Relationship between normalized difference vegetation index (NDVI) and forage biomass yield in the Vakinankaratra region, Madagascar

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Abstract

Dairy cow production is an important livestock activity in the highlands of Madagascar and specifically in the Vakinankaratra region. Despite the increase of global milk production over the last decades, cow productivity remains low due to both quantity and quality feed constraints. Elephant grass and Italian ryegrass are the most cultivated forage grass, during the wet and warm season and the dry and cool season, respectively. An experiment under field conditions was carried out to evaluate the ability of the satellite-derived normalized difference vegetation index (NDVI) to develop a tool for estimating biomass yields of Elephant grass and Italian ryegrass. Results showed moderate to strong but significant relationship between plant height and biomass yield (R^2 = 0.64 to 0.92), between NDVI and biomass yield (R^2 = 0.52 to 0.73) and between NDVI and plant height (R^2 = 0.61 to 0.74) of Elephant grass and Italian ryegrass, respectively. These results suggest that NDVI has potential to provide a tool for dynamic monitoring and management of pastureland forage production.

Keywords: *biomass, forage, growth, monitoring, NDVI, precision agriculture, remote sensing*

Introduction

The agriculture sector is a major contributor to Madagascar's economy, employing 70% of the economically active population and accounting for about 29% of the GDP (WDI 2009; FAO/PAM 2010). The livestock sub-sector is a potential source of income for rural households (FAO 2009). In the highlands and specifically in the Vakinankaratra region, semi-intensive dairy cattle farming involved about 40 to 50% of the farmers in 2005 (INSTAT 2010).

Despite increased global milk production in this region which was estimated to be around 43 million liters in 2009, individual milk yields remain relatively low averaging 2,500 liters per cow per year (FIFAMANOR 2009). Low cow milk production per cow is mainly attributed to lack of feed and poor quality fodder. Basal diet is primarily consisted of natural pasture and crop residues of inherently low quality. Feed shortage is particularly severe during the dry and cool season, extending from April to September leading to severe body weight loss and milk yield decline. Owing to their good adaptability to zero-grazing, Elephant grass (Pennisetum purpureum) and Italian ryegrass (Lolium multiflorum) are the most cultivated forage grasses during the wet and warm season and the dry and cool season, respectively (Rakotondramanana 1999).

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A monitoring system of forage production could be suitable to improve ruminant feeding. For this purpose, remote sensing techniques applied in precision agriculture are alternative options as they provide tools for measuring spatial and temporal variability associated with crop growth. Remote sensing-based approaches also provide quick, reliable and long-term studies of pasture production at relatively low costs compared to conventional methods. Applications of remote sensing techniques in pastureland monitoring for crop type mapping and feed management improvement have been reported in numerous studies (Hill et al 1999; Seaquist et al 2003; Grigera et al 2007; Numata and Roberts 2007; Erdenetuya 2009). The most commonly used techniques involve satellite-derived vegetation indices such as the normalized difference vegetation index (NDVI).

The present study aims to investigate the correlations between NDVI and growth parameters of Elephant grass and Italian ryegrass in order to develop a large-scale and temporal biomass yield estimation tool for forage production monitoring and management in the Vakinankaratra region.

Material and methods

Experimental sites

The experiment on Italian ryegrass (Lolium multiflorum Lam. cv Tama) was carried out at one site (19° 48'S - 47° 08'E, 1,600 masl.) located in the Vakinankaratra region, in the central highlands of Madagascar from July to September 2012. The climate of the Vakinankaratra region is humid subtropical (Cwa type according to Köppen's classification) with a mean annual rainfall of 1,300 mm, a warm and wet season extending from October to March and a dry and cool season extending from April to September.

A total of six conventionally-tilled plots with standing Italian ryegrass grown under surface-irrigated conditions were chosen for the experiment. Three plots were freshly renewed swards (2-month old) and three plots were one year old established swards (14-months old). Plot size ranged from 0.5 to 0.8 ha (Figure 1).

The experiment on Elephant grass (Pennisetum purpureum) was also carried out at one site (19° 49'S - 47° 04'E, 1,550 masl) located in the Vakinankaratra region, from October to December 2012. Two conventionally-tilled plots of 1 and 2.5 ha with standing Elephant grass of 1 and 3 years old, grown under rainfed conditions were chosen for the experiment.

