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ORIGINAL RESEARCH ARTICLE



## Use of GreenSeeker and CM-100 as manual tools for nitrogen management and yield prediction in irrigated potato (*Solanum tuberosum*) production

Felix Satognon\* , Joyce J. Lelei and Seth F.O. Owido

Egerton University, Department of Crops, Horticulture and Soils, P.O. Box 536-20115, Egerton, Njoro, KENYA  
\*Corresponding author's E-mail: [felixsatognon@gmail.com](mailto:felixsatognon@gmail.com)

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### ABSTRACT

This study evaluated the possibility of the use of GreenSeeker sensor and CM-100 chlorophyll content meter for in-season N and yield prediction in order to promote timely split N application in potato production in Kenya. Four N-fertilization rates; N<sub>0</sub>(0), N<sub>1</sub>(60), N<sub>2</sub>(90) and N<sub>3</sub> (130 kg N/ha) were laid out in a Randomized Complete Block Design (RCBD) in a Greenhouse for two seasons. The results showed that % N leaf content was significantly affected by N rates. The % N leaf content and potato leaf chlorophyll content decreased as the season continued whereas the Normalized Difference Vegetation Index (NDVI) increased as the season continued. CM-100 values were significantly correlated with % N leaf content at vegetative ( $r=0.86^{***}$ ) and tuber initiation ( $r=0.74^{***}$ ) growth stages of the crop whereas the NDVI values were only significantly correlated with % N leaf at tuber initiation ( $r=0.82^{***}$ ). A significant relationship was found between CM-100 values taken at different potato stages (end of vegetative, tuber initiation, bulking and maturation stages) and tuber yield ( $r=0.90^{***}$ ,  $0.82^{***}$ ,  $0.47^*$  and  $0.41^*$ ). The NDVI values at end of vegetative growth, tuber initiation and maturation of potato were also significantly correlated with tuber yield ( $r=0.81^{***}$ ,  $0.43^*$  and  $0.54^*$ ), except at bulking stage ( $r=0.33$ ). For efficient in-season N management and yield prediction, CM-100 and GreenSeeker are recommended at an early stage of the crop. Further research in the different potato growing areas in Kenya to establish the different thresholds at different potato growth stages is recommended.

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### INTRODUCTION

Nitrogen (N) is a vital element for potato growth because of its roles in photosynthetic activities, chlorophyll accumulation, crop growth, potato tuber yield and dry matter accumulation (Goffart *et al.*, 2011; Chlingaryan *et al.*, 2018). It is the most often limiting nutrient for potato growth and the value of the other inputs cannot be fully achieved unless the amount of mineral N applied is optimal (El Mokh *et al.*, 2015; Marouani *et al.*, 2015). Soil nitrogen is largely tied up in organic matter which cannot readily be available during the potato cycle hence an application of mineral N is necessary (Koch *et al.*, 2019). Adequate and sufficient N nutrition throughout the crop cycle is important

(El Mokh *et al.*, 2015; Mengist *et al.*, 2021).

The N requirement of potato is relatively low during the first 35 days after planting and high N application during the vegetative growth stage can delay or inhibit potato tuberization (Jackson, 1999; Zebarth and Rosen, 2007). Nitrogen is one of the elements that are deficient in different potato growing areas of Kenya. This is due to nutrient depletion with inappropriate replenishment as a result of continuous production. This can not only cause economic losses to the farmers by stifling crop growth but also pollute the environment (Waaswa and Satognon, 2020). To replenish the depleted N and ensure a vigorous growth of the crop, the smallholder potato farmers of Kenya apply 80% of the total required N at planting in form of diammonium

