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Growth, Yield and Quality of Onion (*Allium cepa* L.) as Influenced by Nitrogen and Time of Topdressing

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Authors' contributions

This work was carried out in collaboration between all authors. Authors MWG, RN and JA designed and implemented the study, wrote the protocol and wrote the first draft of the manuscript. Authors MWG and AWM performed the statistical analysis. All co-authors managed the analyses of the study. Authors MWG and AWM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Onion (*Allium cepa* L.) is an important commercial vegetable crop grown by small-holder farmers in Kenya for both local and export markets. The national average production is low and quality is highly compromised due to use of low yielding varieties and poor agronomic practices. Field experiments on the influence of nitrogen and time of application on growth, yield, and quality of onion bulbs were conducted in 2014 and 2015 at the National Agricultural Research Laboratories. The experiments were laid out in a Randomized Complete Block Design (RCBD) with a split-split arrangement and replicated three times. Nitrogen (N) was applied as Calcium Ammonium Nitrate at five levels including, 0 (control), 26, 52, 78 and 104 kg N ha^{-1}. These were applied at four different times of applications at three, six, nine and twelve weeks after transplanting. Two onion varieties popularly grown in Kenya were used, the Red Creole and Red Tropicana F1 hybrid. Nitrogen and time of application showed significant differences in all parameters studied except bolting. Nitrogen

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at 104 kg N ha^{-1} applied at 6 weeks gave the best results with regard to plant height, number of leaves, bulb ratios, bulb diameter, average bulb weight, yield and marketable yield. Six weeks after transplanting was the best application time with regard to most parameters and maturity of the crop. Yields increased linearly with increased N rates but declined by over 23% with late application at 12 weeks. High rates resulted to thick necks and increased split bulbs especially with late application at 9 and 12 weeks. Red Tropicana F1 hybrid was the best performing variety with regard to most parameters especially total and marketable yield. Nitrogen applied at the right time improves growth, increases yield and improves quality. Since the yield response was linear in both seasons, higher rates should be evaluated to get the optimal rate.

Keywords: Onion; varieties; fertilizer; application time; growth; yield; quality.

1. INTRODUCTION

Onion (*Allium cepa* L.), the dry or bulbing onion is a biennial plant belonging to family *Amaryllidaceae* (*Alliaceae*) and native to South East Asia [1]. It is one of the oldest vegetables known to man having been in cultivation since the recorded history of mankind, at least 5000 years ago [2]. The onion is popularly grown for its pungent bulbs which are used in almost every house hold as a seasoning or a vegetable in various dishes. Although their nutritional value is low, onions are high in Vitamin C, Vitamin B_6, Calcium, Magnesium, Phosphorus and Potassium. They also have a reputation for good medicinal properties including anticancer, antidiabetic, antimicrobial, anti-cholesterol, anti-asthmatic, antithrombotic, anti-inflammatory and anti-oxidative [3,4,5,6].

The onion is grown commercially in many parts of the world, the leading in order of importance being China (23.9), India (19.1), Egypt (3.1) and United States of America (3.0) million MT [7]. These countries combined produce about half of the world's dry onions. Other producers among the top include Iran, Pakistan, Turkey, Russian Federation, Bangladesh and Brazil. Exporting countries (in dollar value worth of onions) are Netherlands (15.8%), China (14.7%), Mexico (13.5%), India (12.3%) and United States of America (7.4%) [8].

The onion is one of the most consumed vegetables on the planet with an average annual per capita consumption of approximately 11 kg. Tajikistan and Uzbekistan are the leading consumers with an astounding per capita consumption of 36 and 34 kg respectively [9]. In Kenya, the onion is the third most important vegetable after brassicas and tomatoes [10]. Records indicate that the National average production is low (96,000 tons annually) and does not meet the local demand necessitating importation of about half the required capacity from India, Egypt and Tanzania [11,12]. This presents a golden opportunity for Kenyan growers to expand production and sales of the crop. Despite the big deficit, Kenya exports about 60 tons a year of salad onions into the EU market as vegetable mixes in pre-packs [13].

Although favourable conditions for production exist in Kenya, yields are still very low averaging 14.3 MT/ha compared to countries like Korea Republic (65.3), USA (56.4), Australia (56.2) and Spain (54.1) MT/ha [7]. The low yield is attributed to use of low yielding varieties, pests and diseases and poor agronomic practices among them improper use of fertilizers. Growers fertilize the crop at the late stages of bulb growth perhaps to compensate for losses incurred through leaching or merely from anxiety that the yields will be less than needed to maintain profitability. Post-harvest losses estimated at 40 – 60% [14] contribute to further reduction of marketable yield due to poor quality and handling practices. Among the quality attributes, bulb splitting, bolting and wide neck diameters are some of the aspects that make Kenyan onions less competitive in the market.

