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Finger Millet (*Eleucine coracana*) Yield Estimation: Integrating Remote Sensing and Farm Management Practices in Busia-Kenya

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Abstract

Early crop yield prediction is important for planning and taking various decisions by the farmer. Conventional techniques of data collection for crop monitoring and yield estimation rely on ground-based visits and reports. These methods are subjective, very costly and time consuming. With the launching of satellites, remotely sensed data is being used for crop monitoring and yield prediction. This study applied space-borne satellite based NDVI to predict crop yield at field level. It was carried out in Kenya's Busia County. The purpose of the study was to investigate the relationship between space-borne Satellite based NDVI and Finger millet (Eleucine coracana) yield and combining NDVI with farmer's indigenous knowledge (IK) and practices for yield prediction at field level. A survey was carried out to investigate management and land factors in Finger millet growing area during the long rains growing season, January-June 2014. This was followed by satellite image analysis of farms during different stages of Finger millet growth. Data collected was correlated against Finger millet yield in order to analyse the relationships among Remote sensed data, indigenous practices and crop yield. The results showed that there is significant correlation between remotely sensed NDVI and field level finger millet yield (r = 0.19, p =0.040, N = 57). The most yielding farms were those with mixed variety of seed (i.e local and improved u15 variety) and broadcasting as a planting technique. The study also showed that not all the factors affecting yield also affect NDVI. This paper concludes that remote sensing can be used as a tool for monitoring crop growth and vigor based on different farm management practices. The paper further suggests that the integration of farmer IK in the management of finger millet crop and use of mixed variety of seed is likely to improve yield.

Key Words: *Eleucine coracana*, Remote Sensing, Indigenous Knowledge

INTRODUCTION

With recent trends in climate change, staple crops are becoming increasingly vulnerable thereby threatening food security of the most vulnerable countries of the world (FAO, 2008). However, there is a large untapped potential for Neglected and Underutilized Species of plants which can be adopted as food security crops. In 2008 FAOSTAT estimated that 20 most important crops are cultivated on 82% of the global agricultural area, while the other 117 crops combined contribute to only 18% (FAOSTAT, 2008). Finger millet (Eleucine coracana) has been adopted as a food security crop in some countries (Basavaraj *et al.*, 2010; Fetene *et al.*, 2011; Lawler, 2009; Mukarumbwa and Mushunje, 2011). Over the course of history, and up to this day, traditional communities have relied on indigenous knowledge to conserve the environment as well as deal with natural disasters. This knowledge is the sum of skills, practices and technologies that are known or acquired from experience and handed down from generation to generation. Pastoralism land use system has assured the

Maasai a stable livelihood for generations, enabling them to maximize utilization of rangeland resources for optimum meat and milk production (Fratkin and Mearns, 2003). However, disregard of Indigenous Knowledge can sometimes be detrimental. In the 1950's and 1960's four species of tilapia and the Nile perch were released in Lake Victoria in disregard of the local indigenous knowledge (Pringle, 2005). The result over the years has been that the lake's ecosystem and habitat has been altered. The application of indigenous knowledge systems can enhance crop vigor which can be detected by modern techniques such as remotely sensed satellite images. With the development of satellites, remotely sensed images provide access to spatial information at any scale of features on earth. Studies indicate that remote sensed images can identify crop classes, monitor crop growth and estimate crop yield (Singh *et al*., 2002; Schuler, 2002)

The impact of variability of rainfall on food grain production has remained large, despite the significant advances in agricultural research. Therefore, it is critical to identify strategies that can help sustain high levels of production in vulnerable regions of the world and free the masses from food insecurity. Finger millet (Eleucine coracana) has been identified as one of the food security crops (FAOSTAT, 2008). Although considered less competitive to maize in Kenya, Finger millet is an important drought tolerant cereal which is likely to be a food security crop. A high maize price encourages maize planting in the Finger millet zones instead of the drought resistant Finger millet varieties requiring less water (Doorenbos and Pruitt, 1977). Only if the altitude is about 800 m maize out yields Finger millet, and only as long as there is at least 250mm of well distributed rainfall during growing season (Doorenbos and Pruitt, 1977; Min of Agric, 1995). But the higher risk with maize is taken because people rely on internationally aided famine relief in case of crop failure. Due to social change, mobility and changing nutritional habits, maize flour is preferred to Finger millet which can be slightly sour. Thus, some areas may be presently dominated by maize but are considered to yield more if Finger millet is grown (Fig 1).

