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Evaluating the effect of plant population densities and nitrogen application on the leaf area index of maize in a reclaimed wetland in Kenya

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Abstract: Maize is the main staple food in Kenya with over 90% of Kenyans relying on it. While the annual national consumption is increasing, the production of this crop has been on the decline in the last two decades. Maize production in Kenya fell by 33.4% in 2013 with Nyeri among the counties said to be grappling with the production of this crop. Land pressure is one of the major causes of decreased availability of food as well as soil depletion and encroachment upon fragile ecosystems such as wetlands. Nitrogen is a key nutrient in the production of maize, and its deficiency is a major factor limiting its production. This study investigated the effect of N application at 120 kg N/ha and maize density on the Leaf Area Index in reclaimed wetland soils in an experimental set-up comprising a randomized complete block design with three replications. The research was carried out in Nyeri County, Kenya. Leaf Area Index (LAI) was determined using the given SunScan formula. Measurements were done continuously until crop physiological maturity. Results indicated that the leaf area index increased with nitrogen application and reduced with spacing for most treatments. There were no significant differences between the two methods (Copy Method and SunScan). Leaf Area Index (LAI) was high in treatments containing nitrogen and high plant density. It was concluded that high plant density gives high LAI. 50 cm * 12.5 cm (-N) and 50 cm * 12.5 cm (+N) are the recommended plant densities for the site.

Keywords: maize density, land use, N application, food supply, agriculture

1. Introduction

Crop yield commonly depends on the total amount of the intercepted photosynthetic active radiation (PAR), particularly when crop growth is not limited by other factors such as nutrients, water deficiency, or temperature extremes. The availability or deficiency of nitrogen also determines the leaf area index of crops, such as maize, since it is very essential for proper leaf formation, and thus very important in the determination of the photosynthetic ability of the crop, and hence productivity. Leaf Area Index (LAI) is defined as the total one-sided green leaf area per unit ground surface area [1]. LAI controls photosynthetic activity, influences CO_2 exchange in the atmosphere, and thus plays an important role in ecological studies. LAI is used in ecosystem analysis to monitor canopy structure, water and energy exchange, and to scale up ecosystem processes from land to landscape level. LAI is also important in environmental sciences in detecting anthropogenic and natural stresses of forest systems that may affect water quality and results in drought, desertification, and deforestation.

Planting densities have been found to contribute towards significant increase in grain yield [12]. Maize yield response to density depends on the variety [3], nutrition, and environmental factors [4]. Biomass yield, plant height, and ear length have been found to increase with increase in plant density and N rate [12], thus increasing the leaf area [5].

Management practices, such as fertilizer application or thinning, have a strong effect on LAI. The leaf area may be decreased by N deficiency, depending on the severity. According to [7], leaf breadth decreased under high soil nitrogen level and high plant density, while leaf area and yield increased with a higher rate of nitrogen. Thus, a combination of factors, which include the difference in assessment methods, nitrogen rate, and planting density, may therefore lead to widely varying LAI values. The objectives of this study were (i) to assess the effects of varying plant densities on the Leaf Area Index of maize, (ii) to assess the effects of nitrogen fertilizer application on the LAI of maize on reclaimed wetlands in Nyeri County, and (iii) to determine the relationship between the SunScan and Copy methods of LAI determination.

2. Materials and methods

The research was carried out for two rainy seasons (short rains 2012 and long rains 2013) in a ‘small wetland’ in the Karatina – Mathira Constituency, Nyeri County. The wetland lies on a plateau directly below the southern side of Mount

Kenya. The main economic activity of people here is subsistence farming of vegetables, maize, beans, arrowroot tea, and coffee [4]. The area is densely populated with 304 inhabitants per km^2. The experimental plots, each measuring 5 by 1.5 m, were laid out randomly and planted with maize (Hybrid 516 – Kenya Seed Company). Different spacing was applied on the plots while nitrogen was applied as split-plot (some plots were treated with nitrogen, while others remained without) and laid out in a randomized complete block design. A basal application of Muriate of Potash (MOP) was applied to provide phosphorus for maize (tables 1 and 2).

Table 1. Biophysical characteristics of the study site

Description	**Characteristics**
Longitude	37^{0}05'57"E
Latitude	00^{0}27'58"S
Altitude (m.a.s.l.)	1868
Agro-ecological zones (AEZ)	Upper Midland Zone
Annual rainfall (mm)	1450
Temperature range (^{0}C)	11–27
Population density (inhabitants/km^2)	304
Soil properties	
Sand (%): Silt (%): Clay (%)	16:26:58
Textural class	Clay
Soil type	Fluvisols/ Gleysols
Moisture Regime	Hydric

In this study, both direct (non-destructive) and indirect (destructive) methods were applied in the measurement of LAI. Leaf Area Index (LAI) was determined directly by taking a set of sample (based on previous research data) foliage from a plant canopy, measuring the leaf area per sample plot, and dividing it by the plot land surface area. Indirect methods of LAI measured the canopy geometry or light extinction using LAI equipment (Sun Scan) and related it to LAI.