phosphate. However, an earlier study in northern China showed that only 20% of total mineral N supplied at planting is taken up by potato crop (Dai *et al.*, 2000). The highest amount of N is required during tuber bulking, which is the stage at which the plant takes up about 58-70% of the total N from soil (Ojala *et al.*, 1990). Therefore, N management is crucial as it can volatilize or leach out of the soil and the probability that its requirement is the same in different growing seasons is only about 1% (Zheng *et al.*, 2015). In addition, the standard N fertilizer references and recommendations cannot include the spatial and in-season variability in soil N supplying capacity during the crop cycle (Gabriel *et al.*, 2017; Bijay and Ali, 2020). Therefore, a split application method is seen as the best way to increase fertilizer use efficiency under potato production. To avoid N losses or deficit at the time of top dressing and maximize N utilization, the N supply should match with the crop's requirements at different stages. The optimization and efficient use of mineral N fertilizers has become the purpose of many researchers in various crops due to its cost-effective and environmental impacts (Muñoz-Huerta *et al.*, 2013).

The best method to assess N status during the crop growth stages is plant tissue analysis using Kjeldahl Digestion and Dumas Combustion methods (Muñoz-Huerta *et al.*, 2013; Sharma and Bali, 2018). These methods are precise but expensive, destructive, time-consuming and require technical knowledge in sampling which is lacking among farmers. Some manual tools that have aroused interest for in-season N status assessment and crop yield prediction are Crop Circle ACS-470 sensor, GreenSeeker sensor, SPAD chlorophyll meter, CM-100 Chlorophyll meter, Yara N-Sensor, Crop Circle ACS-430 multiplex sensor, hand-held Field Spectro-Radiometer sensor (Analytical Spectral Devices, Inc., Boulder, CO, USA) and CropScan (Muñoz-Huerta *et al.*, 2013; Cilia *et al.*, 2014; Maresma *et al.*, 2016, 2018; Chlingaryan *et al.*, 2018; García-Martínez *et al.*, 2020). GreenSeeker sensor and CM-100 Chlorophyll meter are mostly used as tools to assess in-season N status and predict crop yield in various crops due to their ease of use and portable aspect. GreenSeeker is a ground-based remote sensor or Canopy Reflectance Sensor with two LEDs as a source of light. This sensor has a reflectance of 650 and 770 nm bandwidth which is used to detect the reflection of vegetation index. It computes NDVI as a ratio of visible (VIS) and near-infrared (NIR) reflectance data (NIR/VIS). GreenSeeker takes into account the N status and the biomass of the crop to access additional N fertilizer recommendations. It showed a high correlation with in-season N status in wheat (Németh *et al.*, 2007; Bijay and Ali, 2020). However, chlorophyll is the main pigment of plant leaves and responsible for their greenness. The leaf chlorophyll concentration is used as an indicator to access N status in many crops. CM-100 Chlorophyll meter manufactured by Apogee Instrument Inc. (Logan, UT, USA) is a chlorophyll measuring machine. It has a transmittance of 653 and 931 nm and used at leaf scale.

These tools are used for N management in developed countries. As cited in Bijay and Ali (2020), few studies carried out in devel-

oping countries to develop the strategies of in-season N assessment and management using these tools have focused on wheat, maize and rice. The use of these sensors for N management in potato has not been documented in Africa especially in Kenya. This study was designed compare the possibility of the use of GreenSeeker and CM-100 chlorophyll content meter for in-season N and yield prediction to promote timely split N application in potato production in Kenya. Also, this study provides knowledge on N management in potato using GreenSeeker sensor and CM-100 chlorophyll meter, considering that N is the most limiting nutrient of potato yield. The greater demand for potato due to the growing population moreover in the face of climate change (Waaswa *et al.*, 2021) and this coupled with the difficulty in N management in potato justifies the need for new and quick access methods of N status in potato production. Thus farmers who might apply this knowledge could be able to access N status at different growth stages of potato growth and hence being in position to match the crop requirements with the N supply. This reduces N losses and increase mineral N fertilizer utilization which in turn lowers the negative effects it poses on the environment.