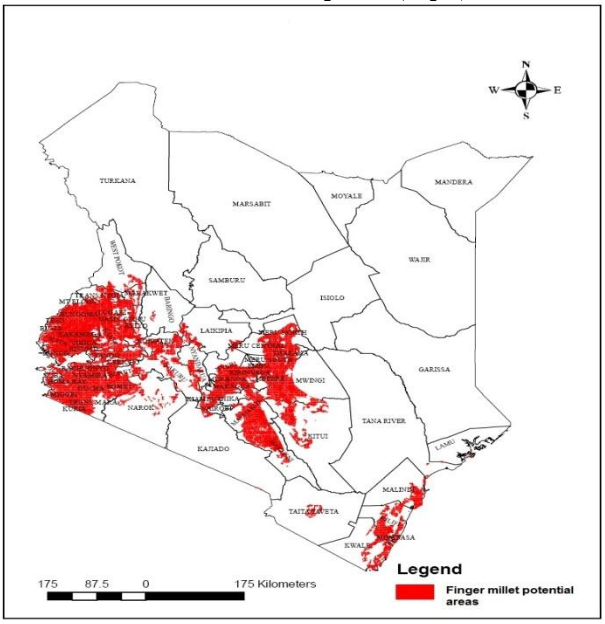

Figure 1. Suitable Areas for Finger Millet Growth in Kenya based on Agro-Ecological Conditions (Adopted from Jätzold and Schmidt, 1982)

Among Kenyan farmers who grow Finger millet, there is a tendency to practice traditional skills and technologies to boost the yield (Fetene *et al*., 2011). However, these practices have been overlooked by national research and extension services and there is little documentation of this indigenous knowledge. Still, the researches concentrate on staple and cash crops such as rice and corn (*Zea mays*), and yet yields to these crops are unpredictable in the face of climate variability. Predicting crop yield before harvest is vital especially in regions characterised by climatic uncertainties. This enables the government and other stakeholders to put in place strategic contingency measures for redistribution of food during times of hunger. Remote sensing has been used extensively as a tool to assess and monitor vegetation parameters, crop vigour and yield estimation. Most studies have established that there is correlation between Normalized Difference Vegetation Index analysed from remote sensed data, the green biomass and yield (Singh *et al*., 2002; Schuler, 2002). However, these studies are mostly done at regional/national level covering very large areas by using low-resolution satellite images resulting into generalization of the crop condition and yield estimates. At a small scale, as is the case for many Finger millet farms in Kenya, yield is a result of complex environmental factors including farmers' management. These small farms may not be detected with very low resolution satellite images. This study, therefore sought to estimate Finger millet yield at field level based on Indigenous practices by farmers using high resolution remote sensed data. Vegetation density is the most obvious physical manifestation of yield from crops. The density was monitored using remotely sensed images that measure chlorophyll and vegetation vigor. The spectral reflectance is a representation of factors affecting crop growth. Therefore, remote sensed data can be used to monitor crop condition through Normalized Density Vegetation Index. The study worked with the hypothesis that; Indigenous Management practices when applied to finger millet production is likely to increase vegetation density and hence increase in crop yield. The specific objectives for this study were as follows:

1. To estimate Finger millet yield using remote sensing and farm management strategies
2. To assess traditional technologies practised by farmers to improve Finger millet (Eleucine coracana) productivity
3. To analyze the relationship between finger millet vegetation density from remote sensed images and indigenous farm management practices.

MATERIALS AND METHODS

The purpose of the study was to provide support for production of Finger millet (Eleucine caracana) a drought resistant crop variety in Kenya semi arid zones. The research sought to investigate farmer local knowledge on the best management practices that could enhance crop production. The project further assessed use of remote sensed data to predict future crop yields. To achieve the project objectives, the following activities were carried out:

Baseline Survey

A survey was carried out to identify farmers who relied on Finger millet for crop production. This involved purposeful and snow ball sampling of the villages in the area under study. The survey was complemented by visits to the local agricultural and administrative offices to collect information on farming in the study area with emphasis on Finger millet growing areas. The farmers who grew Finger millet formed the sampling frame. A sample was drawn randomly from among the Finger millet farmers. The selected farmers were provided with sheets to maintain farmer calendars and fill in data on agronomic practices whenever the researcher was away. The researcher monitored the farmer calendars during all subsequent field visits.

