Handheld NDVI Sensor-based Rice Productivity Assessment under Combinations of Fertilizer Soil Amendment and Irrigation Water Management in Lower Moshi Irrigation Scheme, Tanzania

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Abstract

Handheld Optical Sensor was used to measure canopy reflectance at red region (656 nm) and near-infrared region (774 nm) to generate NDVI data for monitoring rice productivity under soil amendment with combinations of fertilizers at two levels of water regime in smallholder Irrigation Scheme, in Lower Moshi, Tanzania. The study was carried out in an experimental design consisted of two irrigation water levels (flooding and system of rice intensification) with multi-nutrients (NPK) and single nutrient (urea) application replicated three times in a randomized complete block design. Flood irrigation water was applied at 7 cm height throughout the growing season, while SRI treatment irrigation water was applied at 4 cm height under alternate wetting and drying conditions. The annual rate of fertilizers applied was 120 kg N/ha, 20 kg P/ha, and 25 kg K/ha. The variety SARO-5 was used in this experiment. Simple correlation coefficient (r) was used to measure the degree of association between field crop performance parameters (plant height, number of tillers, biomass, yield) and NDVI across growth stages and three positions of the sensor above the canopy in the tested fertiliser combinations and water regimes. Results show that at any given fertiliser combinations and water levels, there was no significant correlation between plant height and NDVI except for the plant height at a vegetative stage for 0.6 m above the crop canopy and booting stage at 0.3 m and 0.6 m above the canopy respectively ($p < 0.05$). A good correlation was also observed between NDVI at booting and full booting stage regardless of the position of the sensor above the canopy and the number of tillers at full booting growth stage ($p < 0.05$). A significant relationship was observed between rice grain yield and NDVI at the vegetative, booting, and full booting stage. The simple linear regression models explained only slightly less than 30% of the yield predictions by NDVI at the early stage of the crop growth, decreasing gradually to 5% at the full booting growth stage. Results from this study have demonstrated a positive linear relationship between rice grain yield and NDVI for the tested soil fertiliser amendments and irrigation water regimes. The study conclude that handheld NDVI-based sensor can be used in smallholder rice yield predictions for optimising soil fertiliser use and irrigation water management.

1. Introduction

Grain crop production plays a dynamic role in the economy of Tanzania with the main crops being maize, rice, beans, sorghum, millet, wheat, cassava, potatoes, bananas, and plantains (URT, 2012). Rice (*Oryza sativa* L.) is a staple cereal crop that constitutes a major part of the diet for more than 230,000 smallholder households in Tanzania. It has been estimated that more than 60% of Tanzanian populations do eat rice frequently (Tusekelege et al., 2014). Tanzania is the second-largest rice producer in the Eastern and Southern Africa region (Drame *et al*., 2014). In 2009/10, the area under rice was 1,136,290 ha having a production of 2,650,120 tons with an average of 2.33 tons/ha (Rural Livelihood Development Company, 2009; Tusekelege et al., 2014). Rice production in Tanzania is mainly practiced in semiarid plains (Kanyeka et al., 1994; Hatibu, 1999). However, the semiarid plains of Tanzania are faced with poor soils, increased risks of soil degradation, soil fertility loss and increased frequency of drought under changing climate and dwindling water resources (Bell et al., 2015). This situation challenges the current agricultural practices and jeopardize the livelihood of smallholder famers households. In these areas, rains are so erratic that harvest is negligible and people survive on food-for-work.

The agricultural water demand in Tanzania exceeds the available water supplies (Katambara et al., 2013). For example, in about 70% of subsistence farmers in Usangu Plain in Tanzania, have limited access to the highly needed water resource for irrigation as well as for maintaining the ecosystem in the Ruaha National Park and beyond (Kadigi et al., 2007). Likewise, the demand for food to feed the growing population is increasing which calls for technologies and farming practices to ensure food securities at the same time reducing agricultural water use (Katambala *et al*., 2013). Rice in Tanzania is produced at subsistence level and most farmers practice continuous flooding, a practice that uses large amount of water. Rice water use efficiency (WUE) in Tanzania is estimated to be 0.3 kg grain yield/ha land with an average water demand for a single growing season to be 8000 m^3 water/ha land (Michael et al., 2014). Therefore, it is essential that new systems of rice production should be explored that will increase yields as well as increase water use efficiency in rice. Additionally, such systems should be tailored to smallholder farmers in that they require relatively low amounts of input such as fertilizers and water. One such systems currently promoted is the System of Rice Intensification (SRI). The System of rice intensification (SRI) is an array of practices developed to improve the productivity of rice grown in paddies. The system was first developed in Madagascar in 1980s through farmer experimentation by changing water application techniques, crop spacing and seedling age and later up scaled in other countries in Africa including East Africa (Katambara et al., 2013). SRI was developed as a rice-cultivation strategy that may offer an opportunity to increase rice yield with less external inputs in particular the use of less water in the face of changing climate (Uphoff, 2003).

In East and Southern African countries, and sub-Saharan Africa there is limited application of mineral fertilizer (Bationo et al., 2012). Continued extraction of nutrients in the form of crop yields and crop residues, soil erosion, and insufficient recycling of nutrients (such as compost or manure) has rendered the originally fertile soils very low-productive (Thierfelder et al. 2013). The combined average depletion rate of N, P and K of all SSA countries is 54 kg/ha/yr (Sommer et al., 2013). Thus, nutrient limitation is the major impediment for increasing yields especially of rice in Africa. Nutrient depletion rates vary significantly spatially, depending on the overall crop productivity level and farmer's access to fertilizer (Sommer et al., 2013). Therefore, site/region-specific knowledge of the soil fertility levels is thus a prerequisite for the establishment of profitable and sustainable nutrient management systems. According to Sommer et al. (2013), fertilizer recommendations developed in the past often ignored differences between soils and practices such as irrigation water regimes and are highly incompatible with smallholders' resources. Taking into consideration the importance and challenges of rice production in Tanzania, monitoring and improving rice productivity dominantly under smallholder management practices including soil fertilizer use and irrigation water management is vital for prompt decisions at farm level and marketing agencies. Such efforts are also in line with Global Sustainable Development Goals (SDG's). Directly, they contribute to increase resilient to climate extremes (SDG 13), (SDG 2) (reduce/end hunger, achieve food security & improved nutrition and promote sustainable agriculture) and (SDG 1) (alleviate/end extreme poverty in all its forms everywhere) (UN, 2016; FAO, 2019).

