model will provide timely data. To this end, it improves the framework for assessing the vulnerability of pastoral populations by identifying areas at risk of feed insecurity for livestock, and provides guidance to policymakers through the Harmonized Framework, which is a multi-sectoral framework for population vulnerability analysis and decision-making [14, 21]. The use of geographic information system tools makes it possible to estimate biomass production on a larger scale at territorial level. This contributes to pasture management based on biomass availability and livestock movement. This could reduce the risk of conflicts and feed shortages [19, 15]. Also, these tools, without replacing in situ data, offer a great possibility of having data anytime and anywhere without being in the field. This capability gives them an early warning and pasture management role, as well as providing data without being in the field. This will enable countries facing insecurity to have data while in the office. Regarding the results of different authors on the similar studies, the model found can be used to estimate pasture biomass. However, the model is not yet stable as it is the first year of experimentation. In this consideration, the investigation must continue for at least five years of season and in other pastoral areas of the country. The investigation must consider also woody biomass. This tool will help to make available biomass production data and contribute for decision-making on grazing land management which may enhance pastoralists resilience for livestock feed insecurity. For a model to be of high quality and more robust, it is important to have many samples that are very strong in time and space [22], i.e. a historical data series of at least five (05) years many time series, [22]. In the face of pasture degradation and insecurity, a bioavailability map would enable rural development stakeholders to act in response to potential food crises, and thus enable pastoralists and agro-pastoralists to better direct their livestock movements. It would therefore be wise to continue research, considering the forage biomass of woody plants and other parameters such as the effect of grazing.

5. Conclusion

This work shows that by linking remote sensing to ground-based biomass, it is possible to estimate the production of herbaceous biomass of a given entity when NDVI data are available for that entity. This tool makes it possible to quickly estimate the biomass and thus calculate fodder balance or to estimate the carrying capacity of a given area. This study improves the quality of information on the availability of fooder biomass. Knowledge of pasture e biomass production allows their better management in relating to fodder availability and livestock numbers. In the face of deteriorating pastures and insecurity, a bioavailability map would allow rural development actors to take action to respond to possible feed crises and thus allow pastoralists and agro-pastoralists to properly orient their livestock movement. It would therefore be wise to conduct further research, considering woody biomasses and other parameters such as the effect of grazing.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors (Ghislain Tontibomma BAMBARA; André KIEMA; Valérie M.C. BOUGOUMA-YAMEOGO; Abroulaye SANFO and Wièmè SOME) declare that they have no conflict of interest.

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