Applying sufficient plant nutrients and use of suitable varieties are critical to sustain increased production in the face of depleting soil fertility, continuous cropping and reduced arable land. Onions have relatively high demand for soil nutrients particularly nitrogen which is one of the primary macro-nutrients necessary for plant growth, development and good yields. Different levels of this nutrient have been reported to affect differently the yields, marketable quality, taste and even shelf-life of the crop in storage. Henerisken [15] reported that the yield of marketable onion bulbs increased with N applied at planting and at the flag stage up to 120 kg N/ha. Pandy [16] reported significantly higher yields with 80 and 120 kg N/ha. Kumar [17] reported that N at 130 kg/ha applied in splits (half as basal, ¼ at 3 weeks and the rest during bulb formation) gave the best results with regard to survival of seedlings, plant height, number of leaves/plant, bulb maturity time, bulb diameter, diameter of the thickest stem, length of the longest root, number of roots, bulb fresh weight and total bulb yield. Abdisa [18] reported a significant reduction in number of bolters at 92 kg N/ha (half dosage applied at transplanting and the other half 61/2 weeks later) but reported an extended physiological maturity and a significant increase in split bulbs. He also reported a significant increase in plant height, number of leaves, leaf length, average bulb weight, bulb diameter, and total and marketable yield at only 69 kg N/ha.

In view of this, the present experiment was undertaken to investigate the influence of varying rates of nitrogen fertilizer and time of topdressing on growth, yield and quality of two onion varieties. The efforts were geared towards improving production and quality to curb post-harvest losses and to make the commodity more available and competitive in the market.

2. MATERIALS AND METHODS

2.1 Description of the Experimental Site

The experiment was conducted at the National Agricultural Research Laboratories for 2 seasons from 2014 to 2015 with supplemental drip irrigation. The farm is situated 8 km North West of the city of Nairobi at longitude 36^{o} 46' E and 01^{o} 15' S. The Altitude is 1,787 m above sea level in the upper semi-humid agro-ecological zone UM3 [19]. The area receives a bimodal rainfall distribution, the first season from mid-March to May and second from mid-October to December averaging 409 and 220 mm respectively. The mean annual temperatures range from 18 – 21^{o}C [19].

The soils are classified as Humic Nitisols [20], known locally as Kikuyu Red Clays. They are of volcanic origin, reputed to be fertile, deep and friable. The top soil extends 15 cm depth, dark reddish brown in colour and well drained.

2.2 Soil Sampling

Prior to planting, the soil was sampled for analysis to establish the soil fertility status of the experimental plots. Sampling was done from twelve representative points of the entire plot using a zig-zag pattern, from a depth of 0 – 20 cm. The soil from these points was thoroughly mixed to form a composite sample from which a 500 gm portion was picked and subdivided into working samples. Analysis for major nutrients such as Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Cation Exchange Capacity (CEC) and pH was carried out and the soil types adequately described for soil physical characteristics.

2.3 Experimental Material, Treatments and Experimental Design

The planting material was selected from two popular varieties of *A. cepa* L. grown in Kenya, the Red Creole and Red Tropicana F1 Hybrid. The two varieties look very similar but the Red Creole variety has a deeper red colour while the Red Tropicana F1 hybrid is lighter with a reddish purplish colour. The Red Creole variety is reputed to have better storage qualities, while the Red Tropicana is higher yielding and more resistant to pests and diseases. Both are short day varieties and mature at the same time (165 days). Experimental material was raised from certified seeds of these varieties in a nursery and transplanted 8 weeks later.

The main treatments were Nitrogen (N) rates applied as Calcium Ammonium Nitrate (CAN) at different times, and two onion varieties. The CAN rates comprised of 0 (control), 100 (26 N), 200 (52 N), 300 (78 N) and 400 (104 N) kg/ha applied at 3, 6, 9 and 12 weeks after transplanting. The experimental design was a split–split plot laid in a Randomized Complete Block Design (RCBD) with 5x4x2 treatments. The two varieties occupied the main plots, the five N levels the sub plots and the time of application the sub- sub plots. All the variety and treatment combinations were replicated three times. Allocation of treatments and experimental material on the plots and blocks was through randomization according to principals and procedures of [21].

At transplanting, TSP fertilizer was used at the rate of 200 kg/ha. Each variety was planted in 5 rows comprising of 10 plants at the spacing of 30 x 10 cm giving a population of 50 plants in a sub – sub plot of 1 x 1.2 m. Each block occupied an area of 9 x 17.6 m^{2} including paths with 40 sub – sub plots. Since treatments were replicated 3 times, the main experimental area had 120 sub – sub plots. Main plots were separated by 2 m, sub-sub plots by 1 m and blocks by 3 m. During the growth period, routine cultural practices on weeds, pests and disease control were carried out.