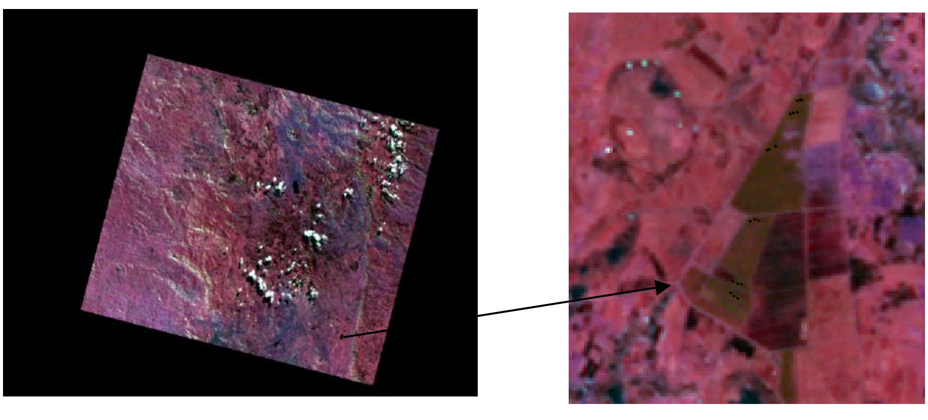

Figure 1: Satellite image acquisition (03 August 2012) showing Italian ryegrass experimental plots ©CNES (2012), Distribution Spot Image S.A

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Ground measurements of agronomic parameters

Ground measurements of above-ground biomass in Italian ryegrass and Elephant grass plots
Ground measurements of above-ground biomass in Italian ryegrass and Elephant grass plots were carried out during 6 to 8-weeks. They were conducted in the frequency of 1-week to 2-week to correspond with SPOT 5 satellite overpasses. Agronomic parameter measurements were performed on three to five random quadrats of 0.25 m² at each sampling date and within each plot. A buffer zone of 20 m was isolated from the borders of each plot to avoid pixels located in the buffer zone to be analyzed. Geographic coordinates of each quadrat were recorded using a Garmin 60 Global Positioning System (GPS) receiver.

Plant height was measured from the soil surface and fresh matter (FM) yield was evaluated after cutting the herbage to leave a stubble of 5.0 cm above ground level. Forage samples were taken from the harvested herbage, weighed and oven dried during 72 hours at 60°C. After drying, samples were weighed again for determination of dry matter (DM) content. DM yield was calculated from multiplying FM yield by DM content.

Satellite imagery

A serial, multispectral image from SPOT 5 satellite, with high spatial resolution (10 m) was scheduled with a temporal resolution of 15-day. Analysis of the multispectral images was accomplished using the image processing Earth Resource Data Analysis (ERDAS imagine ®) software. SPOT-5 images were first converted to top of atmosphere reflectance and NDVI was calculated using the standard equation (Rouse et al 1973): NDVI = (RNIR – RRED) / (RNIR + RRED) where RNIR was the reflectance of the near infrared band (790-890 nm) peak and R RED was the reflectance of red light band (610-680 nm) minimum.

The NDVI value, ranging from -1 to +1 increases with increased green biomass as a result of increased red reflectance due to greater absorption of incident red light by plant chlorophylls and decreased near-infrared reflectance associated with radiation scattering by the hydrated wall of leaf cells.

Statistical analysis

Agronomic and spectral data were imported into Genstat statistical software and subjected to statistical t-test, analysis of variance, linear and non-linear regression analysis (Buysse 2004).

Results and discussions

Agronomic data

Above-ground biomass measurements in Italian ryegrass plots were carried out at seven sampling dates (09 July 2012, 23 July 2012, 06 August 2012, 14 August 2012, 23 August 2012, 29 August 2012 and 07 September 2012). There were significant differences between the sampling dates and across the experimental plots but not for their interaction (unpublished data). Summary statistics of agronomic data collected over all sampling dates for each plot are reported in table 1. The highest values for fresh matter yield (5.12 kg m-2) and plant height (77.75 cm) were obtained from freshly renewed plots (plots 3 and 1, respectively).

