BULB YIELD AND QUALITY OF ONION (*Allium cepa* L.) AS AFFECTED BYSOWING TIME AND POTASSIUM SUPPLY

THEINT THANDAR LATT

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A Thesis Submitted to the Post-Graduate Committee of the Yezin Agricultural University in Partial Fulfillment of the Requirements for the Degree of Master of Agricultural Science (Horticulture)

Department of Horticulture
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The thesis attached hereto, entitled **"BULB YIELD AND QUALITY OF ONION *(Allium cepa L.)* AS AFFECTED BY SOWING TIME AND POTASSIUM SUPPLY"** was prepared under the direction of chairman of the candidate's supervisory committee and has been approved by all members of that committee and board of examiners as partial fulfillment of the requirements for the degree of **MASTER OF AGRICULTURAL SCIENCE (HORTICULTURE).**

U San Shwe Myint
Chairman of Supervisory Committee
Lecturer
Department of Horticulture
Yezin Agricultural University

Dr. Su Su Win
External Examiner
Deputy Director and Section Head
Soil Science Section, Soil, Water
Utilization and Engineering Division
Department of Agricultural Research

Dr. Yi Yi Soe
Member of Supervisory Committee
Assistant Lecturer
Department of Horticulture
Yezin Agricultural University

Daw Yinn Mar Soe
Member of Supervisory Committee
Assistant Lecturer
Department of Agricultural Chemistry
Yezin Agricultural University

Dr. Khin Thida Myint
Professor and Head
Department of Horticulture
Yezin Agricultural University

This thesis was submitted to the Rector of the Yezin Agricultural University and was accepted as a partial fulfillment of the requirements for the degree of **MASTER OF AGRICULTURAL SCIENCE (HORTICULTURE).**

Dr. Tin Htut
Rector
Yezin Agricultural University
Nay Pyi Taw

Date------------------------

DECLARATION OF ORIGINALITY

This thesis represents the original work of the author, except where otherwise stated. It has not been submitted previously for a degree at any University.

Theint Thandar Latt

Date------------------------

DEDICATED TO MY BELOVED PARENTS,
U KHIN MAUNG LATT AND DAW SAN SAN YIN

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ABSTRACT

The two experiments were conducted at the Horticulture Department, Yezin Agricultural University from October 2010 to April 2012 in order to examine the effects of various levels of K supply and different sowing times (ST) on yield and quality of onion. Two ST (31 October, 21 November) and four K levels (0, 50, 100, 150 kg K_2O ha^{-1}) in experiment I and three ST (7 November, 21 November, 5 December) and three K levels (0, 50, 100 kg K_2O ha^{-1}) in experiment II were laid out as main plot and sub-plot factors respectively. The growth parameters were recorded weekly and the yield parameters were measured at two harvests in experiment I and five harvests in experiment II. The quality parameters were evaluated at final harvest times and post harvest weight loss during the one month storage for both experiments.

In experiment I, the plants heights from 21 November ST (farmers' sowing time) showed higher than that from 31 October ST. The significantly higher values of shoot weight, bulb weight and bulb diameter but lower bulbing ratio were recorded in plants of 31 October ST in comparison to 21 November ST at 91 days after transplanting (DAT). Consequently higher weight loss % was observed in the onion bulbs from 31 October ST after one month of storage. Regarding the K supply, the plants treated with high K levels (100 and 150 kg K_2O ha^{-1}) produced the more number of leaves along the growth period, and showed the higher values in bulb weight, bulb diameter, bulb N and protein contents, shoot K content and total soluble solid (TSS %) at final harvest (91 DAT) and lower weight loss % at 28 days after storage as compared to control. Among the K levels, 100 kg K_2O ha^{-1} revealed the significantly higher bulbing ratio than control.

In experiment II, the plants from 7 November ST showed the maximum values of all vegetative parameters and bulb weight, but the minimum values of bulbing ratio, bulb K and TSS %. The plants from 5 December ST showed the minimum values of leaf number at 8 weeks after transplanting, shoot weight, bulb weight, bulb diameter and neck diameter but maximum bulbing ratio and bulb K contents at 97 DAT. Post harvest weight loss % was the highest from 21 November ST and the lowest from 5 December ST. Regarding the K supply, the highest value of shoot weight and the lowest weight loss % was observed in the treatment of 50 kg K_2O ha^{-1}. The highest bulbing ratio and bulb K content was obtained from the treatment of 100 kg K_2O ha^{-1}.

Key words: bulbing ratio, TSS, protein, K contents, weight loss

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I. INTRODUCTION

Onion (*Allium cepa* L.) is a member of the family Alliaceae. It is one of the most important bulb crops ranking second position in importance after tomato in the tropics (Gardin et al., 1992).*Allium cepa* probably originated from Afghanistan, Iran and Pakistan, but is now widely cultivated in many areas of the world including the tropics and the temperate regions (Astey *et al*., 1982). The range of cultivation areas of onion and its uses have led to a large number of cultivars and types.

The horticultural divisions of onions include dry bulb (including pickling onions), bunching onions (salad onions) and shallots (aggregatum onion) (George, 2009). Onion cultivars grown in Myanmar are short-day tropical cultivars belonging in the dry bulb group and called various names depending on the shapes of the bulb (e.g Shwephalar, the golden bowl) and also on the place of production (e.g Myingan, Myittha, Pyawbwe, Mahlaing etc.). The major cultivars grown in Myanmar are Shwephalar, Baungsauk, Shwephalar Hteikmauk, Sint – th and Mindon (shallot) (Thein, 1994). Among them, the cultivar "Shwephalar", used in this experiment, is the most popular which seemed to be introduced from Grokak canal, India (Ba Maung, 1954).

Onions can be eaten as raw or cooked in most nations of the world. It is used in soups, sauces and for seasoning many foods. The small bulbs are pickled in vinegar and mild flavor onions are often chosen for salad. It is considered as a rich source of carbohydrates, proteins and vitamin C besides minerals like phosphorous and calcium (Jaggi, 2005). Furthermore, onion is high in medicinal properties for human. Many researchers have suggested that onion in the daily diet may play a role in suppressing stomach cancer and preventing heart disease and other ailments (Currah and Proctor, 1990).

In Myanmar, onion is used daily in cooking foods and becoming major growing vegetable crops for farmers in some regions (eg. Mandalay, Magway, Sagaing Region and Shan State).In 2012-2013, onions were sown in72,000 ha and about 1,161,000MTof dry bulb onions with the average yield of 16.11 MT/ha were produced (DAP, 2013).

In onion production, many agricultural practices such as planting and harvesting date may affect onion productivity (Brewster, 1997). Bulb formation and subsequent growth are mainly influenced by photoperiod. Long-days and high temperature promote bulb formation (Kato, 1964). Accordingly, the sowing date may account for the better development of foliage parts and bulb size (Gaskell et al., 1998). Therefore the sowing or planting dates play a significant role in onion growth and yield (Campeglia, 1976). Yield reduction was estimated to range from 4.5-70.5 % depending on the growing season (Garcia et al., 1994).

As nutrient supply, potassium (K) plays a vital role among the major nutrients in plant metabolism such as photosynthesis, regulation of plant pores, activation of plant catalysts and resistance against pests and diseases (Islam et al., 2006; Resende and Costa, 2008). In onion, K is considered to be very important element due to its influence for translocation of photosynthates, storage quality, bulb size, bulb numbers and yield per plant (Sangakkara et al., 1993). Moreover, the values of total soluble solids in onion bulbs tissue are in good association with potassium rate (Masalkar et al., 2005; Yaso et al., 2007). Potassium can also improve colour, glossiness and dry matter accumulation besides improving keeping quality of the onion (Subhani et al., 1990). However, K application has been ignored by the local onion growers.

Onion production in Myanmar is limited to two specific seasons: rainy and winter season although it can be produced throughout the year in some countries. Most onion growers in Nay Pyi Taw sow the plant within 3^{rd} and last week of November. How extent sowing time can be shifted while keeping the optimum yield is not yet known. In Myanmar, there is a few numbers of academic researches on onion production with regard to sowing times and nutrient management.

Therefore, this experiment was carried out to examine the effects of various levels of potassium supplies and different sowing times on yield and quality of onion.

II. LITERATURE REVIEW

2.1 Description of *Allium cepa*

Allium cepa is cultivated mainly as a biennial. It is propagated by seeds, bulbs or sets (small bulbs). Bulbs have a reduced disc-like rhizome at the base. Scapes are up to 1.8 m tall and gradually tapering from an expanded lower part. The leaves have rather short sheaths and differ in size and are near circular in cross-section but somewhat flattened on the adaxial side. The umbel is subglobose, dense, many-flowered and with a shore persistent spathe.

Bulb weight may be up to 1kg in some southern European cultivars, and the shape covers a wide range from globose to bottle-like and to flattened-disc form. The colour of the membranous skins may be white, silvery, buff, yellowish, bronze, rose red, purple or violet. The colour of the fleshy scales can vary from white to bluish-red. There is also much variation in flavor, the keeping ability of the bulbs in the first season. There exist varieties adapted to bulbing in a wide range of photoperiodic and temperature conditions (Fritsch and Friesen, 2002).

2.2 Horticultural Classification of *Allium cepa*

According to simple informal classification, *Allium cepa* can be divided into two large (Common onion and Aggregatum onion) and one small (Ever-ready onion) horticultural groups (Jones and Mann, 1963).

2.2.1 Common onion group

This group is the most economically important *Allium* crop. It includes hundreds of open-pollinated traditional and modern cultivars, F1 hybrids and local races, cultivated in most regions of the world. The bulbs are large and normally single, and plants reproduce from seeds or from seed-grown sets. The majority of cultivars grown for dry bulbs belong to this group, as do salad or pickling onions.

2.2.2 Aggregatum onion group

In this group, the bulbs are smaller than those in common onions, and many of them form an aggregated cluster. Traditional reproduction is almost exclusively vegetative via daughter bulbs. The group is of minor economic importance. Locally adapted clones and cultivars are grown mainly in home gardens in Europe, America and Asia for dry bulbs and, more rarely, for green leaves. Cultivation on a large scale takes place in France, Holland, England and Scandinavia, in Argentina and in some tropical regions, e.g. West Africa, Thailand, Sri Lanka and other South-East Asian countries, and the Caribbean area.

2.2.3 Ever-ready onion group

This third group may be distinguished from the other two by its prolific vegetative growth and by lack of a dormant period. Bulbs or leaves can be gathered at all times of the year. It is used mainly as a salad onion and was commonly cultivated in British gardens in the mid-20th century (Fritsch and Friesen, 2002).

2.3 Production Status of Onions

According to 2012 statistics, approximately 74.25 million tons of onions are produced each year in the world, of which 20.5 million tons are produced in China, 13.37 million tons in India and 3.32 million tons in USA, with the remainder being produced in Egypt, Iran, Turkey, Pakistan, Brazil, Russia and Republic of Korea (FAO, 2012).

In Myanmar, onions are generally grown in rainy season and winter season of all growing area. Onion sets are planted during rainy season for green onion production and onion seeds are usually grown during winter season for dry bulb onion production. Generally, the winter onions are sown at the end of rainy season (October-November) and harvested at the beginning of summer (March-April). Among the onion cultivars grown in Myanmar, the Shwephalar cultivar is the most popular one. In Ye Ni Township, some growers transplant the crop at the end of November and harvest at the end of March. Most of the growers transplant the seedlings at about 35 days after sowing while some growers transplant the seedlings 45 days after sowing. Most of the growers grow the dry bulb onion from saved seeds obtained from previous growing season. In Naypyitaw area, the normal yield is 4,000-6,000 viss per acre but sometimes the yield can be reduced to about 3,000 viss (personal communication).

2.4 Morphology and Formation of Bulb

When conditions of daylength and temperature favor bulbing in the onion, the leaf base begins to function as a storage organ at bulb initiation. During bulbing, much of the dry matter in the leaves, including the nutrients, is transferred into the bulb which can contribute the swelling of the leaf sheaths. Less conspicuous are the changes in the form of the new leaves which are being produced in the bulb centre, the production of lateral buds, and finally the cessation of root production and the entry of the entire plant into a state of rest.

The enlargement of the bulb is first brought about by the thickening of the bases of the foliage leaves, and the bulk of the mature bulb may consist of these. However, as bulbing progresses, leaves near the bulb centre abort their blades and become storage sheaths while the sheaths of the blade-bearing leaves normally extend well above the top of the bulb, so that only their lower part becomes thickened, the sheaths of leaves with aborted blades do not extend beyond the bulb, and entire sheath thickened. Within these thickened storage sheaths and near the bulbs centre are the last 5 or 6 leaves formed during the growing season. These young leaves remain small but protrude as sprouts if conditions following storage become favorable.

As bulb mature, the leaf sheaths weaken just above the bulb and the tops may fall over under their own weight. The weakening of the neck is usually attributed to the fact that the central leaves of the bulbs have ceased to elongate into the neck. At maturity, the falls of the tops occur because of the collapse of the neck tissues (Jones et al.,1973).

2.5 Environmental Factors for Onion Bulbing

The developing onion plant goes through a sequence of distinct morphological phases, which occur in response to environmental conditions (Albdallah and Mann, 1963). Onion is not suited to regions with very heavy rainfall in the lowland humid tropics. The main environmental factors which affect on onion bulb and set production are temperature and photoperiod and interaction between them (Lim-chaeshin et al., 2002; Diaz Perez et al., 2003; Huh et al., 2002; Mettananda, 2003). In the tropics, where small changes in day length occur, temperature has been suggested as the more important factors influencing bulbing (Abdalla, 1967; Robinson, 1971).

2.5.1 Temperature

Temperature affects on all functions of onion plant (Coolong and Randle, 2003; Abu-Rayyan and Abu-Irmaileh, 2004). Temperature variations influence the rate of vegetative growth (Butt, 1968; Brewster, 1979; Seabrook, 2005), leaf initiation, and emergence (de Ruiter, 1986). Optimum temperature for germinating onion seed is 20ºC (Parmar et al., 2001), but suitable temperature at which 70 % of seeds germinate is13-28ºC (Voss et al., 1999). Relative growth rate of onion leaf depends on temperature changes. Minimum temperature for leaf growth is 6ºC. Relative growth rate of onion leaf increases linear at 6 to 20ºC. If environmental temperature reaches above 27ºC, relative growth of leaf decreases (Brewster, 1997). The best root development occurs at soil temperature of 12-20ºC. Cool conditions (20-21 ºC) with adequate moisture supply are most suitable for early growth before bulbing takes place. Under excessive hot or wet condition, the onion production presents problems due to fungal and bacterial diseases that attack the plants at leafy stage and are difficult to control (Currah and Proctor, 1990).