Several tools have been developed to monitor crop growth and development for improving field soil-water management practices and decision-making options. For example, Normalized Difference Vegetation Index (NDVI) was used to assess N status and predict grain yield in rice in the Sacramento Valley rice growing area of California, USA. In that study NDVI was measured at the panicle initiation (PI) rice growth stage to assess crop N status and predicts final rice grain yield (Rehman et al., 2019). A study was also conducted in Haryana, India to examine input efficiencies focused on combinations of N-fertiliser and irrigation input in wheat crops grown with four rotations (rice-wheat, cotton–wheat, pearl millet–wheat, and cluster bean–wheat) (Coventry et al., 2011). The use of the GreenSeeker sensor in that study resulted in N fertilizer savings of 21–25 kg N ha^{-1} with similar grain yield, protein, and grain hardness to that provided by using the recommended 150 kg N ha^{-1}. Furthermore, where the GreenSeeker was used the apparent fertilizer recovery was 70–75% compared with the 60% recovery with the recommended rate. In another study conducted in Taiwan Agricultural Research Institute in Taiwan, water management with field sensors was carried out for water and fertilizer use efficiency (Li, G.-S *et al*., 2021). In that study different irrigation methods and nitrogen fertilizer levels were evaluated. Results of that study indicated that plant nitrogen and chlorophyll content at the maximum tillering stage were significantly influenced by the interaction between water and fertilizer (Li, G.-S *et al*., 2021). Furthermore, NDVI obtained from the multispectral images captured by the sensors, correlated well with plant nitrogen content and rice growth stages.

NDVI sensor (GreenSeeker Hand-Held Optical sensor unit) (Figs. 1, 2) is a tool in precision agriculture technology for providing useful data to monitor the growing status of crops at different soil and fertilizer management practices and across growth stages (Lan et al., 2009). The multispectral camera of this sensor was developed mainly for biomass estimation (Inoue et al., 2000; Jones et al. 2007), and the hyper spectroradiometer for close monitoring of crop conditions including crop stress (drought and soil nutrient deficiency) (Laudien et al., 2003; Darvishzadeh et al., 2008). Many of these sensors and instruments have been used to measure real-time crop conditions in many countries of the world. Green-Seeker Hand-Held Optical sensor unit, (Figs. 1, 2) has been used as a tool to measure Normalized Difference Vegetation Index (NDVI) above the canopy of wheat at 50 cm height across different growth stages during the season for yield estimation in Faisalabad, Pakistan (Sultana et al., 2014). The potential of NDVI to differentiate wheat cultivars for grain yield under different nitrogen levels was demonstrated under agroclimatic conditions of Pakistan.

Prediction of dry direct-seeded rice (DDSR) yields using Chlorophyll Meter (SPAD), Leaf Colour Chart (LCC), and Green SeekerHand-Held optical sensor was conducted in north-western India (Ali et al., 2014). Results revealed that the yield of DDSR can be satisfactorily predicted by the sensors. The NDVI readings measured by Green SeekerHand-Held optical sensor were superior to SPAD meter readings. In Kenya and Zimbabwe, it was possible to forecast maize yield using NDVI data derived from images acquired by the SPOT VEGETATION sensor (Lewis et al., 1998; Kuri et al., 2014). However, in those studies it was observed that the use of handheld sensors is advantageous over remotely sensed imagery which can also detect N variability and forecast yield in crops but have some limitations such as the timeliness in which the imagery is acquired. Hand-held active remote sensing devices like Green-Seeker Hand-Held optical sensors may overcome these limitations. The use of such sensors in tropical Sub-Saharan Africa (SSA) and particularly in Tanzania, is lagging behind. In this study, the GreenSeeker Hand-Held NDVI-based sensor, was used for monitoring rice productivity under soil amendment with combinations of fertilizers at two levels of irrigation water in the semi-arid plains of Tanzania. Specifically, the objective of the study was to assess rice productivity using handheld NDVI-based sensor under the condition of smallholder irrigated rice farming for optimising soil fertiliser use and irrigation water management.

2. Methodology

2.1. Study area

The experimental study was carried out at the Lower Moshi irrigation scheme in Mabogini village, Moshi District, NE Tanzania. There, farmers practice rice farming under inadequate rainfall and scarce water for irrigation. The study area is located between Universal Transverse Mercator (UTM) coordinates 314996 and 320988 E and 9619988 and 9626979 N, UTM Zone 37 M (Fig. 3). The Lower Moshi irrigation scheme is located in the semi-arid lowland plains lying below 740 m asl and receiving an annual rainfall of < 800 mm. The study area is located on a fluvial-volcanic plain of low relief stretching out of the foot of Mountain Kilimanjaro. Rau River is the main source of irrigation water. Present land uses practiced include irrigated rice farming; rain-fed maize farming with supplemental irrigation, and light grazing.

2.2. Experimental design and treatments

The experimental design consisted of two irrigation water levels (Flooding and System of Rice Intensification (SRI)) with nutrient management (1) multi nutrients (NPK) and (2) single nutrient (urea) application) replicated three times (each Replication plot measuring 8 m by 20 m) in a Randomized Complete Block Design (RCBD). Flood Irrigation water was applied at 7 cm height (equivalent to the total water volume of 11,900 m^3/ha) throughout the growing season, while under SRI treatment irrigation water was applied at 4 cm height (equivalent to the total water volume of 6,750 m^3/ha) under alternate wetting and drying conditions (AWD). Water was applied to the plots at seven days intervals. The rate of fertilizers applied were 120 kg N/ha, 20 kg P/ha, and 25 kg K/ha. A multi-nutrient treatment received all three nutrients (NPK), while in a single nutrient treatment only N was applied as urea. An improved rice variety named SARO-5 was used in this experiment.

