African Crop Science Journal, Vol.1, No. 1, pp. 15–23, 1993
Printed in Kenya.

INFLUENCE OF THE ENVIRONMENT ON THE PERFORMANCE OF SOME ONION CULTIVARS IN KENYA

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(*Received* 13 *April* 1993; *accepted* 5 *June* 1993)

ABSTRACT

Eight introduced and three local onion (*Allium cepa*) cultivars were evaluated at four locations for two seasons in Kenya to determine genotype x environment interactions and stability for bulb yield and other agronomic characters. The genotype x environment interactions and stability were investigated by regression analysis. Genotypic effects were highly significant for all traits except days to maturity. Bulb yields for the 11 cultivars varied between 16.2 and 35.6 t ha^{-1}; introduced cultivars out-yielded the local ones. Environment (E), and genotype (G) x environment interaction effects were highly significant for all traits. A considerable portion of genotype x environment interaction effects for bulb yield was linear. The significant G x E (linear) variance indicated that there were genetic differences among the cultivars in their response to the environment.

Key Words: **Adaptability, days to maturity, shape index, stability analysis.**

INTRODUCTION

Onion cultivars differ greatly in their quantitative responses to environmental factors (2, 17). Information on the interaction of genotypes with environment is crucial in developing new cultivars for production in diverse regions. Such information guides the breeder in choice of selection methods and test sites for optimal character expression.

Little work has been published on genotype x environment interactions in onions. Dowker and Fennel (7) reported significant genotypic effects for bulb yield, shape ratio, storage qualities and optimal sowing dates for two varieties, their inbreds and F_1 hybrids. There was no evidence of genotype x environment interaction for these characters. In another trial, they found significant year and time of harvest effects for bulb yield and shape ratio. Genotype x harvest x year interactions occurred for yield and percentage of sprouted bulbs, and also the genotype x year interaction was significant for sprouted bulbs. Fennel and Salter (9) and Hosfield *et al.* (11) also reported significant genotype x environment interactions for onion cultivars of Japanese and European origins.

Abdalla (1) studied onion bulbing in Sudan, and suggested that under arid tropical conditions temperature was the more important controlling factor, it being relatively more variable than day length . In trials on 12 cultivars which were sown at 2-month intervals from June to December, mean number of days to bulbing varied from 77 for the June-sown crop to 110 days for the October-sown crop which grew during the coolest period of the year. He noted that when temperatures reached 45°C in the glasshouse, bulbing was retarded in 10 out of 12 cultivars, although leaves were still produced.

In Kenya onions are grown in a wide range of climates, from relatively hot and dry to fairly cool and humid zones stretching from coastal to the high altitudes (over 2500 m). The wide variation in temperature in growing areas are attributed to differences in altitude and seasonal effects. In 1990, an onion improvement program was started in the country to develop short day cultivars with long shelf life and stable yields. Local and introduced genotypes were evaluated in seven environments to seek information on selection of suitable parental material, screening environments, and to determine the magnitude of genotype x environment interactions. This paper reports on the results of these experiments.

MATERIALS AND METHODS

Eight recently introduced and three local onion cultivars that differed in maturity period, shape, yield, bulb color and shelf life were grown in the long (March–June) and short (October to December) rainy seasons, at four locations in Kenya. The cultivars introduced from Israel were Arad (KON 1) , H-710 (KON 2), Granex (KON 3), Sivan (KON 4), H-508 (KON 5), Early Red (KON 6), Grano No.4 (KON 7) and Red Synthetic (KON 8). The local cultivars were Bombay Red, Red Creole and Tropicana Hybrid. The experiments were conducted at Kabete, Kibirigwi and Ol Jorok during the two seasons and at Marigat during the short rains. Table 1 shows the altitude, temperature, rainfall and soils at the experimental sites. All the sites have a bimodal rainfall with peaks in March/ April and October/ November.

TABLE 1. Altitude, mean annual temperature and rainfall and soil characteristics at the experimental sites

Site	Altitude (m)	Temp. (°C) (min./max.)	Rainfall (mm)	Soil characteristics
Kabete (11S,36E)	1820	12.0/23.0	1046	Well drained, very deep, dark reddish brown, friable clays (nitosols)
Marigat (0.5N, 36E)	1065	17.0/33.4	652	Well drained, very deep, brown to greyish brown calcareous, saline often sodic, firm, fine sandy, clay loam
Ol Jorok (0,36E)	2371	6.9/21.6	977	Well drained, deep to very deep, very dark greyish, brown to dark brown, friable and slightly smeary clay loam
Kibirigwi (0, 37E)	1400	14.0/21.0	1100	Ferrisols with dark brown to dark reddish friable clay loam, deep and well drained

Source references (12, 13, 16, 18).