Field Visits

Five field surveys were carried out. The first one was during land preparation. Interviews with the farmers identified formed key informants for the subsequent household survey involving assessing the indigenous practices. Data on farm management practices with regard to land preparation were collected using informal interviews, observation and photographs. The boundaries of farmer fields were first recorded using hand held Global Positioning Systems (GPS) during field preparation stage. The geographical coordinates of farmer fields were then projected on topographical maps and digitized. The second field survey took place during the planting season. An interview guide associated with seed planting, fertilizer and other inputs were used during this stage, documenting all the information observed. Photographs were used to capture the farm management practices. Data collected included spacing, depth of holes for planting the seed and type and amount of fertilizers applied, among others. The third stage was carried out during weeding and tending of the crop. Interviews with farmers, observation and photographs were used to collect data on the different agronomic techniques practised by farmers. Data collected included number of weeding times, thinning, and amount of fertilizers applied among others. The fourth field visit was done during harvesting of finger millet while the fifth visit was during preparation and storage of the finger millet grain. During harvesting and storage of the grain, data on the quantity and type of yields were collected.

Remote Sensing

The Finger millet crop quality was mapped from high spatial resolution data and ground-truth surveys. The remotely sensed data was accessed through the Regional Centre of Mapping of Resources for Development in Nairobi. The data was a multiple component source from which variation in crop growth and reflectance was analyzed. Change in the temporal pattern of variation in Normalised Difference Vegetation Indices throughout the crop season from planting to harvesting was calculated. Quantitative and spatially explicit estimates of Normalised Difference Vegetation Index change on Eleucine caracana was described using visual inspection of higher resolution images using IDL Virtual Machine and Erdas Imagine. The study used SPOT vegetation images (VGT). The VGT sensor was launched in March, 1998 on board of the SPOT 4 satellite, to monitor surface parameters with a frequency of about once a day on global basis at a spatial resolution of 1 km. It has four bands; blue (0.430 – 0.470 micrometres), red (0.61 – 0.68 micrometres), NIR (0.78 – 0.89 micrometres) and SWIR (1.550 – 1.750 micrometres). Unlike the NOAA- AVHRR, the resolution does not degrade with increasing angle of view. The VGT sensor was designed to provide highly accurate georeferenced images combined with a stable and accurate radiometric calibration. Its layout is better adapted towards terrestrial application like land cover mapping (de Wit and Boogaard, 2001, Mather, 2004).VGT images are provided in three standard products to users: VGT- P (physical) products, VGT-S1 (daily synthesis products) and VGT S-10 (10 day synthesis products). In this study, the S-10 images were used. The S - 10 images represent maximum S-1 values within a 10 day period to minimise the effects of clouds and atmospheric optical depth. Atmospheric corrections for ozone, aerosols and water vapour are done on the images before they are delivered to users (Janssen and Huurneman, 2001).