The non-destructive leaf area index measurements were carried out using the SunScan canopy analysis system (Delta-T Devices, Cambridge, UK). The SunScan probe has an array of 64 PAR sensors embedded in a 1-metre-long probe and is connected via cable to a handheld PDA (*Figure 1*).

Figure 1. Delta-T Sunscan equipment for measurements of LAI

Table 2. Description of the treatments' application in the experiment

Treatment description	Plant density/ha	Nitrogen applied (Urea)
100 * 12.5 (-N)	80,000	0
100 * 12.5 (+N)	80,000	120 kg N/ha
100 * 25 (-N)	40,000	0
100 * 25 (+N)	40,000	120 kg N/ha
50 * 12.5 (-N)	160,000	0
50 * 12.5 (+N)	160,000	120 kg N/ha
50 * 25 (-N)	80,000	0
50 * 25 (+N)	80,000	120 kg N/ha

The probe is placed under the canopy, where 3 readings are taken from every point (6 points per plot), which amounts to 18 readings from every plot (*Figure 2*). When taking measurements, the rod is held in the same angle and in the same direction from the beginning to the end of sampling to minimize variations. SunScan readings are taken when the sky is clear to avoid the interference of the clouds. The Leaf Area Index model for SunScan is as follows:

Equation 1: $K(X, \theta) = \sqrt{(X^2+\tan(\theta)^2)} / X+1.702(X+1.12)^{-0.708}$ (1)

θ – Zenith angle of the direct beam
X – ELADP (Ellipsoidal Leaf Angle Distribution Parameter)

Readings are in units of PAR quantum flux (mol m^{-2} s^{-1}) and units of LAI ($m^2.m^{-2}$).

2.1. Procedure for determining Leaf Area Index using the Copy method (destructive method)

Another method known as the Copy method was also used as a comparison for the leaf area index measurement since it is affordable. The method requires stripping off the leaves from the plant in the field, storage (to avoid shrinkage), and copying of the leaves using a normal photocopy machine. The copied leaf images from the paper were cut and weighed and a plain paper of the same size as the paper leaves was also weighed to assist in calculating the leaf area. The paper leaves were then air-dried and leaf area was calculated as follows:

Equation 2: LAI = weight of leaf paper (g) / (weight of paper/area of paper) (2)

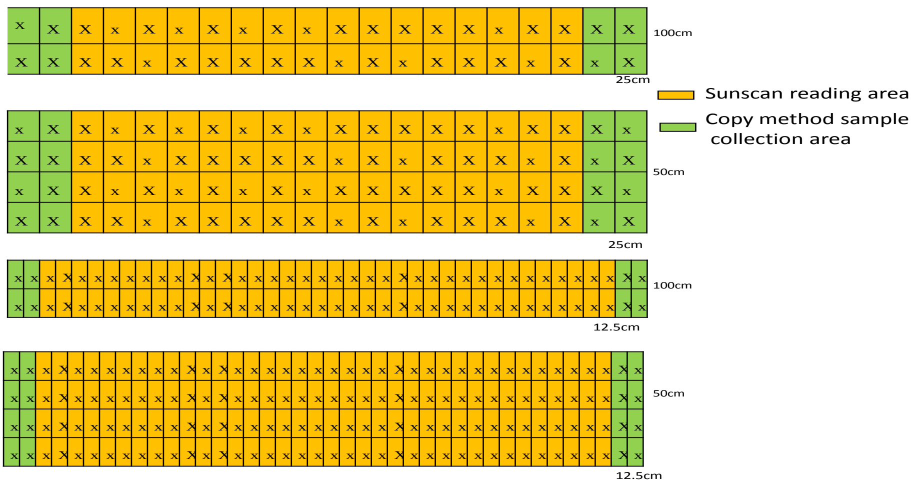

Figure 2. A schematic drawing of maize spacing in the field and the positions where the SunScan probe was positioned while taking the readings for the Leaf Area Index

Data analysis

Statistical analysis was done using the following model, as applicable to the RCBD design.

$$Y_{ij} = \mu + \alpha_i + \beta_j + \sum_{ij}, \quad (3)$$

where: Yij = Plot Observation, μ = Mean of observations, α = Effect due to treatment application, β_j = Effect due to blocking, $\sum_{ij}$ = Experimental error.

Data was managed using Microsoft Excel and subjected to Analysis of Variance (ANOVA) with Least Square Difference (LSD) using Genstat statistical software version 12.

