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THE INFLUENCE OF RATE AND TIME OF NITROGEN TOP DRESSING ON THE STORAGE QUALITY OF ONION (*ALLIUM CEPA* L.)

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ABSTRACT

Onion (*Allium cepa* L.) is one of the most important commercial vegetable crops grown by small-holder farmers in Kenya, for both local and export markets. Losses in storage which are mainly due to rotting and sprouting contribute greatly to post-harvest losses which average 40%. Nitrogen (N) is one of the most important crop nutrients affecting growth and quality but with an impact on shelf-life of the crop. An investigation was therefore conducted with an objective to optimize N and time of application for onion bulb yield and storage life. The experiment was carried out in 2014 and 2015 at the National Agricultural Research Laboratories and the bulbs stored at room temperature for 3 months at the University of Nairobi botany laboratory. Nitrogen was applied as Calcium Ammonium Nitrate at five levels including (0, 26, 52, 78 and 104kg N ha-1) at different times (3 weeks, 6 weeks, 9 weeks and 12 weeks) after transplanting. Two commonly grown varieties, Red creole and Red Tropicana F1 hybrid were used. The treatments were laid in a Randomized Complete Block Design (RCBD), with a split-split arrangement and replicated three times. Analysis of variance (ANOVA) showed that N application had significant effect on bulb splitting and neck thickness at harvest and adversely affected storage life through increased PLW and rotting and sprouting of bulbs. Time of application also significantly affected these parameters, with early application leading to increased PLW, rotting and late application splitting and sprouting of bulbs. The Red creole variety exhibited a better shelf-life compared to the Red Tropicana F1 hybrid. Nitrogen application is important for increased yields but excessive application beyond 52 kg N ha-1 should be avoided for bulbs intended for storage. Application time is increasingly important in enhancing quality of onion before and after storage.

Keywords: Harvest quality, Nitrogen, Onion, Post-harvest quality, Storage

1. INTRODUCTION

Onion (*Allium Cepa* L.) is an important vegetable belonging to family *Alliacea* and originated in South East Asia (Brewster, 1994). It is a popular vegetable with an old track record of cultivation dating back to at least 5000 years (Shultz, 2010). Its popularity lies in its unique flavouring ability, being used world over in almost every house hold for seasoning a variety of dishes. In addition, onions contain phytochemicals that render health benefits including reduction of factors that cause cancer, diabetes, cardiovascular and inflammatory diseases among others (Pareek, *et al*., 2017; Lanzotti, 2006; Griffith, *et al*., 2002; Augusti, 1996)

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In Kenya, the onion is the third most important vegetable crop for the domestic market after brassicas and tomato (MOA, 2004). It is also an important source of income for small holder farmers and business community involved in local and cross border trade (Kimani *et al*., 1990). However, onion is a seasonal crop and has a comparatively low storage ability. Significant post-harvest losses in quality and quantity of the crop occur which are estimated to range between 40 – 60% (Maini *et al*., 1984). Due to seasonal glut, farmers are forced to sell onions at low prices to avoid storage and related losses (Abate, 2012). Storage of onion bulbs has therefore become a serious problem for producers and traders in Kenya. The post-harvest losses contributing to this include poor quality, sprouting, physiological loss in weight and rotting of bulbs. The problem can be improved by application of better pre and post-harvest practices.

Storage losses of onions have been reported to reduce considerably by treatment of Maleic hydrazide (Pandey *et al*.,1994), ultra violet radiation (Lu *et al*.,1987), controlled atmosphere storage (Poldma *et al*., 2012), low temperature storage (Proctor *et al*., 1981) and high temperature storage (Ramin, 1999). Although these techniques work well to control post-harvest losses, most of them involve costly investment with specialized equipment and storage structures not feasible for the small-scale Kenyan farmer. Low cost farm level technology is required to extend the shelf-life of the crop. The main aim is to preserve quality and to make the bulbs available during lean periods.