## MATERIALS AND METHODS

### Experimental site description

Greenhouse experiments were conducted between July and October 2020 and December 2020 and March 2021 at the Agro-Science Park experimental farm of Egerton University in Nakuru County, Kenya. The experimental farm is located in agro-ecological zone III of Kenya (0.3031° S, 36.0800° E) at 2670 m above sea level. To determine initial soil properties, subsamples of soil were randomly collected using a soil auger from six locations of the site at two different depths (from 0-0.15 and 0.15-0.45 m) since potato rooting falls between (0-0.4m). The subsamples were mixed to obtain one composite soil sample per depth for basic soil fertility analyses. Soil pH was measured in a 1:1 (w/v) ratio. The total N of the composite samples was determined using the Kjeldahl digestion method (Okalebo *et al.*, 2002). The mass analysis of Cornell Morgan was used to extract P, K, Mg, Ca, Mn and Zn. Sieved (<0.02 mm) dry oven composite soil sample (40° C) was used for determination of the total organic carbon using the calorimetric method (Anderson and Ingram, 1993). Exchangeable acidity was measured at pH < 5.5 (Okalebo *et al.*, 2002). Available Fe and Cu were extracted in a 1:10 (w/v) ratio with 0.1 M HCL followed by Atomic Absorption Spectrophotometer reading. All the analyses were carried out at the laboratory of Kenya Agricultural and Livestock Research Organization (KALRO) in Nairobi. The results of basic soil fertility analyses are presented in Table 1.

Irrigation water had a medium salinity level and high sulfate. The quality of water used was suitable for irrigation because the soil is permeable with adequate drainage (this interpretation was based on USDA classification of irrigation water) (Wilcox, 1955; Scherer *et al.*, 1996; Bauder *et al.*, 2011). For the physical properties, the Hydrometer method was used to determine the soil

texture of the experimental site (Bouyoucos, 1962). Soil bulk density ( $\rho_b$ ) and Field Capacity (FC) were measured using the oven-dry method (Black and American Society of Agronomy, 1965; Aschonitis *et al.*, 2013). Permanent Wilting Point (PWP) was determined at a pressure of 1.5bar. Available Water (AW) was computed by subtracting the permanent wilting point from the field capacity using equation 82 of FAO 56 (Allen *et al.*, 1998). The physical properties of experimental soil are shown in Table 2.

### Experimental design and treatments

The land was ploughed at 0.2 m depth after which the plots were prepared by raising the soil. The experiment was led out in RCBD with three replications. Each block was separated by 1.5 m. The experimental units within the blocks were separated by 1.5 m. The treatments were N-fertilization levels; N<sub>0</sub>(0), N<sub>1</sub>(60), N<sub>2</sub>(90) and N<sub>3</sub>(130 kg N/ha). The fertilizer was split applied in all treatments at 10 (40%), 30 (40%) and 50 (20%) days after planting. In this experiment, urea fertilizer was used as a source of N. Each experimental unit (2.5 m<sup>2</sup>) received 9 apical rooted cuttings of Shangi potato variety. They were planted at a spacing of 0.30 m and 0.70 m (between rows and lines, respectively) in a set of three rows. This led to a density of 47,617 plants/hectare. The potato was planted on 7 Jul. 2020 and 3 Dec. 2020 and harvested on 8 Oct. 2020 and 20 Mar. 2021, respectively. During planting, 50kg/ha of triple superphosphate (TSP) and 90kg/ha of potassium sulphate (SOP) fertilizers were added to the experimental unit based on the universal recommendations of the area. Irrigation was done through drip irrigation method. Lateral driplines with 1.6 L h<sup>-1</sup> at 100 kPa inline drippers spaced at 30 cm were placed for each row. All the experimental units received the same amount of water for each irrigation. The soil moisture content was monitored with a TDR moisture meter. To control the prevailing potato diseases (the early and late blight) and pests, Ridomil Gold MZ 68 WG (1 kg/ha) combined with

mancozeb (1 kg/ha) fungicides and VOLTAGE 5EC (350 ml/ha) were used, respectively. Weeding was manually done every three weeks while earthing up was done one month after planting.