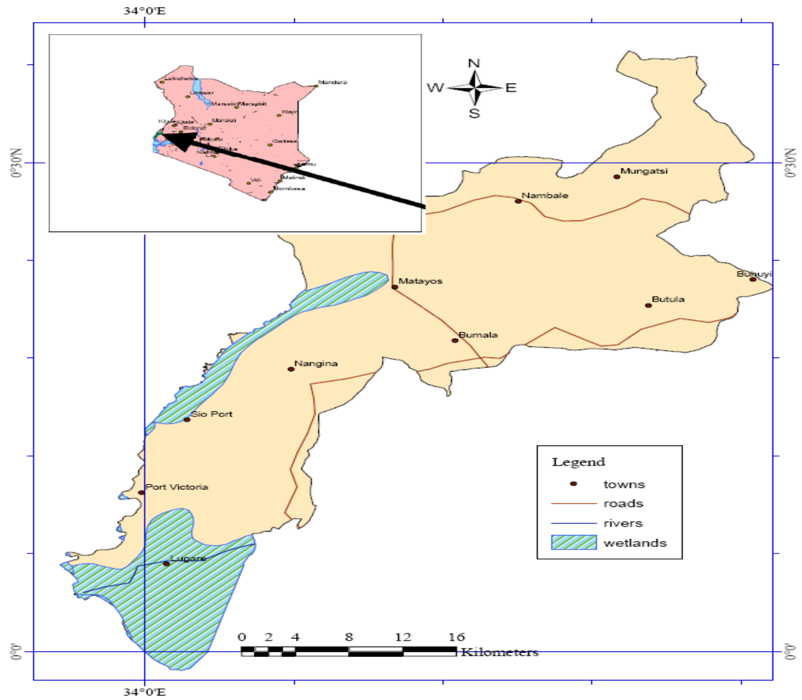

Fig 2. Map of Busia County, Kenya

RESULTS AND DISCUSSION

Yield Estimation Based on NDVI & Land Management Strategies

Data on land and management practices to grow Finger millet and the respective yield data were collected from farmers through questionnaires interviews between January and July 2014. Data units as reported by farmers were converted into standard metric (S.I.) units. The satellite images of March, April and June 2014 provided the field level NDVI data. The total sample size for this study consisted of 57 valid fields. The yields from the surveyed fields ranged from 6 to 720 kg/acre with a mean of 177.83 kg/acre and median of 160 kg/acre. The average NDVI values for the fields ranged from 0.023 to 0.042 with Mean of 0.032 and median of 0.032. When these data were compared, the results showed that there is significant correlation between remotely sensed NDVI and field level finger millet yield ($r = 0.19$, $p = 0.040$, $N = 57$) at 0.05 statistical significance level. These results indicate a direct positive relationship between finger millet vegetation density and the amount of harvest. In other words, the farms that had the highest density of vegetation produced more yield. In order to establish the cause of variation in vegetation density and consequently variation in yields across finger millet farms, the study sought to interrogate the specific farm management practices by farmers. Results indicate that different land management strategies yielded differently.

The Effect of Land Management on Yield

Findings indicate that farmers applied different management practices to get reasonable yields from their plots and they operated at different technological levels. Data on operation sequence that was followed by individual farmers was collected and analysed. The data included all levels of technological operations and production levels practiced in the area. It was revealed that farms with mixed planting strategies (i.e both harrowing and broad casting) yielded more finger millet produce with a mean of 210 kg/acre. This was followed by Broadcasting only at 182.3 kg/acre with Harrowing only with a yield of 170.4 kg/acre.

Study findings reveal that farmers who applied artificial fertilizers harvested more yield (i.e. an average of 186.4 kg /acre) of finger millet than those who applied the organic manure or a mixture of organic and artificial fertilizers. Farmers who did not apply any fertility measure on their fields harvested the second highest amount of at 182.7 kg/acre (Table 1).

Table 1. Fertility Management

Field Practice	**Fertility Management**			
Strategy applied	Fertilizer	Organic	Mixed	None
Mean yield (kg/acre)	186.4	176	133.3	182.7

However, the mean difference in yield between farms that were applied with artificial fertilizer, organic manure or no manure was very small suggesting that fertility management was not a significant variable in explaining differences in yields among the Finger millet farmers.

The study findings revealed that fields that were planted with the start of rains (onset) yielded more (i.e mean of 185.4 kg/acre) than those that was planted before the start of rains (dry planting) which yielded on average 157 kg/acre (Table2).

Table 2. Planting Time

Field practice	**Planting time**	
Strategy applied	Onset	Dry
Mean yield (kg/acre)	185.4	157

With climate variability being common in Kenya, timing of rains is vital for farmers. During interviews with farmers, it was revealed that in the past (about two to three decades earlier) it was common for farmers to practice dry planting. The finger millet farmers could easily predict when rains would start and place the seed in the soil before it started raining to ensure efficient use of the rains and also ensure that most of the seed germinated. However, in the recent times, the respondents observed that it was not possible to predict with precision the beginning of rains. As a result, it was a risky endeavour to practice dry planting because in the event of delayed rains, most of the seed would not germinate.

In terms of cropping systems, there was a small difference (i.e 7.6 kg/acre of yield) between farms that had mixed cropping and those with Monocropping (Table 3).