At harvest, sampling was done from the 3 inner rows of a sub-sub plot excluding the guard plants. From each sampling row, the outer 2 plants were regarded as guard plants and samples were taken from the inner 5 plants giving a sample of 15 onions from which data was taken. Harvesting was done when 50% of the plants had fallen over.

2.4 Data Collection and Analysis

The parameters under study included plant height, number of leaves, bulb ratios, % fallen plants at maturity, total and marketable yield, bulb weight, bulb diameter, neck thickness, number of split bulbs and % bolters. Data were collected from 15 plants selected from the 3 innermost rows. Procedures taken for each parameter were as follows.

2.4.1 Plant height

Plant height was measured just before leaf fall and it was taken from the ground level up to the highest leaf using a standard ruler.

2.4.2 Number of leaves

Data on leaf number commenced 3 weeks after transplanting and was monitored every 3 weeks until time of harvest. The number of fully developed leaves capable of photosynthesis (>5 cm) were visually counted from 15 plants within the sampling area

2.4.3 Bulb ratio

This is the ratio of the bulb diameter to the neck diameter. The diameter of the neck and bulb of six labelled onions from each plot was measured every 3 weeks using a Vernier caliper. The soil was carefully removed not to damage the roots in order to take the diameter from the widest region of the bulb as the plant was growing.

2.4.4 % fallen over at maturity

Tops fallen over were determined by visually counting plants with fallen tops in each plot when generally 50% of the tops were fallen in the main experimental area. Percentage fallen tops were calculated in reference to the total number of plants in a plot.

2.4.5 Total yield

After harvesting, leaves and roots were carefully cut from the bulbs and fresh weight of the sample taken using an electronic weighing scale. The weight was converted to kg/ha in order to estimate the yield.

2.4.6 Bulb weight

This is the average weight of a single bulb. It was determined from the average of the sample bulb weight in each treatment by dividing the total weight of the sample with the number of bulbs in the sample.

2.4.7 Marketable yield

The marketable yield took into consideration the diameter of the bulbs excluding any bulbs within <20 cm diameter. It also excluded split, bolted, sprouted and rotted bulbs. It was taken using an electronic weighing scale and expressed in kg/ha

2.4.8 Bulb diameter

The diameter of the bulbs was taken at right angles to the longitudinal axis at the widest circumference of the bulb using a Vernier caliper. The onions were grouped according to the following sizes.

SIZE A; < 40 mm diameter - small (grade 3)
SIZE B: Between 60-80 mm diameter – medium (grade 2)
SIZE C: >80 mm diameter – large (grade 1)

2.4.9 Neck size (diameter)

The neck diameter for all the sampled bulbs was taken at the narrowest part 5 mm above the top of each bulb using a Vernier caliper.

2.4.10 % bolters

Bolters were visually counted in each plot, recorded and later expressed in percentage in relation to the number of plants in the plot.

2.4.11 Number of split bulbs

Number of split bulbs in a sample were visually counted and recorded.

The data was subjected to Analysis of Variance (ANOVA) using GenStart computer software package. When ANOVA showed significant differences, mean separation was carried out using Fisher's protected Least Significant Difference (LSD) test at 5% probability level of significance. Correlations between parameters were only done where deemed applicable. The data thereof was presented in tables and graphs.

3. RESULTS

3.1 Soil Physical-chemical Properties

Results of laboratory analysis of selected properties of the soil of the experimental site are presented in Table 1. The analysis showed that the soil of the site is sandy clay loam in texture with an acidic (pH 4.35) reaction. The soil organic carbon and total nitrogen are low while phosphorus (P), potassium and other macro and micronutrients are adequate. The soils Cation Exchange Capacity (CEC) is also adequate.

3.2 Growth Parameters

Analysis of variance (ANOVA) showed that the interaction of N and that of time (T) of topdressing significantly influenced plant height in both seasons and that of N and variety (V) in season two (Tables 2 and 3). Application of 104 kg N/ha at 6 weeks recorded maximum plant height of 45.4.and 44.8 cm in season 1 and 2 respectively. Variety Red Tropicana recorded the highest plant height of 45.1 cm at 104 kg N/ha.

The analysis also showed a significant ($P<0.05$) interaction between N and T on bulb ratios in season 2 (Table 3). Application of 104 kg N/ha at 3 weeks gave the highest ratio of 3.5. A very highly significant ($P \leq 0.001$) effect of N application occurred on the number of leaves in both seasons and bulb ratios in season one. A maximum number of leaves of 8.5 in season 1 and 8.7 in season 2 and a bulbing ratio of 2.5 were recorded with 104 kg N/ha. Although % fallen plants at harvest increased with increasing N levels, a significant ($P \leq 0.001$) difference was only obtained in season 1. The lowest values of plant height, number of leaves bulb ratios and % fallen plants in both seasons were recorded with the control (Tables 2 and 3).