Seeds for all cultivars were sown in raised nursery beds at Kabete in February and July 1990, and fertilized with calcium ammonium nitrate (CAN, 26%N) at the rate of 100 kg ha^{-1}. The seedlings were transplanted after 60 days when they were pencil thick.

At each location, the experiment was laid out in a randomized complete block design with five replicates. Plots were 0.9 m wide and 3 m long, with two guard rows on all sides. Seedlings were transplanted at a spacing of 8 cm within rows and 30 cm between rows (56 plants/m^2). Diammonium phosphate (DAP) fertilizer was applied at 200 kg ha^{-1}. To control purple blotch (*Alternaria pori*), the crops were sprayed with Dithane M-45 at a rate of 1 kg ha^{-1}, at two-week intervals. Ridomil was sprayed to control downy mildew (*Peronospora destructor*) at a rate of 3.5 kg ha^{-1} at 14-day intervals. Thrips were controlled by spraying dimethoate (Rogor L40) at a rate of 1.5 l ha^{-1} as necessary. The crops were kept weed-free and irrigated when necessary. Irrigation was stopped three weeks before harvesting. Mature bulbs were harvested when 75 percent of the tops had fallen.

Days from sowing to maturity were recorded when 75 percent of the plants had fallen tops. Bulb yield was the total weight of bulbs harvested from a net plot of size 2.7m^2 expressed in t ha^{-1}. Mean bulb weight was the average weight (g) of ten randomly selected bulbs in each plot. Bulb shape was expressed as shape index, which is the ratio of bulb diameter to height . Bulb height was measured as the vertical length from the base plate to the neck constriction at a point where curvature changes from convex to concave. Diameter was the longest bulb diameter on a horizontal plane. Measurements were made with a vernier callipers. Dry-matter content was determined using a hand-held refractometer (HRN -32, Kross, Tokyo, Japan), which provides a good estimate of total soluble solids (5; 10; 14). A single drop of juice was squeezed out of each bulb onto the glass plate of the refractometer for each of ten randomly selected bulbs per plot. The refractometer reading gave percentage dry matter.

Data analysis. Each location in a given season was considered as a distinct environment. Data from each environment was subjected to analysis of variance followed by a combined analysis for all environments. Prior to combined analysis, Bartletts' test was used to assess homogeneity of variances (19). Environments were considered random effects and genotypes fixed. *F*-tests for individual environment and combined analysis were conducted as suggested by McIntosh (15). The pooled error was used to test for the significance of variance due to genotype x environment interaction. Where variance was significant, the data was subjected to stability analysis as described by Eberhart and Russell (8).

RESULTS AND DISCUSSION

The analysis of variance showed that environmental effects were significant for all traits (Table 4). Genotypic effects were also highly significant for all traits except maturity.

Days to maturity. The earliest maturing cultivar over all environments was KON 5 while KON 8 took longest to mature (Table 2). There was little variation in maturity between the recently introduced and local cultivars. However, maturity varied with environments. All cultivars matured earliest at Marigat (155 days) and latest at Ol Jorok (205 days), sites with mean maximum and minimum temperatures of 33.4/17.0° and 21.6/6.9°C, respectively.

Brewster (2) showed that relative growth rate (RGR) of onions increased with temperatures up to 25°C, and concluded that RGR is largely determined by temperature. Butt (3) reported that the most rapid bulb growth rate and the earliest onset of a decline in leaf occurred at temperatures of 25 and 30°C. Lower temperatures gave successively less rapid bulbing and maturity. Steer (20) also reported more rapid bulbing at high temperatures (34/26°C) and longer day lengths (17 hours).