### Data collection

Data was collected on the yield, % N leaf content, leaf chlorophyll content and NDVI. The yield data was taken from the nine plants of each experimental unit. Composite samples of the leaves were taken from the nine plants of each unit at the different stages of the crops (57, 67, 88 and 103 days after planting (DAP)) for % N leaf content analysis using the Kjeldahl method. The chlorophyll content in the leaf was measured every two weeks till maturity using a CM-100 chlorophyll concentration meter. Chlorophyll content was assessed on the top leaflet of the fourth compound leaves from the apexes of plants (Li *et al.*, 2012 and Li *et al.*, 2019). The NDVI was also taken every two weeks till maturity using the GreenSeeker sensor. It uses a self-illuminated light source in the near-infrared and red wavelengths, (650 ± 10 nm) and (770 ± 15 nm), respectively (Crain *et al.*, 2012).

### Data analyses

Before analysis, data were subjected to a normality test of the Shapiro Wilk at ≤0.05 in R software (version 3.6.3). For any data not normally distributed, fitting data transformation was performed. Analysis of variance (ANOVA) was performed to test the differences in CM-100 values, % total leaf nitrogen content, NDVI values and crop yield. Regression analyses at 5% were carried out to determine the response of % N total leaf content to N levels at different growth stages of the crop in mollic Andosols. Pearson's correlation coefficient was used for determining the relationship between CM-100 values, % total leaf nitrogen content, NDVI values as well as crop yield. During the analysis, any data in the outlier and not due to the treatment effect was deleted from the model.

**Table 1.** Soil chemical analyses.

Soil depth cm	0-0.15 m		0.15-0.45	
Parameters	Value	Class	Value	Class
Soil pH	5.43	medium acid	5.46	medium acid
Exch. Acidity meq%	0.20	adequate	0.21	Adequate
Total Nitrogen %	0.16	low	0.14	Low
Total Org. Carbon %	1.69	moderate	1.61	Moderate
Phosphorus ppm	21	low	19.1	Low
Potassium meq%	1.14	adequate	1.11	Adequate
Calcium meq%	5.6	adequate	5.4	Adequate
Magnesium meq%	1.61	adequate	1.43	Adequate
Manganese meq%	1.37	adequate	1.25	Adequate
Copper ppm	1.80	adequate	1.71	Adequate
Iron ppm	12.2	adequate	12.2	Adequate
Zinc ppm	2.45	low	2.42	Low
Sodium meq%	0.18	adequate	0.17	Adequate

**Table 2.** Physical properties of the experimental soil.

Depth (m)	Soil texture			Class	Moisture Retention %				Bulk Density (g/cm <sup>3</sup> )
	Sand%	Silt %	Clay %		FC	PWP	AW	RAW	
0-0.15	63.7	26.2	10.1	SL	19.9	12.3	7.6	2.66	1.26
0.15-0.45	57.6	30.2	12.2	SL	20.3	11.8	8.5	2.98	1.34

SL= Sand Loam, RAW = Readily Available Water

## RESULTS AND DISCUSSION

### Leaf N content, CM-100 and NDVI values

The values of leaf N content, CM-100 and NDVI are shown in Table 3. The % N leaf and potato leaf chlorophyll content decreased as the season continued whereas the NDVI values increased as the season continued (Figures 1, 2 and 3). After the vegetative stage, leaf chlorophyll content decreases generally as the season continued (Zheng *et al.*, 2015; Elsaid and Silva, 2017). The same trend was also obtained in cotton crop (Ballester *et al.*, 2017). The mean of % N leaf content ranged from 3.97 to 5.78, 2.85 to 4.72, 0.79 to 2.55 and 0.22 to 0.59 at the end of vegetative, tuber initiation, bulking and maturation growth stage, respectively. The results showed that % N leaf content significantly responded to N levels ( $P < 0.001$ ). The lowest value of % N leaf content was recorded in N0 treatment while the highest was obtained with N3 ( $P < 0.001$ ). The % N leaf content generally increases with an increase of the amount of N applied (Németh *et al.*, 2007; Majić *et al.*, 2008; Zheng *et al.*, 2015; Elsaid and Silva, 2017). CM-100 values and NDVI values, recorded with GreenSeeker, increased with N levels. However, at the late stages of the crop, the means of % N leaf content of the different N treatments did not differ significantly. This trend was also reported in previous studies (Elsaid and Silva, 2017; Zaen, 2020).