The time of N application was also very highly significant ($P \leq 0.001$), with early application at 3 and 6 weeks after transplanting recording the best results in terms of leaf number in both seasons and bulb ratios in season 1 (Tables 2 and 3). With regard to maturity of the crop, N application at 6 weeks after transplanting gave the highest means of crop fallen over in both seasons which was significantly ($P \leq 0.05$) different from the rest in season 1 and from 9 and 12 weeks in season 2.

Variety Tropicana F1 Hybrid recorded the best growth characters with a significant ($P \leq 0.05$) difference occurring in bulb ratios and plant height in season 2 (Table 3).

3.3 Yield Parameters

The Analysis of Variance (ANOVA) showed that N application significantly ($P<0.001$) affected the yield (total and marketable) of the onion crop in both seasons with an interaction of N and V affecting marketable yield in season 1 (Table 2). Variety Red Tropicana at 104 kg/ha gave the highest marketable yield of 27,022 kg/ha. Application of 104 kg N/ha increased total yields over the control by 59% in season 1 and almost

Table 1. Physical and chemical properties of experimental soil (0-20 cm)

Particulars	Value	Methods
Sand (%)	58	Hydrometer method [22]
Silt (%)	8	Hydrometer method [22]
Clay (%)	34	Hydrometer method [22]
Total N, (%)	0.05	Modified Kjeldahl Method [23]
Organic Carbon (%)	0.46	Colorimetric Method [24]
pH (1:1: Soil : Water)	4.35	Glass Electrode pH Meter [25]
CEC (me %)	0.5	Ammonium Acetate Method [26]
$P_{Melhlich\ 1}$ (ppm)	55	Mehlich Double acid method [25]
Magnesium (me %)	1.22	Mehlich Double acid method [25]
Sodium (me %)	0.049	Mehlich Double acid method [25]
Calcium (me %)	2.9	Mehlich Double acid method [25]
Potassium (me %)	0.80	Mehlich Double acid method [25]
Manganese (me %)	0.64	Mehlich Double acid method [25]
Zinc (ppm)	5.00	HCL Extractable [27]
Copper (ppm)	89.9	HCL Extractable [27]

doubled the yields (84% increase) in season 2. The yield increased linearly with increase in N rates in both seasons (Fig. 1). In both seasons, the marketable yield was lower but followed a similar trend like that of total yield (Tables 2 and 3). Likewise the yield attributing characters, the bulb diameter and average bulb weight increased significantly (P<0.001) with increasing N rates with 104 kg N/ha recording the highest bulb diameter and average bulb weight of 51.4 cm and 67.4 g in season 1 and 57.2 cm and 71.0 g in season 2 respectively. Application of N decreased grade 3 bulbs while increasing grade 1 and 2 bulbs which are demanded in the market.

The time of application also had a significant (P<0.001) effect on the yields. The total and marketable yields decreased with late application of N. Highest total yield was recorded when N was applied at 6 weeks after transplanting. Late application at 12 weeks decreased the yield by 19% in season 1 and by 24 % in season 2. Market yield decreased by 25% in both seasons. Similarly bulb diameter and average bulb weight were significantly (P<0.001) affected, registering the highest values at 6 weeks and the lowest at 12 weeks of topdressing (Table 3).

In both seasons, the Red Tropicana F1 hybrid recorded the highest mean total and marketable yields, mean bulb diameter and average bulb weight. Except for bulb diameter, the difference was significant (P<0.05) in season 2 (Table 4). The highest weight loss in market yield due to curl bulbs was recorded with Red Creole variety which had a very high percentage of split bulbs in both seasons.

3.4 Quality Parameters

Apart from bolting, bulb splitting and neck sizes were both significantly affected by N application. The interaction of N and V influenced neck size in season 2 where the Red creole variety recorded the highest neck diameter of 11 cm at 78 and 104 kg N/ha. Application of N significantly (P<0.001) affected the formation of thick necked bulbs. Neck diameters were seen to increase with increasing N rates realizing 18% increase over the control in season 1 and 32% in season 2 (Tables 2 and 3). Time of application affected neck diameters only in season two where a significant (P<0.001) decrease was realized with late application of N (Table 3). There was no significant difference in neck diameters between the two varieties.

