HIGH DENSITY PLANTING AND SEED TUBER SIZE ON PRODUCTIVITY ENHANCEMENT OF LESSER YAM
[*Dioscorea esculenta* (Lour.) Burkill]

By

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(2017-11-019)

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KERALA, INDIA

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THESIS

Submitted in partial fulfillment of the requirement for the degree of

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2019

DECLARATION

I, Anasooya Sebastian (2017-11-019) hereby declare that this thesis entitled **"High density planting and seed tuber size on productivity enhancement of lesser yam [*Dioscorea esculenta* (Lour.) Burkill]"**is a bonafide record of research work done by me during the course of research and that the thesis has not been previously formedfor the award of any degree, diploma, fellowship or other similar title, of any other University or the basis Society.

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Date: 18-10-2019

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CERTIFICATE

Certified that this thesis entitled **"High density planting and seed tuber size on productivity enhancement of lesser yam [*Dioscorea esculenta* (Lour.) Burkill]"**is a record of research work done independently by **Ms. Anasooya Sebastian** (2017-11-019) under my guidance and supervision and that it has not been previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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We, the undersigned members of the advisory committee of **Ms. Anasooya Sebastian (2017-11-019)**, a candidate for the degree of **Master of Science in Agriculture**, with major field in **Agronomy**, agree that this thesis entitled **"High density planting and seed tuber size on productivity enhancement of lesser yam [*Dioscorea esculenta* (Lour.) Burkill]"** may be submitted by **Ms. Anasooya Sebastian** (2017-11-019) in partial fulfillment of the requirement for the degree.

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1. Introduction

1. INTRODUCTION

Root and tuber crops are the major cultivated sources of carbohydrates after cereals in the tropical regions of the world. Apart from dietary energy, they provide proteins, fibre, vitamins, and minerals along with bioactive compounds such as saponins, phenolic compounds, alkaloids, phytic acids, carotenoids, and ascorbic acid. Reports on antioxidant, immune-modulatory, antimicrobial, antidiabetic, antiobesity, and hypocholesterolemic properties mark their pharmaceutical importance. Besides, they are used as constituents in livestock feeds and raw materials for some of the industrial products.

Yams belong to the monocotyledonous family *Dioscoreaceae* constituting the predominant starchy staple in tropics where food security for growing populations is a critical issue. The annual global production of yams constitutes about 73.02 million tonnes (FAO, 2017). These crops are adapted to diverse soil and environmental conditions, and are comparatively free of pest and disease attacks, which make them suitable to low input production systems (Onwueme, 1978). The world yam production is distributed over 50 countries, specifically America, Africa, Madagascar, south-east Asia, Australia and Melanesia. Among the 600 species recorded, the major cultivated ones are *Dioscorea alata*, *Dioscorea bulbifera*, *Dioscorea cayenensis*, *Dioscorea esculenta*, *Dioscorea opposita-japonica*, *Dioscorea nummularia*, *Dioscorea pentaphylla*, *Dioscorea transversa*, *Dioscorea rotundata* and *Dioscorea trifida* (Lebot, 2009).

Dioscorea esculenta (Lour.) Burkill, is a member of the family *Dioscoreaceae* with characteristic small clustered tubers. It is commonly called Lesser Yam, Hausa Potato, Sweet Yam or Spiny Chinese Yam. It is native to Indo-China and at present they have widely been distributed throughout Madagascar, West Africa, India, Sri Lanka and New Guinea as a leading food crop. In India it is being cultivated in Kerala, Tamil Nadu, Bihar, Assam, West Bengal, Rajasthan, Orissa, and Maharashtra.

In Kerala, lesser yam is commonly known as *Cherukizhang/ Nanakizhang/ Cheruvallikizhang*. It is common in homesteads as an intercrop and commercial cultivation is limited. It is often cultivated as a rainfed crop with duration of 7-8 months, planted at the early monsoon period of April-May and harvested during November-December. The oval to spindle-shaped, soft, mucilaginous tubers are rich in starch and are eaten like potatoes after cooking, boiling or roasting. They have a slightly sweet and agreeable taste. The starch is more easily digestible than that of other yams; therefore, this species is used in special diets for persons with alimentary disorders. Lesser yam tubers contains starch 62.40 g, crude protein 9.76 g, crude lipid 4.68 g and crude fibre 6.62 g per 100g of tuber on dry weight basis (Shajeela *et al.*, 2011).

Apart from its major use as a food crop, it is well known for its medicinal properties due to the presence of bioactive components namely, mucin, dioscin, dioscorine, allantoin, choline, polyphenols, diosgenin, and vitamins such as carotenoids and tocopherols (Chandrasekara and Kumar, 2016). Several studies have indicated the hypoglycemic, antimicrobial, and antioxidant activities of lesser yam. In addition to the food and medicinal values, lesser yam has a vital role in socio-cultural traditions, rituals and religions, that there remains an ethnocentric attachment between the crop and certain ethnic groups in tropics. In spite of all the qualities, unfortunately lesser yam production is restricted to a very few pockets and is underutilized in India. But, orphan crops like lesser yam are gaining importance due to emerging awareness about their nutraceutical and health benefits and post-harvest technologies available for product diversification and value addition.

In agriculture, agronomic practices have a prominent influence on production and productivity of crops. There is scope for commercial cultivation of minor and under exploited tuber crops and standardization of management practices for intensive cultivation can help the farmer to maximize income especially in the context of limitation in area expansion. Lesser yam is vegetatively propagated through whole tubers weighing 100-150 g at the recommended spacing of 75 x 75 cm (KAU, 2016). For this, the seed tuber requirement will work out to about 1.8-2.7 t/ha. Hence, a considerable part of the harvest has to be set apart as planting material for the next crop. Seed tubers are expensive, accounting sometimes for about as much as 50 per cent of total variable cost (Manyong, 2000). Thus a saving in quantity of seed tuber can considerably reduce the cost of cultivation and can maximize profit. For seed purpose though larger tubers of 100-150g is recommended, farmers have a tendency to use the small unmarketable tubers for planting. In this situation, there is a scope for accommodating more plants by adjusting the planting geometry.

Under this backdrop, the present investigation was undertaken with the main objective of arriving at suitable planting geometry and seed tuber size to maximize productivity and profitability of cultivation of lesser yam under intensive agricultural production systems.

2. Reviewofliterature

2. REVIEW OF LITERATURE

India is blessed with the richness of its biodiversity in root and tuber crops. The two major biodiversity hotspots namely Western Ghats and North-Eastern regions harbor numerous wild relatives of cultivated tuber crops, identified and conserved by different tribal and ethnic groups (Edison *et al*., 2006). Globally, the major cultivated tuber crops are potato, cassava, sweet potato, yams and aroids (Lebot, 2009). Except the highly researched and well developed crops like potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), and cassava (*Manihot esculenta*), other regionally important starchy tuber crops, particularly yams are yet to be exploited for their health and nutritional benefits to use them as functional foods (Andres, 2017).

As research publications in lesser yam are limited, relevant literatures in other tuber crops are also reviewed here.

2.1 GENERAL DETAILS OF LESSER YAM

Yams are a group of primitive monocots, bearing carbohydrate rich underground tubers having a place in the genus *Dioscorea*, and family *Dioscoreaceae*. Of the many edible yams found in the tropics, *Dioscorea esculenta* commonly called as 'Lesser yam' (Burkhill, 1960) ranks third in production and utilization after African yam (*Dioscorea rotundata*) and Asian greater yam (*Dioscorea alata*). Taxonomically, it belongs to the section *Combilium*, bearing left twining vines and producing larger number of smaller tubers. The fresh tubers are widely used as starch source for both edible and industrial purposes. Because of its fine, easily digestible starch and good protein content, it is preferred to other yams (Martin, 1974). Rather than large scale cultivation, lesser yam is only being cultivated in home gardens, even if it is favoured for its cooking quality among the food yams (Martin, 1976). However, because of the larger tubers, *Dioscorea alata* is being widely cultivated all through the tropics as a cash crop than the other yams.

Lesser yam is a crop of warm and wet tropics. It grows profusely in well-drained, friable, organic matter rich soils with pH 5-7. A warm climate with an optimum temperature of 25-30ºC along with adequate moisture is needed for proper vegetative growth and tuber bulking (Palaniswami and Peter, 2008).

The tubers are consumed like potatoes or sweet potatoes. They are oval to spindle in shape, and mucilaginous with high amounts of starch and are consumed after cooking, boiling or roasting. As the starch is easily digestible, lesser yam tubers are good for people with alimentary disorders. When cooked, the tubers possess appreciable palatability and soft flesh texture similar to that of Irish potato. Tubers as well as plant parts contain value raphides and calcium oxalate crystals (Lebot, 2009). Generally, root and tuber crops like cassava, sweet potato and yams are known to establish even in poor and low fertile soils. However, a high level of natural fertility is essential for maintaining yam yield under continuous cultivation (Carsky *et al.*, 2010).

Lesser yam is indigenous to tropical Asia especially Indo-China and at present they are broadly being spread over Africa, Asia, portions of South America, the Caribbean and the South Pacific islands. Papua New Guinea has been perceived as a major centre of its diversity. It is being widely cultivated as a staple food in most parts of West Africa, especially Nigeria (Lim, 2016). It is popular under the names *Mou Alu* (Bengali), *Kodikkilangu/ Siruvalli Kilangu* (Tamil), *Tippa Tiga* (Telugu) or *Cherukizhang/ Nanakizhang* (Malayalam) in various parts of our country.

2.2 NUTRITIVE PROPERTIES OF LESSER YAM

In 2007, Olayemi and Ajaiyeoba reported the presence of saponins, disgenin, β-sitosterol, stigmasterol and cardiac glycosides in the tubers. The tubers consisted of (mg/100 g dry weight) saponins 20.01 mg, flavonoids 12.4 mg, and alkaloids 1.89 mg. In Orissa, among the various yam species, *D. esculenta* was found to have a reasonable content of diosgenin, 533.33 mg and vitamin C content of 4.16 mg per100 g of dry tubers (Behera *et al*., 2010). Lesser yam flour contains 7.19 per cent protein and 1.10 per cent fat as reported by Ukpabi (2010). Harmayani *et al*. (2011) found that higher amounts of inulin could be obtained from *D. esculenta* compared to that of other tubers. Studies conducted by Shajeela *et al*. (2011) in the lesser yam tubers revealed that it contains 62.40 g starch, 9.76 g crude protein, 4.68 g crude lipid, 6.62 g crude fibre, 41.36 mg niacin and 84.06 mg ascorbic acid. A mineral composition of 86.40 mg Na, 1594.31 mg K, 314.01 mg Ca and 436.06 mg Mg per 100 g of dry matter is also reported in lesser yam.

2.3 SEED SIZE AND SPACING ON GROWTH PARAMETERS

Emergence percentage

Early field experiments conducted especially in the yam belts of Africa in late 20^{th} century revealed that both physiological and growth characteristics in yams were influenced by sett size. Major works of Onwueme (1972) substantiated that the formation of higher number of shoots in large seed tubers of *Dioscorea* sp. had resulted out of the dominance of early sprouts over the later formed ones that were relatively remote from the initial sprout. Again, Onwueme (1975) observed that larger setts sprouted more readily, emerged more quickly, and produced more vigorous plants with more extensive leaf area. The bigger setts were most likely able to mobilize greater amount of food material from the sett to the developing vine. In yams, the primary nodal complex provides a vascular connection between the developing shoot and the stored reserves of the mother tuber, hence large seed tubers by utilizing more reserves have a potential to produce more sprouts per tuber (Wikham *et al.*, 1980). Studies conducted by Ferguson *et al.* (1983) in White Lisbon yam (*Dioscorea alata*) revealed that the plants that emerged from larger setts (355g) emerged earlier than medium (170g) and smaller setts (85g). Masarirambi (2012) reported that in potato, the days to emergence was significantly influenced by seed tuber size whereas the population density had no significant effect on emergence.

Vine length, shoot number and leaves

Haynes *et al*. (1967) observed that in greater yam (*Dioscorea alata*) the leaf area declined with the commencement of active tuber formation. Osaki *et al*. (1996) reported that in order to obtain the maximum yield, a sufficient equilibrium between shoot, root and tuber growth should be attained in tuber crops. Higher productivity in tuber crops like yams is attributed to the balance between shoot and root activity as the photosynthates have to be actively distributed to the underground sink.

Studies conducted by Sikder *et al*. (2014) in *Colocasia esculenta*, the number of suckers per hill was statistically superior in seed tubers of 10-12.5 g size (8.0) compared to that of small seed tubers weighing 5-7.5 g (6.5) at 150 DAP. The higher number of suckers per hill obtained from the large cormels was due to more number of potential eyes present in bigger seed tubers. Also a higher number of leaves (4.5), plant height (53.7 cm) and foliar coverage (47.3 %) were also registered for large seed tubers at harvest.

In Taro (*Colocasia esculenta*) variety *Boloso-1*, Gebre (2015) reported a significant increase in plant height, leaf number, shoot number, leaf area index, corm and cormels number per plant, corm and cormels yield per hectare with increase in corm size. An increased plant population density had a positive correlation with all these factors except for plant height and number of leaf per plant.