3. Results and discussion

N values were above 0.25% before planting the maize, and are therefore considered high according to [10] and [11]. At the start of the experiment, the % soil N ranged from 0.44 to 0.48%, while at the end of Season 1 the range was 0.34–0.36%. This was a minimal decline in soil N, and therefore the soil may not be considered to have lost a lot of nitrogen through the various mechanisms like leaching. At the end of Season 2, the values of soil N did not differ so much as compared to the values at the end of Season 1, indicating that the rate at which the crops used soil N in both seasons was constant (*Figure 3*).

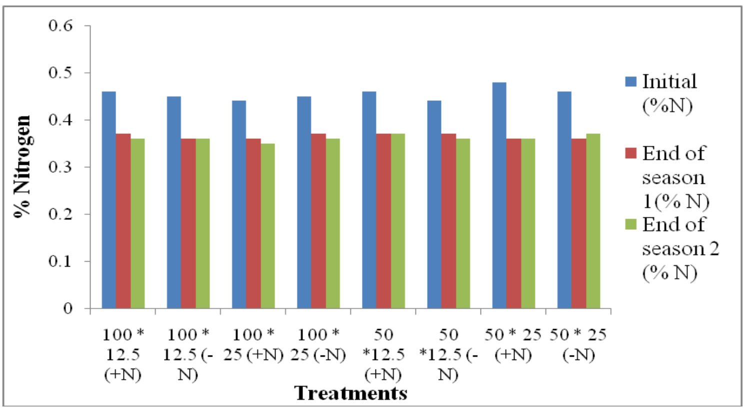

Figure 3. Shows nitrogen values of the soil at the site

Effect of nitrogen fertilizer application and plant population density on the leaf area index

LAI measurements using SunScan direct method

The LAI means for the growing period indicated as day of year (DOY) for treatments with nitrogen and without nitrogen are as shown below. The LAI values obtained during the first season indicated that the treatments with nitrogen application had higher LAI values compared to those treatments without N application. Maize spacing of 50 cm ∗12.5 cm for the treatments to which nitrogen fertilizer was added had the highest LAI ranging between 4.7 and 6. The spacing of 100 cm ∗ 12.5 cm recorded the lowest LAI values ranging between 2.2 and 3. This indicates that the high plant density limited the light penetration to the crop, and hence the lower LAI values observed. An increase in LAI index was observed from the early stages of maize growth to physiological maturity, and this is due to the transfer of products, which occurs after silking. A similar observation was reported by [10] (*Figure 4*). It also shows a trend of the leaf area index of maize between the beginning of the season or 21 days after emergence of maize up to physiological maturity. The treatment 100 ∗ 12.5 (+N) had the highest mean value for LAI, but it was not significantly different from the mean of LAI on treatment 50 ∗ 12.5 (+N) at 99% level of probability. LAI was highest ($P \leq 0.01$) on DOY 19, which was taken when the maize was at physiological maturity.

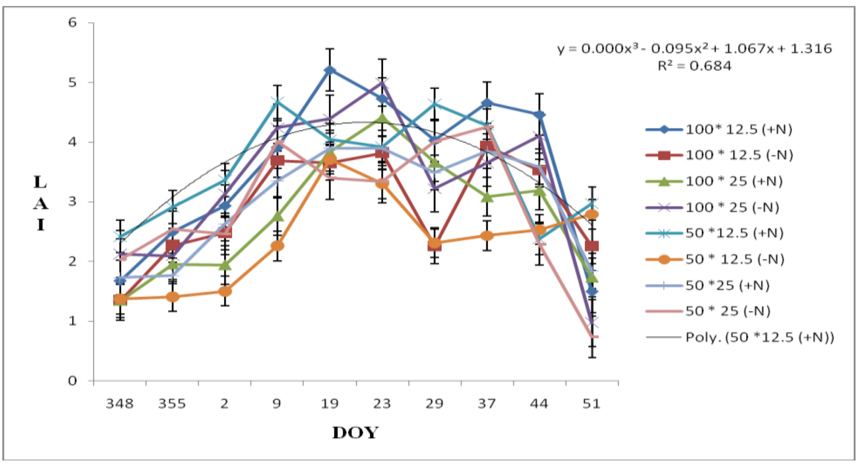

Figure 4. Changes in LAI with time (Days Of the Year) in the different treatments. (The arrows indicate hailstone attack during the growing period)

LAI measurements using the Copy method – indirect method

The spacing of 50 cm ∗ 12.5 cm (+N) had the highest LAI ranging between 2.7 and 5.8. The spacing of 100 cm ∗ 12.5 cm (-N) recorded the lowest LAI values ranging between 1.8 and 3.5. However, the trends of LAI when measured using the copy method were different from the SunScan method. This is attributed to possible errors – a common disadvantage of the manual method of LAI determination (*Figure 5*).