At farm level, crop maturation at the time of harvesting, care at harvest, premature defoliation, skin integrity, curing and storage conditions are the main factors contributing to quality of bulbs in storage (Brewster, 1994). However, quality of bulbs can also be affected by mineral nutrition, irrigation scheduling or rainfall (Chung, 1989), cultivar differences and use of growth factors (Hussein, 1996). Manipulation of these factors can be done to extend shelf-life and increase marketability of the commodity.

Nitrogen (N) is the most influential macronutrient which has been reported to affect marketable quality, taste and even shelf life of onions in storage. Brewster 1994, reported that application of N caused significant improvement in growth and bulb yield but high level application shortens the storage life of the crop. Singh *et al*., 1994 concluded that storage quality of CV. Pusa Red held at room temperature decreased with increasing rates of N up to 200 kg/ha. Sorensen and Grevisen, 2001 also concluded that too much nitrogen can result in increased susceptibility to diseases, increased double centre in onions, reduced dry matter contents and storability and thus result in reduced marketable quality. Improved N fertilizer management for onion may help storability and ensure supply of bulbs during lean periods thus offering farmers premium prices.

2. MATERIALS AND METHODS

2.1 Description of the experimental site

The experiment was conducted at the National Agricultural Research Laboratories for two seasons from 2014 to 2015 using 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 (Jaetzold *et al*., 2006). A bimodal rainfall distribution is experienced in the area, 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 18º – 21ºC (Jaetzold *et al*., 2006).

The soils are classified as Humic Nitisols (UNESCO, 1974), which are of volcanic origin. They are reputed to be fertile, deep and friable. Laboratory analysis conducted before planting indicated that the texture of the soil is sandy clay loam with sand, clay and silt contents of 58, 34 and 8% respectively. The results also showed that the soil is acidic in reaction (pH 4.35), with low Organic Carbon (0.46%) and total N (0.05%) but with high CEC (0.5 me %) and adequate available P (55 ppm) as well as exchangeable bases Ca^{+2}, Mg^{+2},K^{+}, Na^{+} and Mn^{+2} of 2.9, 1.22, 0.80, 0.049 and 0.64 % me respectively.

2.2 Experimental material

The experimental material was from two popular varieties of *A. cepa* L. grown in Kenya, the Red Creole and Red Tropicana F1 Hybrid. Although the two varieties look very similar, 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). The planting material was raised from certified seeds of these varieties in a nursery and transplanted after 8 weeks of growth.

2.3 Treatments, Experimental design and Transplanting

The treatments were a 5x4x2 factorial combination of five nitrogen (N) rates applied as Calcium Ammonium Nitrate (CAN) and four different times of application, using 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 out in a Randomized Complete Block Design (RCBD) and replicated three times. The two varieties occupied the main plots, the five N levels the sub plots and the time of application the sub- sub plots. Allocation of treatments and experimental material on the plots and blocks was through randomization according to principals and procedures of (Steel and Torrie, 1990)

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. This gave a population of 50 plants in a sub – sub plot of 1 x 1.2 m. Each block occupied an area of 9 x 17.6m^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 2m, sub plots and sub-sub plots by 1m and blocks by 3m. During the growth period, routine cultural practices on weeds, pests and disease control took place as recommended.

2.4 Harvesting, Post-harvest storage and Data collection

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 generally 50% of the plants had fallen over.

After harvesting, quality data including the number of split bulbs, neck size and % bolters was taken. To study the effect of treatments on storability, onion bulbs from each treatment were subjected to storage treatment at ambient conditions on clean wooden benches in the laboratory. The bulbs were put in khaki paper bags that were opened and well labelled. Storability parameters which included physiological loss in weight (PLW), bulbs sprouted, number of sprouts, length of sprouts, rotted bulbs and extent of rotting were taken at 1 month interval for a period of 3 months. The Procedures taken for each parameter were as follows.

2.4.1 Quality at harvest

2.4.1.1 Neck Size

The neck size for all the sampled onions were taken at harvest using a Vernier calliper. The measurement were taken 5 mm above the top of each bulb.

2.4.1.2 Split Bulbs

The number of split bulbs in the sample was determined by simply counting the number of bulbs splitted in the sample.