Number of tubers

Enyi (1972) indicated that in lesser yam when many tubers were initiated from a single plant, the size of individual tubers was small and percentage of initiated tubers that never reached the harvestable size was more. Enyi also reported that, the difference in duration of tuber bulking between the large and small tubers was non-significant, even though the vegetative parameters like leaf area and higher bulking rates were observed in larger setts. In White Lisbon yam, Ferguson (1983) observed an increase in number of tubers up to six months after planting followed by a reduction in number of productive tubers while reaching the senescence phase.

As tubers are the major economic part in yams, the emergence and number of tubers are crucial. In yams, the timing of tuber initiation and the duration of tuber formation was different within and between species, and are affected by the environmental factors. For example, tuber initiation in *D. rotundata* has been reported to occur from sprouting to 84 days after sprouting (Okezie *et al*., 1981).

Within 11 weeks after planting, more than ten primary roots were observed in*Dioscorea esculenta* and the average number of roots per plant increases up to 24 weeks after planting after which remains stable. Tubers were first observed at 21 weeks after planting. The number of tubers increased significantly over the following months reaching a maximum around 27 tubers per plant between 37 and 41 weeks after planting (Melteras, 2008).

Dry matter production

Haynes *et al.* (1967) observed that in greater yam (*Dioscorea alata*) leaf area declines with the commencement of active tuber formation which resulted in a reduction in total dry matter production during the senescence phase. In tulip, an ornamental bulbous crop, substantial differences in leaf area and shoot dry weight was observed and the higher values were registered with larger bulbs (Rees, 1968).

The effect of staking in exposing the leaves towards sunlight is an important determinant of photosynthetic efficiency in yams. Enyi (1972) also reported that the dry matter accumulation in lesser yam was greater in staked than in unstaked plants. Staking, nitrogen and potassium application tended to increase the proportion of dry matter diverted into the tubers also.

Tuber yield is proportional to the total dry matter accumulated during the active vegetative phase. According to Okoli (1980), the total amount of dry matter accumulated in the aerial portions (vines, leaves, and flowers) of the yam was observed to be higher between the 112 and 126 days after planting, after which it decreased as growth commenced. Also he opined that the decrease in dry matter of aerial portions was partly due to the emergence of the sink organ (tuber) in the developmental sequence of the plant and partly due to abscission of leaves following browning and senescence of vines and leaves. Irizarry and Rivera (1985) reported that 84 per cent of total dry matter in *D. rotundata* was accounted by the tubers and it exceeded 50-67 per cent in *D. esculenta* as reported by Enyi (1972). Melteras *et al.* (2008) observed that in *D. rotundata,* the tubers constituted 87 per cent of total dry matter at 315 days after planting.

2.4 SEED SIZE AND SPACING ON CROP GROWTH INDICES

Optimum growth indices favoured the better growth and development of yam crop. Holliday (1960) concluded that the yield/plant population relation of vegetatively propagated crops, such as yams, followed an asymptotic curve. Onwueme, (1972) opined that in white yams, the higher yields of large setts under the farm conditions resulted from a combination of direct food transfer and larger photosynthetic area and capacity of plants developed from them. With respect to the sett size both leaf area per plant and tuber yield per plant increased. He also reported that the onset of tuber germination was lagging for the smaller setts whereas the senescence occurred in all treatments at the same time irrespective of seed size or spacing. Net assimilation rate (NAR) is defined as a measure of the efficiency of leaves in total dry matter production. During the major part of growth period, NAR was registered between 0.30 to 0.47 g/g/week in *D. alata* (Sobulo, 1972). At the initial harvest, value of NAR was found to be 3.3 g/g/fortnight was probably due to decreased mutual shading of lower leaves. Enyi (1972) reported that LAI increased with increase in seed size from 15 g to 110 g and decreased with wider spacing.

According to Maduakor *et al*. (1984) in white yam, the crop growth rate represented photosynthetic capacity. It followed a similar trend with respect to vine dry weight exhibiting an increase up to active tuber bulking stage, but declined more sharply in the senescence period, as declining photosynthetic capacity of the senescing leaves added to decline in leaf biomass. Relative growth rate was moderately stable, around 0.13 g/g/week during the initial vegetative phase, but declined at tuber bulking due to the effect of unproductive tuber mass. The rate of tuber bulking, however, remained high after the completion of vine growth.

During crop growth, the extent of leaf area and its display and duration determines its capture of solar energy for photosynthetic carbon assimilation. Photosynthetic efficiency of yams is closely related to the effective display of leaf area to ensure maximum light reception (Akoroda, 1993).

Suja and Nair (2006) also observed a low leaf area index at wider spacing (120 cm x 120 cm) compared to that of medium (90 x 90 cm) and closer spacing (60 x 60 cm) in greater yam. In case of leaf area index, the canopy growth progressed proportionally with the seed rate. Higher LAI resulted from a higher seed rate (larger setts) resulted in higher leaf area duration (LAD) and better light interception throughout the growth period. The effect of plant density was only considerable for the marketable tuber yield as plant population is a function of tuber yield per hectare. Nedunchezhiyan *et al.* (2008) opined that large sized seed tubers channelized more food reserves which resulted in increased vine length and higher leaf area development in greater yam. Crop growth rate reflects the photosynthetic efficiency of a plant. It has the same trend as that of total dry matter. It declines rapidly during the vine senescence. Relative growth rate was found to be steady during the initial vegetative stage, but declined during tuber bulking in lesser yam (Melteras, 2008).

Studies conducted by Law-Ogbomo and Osaigbovo (2014) on the growth and tuber yield of *Dioscorea rotundata* under varying plant densities (10000, 13333, 17778, 20000 and 266667 plants per hectare), revealed that significantly higher fresh tuber yield and lower number of tuber per plant, tuber size, and per cent unmarketable tubers were obtained under higher densities of planting. Also an increase in plant density and fertilizer application rate resulted in increased leaf area index (LAI) and imparted higher photosynthetic capacity and translocation leading to higher total dry matter production and tuber yield.

2.5 SPACING AND TUBER DEVELOPMENT

In tuberous crops, variation in sizes of seed tubers and their spacing in the field affects final tuber yield (Bremner and Taha, 1966). According to Enyi (1972), closer spacing decreased leaf area index, leaf-area duration and plant dry matter, but increased dry matter production per unit area and yields of marketable or ware tubers in *Dioscorea esculenta*. He observed that the total tuber yield was positively correlated with leaf-area duration between tuber initiation and harvest.

Williams (1972) explained the relation between yield and spacing as a function of time in cassava. He found that in case of a leafy variety *Sakai*, up to nine months a significant increase in total yield occurred in plant densities of 11,910 per acre, although the proportion of tuber to stem and leaf showed a decrease at higher densities.

In 1973, Gurnah reported that spacing had a substantial effect on the yield of tubers of *Dioscorea rotundata*, and the highest plant population giving the maximum yields, without influencing the number of tubers per plant. Individual tuber weights were also affected by the spacing and the heaviest tubers were found among the widely spaced plants.

According to Sen *et al.* (1990), higher tuber yields of sweet potato were observed when the vine cuttings were closely planted. From the studies conducted in potatoes, Beukema and Van der Zaag, (1990) suggested that plots with high plant densities produced higher yield due to large crop stand but resulted in low tuber weight per plant. The increment in yield is attributed to earliness in foliage spread, fewer side branch formation and early development of tubers. Also, Ariyo *et al.* (1991) reported that the crop yield is influenced largely by the number of plants occupied per unit area more than on the production capacity of individual plants.

It is well established that spacing is a major economic concern in potato cultivation (*Solanum tuberosum* L.). In 1999, Love and Thompson-Johns determined the effect of seed piece spacing on yield, tuber size distribution, net profit, and stem and tuber density of three commercial potato cultivars namely *Russet Burbank, Frontier Russet, and Ranger Russet*, which were planted at 8, 15, 23, 31, 46, 61, 76, and 91 cm spacing. The three cultivars yielded superior yields at the narrowest (8 cm) spacing. In case of maximum marketable and midsize tuber yield, distribution shifted from a predominance of small tubers at narrow spacing to a predominance of large tubers at wide spacing (cultivar-dependent).

The effect of planting density on the marketable corm yield of Taro (*Colocasia esculenta*), variety '*Numkowec'* was studied by Genuda *et al.* (2001) in Papua New Guinea, taking the plant densities as 10,000, 20,000, 40,000, 80,000 and 160,000 plants per hectare as treatments. It was observed that with a higher planting density the total corm yield increased, but decreased the mean corm weight. Total marketable yield increased with increasing planting density up to 80,000 plants/ha, but decreased at 160,000 plants/ha. Abd-Ellatif *et al.* (2010) explained that early plantings in mid-November or mid-December along with close spacing of 20 cm could be recommended for obtaining early and high production of taro. In *Colocasia esculenta* the highest total dry weight and corm dry weight yield were obtained from larger corms (5 cm) compared to that of smallest corm size (1 cm) which gave the lowest (Thititaweesin *et al.*, 2010).

Sibiya (2015) reported that at a higher planting density (0.5 m x 0.5 m) in Taro (*Colocasia esculenta*), the plants emerged slower while comparing to lower densities (1 m x 1 m). Also, a positive growth and yield response was observed while increasing plant density with yield being highest at high plant density. Srivastava *et al*. (2016) observed that in potatoes, more number of tubers per plant was observed at closer spacing of mini tubers (15cm x 10 cm), but better yield was obtained at wider spacing (20cm x10cm).

Woelore *et al.* (2016) reported in ginger that the sett size significantly increased the rate of emergence, maturity, number of tillers per plant, plant height, leaf length & width, shoot dry weight, leaf area, leaf area index rhizome fresh weight/ ha and harvest index, a maximum at a higher seed size of 6.1 to 9 cm than

3.1 to 6 cm and less than 3cm. Also in ginger the maximum yields were obtained at higher densities of 20 x15 cm and 30x10cm inter row and intra-row spacing interchangeably.

In sweet potato, Adubasim *et. al.* (2017) found an increase in tuber weight per plant with respect to a decrease in plant density. This was substantiated as the result of less intra-specific competition for growth resources among plants. They opined that in plots with low densities showing high tuber weight per plant, an unrestricted access to resources was feasible.

In 2018, Szarvas *et al.* studied influence of planting densities on the yield of sweet potato variety '*Ásotthalmi-12*'. In the experiment, they analyzed the yield data for one hectare at different planting densities. After increasing the plant density from 3.33 plants per m^2 (100 cm x 30 cm) to a higher level of 6.25 plants per m^2 (80 cm x 20 cm), an increase in the total tuber yield from 13.16 t/ha to 13.93 t/ha. Even though a decrease in plant yield was recorded at higher plant density of 6.25 plants m^2 (80 cm x 20 cm), the storage root yield per hectare was the highest.

2.6 SEED SIZE AND TUBER DEVELOPMENT

Seed size significantly affected the yield in tuber crops especially yams. Bremner and Taha (1966) found that in potato, the higher yield of larger setts resulted from a longer bulking duration because of earlier tuber initiation. In potato, large seed outyielded small seed, although the difference in marketable yield was relatively small. The seed size significantly influenced the length of bulking period, as they resulted in variations in the time of tuber initiation. With a decrease in spacing distance, the total yield increased. The ware yield increased as spacing distance decreased from 24 to 18 inches

Enyi (1972) found that in *D. esculenta,* the plants from larger setts had higher leaf area duration and higher mean bulking rates than plants from small setts. There was no significant difference in the duration of tuber bulking with respect to seed size. Effect of sett size and sett position in *Dioscorea alata* was studied by

Onwueme (1973) in an experiment based on the sprouting process of (*Dioscorea* sp.) tuber pieces. He observed that from the tuber pieces weighing 70 g (large) and 20 g (small) when planted in sawdust, the larger setts had attained a more advanced stage of sprouting, had larger individual sprouting loci, and had a greater number of sprouting loci per sett than the smaller ones.

Martin (1974) reported that yield of lesser yam is closely related to tuber size, and seed tubers of 50-75 g are ideal for planting with a spacing 100cm x 30cm.It has been reported that plants that emerged from larger setts formed tubers earlier than from small setts (Onwueme, 1978).

According to Coursey (1981), with a higher number of shoots developed in larger setts, better yield was registered in large setts than smaller setts. Ferguson (1983) reported that plants from large setts of White Lisbon Yam emerged earlier, produced larger primary nodal complexes, greater leaf area, initiated rapid tuber bulking earlier. The plants from larger setts had longer duration of tuber bulking than those from small setts.

Fergusan *et al.* (1983), on studying the effect of spacing and sett size on some aspects of growth, development and yield in White Lisbon yams observed that an increase in seed rate resulted in an asymptotic response in yield. The higher yield of large setts resulted from longer duration of rapid tuber bulking. Larger setts emerged earlier, produced greater plant dry weights and higher mean tuber bulking rates. Head setts of yams have out yielded more than middle and tail setts.

Kayoed (1984) reported that spacing and sett size significantly affected tuber yield in the forest zones and savanna of Ibadan and Benin. The heaviest yam setts (average 400 g) gave the largest tuber yield at all spacings, with the 150 cm spacing outyielding the 300 g and 350 g seeds. The larger tuber yields recorded in the forest zones over the savanna zone was reported as the result of greater soil organic matter and total N contents in the forest zone soils.