Onion life cycle before bulb formation till seed stalk in response to temperature and daylength is described in Appendixfigure 1. During early growth and development, onions require cool temperatures (6 to 20°C), but during bulb initiation and development, warmer temperatures (25 to 27°C) are required (Comrie, 1997; Ansari, 2007). Steer (1980) reported that the rate of bulbing increased with increasing night temperature. The higher the soil temperature, the higher the onion pungency and flavor volatile (Yamaguchi et al., 1975).

2.5.2 Photoperiod

The production of bulb is mainly controlled by the photoperiod, the stimulus being received through the leaves. The critical daylength varies from 11-16 hours, depending on the cultivars. All onions are physiologically long-day plants, but the mechanism that controls onion bulbing is really a phytochrome response to the length of the night(Currah and Proctor, 1990). Therefore, in the so-called short day onions that are grown in the tropics, bulbing is in fact induced in response to night lengths, which are relatively long, at around 12hr. Intermediate-day (ID) and long-day (LD) cultivars grown at higher latitudes are induced to form bulbs by nights that are relatively shorter (i.e. nights of 11-8h, corresponding to days of 13-16 h) (Currah and Proctor, 1990). Long-day cultivars developed in temperate countries will not form bulbs in the shorter days of the tropics (Brice et al., 1997). Tropical onion varieties can be classified as "short day onion" because these plants will initiate and form bulbs in less than12 hrs of photoperiod (daylength) (Rabinowitch and Currah, 2002).

Generally, increasing length of photoperiod hastens maturity. Since, onion cultivars are specific with regard to minimum day length required for bulbing, time of sowing is critical and may also differ from year to year (Brewster, 2008).Varietal maturity mainly depends upon the rate of development during each length of day in excess of the indicated minimum needed for bulb formation. Although there is no minimum plant size for bulbing, larger plants tend to initiate bulbs earlier even though the required photoperiod is not met (Smittle, 1993). Uzo and Currah (1990) observed that under short day conditions, onion plants produced new leaves indefinitely without bulb formation while at longer daylength, bulbs were formed. Although the temperature is warm enough for bulbing, if daylength is not long enough, the plant continues its growth rather than bulb development.

2.5.3 Interaction between temperature and photoperiod

Brewster (2008) suggested that sowing dates should therefore be chosen to ensure that growth takes place under optimum temperatures (6 to 20°C). High temperatures ranging from 25 to 27°C can accelerate bulb initiation causing it to occur at a slightly shorter day length than required for a specific cultivar (Van den Berg et al., 1997). However, if bulbing is stimulated when plants are still small, leave senescence will occur rapidly and small bulbs will be produced due to a small leaf area (Wickramasinghe et al., 2000; Brewster, 2008). If the temperature is low (10-15ºC) and the day length is short, the plant produces seed stalk instead of developing bulb, and bulb maturation will not occur if the temperature is too low. Low temperatures between 9 to13°C which is close to bulb formation will cause plants to bolt instead of forming bulbs even though day length is long enough for bulbing. Lancaster et al. (1996) stated that a minimum day length is necessary for each onion cultivar and that a plant needs to accumulate thermal time of approximately 600 degree days from emergence (growing degree days above 5°C). Both of these requirements need to be met before bulb initiation will occur.

2.6 Role of Potassium in Plant

Next to nitrogen, potassium (K) is the mineral nutrient required in the largest amount by plants. In general K requirement for optimal plant growth is in the range of 2-5% of the plant dry weight of vegetative parts, fleshy fruit, and tubers.With the exception of nitrogen, K is required by plants in much greater amounts than all other soil supplied nutrients (Tisdale et.al., 1985).

Potassium has a crucial role in the energy status of the plant, translocation of sugars, and formation of carbohydrates and maintenance of tissue water relation. It also provides resistance against pest and disease and drought as well as frost stresses. Optimum K nutrition may result in higher concentration of starch in the plant, and therefore on quality of crops grown for this material (Marchner, 1995). Furthermore stomatal closure is associated with a steep increase in the concentrations of K. Therefore K can affect the rate of transpiration and water uptake through regulation of stomata openings. Improved K nutrition reduces the transpiration rate by stomatal closure (Cooke, 1986). Tester et al., (1989) reported that inadequate K supply and correspondingly lower leaf contents may reduce the rate of photosynthesis. In K deficient plant, translocation of sugar from leaves is greatly reduced (Kilmer et al., 1968), growth is retarded and net retranslocation of K is enhanced from mature leaves and stems, and the leaves become chlorotic and necrotic in severe case (Marschner and Cakmak, 1989).

Potassium is involved in the activation of more than 60 enzymes which are necessary for essential plant processes such as energy utilization, starch synthesis, N metabolism and respiration (Wallingford, 1980). In fact, K is required for protein synthesis in higher concentrations than for enzymes activation (Jones et al, 1979). K not only promotes the translocation of newly synthesized photosynthates but also has a beneficial effect on the mobilization of stored material (Mengel and Kirby, 1982).

Another function of K in plant is related to the necessity to maintain a high pH in the sieve tubes for sucrose loading and osmotic potential in the sieve tubes and thus, the transport rates of photosynthates from source to sink (Marschner, 1995). Similarly K plays as an important role in the transport of water and essential nutrient throughout the plant in the xylem (Alam and Naqvi, 2004).

2.7 Effect of Potassium Supply in Onion Production

Nitrogen, potassium and sulphur are nutrient elements that play important role on bulb formation, elongation, skin colour development and pungency of onion (Bose and Som, 1986; Vachhani and Patel, 1993). According to Zink (1996) the nutrient were removed from the soil only slowly during growth, but when two-third of the crop fresh weight was accumulated during the bulbing period, plants used approximately 68% of their total N, 75% of P, and 47% of K.

2.7.1 Nutrients uptake of onion

According to Nagaich et al. (1999), uptake of minerals P and K can be increased with K application. It was also found that K application resulted in increase of N and K uptake by onion plants (Singh and Verma, 2001; Vidigal et al., 2002). Average K content of the onion bulb and leaves may be around 1.2 and 4.3 % respectively based on the study of Sagadraca (1988) who also reported that K content of leaves and bulbs at the green stage was not affected by the different levels of K fertilizer regardless of planting method used. Salimath (1990) studied the effect of K on onion and found that nutrient uptake of N, P, K and S increased with increasing levels of K from 0 to 150 kg K_2Oha^{-1}.

Vachhani and Patel (1993) reported that increasing application of K (100 kg K_2Oha^{-1}) enhanced the N and K contents in onion bulb significantly besides the higher % of S and P contents. Mallangowda et al. (1995) showed that onion crop when supplied with 155:50:125 kg N: P_2O5:K_2Oha^{-1}exhibited the highest nutrient uptake of N,P and K compared to other treatments. Also in the study of Kumar et al. (2001), the uptake of N and K increased with increase in application of K and maximum uptake was recorded with the application of 80 kg K_2Oha^{-1}.

2.7.2 Growth and bulb yield of onion

In a number of studies, onion plant growth i.e plant height and number of leaves as well as fresh and dry weight of plants were recorded to be increased with increasing level of K application (Mohanty and Das, 2001; Salimath, 1990; Hariyappa, 2003; Sing et al., 2004), Moreover, increased bulb height, diameter and weight were also found in the onion plants applied with high level of K supply (Mahmoud, 1999). Vacchani and Potel (1993) also recorded the higher number of leaves per plant, weight of bulb and bulb yield with increase in potash application. Yadav et al. (2002) noticed significantly higher yield of bulb and fresh weight of bulbs with application of 150kg K_2Oha^{-1} over other levels.In a study ofSingh et al. (2004), the maximum plant height, fresh weight of leaves and total chlorophyll content at 45 DAT and 90 DAT were noticed with application of K at 120kg ha^{-1}.

2.7.3 Post harvest quality of onion bulb

The fertilization of K can improve the onion storage quality as described in many research evidences. Singh et al. (1991) found that bulb weight loss and the incidence of rotting and sprouting were reduced by application of K_2O at 100kg ha^{-1}. Nandi et al. (2002) also noticed that the lowest sprouting, rotting and weight loss were recorded with application of K compared to control. In one investigation with red varieties of onion, higher total soluble solids and total sugar content of bulb were reported due to K application (Pramanick et al., 1999). Lowest total weight loss of onion bulb was obtained in the treatment receiving K at 125kg ha^{-1} (Hariyapp, 2003). In the findings of Singh and Dhankar (1989b) during storage, the bulbs produced by the application K_2O at 100kgha^{-1} resulted in considerable reduction of rotting, sprouting and total bulb weight loss.

III. MATERIALS AND METHODS

3.1 Experimental Site and Period

The field experiments were conducted at the Department of Horticulture, Yezin Agricultural University from October, 2010 to April, 2011 (Experiment I) and from November, 2011 to May, 2012 (Experiment II).Yezin is situated between (19º 51′ N and 96º 7′ E) at an altitude of 102 m. Before conducting the experiment, the initial soil sample of the experimental plot was taken and analyzed at the laboratory of Soil Science Section, Department of Agricultural Research (DAR). The soil type was classified as loamy sand and characterized by 76 ppm N, 3 ppm available P and 74 ppm available Kin experiment I. In experiment II, the amount of N, P, K contents was 76 ppm, 14 ppm and 81 ppm respectively (Appendixes table 1 and 2). Monthly data for temperature and rainfall during experimental period was obtained from meteorological station, Yezin (Appendix figure 5).

3.2 Experimental Design and Treatments

Both experiments were laid out in a split-plot design with four replications**.**Different sowing times were assigned as main-plot factor and various levels of K supply as sub-plot factor respectively. As treatments, two sowing times and four levels of K supply for experiment I and three sowing times and three levels of K supply for experiment II were given as follow.

Experiment I

Main-plot factor (Sowing time)	**Sub-plot factor (K supply)**
(1)31October, 2010	(1)0kg K_2O ha^{-1} (K0)
(2)21November, 2010 (Farmer's sowing time)	(2)50kg K_2O ha^{-1} (K50)
	(3)100kg K_2O ha^{-1} (K100)
	(4)150kg K_2O ha^{-1} (K150)

Experiment II

Main-plot factor (Sowing time)	Sub-plot factor (K supply)
(1) 7November, 2011	(1)0kg K_2O ha^{-1} (K0)
(2)21November, 2011 (Farmer's sowing time)	(2)50kg K_2O ha^{-1} (K50)
(3) 5December, 2011	(3)100kg K_2O ha^{-1} (K100)

The sizes of experimental plots were1m x 2m (Experiment I) and 1m x 3m(Experiment II) and the plants were spaced at 12cm x 10cm between and within rows for both experiments. Population densities in each plot were 160 plants in experiment I and 240 plants in experiment II. Muriate of potash (MOP) was used for Potassium supply which was applied at the time of transplanting (50%) and 30 days after transplanting (50%).

3.3 Crop Management

The onion cultivar used in this experiment was 'Shwephalar', a popular variety among onion growers, and traders in Myanmar (Mun Mun Aung, 1999).The onion seeds used in both experiments were collected from farmers lived in Kinpundan village, Naypyitaw. The seeds were first germinated and raised in seed beds at different sowing times according to treatments. Ten days prior to transplanting, irrigation was cut to ensure the hardening of the seedlings. Five to six week-old seedlings were then transplanted to the experimental plots. The experimental plots were given uniform care and management as much as possible. Watering and weeding were done as needed. Watering was halted two weeks ahead of harvest time. Pests (e.g. thrips and cut-worm) and diseases (e.g. purple blotch and downy mildew) were controlled by the alternate application of recommended chemicals. After the preparation of experimental plots, 50 kg N ha^{-1}(Urea) and 80 kgP_2O_5 ha^{-1} (Triple super phosphate) were applied five days before transplanting and 50 kg N ha^{-1}(Urea) was applied 30 days after transplanting.

3.4 Data Collection

Data on the growth parameters (non-destructive) were recorded at two week intervals and yield and quality parameters (destructive) were recorded at each of the harvest times as follows.

Growth parameters

(a)Plant height (cm)

(b) Number of leaves per plant

Yield parameters

(a) Shoot fresh weight per plant (g)

(b) Bulb diameter (BD) (cm)

(c) Neck diameter (ND) (cm)

(d) Bulbing ratio (BR) (BD/ND)

(e) Bulb weight (g)

(f) Bulb yield (ton ha^{-1})

Quality parameters

(a)K, S and N contents (mg. g^{-1}DW)

(b) Soluble proteins and sugar contents (mg.g^{-1}DW)

(c)Total soluble solid (TSS %)

(d) Weight loss (%)

Data on plant height (cm) and number of leaves were collected from 10 sample plants to assess plant growth at weekly and two weeks interval at first and second experiments respectively until eight weeks after transplanting. Moreover, data on shoot weight, bulbing, bulb yield and quality parameters were measured using 10 sample plants at two harvest times (56 and 91 DAT)in experiment Iand five harvest times (57, 67, 77, 87, 97 DAT)in experiment II respectively.Bulb weight loss percent was measured from 10 sample plants at 0, 7, 14, 21 days after storage (DAS) for one month.

Bulbing ratio (BR) was computed as bulb diameter at the widest point divided by neck diameter(BD/ND). BR value greater than 2 is used as the criteria that bulbing has began (Clark and Heath, 1962). Total soluble solid content was measured using refractometer.

3.5 Chemical Analysis

Plant samples taken from experiment I was analyzed for total S and Nby using CNS analyzer (Elementar, Vario EL III, Germany). Soluble proteins was measured according to Bradford (1976) and total sugar content was determined with Anthrone according to Umbreit et al. (1972)at the Institute of Plant Nutrition, University of Hanover in Germany. The chemical analysis on K contents of bulb and leaf sheaths were carried out at soil and plant analysis laboratory, Department of Agricultural Research for both experiments through using Atomic Absorption Spectrometry.