Herbage ground measurements in Elephant grass plots were carried out at three sampling dates (30 October 2012, 13 November 2012, and 07 December 2012). Elephant grass fresh

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matter yield and height were also affected by sampling date and by plot but not by their interaction (unpublished data). Summary statistics of agronomic data averaged over all sampling dates for each plot are reported in Table 2. The highest values for fresh matter yield (2,292 kg m -2) and plant height (87cm) were recorded for the one year old stand. Glassey et al (2010) also reported higher biomass yield and quality of renewed swards compared to older established swards.

Table 1. Summary statistics for agronomic data of Italian ryegrass

Parameter	Size	Mean	Min	Max	St dev	Variance
FM yield (kg m^{-2})						
Plot 1*	18	1,660	0,252	3,676	1,088	1,184
Plot 2*	18	1,369	0,192	4,520	1,082	1,171
Plot 3*	18	1,802	0,220	5,120	1,485	2,206
Plot 4**	18	0,963	0,324	2,980	0,733	0,537
Plot 5**	18	1,184	0,348	4,252	0,907	0,823
Plot 6**	18	1,215	0,536	2,620	0,568	0,323
Plant height (cm)						
Plot 1*	18	44,36	22,50	77,75	18,57	344,9
Plot 2*	18	37,28	18,25	67,25	12,86	165,3
Plot 3*	18	44,96	22,25	72,38	17,01	289,3
Plot 4**	18	37,16	26,50	56,25	8,90	79,2

Min: minimum, Max: maximum, St dev: standard deviation, *: plot of 2-month old at the first sampling date, **: plot of 14-month old at the first sampling date

Table 2. Summary statistics for agronomic data of Elephant grass

Parameter	Size	Mean	Min	Max	St dev	Variance
FM yield (kg m^{-2})						
Plot 1*	10	0,975	0,300	2,292	0,619	0,383
Plot 2**	8	0,514	0,236	1,164	0,326	0,106
Plant height (cm)						
Plot 1*	10	50,43	22,33	87,00	22,45	504,1
Plot 2**	8	32,43	18,06	51,33	14,44	208,5

Min: minimum, Max: maximum, St dev: standard deviation,*: plot of 1-year old, **: plot of 3-year old

Relationships between agronomic data

Linear regression analysis of agronomic data averaged over all sampling dates and over all plots of the two forage grasses were reported in figures 2a and 2b. Figure 2a shows moderate but significant relationship ($R^2 = 0.64$; $P<0.001$; n=105) between fresh matter yield and plant height of Italian ryegrass. However, figure 2b shows strong and significant relationship ($R^2 = 0.92$; $P<0.001$; n=25) between fresh matter yield and plant height of Elephant grass. The moderate relationship between fresh matter yield and plant height of Italian ryegrass compared to Elephant grass may be related to the horizontal growth or the bunch-type growth habit of this forage grass. Harmony et al (1997) and Schmer et al (2010) also reported that plant height alone could be a good predictor of forage biomass yield.

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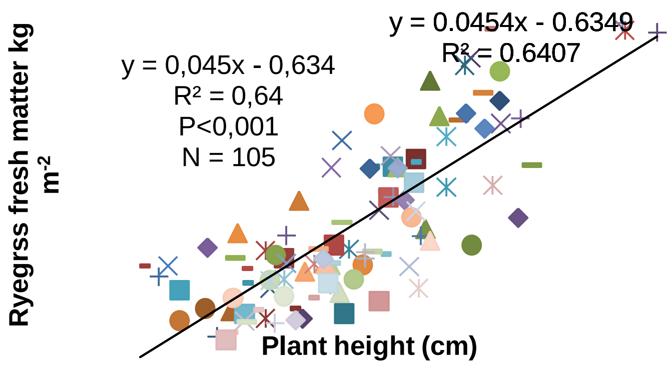

Figure 2a: Relationship between height and Italian ryegrass FM yield

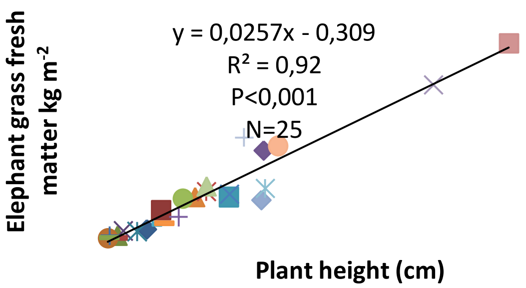

Figure 2b: Relationship between height and Elephant grass FM yield

Satellite images data

Owing to technical problems, the SPOT-5 data were acquired on 03rd August 2012 for Italian ryegrass plots and on 09th October, 15 th November and 05th December 2012 for Elephant grass plots. The NDVI values were related to sampling points at close sampling dates.