Application of N significantly (P<0.01) affected bulb splitting. The splitting increased with increase in the rate of N applied in both seasons with a stunning 49% increase recorded over the control in season 1 (Table 2). Late application of N also accelerated splitting (P<0.01) with a 42% increase recorded in season 1 at 12 weeks and 81% increase recorded in season 2 at 9 weeks of topdressing (Tables 2 and 3). The Red creole variety recorded the highest number of split bulbs of 39% in season 1 and 15% in season 2 compared to Red Tropicana F1 hybrid which recorded a small number of 10% in season 1 and 3% in season 2.

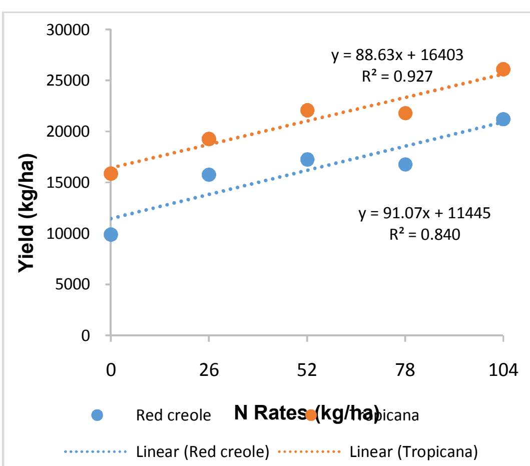

Fig. 1a. Yield response curve season 1

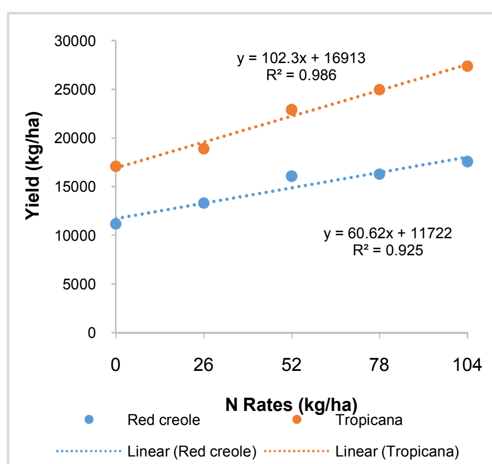

Fig. 1b. Yield response curve season 2

Table 2. Effect of N, Time (T) of application and Variety (V) on total yield, marketable yield, bulb weight, bulb diameter, % fallen, split bulbs, neck thickness, plant height, leaf number, bulb ratios and % bolters of onion grown in 2014

Treatment season 1	Total yield (kg/ha)	Market yield (Kg/ha)	Bulb weight (g)	Bulb diameter (cm)	Fallen at harvest (%)	Split bulbs (No.)	Neck thickness (cm)	Plant height (cm)	Leaf number (No.)	Bulb ratios	Bolters (%)
N (Kg/ha)											
0	14,123 c*	12,916 c	42.37 c	41.9 c	15.63 b	2.875 c	12.59 d	33.48 e	7.499 b	2.083 d	-
26	16,098 c	14,264 c	48.3 c	45.06 b	31.75 a	3.333 bc	13.54 c	37.54 d	7.887 b	2.217 c	-
52	19,481 b	17,396 b	58.44 b	48.98 a	37.71 a	3.583 b	14.46 b	39.91 c	8.336 a	2.306 bc	-
78	20,612 ab	17,087 b	61.84 ab	50.14 a	37.88 a	4.292 a	14.58 b	41.56 b	8.415 a	2.329 b	-
104	22,459 a	19,770 a	67.38 a	51.44 a	38.17 a	4.292 a	14.87 a	43.49 a	8.472 a	2.469 a	-
LSD (5%)	2099.4	1629.8	6.298	2.537	9.49	0.693	0.269	0.47	0.41	0.112	-
T (weeks)											
3 weeks	19,429 ab	17,471 ab	58.29 ab	48.71 a	37.47 b	3.1 c	14.058 a	39.63 b	8.240 a	2.338 a	-
6 weeks	20,476 a	18,070 a	61.43 a	49.88 a	46.70 a	3.267 bc	13.891 a	40.63 a	8.258 a	2.329 ab	-
9 weeks	18,655 b	16,139 b	55.96 b	48.35 a	33.07 b	3.93 ab	13.998 a	39.15 b	8.121 ab	2.365 b	-
12 weeks	15,660 c	13,467 c	46.96 c	43.11 b	11.67 c	4.4 a	14.087 a	37.50 c	7.869 b	2.191 c	-
LSD (5%)	1728.1	1609.4	5.184	1.891	8.32	0.704	0.273	0.50	0.28	0.073	-
Variety											
Red creole	14,874 a	10,789 a	44.96 a	44.96 a	29.4 a	5.88 a	13.91 a	37.55 a	8.40 a	2.18 a	-
Tropicana	22,236 a	21,785 a	66.71 a	50.06 a	35.1 a	1.47 b	14.08 a	40.84 a	7.85 a	2.39 a	-
LSD (5%)	18,451.7	14,200.1	55.354	20.131	48.4	3.204	0.376	5.38	2.92	0.23	-
CV%	18	19.1	18	7.7	50	37.1	3.8	2.4	6.6	6.2	-
F-Test											
N	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	-
T	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.497	<0.001	0.026	<0.001	-
V	0.228	0.079	0.228	0.39	0.664	0.027	0.224	0.119	0.503	0.058	-
N X T	0.671	0.182	0.671	0.575	0.338	0.214	0.057	0.006	0.192	0.339	-
N X V	0.204	0.003	0.204	0.656	0.582	0.059	0.151	0.022	0.765	0.220	-
T X V	0.806	0.384	0.805	0.891	0.989	0.476	0.879	0.085	0.831	0.633	-
N X T X V	0.941	0.382	0.941	0.948	0.450	0.943	0.912	0.995	0.601	0.396	-