Table 3. Cropping Systems and Seed Variety

Field Practice	**Cropping**		**Seed Variety**		
Strategy applied	Mixed	Monocropping	u15	Local	Mixed seed
Mean yield (kg/acre)	171.6	179.5	175.7	180.6	200

In terms of seed variety, farms with mixed variety (i.e the hybrid u15 variety and the local varieties) yield more with 200 kg/acre as compared to those with single seed variety. However, when farm yields were compared between the different varieties, the local seed variety yielded more than the hybrid (u15) variety by a small margin of 4.9kg/acre.

Indigenous Knowledge in Finger Millet Farming

It was also observed in the study that about 55 % of farmers applied organic manure in their fields as a way of managing soil fertility. During interviews with some of farmers, the respondents revealed that using organic manure is part of their local knowledge that they have always applied in farming of such indigenous crops as finger millet and sorghum. When asked why some farmers were no longer applying organic manure on their farms, they responded that they believed that soils in their farms had been exhausted of major nutrients and hence they believed that artificial fertilizers were more efficient in restoring farm soil fertility. Some were of the opinion that the presence of sugarcane[1] farming in the county made it easier to access artificial fertilizers which were supplied by the sugar companies to cane farmers.

Another local knowledge applied by farmers in farming of finger millet is dry planting as opposed to planting at the onset of the rains. However, only 26% of farmers practiced dry planting. When asked why only a few farmers were practising dry planting, respondents in focus group discussions explained that since they were planting mainly hybrid seed, they needed to be sure that there was ample moisture in the soil before planting.

They however acknowledged that dry planting was widely practised by the finger millet farmers in the past when they planted local seed. They also explained that dry planting was used as a strategy of adapting to climate variability. Dry planting was also used as an on farm species conservation strategy[2].

Farmers explained that diseases are not a real problem during Finger millet growing season. In a few cases Pesticides and fungicides were applied as a preventive measure. Still, few farmers experienced pest and disease attacks in their fields. The pests reported were brown plant hopper, Stem borrers, leaf folders and rats. It was observed that some farmers were using *desmodium spp* as a way of controlling *striga* weed. *Desmodium* not only controlled the weed away from the finger millet but also increased the soil fertility of the farms (Plate1).

In general, farmers argued that majority of local practices in farm management had been abandoned due to changes in the soil moisture and fertility of their farms. They explained that they resorted to use of artificial fertilizers, hybrid seed and onset planting among other practices as a way of increasing crop yield. They also argued that growing of Finger millet is also part of their indigenous cropping system which has been abandoned due to lack of market for the crop. They further explained that residents of Busia preferred maize meal to finger millet meal

[1] Sugarcane farming was introduced in western Kenya in the early 1970s. In Busia County the cash crop was adopted by majority of farmers in the 1990s. It is believed that farmers can easily access the fertilizers at cheaper prices from their cane farming colleagues who are supplied by Mumias sugar company

[2] Farmers explained that they used the harvest from one season as seed in the next season. The time difference between the two seasons would range from a few days to a few weeks. This strategy allowed them to preserve seed efficiently.

Plate 1. *Desmodium spp* Planted between Two Finger Millet Fields in Busia, Kenya in 2014.

CONCLUSION

This study established that there is a significant positive relationship between remotely sensed Normalised Difference Vegetation Index and field level yield where production is at the mercy of many factors acting on the crop. This clearly adds credence to the growing body of literature that shows the potential of using NDVI for yield prediction at field level. It is noted in this analysis that not all the parameters affecting yield and NDVI at field level have been exhausted. Factors like soil properties have not been explored to find its effect on yield and NDVI due to insufficient data available for this analysis. In the analysis some parameters have been found to explain yield and NDVI variability. Summary of the parameters that turn out to be significant is as follows: Yield = f(NDVI, seed variety, planting date, type of fertiliser Application, precipitation, temperature, solar radiation).

The study has identified some of the local practices that farmers can use to manage the finger millet crop at field level. It is worth noting that Finger millet farming is considered by residents of Busia in Kenya to be one of the abandoned traditional practices. Therefore, this paper proposes enhancing the production and marketing of finger millet in areas where it has good potential in Kenya as a way of contributing to resilient societies in the face of climate variability.

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