There were significant differences of NDVI values extracted from the single-date satellite image of Italian ryegrass plots across the experimental plots (table 3). The lowest mean NDVI values (0.417, 0.424 and 0.425) of NDVI were recorded for older stands (plots 4, 6 and 5, respectively) while the highest mean NDVI values (0.453, 0.444 and 0.443) were obtained from freshly renewed stands (plots 3, 2 and 1, respectively) (Table 4). The corresponding ground measurements indicated that the lowest mean FM yield values (0.576 to 0.943 kg m-2) and the highest mean FM yield values (1.884 to 2.933 kg m -2) were also recorded for older and younger stands, respectively (unpublished data).

Therefore, the narrow range of NDVI values (0.417 to 0.453) over relatively large range of FM yield values (0.576 to 2.933 kg m-2) could be attributed to the sensitivity of NDVI to factors not related to vegetation. In fact, one limitation in the use of NDVI arises from its susceptibility to factors that have no relationship with vegetation such as the variations in atmospheric conditions, the background reflectance and the sensor characteristics (Shin 2000; Gitelson 2003). Specifically, NDVI is reported to be highly sensitive to the atmosphere radiant energy absorbing and scattering. Visibility representing aerosol optical thickness, relative humidity or the proportion of the actual water vapor to the saturated water vapor in the atmosphere and temperature were important parameters in determining atmospheric effects on NDVI value. Therefore, satellite images should be preprocessed to remove the

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atmospheric effects before they are converted to NDVI images. Multi-temporal satellite image acquisitions are also required to select scenes least affected by the atmosphere effects.

Figure 3 shows the NDVI image of the study area on the 03rd August 2012 acquisition.

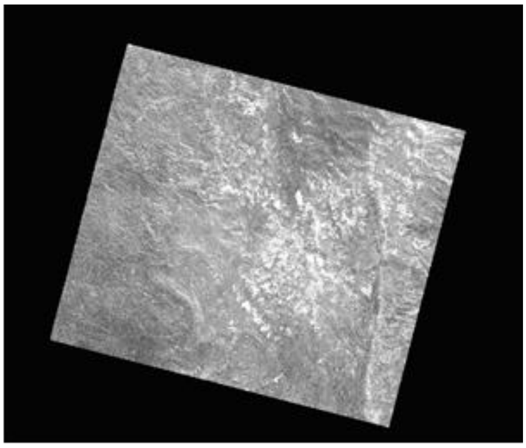

Figure 3: NDVI image of the study area from 03 August 2012 acquisition
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The NDVI values of Elephant grass extracted from the three satellite image acquisitions were affected by sampling dates but not by plot (table 3). The lowest mean NDVI value (0.239) and the highest mean NDVI value (0.702) were recorded for the first and the last sampling dates, respectively (table 4). The corresponding mean FM yield varied from 0.338 to 2.517 kg m-2 (unpublished data). Similar results of variation of NDVI values across sampling dates or phenological stages have also been reported by Gaston et al (1983) and Wagenaar and de Ridder (1986).

Table 3. Statistical t-test results of NDVI values

Parameter	**Forage grass**	**Size**	**Mean**	**SD**	**VR**	**SED**	**CI (95%)**	**P value**
NDVI	Elephant grass	25	0,475	0,197	0,0386	0,0393	(0,3942, 0,5565)	<0,001
	Italian ryegrass	18	0,434	0,0163	0,00026	0,0038	(0,4263, 0,4425)	<0,001

SD: standard deviation; VR: variance; SED: standard error of difference; CI: confidence interval for differences in mean

Table 4. Summary statistics of NDVI values

Parameter		**Size**	**Mean**	**Min**	**Max**	**St dev**	**Variance**
NDVI	**Elephant grass**						
	1st sampling date	9	0,239	0,193	0,257	0,0194	0,00037
	2nd sampling date	9	0,539	0,450	0,616	0,0562	0,00316
	3rd sampling date	9	0,702	0,623	0,739	0,0426	0,00182
	Italian ryegrass						
	Plot 1*	3	0,443	0,436	0,448	0,0061	0,000037
	Plot 2*	3	0,443	0,439	0,448	0,0047	0,000022
	Plot 3*	3	0,455	0,436	0,476	0,0201	0,000403
	Plot 4**	3	0,417	0,409	0,424	0,0075	0,000056
	Plot 5**	3	0,425	0,419	0,433	0,0072	0,000052
	Plot 6**	3	0,424	0,414	0,431	0,0091	0,000082