[*]Mean separation within columns by Fishers protected Least Significant Difference (LSD) test at 5% probability level. Means followed by the same letter in a column within a treatment are not significantly different. g=grams, cm=centimeters, No. = number, %=percent and kg ha^{-1}=Kilograms per hectare

Table 3. Effect of N, time (T) of top dressing and variety (V) on total yield, marketable yield, bulb weight, bulb diameter, % fallen, split bulbs, neck thickness, plant height, leaf number, bulb ratios and % bolters of onion grown in 2015

Treatment season 2	Total yield (Kg/ha)	Market yield (Kg/ha)	Bulb weight (g)	Bulb diameter (cm)	% Fallen at harvest (%)	Split bulbs (No.)	Neck thickness (cm)	Plant height (cm)	Leaf number (No.)	Bulb ratios	Bolters (%)
N (Kg/ha)											
0	12,864 d *	12,804 c	38.93 d	40.86 d	31.00 a	0.750 c	7.942 d	33.48 e	7.406 c	2.912 d	3.42 a
26	17,516 c	17,321 b	52.56 c	47.66 c	38.67 a	1.083 bc	9.008 c	37.44 d	8.135 b	3.077 c	3.08 a
52	19,651 b	18,160 b	57.96 c	49.59 bc	40.33 a	1.542 ab	9.686 b	39.57 c	8.405 ab	3.145 bc	2.839 a
78	19,300 c	18,856 b	59.70 b	50.28 b	40.67 a	1.667 a	9.956 b	41.22 b	8.471 a	3.204 ab	3.08 a
104	23,652 a	23,175 a	70.96 a	57.21 a	35.67 a	2.042 a	10.475 a	43.06 a	8.681 a	3.294 a	4.0 a
LSD (5%)	2119.1	2288.6	6.885	2.60	7.804	0.568	0.30	0.54	0.31	0.123	2.542
T (weeks)											
3 weeks	19,881 a	19,804 a	59.95 a	50.19 ab	47.73 a	1.033 b	9.524 ab	39.50 b	8.429 a	3.225 a	2.60 a
6 weeks	21,079 a	19,816 a	63.85 a	51.56 a	49.27 a	1.367 b	9.636 a	40.37 a	8.309 ab	3.174 a	3.87 a
9 weeks	18,383 b	17,728 b	55.15 b	49.42 b	42.73 b	1.867 a	9.353 b	38.77 c	8.231 b	3.067 b	3.60 a
12 weeks	15,044 c	14,904 c	45.13 c	45.30 c	37.27 c	1.400 b	9.140 c	37.19 d	7.908 c	3.04 b	3.07 a
LSD (5%)	1257.6	1491.8	3.963	1.50	4.588	0.459	0.20	0.35	0.18	0.10	1.460
Variety											
Red Creole	16,181 b	15, 154 b	48.70 b	48.00 a	31.0 b	2.33 a	10.05 a	37.84 b	8.10 a	2.74 b	0.07 b
Tropicana	21,012 a	20,973 a	63.34 a	51.00 a	57.5 a	0.50 b	8.78 a	40. 07a	8.34 a	3.51 a	6.50 a
LSD (5%)	2799.9	2477.2	9.580	3.3	14.969	1.434	1.70	1.12	1.23	0.43	6.07
CV%	13.1	16	13.7	5.7	20.1	62.7	4.2	1.7	4.2	5.9	86
F-Test											
N	<0.001	<0.001	<0.001	<0.001	0.071	0.002	<0.001	<0.001	<0.001	<0.001	0.885
T	<0.001	<0.001	<0.001	<0.001	<0.001	0.007	<0.001	<0.001	<0.001	<0.001	0.319
V	0.018	0.01	0.022	0.069	0.017	0.032	0.08	0.013	0.492	0.017	0.045
N X T	0.398	0.097	0.207	0.238	0.351	0.637	0.715	<0.001	0.061	0.047	0.345
N X V	0.656	0.585	0.869	0.161	0.232	0.130	0.002	0.980	0.570	0.473	0.827
T X V	0.934	0.712	0.993	0.244	0.132	0.103	0.058	0.147	0.601	0.633	0.358
N X T X V	0.601	0.801	0.535	0.418	0.721	0.624	0.312	0.378	0.159	0.872	0.251