Treatments:

I = Flood irrigation water – no control of the height of flooded water at 7 cm height + farmers recommended soil fertility management (120 kg N/ha as urea only) (CU)

II = SRI – low irrigation water (controlled height of flooded water) + farmers recommended soil fertility management (120 kg N/ha as urea only) (SU)

III = SRI – low irrigation water (controlled height of flooded water at 4 cm height) + NPK (SN)

IV = Flood irrigation water – no control of the height of flooded water at 7 cm height + NPK (CN)

2.3. GreenSeeker™ Hand-Held optical NDVI sensor data collection

Near-Infrared (NIR)-reflectance measuring "GreenSeeker" handheld sensor was used for online monitoring of rice growth at the experimental site. Optical sensor readings were taken with a handheld GreenSeeker™ sensor (NTech Industries Inc., Ukiah, CA, USA). The sensor measured canopy reflectance at the red region (656 nm) and near-infrared (NIR) region (774 nm) to generate NDVI data. NDVI was determined as shown in Eq. 1 (Ali et al., 2014). The sensor was passed over the crop at a height of 0.3 m, 0.6 m, and 0.8 m across growth stages (early, vegetative, booting, and full booting development stages) during the season. The readings were recorded every 14-d interval starting from 14 d after transplanting (DAT) and continued up to the full booting stage before flowering started. Five healthy plants were selected systematically from each treatment plot on which measurements of NDVI were determined.

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

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The sensor takes readings at a very high rate (approximately 1000 measurements per second) and averages measurements between readings. In that way, the sensor automatically calculates average NDVI readings for each measured sample sequence. The NDVI data from the sensor is then transmitted serially to an HP iPAQ Personal Digital Assistant which was later exported to a LAPTOP computer for analysis.

2.4 Measurements

Plant height and number of tillers

Five healthy plants were selected systematically from each treatment plot on which measurements of plant height and number of tillers were done. The plant height was measured at every 14 days interval starting from 14 days after transplanting (DAT) and continued up to full booting stage before flowering started. Plant height was determined by measuring the distance from the soil surface to the tip of the leaf before heading and to the tip of the flag leaf after heading. Number of tillers per hill was counted at every 14 days interval starting from 14 DAT (early stage) and continued up to full booting stage before flowering started. The collected data were entered in a specially designed form for further analysis.

Biomass (AGB)

Five hills from each treatment plot were uprooted and left dried for approximately three weeks from which the dry matter weight was determined. Dry biomass (oven dried for 24 hours or more until no change in weight) of different plant organs (stem, leaves and panicles) were also weighed.

Thousand Grain weight (TGW)

Thousand grains were counted from the grain yield of each treatment unit based on two observations (e, g 00.0g) and weighed by a portable automatic electric balance after oven-drying at 70^0c for 24 hours in an oven until a constant weight was obtained.

2.5. Data analysis

Data analysis was carried out in GENSTAT64 software, 15th edition to test the applicability of the sensor. Analysis of Variance (ANOVA) was used to compare statistically the means between variables as per randomized complete block design (RCBD) with the treatments. The means were separated by using Least Significant Difference (LSD) at alpha = 0.05. Simple Correlation coefficient (r) was used to measure the degree of association between field crop parameters (plant height, number of tillers, thousand-grain weight (TWG), biomass, number of panicles, yield) and NDVI at the four treatments (management practices) and across growth stages. In addition, a simple linear regression model (coefficient of determination R^2) was used to establish the prediction efficiency of the sensor.

3. Results And Discussion

3.1 Plant height across crop growth stages and management practices

Results of plant height parameter across crop growth stages and management practices are presented in Table 1. Plant height varied from 21.07 cm to 80.5 cm across growth stages and management practices for the whole dataset though statistically were not different. Plant height across growth stage at SRI with urea fertilizer was higher than in the other management practices although not significant. These results are in agreement with earlier observation by Aide and Beighly (2006) who noted that plant height was significantly correlated with nitrogen fertilizer application. Similar results were obtained by Islam (2008) who noted that plant height was significantly influenced by the amount of fertilizers applied. The increase in plant height could also be explained by the application of increased levels of nitrogen which might be associated with stimulating effect of nitrogen on various physiological processes including cell division and cell elongation of the plant. Materu (2014) observed that plant height for 100% SRI was significantly ($p< 0.05$) higher than 80% and 50% SRI (at reduced SRI water level). In Bihar, India, similar observation was reported by Chowdhury *et al.* (2014) that plant height of rice crop increased with increasing irrigation and levels of nutrients. Increasing nutrient levels has direct influence on increasing the uptake of N which in turn might have increased the plant height.

Table 1: Plant height as influenced by water regime and nutrient management at different rice growth stages

Treatments	H1 (Early stage) cm	H2 (Vegetative stage)cm	H3 (Booting stage) cm	H4 (Full booting stage) cm
Farmers Practice	24.57NS	55.6NS	64.9NS	77.3NS
SRI + Urea	**26.90NS**	**56.3NS**	**67.3NS**	**80.5NS**
Flooding + Urea	24.97NS	55.4NS	61.5NS	75.7NS
SRI + NPK	25.33NS	56.7NS	66.5NS	74.9NS
Flooding + NPK	21.07NS	54.0NS	64.1NS	78.1NS
PROBABILITY ($P<0.05$)	0.112	0.871	0.593	0.675

NS: Not significant

H1= Plant height at early stage; **H2**=Plant height at vegetative stage; **H3**=Plant height at booting stage; **H4**=Plant height at full booting stage

3.2 Correlation Coefficient between Plant height and NDVI score at Various Growth Stages

Table 2 presents the simple correlation between rice plant height and NDVI scores across growth stages and at three positions of the sensor (0.3 m, 0.6m, and 0.8 m) above the crop canopy. Generally, no significant association was observed between plant height and NDVI except for the plant height at a vegetative stage for 0.6 m above the crop canopy and booting stage at 0.3 m and 0.6 m above the canopy respectively (Table 2). These results disagree with other results by Wijesingha *et.al*. (2015) who observed a direct relationship between rice plant height and MODIS NDVI in Sa kaeo province, Thailand. Furthermore, Rahetlah *et al*. (2014) observed a moderate relationship between NDVI derived from SPOT5 satellite image and height of Elephant grass ($R^2 = 0.74$; $P < 0.001$) in the Vakinankaratra region, Madagascar. Laboratory evaluation of the GreenSeeker™ hand-held optical sensor using corn as a test crop in Texas, USA, showed that the sensor is highly sensitive ($P < 0.0001$) to the positions ranging from 30.5 cm to 91.5 cm above the crop canopy (Martin *et al*., 2012). In Tennessee, USA, a strong positive correlation ($r > 0.72$) between NDVI and plant height of cotton was observed (Marisol, 2010). In this study, it is apparent that studies to evaluate the relationship between rice plant height and sensor measured NDVI is lacking. These results suggest that the evaluated GreenSeeker sensor requires further testing to assess the general rice plant height performance over a wide range of conditions.