Min: minimum, Max: maximum, St dev: standard deviation, *: Italian ryegrass plot of 2-month at the first sampling date, **: Italian ryegrass plot of 14-month at the first sampling date

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Relationships between agronomic parameters and NDVI

There were moderate but significant linear relationships between NDVI and fresh matter yield ($R^2 = 0.68$; $P<0.001$; n=15), between NDVI and dry matter yield ($R^2 = 0.52$; $P<0.001$; n=15), and between NDVI and height of Italian ryegrass ($R^2 = 0.61$; $P<0.001$; n=15) (figures 4a, 4b and 4c, respectively). Numerous studies have reported correlations between NDVI and crop growth parameters (plant height, vegetation cover, yield) (Tucker and Sellers 1986; Todd et al 1998; Yang et al 2007; Mašková et al 2008; Dobignard 2011).

Figures 4d, 4e and 4f show moderately strong and significant exponential relationships between NDVI and fresh matter yield ($R^2 = 0.73$; $P<0.001$; n=25), between NDVI and dry matter yield ($R^2 = 0.69$; $P<0.001$; n=25), and between NDVI and height of Elephant grass ($R^2 = 0.74$; $P<0.001$; n=25). The fitness of the models is increased by exponential relationship ($R^2 = 0.69$ to 0.74) compared to linear relationship ($R^2 = 0.51$ to 0.56). The current results support the suggestion of a non-linear relationship between NDVI and ground measurements with saturation of NDVI values for high biomass values (Tucker et al 1986; Santin-Janin et al 2009).

Large changes in NDVI value at the two first acquisitions dates compared to the last acquisition date could be explained by the sensitivity of NDVI to the spatial distribution of green plant density or the increase of tiller density at the beginning of the growth cycle. In other words, vertical growth would have lower effect on NDVI values compared to tillering. The same findings have been reported in other studies (Weiser et al 1986; Serrano et al 2000).

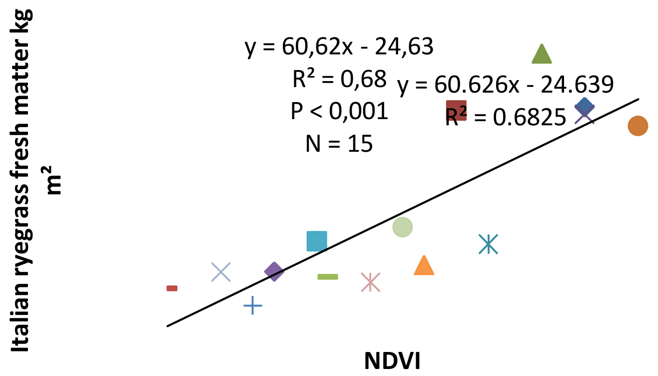

Figure 4a: Relationship between NDVI and Italian ryegrass FM yield

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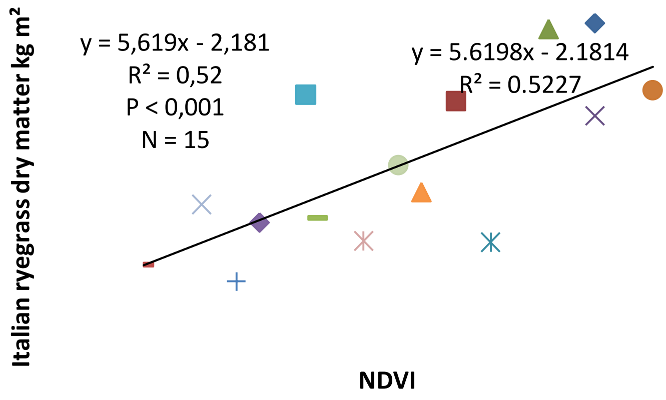