3.6 Data Analysis

Collected data were analyzed by using SAS 9.1 (SAS Institute Inc., Cary, NC, USA, 2004). Mean comparison was performed with least significant difference (LSD) at 5 % level.

IV. RESULTS AND DISCUSSION

4.1 Effects of Two Sowing Times and Various Levels of K Supply on Growth, Yield and Quality of Onion (Experiment I, 2011)

4.1.1 Growth Parameters

4.1.1.1 Plant height (cm)

Table 4.1 describes plant height of onion in response to K supplies at different sowing times. At all measured time points, the plants of 21 Novembersowing time (ST) resulted in significantly higher values of plant height than 31October ST.This was not in line with an experimentconducted in Bangladesh (UD-Deen, 2008) which showed the longest plant height and the highest number of leaves per plant in October 30 planting compared to other planting times (November 15 and 30). Temperature difference during early vegetative growth stage under21 NovemberSTmight have enhanced the plant height to be higher than the plants sown on 31 October(Appendix figure 5).

Regarding the K supply, high K levels (100 and 150 kg K_2O ha^{-1}) fairly gave higher plant heights at all measured dates compared to other lower levels (0 and 50 kgK_2O ha^{-1}).Those plants under 100 kg K_2O ha^{-1} were significantly higher than control. According to Hariyappa (2003), the application of K at 125 kgK_2O ha^{-1} recorded significantly the highest in plant height and total dry matter production of field grown onion. Singh et al. (2004) also noticed the maximum plant height, fresh weight of leaves and total chlorophyll content with the application of K_2O at 120 kg ha^{-1}. No interaction effect was observed between the two factors.

Table 4. 1 Mean effects of sowing time and potassium supply on plant height of onion recorded at two weeks interval

Treatment	Plant height (cm)			
	2 WAT	4 WAT	6 WAT	8 WAT
Sowing time (ST)				
31October	47.86b	34.96b	51.98b	43.95b
21November	51.18a	63.24a	58.78a	67.39a
$LSD_{0.05}$	1.28	1.09	1.61	0.85
Potassium(K)				
K0	49.43	49.33	54.95b	55.69
K50	49.42	48.79	55.29ab	55.33
K100	49.63	48.97	55.76a	55.73
K150	49.59	49.32	55.51ab	55.95
$LSD_{0.05}$	0.53	0.60	0.77	0.84
ANOVA				
ST	**	**	**	**
K	ns	ns	ns	ns
ST x K	ns	ns	ns	ns
CV % (a)	2.29	1.96	2.58	1.35
CV % (b)	1.02	1.16	1.32	1.44

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; WAT, weeks after transplanting; ns, not significant; **significant at $p \leq 0.01$.

4.1.1.2 Number of leaves

Number of leaves recorded at two weeks intervals as affected by treatments are described in Table 4.2. In all treatments, this parameter showed a steady increase throughout the growth period. Except 8 WAT, a significant effect of sowing time was found at all growth stages of measurement, where the plants grown on November21 produced more number of leaves than that on October31. It seemed that the leaf development period underNovember21 ST may have coincided with the favorable ambient temperature (17-30ºC) for leaf development.Brewster (1997) also indicated in his study that the relative growth of onion leaf increased linear at 6 to 20ºC.

With regard to K application, significant differences were observed at 2 and 4 WAT. The maximum number of leaves was recorded at 100 kgK_2Oha^{-1}(K100), which was significantly higher than control at 2 and 4 WAT.Although not significant, the plants of K100 treatment showed 6.1 % (8.18vs.7.71) and 3.8 % (9.94vs.9.58) more number of leaves than that of control (K0) at 6 and 8 WAT respectively. This reflected the positive effect of K application on the leaf growth where the application rate of 100 kg K_2Oha^{-1} revealed the optimum level for onion plant growth.According to the data, 50 kg K_2O ha^{-1}seemed to be not enough for proper leaf development.However, Kumar (2006) found that the application of 50 kg ha $^{-1}$(K50) appeared to be more advantageous over higher K supply level (150 kg ha^{-1}) (K150). The interaction effect between ST and K supply was not observed at all recorded times.

Table 4.2 Mean effects of sowing time and potassium supply on number of leaves recorded at two weeks interval

Treatment	Number of leaves			
	2 WAT	**4 WAT**	**6 WAT**	**8 WAT**
Sowing time (ST)				
31October	3.59b	5.36b	7.53b	9.43
21November	6.68a	7.79a	8.38a	10.04
$LSD_{0.05}$	0.38	0.87	0.62	0.89
Potassium (K)				
K0	4.84b	6.31b	7.71	9.58
K50	5.09ab	6.50ab	7.90	9.81
K100	5.34a	6.88a	8.18	9.94
K150	5.28a	6.60ab	8.03	9.60
$LSD_{0.05}$	0.42	0.50	0.55	0.58
ANOVA				
ST	**	**	**	ns
K	**	ns	ns	ns
ST x K	ns	ns	ns	ns
CV % (a)	6.52	11.76	6.89	8.16
CV % (b)	7.84	7.29	6.59	5.67

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; WAT, weeks after transplanting; ns, not significant; **significant at $p \leq 0.01$.

4.1.2 Yield Parameters

4.1.2.1 Shoot weight and bulb weight (g)

According to the datadescribed in Table 4.3, no significant difference between two sowing times (ST) was observed for shoot weight at first harvest time (56 DAT). But the bulb weight of the plants in 21November ST (16.14 g) showed significantly higher values than those in 31October ST (8.32 g).

At final harvest time (91 DAT), the shoot fresh weight decreased while the bulb weight increased in both of ST. Both shoot weight and bulb weight were significantly higher in the plants of 31October ST in comparison to those sown on November21. The shoot weight of the onion plants from 31October ST (28.4 g) revealed about three times that of the 21November ST (9.41 g). In the case of bulb weight, the plants from 31October ST (52.8 g) showed 12.4 % superior to those from 21November ST (46.97 g).

The higher value of shoot weight observed in the plants sown on October31 was linked to the average value of cooler ambient temperature (21.65 ºC) during the early vegetative phase in December (Appendix figure 5).It was well documented that onion plants require short days and cooler temperatures in the early stages of crop establishment to enhance vigorous vegetative growth prior to the onset of warm temperatures and longer days later in the growing season which promote bulbing (Jones and Mann, 1963). The higher vegetative growth of the plants from the 31October ST showed more efficient photosynthesis to ensure more sugar synthesis. But the higher top growth recorded at 31October ST at 91 DATindicated that there may have been delayed bulb formation which can lead to a thicker neck, beingsubject to a risk of more postharvest weight loss compared to 21 November ST.

These findings were similar to the results of an experiment conducted in Bangladesh by UD-Deen, 2008 who reported that bulb volume, bulb weight per plant and bulb weight yield were decreased with the delay of planting time (November 30). It may be because of lower atmospheric temperature and short daylength encountered during the bulbing period (December to

January).Moreover, similar results were found by many scientists (Lisabao et al., 1985; Sigh et al., 1991; Khokhar et al., 1970).

Considering the case of K application, no significant effect was found for both parameters. But there was a tendency of positive contribution by all levels of K application in both shoot weight and bulb weight. Shoot weight of the plants treated with 150 kg ha^{-1} was found 11.93% (35.28 g) and 9.9% (19.55 g) higher than that of the plants from control treatment (31.52 , 17.79 g) at first and second harvest times respectively. For each of harvest time, bulb weight of the plants under 150 kg ha^{-1} of K application showed 20 % (12.78 g) in first harvest and 5.4 % (48.97 g) in second harvest higher than that under the control treatment (10.65, 46.46 g).

According to this result, the effects of variousK application levelson shoot and bulb weight of onion plants were not so strong.In principle, the plants grown under K deficient soil should reveal poor vegetative growth and bulb yield. Many authors reported that shoot and bulb weights of onion were improved by increasing level of K application (Mohanty et al., 2001; Hariyappa, 2003; Singh and Dhankhar, 1998a).Thismay partly be due to sufficient initial K status in the soil which can support early vegetative growth and make the treatment effects indifferent.

In both of harvest times, there was no significant interaction effect not only on shoot weight but also on bulb weight, which meant that the effect of sowing time was not interrupted by the application of variousK supply levels.

Table 4.3 Mean effects of sowing time and potassium supply on shoot and bulb weight of onion recorded at 56 and 91 DAT

Treatment	Shoot weight (g)		Bulb weight (g)	
	56 DAT	91 DAT	56 DAT	91 DAT
Sowing time (ST)				
31Oct	32.49	28.40a	8.32b	52.80a
21Nov	33.77	9.41b	16.14a	46.97b
$LSD_{0.05}$	5.17	2.61	1.99	4.63
Potassium (K)				
K0	31.52	17.79	10.65b	46.46
K50	33.54	20.51	13.51a	55.22
K100	32.19	17.76	12.46ab	48.89
K150	35.28	19.55	12.78ab	48.97
$LSD_{0.05}$	7.31	6.29	2.82	9.43
ANOVA				
ST	ns	**	**	ns
K	ns	ns	ns	ns
ST x K	ns	ns	ns	ns
CV % (a)	20.99	12.26	21.98	8.25
CV % (b)	20.99	31.65	21.99	17.99

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; DAT, days after transplanting; ns, not significant; **significant at $p \leq 0.01$.

4.1.2.2 Bulb and neck diameter (cm)

Table 4.4 describes the bulb diameter and neck diameter measured at two harvest times. Significant effect of sowing time on bulb diameter was found at first harvest time (56 DAT), when the higher diameter of bulb (3.1 cm) was produced from the onions sown on November21as compared to those from 31October ST (2.3 cm). Heath (1943) reported that higher temperature enhanced bulbing process and lower temperature delayed it. The plants of the 21 November ST escaped from cold temperature and received the optimum warm temperature (15-34°C) when the bulbing started in February, 2011 (Appendix figure 5). This condition might have been advantages for early phase of bulbing until the time offirst harvest (56 DAT).At final harvest (91 DAT), the bulb diameters from two sowing times were evaluated no significantlydifferent. For the early planted onions (31 October) the ambient temperature range (19-34°C) in November and early December turned out to beoptimum for superior vegetative growth which grantee a good support for linear phase of bulb formation. The bulb diameter of early sown onion (31 October) even showed a slightly higher values than that of the 21 November ST. The result wasfairly in agreement to Abdulrahman (2007) who stated that the early planting showed significantly higher values of bulb diameter in Saudi Arabian condition.

With regard to K application, there was no significant effect on bulb diameter for both harvest times. But there was a tendency of increasing bulb diameter in the plants treated with K application, where 50 kg ha^{-1} produced significantly larger bulb size than the control at both harvest times. This was in line with the finding of Mahmoud (1999) who reported that bulb diameter was increased with increasing the level of K application up to 300 kg K_2SO_4 per feddan (0.42 ha).

In the case of neck diameter, significantly higher values (about 2-folds) of neck diameter (1.43 cm) were resulted from the plants that grown on31 Octoberin comparison to that from 21 November ST (0.79 cm) at 91 DAT. It can be assumed that the bulb maturation of plants from 31 OctoberST were still going on at the time of harvest which needed some more time to reach a complete maturation. Similar result was obtained in a study conducted in Pakistan by Jilani

(2004) who found that the thickest necks of onion bulb was produced with early planting (27 October) compared to late planting (26 December).He also observed that attainment of thinner neck with later planting is associated with small plants caused by earlier bulb initiation for late planted plants than for earlier plantings.Regarding the K supply, no significant effect on neck diameter was observed.

There was no significant interaction effect between sowing time and K supply on both of bulb diameter and neck diameter, implying that the effect of one factor did not alter due to the presence of other factor.

4.1.2.3 Bulbing ratio (BD/ND)

At 56 DAT, bulbing ratio of onion plants from 21 November ST indicated the bulbing (2.02), while that of 31 October ST showed no bulbing (1.51) (Table 4.4). At final harvest time (91 DAT), the plants of 21November ST showed the bulbing ratio nearly double(6.83) that of 31October ST (3.61) and the difference washighly significant. This result indicated that the bulbing from 31October ST were relatively slower compared to that from 21November ST. Generally, the plants can start bulbing under short day lengths (11.5hr), but would not form a bulb unless a critical daylength is attained. Instead, they remain vegetative and produce thick-neck bulbs (Tesfay et al., 2011). In the current study, daylength did not seem to be a limiting factor as there was not so much fluctuation for both of the sowing times, making the temperature more important for bulbing.

Regarding the K supply, the plants treated with various levels of K application, except 150 kg ha $^{-1}$resulted in more rapid bulbing than control in both of harvests.At 56 DAT, bulbing had not yet started(BR< 2) in all treatments.Even that the plants treated with 50 and 100 kg ha^{-1}of K supply produced significantly higher bulbing ratio (1.85, 1.88) than control (1.70) respectively. At 91 DAT, K supply level of 100 kg ha^{-1}resulted in significantly higherbulbing ratiothan others.

Generally, the higher values of bulbing revealed to link to the largerbulb size. Interaction between sowing time and K supply was notsignificant at 56 DAT but significant at 91 DAT.

Table 4.4 Mean effects of sowing time and potassium supply on bulbing of onion recorded at 56 and 91 DAT

Treatment	Bulb diameter (cm)		Neck diameter (cm)		Bulbing ratio (BD/ND)	
	56 DAT	91 DAT	56 DAT	91 DAT	56DAT	91 DAT
Sowing time (ST)						
31October	2.30b	5.09a	1.53a	1.43a	1.51b	3.61b
21November	3.10a	4.95a	1.49a	0.79b	2.08a	6.83a
$LSD_{0.05}$	0.22	0.32	0.14	0.36	0.46	2.68
Potassium (K)						
K0	2.54b	4.83b	1.50	1.05	1.70c	4.95b
K50	2.87a	5.29a	1.55	1.18	1.85ab	5.06b
K100	2.72ab	5.00ab	1.45	1.05	1.88a	6.09a
K150	2.68ab	4.96ab	1.55	1.16	1.74bc	4.78b
$LSD_{0.05}$	0.31	0.36	0.19	0.19	0.11	0.99
ANOVA						
ST	**	ns	ns	**	**	**
K	ns	ns	ns	ns	*	*
ST x K	ns	ns	ns	ns	ns	*
CV % (a)	10.99	5.70	23.88	28.63	14.52	45.73
CV % (b)	10.95	6.76	12.04	15.94	6.03	18.15

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; DAT, days after transplanting; ns, not significant; * significant at $p \leq 0.05$; **significant at $p \leq 0.01$.