Bulb shape. Bulb shape differed among cultivars and was affected by environmental conditions (Table 3). Although there was little variation in bulb shape among sites within years, there were differences between the two years. Bulbs of the 1990 trials were nearly round while those of

TABLE 2. Mean and range of days to maturity,bulb shape index, dry matter content, bulb weight and bulb yield of eleven onion cultivars grown in seven environments in Kenya , 1991/92

Cultivar	Days to maturity		Shape index (%)		Dry matter (%)		Bulb weight (g)		Bulb yield (t/ha)	
	mean	range	mean	range	mean	range	mean	range	mean	range
KON 1	173.9	156.8 –206.8	1.0	0.9 – 1.1	6.6	4.6 – 8.6	137.1	65 –190	32.8	8.4 – 53.9
KON 2	169.1	146.0 – 198.8	1.0	0.6 – 1.2	6.4	5.2 – 7.8	112.3	61 –136	26.9	7.4 – 40.1
KON 3	172.4	153.3 –207.0	1.0	0.8 – 1.1	5.3	3.9 – 6.8	123.0	72 – 163	35.6	6.2 – 59.2
KON 4	169.4	149.8 – 207.8	0.9	0.7 – 1.2	6.0	4.8 – 7.3	126.7	73 – 166	29.4	7.7 – 52.4
KON 5	167.4	144.6 –202.0	0.9	0.7 – 1.2	6.3	4.7 – 7.9	102.1	35 – 155	22.7	3.9 – 42.0
KON 6	168.5	152.2 –198.4	0.9	0.6 – 1.2	6.2	3.4 – 8.4	110.1	58 – 159	22.3	6.0 – 39.8
KON 7	175.3	154.2 – 211.0	0.9	0.7 – 1.2	5.7	4.0 – 7.2	133.2	79 – 186	34.7	8.2 – 64.4
KON 8	180.9	159.2 – 215.4	0.9	0.8 – 1.0	9.1	7.2 – 10.6	87.3	42 –123	20.6	8.1 – 31.3
Red Creole	178.1	161.2 – 212.6	0.9	0.8 – 1.0	10.1	8.4 – 11.6	84.1	32 – 140	18.0	4.2 – 32.1
Tropicana	176.6	160.0 – 207.2	1.0	0.8 – 1.1	10.8	9.2 –12.4	89.1	58 – 127	20.7	4.7 – 38.1
Bombay Red	172.6	160.4 – 197.4	1.0	0.9 – 1.1	8.9	7.7 – 10.7	72.0	34 – 102	16.2	3.4 – 30.5
Mean	173.1	155.3 – 205.9	0.9	0.8 –1.0	7.4	5.9 – 8.3	107.3	59 – 131.6	25.5	9.7 – 35.9
C.V (%)	3.1		13.1		11.1		12.5		4.4	
LSD (0.05)	6.80		0.20		1.00		17.10		15.50	

1991 tended towards oval-shape. The local cultivars were more globous than most of the new cultivars. The new cultivars with almost ideal shape were KON 1, KON 2, and KON 3.

Bulb shape is an important selection criteria, the preferred shape depending on the market. Generally, globe shaped (shape index =1) are preferred by consumers. This trait varied among cultivars and environments. Dowker and Fennel (6) observed that bulb-shape and bulb weight are negatively correlated. They argued that variation in bulb shape over environments was due to the effect of the environment on bulb weight. Our results indicated no correlation between shape index and bulb weight (r = -0.01).

Dry matter. Dry matter content varied significantly from 3.4–10.6 % to 8.4–12.4 % for the new and local cultivars, respectively (Table 2). In both years, the local cultivars had higher dry matter content than the exotics. However, there was little variation in dry matter content between the two years. Tropicana had the highest dry matter content over all environments (10.8%) and KON 3 had the lowest (5.3%). Dry matter in bulb onions varies from low levels of 7–10% to high levels of 15–20 % (5). Onions with high dry matter (>20%) are preferred for processing.

Currah and Proctor (5) showed that onions with high dry matter tend to yield less than those with low dry matter content. The latter also exhibit rapid bulbing. The results of this study suggest that none of the eleven cultivars are specially suitable for processing (dry matter contents 3.4–12.4%) but could be utilized for fresh markets. Currah and Proctor (5) also noted that onions with higher dry matter are firmer and hence more resistant to damage and storage, and have thicker, well adhering skins which retain water better than thin skins. However, their yields are relatively low.

The present demand in Kenya is for onions with high yield potential but, as the processing industry grows, breeding programmes will need to introduce germplasm with higher dry matter content. Several workers have associated high dry matter content with good shelf-life (4; 5; 10).

Bulb weight. Bulb weight varied between cultivars and environments. The newly introduced cultivars had higher bulb weight than the local ones (Table 2). KON 1 had the largest bulbs and Bombay Red the smallest over the seven environments. The maximum expression of this trait for most of the cultivars was recorded at Kabete and the poorest expression at Kibirigwi, especially in 1991 (Table 2). Temperature, pre-bulbing plant size, light intensity, nutrient status and moisture availability, among other factors, have been shown to influence bulb growth and its ultimate size (2). In these sites, temperature and moisture availability were generally the most critical factors.