**Mean separation within columns by Fishers protected Least Significant Difference (LSD) test at 5% probability level. Means followed by the same letter in a column within a treatment are not significantly different. . g=grams, cm=centimeters, No. = number, %=percent and kg ha^{-1}=Kilograms per hectare*

Table 4. Correlation between yield and growth parameters in the two seasons

Parameter	Season			
	1		2	
	Pearson correlation (r)	P-value	Pearson correlation (r)	p-value
Bulb Diameter (cm)	.919**	<0.001	0.627**	<0.001
No. of leaves	.455**	<0.001	0.483**	<0.001
Plant Height (cm)	.249**	0.006	0.115	0.214
Average B. wt. (g)	1.000**	0.000	0.993**	<0.001
Bulb Ratios	.046	0.618	0.181*	0.048
Neck Thickness (cm)	.041	0.655	0.170	0.063

**P < 0.05; ** P < 0.001*

3.5 Correlation Analysis

Yield had a significant (*P*<0.001) positive correlation with plant height, number of leaves, bulb diameter and average bulb weight in season 1 (Table 4).

In season two, a similar observation was made. The yield had a significant (*P*<0.001) positive correlation with bulb diameter, number of leaves and average bulb weight. It also had a significant (*P*<0.05) positive correlation with bulb ratios.

4. DISCUSION

4.1 Soil Physical and Chemical Properties

The analysis of the soil showed that the organic carbon and total N were low, meaning that the soil was poor in supplying organic carbon and also as a source of mineralized N for uptake by the crop. Hence external sourcing would be appropriate and a response was expected. Although onions can grow in acidic soils of up to pH 4.0, the optimum ranges between 6 and 8 [28], of which the crop in this site would benefit from liming.

4.2 Growth Parameters

Application of N significantly improved all growth parameters (plant height, leaf number, bulb ratios and crop maturity). These findings are in agreement with those of [29] who reported a significant increase in plant height and number of leaves at only 50 kg N/ha. Similarly, [30] and [31] reported significant increases in plant height and leaf number with increasing nitrogen up to 138 and 120 kg N/ha respectively. [32,33] and [14] reported hastened crop maturity with increased N levels.

The improved growth observed is because N plays a vital role in chlorophyll, enzyme and protein synthesis responsible for growth and development. Abundant proteins tend to increase the size of the plant, particularly the leaves (number, length and width) and accordingly an increase in photosynthates which are channeled to the bulbs to cause the changes in bulb ratios. The earlier maturity with increased N levels is also attributed to the greater growth associated with N. The higher leaf canopy produced absorbs a higher proportion of incident light decreasing the red: far red (R: FR) in going from the top to the bottom of the leaf canopy [34]. Bulb scale initiation is accelerated by decrease in R: FR [35], hence the hastened maturity.

The best growth performance was achieved when the crop was top-dressed early at 6 weeks. The crop was well established at this time which might not have been the case at 3 weeks. Late top dressing at 9 and 12 weeks does not give the crop enough time to grow and bulbing sets in before substantial growth is achieved. The time of top dressing was crucial for maturity of the crop such that even at high levels, maturity was delayed with late application due to the reduced canopy. [34] found a significant delay in maturity by delaying N application 3 months later after planting.

4.3 Yield Parameters

Nitrogen application significantly increased total and marketable yield, average bulb weight, bulb diameters and sizes (grades 1 and 2) in both seasons. These results are in conformity with results of several other workers. [36,18,31] reported significant results with increasing N levels up to 120 Kg N/ha. [37] reported a general increase in grade 1 and 2 bulbs with increasing N levels up to 39 kg N/ha with the highest percentage of 36.7% of bulbs in grade 3 at the control (0 kg N/ha).

The bulb is a sink for the accumulation of photosynthates and nutrients from the soil. The greater vegetative growth experienced with higher levels of N led to more assimilate being channeled to the growing bulbs hence increasing bulb weight, diameters and sizes and ultimately the final yield. However, marketable yield was lower than total yield in both seasons with losses primarily due to split bulbs and bolters and minimally due to sprouted bulbs and undersize bulbs (less than 20 mm in diameter). While the Red Tropicana recorded higher total and marketable yield, the Red creole recorded the highest number of curl bulbs due to split and undersized bulbs.