In yams, maximum yields were obtained from large seed tubers rather than the smaller ones. Higher yield in larger setts was contributed by higher yield attributes. In vegetatively propagated plants like tuber crops, the final yield is depended on the initial size of the planting materials (Siddique *et al*., 1988).

In an experiment for the determination of optimum sett size of mini setts in *Dioscorea rotundata*, Gyansa-Ameyaw *et. al*. (1991) showed that sprouting usually increased with an increase in the mini sett size, attributed to relatively greater amounts of food reserves in larger setts. Also the survival of plant at harvest, number of tubers per plant and total fresh tuber yield were higher in case of larger setts.

Patel *et al*. (2003) studied the effect of spacing and corm size on growth and yield of elephant foot yam (*Amorphophallus paeoniifolius*) under South Gujarat conditions. The study indicated that the corms weighing 500 g planted at a spacing of 75 cm x 60 cm was beneficial for getting significantly higher yield of 74.59 t/ha in elephant foot yam.

Big and medium setts of lesser yam produced significantly more vigorous plants while small setts produced less vigorous ones as seedlings produced from bigger tubers have an advantage over those from smaller ones at the early growth stages (Legaspi and Malab, 2013).

In an experiment conducted by Sikder *et al.*(2014) to determine the optimum cormel size for higher yield of *Colocasia esculenta*, the maximum number of leaves (4.5 at harvest), tallest plant (53.7 cm at harvest), foliage coverage (47.3% at harvest), sucker/hill (8.0), weight of individual corm (80.9 g), number of cormels/plant (21.8), yield of corm (5.9 t/ha) and yield of cormels (23.9 t/ha) were found from larger ones (10-12.5 g), while minimum from small sized tubers (5.0-7.5 g).

2.7 WEED COMPETITION IN YAMS

In case of cassava, it has been shown that the most damaging effect on yield was more from weed competition during canopy formation and early tuberization period (third month after planting) and less from the fourth month until harvest (Onochie, 1975). Weeds are the major components in cultivation that interferes with the growth and development of crops. Tuber crops such as cassava, yams, cocoyams or potatoes possess a slow rate of primary growth making them poor weed competitors (Onochie, 1978).

Yams are traditionally grown on small scale farms as components of multiple-cropping systems and the crop requires a minimum of three weeding during the first 16 weeks after planting according to Akobundu (1987). While studying the effect of tropical weeds on the yield of white yam, Unamma and Akobundu (1989) found a reduction of 76-79 per cent of tuber yield when the foliage and roots of weeds came into direct contact with the crop until harvest. Also the highest LAI values were noted in the weed-free plots whereas the lowest values were observed in plots with weed interference. Reduced LAI resulted in lower capacities to produce photosynthates needed for food storage that further decreased the yields.

In case of yams, severe weed competition at the early stages of growth resulted in a crop loss of 70-91 per cent in Nigeria (Oerke *et al*., 1994). Weeding alone consumes approximately 30-50 per cent of total labour budget depending on the crop and the level of other available resources (Agboola, 2000; Akobundu, 1991).

2.8 ECONOMICS OF PRODUCTION

Yam cultivation on a commercial scale greatly depends on the availability and feasibility of inputs. Conventionally, yams are cultivated by using whole tubers (*D. esculenta*) or large pieces of seed tubers (*D. alata*) of 200 g or more (Okoli *et al.*, 1982). Hence, the propagation rate is inadequate and a share of marketable tubers must be held in reserve for planting. Moreover, as reported by Okoli and Akoroda (1995), the expenditure on planting material was over 33% of the total cost of cultivation for yam production, pointing the need to improve the productivity of yams by effectively utilizing the planting material, space and other inputs. Seed tubers were expensive and accounted for about as much as 50 percent of total variable cost (Manyong, 2000).

Srinivas and Ramanathan (2005) reported that profitability of elephant foot yam production in Tamil Nadu, depended on size and availability of planting material among the various inputs. Management of resources was important to reduce the cost of cultivation and to achieve higher productivity as well as higher gross returns.

3. *Materials and Methods*

3. MATERIALS AND METHODS

The experiment on the effect of plant geometry and seed tuber size on the productivity of lesser yam was conducted during the period of May to December 2018 at College of Horticulture, Vellanikkara, Thrissur. Materials and methodology adopted for the study are described in this chapter.

3.1 LOCATION, CLIMATE AND SOIL

The experiment was conducted at Agronomy Farm of Department of Agronomy, College of Horticulture, Vellanikkara, located at 10°33'N latitude, 76°16'E longitude at an altitude of 40.3 m above Mean Sea Level. The field was under the tuber crop *Xanthosoma sagittifolium* (Tannia) in the previous cropping season.

The data on weather parameters (monthly rainfall, number of rainy days per month, maximum temperature, minimum temperature, relative humidity, evaporation and sunshine hours) during the cropping period are furnished in Appendix 1.

The soil of the experiment site was sandy clay loam with an acidic pH of 3.8. The physico-chemical properties of soil and methods used for the estimation of available nutrients are detailed in Table 1.

Table 1. Physico-chemical properties of soil

Particulars	Value	Method used
1. Physical properties (Particle size composition)		
Coarse sand (%)	31.90	Robinson international pipette method (Piper, 1942)
Fine sand (%)	27.30	
Silt (%)	18.64	
Clay (%)	22.16	

2. Chemical properties		
pH	3.80	1: 2.5 soil water ratio (Jackson, 1958)
Organic carbon (%)	1.13	Walkley and Black method (Jackson, 1958)
Available N (kg/ha)	155.40	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg/ha)	26.04	Ascorbic acid reduced molybdo phosphoric blue colour method (Bray and Kurtz, 1945; Watanabe *et al.*, 1965)
Available K (kg/ha)	283.36	Neutral normal ammonium acetate extraction and estimation using flame photometry (Jackson, 1958)

3.2 TREATMENTS

Design : R B D (Factorial)

Replication 3

Treatments 9

Plot size : 5m x 3m

Treatment components

a) Average seed tuber weight

1. 50 g
2. 100 g
3. 150 g

b) Spacing

1. 75 x 75 cm (17780 plants per ha)
2. 75 x 50 cm (26670 plants per ha)
3. 50 x 50 cm (40000 plants per ha)

The experiment consisted of nine treatment combinations of seed tuber size and planting densities. Seed tubers of 50 g, 100 g, and 150 g were planted at spacings of 50 cm x 50 cm (high density planting), 75 cm x 50 cm (medium density planting) and 75 cm x 75 cm (low density planting: recommended spacing.

List of treatment combinations

Treatments			
T1	50 g @ 75 cm x 75 cm	T6	100 g @ 50 cm x 50 cm
T2	50 g @ 75 cm x 50 cm	T7	150 g @ 75 cm x 75 cm
T3	50 g @ 50 cm x 50 cm	T8	150 g @75 cm x 50 cm
T4	100 g @ 75 cm x 75 cm	T9	150 g @ 50 cm x 50 cm
T5	100 g @75 cm x 50 cm		

Total seed requirement with respect to spacing (kg/ha)

Seed size \ Spacing	75 x 75 cm	75 x 50 cm	50 x 50 cm
50 g	889	1334	2000
100 g	1778	2667	4000
150 g	2667	4001	6000

Layout plan of the experiment is presented in Figure 1.

3.3 CULTIVATION PRACTICES

1. Field preparation

The experimental field was ploughed thoroughly with disc plough, followed by a cultivator. Weeds and stubbles were removed and experiment was laid out as per Figure 1. Mounds were taken at prescribed spacing as per the treatments. Bunds were made around the plots and channels were laid for drainage.

2. Application of lime, manures and fertilizers

Farm yard manure was applied basally. Urea (46 per cent N) and Factomfos (20 per cent N, 20 per cent P_2O_5 and 13 per cent S) were used as the sources of nitrogen (N) and phosphorus (P), and MOP (60 per cent K_2O) as the source for potassium (K).

Lime (30-40 g per mound) and dried cattle manure (@ 1 kg per mound) were applied as per the Package of Practices Recommendations – Crops of the Kerala Agricultural University (KAU, 2016) and incorporated into the soil. Nitrogen, phosphorus and potash were applied on per plant basis based on normal NPK recommendation of 80, 60 and 80 kg/ha (KAU, 2016). Half dose of nitrogen and potassium and full dose of phosphorus were applied at one week after vine emergence. Second application of fertilizers was done one month after the first application.

3. Planting material

Variety Sree Latha was used in the experiment. It is a high yielding variety of lesser yam, a selection from Thiruvananthapuram district released from ICAR- Central Tuber Crops Research Institute, Thiruvanathapuram. It climbs to a height of 2.5-3 m, and has duration of 7.5- 8 months and an average yield of 25 t/ha. The tubers are non- bitter with good flavor, taste and cooking quality. The starch content is 24.4 per cent and shelf life of tuber is 2.5-3 months. Seed tubers were collected from the ICAR- Central Tuber Crops Research Institute, Thiruvanathapuram.

4. Planting

Planting was done on 5th May 2018. As per the treatments the tubers were graded and planted on the mounds. Immediately after planting, mulching was done uniformly using *Macaranga peltata* (*Vatta*) leaves and twigs to maintain optimum moisture and temperature in the soil. Gap filling was done after one month of planting to maintain the optimum plant population.

5. Weeding

One week before planting, pre-emergent spray of Oxyflourfen 23.5% EC@ 0.15 kg/ha was done. Two manual weedings were done at 30 and 60 days after planting just before fertilizer application and earthing up.

6. Staking

Staking influences the tuber yield of yam cultivars. Poles of *Casuarina equisetifolia* (locally called *Choolamaram*) were used for staking. At 15 days after sprouting, the vines were trailed onto coir ropes attached to the poles. The system of pyramidal staking was done and four plants were trailed to a single pole with the help of coir ropes.

7. Plant protection

Pest and diseases were noticed and recorded timely. Necessary control measures were taken to control tuber rot which was a major disease being observed at five months after planting. Infected plants were dug out and removed. Soil drenching with the systemic fungicide Saaf® (Carbendazim 12% + Mancozeb 63%) at the rate of 3 g/L of water was done in the infected areas. A prophylactic spray of *Trichoderma harzianum* (20 g/L of water) was also done to prevent the incidence of fungal leaf spot.

8. Harvesting

Harvesting was done on 22nd December, 2018 when the vines turned yellow and dry. Tubers were dug out using hoes. The days to harvest was uniform among the treatments and it was noted as 225 days after planting.

3.4 OBSERVATIONS

Observations on biometric characteristics, physiological parameters, yield and yield attributing factors of lesser yam were recorded and the mean values were worked out.

Sampling procedure

For taking observations on growth and yield, five plants were selected at random and tagged from each plot omiting the border rows. Destructive sampling was done for dry matter estimation and plant analysis at 45 days intervals.

1. Crop growth characters

Crop growth characters were recorded at 45 days interval.

a) Days to emergence

It was calculated by counting the number of plants that have emerged in each plot at ten days interval and was recorded up to the completion of emergence.

b) Number of shoots per mound

The number of shoots per plant was counted at 45 days after planting and the mean was worked out.

c) Length of the vine

The length of vine was measured from the ground level to the growing tip of the vines at 45 and 90 days after planting and expressed in cm.

d) Number of leaves per vine

The number of fully opened leaves was counted from the sample plants at 45 days interval and their mean was worked out.

e) Number of tuber forming roots

The number of tuber forming roots per plant was counted at each destructive sampling (45 DAP) and the mean was worked out.

f) Dry matter production

Dry matter accumulation per vine was recorded at 45 days interval up to harvest by destructive sampling of random plants (one plant per plot). These plants were uprooted from each plot carefully without damaging the roots and tubers. The foliage was dried under shade and then oven dried at 70 ± 5°C till consecutive weights obtained. Cut tubers were also dried in the same manner. The dry weight of the whole plant was found out by adding weights of aerial and underground parts and was expressed as g per plant.

2. Physiological parameters

Physiological parameters were recorded at 45 days interval up to harvest.

a) Leaf area and Leaf area index (LAI)

Total number of leaves was counted and leaf area of representative sample leaves were read using a leaf area meter (Licor leaf area meter). The average leaf area per leaf was multiplied with total number of leaves to get total leaf area per vine and expressed in cm^2 per plant. LAI was calculated by dividing total functional leaf area per vine by spacing.

b) Crop growth rate (g/ m^2/ day)

The crop growth rate (CGR)is the dry matter accumulated per unit land area per unit time (g m^2 /day).