2.4.2.3 % Bolters

Bolters were visually counted from the plots, recorded and later expressed in percentage (%) in relation to the number of plants in the plot.

2.4.2 Quality during storage

2.4.2.1 Physiological loss in weight.

Weight of bulbs was recorded using an electronic weighing scale after every four weeks interval. The cumulative physiological loss in weight (PLW) was calculated using the formula

PLW = initial weight – weight at 4^{th} week interval.

An average was calculated at the end of the storage period.

2.4.2.2 Sprouted bulbs

The number of sprouted bulbs was taken in each sample every 4^{th} week interval by visually counting the number sprouted in the sample. An average was calculated at the end of the storage period.

2.4.2.3 Number of sprouts

The number of sprouts in each sprouted bulb in a sample was visually counted and recorded every 4^{th} week interval. An average was calculated at the end of the storage period.

2.4.2.4 Length of sprouts

The length of each sprout in each sprouted bulb in a sample was taken every 4^{th} week using a ruler. An average was calculated at the end of the storage period.

2.4.2.5 Rotted bulbs

The incidence of rotting was determined by visually counting the bulbs rotted in each sample every 4th week. The total number of rotted bulbs was calculated by taking the average at the end of the storage period.

2.4.2.6 Extent of rotting (%)

The extent of rotting was determined by visually examining the rotted bulb and deciding what percent of bulb had rotted. An average was calculated at the end of the storage period.

2.5 Data analysis

Data of the measured parameters were subjected to Analysis of Variance (ANOVA), using GENSTAT statistical program, 15th (SP1) edition (VSN International, 2012). Significance of differences between means of treatments were evaluated using Fishers Protected Least Significance Difference (LSD) test at 5% probability level ($P<0.05$).

3. RESULTS

3.1 Quality parameters at harvest

Analysis of variance (ANOVA) showed a significant ($P<0.002$) interaction effect of nitrogen and variety on neck thickness in season 2 but none for splitted bulbs or bolters (Tables 1 and 2). Nitrogen application had a highly significant ($P<0.001$) effect in season 1 where the neck size increased progressively with increased N rates with the highest of 14.87 cm in season 1 and 10.48 cm in season 2 being recorded at 104 kg N/ha. Time of application affected neck diameters only in season two where a significant ($P<0.001$) decrease was realized with late application of N. There was no significant difference in neck size between the two varieties in both seasons.

With regard to bulbs splitted, nitrogen had a significant ($P<0.002$) effect in both seasons, with bulbs in this category increasing with increased N rates (Tables 1 and 2). The lowest number was recorded at the control while the highest was recorded with the highest rate of 104 kg N/ha in both seasons. The time of application was highly significant ($P<0.001$) in season 1 with the highest number of bulbs splitted being recorded with late application at 9 and 12 weeks after transplanting. Variety Red Creole recorded the highest number of split bulbs in both seasons of which a significant difference was realized in season 1.

Bolting occurred only in season 2 where the Red Tropicana recorded significantly the highest incidence (Table 2). Both nitrogen and time of top dressing did not affect bolting significantly.

3.2 Quality parameters during storage

ANOVA results showed that there was an interaction effect of nitrogen, time of application and variety on PLW in season 1 (Table 1). In season 2, physiological loss in weight increased significantly with increasing nitrogen rates. The highest PLW of 72.01 was recorded at 78 kg N/ha in season 2 (Table 2). Time of application was only significant ($P<0.001$) in season 2 but generally late application reduced PLW of bulbs with the highest loss experienced when the crop was top dressed early at 3 weeks after transplanting. In season 2, the Red Tropicana F1 hybrid

had a significantly higher PLW of 87.7 g compared to Red Creole variety which had a loss of only 28.8 g.
With regard to bulbs sprouted no interaction of factors was observed. Both nitrogen and time of top dressing were significant ($P<0.001$) and ($P<0.01$) respectively in season 1 while remaining non-significant in season 2. Application of N reduced the number of bulbs sprouted while late application at 12 weeks after transplanting increased the number of bulbs sprouted (Table 1). Varietal effect was only significant in season 2 where the Red Tropicana had a significantly higher mean number of bulbs sprouted (7.96) compared to the Red Creole (0.71).