Table 2: Correlation coefficient between plant height and NDVI score at various growth stages

NDVI at various growth stages	H1	H2	H3	H4
ND-11_earlystg	0.06 NS	0.39 NS	0.38 NS	0.56 NS
ND-21_vegtv stg	0.29 NS	0.19 NS	0.25 NS	0.52 NS
ND-22_vegtv stg	**0.67***	0.59 NS	0.47 NS	0.40 NS
ND-23_vegtv stg	0.49 NS	0.36 NS	0.39 NS	0.41 NS
ND-31_Bootng stg	0.36 NS	0.35 NS	0.25 NS	**0.78***
ND-32_Bootng stg	0.22 NS	**0.74***	0.10 NS	0.61 NS
ND-33_Bootng stg	0.51 NS	0.58 NS	0.32 NS	0.23 NS
ND-41_Full btng stg	0.31 NS	0.51 NS	0.31 NS	0.62 NS
ND-42_Full btng stg	0.30 NS	0.58 NS	0.11 NS	0.63 NS
ND-43_Full btng stg	0.19 NS	0.27 NS	0.08 NS	0.61 NS

* Significant at 5% level; NS: Not significant; n = 10

H1 = Plant height at early stage; **H2** = Plant height at vegetative stage; **H3** = Plant height at booting stage; **H4** = Plant height at full booting stage; **ND-11** = NDVI at early stage (sensor 0.3 m above the canopy); **ND-21** = NDVI at vegetative stage (sensor 0.3 m above the canopy); **ND-22** = NDVI at vegetative stage (sensor 0.6 m above the canopy); **ND-23** = NDVI at vegetative stage (sensor 1.0 m above the canopy); **ND-31** = NDVI at booting stage (sensor 0.3 m above the canopy); **ND-32** = NDVI at booting stage(sensor 0.6 m above the canopy); **ND-33** = NDVI at booting stage (sensor 1.0 m above the canopy); **ND-41** = NDVI at full booting stage (sensor 0.3 m above the canopy); **ND-42** = NDVI at full booting stage(sensor 0.6 m above the canopy); **ND-43** = NDVI at full booting stage (sensor 1.0 m above the canopy).

3.3 Number of tillers across rice growth stages and management practices

Number of tillers across rice growth stages and management practices are presented in Table 3. Results show that number of tillers for SRI with NPK was significantly higher ($p < 0.05$) than rest of the four treatments followed by SRI with urea (Table 3). The higher number of tillers per hill for SRI with NPK is an indicator of improved potential yield associated with the applied management practices (treatments). This could be attributed to the fact that the tillering system is determined both by variety, management practices and the nitrogen level in the soil (Ceesay, 2004; Laghari, 2010)

Table 3: Number of tillers as influenced by water regime and nutrient management across different rice growth stages

Treatments	T2	T3	T4
Farmers Practice	14.33 ab	18.93 abc	16.87 abc
SRI + Urea	**21.00 a**	**19.33 ab**	**19.33 ab**
Flooding + Urea	11.33 b	14.00 c	15.33 c
SRI + NPK	**19.67 a**	**21.33 a**	**21.00 a**
Flooding + NPK	13.67 b	16.67 bc	15.67 bc
	$LSD_{5\%}$ =5.597	$LSD_{5\%}$ =4.455	$LSD_{5\%}$ = 2.395

Means not sharing any two letters differ significantly at ($P \leq 0.05$)

T2=Number of tillers at vegetative stage; **T3**=Number of tillers at booting stage; **T4**=Number of tillers at full booting stage, **SRI** = System Rice Intensification, **NPK** = Nitrogen-phosphorus-potassium (22-6-12) fertilizer

This is to say that if there is more nitrogen in the plant tissues it would likely promote active tillering. Generally, rice yield is a function of the leaf area and the panicles attached to the tillers (Materu, 2014). Therefore, number of tillers are usually an indicator of rice yield and hence the higher the number of tillers the likelihood for increased rice yield. Several studies have reported the benefit of SRI technique in enhancing number of tillers and yield (Li, 2001; Sato and Uphoff (2007); Mati, *et al.*, 2011; and Katambara *et al.* (2013)). The SRI promotes soil aeration, healthier root systems and beneficial microbial activities which enhance tillering while at the same time conserving water (Pandian, 2010; Ndiiri *et al.*, 2012). In a study conducted in Hunan, China, Badshah *et al.* (2014) reported a positive correlation between number of tillers and panicles which was also correlated with grain yield under a combination of conventional tillage and transplanting of rice seedlings when compared to direct seeding. Tillering is an important characteristic for grain production and therefore an important crop performance parameter of rice growth and development.

3.4 Correlation coefficient between number of tillers and NDVI score at various growth stages and height above the canopy

Table 4 presents the simple correlation coefficients between crop tillering and NDVI scores. It is apparent that there is a good correlation between NDVI at booting and full booting stage regardless of the position of the sensor above the canopy and the number of tillers at full booting growth stage (Table 4). Therefore, GreenSeeker measured NDVI as a good indicator of crop performance with respect to the number of tillers at the booting stage. A close relationship was also observed between NDVI at booting (0.3 m above the canopy) and full booting (0.8 m above the canopy) stage and the number of tillers at the vegetative growth stage (Table 4). Results show further that there was no correlation between NDVI and the number of tillers at the booting growth stage regardless of the position of the sensor above the canopy.

Table 4: Correlation coefficient between number of tillers and NDVI score at various growth stages

NDVI at various growth stages	T1	T2	T3	T4
ND-11_earlystg	0.02 NS	0.10 NS	0.14 NS	0.01 NS
ND-21_vegtv stg	0.06 NS	0.21 NS	0.08 NS	0.33 NS
ND-22_vegtv stg	0.13 NS	0.10 NS	0.13 NS	**0.52***
ND-23_vegtv stg	0.11 NS	0.23 NS	0.02 NS	0.23 NS
ND-31_Bootng stg	0.35 NS	**0.53***	0.06 NS	**0.71***
ND-32_Bootng stg	0.27 NS	0.47 NS	0.04 NS	**0.8***
ND-33_Bootng stg	**0.51***	0.38 NS	0.08 NS	**0.52***
ND-41_Full btng stg	0.22 NS	0.45 NS	0.29 NS	**0.89***
ND-42_Full btng stg	0.40 NS	0.45 NS	0.34 NS	**0.67***
ND-43_Full btng stg	0.37 NS	0.56*	0.42 NS	**0.86***