Just like with growth, a better performance with these parameters was obtained with early topdressing at 6 weeks after transplanting. This shows that for onion, the final yield depends on the amount of vegetative growth before bulb formation. According to [38] it is critical that crop nutrients are made available before peak crop demand because nutrients for grain/bulb/seed fill comes from the stem, leaves and the head rather than directly from the soil. Topdressing late at 12 weeks after transplanting gave poor results perhaps due to delayed growth.

4.4 Quality Parameters

Quality parameters are important for the purpose of marketability or storage of the crop. Application of N significantly influenced formation of thick necks in both seasons. The wider neck diameters could be attributed to vigorous growth of the onion plant as a result of the higher doses of N. This result is consistent with that of [39] who reported that application of N at 200 kg/ha increased significantly the number of thick necked bulbs. Early application of N was also observed to increase bulb neck diameters of which significant differences occurred in season two. Adequate N during the juvenile phases allows for rapid growth of the crop leading to thick necks as observed. [40] reported that neck thickness is a physiological disorder that is influenced by seasons, sites and cultural practices.

Bolting which only occurred in season two varied greatly between the two cultivars with Red Tropicana recording a significantly higher incidence regardless of N levels or time of application. This result is consistent with [41], that bolting varies from year to year and that genotype influences. However, he also reported that C/N ratio determines whether the onion crop remains vegetative or produces a flower stalk, alluding to the fact that appropriate N fertilization at the time onion plants are susceptible to flower induction may reduce the incident of bolting. In support to this claim and contrary to these results, [42] found a steadily declining incidence of bolting with increasing N rates up to 192 kg/ha. [18] also reported a decline of bolters up to 22% in response to only 92 kg N/ha. Since no significant results were obtained with N application in this experiment, the incidence of bolting was attributed to cultivar and low temperatures that prevailed in the season.

The formation of split bulbs was significantly influenced by N and time of its application with the highest mean number achieved at the highest rate applied and late top dressing (9 and 12 weeks). This is because N promotes multiple growing points to increase lateral shot development and the effect is enhanced with late application. Similar results were obtained by [18] who reported a 57% increase in doubling or splitting with increased fertilizer rates up to 138 kg N/ha. Highly significant differences were observed between the two varieties in their tendency to split. In both seasons, the Red Creole variety recorded the highest mean number reaching over 30% in season 1. This result is consistent with [36] who recorded a 34% of splits in Red creole variety for two seasons in the same area. Although split bulbs are perfectly edible, they have been found to be of low quality often being discounted [43].

4.5 Correlation Analysis

Correlation analysis showed the apparent association of yield and other growth parameters. This correlation suggests that application of N fertilizer at the right time could improve certain plant parts particularly the leaves which could improve the capacity of the plant to produce more photosynthates that are mobilized to the organ of economic value increasing bulb weight and bulb diameter that ultimately led to increased yield per unit area. Similar results were reported by [17,30] and [29].

5. CONCLUSION

Increasing N rates from 0 – 104 kg N/ha increased vegetative growth, yield (total and marketable) and yield components (bulb average weight and diameters) but affected quality by increasing the number of split bulbs and neck sizes. Application of N also accelerated maturity of the bulbs. Hence N has appreciable benefits on growth and yield but negative on some quality parameters of onion. A linear relationship was found between the total bulb yield and the amount of N applied. Since the optimum was not reached, the best rate predicted from this study was 104 kg N/ha. It is quite economical to apply this rate as the yield linearly increased with the N application. However, higher rates should be tried to reach the optimum.

Time of application equally affected growth, crop maturation and yield as well as yield components with late application negatively affecting these parameters. From this observation it is apparent that sufficient N is required early in the season. When it is deficient in the juvenile stage, rapid growth is restricted, resulting to loss of yield and poor quality bulbs. Thus it is essential that an optimum level of N is supplied early for maximum yield and improved bulb quality. The predicted optimum time of N application from this study was six weeks after transplanting. Nitrogen at 104 kg/ha applied at 6 weeks after transplanting gave the best growth, yield and quality of bulbs. Application of too much N late in the season (9 and 12 weeks) increased split bulbs and neck sizes. Excessive application late in the season (as farmers do) should be discouraged and avoided in the regime for best results.

Although hybrid seed was expensive, the yield obtained was high and quality was fairly good. The Red Tropicana F1 hybrid obtained maximum yield of 30,533 kg/ha at 104 kg N/ha applied at 3 weeks while the Red Creole obtained a maximum yield of 24,674 kg/ha with the same level applied at the same time. To improve production and marketability, Kenyan farmers should adopt the hybrids.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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