The CGR was calculated by the formula,

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where, W_1: Initial dry weight, W_2: Final dry weight, t_1: Initial time, t_2: Final time, P: Land area

c) Relative growth rate (g /g /day)

Relative Growth Rate (RGR) is the total plant dry weight increase in a time interval relative to the initial dry weight and was expressed as g/g/day.

$$RGR = \frac{Log_e W_2 - Log_e W_1}{t_2 - t_1}$$

Where, W_1: Initial dry weight, W_2: Final dry weight, t_1: Initial time, t_2: Final time

d) Net assimilation rate (g/ m^2 / day)

It gives the average photosynthetic efficiency of leaves in a plant population.Net assimilation rate (NAR) can be expressed as the dry matter augmentation per unit leaf area or per unit leaf dry weight per unit time (), and was calculated as per the formula given below

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{Log_e A_2 - Log_e A_1}{A_2 - A_1}$$

Where, A_1: Total leaf area at initial time (t_1), A_2: Total leaf area at final time (t_2), W_1: Initial dry weight, W_2: Final dry weight

3. Yield attributes

a) Number of tubers per plant

Total number of tubers from sample plants from each plot were counted and averaged to get number of tubers per plant.

b) Individual tuber weight (g)

Weights of tubers were recorded from the five randomly selected plants and average was worked out. Tubers were graded into small (average 50 g), medium (average 100 g) and large tubers (average 150 g) and number of tubers was recorded.

c) Fresh tuber yield (g/plant)

Weight of tubers from five randomly selected plants were taken and averaged to get weight of tubers per plant and expressed in g/vine. The tubers from net plot was also harvested, weight recorded and was expressed in kg/ha.

d) Average length and girth of tuber (cm)

Length and girth of small, medium and large sized tubers collected from each treatment were measured to obtain average length and girth of tubers.

4. Observation on weeds

a) Weed spectrum

Weeds from each plot were identified at species level and recorded.

b) Weed count and dry matter production

A quadrat of 0.25 m X 0.25 m was placed at random and weeds from this area were uprooted and counted species wise. The uprooted weeds from sampling area of each plot were dried in shade and then in hot air oven at 70°C. The dry weight was expressed in g/m^2**.**

3.5 INCIDENCE OF MAJOR PESTS AND DISEASES

Incidence of major pest and diseases during crop period was observed and recorded.

3.6 SOIL AND PLANT NUTRIENT ANALYSIS

After the harvest of lesser yam, soil samples were collected from the field randomly and pooled to obtain a representative sample. It was analyzed for organic carbon, available nitrogen, phosphorus and potassium as per the standard procedures mentioned in Table 1.

After harvest, plant samples were processed and analyzed for nitrogen, phosphorus and potassium. The samples were dried to constant weight in an electric hot air oven at 70 ± 5°C, ground into fine powder and used for analyzing N, P and K contents (%). Uptake of nutrients at harvest was calculated by multiplying the values of dry matter content and per cent nutrient content in plant and expressed in g/plant and kg/ha.

Methods used for plant analysis

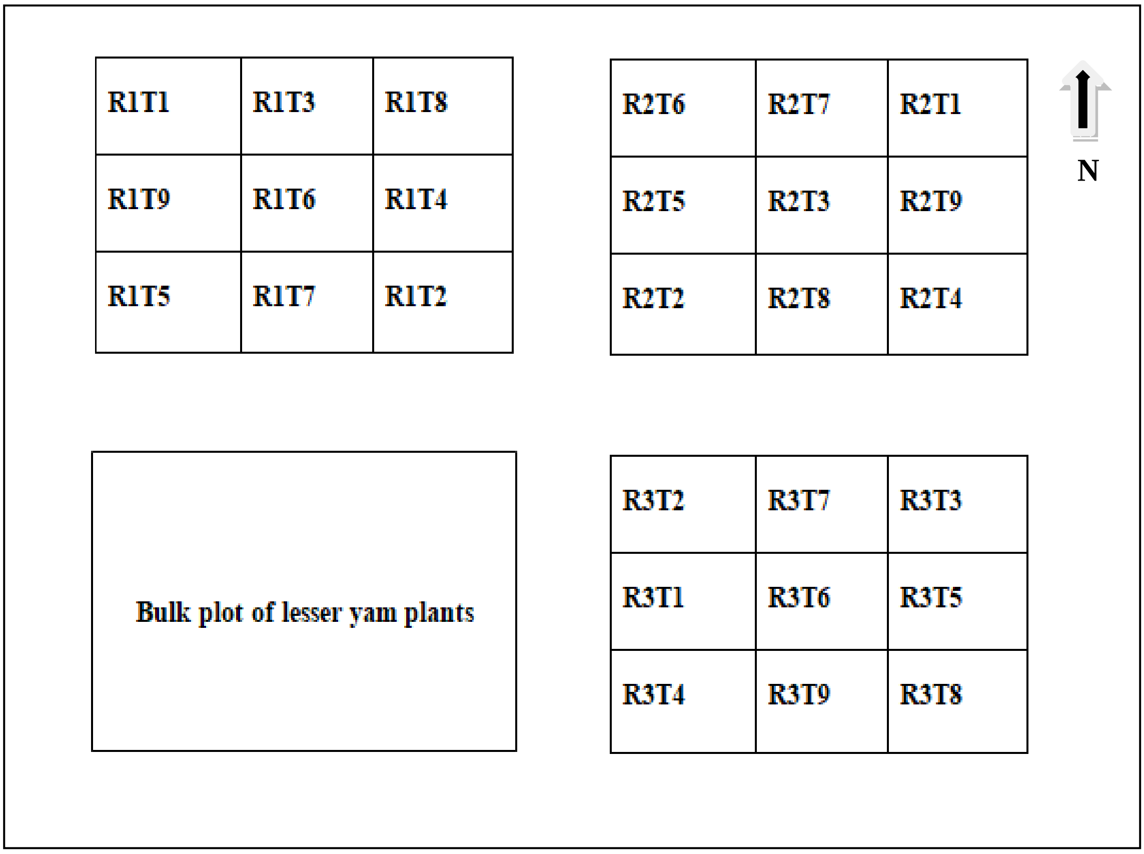
Nutrients	**Method used**	**Reference**
N	Modified micro Kjeldahl method	(Jackson, 1973)
P	Vanado-molybdo phosphoric yellow colour method using spectrophotometer	(Jackson, 1973)
K	Flame photometry	(Jackson, 1973)

3.7 COST-BENEFIT ANALYSIS

Cost of cultivation was calculated based on the expenditure incurred. The current market price of lesser yam was considered for working out the gross income and was expressed in ₹/ha. Net income was estimated by subtracting cost of cultivation from gross income and expressed in ₹/ha. Benefit cost ratio was worked out as the ratio of gross income to the total cost of cultivation.

3.8 STATISTICAL ANALYSIS

The data was analyzed statistically by applying the techniques of Analysis of Variance (Gomez and Gomez, 1984). The collected data were analyzed using OP Stat and WASP 2.0.



Plot size: 5 m x 3 m

Treatment combinations

T_1	50 g @ 75 cm x 75 cm	T_6	100 g @ 50 cm x 50 cm
T_2	50 g @ 75 cm x 50 cm	T_7	150 g @ 75 cm x 75 cm
T_3	50 g @ 50 cm x 50 cm	T_8	150 g @ 75 cm x 50 cm
T_4	100 g @ 75 cm x 75 cm	T_9	150 g @ 50 cm x 50 cm
T_5	100 g @ 75 cm x 50 cm		

Figure 1. Layout of the experiment

Plate 1. Land preparation and liming

Plate 2. Seed tubers of three grades

Plate 3. Planting on mounds and mulching

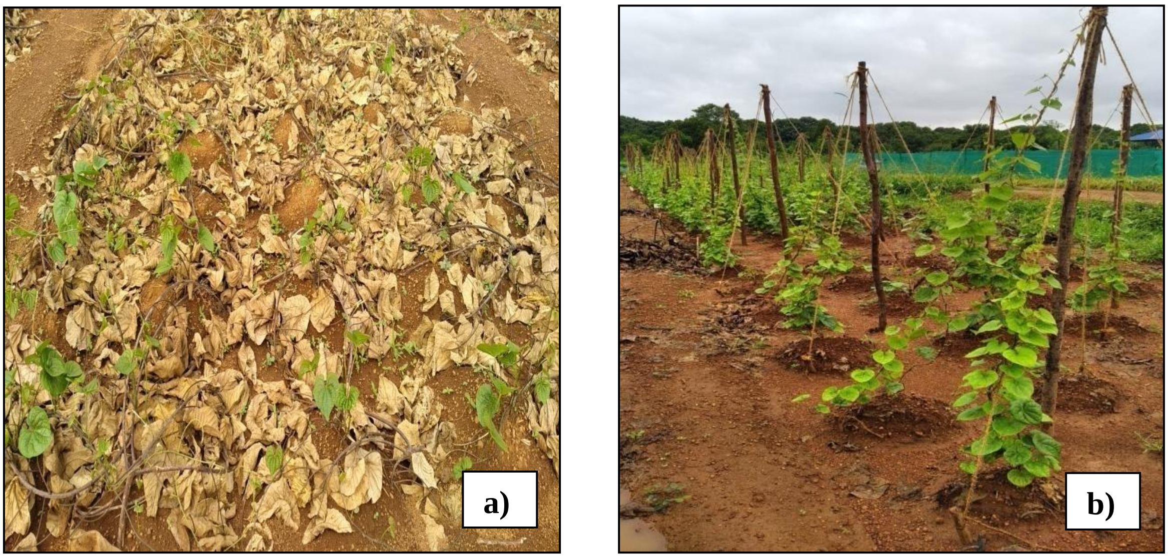


Plate 4. Field view a) Vine emergence (20 DAP) b) Staking (45 DAP)

Plate 5. Lesser yam plants at four months after planting

4. Results

4. RESULTS

The results of the experiment entitled 'High density planting and seed tuber size on productivity enhancement of lesser yam [*Dioscorea esculenta* (Lour.) Burkill]' conducted at the Agronomy Farm, Department of Agronomy, College of Horticulture, Vellanikkara during the period from May 2018 to December 2018 are documented in this chapter after appropriate statistical analysis.

4.1 EFFECT OF SEED SIZE AND SPACING ON GROWTH PARAMETERS

Emergence was recorded at 10, 20, 30 and 40 days after planting (DAP). Number of shoots emerged was recorded at 45 DAP. The observations on leaf number, leaf area, number of tuber producing roots and tubers per plant, and total dry weight were estimated by destructive sampling at 45 days interval (45, 90, 135, 180 and 225 DAP).

a) Emergence percentage

The data on emergence percentage are presented in Table 2. The effect of size of planting materials on the days to emergence was evident up to 30 DAP and by 40 DAP 100 per cent emergence could be observed irrespective of seed tuber size. Spacing had no effect on emergence pattern.

The seed tubers with largest size (150 g) showed early sprouting and development of buds during storage itself. Hence at 10 DAP, 74 per cent emergence was observed for 150 g seed tubers, whereas the emergence was 56 per cent and 47 per cent for 100 g and 50 g tubers respectively. At 20 DAP, 75 per cent shoot emergence was observed in all plots. Within 30 days, 87 per cent and 89 per cent of plants emerged in the treatment combinations comprising small and medium tubers respectively, which were comparable statistically. Whereas, 97 per cent of emergence was observed in treatment combinations with large tubers. All tubers irrespective of sett size and spacing showed complete emergence (100%) within 40 DAP.

b) Vine length

Vine length was recorded at 45 and 90 DAP; after which it was tedious to separate out the plants from the poles. Staking was provided uniformly to all plants irrespective of seed tuber size and spacing. The height of *Casuarina* poles was 2 m. As four plants were trailed using coir rope to a central pole, the vines intermingled and observations on vine length could not be recorded after three months of planting.

The data on vine length as influenced by seed size are given in Table 3. The length of the vines increased on an average up to 3 m within 4 months of planting. It was found that effect of seed tuber size on vine length was pronounced only during the initial growth phase but the planting density had no significant effect. Vine length was significantly higher for plants emerged from 150 g tubers (160.89 cm), followed by 100 g (115.44 cm) and 50 g tubers (96.00 cm) at 45 DAP. However, at 90 days of planting, all the vines exhibited comparable length irrespective of seed size or spacing.

The interaction effect of seed size and spacing on vine length was significant only at 45 DAP. A significantly higher vine length of 176 cm was recorded for plants emerged from 150 g seed tubers planted at a spacing of 75 cm x 75 cm, which was on par with that planted at a spacing of 75 cm x 50 cm (163.67 cm). At all the three planting densities, plants that emerged from small tubers had shorter vines (99.33 cm, 100.33 cm and 88.33 cm) than large and medium tubers.