The interaction of time of top dressing and variety affected the number of sprouts in season 2 (Table 2). In season 1 nitrogen significantly ($P<0.006$) affected the number of sprouts with the number reducing with increased N rates. Time of application had no significant influence in both seasons. Variety Red Tropicana F1 hybrid had the highest mean number of sprouts in both seasons which was significant ($P<0.05$) in season 2.

With length of sprouts, no interaction of factors was observed. Application of N significantly increased the length of sprouts in both seasons. The length of sprouts increased with increase in N up to 78 kg/ha above which a downward trend was observed in both seasons (Tables 1 and 2). The time of application had no significant influence on the length of sprouts in both seasons. Significant ($P<0.05$) differences in the length of sprouts were observed between the two varieties in both seasons with Red Tropicana exhibiting the longest sprouts in both seasons.

There was an interaction effect of nitrogen, time of application and variety on the number of rotted bulbs in season 1 and that of nitrogen and time of application in season 2. Application of N increased the number of rotted bulbs in both seasons while late of application at 12 weeks reduced the number of rotted bulbs. The main effect of variety had no significant effect on the number of bulbs rotted in both seasons. However the Red Tropicana recorded the highest number of rotted bulbs.

The interaction effect of all factors (nitrogen, time of top dressing and variety) influenced the extent of rotting in season one, but had no effect in season 2. Application of nitrogen generally increased the extent of rotting with a highly significant ($P<0.001$) difference being realized in season 2. The highest percentage of 39.46 was recorded at 78 kg N/ha in season 2 (Table 2). The extent of rotting decreased with late application of N in both seasons with a significant ($P<0.05$) difference in season 2. The lowest percentage of extent of bulb rotting of 5.7 and 15% in season 1 and 2 respectively were recorded with 0 kg N/ha. Varietal difference was only significant in season 2 where the Red Tropicana F1 hybrid registered a significantly ($P<0.05$) higher percentage of extent of bulb rotting.

Table 1: Effect of N, Time (T) of application and Variety (V) on PLW, Bulbs sprouted, Number of sprouts, Length of sprouts, Bulbs rotted, Extent of rotting, Bulbs splitted, Neck size and Bolters of onion bulbs grown and stored in 2014.

Treatment Season 1	PLW (g)	Bulbs sprouted (No.)	Number of sprouts (No.)	Length of sprouts (cm)	Bulbs rotted (No.)	Extent of rotting (%)	Bulbs splitted (No.)	Neck Size (cm)	Bolters (%)
N (kg/ha)									
0	21.32 c *	6.819 a	8.306 a	2.609 b	0.1250 b	5.7 a	2.875 c	12.59 d	-
26	34.43 b	5.014 b	7.444 ab	4.053 a	0.5833 ab	24.4 a	3.333 bc	13.54 c	-
52	29.76 bc	4.631 b	6.278 bc	3.818 a	0.5972 ab	22.9 a	5.583 b	14.46 b	-
78	33.03 b	4.333 b	6.028 c	4.483 a	1.3056 a	30.2 a	4.292 a	14.58 b	-
104	49.32 a	4.389 b	6.014 c	4.053 a	1.2917 a	30.4 a	4.292 a	14.87 a	-
LSD (5%)	10.28	0.347	1.312	0.951	0.815	21.79	0.693		-
T (weeks)									
3 weeks	39.5 a	4.833 b	6.36 a	3.77 a	1.09 a	24.9 a	3.1 c	14.058 a	-
6 weeks	34.9 a	4.644 b	6.63 a	4.10 a	0.99 a	21.0 a	3.267 bc	13.891 a	-
9 weeks	30.6 a	4.667 b	6.83 a	4.67 a	0.54 a	19.5 a	3.930 ab	13.998 a	-
12 weeks	29.3 a	6.044 a	7.43 a	3.46 a	0.72 a	15.6 a	4.4 a	14.087 a	-
LSD (5%)	8.16	0.328	1.378	0.828	0.67	15.05	0.704	0.273	-
Variety (V)									
Red Creole	31.7 a	5.11 a	7.47 a	2.88 b	0.94 a	27.7 a	5.88 a	13.91 a	-
Tropicana	35.5 a	4.99 a	6.16 a	4.82 a	0.62 a	17.7 a	1.47 b	14.28 a	-
LSD (5%)	20.47	0.835	4.331	1.037	0.538	30.11	3.204	0.376	-
CV%	47.1	35.6	39.1	20.2	188.3	128.1	37.1	3.8	-