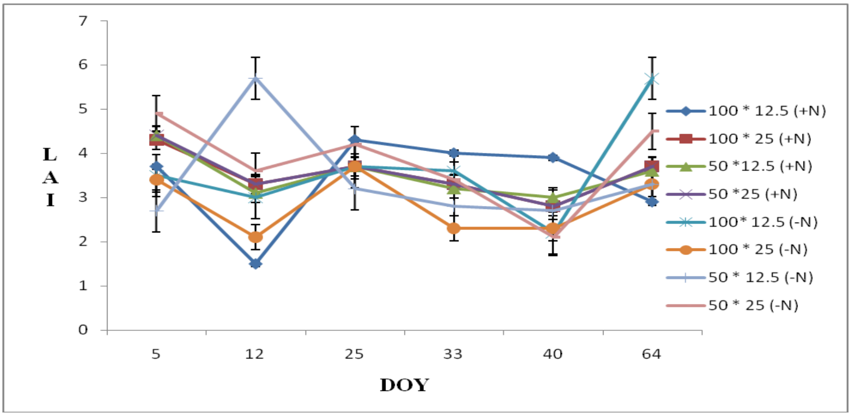

Figure 5. LAI means for the growing period (DOY) using copy method

Several studies have used indirect methods to estimate LAI in field crops and forests with reasonable successes. The values of LAI were also high in the treatments which contained additional nitrogen compared to those which had no Nitrogen added. This, therefore, shows that nitrogen is an important nutrient since it has a positive effect on the Leaf Area Index of maize. Leaf area serves as the dominant control over primary production (photosynthesis), transpiration, energy exchange, and other physiological attributes pertinent to a range of ecosystem processes. LAI constantly changes during the growing period of the crop and the vegetative stage showed higher LAI values compared to the stage after silking, which is attributed to the transfer of products as the crop enters the physiological maturity stage [7].

Comparison of the SunScan and Copy methods of LAI measurements during the growing period

There was an increase in leaf area index from emergence to physiological maturity, as observed in figures 5 and 6. The Copy method, which was an indirect method of measuring leaf area index, showed slightly lower values for the LAI compared to the SunScan method during all measuring times.

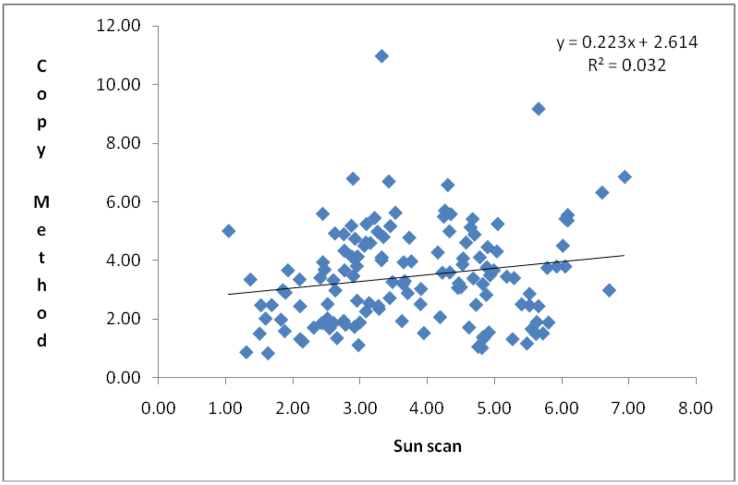

Figure 6. Correlation between the Copy method and SunScan method of measuring Leaf Area Index

However, there was a similar trend in the values with treatments with N application having higher values than those without N application.

This confirms that, depending on the availability of resources, either of the methods can be used to determine the LAI, and thus the productivity of the crop. Specifically on smallholder farms and in research institutions in Africa where capital resources are limited, the copy method may be used to obtain indicative results of the LAI. Results showed a positive linear correlation between the two methods, but a low R^2 value (*Figure 6, Table 3*).

Table 3. Effect of the spacing and N application on Leaf Area Index during the growing season

Treatments	**LAI**	**Grain yield**
25*100 –N	1.87a	1.739a
25*100 N	2.19b	1.727a
25*50 –N	2.33b	1.556a
25*50 N	2.93c	3.614b
12.5*100 –N	3.37d	3.077b
12.5*100 N	3.41d	3.2b
12.5*50 –N	4.24e	3.822b
12.5*50 N	4.54f	2.646ab
LSD	0.1607	1.3
Probability	<.001	0.009

LAI and grain yield were significantly high in treatments with high plant density and Nitrogen.

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