Table 2. Effect of seed size on percentage of plants emerged

Treatment	**Percentage of plants emerged (%)**			
	10 DAP	**20 DAP**	**30 DAP**	**40 DAP**
Seed size				
50 g	46.56	75.78	87.00	100
100 g	55.78	76.89	89.44	100
150 g	74.44	91.11	97.89	100
CD (0.05)	3.82	3.29	3.80	0.00

Table 3. Effect of seed size on length of vine in lesser yam

Treatment	**Vine length (cm)**	
	45 DAP	**90 DAP**
Seed size		
50 g	96.00	278.89
100 g	115.44	280.22
150 g	160.89	289.00
CD (0.05)	13.17	NS

Table 4. Interaction effect of seed size and spacing on vine length (45 DAP)

Treatment (Seed size x Spacing)	**Vine length(cm)**		
	50 g	**100 g**	**150 g**
75 cm x 75 cm	99.33	122.33	176.00
75 cm x 50 cm	100.33	105.67	163.67
50 cm x 50 cm	88.33	118.33	143.00
CD (0.05)	22.80		

c) Number of shoots per tuber

The data on the effect of treatments on number of shoots emerged are presented in Table 5. In lesser yam, sprouting occurred from the head end and was influenced by seed size. The maximum number of shoots emerged was observed from large tubers compared to medium and small seed tubers at 45 DAP. Large seed tubers (150 g) on an average produced significantly higher number of shoots (5.44), whereas medium (100 g) and small tubers (50 g) put forth 4.22 and 2.78 shoots respectively, which also differed statistically from each other. It was observed that number of shoots per seed tuber was not affected by planting density.

d) Number of leaves per vine

Total number of leaves from the destructed sample vines were counted manually. The data shows the significant effect of seed size and spacing on number of leaves formed (Table 7). At 45 and 90 DAP, the maximum and significantly higher number of leaves was observed in vines that emerged from large seed tubers (121.84 and 296.78). Performance of 50 g and 100 g tubers were on par at 90 DAP, whereas by 135 DAP 150 g and 100 g seed tubers produced comparable and higher leaf count. Peak vegetative phase in lesser yam was observed at four months after planting when the number of leaves were maximum (135 DAP). A gradual decline in the number of leaves was found towards 180 DAP. Spacing also had a significant effect on the number of leaves per vine except at the initial stage of growth (45 DAP). By 90 DAP, a higher leaf count was observed in plants at wider spacing of 75 x 75 cm. At both 135 and 180 DAP, leaf count in all the three planting densities differed significantly from each other, with significantly higher values obtained with wider spacing. Significant interaction effect of seed size and spacing on number of leaves was registered at all stages of growth in lesser yam. At peak vegetative phase (135 DAP) the highest leaf count was for vines emerged from 150 g tubers planted at wider spacing of 75 x75 cm which was superior (591 leaves) to all other treatments. Next higher values were for 100 g and 50 g seed tubers planted at wider spacing which differed from each other statistically (574.33 and 495.33 leaves respectively).

Table 5. Effect of seed size and spacing on number of shoots per plant

Treatment	**Number of shoots per plant (45 DAP)**
Seed size	
50 g	2.78
100 g	4.22
150 g	5.44
CD (0.05)	0.76
Spacing	
75 cm x 75 cm	4.00
75 cm x 50 cm	4.33
50 cm x 50 cm	4.11
CD (0.05)	NS

Table 6. Interaction effect of seed size and spacing on number of shoots per plant

Treatment (Seed size x Spacing)	**Number of shoots per plant (45 DAP)**		
	50 g	100 g	150 g
75 cm x 75 cm	2.67	3.67	5.67
75 cm x 50 cm	3.00	4.33	5.67
50 cm x 50 cm	2.67	4.67	5.00
CD (0.05)	1.31		

Table 7. Effect of seed size and spacing on number of leaves

Treatment	**Number of leaves per vine**			
	45 DAP	**90 DAP**	**135 DAP**	**180 DAP**
Seed size				
50 g	73.13	271.56	399.45	253.78
100 g	91.60	270.33	475.22	337.00
150 g	121.84	296.78	474.33	241.78
CD (0.05)	6.22	10.83	9.00	8.97
Spacing				
75 cm x 75 cm	95.37	292.33	553.56	372.56
75 cm x 50 cm	93.13	271.89	425.44	260.22
50 cm x 50 cm	98.07	274.44	370.00	199.78
CD (0.05)	NS	10.83	9.00	8.97

Table 8. Interaction of seed size and spacing on number of leaves

Treatment (Seed size x Spacing)		**Number of leaves per vine**			
		45 DAP	**90 DAP**	**135 DAP**	**180 DAP**
50 g	75 cm x 75 cm	66.45	290.00	495.33	365.33
	75 cm x 50 cm	75.33	264.67	394.33	206.00
	50 cm x 50 cm	77.62	260.00	308.67	190.00
100 g	75 cm x 75 cm	94.00	263.00	574.33	394.00
	75 cm x 50 cm	91.55	264.00	445.33	373.00
	50 cm x 50 cm	89.26	284.00	406.00	244.00
150 g	75 cm x 75 cm	125.67	324.00	591.00	358.33
	75 cm x 50 cm	112.52	287.00	436.67	201.67
	50 cm x 50 cm	127.33	279.33	395.33	165.33
CD (0.05)		10.77	18.77	15.59	15.54

e) Leaf area (cm^2/plant)

The seed tuber size had a significant effect on leaf area (Table 9) and the trend was similar to that of leaf number per vine. The highest leaf area for the plants was observed during 135 DAP (active vegetative phase). In general vines from large tubers showed significantly higher leaf area compared to the medium and small seed tubers at all stages except 180 DAP. There was a marked increase in leaf area from 45 DAP to 90 DAP. Vines from medium (10605.14 cm^2/plant) and small seed tubers (10176.54 cm^2/plant) were on par with respect to leaf area at 135 DAP and 90 DAP. However, at 180 DAP, medium sized tubers displayed significantly higher leaf area of 12299.35 cm^2 /plant compared to large (11133.61 cm^2/plant) and small tubers (8532.33 cm^2/plant).

Spacing also significantly influenced leaf area development at 135 and 180 DAP. Marked superiority in leaf area was observed among the widely spaced plants. At 135 DAP, higher leaf area was found in plants under wider spacing (14355.84 cm^2/plant) and medium spacing (10240.72 cm^2/plant) which were comparable, whereas vines at closer spacing recorded significantly lower leaf area (8376.494 cm^2/plant).

The interaction effect of seed size and spacing on leaf area is shown in Table10. In general, higher and statistically comparable leaf area was observed in the treatment combination of 150 g seed tubers planted at wider as well as medium spacing.

Table 9. Effect of seed size and spacing on leaf area per plant

Treatment	**Leaf area (cm^2/plant)**			
	45 DAP	**90 DAP**	**135 DAP**	**180 DAP**
Seed size				
50 g	1866.22	7283.08	10176.54	8532.33
100 g	2506.15	7808.80	10605.14	12299.35
150 g	3705.62	9264.57	12191.37	11133.61
CD (0.05)	177.03	535.14	773.70	771.57
Spacing				
75 cm x 75 cm	2675.67	8666.69	14355.84	14011.95
75 cm x 50 cm	2639.71	8163.32	10240.72	9977.81
50 cm x 50 cm	2762.60	8163.32	8376.49	7975.52
CD (0.05)	NS	NS	773.70	771.57

Table 10. Interaction effect of seed size and spacing on leaf area per plant

Treatment (Seed size x Spacing)		**Leaf area(cm^2/plant)**			
		45 DAP	**90 DAP**	**135 DAP**	**180 DAP**
50 g	75 cm x 75 cm	1744.31	7390.25	11838.39	11690.56
	75 cm x 50 cm	1898.32	7733.88	10449.75	7245.02
	50 cm x 50 cm	1956.02	6725.12	8241.49	6661.40
100 g	75 cm x 75 cm	2632.00	8338.00	14840.69	14428.28
	75 cm x 50 cm	2476.43	7661.28	8870.97	12861.04
	50 cm x 50 cm	2410.02	7427.12	8103.76	9608.72
150 g	75 cm x 75 cm	3650.71	10271.80	16388.43	15917.02
	75 cm x 50 cm	3544.38	9094.80	11401.45	9827.38
	50 cm x 50 cm	3921.76	8427.09	8784.23	7656.43
CD (0.05)		306.63	926.90	1340.08	1336.40

f) Leaf area index (LAI)

The data regarding the leaf area index is presented in Table 11. Treatment differences were significant in the case of seed tuber size and spacing throughout the crop growth period of lesser yam. LAI increased with an increase in plant growth up to 135 DAP and showed a declining trend at 180 DAP. Higher values of LAI were observed in vines from larger seed tubers (1.06, 2.54 and 3.16 respectively at 45, 90 and 135 DAP). By 135 DAP, 50 g seed tubers and 100 g seed tubers registered comparable values of LAI (2.73and 2.75). At 180 DAP, LAI values differed significantly from each other with respect to seed tuber size. The lowest value was recorded for 150 g seed tubers (2.84) and highest for 100 g tubers (3.28).

At all crop growth stages, closer spacing resulted in the highest LAI which was significantly superior to other two spacings tried. The LAI in different planting densities differed significantly from each other except at 135 DAP. Leaf area index increased from 0.48 to 2.55 in 75 x 75 cm spacing, from 0.71 to 2.73 at 75 x 50 cm spacing and from 1.11 to 3.35 in 50 x 50 cm spacing.

Interaction effect was also significant. Highest LAI at 45 DAP was registered for 150 g tubers at 50 x 50 cm spacing (1.57) followed by 100 g at 50 x 50 cm spacing (0.96) which were statistically different. The lowest values were recorded for the plants grown under lower planting densities. At 90 DAP, the larger seed tubers planted at closer spacing of 50 x 50 cm registered statistically superior value (3.37) than others. The 100 g and 50 g seed tubers planted at closer spacing had the next higher LAI which were statistically different (2.97 and 2.68).

At peak vegetative phase (135 DAP), LAI of 150 g seed tubers planted at high density (50 x 50 cm) was statistically superior to others with a value of 3.51. This was closely on par with the LAI of vines from 50 g seed tubers planted at 50 x 50 cm spacing (3.29) and 100 g seed tubers planted at 50 x 50 cm spacing (3.24). The medium sized tubers maintained significantly higher LAI value of 3.85 at 180 DAP. In the respective treatment an increasing trend of LAI was found and it ranged from 0.96 to 3.87 within a duration of 45 to 180 DAP. Also the treatment experienced an increase in LAI during

135 to 180 DAP from 2.37 to 3.43. All the treatments except the combination of 100 g seed tuber planted at medium density (75 x 50 cm), the LAI showed a sharp decrease from 135 to 180 DAP. Towards the end of crop cycle, vines showed a decrease in leaf area index due to shedding and drying of leaves.

Table 11. Effect of seed size and spacing on leaf area index of lesser yam

Treatment	Leaf area index			
	45 DAP	**90 DAP**	**135 DAP**	**180 DAP**
Seed size				
50 g	0.53	2.02	2.73	2.22
100 g	0.70	2.17	2.75	3.28
150 g	1.06	2.54	3.16	2.84
CD (0.05)	0.05	0.14	0.18	0.18
Spacing				
75 cm x 75 cm	0.48	1.54	2.55	2.49
75 cm x 50 cm	0.71	2.18	2.73	2.66
50 cm x 50 cm	1.11	3.01	3.35	3.19
CD (0.05)	0.05	0.14	0.18	0.18

Table 12. Interaction effect of seed size and spacing on leaf area index

Treatment (Seed size x Spacing)		**Leaf area index**		
		75 cm x 75 cm	75 cm x 50 cm	50 cm x 50 cm
45 DAP	50 g	0.31	0.51	0.78
	100 g	0.47	0.66	0.96
	150 g	0.65	0.95	1.57
CD (0.05)	0.08			
90 DAP	50 g	1.31	2.06	2.69
	100 g	1.48	2.04	2.97
	150 g	1.83	2.43	3.37
CD (0.05)	0.24			
135 DAP	50 g	2.1	2.79	3.29
	100 g	2.64	2.37	3.24
	150 g	2.91	3.04	3.51
CD (0.05)	0.32			
180 DAP	50 g	2.08	1.93	2.66
	100 g	2.56	3.43	3.85
	150 g	2.83	2.62	3.06
CD (0.05)	0.32			

g) Dry matter production

Dry matter production by aerial parts and tubers were recorded separately at45, 90, 135, 180 and 225 days after planting.

Dry matter production of aerial portion

The results on plant dry weight of aerial portion are detailed in Table 13. Plant dry matter production was highly influenced by seed tuber size. Significantly higher dry weight (45.17 g) was observed with large seed tubers at 45DAP. Medium and small seed tubers registered lower values (26.61 g and 17.22 g) and differed significantly from each other. The same trend was registered at 90, 135, and 180 DAP.

Effect of spacing on aerial dry matter accumulation was observed only at 180 and 225 DAP. Higher plant dry weight was recorded for 75 x 75 cm (157 g/vine) and 75 x 50 cm (149 g/vine) spacing at 180 DAP, which was statistically superior to closer spacing (142.22 g/vine).

Interaction effect of seed tuber size and spacing had significant effect on aerial dry matter production, particularly showing higher values for large seed tubers at active vegetative growth phase at 135 DAP (252.67, 249.67 and 266.67 g/vine).

Dry weight of tubers

The data pertaining to tuber dry weight influenced by seed size and spacing are furnished in Table 15. Tuber initiation begun within 45 DAP and bulking was noticed at 90 DAP. In general, significantly higher weight of tubers was noticed in vines that emerged from 150g seed tubers. However, by 180 DAP, the performance of 100g and 150 g seed tubers were comparable (257.11 and 279.67 g/vine). At all stages lower values were recorded for small seed tuber.

Statistically, spacing had significant effect on tuber dry matter production only at 180 DAP. Wider spacing resulted in significantly lower tuber dry weights (244.00 g/vine) as compared to medium (268.67 g/vine) and closer spacing (245.60 g/vine), which were on par. At 225 DAP comparable values were recorded in all the three spacings tried.