* Significant at 5% level; NS: Not significant; n = 10

T1 = Number of tillers at early stage; **T2** = Number of tillers at vegetative stage; **T3** = Number of tillers at booting stage; **T4** = Number of tillers at full booting stage; **ND-11** = NDVI at early stage (sensor 0.3m above the canopy); **ND-21** = NDVI at vegetative stage (sensor 0.3m above the canopy); **ND-22** = NDVI at vegetative stage(sensor 0.6m above the canopy); **ND-23** = NDVI at vegetative stage (sensor 1.0m above the canopy); **ND-31** = NDVI at booting stage(sensor 0.3m above the canopy); **ND-32** = NDVI at booting stage(sensor 0.6m above the canopy); **ND-33** = NDVI at booting stage(sensor 1.0m above the canopy); **ND-41** = NDVI at full booting stage(sensor 0.3m above the canopy); **ND-42** = NDVI at full booting stage(sensor 0.6m above the canopy); **ND-43** = NDVI at full booting stage(sensor 1.0m above the canopy)

3.5 Biomass

Table 5 presents the above ground biomass (AGB) across different management practices. The AGB varied from 55.15 g/hill to 103.88 g/hill across different management practices (Table 5). Results show that above ground biomass for SRI with NPK and SRI with UREA was significantly higher ($p < 0.05$) than rest of the treatments (Table 5). These results are in agreement with earlier studies. For example, in Madagascar, Uphoff (1999) observed positive response in terms of plant height and biomass production with the application of recommended nitrogen fertilizer levels over farmers practices. Ceesay (2004) observed similar results in the study carried out in Gambia West Africa. Barison (2002) reported enhanced crop growth and biomass production of rice in Madagascar attributed to SRI and compost manure. Also in Madagascar, greater biomass (165.27 g/hill) was obtained from a combination of 50 % poultry manure/FYM and RDN fertilizer with SRI (Prabhakara Setty *et al*., 2007).

Table 5: Variations in rice biomass across different management practices

Treatments	BIOMASS (g/hill)
Farmers Practice	66.3abc
SRI + Urea	**103.88a**
Flooding + Urea	55.15c
SRI + NPK	**96.75ab**
Flooding + NPK	63.19c
	$LSD_{5\%}$ = 25.72; (p<0,05)=0.036

Means not sharing any two letters differ significantly at ($P \leq 0.05$)

3.6 Correlation coefficient between biomass and NDVI score at various growth stages

Table 6 presents the simple correlation coefficients between the above-ground biomass (AGB) and NDVI across various growth stages. A good relationship was observed between biomass and NDVI at booting (0.3 m and 0.6 m above the canopy) and full booting stage (0.8 m above the canopy). These results concur with earlier studies that reported a good correlation between NDVI and above-ground biomass (Verhulst *et al*., 2009; Li *et al*., 2010). For example, in the subtropical highlands of Central Mexico Verhulst *et al*. (2009) observed a close correlation between NDVI and biomass of maize. Similar results were reported by Li *et al*. (2010) who correlated GreenSeeker NDVI with biomass of winter wheat (*Triticum aestivum*). The results are also in agreement with a study by Liu and Kogan (2002) who reported a close relationship between NOAA/AVHRR measured NDVI and biomass of soybean in Brazil.

Biomass assessment is thus essential not only for studies which monitor crop growth but also in cereal breeding programs as a complementary selection tool (Araus *et al*., 2009). Tracking changes in biomass may also be a way to detect and quantify the effect of stresses on the crop, since stress may accelerate the senescence of leaves, affecting leaf expansion (Royo *et al*., 2004) and plant growth (Villegas *et al*., 2001). The measurement of spectral reflectance characteristics of crop canopies is largely proposed as a quick, cheap, reliable and non-destructive method for estimating plant above-ground biomass production in small-grain cereals (Aparicio *et al*., 2002) and individual plant level (Álvaro *et al*., 2007). Near-infrared (NIR) reflectance of rice is directly related to green biomass (Niel and McVicar, 2001). High NDVI values are indicative of high chlorophyll content. Chlorophyll is the most important part of the rice plant for photosynthetic activity, which produces carbohydrates to form rice plant tissue and rice grain, and thus has a significant effect on the crop yield. It is also vivid from our study that the GreenSeeker sensor for monitoring rice crop growth parameters like biomass has not been addressed widely. Therefore, it is important to point out that results obtained from the initial stage for further evaluation of the sensor in a wide range of conditions.

Table 6: Correlation coefficient between biomass and NDVI score at various growth stages.

NDVI at different growth development stages	Biomass
ND-11_earlystg	0.07 NS
ND-21_vegtv stg	0.25 NS
ND-22_vegtv stg	0.15 NS
ND-23_vegtv stg	0.06 NS
ND-31_Bootng stg	**0.92 ***
ND-32_Bootng stg	**0.81 ***
ND-33_Bootng stg	0.17 NS
ND-41_Full btng stg	0.31 NS
ND-42_Full btng stg	0.31 NS
ND-43_Full btng stg	**0.58 ***

* Significant at 5% level; NS: Not significant; n = 10

ND-11 = NDVI at early stage (sensor 0.3m above the canopy); **ND-21** = NDVI at vegetative stage (sensor 0.3m above the canopy); **ND-22** = NDVI at vegetative stage(sensor 0.6m above the canopy); **ND-23** = NDVI at vegetative stage (sensor 1.0m above the canopy); **ND-31** = NDVI at booting stage(sensor 0.3m above the canopy); **ND-32** = NDVI at booting stage(sensor 0.6m above the canopy); **ND-33** = NDVI at booting stage(sensor 1.0m above the canopy); **ND-41** = NDVI at full booting stage(sensor 0.3m above the canopy); **ND-42** = NDVI at full booting stage(sensor 0.6m above the canopy); **ND-43** = NDVI at full booting stage(sensor 1.0m above the canopy)

3.7 Thousand Grain weight yield

Table 7 presents the Thousand Grain weight (TGW) across different management practices. Results show that the TGW varied from 31.33 to 32.33 across different management practices (Table 7). Results show further that SRI with NPK was relatively higher than SRI with Urea and also with other treatments though not significant ($p < 0.05$). Similarly, the treatment with flooding and NPK combination registered higher yield than flooding with urea also though not significant ($p < 0.05$).