### Correlation values between Leaf N CM100 and NDVI values

The highest correlation coefficients between % N leaf content and both CM-100 ( $r = 0.86^{***}$ ) and NDVI values ( $r = 0.82^{***}$ ) were

obtained at the vegetative stage of the crop (Table 4). At the tuber initiation stage, a significant Pearson's correlation was found between % N leaf content and CM-100 ( $r = 0.74^{***}$ ) but not between % N leaf content and NDVI values ( $r = 0.36$ ). However, at the bulking and maturation growth stages, the Pearson coefficients obtained between % N leaf content and both CM-100 and NDVI values were not significant. As observed CM-100 can be used for an in-season N status determination at vegetative and at tuber initiation stages of the crop. However, GreenSeeker can only be used for N management at the vegetative stage of the growing season. Leaf chlorophyll content values taken with SPAD and % leaf N content showed a significant Pearson's coefficient at various stages of potato crop (Li *et al.*, 2012; Fernandes *et al.*, 2021). This showed that CM-100 can be used as a SPAD chlorophyll meter for N management at vegetative and at tuber initiation stages of the crop. NDVI values recorded in this study reached saturation at the vegetative stage of the crop. This is in line with the early studies in which NDVI values from GreenSeeker reached saturation at the vegetative stage when measuring N status in wheat and maize (Muñoz-Huerta *et al.*, 2013; Maresma *et al.*, 2016; Chlingaryan *et al.*, 2018). These results imply that GreenSeeker Sensor and CM-100 cannot be used for late nitrogen management in potato. This demonstrates the need for the development of a manual remote sensor for late N management in potato. Cohen *et al.* (2010) has successfully assessed N at the tuber bulking stage using VENIS satellite. This method might be expensive for farmers. Hence, manufacturing it as a handheld crop sensor could be easy to use.

**Table 3.** Means separation and ANOVA of Yield, CM-100, % N leaf content, NDVI Values from GreenSeeker readings in potato after 57, 67, 88 and 103 days after planting (DAP) in different N treatments.

Treatments	Yield		% N leaf content				CM-100 values				NDVI Values			
	57	67	88	103	57	67	88	103	57	67	88	103		
N3	58.28a	5.78a	4.72a	2.55a	0.59a	50.57a	41.78a	35.86a	32.06a	0.73a	0.82a	0.85a	0.91a	
N2	47.77b	5.16b	4.09b	2.00b	0.47a	41.65b	35.55b	30.20b	27.38b	0.68b	0.83a	0.85a	0.90a	
N1	33.23c	4.76b	3.63c	1.65c	0.47ab	35.75c	32.59c	27.09c	25.26c	0.63c	0.80ab	0.85a	0.89ab	
N0	28.412c	3.97c	2.85d	0.79d	0.22b	32.96c	28.78d	24.81c	22.27d	0.50d	0.76b	0.84a	0.86b	
Means	41.92	4.92	2.92	1.75	0.44	40.23	34.68	29.49	26.74	0.64	0.80	0.85	0.89	
ANOVA														
Season	**	**	**	**	ns	ns	**	***	***	**	ns	ns	ns	
Replicate (Season)	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	
Nitrogen	***	***	***	***	***	***	***	***	***	***	***	***	*	
CV	9.74	6.98	8.89	15.13	17.89	8.52	6.48	6.48	5.82	5.22	6.68	4.48	2.81	
R <sup>2</sup>	93.34	0.82	0.89	0.91	0.45	0.86	0.89	0.94	0.96	0.92	0.69	0.48	0.64	