At 135 DAP, higher tuber dry weight was observed for large seed tuber under all plant densities and were statistically on par. At 180 DAP, the highest dry matter was recorded in the combination of 150 g tuber planted at 50 x 50 cm spacing (366.67 g per vine). At harvest, the performance of 100 and 150g seed tubers respectively at both 75 x 75 cm and 75 x 50 cm spacing were comparable in terms of tuber dry weight.

Total dry matter production of lesser yam

Seed size influenced total plant dry matter accumulation also (Table 17). Significant difference was observed at 45, 90, 135 and 180 DAP. At every interval of sampling the plants emerged from large mother tubers showed the highest dry matter accumulation. At harvest, both medium and large tubers showed uniform dry weights (412.89 g/vine and 446.78 g/vine) which were on par.

Effect of spacing on the total dry matter accumulation was not significant. However, the interaction effect of seed size and spacing on total dry matter production was significant. At all stages of growth larger seed tubers had superiority over others. At harvest interaction effect was non-significant.

h) Days to harvest

Symptoms of physiological maturity were seen uniformly among the treatments from early December. Total crop duration was 225 days.

Table 13. Effect of seed size and spacing on dry weight of aerial portion

Treatment	Dry weight of aerial portion (g/plant)				
	45 DAP	**90 DAP**	**135 DAP**	**180 DAP**	**225 DAP**
Seed size					
50 g	17.22	104.00	110.90	94.33	84.33
100 g	26.61	160.00	172.00	139.56	111.90
150 g	45.17	245.11	257.33	214.33	88.33
CD (0.05)	3.32	8.80	12.17	8.60	12.85
Spacing					
75 cm x 75 cm	30.11	170.56	178.11	157.00	98.78
75 cm x 50 cm	27.72	167.11	178.22	142.22	99.78
50 cm x 50 cm	31.17	171.44	183.90	149.00	86.00
CD (0.05)	NS	NS	NS	8.60	NS

Table 14. Interaction effect of seed size and spacing on dry weight of aerial portion

Treatment (Seed size x Spacing)		Dry weight of aerial portion (g/plant)				
		45 DAP	**90 DAP**	**135 DAP**	**180 DAP**	**225 DAP**
50 g	75 cm x 75 cm	19.00	116.67	130.33	115.33	93.67
	75 cm x 50 cm	15.67	110.33	113.67	100.67	96.00
	50 cm x 50 cm	17.00	85.00	88.67	67.00	63.33
100 g	75 cm x 75 cm	26.33	146.67	151.33	128.00	98.67
	75 cm x 50 cm	25.33	162.67	171.33	134.33	118.33
	50 cm x 50 cm	28.17	170.67	193.33	156.33	118.67
150 g	75 cm x 75 cm	45.00	248.33	252.67	227.67	104.00
	75 cm x 50 cm	42.17	228.33	249.67	191.67	85.00
	50 cm x 50 cm	48.33	258.67	269.67	223.67	76.00
CD (0.05)		5.74	15.23	21.08	14.88	22.26

Table 15. Effect of seed size and spacing on tuber dry weight of lesser yam

Treatment	**Tuber dry weight (g/plant)**		
	135 DAP	**180 DAP**	**225 DAP**
Seed size			
50 g	29.00	221.56	278.33
100 g	47.90	257.11	301.00
150 g	96.22	279.67	358.56
CD (0.05)	7.71	23.61	45.64
Spacing			
75 cm x 75 cm	58.11	244.00	323.67
75 cm x 50 cm	54.33	268.67	318.67
50 cm x 50 cm	60.67	245.67	295.56
CD (0.05)	NS	23.61	NS

Table 16. Interaction effect of seed size and spacing on tuber dry weight

Treatment (Seed size x Spacing)		**Tuber dry weight (g/plant)**		
		135 DAP	**180 DAP**	**225 DAP**
50 g	75 cm x 75 cm	29.67	225.67	260.00
	75 cm x 50 cm	24.67	229.00	273.00
	50 cm x 50 cm	32.67	210.00	302.00
100 g	75 cm x 75 cm	45.33	235.33	324.33
	75 cm x 50 cm	41.67	279.00	325.33
	50 cm x 50 cm	56.67	257.00	253.33
150 g	75 cm x 75 cm	99.33	271.00	386.66
	75 cm x 50 cm	96.67	298.00	357.67
	50 cm x 50 cm	92.67	366.67	331.333
CD (0.05)		13.35	40.88	79.05

Table 17. Effect of seed size and spacing on total dry weight of lesser yam

Treatment	Total dry weight (g/plant)				
	45 DAP	**90 DAP**	**135 DAP**	**180 DAP**	**225 DAP**
Seed size					
50 g	17.22	104.00	139.89	315.89	362.56
100 g	26.61	160.00	219.89	396.67	412.89
150 g	45.17	245.11	353.56	494.00	446.78
CD (0.05)	3.32	8.80	15.82	25.24	53.06
Spacing					
75 cm x 75 cm	30.11	170.56	236.22	401.00	422.33
75 cm x 50 cm	27.72	167.11	232.56	410.90	418.33
50 cm x 50 cm	31.17	171.44	244.56	394.67	381.56
CD (0.05)	NS	NS	NS	NS	NS

Table 18. Effect of spacing and seed size on total dry weight of lesser yam

Treatment (Seed size x Spacing)		**Total dry weight (g/plant)**		
		75 cm x 75 cm	75 cm x 50 cm	50 cm x 50 cm
45 DAP	50 g	19.00	15.67	17.00
	100 g	26.33	25.33	28.17
	150 g	45.00	42.17	48.33
CD (0.05)	5.74			
90 DAP	50 g	116.67	110.33	85.00
	100 g	146.67	162.67	170.67
	150 g	248.33	228.33	258.67
CD (0.05)	15.23			
135 DAP	50 g	160.00	138.33	121.33
	100 g	196.67	213.00	250.00
	150 g	352.00	346.33	362.33
CD (0.05)	27.39			
180 DAP	50 g	341.00	329.67	277.00
	100 g	363.33	413.33	413.33
	150 g	498.67	489.67	493.67
CD (0.05)	43.72			
225 DAP		353.33	369.00	365.33
		423.00	443.67	372.00
		490.67	442.33	407.33
CD (0.05)	NS			

4.2 EFFECT OF SEED SIZE AND SPACING ON CROP GROWTH INDICES

a) Crop growth rate (g/m^2/day)

The mean values of CGR taken at 45 days interval are given in Table.19. Significant effect of seed size and planting densities on CGR was revealed from the results obtained. Crop growth rate of lesser yam exhibited relatively higher values both at 45-90 DAP and 135-180 DAP, which marked active vegetative and tuber development stages in lesser yam.

Seed size had a significant effect on the crop growth rate. The highest CGR was obtained for the plants that emerged from large seed tubers at the intervals of 45-90 days (12.32 g/m^2/day), 90-135 days (7.03 g/m^2/day) and 135-180 days (8.62 g/m^2/day). At 135-180 days, higher CGR was obtained for small and medium tubers compared to that of large tubers. Spacing also had a significant effect on CGR in lesser yam. High density planting resulted in superior growth rates among all the treatments. At 45-90 DAP, CGR was found to be highest (12.20 g/m^2/day) at higher density followed by medium (8.26 g/m^2/day) and low density planting (5.55 g/m^2/day). A maximum CGR of 13.54 g/m^2/day was recorded at high density planting in the crop period between 135 and 180 DAP. Negative values for CGR were found at the final phase of crop cycle both in large seeds and high density planting.

Considering the interaction, at initial stage of development 150 g tubers (17.90 g/m^2/day) exhibited superiority over 100 g tubers (12.67 g/m^2/day) at high density planting, it was followed by 150 g seed tubers at medium density (11.03 g/m^2/day). Comparatively lesser growth rate was observed for small seed tubers at low (6.05 g/m^2/day) and medium densities (5.6 g/m^2/day) which were on par, but was significantly inferior at low density planting (3.86 g/m^2/day). At 135-180 DAP, the high density planting of 100g tubers was significantly superior over all other treatments. A relative decline in growth rate was visible at the senescence phase of lesser yam extending from 180-225 days. At this stage, the small seed at high density was found to be significantly superior among the treatments.

Table 19. Effect of seed size and spacing on crop growth rate

Treatment	Crop growth rate ($g/m^2/day$)			
	45-90 DAP	**90-135 DAP**	**135-180 DAP**	**180-225 DAP**
Seed size				
50 g	5.17	2.20	10.78	3.56
100 g	8.52	4.00	11.20	-0.05
150 g	12.32	7.03	8.62	-3.56
CD (0.05)	0.52	0.27	0.65	0.22
Spacing				
75 cm x 75 cm	5.59	2.59	6.51	0.84
75 cm x 50 cm	8.26	3.88	10.53	0.48
50 cm x 50 cm	12.20	6.76	13.55	-1.37
CD (0.05)	0.44	1.19	1.86	4.02

Table 20. Interaction effect of seed size and spacing on crop growth rate

Treatment (Seed size x Spacing)		**Crop growth rate (g/m^2/day)**		
		75 cm x 75 cm	75 cm x 50 cm	50 cm x 50 cm
45-90 DAP	50 g	3.86	5.61	6.05
	100 g	4.75	8.14	12.67
	150 g	8.03	11.03	17.90
CD (0.05)	0.90			
90-135 DAP	50 g	1.71	1.66	3.23
	100 g	1.98	2.98	7.05
	150 g	4.10	6.99	10.01
CD (0.05)	0.46			
135-180 DAP	50 g	7.15	11.34	13.84
	100 g	6.58	11.87	15.13
	150 g	5.79	8.39	11.67
CD (0.05)	1.14			
180-225 DAP	50 g	0.49	2.33	7.85
	100 g	2.36	1.80	-4.29
	150 g	-0.32	-2.70	-7.67
CD (0.05)	0.38			

b) Relative growth rate (g/g/day)

The details regarding the effect of treatments on relative growth rate of lesser yam are presented in Table 21. There was not much effect of treatments on RGR of lesser yam throughout the growth period. The highest value of RGR (0.017 g/g/day) was recorded at the initial phase of growth. During the period of 45-90 DAP, there was no significant differences in RGR with respect to the seed tuber size. But later at the tuber bulking stage, RGR was high for small seed tubers (50 g) compared to larger seed tubers (150 g). RGR was recorded to be 0.008 g/g/day in 50 g whereas it was 0.003 g/g/day in 150 g. Relative growth rate did not vary significantly with plant to plant spacing. However, with respect to spacing, RGR was higher (0.017 g/g/day) during 45-90 DAP. It showed a decline by 90-135 DAP (0.003 g/g/day) and then increased (0.006 g/g/day). Values approaching zero or even negative growth rates were observed during the senescence phase.

Table 21. Effect of seed size and spacing on relative growth rate

Treatment	Relative growth rate (g/g/day)			
	45-90 DAP	**90-135 DAP**	**135-180 DAP**	**180-225 DAP**
Seed size				
50 g	0.017	0.003	0.008	0.001
100 g	0.017	0.003	0.006	0.00
150 g	0.016	0.004	0.003	-0.001
CD (0.05)	NS	NS	0.001	NS
Spacing				
75 cm x 75 cm	0.017	0.003	0.006	0.001
75 cm x 50 cm	0.018	0.003	0.006	0.00
50 cm x 50 cm	0.016	0.004	0.005	0.00
CD (0.01)	0.001	NS	NS	NS

Table 22. Interaction effect of seed size and spacing on relative growth rate

Treatment (Seed size x Spacing)		Relative growth rate (g/g/day)			
		45-90 DAP	**90-135 DAP**	**135-180 DAP**	**180-225 DAP**
50 g	75 cm x 75 cm	0.018	0.003	0.007	0.000
	75 cm x 50 cm	0.019	0.002	0.008	0.001
	50 cm x 50 cm	0.016	0.003	0.008	0.003
100 g	75 cm x 75 cm	0.017	0.003	0.006	0.001
	75 cm x 50 cm	0.018	0.003	0.006	0.001
	50 cm x 50 cm	0.017	0.004	0.005	-0.001
150 g	75 cm x 75 cm	0.017	0.003	0.003	0.000
	75 cm x 50 cm	0.016	0.004	0.003	-0.001
	50 cm x 50 cm	0.016	0.004	0.003	-0.002
CD (0.05)		0.002	0.001	0.001	0.002

c) Net assimilation rate (g/m^2/day)

The results on NAR are displayed in Table23. Seed size significantly influenced NAR at all the sampling intervals. High assimilation rate was observed with large sized tubers (3.14 g/m^2/day and 1.05 g/m^2 /day) during 45-90 DAP and 90-135 DAP. Contradictory to this, NAR in 50 g tubers (1.87 g/m^2 /day) were observed to be superior during 135-180 DAP. Spacing had no significant effect on NAR during the initial stage of vine development. At all other sampling intervals, crops under high density planting exhibited maximum net assimilation rate. During 90-135 DAP, high density planting showed a better effect on NAR (0.99 g/m^2/day) followed by medium (0.67 g/m^2/day) and low density planting (0.54 g/m^2/day). Under the active tuber development phase of 135-180 DAP, a higher NAR was exhibited by the treatments compared to that of active vegetative phase at 90-135 DAP. Interaction effect of treatment factors was significant at all stages of growth. Large tubers in all the spacings tried and medium tubers at planting densities exhibited similar and significantly superior values of NAR at 45- 90 DAP. Small seed tubers at different planting densities and medium tubers at wider spacing found to be inferior to all other treatments with respect to NAR in the initial development phase. During 90-135 DAP, treatment effects were significantly different with respect to NAR. The results were almost similar to that observed during the initial phase of 45-90 DAP. Large seed tubers at high density showed significantly superior NAR which was closely followed by 150 g at 75 x 50 cm, 100 g at 50 x 50 cm, 150 g at 75 x 75 cm and 100 g at 75 x 50 cm. The lowest range of NAR was observed with small seed tubers at different densities tried.