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F-Test									
N	0.001	0.001	0.006	0.006	0.03	0.154	0.002	0.001	-
T	0.064	0.01	0.456	0.374	0.438	0.813	0.001	0.497	-
V	0.511	0.93	0.321	0.015	0.127	0.290	0.027	0.224	-
NXT	0.001	0.124	0.698	0.496	0.119	0.275	0.214	0.057	-
NXV	0.297	0.541	0.190	0.312	0.216	0.516	0.059	0.151	-
TXV	0.119	0.607	0.661	0.843	0.234	0.927	0.476	0.879	-
NXTXV	0.003	0.908	0.272	0.456	0.01	0.005	0.948	0.912	-

*Mean separation within columns by Fishers Protected Least Significance 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 = centimeter, No, = number and % =percent

Table 2: Effect of N, Time (T) of application and Variety (V) on PLW, Bulbs sprouted, Number of sprouts, Length of sprouts, Bulbs rotted, Extent of rotting, Bulbs splitted, Neck size and Bolters of onion bulbs grown and stored in 2015.

Treatment Season 2	PLW (g)	Bulbs Sprouted (No.)	Number of sprouts (No.)	Length of sprouts (cm)	Bulbs rotted (No.)	Extent of rotting (%)	Bulbs splitted (No.)	Neck Size (cm)	Bolters (%)
N (kg/ha)									
0	31.92 c*	4.14 a	8.24 a	5.561 b	0.542 c	15.00 c	0.750 c	7.942 d	3.42 a
26	56.90 b	3.87 a	11.04 a	9.157 a	1.236 bc	26.53 b	1.083 bc	9.008 c	3.08 a
52	61.92 ab	4.51 a	12.04 a	8.120 a	1.639 ab	21.57 bc	1.542 ab	9.686 b	2.839 a
78	72.01 a	4.40 a	12.51 a	10.431 a	2.347 a	39.46 a	1.667 a	9.956 b	3.08 a
104	68.32 ab	4.70 a	14.03 a	10.325 a	2.153 a	35.82 a	2.042 a	10.475 a	4.0 a
LSD (5%)	14.51	1.398	4.182	2.855	1.008	10.22	0.568	0.30	2.542
T (weeks)									
3 weeks	67.37 a	4.52 a	13.20 a	8.22 a	2.189 a	37.69 a	1.033 b	9.524 ab	2.60 a
6 weeks	66.45 a	4.32 a	11.78 a	8.58 a	1.822 ab	30.39 ab	1.367 b	9.636 a	3.87 a

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9 weeks	54.92 b	4.10 a	11.19 a	8.03 a	1.411 bc	23.92 b	1.867 a	9.353 b	3.60 a
12 weeks	44.11 c	4.39 a	10.70 a	10.07 a	0.911 c	21.70 b	1.400 b	9.140 c	3.07 a
LSD (5%)	10.65	0.904	2.099	1.917	0.5461	11.19	0.459	0.20	1.460
Variety (V)									
Red Creole	28.8 b	0.71 b	1.06 b	3.33 b	0.989 a	21.1 b	2.33 a	10.05 a	0.07 b
Tropicana	87.0 a	7.96 a	22.38 a	14.13 a	2.178 a	35.4 a	0.50 b	8.78 a	6.50 a
LSD (5%)	42.84	4.198	16.902	6.301	2.0157	13.42	1.434	1.70	6.07
CV%	35.4	40.4	34.7	42.5	66.8	76.6	62.7	4.2	86
F-Test									
N	0.001	0.726	0.082	0.013	0.011	0.001	0.002	0.001	0.885
T	0.001	0.822	0.106	0.148	0.001	0.023	0.007	0.001	0.319
V	0.027	0.018	0.032	0.018	0.126	0.045	0.082	0.080	0.045
NXT	0.794	0.751	0.252	0.703	0.044	0.995	0.637	0.715	0.345
NXV	0.090	0.880	0.150	0.486	0.533	0.518	0.130	0.002	0.827
TXV	0.058	0.201	0.015	0.714	0.911	0.249	0.103	0.058	0.358
NXTXV	0.963	0.747	0.155	0.181	0.701	0.450	0.624	0.312	0.251