Figure 4b: Relationship between NDVI and Italian ryegrass DM yield

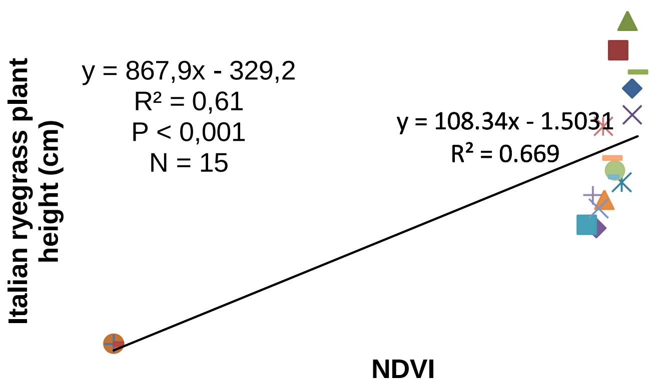

Figure 4c: Relationship between NDVI and Italian ryegrass height

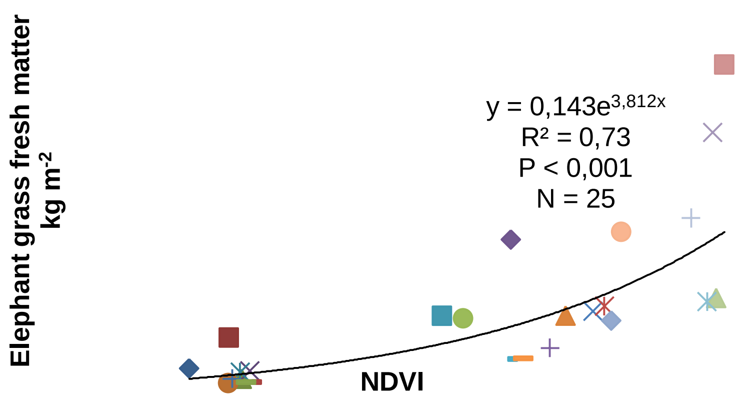

Figure 4d: Relationship between NDVI and Elephant grass FM yield

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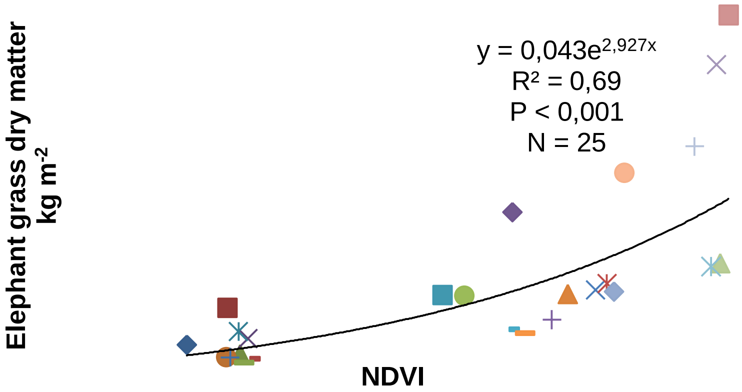

Figure 4e: Relationship between NDVI and Elephant grass DM yield

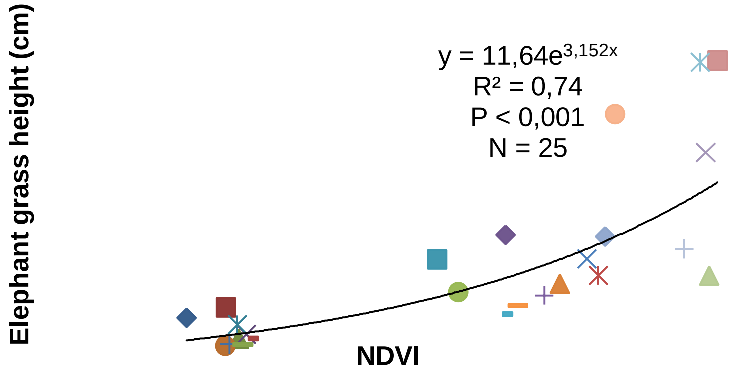

Figure 4f: Relationship between NDVI and Elephant grass height

Conclusion

Plant height and satellite-derived NDVI have potential for estimating biomass yield of Italian ryegrass and Elephant grass. Additional research is required to improve the fitness of the established models between NDVI and agronomic parameters, specifically for Italian ryegrass to provide the best input to forage management decisions and pasture characterization in the Vakinankaratra region.

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http://www.isis-cnes.fr/pages/statique/Multi%20HRG%20&%20SPOT%20DEM.pdf

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