Net assimilation rate recorded during the tuber bulking phase (135-180 DAP) displayed a relatively higher rate compared to that of active vegetative period (90-135 DAP). During 135-180 DAP the small tubers at high and medium densities were significantly superior to all other treatments and were on par (2.11 g/m^2/day and 2.02 g/m^2/day). This was followed by 100 g tubers at 50 x 50 cm (1.86 g/m^2/day) and 75 x 50 cm (1.80 g/m^2/day). NAR of large tubers under medium and low densities (1.29 g/m^2/day and 0.88 g/m^2/day) was lower during this growth phase.

Table 23. Effect of seed size and spacing on net assimilation rate

Treatment	**Net assimilation rate (g/m^2/day)**		
	45-90 DAP	**90-135 DAP**	**135-180 DAP**
Seed size			
50 g	2.10	0.40	1.87
100 g	2.77	0.67	1.59
150 g	3.14	1.05	1.24
CD (0.05)	0.17	0.04	0.10
Spacing			
75 cm x 75 cm	2.61	0.54	1.15
75 cm x 50 cm	2.71	0.67	1.74
50 cm x 50 cm	2.69	0.99	1.81
CD (0.05)	NS	0.04	0.10

Table 24. Interaction effect of seed size and spacing on net assimilation rate

Treatment	**Net assimilation rate (g/m^2/day)**		
	75 cm x 75 cm	75 cm x 50 cm	50 cm x 50 cm
45-90 DAP			
50 g	2.41	2.20	1.70
100 g	2.35	2.89	3.08
150 g	3.07	3.05	3.30
CD (0.05)	0.30		
90-135 DAP			
50 g	0.44	0.30	0.47
100 g	0.43	0.59	0.99
150 g	0.76	1.12	1.26
CD (0.05)	0.07		
135-180 DAP			
50 g	1.48	2.11	2.02
100 g	1.10	1.80	1.86
150 g	0.88	1.29	1.54
CD (0.05)	0.18		

4.3 EFFECT OF SEED SIZE AND SPACING ON YIELD AND YIELD ATTRIBUTES

a) Number of tuber forming roots

The data on number of tuber forming roots are presented in Table 25. Compared to normal feeder roots, these roots were thick and white in appearance. Both seed size and spacing influenced the root number at various phases of growth.

At 45 DAP, the vines showed significant difference in the number of tuber producing roots. Vines that emerged from large tubers produced significantly more number of tuberous roots (12.56) compared to that of medium (5.55) and small tubers (7.00) both of which were on par. At 90 DAP, the 150 g tubers continued to register the highest and statistically superior number of tuber forming roots (22.78). However, this trend changed by 135 DAP, where100 g and 150 g tubers had comparable and higher number of tuber forming roots per vine. The trend again changed by 180 DAP and at this stage 100 g seed tubers were superior with respect to number of tuber forming roots. At all the sampling intervals, the small seed tubers produced least number of potential tuber forming roots.

Spacing had a significant effect on tuber forming roots in all sampling periods except at 45 DAP. Closer planting showed the highest number of productive roots compared to wider spacing at 180 DAP. The number of tuber forming roots increased up to 180 DAP, after which the tuber bulking was noticed.

Interaction effect was significant throughout the period of observation. At the initial growth phase of 45 DAP, significantly higher and comparable root number could be observed in larger seed tubers planted at three different spacing which was comparable to 100 g tuber planted at closer spacing. Performance of all others was statistically inferior. However, there was a change in this pattern and both 150 g and 100 g tubers at closer spacing of 50 x 50 cm had comparable tuber forming roots to that of 100 g tuber at 75 x 50cm. Least and comparable values of 24 and 26.33 tuber forming roots were observed for 50 g tuber at 75 x 75 cm and 75 x 50 cm.

Table 25. Effect of spacing and seed size on number of tuber forming roots

Treatment	**Number of tuber forming roots**			
	45 DAP	**90 DAP**	**135 DAP**	**180 DAP**
Seed size				
50 g	7.00	12.00	23.00	27.78
100 g	5.55	17.00	35.44	39.56
150 g	12.56	22.78	35.22	35.22
CD (0.05)	1.76	1.23	2.75	1.93
Spacing				
75 cm x 75 cm	9.66	16.88	27.55	31.33
75 cm x 50 cm	9.66	18.22	32.67	32.44
50 cm x 50 cm	9.77	16.66	33.44	38.79
CD (0.05)	NS	1.23	2.75	1.93

Table 26. Interaction effect of spacing and seed size on number of tuber forming roots

Treatment		**Number of tuberous roots per plant**		
		50 g	100 g	150 g
45 DAP	75 cm x 75 cm	7.00	9.00	13.00
	75 cm x 50 cm	8.00	9.33	11.67
	50 cm x 50 cm	6.00	10.33	13.00
CD (0.05)	3.16			
90 DAP	75 cm x 75 cm	10.00	19.00	21.67
	75 cm x 50 cm	13.67	17.33	23.67
	50 cm x 50 cm	12.33	14.67	23.00
CD (0.05)	2.14			
135 DAP	75 cm x 75 cm	21.00	32.00	29.67
	75 cm x 50 cm	23.67	38.67	35.67
	50 cm x 50 cm	24.33	35.67	40.33
CD (0.05)	4.76			
180 DAP	75 cm x 75 cm	26.33	35.33	32.33
	75 cm x 50 cm	24.00	41.00	32.33
	50 cm x 50 cm	33.00	42.33	41.00
CD (0.05)	3.38			

Plate 6. Shoot and root development
(20 days after planting)

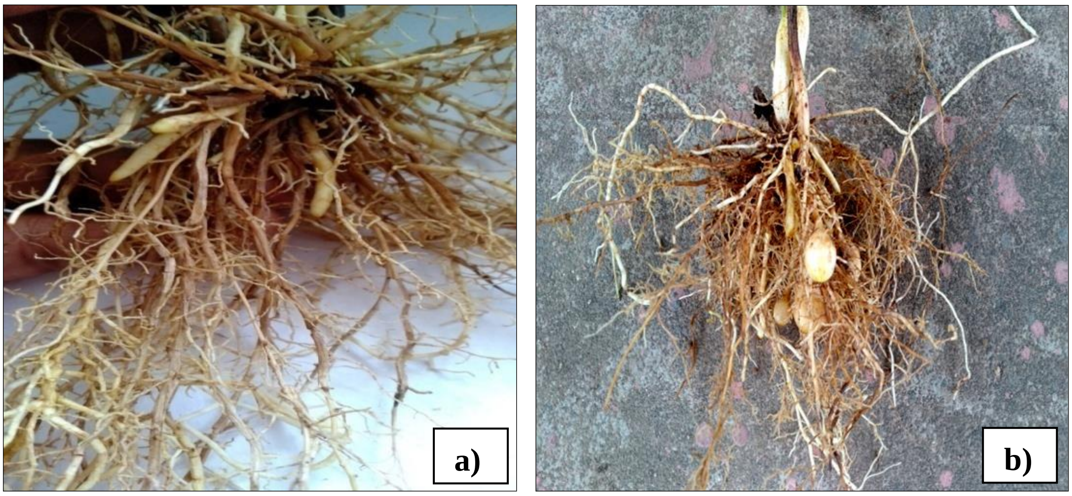


Plate 7. Root development

a) 45 days after planting
b) 90 days after planting

Plate 8. Tuber development (135 days after planting)

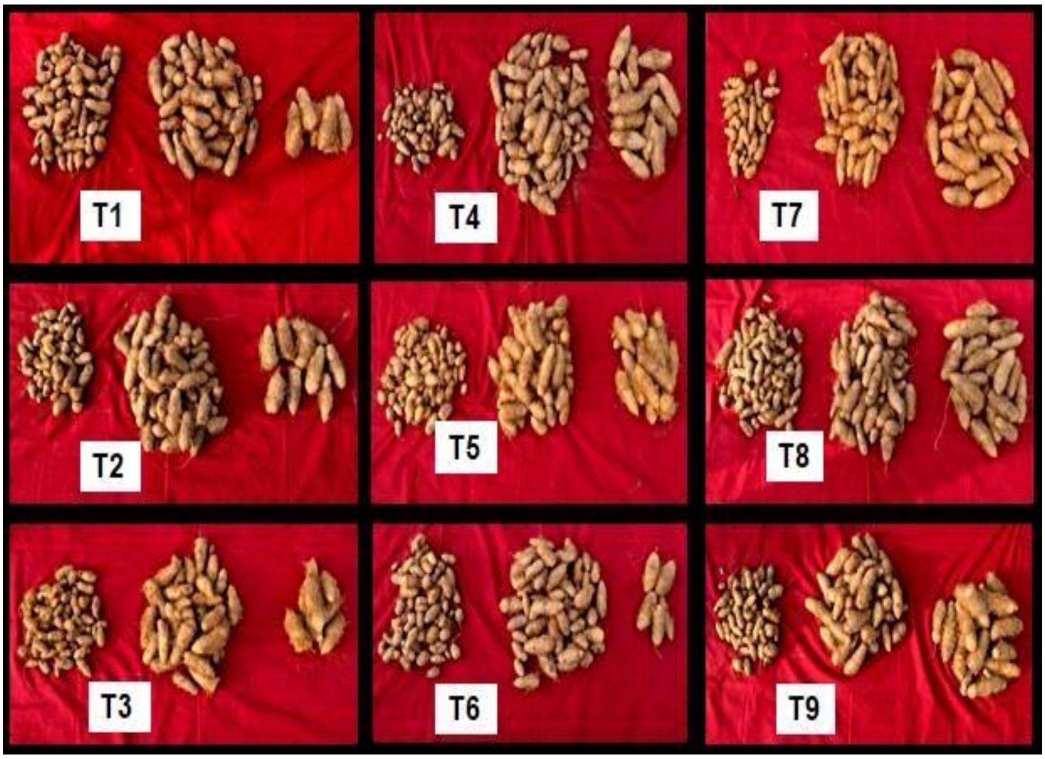


Plate 9. Harvested tubers (225 days after planting)

b) Tuber yield

Sett size had a significant effect on tuber yield of lesser yam (Table 27). Highest yield per vine was obtained from seed tubers of 150 g followed by 100 g and 50 g, which differed significantly from each other. The yield per vine ranged from 929 g in 50 g seed to 1270 g in plants from 150 g seed tuber. Plants grown under wider spacing (75 x 75 cm) registered the highest tuber yield of 1217 g which was significantly higher than per plant yield at medium spacing (1062 g) and closer spacing (972 g).

Interaction effect of seed tuber size and spacing was significant. The highest yield per vine was recorded for the treatment combination of 150 g @ 75 x75 cm spacing (1512 g) which was significantly superior. Next best treatment combinations were 150 g @ 75 x 50 cm (1192 g) and 50 x 50 cm (1105 g) as well as 100 g @ 75 x 75 cm and 75 x 50 cm, which were statistically comparable. Lower yields were observed for the 50 g seeds at all planting densities.

In case of seed tuber size, the performance of 50 g and 100 g tubers were comparable with respect to per hectare yield. Significantly higher yield was for 150 g seed tubers (34.29 t/ha). Closer spacing of 50 x 50 cm resulted in the highest yield and differed significantly from others (38.88 t/ha).

Interaction effect on total tuber yield per hectare showed a different trend and yield ranged from 44.2 t/ha to 17.66 t/ha due to the varied plant populations and sett size. Significantly higher yield was obtained from larger seeds at high density planting (44.2 t/ha). Next best treatment combinations were 100 g (37.09 t/ha) and 50 g seeds (35.36 t/ha) at high density planting. The seed tubers of 100 g and 50 g size when planted at medium spacing (75 x 50 cm), yielded 28.92 t/ha and 24.28 t/ha respectively which were on par. Lowest tuber yields were obtained from 50 g and 100 g tubers planted at widest spacing (17.66 t/ha and 20.37 t/ha respectively). From the results, it was evident that there existed a substantial effect of plant density on productivity of lesser yam.

The data on number of tubers are presented in the Table 27. Seed size had no effect on the number of tubers per vine, whereas, when the plant population decreased, a hike in the number of tubers could be observed. At wider spacing the tuber count was significantly higher (27.67 numbers per vine). Considering the interaction effect, a low tuber count was recorded for the plants at closer spacings. All tubers planted at wider spacing registered significantly higher number of tubers which were on par (27.67, 28.67, 29.67 numbers per vine).