*Mean separation within columns by Fishers Protected Least Significance 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 = centimeter, No, = number and % = percent.

4. DISCUSSION

4.1 Quality parameters at harvest

Quality parameters at harvest are known to affect storage quality of a crop and this is true for onion. Application of nitrogen increased the formation of thick necked bulbs of which significant differences were obtained in both seasons. This result is consistent with Jilan, (2004) who reported that application of N at 200 kg/ha increased significantly the number of bulbs with thick necks. In contrast, Abdisa *et al*., (2011) working with N up to 92 kg/ha reported no significant effect on the formation of thick necked bulbs. Application of N early at 3 and 6 weeks after transplanting was also observed to increase bulb neck sizes of which significant differences occurred in season two. This shows that when adequate nitrogen is applied early during the juvenile phase, rapid growth is experienced, leading to thick necks as observed. According to Jilan and Ghaffor, (2003), onion bulbs with thinner necks (6 – 9 cm) can be stored for a longer period as they can dry and close up quickly minimizing pathogen infection and moisture loss hence sprouting easily.

The formation of split bulbs was significantly influenced by N and time of its application with the highest mean number of split or doubled bulbs achieved at the highest rate of application and late topdressing (9 and 12 weeks) of the crop. Steer, (1980) reported splitting of bulbs to occur as a result of multiple growing points which are influenced by environmental and cultural factors such as nitrogen application. Similar results were obtained by Abdisa *et al*., (2011) who reported an increase in doubling or splitting with increased fertilizer application up to 138 kg N/ha. When applied late in the season, N promotes vigorous growth that increases lateral shoot development resulting to splitting of bulbs. Splitted bulbs do not store well as they continue to sprout in storage (Currah and Proctor, 1990).

The Red Creole variety had significantly higher number of splitted bulbs in both seasons recording 39% of split bulbs in season one. Since the Red Creole is reputed to have good storage ability, perhaps the high number of split bulbs was responsible for the high number of sprouted bulbs recorded with it in season one.

Bolting, which only occurred in season two did so regardless of N fertilizer level or time of application. According to Rabinowitch 1990, the C/N ratio determines whether the onion crop remains vegetative or produces a flower stalk. Appropriate N fertilization at the time onion plants are susceptible to flower induction may therefore reduce the incidence of bolting. In support to this claim and contrary to these results, Diaz-Perez *et al.*, (2003) found a steadily declining incidence of bolting with increasing N rates up to 192 kg/ha. Abdisa *et al*., (2011) also reported a decline of bolters up to 22% in response to only 92 kg N/ha. According to Rabinowitch 1990, bolting is also influenced by cultivar, the reason why the Red Tropicana F1 hybrid had a significantly higher incidence. Bolters allow entry of microorganisms and therefore rot quickly in storage. Perhaps bolting was responsible for the high percentage of rotting (14.5) of Red Tropicana F1 hybrid recorded in season two.

4.2 Quality parameters during storage

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Application of nitrogen fertilizer significantly (P<0.001) influenced physiological loss in weight of the onions in storage in both seasons. The bulbs cumulative weight loss increased with the advancement of storage period due to dry matter and water loss. Generally, the loss in weight increased with increase in N fertilizer rates. Similar results were obtained by Tekalign *et al*., (2012) who reported high onion bulb weight losses as N application rate increased. Also Tesfa *et al*., (2015) found increased bulb weight losses with increasing N fertilizer levels when working with different cultivars of shallots.