Bulb yield. Bulb yield varied among cultivars and was significantly influenced by environment (Table 2). Yields were higher in 1991 than 1990; the new cultivars did better than the local ones in both years. KON 3 was the best among the recently introduced cultivars while Tropicana was the best among the local cultivars for the two years. Bombay Red bolted in all environments and had the lowest mean yield for all environments except at Marigat in 1991 where it outyielded KON 4, KON 5, KON 6 and Red Creole. The best yielding environment was Marigat, followed by Kabete in 1990, while the worst environment was Kibirigwi in 1991. The low yields at Kibirigwi in 1991 were attributed to infection of introduced varieties by pink root rot *P. terrestris* disease which resulted to small sized bulbs.

The results indicated that some of the introduced cultivars have considerable potential for local growers. They outyielded the local ones in all environments except at Kibirigwi in 1991. However, the new cultivars showed severe susceptibility to purple blotch *(A. pori)* and pink root.

Genotype x environment interactions. Environmental indices and mean squares from regression analyses are given in Tables 3 and 4. There were significant differences among the varieties for all traits except days to maturity. Genotype x environment effects (linear) were highly significant for bulb yield and shape index but not for bulb weight, maturity and dry matter. This indicated that bulb yield and shape index varied linearly among varieties in response to changes

TABLE 3: Environmental indices for eleven onion cultivars grown in seven environments in Kenya, 1990–1991

Environment	Days to maturity	Shape index	Dry matter (%)	Bulb weight (g)	Bulb yield (t/ha)
Kabete (1990), long rains	-4.2	0.1	0.8	24.6	9.5
Kibirigwi (1990), long rains	-9.4	0.1	0.2	21.0	0.8
Ol Jorok (1990), long rains	17.8	0.1	0.0	7.9	-12.5
Kabete (1990/91), short rains	-7.3	0.0	0.0	-31.1	8.9
Kibirigwi (1990/91), short rains	-11.8	-0.1	-0.3	-48.1	-15.7
Ol Jorok (1990/91), short rains	32.7	0.0	0.9	6.0	-1.3
Marigat (1990/91), short rains	-17.9	-0.1	-1.5	19.7	10.4

TABLE 4. Mean squares from combined analysis of variance and regression analysis for onion cultivars grown in seven environments in Kenya,1990/91

Source of variation	Df	Days to maturity	Shape index	Dry matter (%)	Bulb weight (g)	Bulb yield (t/ha)
Environments (E)	6	2065.5**	7.1**	7.2*	8820.9**	1249.0**
Reps.(Environment)	28	61.4	0.1	21.0**	71.6	18.8
Genotypes (G)	10	415.1	59.0**	26.3**	3348.4**	327.0**
Genotype x Environment	60	502.0*	3.7**	0.6**	510.4**	79.1**
Pooled error	280	6.1	0.2	0.2	36.7	2.7
E+(G x E)	66	644.1	0.022**	1.2	1266.0	185.4
E (linear)	1	22073.0**	0.425**	43.1**	52930.1**	7496.3**
G x E (linear)	10	55.2	0.068**	0.8	425.3	140.0**
Pooled deviations	55	33.3**	0.006**	6.0**	479.4**	60.7**
KON 1	5	30.3**	0.007*	0.4*	663.9**	46.5**
KON 2	5	43.6**	0.0	0.2	161.8**	5.7
KON 3	5	9.6	0.0	0.2	220.2**	39.8**
KON 4	5	38.5**	0.006*	0.3	270.6**	112.4**
KON 5	5	26.7**	0.001*	0.7**	986.8**	117.0**
KON 6	5	15.4*	0.013**	0.3	552.8**	48.9**
KON 7	5	20.2**	0.0	0.4*	454.5**	50.2**
KON 8	5	26.0**	0.005*	0.2	660.3**	34.6**
Red Creole	5	88.8**	0.006*	1.7**	634.0**	52.2**
Tropicana	5	56.9**	0.005*	0.9**	464.0**	99.0**
Bombay Red	5	9.8	0.006*	1.0**	205.0*	64.8**
Pooled error	308	6.10	0.002	0.20	36.70	2.70

*,** Significant at *P*= 0.05 and 0.01, respectively.