4.1.2.4 Bulb yield (ton ha^{-1})

Figure 4.1 shows the onion bulb yield as affected by sowing time (ST) and K supply. The bulb yield was not significantly different among ST and different K supplies. The higher onion bulb yield was resulted from 31 October ST as compared to 21 November ST. The maximum yield of bulbs was recorded from 31 October ST. These results were in agreement with the findingsof Singh and Singh (1975) who reported that early sowing time favored leaf, root and bulb growth and gave the highest yield. According to the data, higher values of growth parameters were resulted in 31 October ST which might be attributed to the best vigor of plant growth characters previously mentioned.

There was no significant difference among different K supplies. The interaction between ST and K supply was not significant.

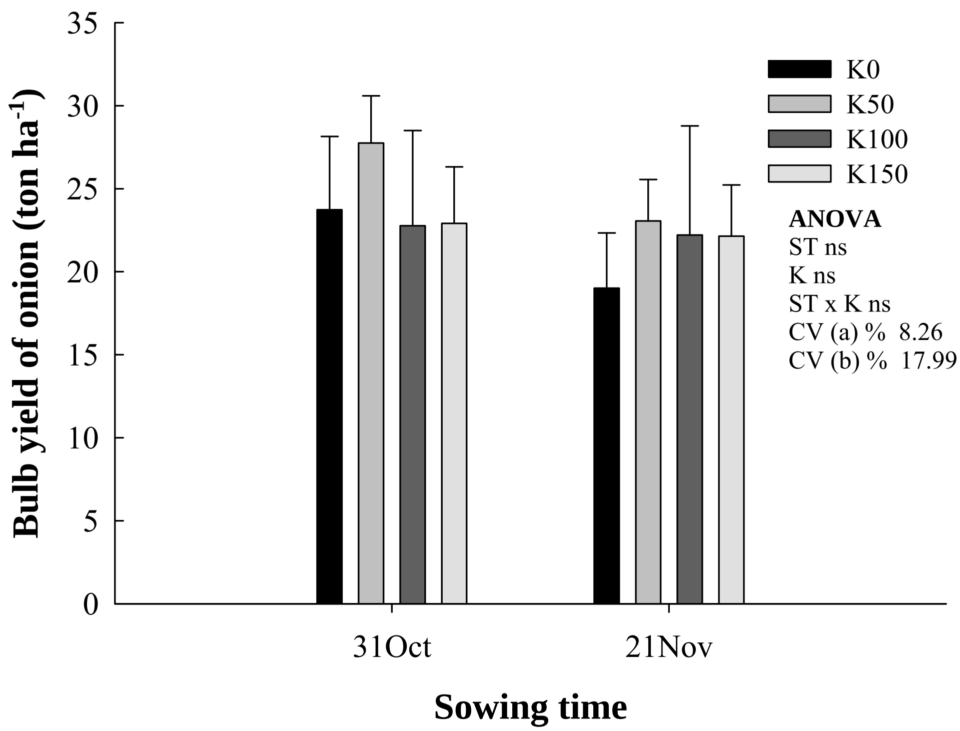

Figure 4.1 Bulb yield of onion as affected by sowing time and K supply taken at 91days after transplanting

4.1.3 Quality Parameters

4.1.3.1 Bulb sulphur, nitrogen, sugar and protein contents

Table 4.5 indicatesthe total S, total N, total sugar and soluble protein contents of bulb measuredat final harvest (91 DAT).Significant effect of sowing time was observed for S and N. Higher value of Sand lower value of N were recorded from the bulb of 31 October ST thanthat of 21 November ST. Although not significant, the plants under 31 October ST were analyzed higher sugar but lower protein content of bulb as compared with 21 November ST. For both of the sowing times, bulb N contents were positively linked to protein contents. Higher sugar content of bulb as found in 31 October ST indicated that bulb maturation was not yet completed, which was proven by the better top growth (shoot weight) (Table 4.3) and thicker neck diameter (Table 4.4) as mentioned earlier.

With regard to K supply, no significant effect on all measured parameters was found. Comparing the mean values, the increasing K supplies generally gave increased values of bulb N, sugars and protein content, where bulb N contents in the plants treated with higher K inputs (100 and 150 kg ha^{-1}) were analyzed significantly higher (21.01 and 21.95) than control (12.87). This finding was coincided with the results of Kumar et al. (2006) who reported that K application showed a synergistic effect on protein content in the onion bulb and also the contents and uptake of N and S were improved.But in the current study, bulb S content was lower in the case of 21 November ST.

In thestudy of Masalkar et al. (2005), TSS, total sugars, non-reducing sugars and dry matter were increased significantly with increased supply of potash levels.Present study also indicated the similar response of sugar contentsto K treatments, except100 kg ha^{-1}. The promotion effects of K fertilizer on the nutritional values of onion bulb tissues might be attributed to that K is prevalent cation in plant and involved in maintenance of ionic balance in cells and it bound ionically to the enzyme pyruvate kinase which is essential in respiration and carbohydrates metabolism(Elmond et al., 1981; Agwah and Mahmoud, 1994; Ahmed et al., 2004; Badawy et al., 1981; El-Bassiony, 2006; Aisha and Taalab, 2008; Shaheen et al., 2009; Shokr and Fathy, 2009).There was no significant interaction between sowing time and K supply for all quality parameters.

Table 4.5 Mean effects of sowing time and potassium supply on chemical composition of onion bulb recorded at 91DAT

Treatment	Chemical composition ($mg.g^{-1}$ DW)			
	Total S	Total N	Sugar	Protein
Sowing time (ST)				
31October	3.69a	13.52b	68.42	5.91
21November	2.87b	23.67a	61.19	7.67
$LSD_{0.05}$	0.76	4.54	12.94	1.85
Potassium (K)				
K0	3.88	12.87b	61.53	5.76
K50	3.25	18.49ab	68.26	6.58
K100	2.81	21.01a	60.02	7.76
K150	3.16	21.95a	69.41	7.08
$LSD_{0.05}$	1.08	6.43	18.30	2.62
ANOVA				
ST	*	**	ns	ns
K	ns	*	ns	ns
ST x K	ns	ns	ns	ns
CV % (a)	26.40	9.03	22.45	30.64
CV % (b)	26.39	27.47	22.44	30.64

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; DAT, days after transplanting; ns, not significant; * significant at $p \le 0.05$; **significant at $p \le 0.01$.

4.1.3.2 Shoot and bulb K contents

Shoot and bulb K contents were analyzed at 91 DAT (final harvest) at the Department of Agricultural Research using composite samples. Higher shoot K content and lower bulb K contents were observed in 31October ST particularly in the cases of high K supply levels (Figure 4.2). This may be attributed to better vegetative growth as observed in 31October ST, which were characterized by more uptake potential of nutrients including K fertilizer. In line with the expectation, there was a direct relationship between increasing K inputs and shoots and bulb K concentration.

Interestingly, K contentsof the bulb revealed approximately half that of the shoot under the treatments of high K levels (Figure 4.2 B).There was an increasing trend of bulb K contents with increased K supply levels, which was more, pronounced in the plants of 21November ST. Higher values of shoot K content and bulb K contents were recorded from 100 and 150 kg ha^{-1} K supply. Kumar et al.(2006) also founded that the maximum value of concentration of K in onion bulb was recorded at 150 kg ha^{-1}. Sagadraca (1988) reported that potassium content of leaves and bulbs at the green stage was not affected by the different levels of K fertilizer regardless of planting method used.

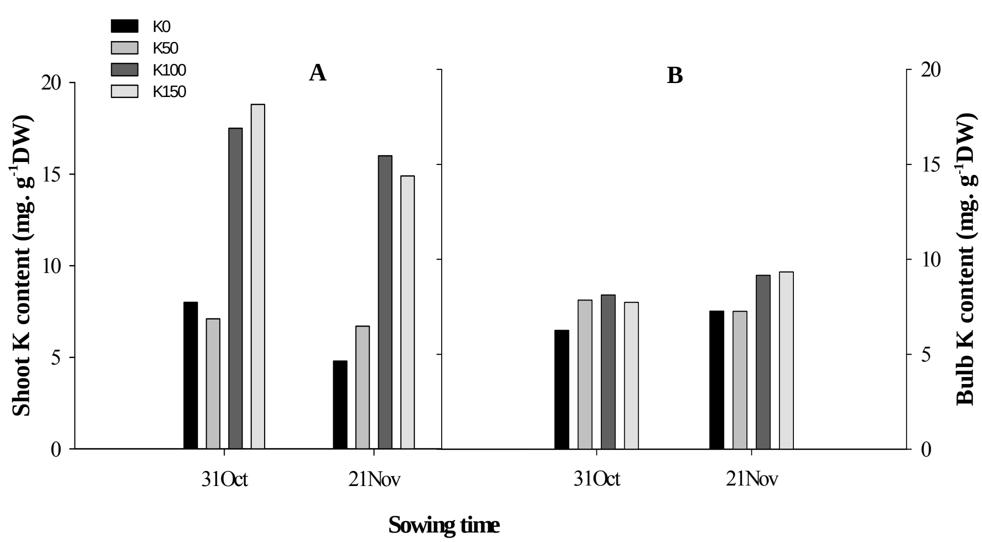

Figure 4.2 K contents of shoot (A) and bulb (B) of onion as affected by sowing time and K supply measured at 91days after transplanting

4.1.3.3 Total soluble solid (TSS %)

According to Table 4.6, there was no significant difference between the two sowing times at the first harvest (56 DAT). At final harvest time (91 DAT), 21November ST produced about two times TSS composition (14.62)in comparison to 31October ST (7.19) and it was highly significant. At both harvest times, significant effects of K application were observed.

The plants treated withall K levels revealed to be higher than control, except 100 kg ha^{-1} at 91 DAT, which was recorded not significantly different from control for unknown reasons. This resultwas in agreement to the findings of Masalkar (2005) and Yaso et al. (2007) who observed that the values of total soluble solid (TSS %) in onion bulb tissues were in good association with potassium rate.The interaction between ST and K supply were not significant for both of harvest times.

4.1.3.4 Weight loss percent

Figure 4.3 indicatespostharvest weight loss percent of onion bulbs during one month of storage as affected by sowing time and K supply. The weight loss in 31October ST was higher than that in 21November ST.The weight loss percentage at 28 DAS ranged from 16 to 25 for 31October ST and 10 to 11for 21 NovemberST respectively. This increase in bulb weight loss in 31 October ST could be attributed to thicker neck diameter which might have led to high moisture losses during storage, reflecting the improper maturation of onion bulb at final harvest (91 DAT).The highest weight loss percent observed in the bulbs from 21November ST was coincided with a sudden precipitation during harvesting at 91 DAT which caused the high moisture uptake of onion plants.

Among different levels of K supply, 0 and 50 kg ha^{-1}showed higher percentage of weight loss at 28 DAS in 21November ST.This was dissimilar to the findings of Singh and Dhankar (1989) who reported that rotting, sprouting, and loss in weight was also reduced considerably during storage in the bulbs produced by the application of 100kg K_2O ha^{-1}.There was no interaction between sowing time and K application on weight loss.

Table 4.6Mean effects of sowing time and potassium supply on total soluble solid (TSS %) of onion recorded at 56 and 91 DAT

Treatment	Total soluble solid (%)	
	56 DAT	**91 DAT**
Sowing time (ST)		
31October	8.41	7.19b
21November	8.36	14.62a
$LS_{0.05}$	0.32	0.79
Potassium (K)		
K0	7.55c	10.63c
K50	8.77a	11.22a
K100	8.28b	10.7bc
K150	8.92a	11.08ab
$LSD_{0.05}$	0.45	0.43
ANOVA		
ST	ns	**
K	**	*
ST x K	ns	ns
CV % (a)	5.07	6.42
CV % (b)	5.08	3.72

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; DAT, days after transplanting; ns, not significant; * significant at $p \le 0.05$; **significant at $p \le 0.01$.