The higher bulb weight loss at higher N levels could be attributed to the larger bulbs produced at higher N rates which have larger surface area, and hence higher rates of respiration. Jilani *et al*., (2004) reported that large sized bulbs stored at 120 days at ambient conditions lost more weight compared to small and medium sized bulbs. The high Physiological Weight Loss (PWL) may be primarily due to rotting and sprouting of bulbs under high nutrient application to the crop. In both seasons, the Red Tropicana F1 hybrid experienced a higher PLW due to larger bulbs and a higher level of sprouting and rotting (Tables 1 and 2).

Application of N fertilizer significantly reduced the number of sprouted bulbs in season one while it had no effect in season two. A significantly (P<0.001) higher number of sprouted bulbs were recorded from plots that had not received any N fertilizer in season one because the plants took longer to mature and were harvested while their leaves were still green. The stage of harvest is crucial because the substances that maintain dormancy are produced in the leaves and are translocated to the bulbs later during maturity (Komochi, 1990). Nitrogen hastens maturity (Henerisken, 1989; Gateri *et al*., 2018) and for those that did not receive, they were slow to mature and were harvested when little of the sprouting inhibitor had been translocated to the growing point hence the bulbs continued to produce leaf initials which were seen as sprouting in storage. Turker *et al*, (1979) reported that sprouting in storage of two cultivars Rijnsburger bola and Robusta occurred earlier in bulbs harvested a month early when the leaves were still erect.

It is for the same reason that the plots that received N late in the season at twelve weeks after transplanting had a significantly higher number of sprouted bulbs in the same season. The plants from these plots were not yet mature as late application of N stimulated growth late in the season. In season two, bulbs were harvested when more tops had fallen (50 - 75% fallen) and nitrogen application had no significant effect. Contrary to these results were those of Tekalign *et al*, (2012) who found 63% increase in sprouting of stored onion bulbs by application of 69 kg N/ha. Danker and Singh, (1991) also reported that high dose of N produced thick necked bulbs that increased sprouting in storage due to greater access of oxygen and moisture to the central growing point. Perhaps the big neck sizes recorded in season one also contributed to the larger number of sprouts recorded.

Differences were observed between the two cultivars with regard to the number of sprouted bulbs with Red Tropicana F1 hybrid recording the highest number sprouted in both seasons which was significant (P<0.05) in season two. Nguthi, (1993) also reported a high number of sprouted bulbs for Red Tropicana F1 hybrid ranging from 43.5 – 52% after a three months

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storage. Currah and Proctor, (1990) reported that application of N had no significant effect on storage loses but cultivars showed significant differences. The high level of sprouting exhibited by Red Tropicana F1 hybrid may be attributed to genetic variation on dormancy characteristics.

With regard to the number of sprouts, application of N was significant (P<0.01) in the first season with the highest number of sprouts recorded with plots that received no N fertilizer. The reason for this as explained above was because these plots were harvested when the leaves were still green and erect and therefore had very little of the sprout inhibitor. In season two where harvesting was done when a higher percentage of plants had matured (50 - 75% top fall), the reverse happened. Though not significant in season 2, application of N progressively increased the number of sprouts so that the highest number was recorded at level 104 kg N/ha while the least was recorded with the control. Celestino, (1961) alluded that the role of N in increasing sprouting could be attributed to the increase in concentration of growth promoters than inhibitors with the high nutrition. The time of application had absolutely no significant effect on the number of sprouts though generally the sprouts appeared to increase with early application of fertilizer.

The Red Tropicana F1 hybrid recorded a very high mean number of sprouts in season two which was significantly (P<0.05) different from that of Red Creole. This showed how prolific this variety was and this too could be attributed to genetic variability in dormancy characteristics between the two cultivars.