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05

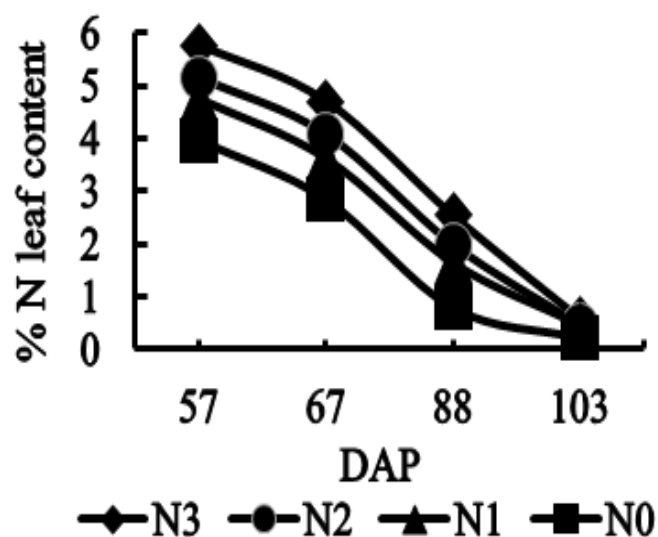


Figure 1. Variation of % N leaf content values day after planting (DAP).

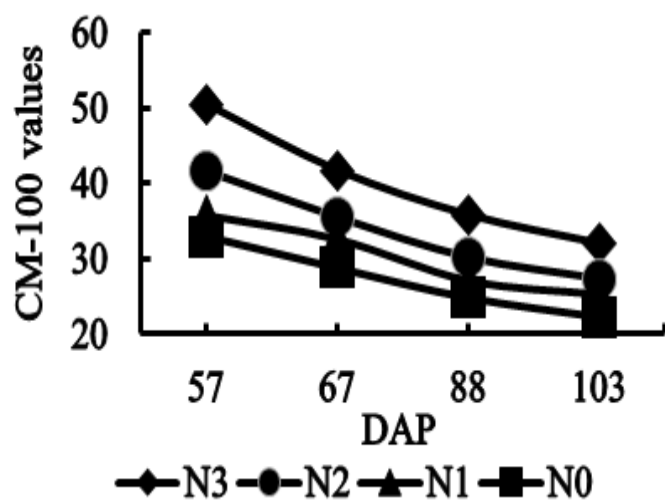


Figure 2. Variation of CM-100 values day after planting (DAP).

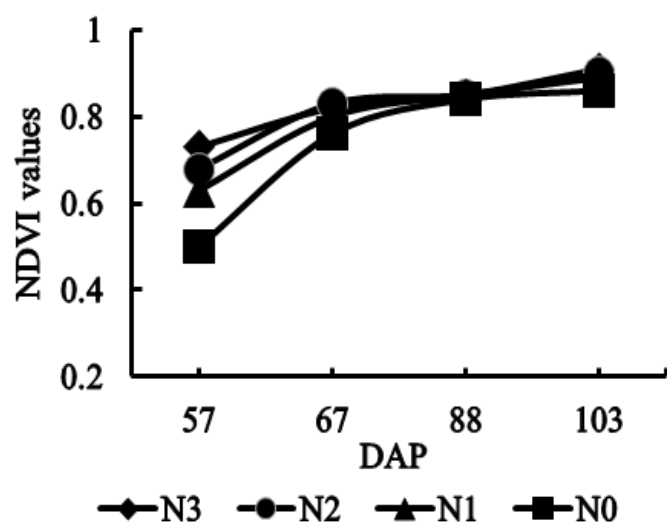


Figure 3. Variation of NDVI values day after planting (DAP).