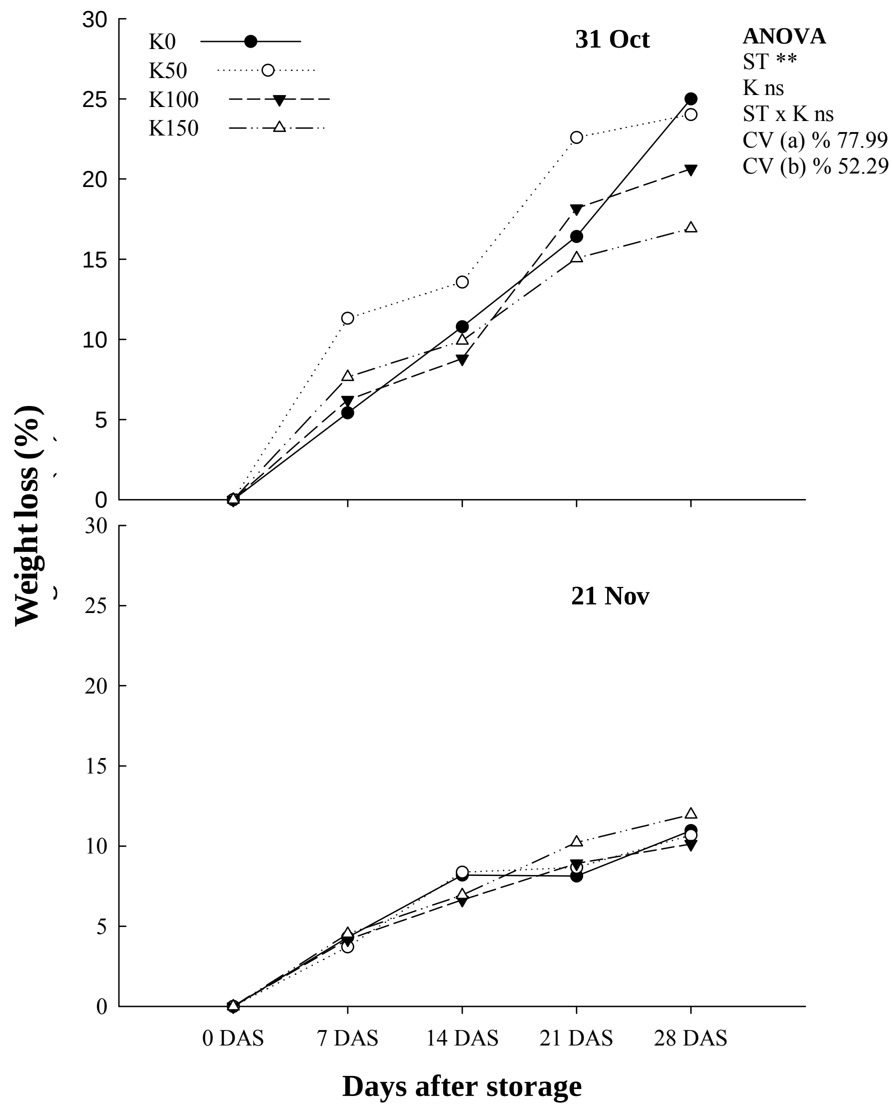

Figure 4.3 Post harvest weight loss (%) of onion bulb as affected by various K supplies at two sowing times; DAS, days after storage

4.2 Effects of Three Sowing Times and Various K Supplies on Growth, Yield and Quality of Onion (Experiment II, 2012)

4.2.1 Growth Parameters

4.2.1.1 Plant height (cm)

Table 4.7indicates the effect of sowing time and K supply on plant height evaluated at biweekly intervals. Highest values of plant height were obtained from the plants of early sowing time (7November) compared to other sowing times. Except 8 WAT, the significantly higher plant height was resulted from the 7 November ST at 2 and 6 WAT which indicated that early sowing time promoted the vegetative growth than late sowing times. The plant height from late ST (5 December)showed comparable to that from 7 November ST only at 4 WAT. This result was similar to the findings of Farug et al. (2003) from Bangladesh who indicated that the minimum plant height was obtained from December 22 planting. Badaruddin and Haque (1997) also reported the similar trend of reduction in plant height with delayed planting.

There was no significant differences in plant height among different levels of K supply at all measured points. However, the values of plant height were higher in response to high levels of K supply. According to the result, either soil K status was not severely depleted or vegetative response to K was less noticeable compared to nitrogen. There was no significant interaction between ST and K supply which meant that each experimental factor acted independently.

Table 4.7 Mean effects of sowing time and potassium supply onplant height of onion recorded at two weeks interval

Treatment	Plant height (cm)			
	2 WAT	4 WAT	6 WAT	8 WAT
Sowing time (ST)				
7 November	47.22a	50.03a	53.03a	54.69
21 November	33.11c	39.04b	45.30b	50.46
5 December	42.20b	46.85a	47.93b	50.54
$LSD_{0.05}$	4.90	4.07	3.93	4.71
Potassium (K)				
K0	39.97	44.42	48.10	51.89
K50	42.09	46.25	49.58	52.80
K100	40.47	45.25	48.57	50.99
$LSD_{0.05}$	3.69	3.42	3.17	3.37
ANOVA				
ST	**	**	**	ns
K	ns	ns	ns	ns
ST x K	ns	ns	ns	ns
CV % (a)	11.02	8.99	8.07	8.01
CV % (b)	10.54	8.81	7.57	7.56

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; WAT, weeks after transplanting; ns, not significant; **significant at $p \leq 0.01$.

4.2.1.2 Number of leaves

Leaf number showed significant effects of different sowing times at all recorded times (Table 4.8). The plants of the 7 Novemberand 5 December ST produced the highest number of leaves than 21 November ST at early measured points (2 and 4 WAT). However, the highest leaf number was resulted from 7 November ST at later times of measurement (6 and 8 WAT). This resultreflected that the plants from 7 November ST met cold and mild temperature which promoted the vegetative growth. Thus, those onion plants sown earlierwill have a longer vegetative period and consequently larger plants with more leaves (Comrie, 1997). It means that higher vegetative growth can be obtained from early sowing time because of the optimum average temperature during later vegetative growth period which ranged from 16 to 36°C. Optimum temperature for leaf growth is 20 to 25 °C as indicated by Brewster (2008). Hussian and Islam (1994) also reported that early planting produced larger number of leaves per plant which decreased gradually with delayed planting. Attar et al. (1991) found that later planting resulted in a decrease in the number of leaves. If bulbing is stimulated when plants are still small, leave senescence will occur rapidly and small bulbs will be produced due to a small leaf area (Wickramasinghe et al., 2000; Brewster, 2008).The finding from the current study was in agreement with the findings of Mohanty et al. (1990) and Bhattarai et al. (1995). However, Faruq et al. (2003)from Africa indicated that November planting favored more vegetative growth than December planting in terms of leaf number production resulting in the highest yield.

There was no significant effect on number of leaves by K supply at all measured points. Generally the higher number of leaves was resulted from the plants treated withK supplies especially at the early growth period (2 and 4 WAT). However, many investigators reported that onion plant growth i.e. plant height and number of leaves as well as fresh and dry weight of plants were increased with increasing of K application (Mohanty and Das,2001; Singh and Verma,2001; Sharma et al.,2003 and Bybordi and Makakouti, 2003). This discrepancy may be attributed to the effect of climatic condition especially the sudden rain which may lessen the positive effect of K supplies. No interaction effect was observed between the two factors.

Table 4.8 Mean effects of sowing time and potassium supply on number of leaves recorded at two weeks interval

Treatment	Number of leaves			
	2 WAT	**4 WAT**	**6 WAT**	**8 WAT**
Sowing time (ST)				
7 November	7.56a	8.69a	9.84a	10.74a
21 November	5.93b	6.60b	7.48c	8.83b
5 December	7.10a	8.09a	8.98b	6.91c
$LSD_{0.05}$	0.79	0.90	0.62	0.96
Potassium (K)				
K0	6.84	7.76	8.69	8.93
K50	6.90	7.80	8.76	8.89
K100	6.85	7.81	8.84	8.66
$LSD_{0.05}$	0.37	0.46	0.50	0.60
ANOVA				
ST	**	**	**	**
K	ns	ns	ns	ns
ST x K	ns	ns	ns	ns
CV % (a)	11.48	11.63	7.04	9.92
CV % (b)	6.36	6.82	6.62	8.93

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; WAT, weeks after transplanting; ns, not significant;*significant at $p \leq 0.05$;**significant at $p \leq 0.01$.

4.2.2 Yield Parameters

Shoot fresh weight and bulb weight were measured at five harvest times (57, 67, 77, 87 and 97 days after transplanting, DAT) as yield parameters. In order to computed the rate of onion bulbing, bulb diameter and neck diameter were recorded for each harvest.

4.2.2.1 Shoot weight and bulb weight (g)

Shoot weight of onion plants as affected by K supply and three ST at different harvest times are shown in Figure 4.4. Shoot weight inearly sowing time increased until 77 DAT but the values in 21November and 5December ST decreased. As shown in Table 4.9, there was no significant difference between three sowing timesat 47 DAT.At 57 DAT, the onion from 7November ST resultedin significantly higher values of shoot weight than the other two sowing times. This result indicated that 7 and 21 November ST produced more vegetative growth for the plants.

In Figure 4.5, the onion bulb fresh weights were gradually increased at later time points. Higher bulb weight was recorded from early ST which may be attributed to that the higher values of shoot weight caused increased photosynthesis activities leading to more accumulation of photosynthates and thereafter production of heaviest bulb. These results were similar with the findings Singh and Singh (1975) and Mingochi and Mpanda (1992) who reported in their experiments that early date of sowing gave maximum bulb weight which was reduced by late sowing. This is also in agreement with the report of Mohanty et al. (1990) which was possibly the case of more fresh weight of bulb per plant of November 22 planting. Many investigators from India also indicated that November 22 planting favored more vegetative growth in terms of leaf number production resulting in the highest bulb yield.

As described in table 4.9, the plant from early ST (7 November) showed the highest values of shoot weight and bulb weight while those from late ST (5 December), the lowest. There was no significant effect of K supply and no interaction effect on both parameters at all harvest times.

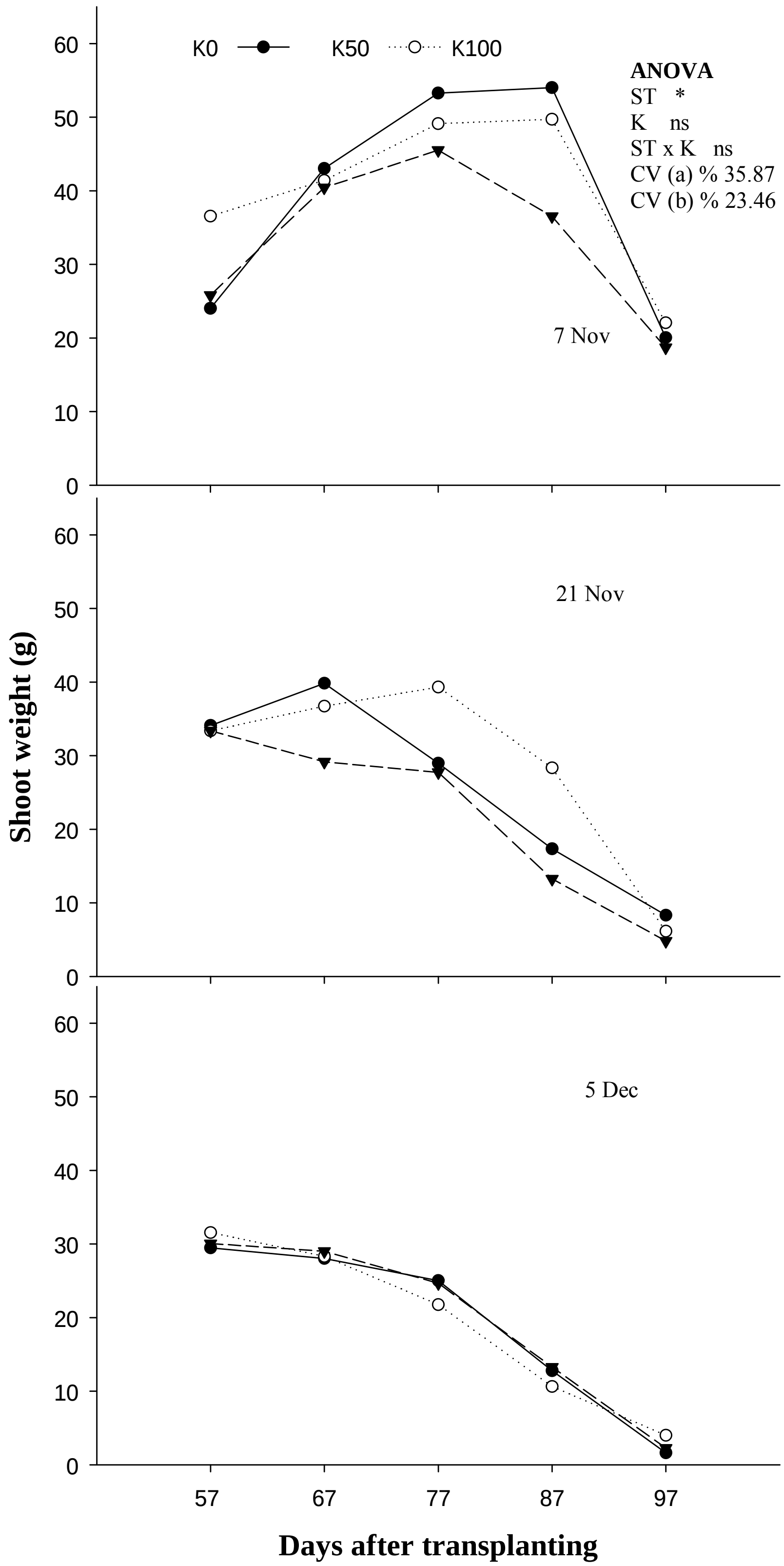

Figure 4.4Changes of shoot weight(g) recorded at different harvest times as affected by K supply in different sowing times

Table 4.9 Mean effects of sowing time and potassium supply onshoot weight and bulb weightof onion recorded at different harvest times

Treatment	Shoot weight(g)			Bulb weight(g)		
	57DAT	77DAT	97DAT	57DAT	77DAT	97DAT
Sowing time (ST)						
7November	28.79	49.29a	20.27a	10.25	40.67	71.11a
21November	33.61	32.98b	6.42b	9.68	49.53	54.98b
5December	30.35	23.81b	2.63c	12.01	43.71	46.64b
$LSD_{0.05}$	12.74	9.80	3.50	3.22	10.77	14.99
Potassium (K)						
K0	29.19	35.75	9.99ab	10.36	42.53	60.66
K50	33.81	36.72	10.73a	10.81	46.83	57.47
K100	29.74	33.61	8.58b	10.77	44.55	54.62
$LSD_{0.05}$	5.48	6.58	1.97	2.65	6.63	7.15
ANOVA						
ST	ns	**	**	ns	ns	**
K	ns	ns	ns	ns	ns	ns
ST x K	ns	ns	ns	ns	ns	ns
CV (a)%	37.70	27.75	35.87	30.24	24.14	26.07
CV (b) %	20.67	21.68	23.46	29.01	17.32	14.49

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; DAT, days after transplanting; ns, not significant; * significant at $p \leq 0.05$; **significant at $p \leq 0.01$.