TABLE 5. Regression coefficients(b), and deviations from regression (S^2d_i) for duration to maturity, shape index, dry matter, bulb weight and bulb yield of 11 onion cultivars grown over seven environments in 1990–1991

Cultivar	Days to maturity		Shape index		Dry matter (%)		Bulb weight (g)		Bulb yield (t/ha)	
	b	S^2d_i	*b*	S^2d_i	*b*	S^2d_i	*b*	S^2d_i	*b*	S^2d_i
KON 1	1.0	24.2**	-0.2**	4.2*	1.5**	0.25*	1.4**	627.2**	1.5**	40.9**
KON 2	1.0	37.5**	2.2**	1.1	0.9	0.0	0.9**	125.1**	1.1	2.3
KON 3	1.2	1.6	1.3	1.5	1.0	0.0	0.9	183.5**	1.6**	37.1**
KON 4	1.0	32.4**	1.9**	4.1*	0.9	0.1	1.1**	233.9**	1.0	109.7**
KON 5	1.1	20.6**	2.6**	-1.6*	1.2**	0.60*	1.3**	950.1**	0.7**	114.3**
KON 6	0.9	9.3*	2.6**	1.0**	1.8**	0.2	1.2**	516.1**	0.8	46.2**
KON 7	1.2**	14.1**	2.0**	2.2	1.0	0.21*	1.1	417.8**	1.7**	47.5**
KON 8	1.2**	19.9**	0.1**	3.0*	1.2**	6.9	0.7**	623.6**	1.0	31.8**
Red Creole	0.9**	82.8**	-0.6	4.0*	0.7**	1.58**	1.2**	597.2**	0.5**	49.5**
Tropicana	0.8**	50.9**	-0.6	2.6	0.7**	0.78**	0.4**	427.3**	0.7	96.3**
Bombay Red	0.8**	3.7	-0.2**	3.7*	0.0**	0.84**	0.9**	168.3**	0.4**	62.1**

*,** Significantly different from one for regression coefficient (*b*) and from zero for deviation from regression at $P = 0.05$ and 0.01, respectively.

in environment. Deviations from regression were highly significant for all traits (Table 5), implying that the varieties differed in their non-linear responses to changes in environment.

Most plant breeding programmes aim at selecting genotypes that are consistently high-yielding over the range of environments that occur in different locations or seasons. However, the failure of genotypes to have the same relative performance in different environments due to genotype x environment interactions reduces efficiency in selection. Such interactions have been reported for some traits in the limited work published on genotype x environment interaction in onions. Dowker and Fennel (7) detected no significant G x E interactions for yield in the cultivars they studied, while Fennel and Salter (9) observed significant G x E interactions for maturity and bulb yield. The lack of significant (linear) G x E interactions for bulb weight, maturity and dry matter in the present study indicates that the relative performance of the cultivars as measured by these parameters was essentially inconsistent in all the environments. The new cultivars were particularly susceptible to purple blotch (*A. pori*) while Red Creole showed some resistance. This may have caused instability of performance reflected by the significant pooled deviations for some of the traits. The significant G x E (linear) interactions observed for bulb yield and shape indicates that selection for average performance over the entire area from which representative experimental sites were drawn may not be profitable. Selection of cultivars for specific agroecological regions seems desirable in the country. For example, the most suitable cultivars for Marigat and Ol Jorok were KON 7 and KON 4. In contrast KON 3 was best for Kibirigwi and Kabete.

Adaptability and stability parameters. The stability and adaptability parameters of the eleven cultivars are shown on Table 5. According to this analyses (8), an ideal cultivar should have above average mean performance, unit regression coefficient ($bi = 1$) and least deviation from regression ($S^2d_i = 0$). All varieties except KON 2 were not stable for bulb yield. KON 4, though not stable, showed good adaptation in all environments and has the red brown color preferred by consumers. Other red colored newly introduced cultivars (KON 6 and KON 8) had poor adaptation and stability. Local cultivars also had poor stability and adaptability.

KON 1, KON 4 and KON 6 were specifically adapted to favorable environment for bulb size. KON 7 and KON 3 had general adaptability, and were also stable for this trait. KON 2, KON 4, KON 5 and KON 6 had general adaptation and good stability for maturity. These cultivars also matured relatively early. Although KON 1 had good adaptation, it was late maturing. Local cultivars showed poor adaptation for maturity. KON 6 and KON 8 had the best attributes of good adaptation and stability for dry matter content. KON 3 was the best cultivar for shape index because it had almost globe-shaped bulbs, wide adaptation and good stability.