### Regression values between Leaf N and N fertilization

The following regression equations and determination coefficients were obtained between % N leaf content at different DAP and N-fertilization. DAP 57:  $Y = 0.0138X + 3.9492$ ,  $R^2 = 0.99$ , DAP 67:  $Y = 0.144X + 2.817$ ,  $R^2 = 0.99$ ; DAP 88:  $Y = 0.0135X + 0.8048$ ,  $R^2 = 0.99$  and DAP 103  $Y = 0.0027X + 0.2454$ ,  $R^2 = 0.93$  (all F-values were significant at 5%) (Figure 4). The regression slopes obtained between % N leaf content vs N-fertilization at vegetative, tuber initiation and tuber bulking growth stages of the crop were high. This implies that optimal % N leaf content is imperative at the vegetative, tuber initiation and tuber bulking growth stages for obtaining high tuber yield. This means adequate soil fertility management needs to be done at these stages of the crop to maintain % N leaf content or leaf chlorophyll content at optimum level. For efficient use of these remote sensors, further study is recommended in the different potato growing areas of Kenya using different potato varieties to determine the threshold of CM-100 and GreenSeeker values at different growth stages of the crop.

### Correlation between tuber yield, CM-100 values and NDVI at different growth stages of potato

The tuber yield significantly responded well to N levels (Table 3). Tuber yield increased continuously with N levels. The highest fresh tuber yield was found with an application of 130 kg N/ha. The means of fresh tuber yield estimated at harvest ranged from 28.41 to 58.28 tonnes/ha. The lowest yield was recorded in the control (0 kg N/ha) but not statistically different from the yield recorded with 60 kg N/ha. The same result was found by Badr *et al.* (2012) and Sharma and Bali (2018). The result showed that the CM-100 values were significantly correlated with the fresh tuber yield at all stages of potato ( $r=0.90^{***}$ ,  $0.82^{***}$ ,  $0.47^*$  and  $0.41^*$ ) (Table 4). Also positive relationship between tuber yield and NDVI values was found at different stages of the crop except for the tuber bulking stage ( $r=0.81^{***}$ ,  $0.43^*$ ,  $0.33$  and  $0.54^*$ ). This showed that CM-100 can be used for potato yield prediction at all potato stages. Moreover, NDVI values from the GreenSeeker sensor can also be used for potato tuber yield prediction at different stages of potato except at the tuber bulking stage. However, the yield prediction at the vegetative stage using any of these sensors might be reliable than the late growth stages of the crop. Early research found a highly significant correlation coefficient between tuber yield and leaf chlorophyll content values measured with SPAD (Majić *et al.*, 2008; Güler, 2009; Wilkinson *et al.*, 2019). A significant correlation was also reported between NDVI values and the yield of grain crops (Lofton *et al.*, 2012; Cao *et al.*, 2015; Zaeen, 2020). Lofton *et al.* (2012) faced challenges in sugarcane yield prediction using GreenSeeker due to a multi-year cropping cycle with a short growth period. The NDVI values recorded using GreenSeeker was successfully used as yield and biomass indicator in the Winter Oilseed Rape crop (Louvieaux *et al.*, 2020).