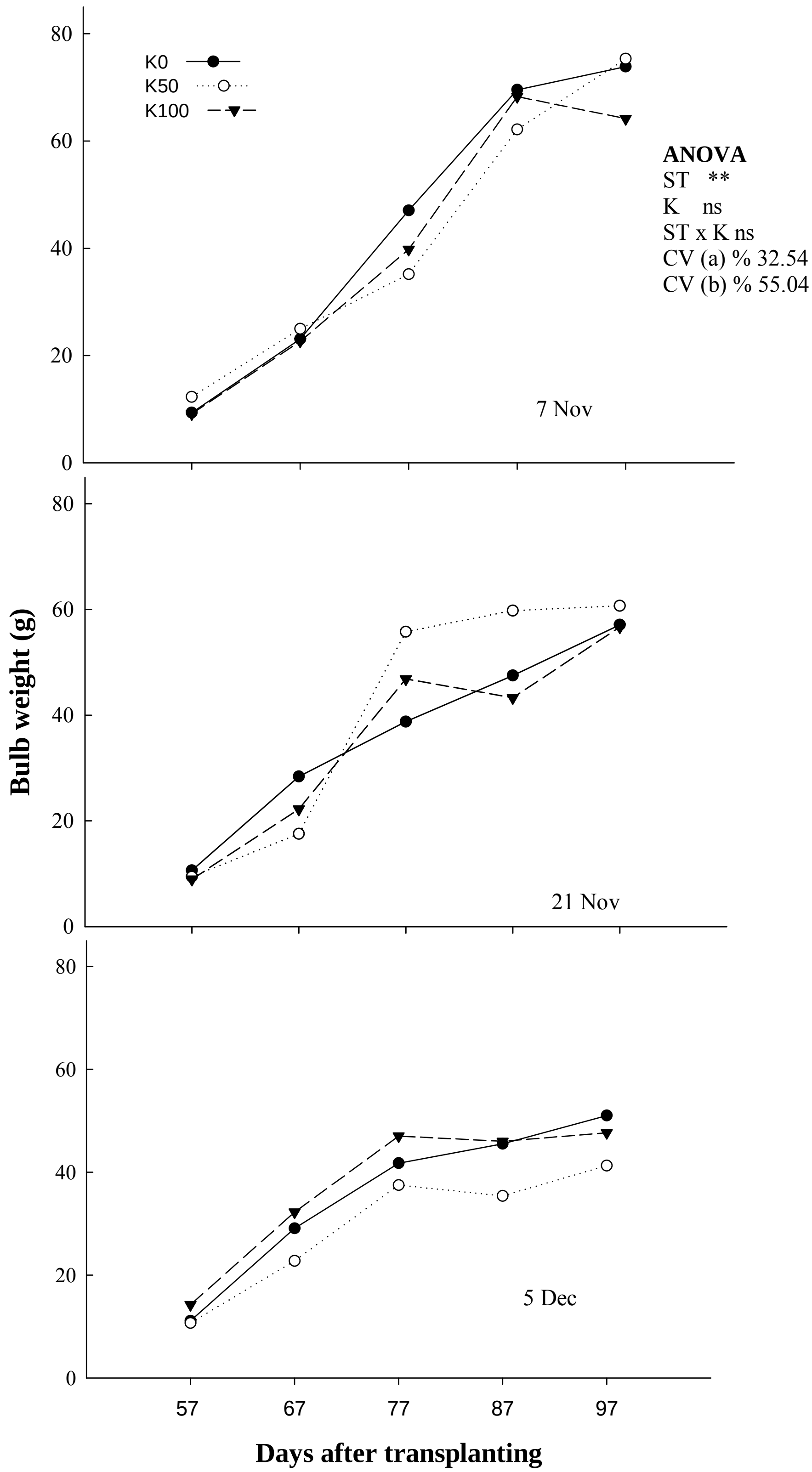

Figure 4.5Changes of bulb weight (g) recorded at different harvest times as affected by K supply in different sowing times

4.2.2.2 Bulb diameter and neck diameter (cm)

The responses of neck diameter in all sowing time are the same trend as mentioned in experiment I (Figure 4.6). Decreasing rate of neck diameter in 7 November ST is lower than the other two sowing time (21 November and 5December) especially at final harvest time and which means that sowing time needs to get more time for maturation. Higher values of neck diameter in 7 November ST may lead to the storage losses such as higher weight loss percent in storage period. Attainment of thinner neck with later planting is associated with small plants caused by earlier bulb initiation for late planted plants than for earlier plantings (Gagopale Bosekeng and Gesine, 2013). Similar observation were made by Uzo and Currah (1990) who reported that under short day conditions, onion plants produced new leaves indefinitely without bulb formation while at longer day lengths bulbs were formed. Wickramasinghe et al. (2000) also indicated that at the lowest temperature tested, bigger bulbs with thick necks were produced.

On the other hand, bulb diameter was gradually increasedwith the increasing rate of bulb diameter showed nearly the same values in all sowing times (Figure4.7). Heath (1943) reported that higher temperature enhanced bulbing process and lower temperature delayed it. Confirming his experience it was observed that higher temperature that prevailed in case of early crop possibly favored bulb growth and development producing bulbs of increased diameter. The onion plants of later sowing time (21November and 5December) faced higher temperature (23.5 and 26.5 ºC) during bulbing period and maturation rate of the onion bulb in later sowing time is higher than the early sowing time. However, this results dissimilar to the findings of Ahmed and Munshi (1995) who reported that plants at early planting showed the highest bulb diameter, bulb volume, individual bulb weight and gave the highest bulb yield per plant and per ha.

According to ANOVA, 7 November ST gave significant thicker neck diameter than other two sowing times at final harvest (91 DAT) while 5 December ST produced the lowest value of neck diameter. No significant effect of ST was observed in bulb diameter except 47 DAT. There was no significant effect of K supply. Interaction effect was significant at 57 DAT for neck diameter.

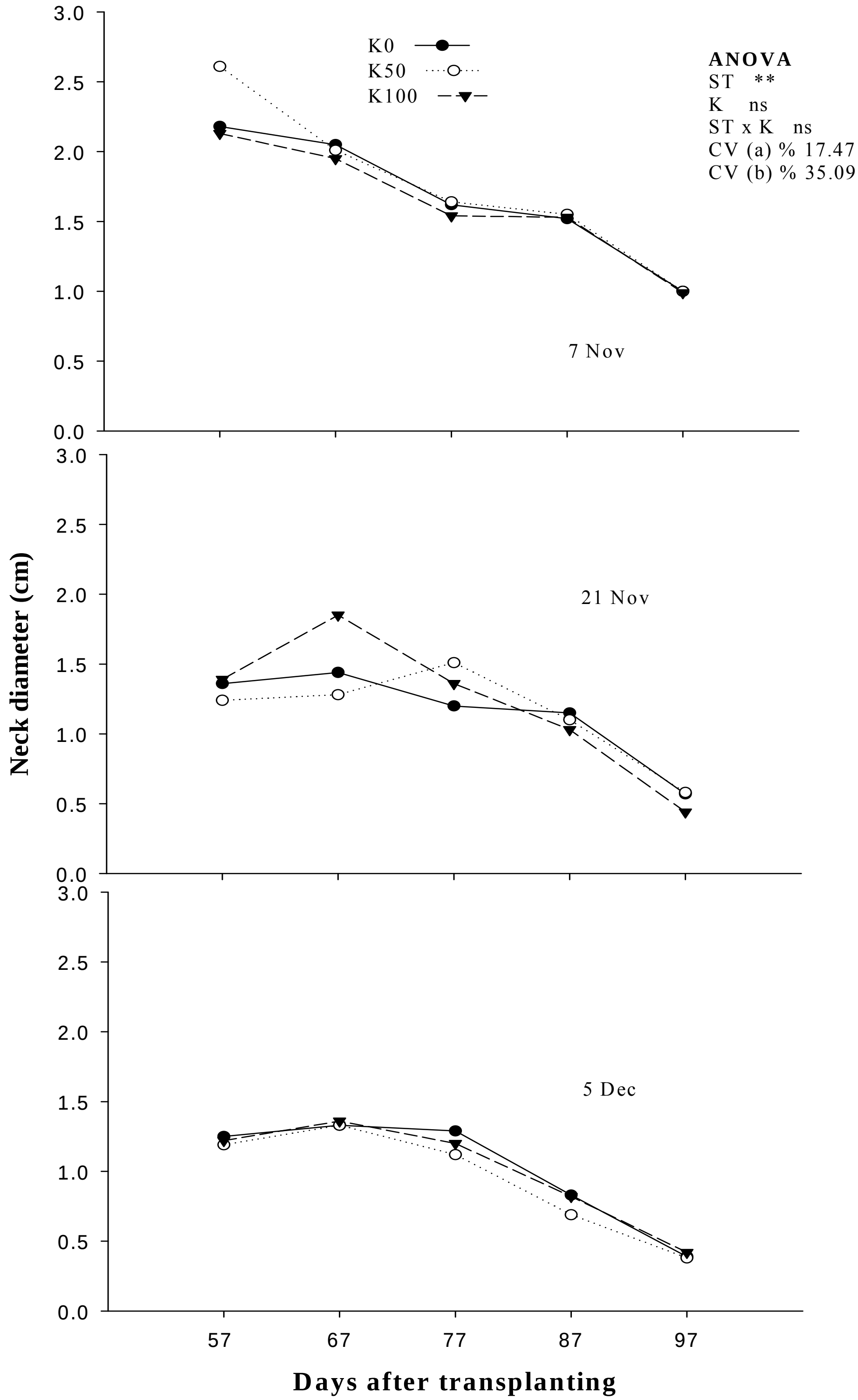

Figure 4.6Changes of neck diameter (cm) recorded at different harvest times as affected by K supply in different sowing times

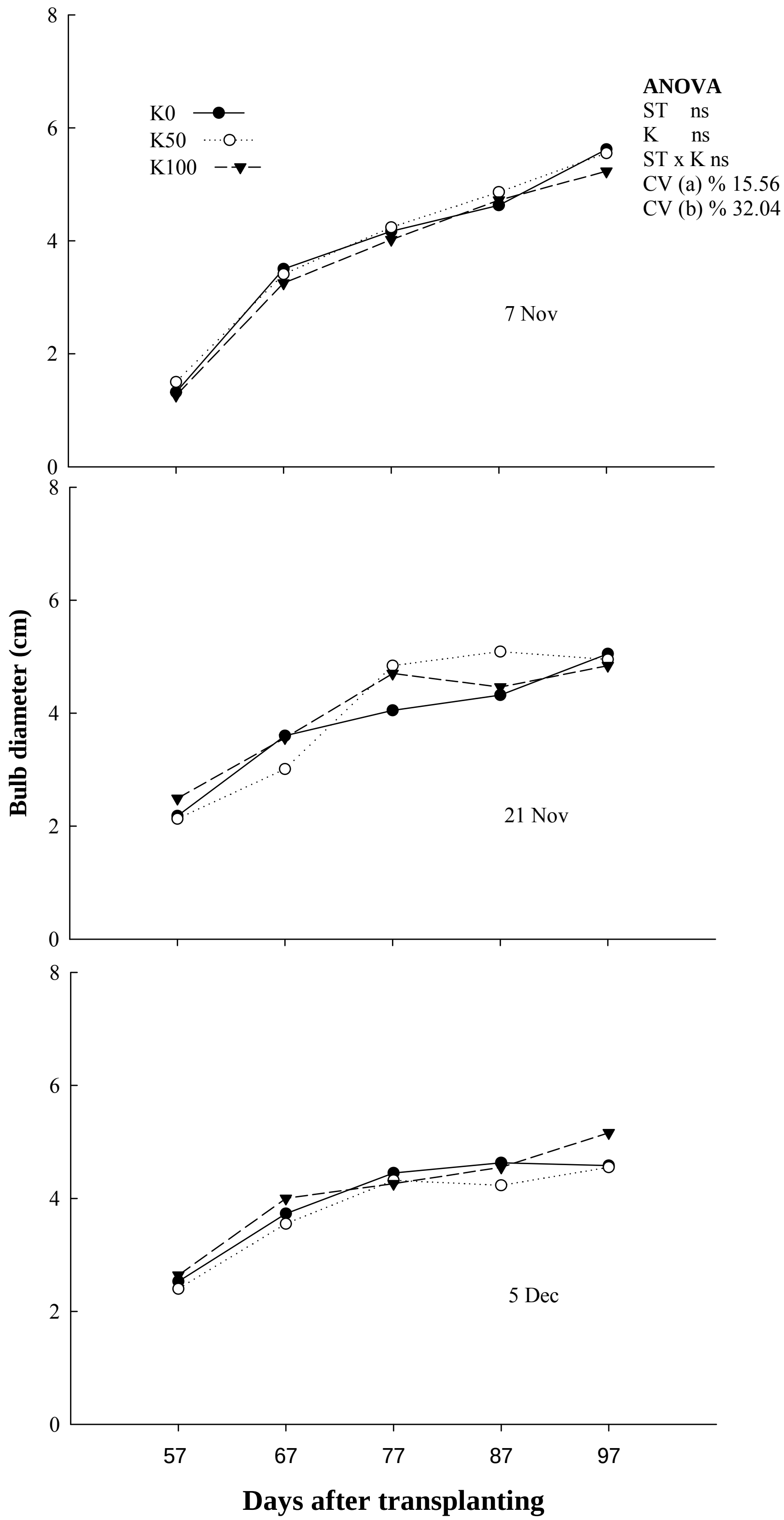

Figure 4.7 Changes of bulb diameter (cm) recorded at different harvest times as affected by K supply in different sowing times

Table 4.10 Mean effects of sowing time and potassium supply on bulb and neck diameterof onion recorded at different harvest times

Treatment	Bulb diameter (cm)			Neck diameter (cm)		
	57DAT	**77DAT**	**97DAT**	**57DAT**	**77DAT**	**97DAT**
Sowing time (ST)						
7November	1.36b	4.14	5.47	2.30a	1.36b	0.99a
21November	2.26a	4.69	4.95	1.33b	1.59a	0.53b
5December	2.52a	4.34	4.76	1.22b	1.20b	0.39c
$LSD_{0.05}$	3.34	0.69	0.79	0.28	0.50	0.10
Potassium (K)						
K0	2.01	4.22	5.08	1.59	1.37	0.65
K50	2.01	4.47	5.01	1.68	1.42	0.65
K100	2.13	4.49	5.07	1.58	1.37	0.62
$LSD_{0.05}$	0.31	0.50	0.30	0.17	0.16	0.09
ANOVA						
ST	**	ns	ns	**	ns	**
K	ns	ns	ns	ns	ns	ns
ST x K	ns	ns	ns	*	ns	ns
CV (a)%	16.18	15.78	15.69	17.46	11.60	15.63
CV (b) %	17.87	13.29	7.02	12.51	13.45	15.95

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; DAT, days after transplanting; ns, not significant; * significant at $p \leq 0.05$; **significant at $p \leq 0.01$.