Nitrogen application also had a significant (P<0.01) influence on the length of sprouts in both seasons. The length of sprouts increased progressively with increasing fertilizer rates and of course with increase in storage time. This too could be attributed to the role of N in increasing the concentration of growth promoters (auxins) with the high nutrition. However, the time of N application had no significant effect on the length of sprouts. After 3 months of storage, the Red Tropicana F1 hybrid had the longest sprouts compared to the Red Creole variety. The sprouts became extremely long in season two hitting a mean of 14.13cm (Plate 1). This difference was again attributed to genetic variability in the ability to sprout. According to Currah and Proctor, (1990), cultivars that bulb rapidly (as Red Tropicana does) are soft textured and generally of low keeping quality sprouting easily in storage. Sprouting leads to the transfer of dry matter and water from the edible fleshy scales to the sprouts, resulting in increased shrivelling and hence loss of market quality (Getenesh, 2015).

Application of N fertilizer significantly (P<0.05) influenced the number of rotted bulbs in both seasons, with the number increasing with the level of fertilizer applied. A 7.87% increase of rotted bulbs in season one and 12.03% in season two were realized with addition of N over the control. Similar results were obtained by Woldetsadik and Workneh, (2010) who reported the highest percentage of rotted bulbs at 150 kg N/ha and the least with 0 kg N/ha. Tekalign *et al.*, (2012) reported the highest number of rotted bulbs with the highest rates of 115 and 138 kg N/ha compared to other treatments and the control. Also Gebisa, (2014) reported highly significant percentage of rotted bulbs at 300 kg N/ha with 70 – 90 days of storage.

The increase in the number of rotted bulbs with increased N rates could be attributed to the fact that higher rates of nitrogen cause plants to produce large bulbs with soft succulent tissues which make them susceptible to attack by disease causing micro-organisms. Also high rates of nitrogen lead to production of bulbs with thick necks which are difficult to dry (close) during curing allowing entry of micro-organisms which cause rotting. The high incidence of bolting experienced with Red Tropicana F1 hybrid in season two might also have contributed to the higher percentage of rotting recorded in the season.

Interaction of variety, fertilizer and time of application also significantly ($P<0.01$) influenced the number of rotted bulbs in season one and that of fertilizer and time ($P<0.05$) in season two. This means that these factors were not independent in their influence, but were acting together to influence rotting of bulbs

Extent of rotting advanced progressively with increased levels of nitrogen which was highly significant in season two though none significant in season one. This shows that the higher the rate of nitrogen, the softer the bulbs become and the more easily the rotting occurs after attack by spoilage micro-organisms. The same explanation goes for time of application. The extent of rotting was highest with early application (3 weeks), meaning the earlier the fertilizer is applied the softer the bulbs become and the more they rot after attack by the spoilage micro-organisms. The varieties recorded a significant difference in season two with Red Tropicana having a higher mean percentage extent of rotting. This could be attributed to bolting and varietal differences in succumbing to microbial attack and in the degree of softness after nitrogen application.

5. CONCLUSIONS AND RECOMMENDATIONS

It was observed that application of N beyond 52 kg N/ha had deleterious effect by increasing the number of split bulbs which easily sprouted in storage. It also increased the neck size which was hard to cure leading to increased rotting in storage. Higher N rates also increased physiological loss in weight due to production of larger bulbs and increased the number and length of sprouts during the period of storage. Hence bulbs intended for storage should not receive more than 52 kg N/ha.

However, the study could not establish an appropriate time for N application for bulbs intended for storage. Early application increased neck sizes, bulbs rotted, extent of rotting and physiological loss in weight. Late application increased the number of split bulbs, delayed maturity by inducing vigorous growth late in the season, and consequently increased the number of bulbs sprouted and the length of sprouts in storage. Perhaps early application has an added advantage of producing better yields with better quality.

Cultivar emerged to be an important factor to consider while growing onions for storage in this study. The Red Tropicana F1 hybrid bolted and easily sprouted and rotted in storage, succumbing to diseases such as bacterial rot, black and white mould. Due to production of large bulbs, the variety also experienced considerable physiological loss in weight in the 3 months period. The conclusion drawn from this was that the Red Tropicana F1 hybrid was not suitable for long term storage. The Red Creole variety lost less weight, had a lower number of sprouted and rotted bulbs, displaying excellent quality and long storage life in both seasons. This variety was therefore recommended if farmers are producing to store and sell in the period of shortage.

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