Table 7: Variations in Thousand Grain weight (TGW) across different management practices

Treatments	% 1000 Grain weight
SRI + Urea	**32.20a**
Flooding + Urea	31.33a
SRI + NPK	**32.33a**
Flooding + NPK	31.93a
	$LSD_{5\%}$ = 4.658; (p<0,05)=0.952

Means not sharing any two letters differ significantly at ($P \leq 0.05$)

Therefore, results presented on Table 7 shows that SRI and NPK insemination had relatively increased the thousand-grain weight to a certain level. These results were in line with the findings of Mohsan, (1999); Hossain *et al*. 2008 and Hashmi, (2013) who reported that application of nitrogen fertilizers in rice farming under good water management had positive effect on the thousand grain weight. Hence, thousand grain weight is also a yield component that can be used for monitoring crop performance when different management practices are applied like SRI and nutrient management. Another study by Malik (2010) in Karor District Layyah, Pakistan demonstrated that application of NPK fertilizer at the rate of 175-150-125 Kg ha^{-1} gave better rice crop growth and higher grain yield 5168 Kg ha^{-1} when compared to the other treatments (75-50-125, 100-75-50, 125-100-75, 150-125-100 and 200-150-125 NPK Kg ha^{-1}) which produced 33.26g, 38.90g, 41.35g, 44.31g and 44.04g of thousand grain weight respectively.

3.8 Correlation Coefficient between Grain Yield and NDVI score at Different Growth Stages

Table 8 presents the simple correlations between rice grain yield and NDVI scores across various growth stages. A significant relationship was observed between rice grain yield and NDVI at vegetative, booting, and full booting stage. Obviously, there is also a close relationship between biomass and NDVI at the booting and full booting stage, regardless of the position of the sensor above the canopy (Table 8). NDVI has been correlated with many plant parameters including biomass, plant height, and number tillers, which are also closely related to crop yield (cf. Wiegand *et al*., 1990; Verma *et al*., 1998). Ali *et al*. (2014) reported a good correlation between GreenSeeker measured NDVI and grain yield of Dry Direct Seeded Rice (DDSR) in India. Similar results were reported by Sultana *et al*. (2014) in Faisalabadin, Pakistan where NDVI was positively correlated with grain yield at stem elongation (r = 0.888), booting (r = 0.950), and maturity stage (r = 0.927). Although many studies have demonstrated a good correlation between GreenSeeker measured NDVI and crop yield, such studies have not been done widely in tropical Sub-Saharan Africa (Teboh *et al*., 2012). It is obvious from the results of this study that wide testing and evaluation of the GreenSeeker Handheld Optical NDVI sensor is of paramount importance.

Table 8: Correlation coefficients between grain yield and NDVI score at various growth stages.

NDVI at different growth development stages	Grain yield
ND-11_earlystg	0.05 NS
ND-21_vegtv stg	0.25 NS
ND-22_vegtv stg	**0.94***
ND-23_vegtv stg	**0.50***
ND-31_Bootng stg	0.38 NS
ND-32_Bootng stg	0.39 NS
ND-33_Bootng stg	**0.82***
ND-41_Full btng stg	**0.86***
ND-42_Full btng stg	0.41 NS
ND-43_Full btng stg	**0.49***

* Significant at 5% level; NS: Not significant; n = 10

ND-11 = NDVI at early stage (sensor 0.3m above the canopy); **ND-21** = NDVI at vegetative stage (sensor 0.3m above the canopy); **ND-22** = NDVI at vegetative stage(sensor 0.6m above the canopy); **ND-23** = NDVI at vegetative stage (sensor 1.0m above the canopy); **ND-31** = NDVI at booting stage(sensor 0.3m above the canopy); **ND-32** = NDVI at booting stage(sensor 0.6m above the canopy); **ND-33** = NDVI at booting stage(sensor 1.0m above the canopy); **ND-41** = NDVI at full booting stage(sensor 0.3m above the canopy); **ND-42** = NDVI at full booting stage(sensor 0.6m above the canopy); **ND-43** = NDVI at full booting stage(sensor 1.0m above the canopy)

3.9 NDVI trend across rice crop growth stages

The relationships between grain yield and NDVI score at various rice crop growth stages are presented in Fig 4. The results show a positive linear relationship between rice grain yield and NDVI. NDVI at early stage predict higher yield (R^2=26%) > vegetative (R^2=10%) > booting (R^2=6%) > full booting stage (R^2=5%) (Fig. 4). The simple linear regression models demonstrated in this study explained only slightly less than 30% of the yield predictions by NDVI at the early stage of the crop growth, decreasing gradually to 5% at full booting growth stage. Sawasawa (2003) reported similar results for rice irrigated fields in India. In that study NDVI derived from space-born satellite data explained only 25% (R^2) of the yield variability at the field level, while land and management factors accounted for 38% (R^2). The study emphasized that not all the factors that affected yield also affected NDVI. Gat *et al.* (2000) echoed that remotely sensed data (NDVI) could be used to estimate yield in various crops. However, the authors suggested that more effective indicators are needed that capture more of the factors that affect crop development and that such parameters can be easily captured by remote sensing data and/or sensors (Gat *et al.*, 2000; Rajak *et al.*, 2002; Ray *et al.*, 2002).

4. Conclusions

The plant parameters monitored in this study have demonstrated good relationship with biomass and grain yield, hence, important plant yield components for monitoring rice crop performance when different management practices are applied like SRI and nutrients. This suggest that rice grain yield, biomass and number of tillers which are important field measured plant parameters can be used for monitoring rice crop growth at different smallholder land management practices across growth stages. The field measured rice performance parameters in this study within the available time and material resources considered only one improved rice variety (SARO 5). Therefore, further research are required to investigate other rice varieties/cultivars such as TXD 88, *Komboka*, IR 64, IR 56, *Tai* (Thailand) and NERICA common in smallholder rice farming system in Tanzania. Response of the measured plant performance parameters under diffrenet levels of fertilizer like nitrogen and phosphorus and the effect on their interactions should also be investigated in the future studies.

The Green-Seeker Hand-Held optical sensor evaluated in this study has demonstrated the potential to detect crop performance under varied smallholder management practices and forecast yield under the conditions of the tropical Sub-Saharan Africa. The study has also demonstrated that GreenSeeker Hand-Held Optical NDVI sensor can precisely forecast and monitor production trends of irrigated rice and improved management practices (soil amendment using fertilisers) under smallholder irrigation farming conditions. Therefore, if the technology is adapted in the agricultural irrigation schemes is likely to enhance smallholder rice production in semi-arid plains of Tanzania. It is important to point out that results from this study calls for wide testing and evaluation of the GreenSeeker Handheld Optical NDVI sensor in a wide range of smallholder farming conditions.