4.2.2.3 Bulbing ratio

According to Figure 4.8,all sowing timesbegun bulbing at 67 DAT. Rapid increase in bulbing ratio was occurred at 77DAT. The increase in bulbing ratio was in a similar pattern between 7 and 21 November ST whilethat in 5December ST revealed a rapid increase which may be attributed to warm temperature to promote bulbing. High temperatures (25 to 27°C) accelerate bulb initiation causing it to occur at a slightly shorter day length than required for a specific cultivar (Van den Berg et al., 1997). At 97 DAT, the onion plants from 7 November ST showed the lowest bulbing ratio while those from 5 December ST the highest. According to Tesfay et al. (2011), the plants can start bulbing under short day lengths (11.5 hr), but not form a bulb unless a critical day length is attained. Instead, they remain vegetative and produce thick-neck bulbs.

According to combined ANOVA, highly significant effect of ST and no significant effect of K supply were observed. Table 4.11 describes the bulbing ratio as the effect of ST and K supply for different time points. Bulbing ratio of the plants from late sowing time (5 December) was observed the highest bulbing ratio while those from early ST (7 November) the lowest especially at 97 DAT. Regarding the K supply, the highest bulbing ratio was observed from 100 kg $ha^{-1}$of K supply which was significant at 67 and 87 DAT (Table 4.11). There was no significant interaction between ST and K supply for all measured points.The higher value of bulbing was linked to larger size of bulb diameters and thinner neckin response to inputs of increasing K levels.

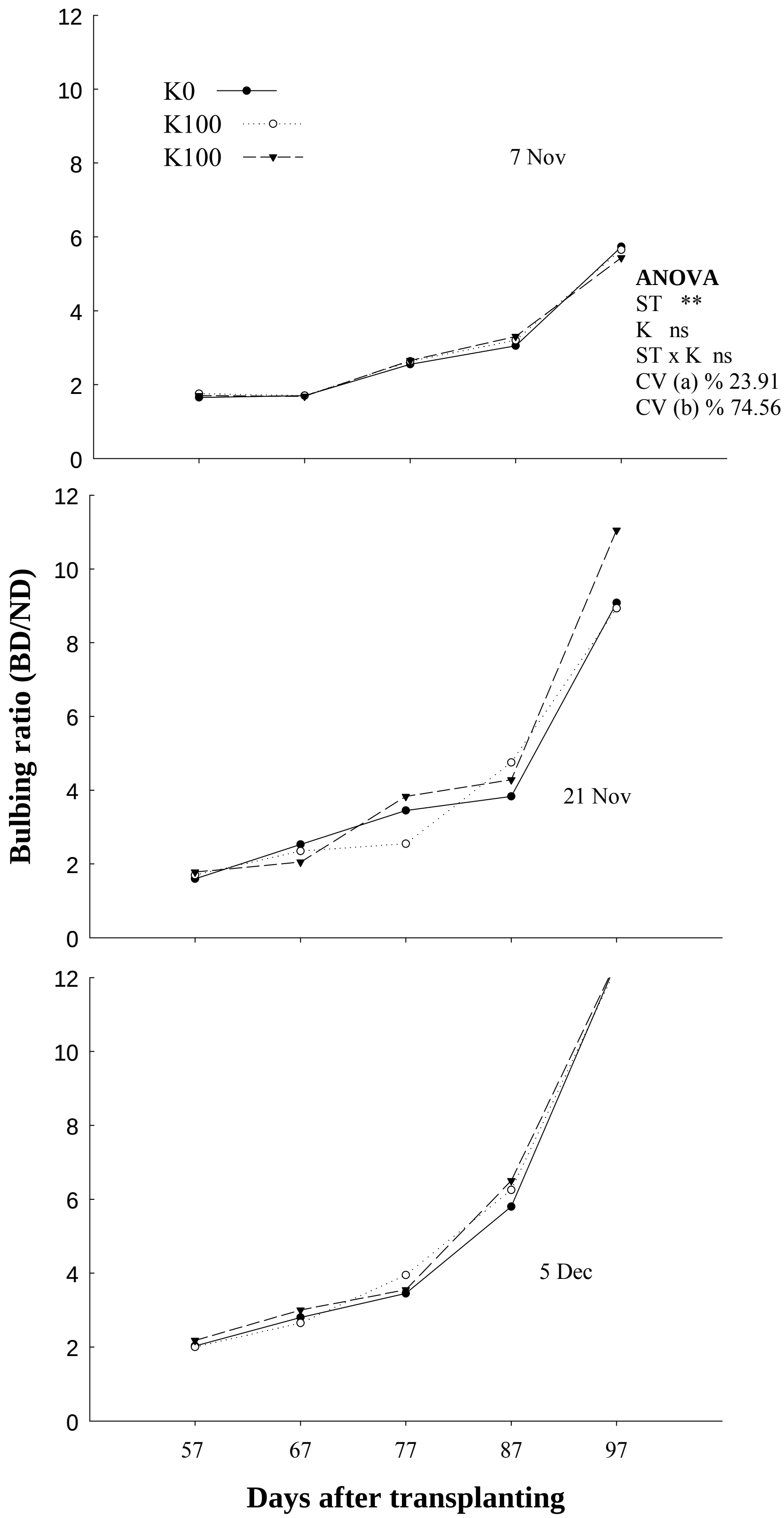

Figure 4.8 Changes of bulbing ratio (ND/BD) recorded at different harvest times as affected by K supply for different sowing times

Table 4.11Mean effects of sowing time and potassium supply on bulbing ratio of onion recorded at different harvest times

Treatment	Bulbing ratio				
	57DAT	**67DAT**	**77DAT**	**87DAT**	**97DAT**
Sowing time (ST)					
7November	1.70b	1.69c	2.70b	3.38c	5.76c
21November	1.69b	2.52bc	3.47a	4.52b	9.98b
5December	2.07a	2.76a	3.73a	5.95a	12.81a
$LSD_{0.05}$	0.19	0.22	0.31	0.39	1.25
Potassium (K)					
K0	1.76	2.28ab	3.15	4.23b	9.28
K50	1.82	2.23b	3.23	4.59ab	9.28
K100	1.88	2.45a	3.52	5.03a	9.98
$LSD_{0.05}$	0.23	0.21	0.38	0.45	1.23
ANOVA					
ST	**	**	**	**	**
K	ns	ns	ns	ns	ns
ST x K	ns	ns	ns	ns	ns
CV % (a)	10.99	9.64	9.09	11.27	13.18
CV % (b)	14.73	10.56	13.39	11.36	15.13

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; DAT, days after transplanting; ns, not significant; * significant at $p \le 0.05$; **significant at $p \le 0.01$.

4.2.2.4 Bulb yield (ton ha-1)

Figure 4.9 shows the bulb yield of onion in response to different treatments. Significantly higher bulb yield was recorded from early sowing time (7 November) as compared to other sowing times. The onion bulb yield was decreased from early to late sowing time. It could be explained that the superiority of the bulb yield might be due to the higher assimilation of photosynthates supported by sufficient vegetative growth as shown in table 4.9. This was in line with the works of many investigators who reported that early dates of sowing gave the highest bulb weight (Khokhar et al, 1990; Mingochi and Mpanda, 1992). There was no significant effect of K supply on bulb yield. The interaction effect between ST and K supply was not observed.

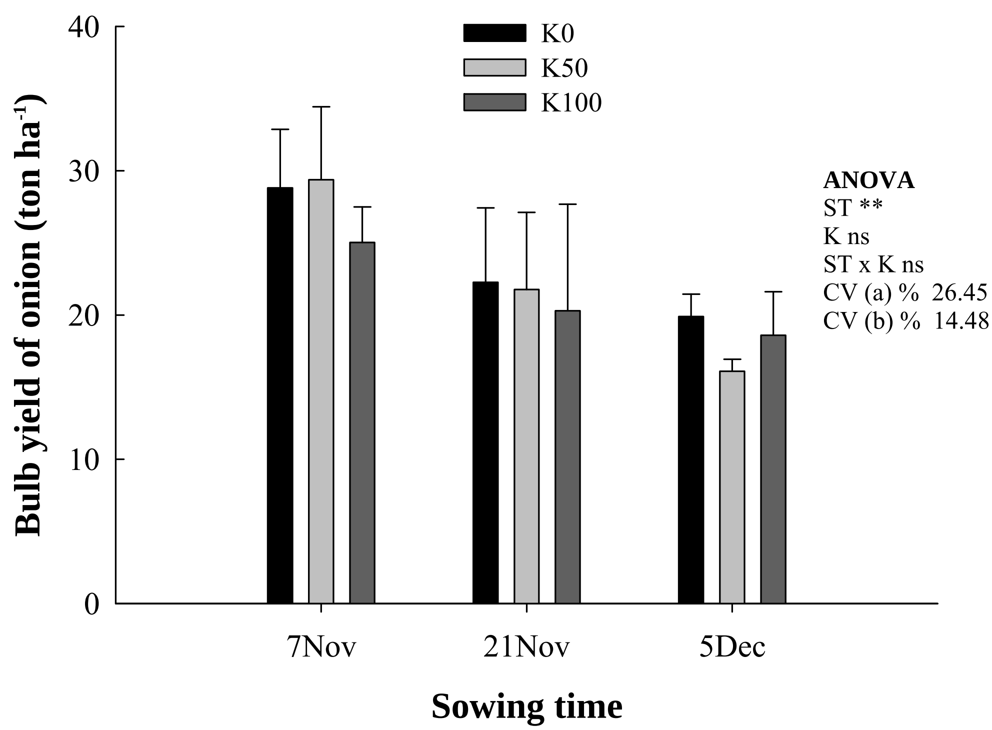

Figure 4.9Bulb yield of onion as affected by sowing time and K supply taken at 97 days after transplanting

4.2.3 Quality Parameters

4.2.3.1 Bulb Potassium content

The onion bulb K content was increased from early to late sowing timeas shown in Figure 4.10.Higher value of bulb K content was significantlyobtained from later STfollowed by 7 November ST.On an average, maximum onion bulb K content was 10 mg g^{-1} DW(1%)entersin 5December ST. The result was supported by the report of Sagadraca (1988) who observed that potassium content of the onion bulb and leaves were 1.2 and 4.39 percent, respectively.

There was a positive trend of bulb K contents with increasing K supply levels, particularly in the plants of 21November and 5December ST. the highest value of bulb K content was recorded from 100 kg ha^{-1} K supply. Salimath (1990) studied the effect of K on onion and found that nutrient uptake of N, P, K and S increased with increasing levels of potassium from 0 to 150 kg K_2O ha^{-1}.

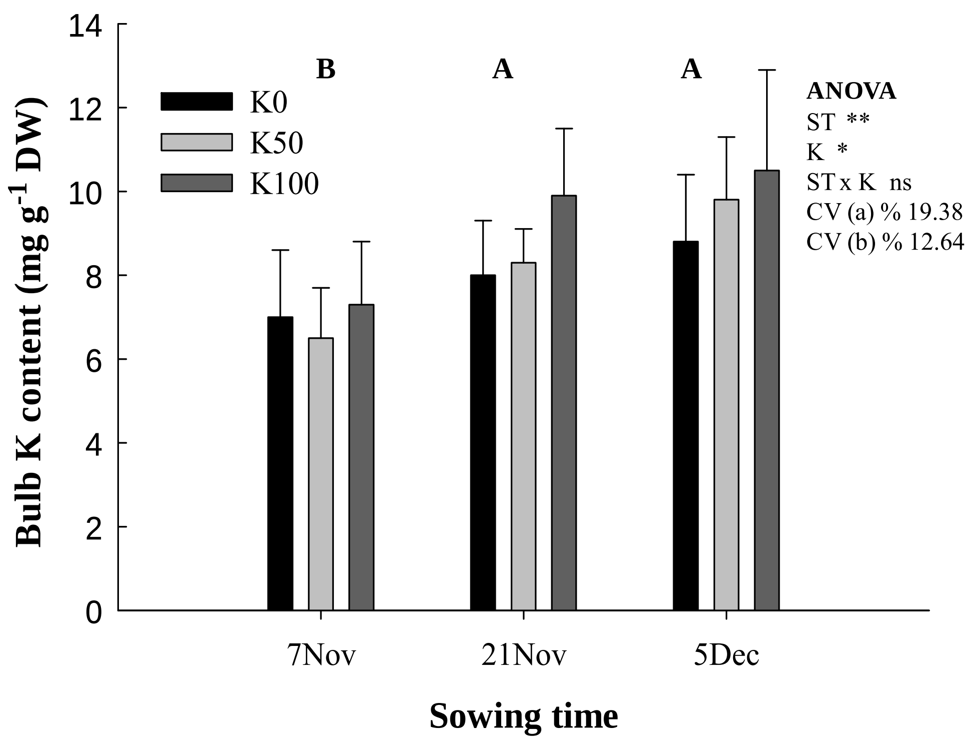

Figure 4.10 Bulb K contents of onion as affected by sowing time and K supply measured at 97 days after transplanting

4.2.3.2 Total soluble solid (%)

According to Table 4.12, there was significant difference between the sowing times at 67, 87 and 97 DAT. Sowing times of 5 December produced the highest TSS composition (9.54, 11.83 and 14.74) in comparison to other sowing times and it was significantly higher than early ST (7 November).The plants from 21 November ST were comparable to 5 December ST in those measured points.

At all harvest times, significant effects of K application were not observed. This result was different from the findings of Masalkar (2005) and Yaso et al. (2007) who observed that the values of total soluble solid (TSS %) in onion bulb tissues were in good association with potassium rate. Pramanick et al (1999) recorded higher total soluble solids and sugar content due to potassium application. The interaction between ST and K supply were not significant for each of harvest times.

4.2.3.3 Weight loss percent

Significantly higher weight loss % was observed from 21November ST followed by 7November ST and 5 December ST as described in Figure 4.11. The trend observed in the case of 21 November ST was linkedto thickerneck diameter of the plantfound at final harvest which means more favorable situation for moisture losses. At the time of final harvest (97 DAT), high precipitation in the plants of 21November ST is seem to increase bulb weight which lead to higher moisture loss along the one month of storage period. High moisture content of the bulbs may be directly linked with more weight loss of the bulbs as reported by Masalkar et al. (2005) and Shakirullah et al. (2002).In 5 December ST, the lowest weight loss % was recorded because of dry condition during the later phase of bulbing.