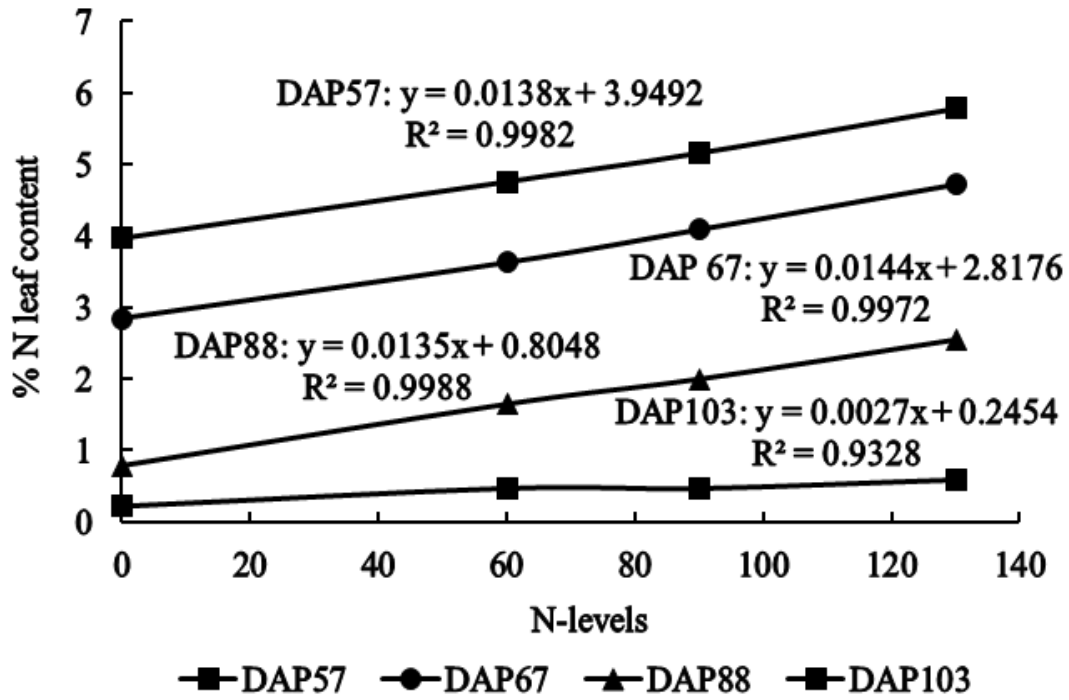


Figure 4. Regression between % N leaf content and N rates at different growth stages of potato.

Table 4. Correlation between Yield, CM-100, % N leaf content, NDVI Values from GreenSeeker reading in potato after 57, 67, 88 and 103 days after planting (DAP).

Tuber yield	0.84***	0.83***	0.84***	0.11	0.90***	0.82***	0.47*	0.41*	0.81***	0.43*	0.33	0.54*
% N leaf content 57		0.98***	0.91***	0.08	0.86***	0.72***	0.23	0.21	0.82***	0.39	0.41	0.43
% N leaf content 67			0.91***	0.059	0.88***	0.74***	0.26	0.23	0.83**	0.38	0.36	0.40
% N leaf content 88				0.10	0.84***	0.76***	0.36	0.33	0.88***	0.45*	0.30	0.39
% N leaf content 103					0.02	0.09	0.200	0.25	0.18	0.17	0.14	0.21
CM-100 57						0.89***	0.47*	0.45*	0.72*	0.26	0.23	0.48*
CM-100 67							0.70***	0.70***	0.71***	0.12	0.22	0.64***
CM-100 88								0.98***	0.36	-0.21	-0.19	0.42*
CM-100 103									0.31	-0.31	-0.15	0.42*
NDVI 57										0.57**	0.23	0.50*
NDVI 67											0.32	0.22
NDVI 88												0.24
NDVI 103												

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05

## Conclusion

To achieve an optimum potato tuber yield and high quality, N fertilization should not only be proportional to the crop need but be applied at right time. Hence, split application of mineral N fertilizer throughout the growing season is the suitable and appropriate approach to match potato N requirement and supply. This study found that CM-100 can be used for in-season N management at vegetative and tuber initiation stages whereas GreenSeeker sensors can only be used at the vegetative stage due to its early saturation. For yield prediction, CM-100 can be used throughout the growing season of potato. The GreenSeeker sensor can also be used for tuber yield prediction at all stages of potato except the tuber bulking stage. For efficient yield and nitrogen recommendation, CM-100 is recommended but GreenSeeker can also be used at an early stage of the crop. The study recommends the development of a manual remote sensor for late N management in potato. This study also recommends further investigations in the subject in the different potato growing areas of Kenya to establish the different thresholds at different stages of the crop.

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## Competing interests

The authors declared that there is no competing interest.

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