Declarations

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Author Contributions

Conceptualization: O.D.K., N.K., P.H., D.N.K., and K.H.F.; methodology. O.D.K., N.K.,P.H.,D.N.K.,S.L.G., and K.H.F., validation, O.D.K., N.K.,P.H.,D.N.K.,S.L.G., and K.H.F.; formal analysis, O.D.K., N.K.,P.H.,D.N.K., and

K.H.F.,; investigation, O.D.K., N.K., P.H., D.N.K. and K.H.F.; data curation, O.D.K., N.K.,P.H.,D.N.K., and K.H.F.; writing—original draft preparation, O.D.K., N.K.,P.H.,D.N.K.,S.L.G., and K.H.F.,; writing—reviewing and editing, O.D.K., N.K.,P.H.,D.N.K.,S.L.G., and K.H.F.; visualization, O.D.K and S.L.G.; All authors have read and agreed to the published version of the manuscript.

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Figures

Figure 1

Wearing/Assembling of GreenSeeker Hand Held^{TM} Optical sensor unit (Lan *et al.*, 2009)

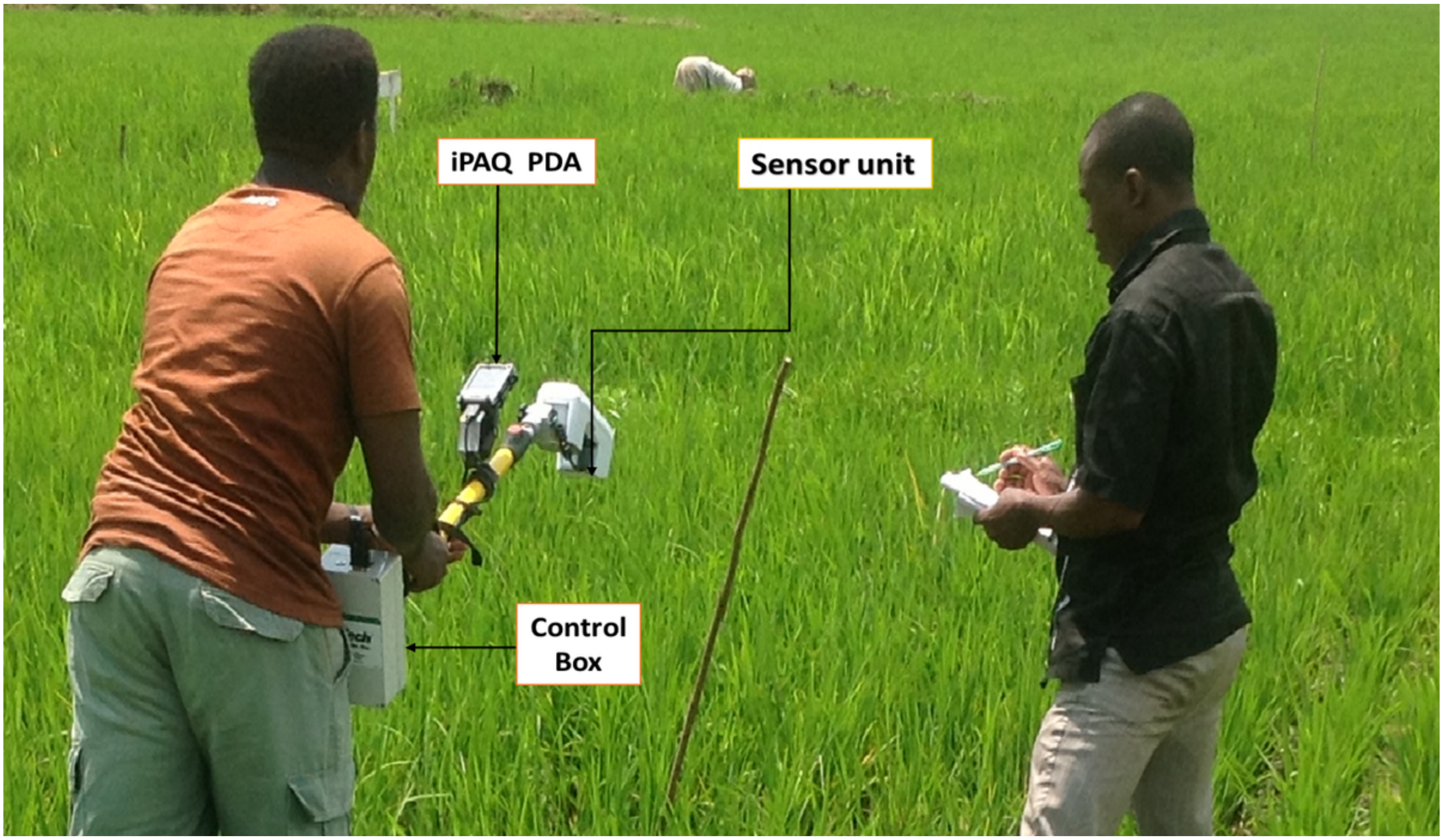

Figure 2

GreenSeeker Hand Held^{TM} Optical sensor unit collecting the reflectance readings (NDVI readings) in smallholder rice irrigation scheme in Lower Moshi, Tanzania.