According to the combined ANOVA as shown in figure 4.11, significant effect of K supplies was observed .The onion bulbs from 50 kg K_2O ha^{-1} showed the lowest weight loss % particularly in 21 November ST. At 5 December ST, the different between the weight loss percent was not pronounced. However, Hariyappa (2003) indicated that increasing levels of K recorded lowest total weight loss of onion bulb. The interactions between ST and K supply were not significant.

Table 4.12Mean effects of sowing time and potassium supply on total soluble solid (TSS %) of onion recorded at different harvest times

Treatment	Total soluble solid (TSS%)				
Sowing time(ST)	**57DAT**	**67DAT**	**77DAT**	**87DAT**	**97DAT**
7November	8.88	8.88b	10.08b	11.42	13.58b
21November	8.83	9.46a	11.29a	13.00	14.74a
5December	9.17	9.54a	11.83a	12.50	14.50ab
$LSD_{0.05}$	0.38	0.39	1.16	1.78	1.06
Potassium (K)					
K0	8.88	9.29	10.92	12.50	14.44
K50	8.88	9.29	11.04	11.46	14.04
K100	9.13	9.29	11.25	12.96	14.33
$LSD_{0.05}$	0.57	0.53	0.64	1.74	0.92
ANOVA					
ST	ns	*	**	ns	*
K	ns	ns	ns	ns	ns
ST x K	ns	ns	ns	ns	ns
CV % (a)	4.32	4.31	10.49	14.46	7.45
CV % (b)	7.42	6.59	6.69	16.52	7.49

Means within each column followed by different letter(s) are significantly different at $LSD_{0.05}$ for each factor; DAT, days after transplanting; ns, not significant;* significant at ≤ 0.05; **significant at $p \leq 0.01$.

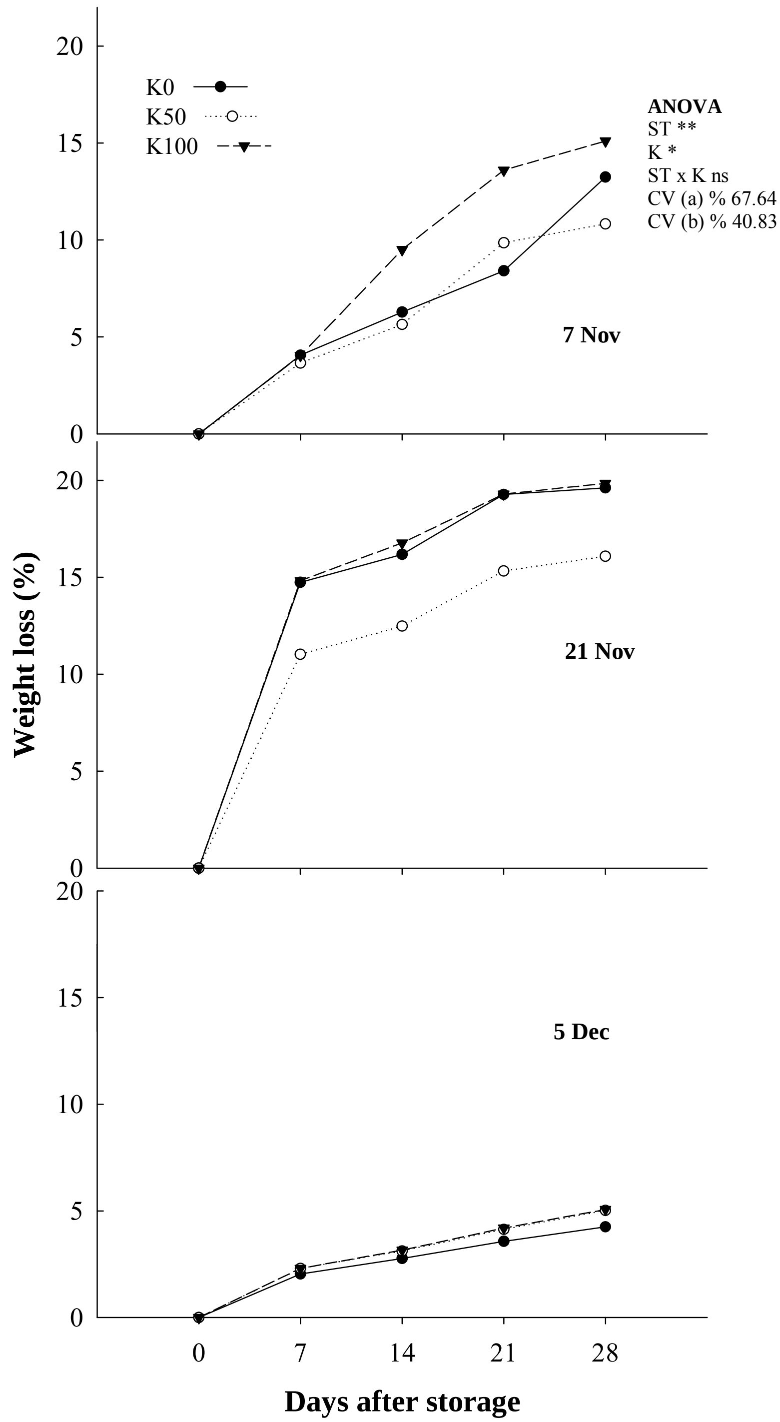

Figure 4.11 Post harvest weight loss (%) of onion bulb as affected by varying K supplies at two sowing times; DAS, days after storage

V. CONCLUSION

This study was conducted to evaluate the various K supply levels and different sowing times on bulb yield and quality of onion. In the first experiment, the plants from early sowing time (31 October) showed better responses in shoot weight, bulb weight and bulb diameter, but slower bulbing in comparison to normal sowing time (21 November). The higher post harvest weight loss was also observed in 31 October sowing time during one month of storage. Regarding the K supply, 100 kg ha^{-1} produced better performances in number of leaves, bulbing and most of the quality parameters such as total soluble solid (TSS %), shoot K content, bulb N content and weight loss % as compared to control. In second experiment, early sowing time (7 November) gave the best growth and yield performances but the lowest value of bulbing ratio. On the other hand, the plants from late sowing time (5 December) provided the early bulbing although poor vegetative growth and bulb yield. Interestingly, the highest bulb K content observed from late sowing time was linked to the lowest weight loss % among the sowing times. Regarding the K supply, the plants treated with 100 kg ha^{-1} showed the highest values of bulbing ratio and bulb K content.

From this study, it can be concluded that early sowing times can promote vegetative and yield performances while late sowing time can improve the quality of bulb onion. Positive contribution of K supply was observed in some quality parameters such as TSS %, bulb and shoot K contents.

Suggestions

Further investigations need to be conducted to confirm the effect of K application on onion production.

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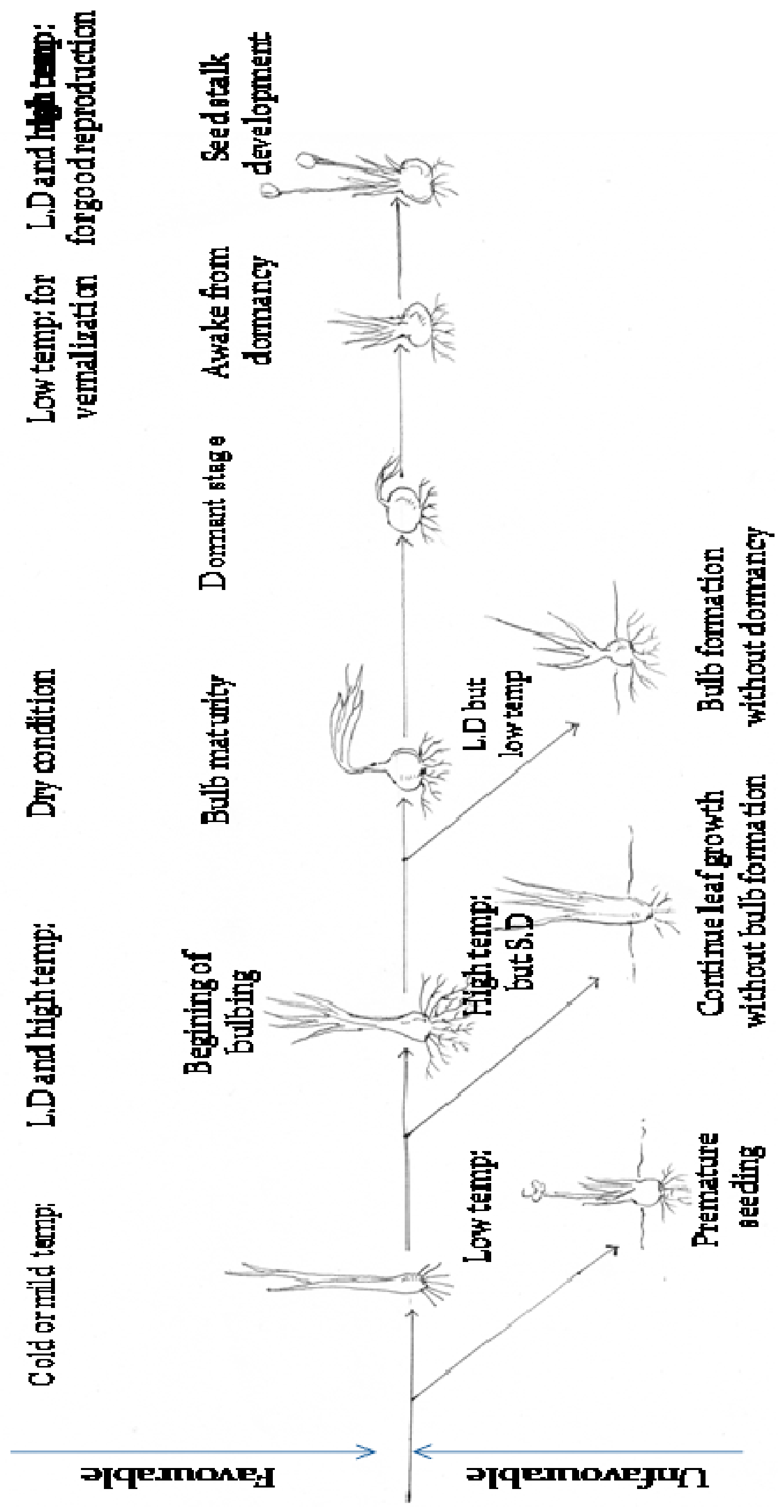
APPENDIXES



Appendix figure 1Illustration of life cycle of onion (from Shinohara, 1977)

Appendix table 2Characteristics of the experimental soil (Experiment I)

Characteristics	Value	Method
PH	6.42(Slightly acid)	1:2w/v soil: water
Available N(ppm)	76(Medium)	Alkaline permanganate method
Available P(ppm)	3(Low)	Olsen's method
Available K(ppm)	74(Low)	1N Ammonium acetate method
Organic matter (%)	0.41(Medium)	Tyurin's method
Soil Texture	Loamy sand	Pipette method
Sand (%)	83.17	
Silt (%)	10.61	
Clay (%)	6.22	

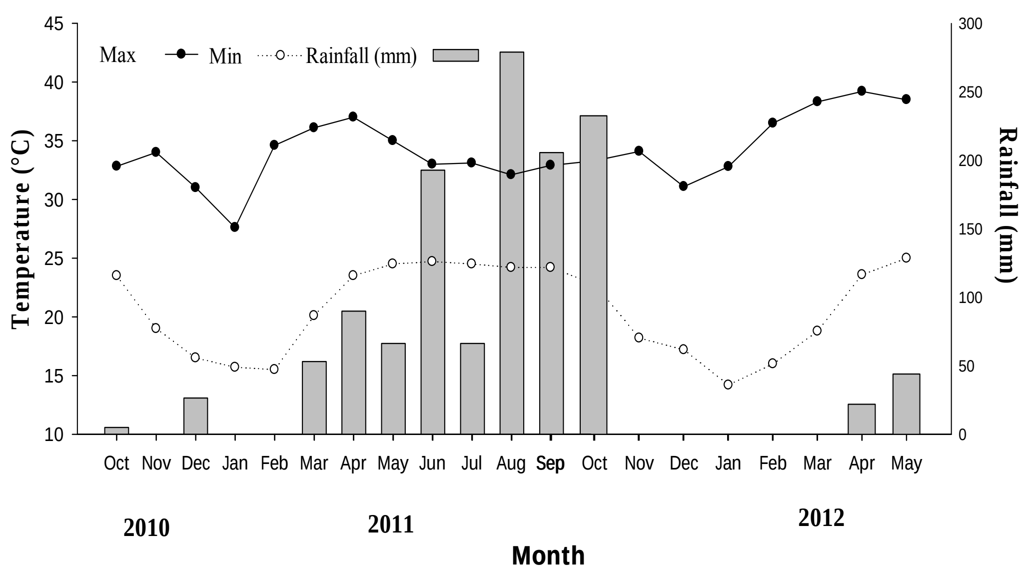
Appendix table 3Characteristics of the experimental soil (Experiment II)

Characteristics	Value	Method
PH	6.94(Neutral)	1:2w/v soil:water
Available N(ppm)	76(Medium)	Alkaline permanganate method
Available P(ppm)	14(Medium)	Olsen's method
Available K(ppm)	81(Low)	1N Ammonium acetate method
Organic matter (%)	2.79(Medium)	Tyurin's method
Soil Texture	Loamy sand	Pipette method
Sand (%)	83.02	
Silt (%)	10.98	
Clay (%)	6.00	

Appendix table4 Plan of harvesting times for Experiment I (A) and Experiment II (B)

(A)	31 October	21 November
1st harvest	30.1.2011	20.2.2011
2nd harvest	5.3.2011	26.3.2011

(B)	7 November	21 November	5 December
1st harvest	8.2.2012	12.2.2012	4.3.2012
2nd harvest	18.2.2012	2.3.2012	14.3.2012
3rd harvest	22.2.2012	12.3.2012	24.3.2012
4th harvest	1.3.2012	22.3.2012	3.4.2012
5th harvest	16.3.2012	6.4.2012	18.4.2012



Appendix figure5 Monthly means (October 2010-May 2012) of temperature and rainfall recorded at Yezin area (Source: Yezin Meteorological Station)