CONCLUSION

Major objectives of onion breeding in Kenya and other onion producing countries is to develop high yielding, early maturity and disease resistant cultivars with long shelf life. Local cultivars have not adequately met these objectives and hence the introduction of other cultivars to broaden the genetic base. Most of the introduced cultivars had specific, wide adaptation and good stability to the environments tested. They outyielded local cultivars and showed other superior bulb characters such as shape and size. However, they were particularly susceptible to purple blotch and pink root, are less pungent than local ones, and only three cultivars (i.e. KON 4, 6 and 8) have the preferred red skins. Considering all attributes , KON 4 seems to have the best potential for local production.

ACKNOWLEDGEMENT

This work was supported by a grant from the German-Israel Agriculture Research Fund (GIARA) and this is gratefully acknowledged.

REFERENCES

1. Abdalla, A.A. 1967. Effect of temperature and photoperiod on bulbing of the common onion (*Allium cepa* L.) under tropical conditions of the Sudan. *Experimental Agriculture* 3 : 137–142.
2. Brewster, T.L. 1977. The physiology of the onion. *Horticultural Abstracts* 47: 17–23 and 103 –112.
3. Butt, A.M. 1968. Vegetative growth, morphogenesis and carbohydrate content of the onion plant as a function of light and temperature under field and controlled conditions. *Mededelingen Landbouwhoge-school Wagenigen* 68: 1–211.
4. Chang, W.N., Y.H. Chang and F.J. Kuo, 1987. Prospects of onion seed production in Taiwan. *Taiwan Extension Bulletin* 255.
5. Currah, L. and F.J. Proctor, 1990. *Onions in Tropical Regions*. Bulletin No. 35. National Resources Institute, Kent, UK.
6. Dowker, B. D. and J.F.M. Fennel, 1974. Heritability of onion bulb shape in some north European onion varieties. *Annals of Applied Biology* 77:61–65.
7. Dowker, B. D. and J.F.M. Fennel, 1974. Some responses to agronomic treatments of different genotypes of bulb onions, *Allium cepa* . *Journal of Horticultural Science* 49 1–14.
8. Eberhart, S.A. and W.A. Russel, 1966. Stability parameters for comparing crop varieties. *Crop Science* 6: 36–40.
9. Fennel, J. F.M. and P.J. Salter, 1977. Stability parameter for comparing varieties. *Theoretical and Applied Genetics* 51:21–28.
10. Foskett, R.L. and C.E. Peterson, 1950. Relation of dry matter content to storage quality in some onion varieties and hybrids. *Proceedings of the American Society of Horticultural Science* 55: 314–318.
11. Hosfied, G.L., G. West, and C.E. Peterson , 1977. Heterosis and combining ability in a diallel cross of onion. *Journal of the American Society of Horticultural Science* 102: 355–360.
12. Jaetzold, R. and H. Schmidt, 1983. *Farm Management Handbook of Kenya*, Vol. II, Central Kenya (Part B) . GTZ - Ministry of Agriculture, Nairobi, Kenya.
13. Kenya Meteorological Department (K.M.D). 1985 *Annual Report*, Nairobi, Kenya.
14. McCollum, G.D. 1968. Heritability and genetic correlations of soluble solids, bulb size and shape in white spanish onion. *Canadian Journal of Genetics and Cytology* 10 : 508–514.
15. McIntosh, M.S. 1983. Analysis of combined experiments. *Agronomy Journal* 75: 153–155.
16. Ministry of Agriculture (M.D.A.), Land

Development Division, 1986. A project proposed for continuation of the Kibirigwi Irrigation Scheme. Nairobi, Kenya.

17. Pike, L. M. 1986. Onion breeding. In: *Breeding Vegetable Crops.* Basset, M.J. (Ed.). Avi Publishing Co., Westport, Connecticut, pp. 357–394.
18. Siderius, W. 1976. Environment and characteristics of a nitosol at Kabete National Agricultural Laboratories (NAL). Ministry of Agriculture and Livestock Development, Nairobi, Kenya.
19. Steel, R.G.D. and J.H. Torrie, 1980. *Principles and Procedures of Statistics.* McGraw-Hill Book Co., New York.
20. Steer, B.T. 1980. The bulbing response to day length and temperature of some Australasian cultivars of onion (*Allium cepa*). *Australian Journal of Agricultural Research* 31: 511–518.