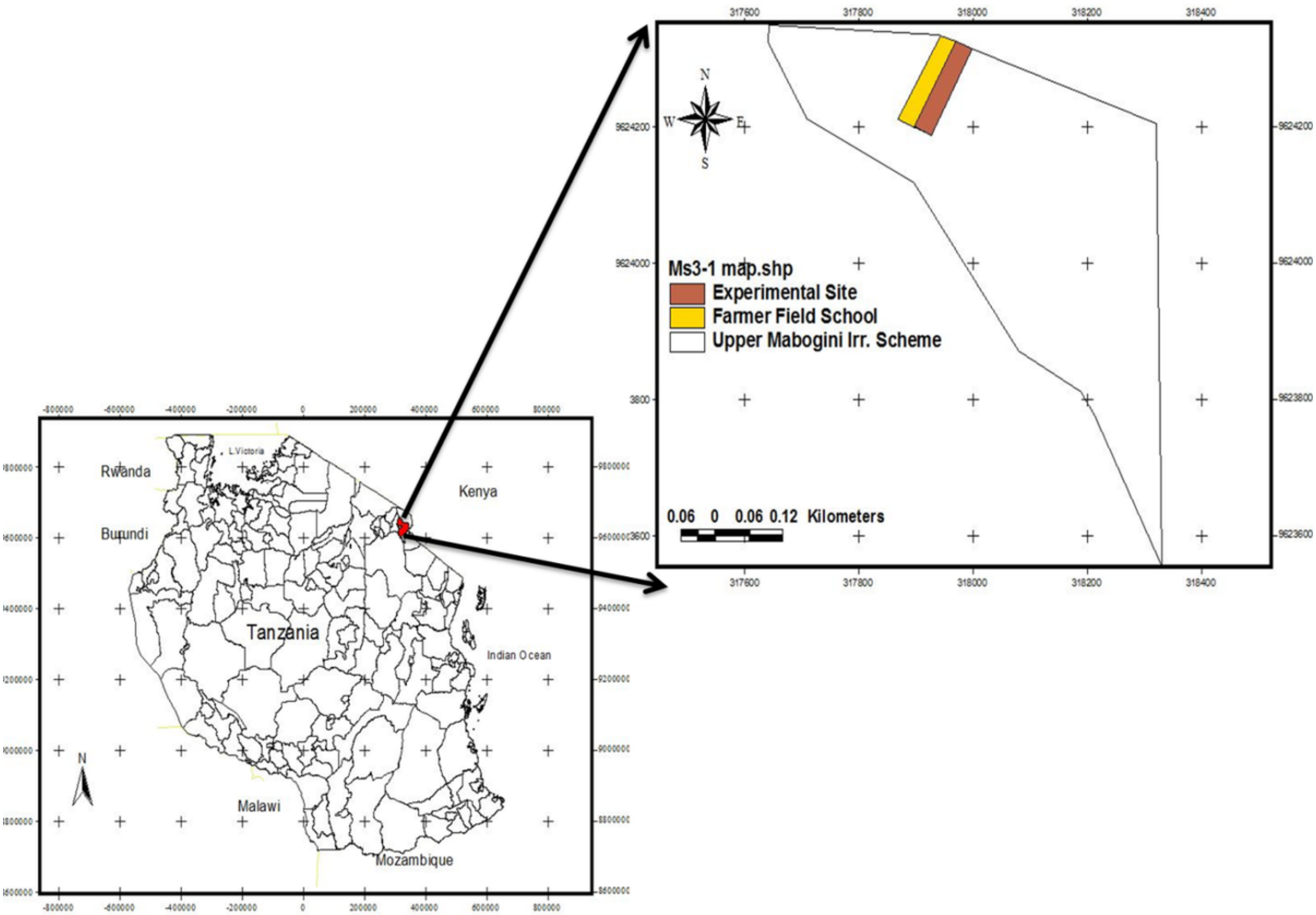

Figure 3

Location of the study area

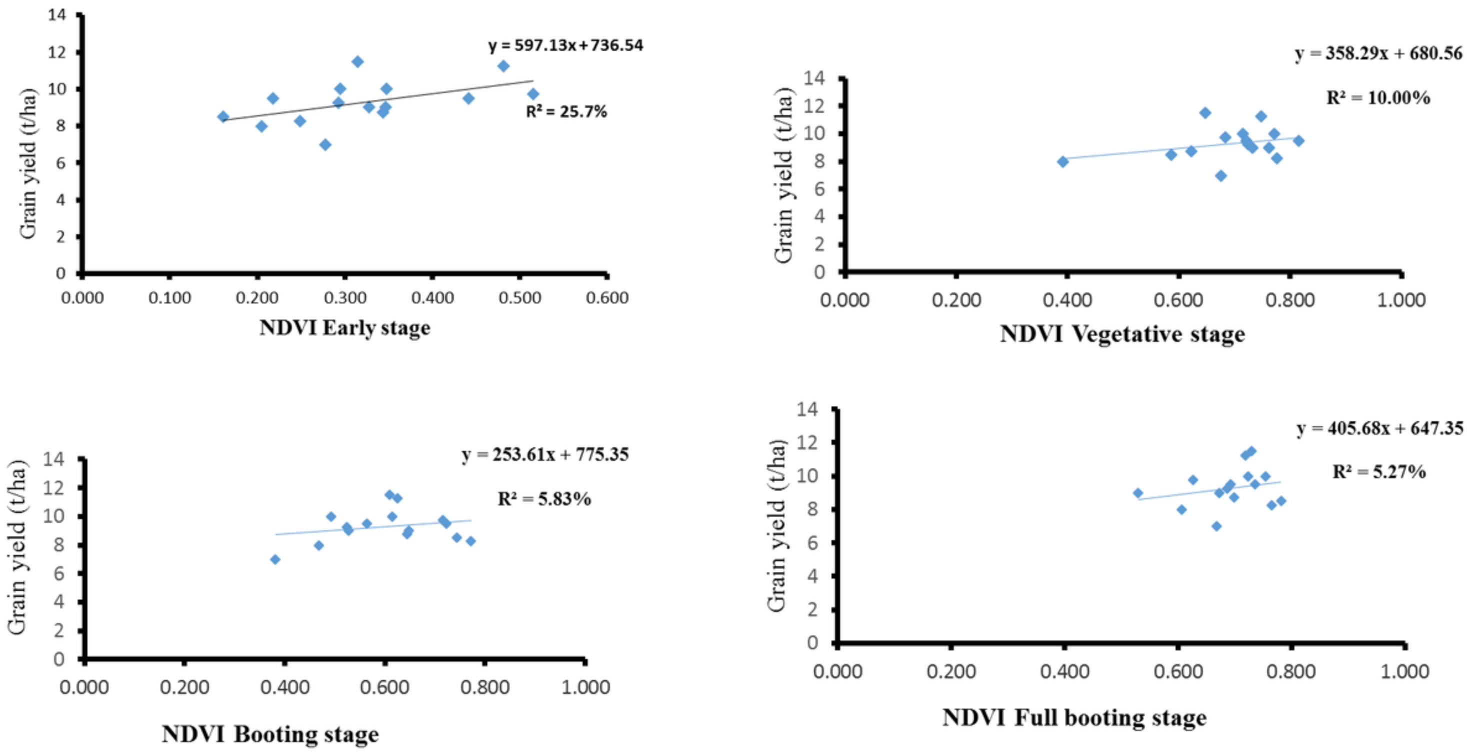

Figure 4

Relationship between grain yield and NDVI at different growth stages.