The tubers were graded into small, medium and large sized based on the weight of individual tubers obtained from each plant. There was no significant effect of seed size and spacing on number of small, medium and large tubers and all the treatments showed uniformity in tuber size distribution. Also the effect of spacing or seed size on length and girth of tubers were non-significant among the treatments.

On an average, the number of small, medium and large seed tubers was observed to be 3.71, 6.66 and 13.48 at harvest. The mean length of small, medium and large tubers was recorded as 5.33, 8.64, and 13.33 respectively, whereas the average tuber girth was registered to be 8.62, 10.62, and 13.26 for small, medium and large tubers.

Table 27. Effect of seed size and spacing on yield and number of tubers at harvest in lesser yam

Treatment	Tuber yield (g/plant)	Tuber yield (t/ha)	Number of tubers per plant
Seed size			
50 g	929.22	25.77	26.22
100 g	1052.56	28.80	25.44
150 g	1269.67	34.29	26.22
CD (0.05)	110.05	3.18	NS
Spacing			
75 cm x 75 cm	1216.89	21.64	28.67
75 cm x 50 cm	1062.44	28.33	25.44
50 cm x 50 cm	972.11	38.88	23.78
CD (0.05)	110.05	3.18	1.94

Table 28. Interaction of seed size and spacing on yield in lesser yam

Treatment	75 cm x 75 cm	75 cm x 50 cm	50 cm x 50 cm
Tuber yield (g/plant)			
50 g	993.33	910.33	884.00
100 g	1145.67	1084.67	927.33
150 g	1511.67	1192.33	1105.00
CD (0.05)	190.62		
Tuber yield (t/ha)			
50 g	17.66	24.28	35.36
100 g	20.37	28.92	37.09
150 g	26.88	31.80	44.20
CD (0.05)	5.52		
Number of tubers per plant			
50 g	27.67	26.67	24.33
100 g	28.67	24.33	23.33
150 g	29.67	25.33	23.67
CD (0.05)	3.36		

Table 29. Effect of seed size and spacing on number of small, medium and large tubers in lesser yam

Treatment	Number of tubers at harvest		
	Small	Medium	Large
Seed size			
50 g	13.22	5.11	3.56
100 g	14.44	6.78	3.07
150 g	12.78	8.09	4.51
CD (0.05)	NS	NS	NS
Spacing			
75 cm x 75 cm	13.56	6.62	3.58
75 cm x 50 cm	14.22	6.76	3.60
50 cm x 50 cm	12.67	6.60	3.96
CD (0.05)	NS	NS	NS

Table 30. Interaction effect of seed size and spacing on number of small, medium and large tubers in lesser yam

Treatment	Number of tubers at harvest		
	75 cm x 75 cm	75 cm x 50 cm	50 cm x 50 cm
Small tubers			
50 g	13.00	13.00	13.67
100 g	17.33	14.33	11.67
150 g	10.33	15.33	12.67
CD (0.05)	4.53		
Medium tubers			
50 g	4.73	5.4	5.2
100 g	6.13	7.47	6.73
150 g	9.00	7.40	7.87
CD (0.05)	1.03		
Large tubers			
50 g	3.13	3.73	3.8
100 g	3.27	2.53	3.40
150 g	4.33	4.53	4.67
CD (0.05)	0.99		

4.4 EFFECT OF SEED SIZE AND SPACING ON WEED INCIDENCE

Diverse weed species were found in the experimental area among which *Borreria diffusa* was the major one. The weed spectrum constituted mainly the broad leaved weeds comprising *Borreria diffusa, Curculigo orchioides, Ludwigia parviflora, Cleome viscosa, Melochia corchorifolia, Ageratum conyzoides, Mimosa pudica, Mollugo pentaphylla, Urena lobata, Scoparia dulcis, Amaranthus viridis, Emilia sonchifolia, Sida cordifolia, Eclipta alba* and *Phyllanthus amara.* The grass species observed were *Panicum maximum, Pennisettum polystachion, Digitaria ciliaris* and *Axonopus compressus* competed with the crop in the vegetative phase. Sedges like *Bulbostylis barbata* and *Cyperus rotundus* were also recorded and their population was very low.

The weed population in treatment plots was comparable irrespective of spacing and seed size during the initial phase of 30 DAP and 60 DAP. Number of weeds per square metre ranged from 69 to 128 (30 DAP) and 61 to 157 (60 DAP) in various plots. At 30 DAP, no significant difference in weed dry matter production was observed with respect to seed tuber size. However, at 60 DAP, the treatments were significantly different (Table 31).

Spacing influenced the weed dry matter production and wider spacing favoured more weed dry matter production as compared to closer spacing at 60 DAP. The second dose of fertilizer application and earthing up were done after 60 DAP and the plots were kept weed free for the rest of the growth period.

Table 31. Effect of seed size and spacing on weed dry matter production

Treatment	Weed dry matter production (g/m^2)	
	30 DAP	60 DAP
Seed size		
50 g	135.11	171.56
100 g	125.33	156.44
150 g	131.50	85.33
CD (0.05)	NS	20.94
Spacing		
75 cm x 75 cm	115.56	179.56
75 cm x 50 cm	171.56	142.22
50 cm x 50 cm	104.89	91.56
CD (0.05)	22.85	20.94

4.5 INCIDENCE OF MAJOR PESTS AND DISEASES

Incidence of pest and diseases during crop period was observed and recorded. Tuber rot was the major disease observed during five months of planting. The causal agent was identified to be *Rhizoctonia solani.* Infected plants were dug out and removed. Soil drenching with the systemic fungicide Saaf® (Carbendazim 12 per cent + Mancozeb 63 per cent) at the rate of 1 g/L of water was done on the infected mounds. Prophylatic application of *Trichoderma harzianum* (20 g/L of water) was also done to prevent the incidence of fungal leaf spot. Anthracnose appeared as a minor disease. No pest incidence was recorded during the growth period.

4.6 SOIL NUTRIENT STATUS AFTER HARVEST

The data on soil pH, organic carbon, available N, P and K after harvest of the crop is as below.

Table 32. Soil nutrient status after harvest

Nutrients	Value
pH	4.96
EC (µS/cm)	126
Organic carbon (%)	1.86
N (kg/ha)	188
P (kg/ha)	29
K (kg/ha)	247

After cultivation the soil pH increased compared to the initial value. The electrical conductivity decreased to 126 µS/cm compared to 130 µS/cm before planting. Organic carbon content increased to 1.86 per cent after harvest. The available nitrogen and phosphorus in soil were recorded as 187.69 kg/ha and 29.32 kg/ha respectively; indicating that there was an increase in these nutrients in soil after harvest. The available potassium content in soil was 246.96 kg/ ha which was less than the initial value substantiating the higher K uptake of yams during the complete growth cycle.

4.7 PLANT NUTRIENT CONTENT AND UPTAKE

Nitrogen, phosphorus and potassium content in the aerial portion of lesser yam showed a declining trend with maturity of vine. N content decreased from 0.35 per cent at 135 DAP to 0.23 per cent by harvest (225 DAP), whereas corresponding values were 0.34 and 0.25 for phosphorus. Compared to nitrogen and phosphorus, the content of potassium was more. Also a sharp decline in potassium content of aerial portion was noticed with maturity of vine that is from 1.35 per cent to 0.81 per cent. However, in case of tubers, the content of nitrogen, phosphorus and potassium, showed a slight increase or remained more or less constant. Potassium content in tubers were considerably higher compared to nitrogen and phosphorus. The harvested tubers on an average had 0.41 per cent nitrogen, 0.51 per cent phosphorus and 1.30 per cent potassium.

Plant uptake of nutrients is shown in Table 34. Both nitrogen and phosphorus uptake of yams were comparable during the growth phase, whereas potassium uptake was twice compared to that of both nitrogen and phosphorus. Among all the treatments the highest nutrient uptake from unit area was more in high density planting due to increased demand for nutrients for a large population compared to that of medium and low density planting. On an average nutrient uptake by plants at harvest was estimated at72.44 kg/ha nitrogen, 86 kg/ha phosphorus and 237.44 kg/ha potassium. Nitrogen and phosphorus uptake by lesser yam was found to be comparable, whereas potassium uptake registered more than twice to that of nitrogen or phosphorus uptake by plants.

Table 33. Average plant nutrient content at different growth stages of lesser yam*

Nutrients	135 DAP	180 DAP	225 DAP
Aerial portion			
N (%)	**0.**35	0.40	0.23
P (%)	0.34	0.46	0.25
K (%)	1.35	1.23	0.81
Tubers			
N (%)	0.30	0.28	0.41
P (%)	0.44	0.49	0.51
K (%)	1.34	1.11	1.30

*Not statistically analyzed

Table 34. Nutrient uptake of lesser yam at harvest

Treatments	Seed size		
Spacing	**50 g**	**100 g**	**150 g**
	Nitrogen uptake (kg/ha)		
75 cm x 75 cm	40	48	56
75 cm x 50 cm	63	76	76
50 cm x 50 cm	94	95	104
CD (0.05)	4.57		
	Phosphorus uptake (kg/ha)		
75 cm x 75 cm	48	57	66
75 cm x 50 cm	75	90	90
50 cm x 50 cm	111	113	124
CD (0.05)	5.42		
	Potassium uptake (kg/ha)		
75 cm x 75 cm	132	158	183
75 cm x 50 cm	207	248	248
50 cm x 50 cm	307	312	342
CD (0.05)	14.98		

4.8 COST BENEFIT ANALYSIS

The analysis of cost of production and economic benefit can help to arrive at a recommendation for commercial production of lesser yam. The tuber yield in various treatments varied from 17.66 t/ha to 44.22 t/ha and shows that there is a scope for enhancing productivity by adjusting the geometry and reducing the seed tuber size.

Among the treatments the highest yield of 44.20 t/ha was obtained from most densely planted (50 x 50 cm spacing) 150 g tubers, followed by 100 g tubers (37.09 t/ha) and 50 g tubers (35.36 t/ha). When the seed tubers of 100 g and 50 g were planted at 75 x 50 cm spacing, tuber yield was 28.92 t/ha and 24.28 t/ha respectively; compared to the normal yield of 26.88 t/ha obtained from 150 g tubers planted at 75 x 75 cm spacing (recommended spacing). Lower yields were obtained from 50 g and 100 g tubers planted at the widest spacing, 17.66 t/ha and 20.37 t/ha respectively.

The cost of cultivation ranged from ₹ 1, 99,588 to ₹ 5, 73,660 (Table 35). The lowest cost was for 50 g seed tubers at wider spacing of 75 x 75 cm, whereas the highest cost was for 150 g tuber at closer spacing. The closer spacing resulted in higher cost of cultivation due to considerable increase in plant population resulting in high labour cost and cost of trailing as well as higher expenditure for seed tubers. Three best treatments with higher profit were of high density planting (50 x 50 cm) due to their superior productivity. The highest net profit was realized when 150 g seed tubers were planted at 50 x 50 cm spacing (₹ 5, 31,340/ ha) compared to ₹ 4, 01,300 for 150 g at wider spacing of 75 x 75 cm. The second best treatment with respect to net profit per hectare was 50 g seed tubers at 50 x 50 cm (₹ 4,70,340) followed by 100 g tubers at same spacing (₹ 4,33,590).

Benefit cost ratio is an important attribute to analyze the feasibility of a technology to be adopted. The various treatments in the experiment gave the B-C ratios ranging from 1.88 to 2.48. Cost of cultivation as well as returns were higher when lesser yam was grown with bigger sized seed tubers under high density planting (B-C ratio 1.93). However, maximum benefit: cost ratio of 2.48 was associated with large size planting material (150 g) at wider spacing (75 x 75 cm). This was followed by medium (100 g) and small (50 g) seed tubers planted at wider spacing (2.21 and 2.17 respectively). All treatment combinations except 100 g and 150 g tubers planted at closer spacing of 50 x 50 cm resulted in B-C ratios more than two.

Table 35. Cost benefit analysis of high density planting in lesser yam

Treatment	Yield (t/ha)	Total cost of cultivation (₹ / ha)	Gross returns (₹ / ha)	Net returns (₹ / ha)	B-C ratio
50 g seed tuber					
75 x 75 cm	17.66	1,99,588	4,41,500	2,41,912	2.21
75 x 50 cm	24.28	2,85,773	6,07,000	3,21,227	2.12
50 x 50 cm	35.36	4,13,660	8,84,000	4,70,340	2.14
100 g seed tuber					
75 x 75 cm	20.37	2,35,144	5,09,250	2,74,106	2.17
75 x 50 cm	28.92	3,39,107	7,23,000	3,83,893	2.13
50 x 50 cm	37.09	4,93,660	9,27,250	4,33,590	1.88
150 g seed tuber					
75 x 75 cm	26.88	2,70,699	6,72,000	4,01,301	2.48
75 x 50 cm	31.80	3,92,440	7,95,000	4,02,560	2.03
50 x 50 cm	44.20	5,73,660	11,05,000	5,31,340	1.93

5. Discussion

5. DISCUSSION

The results of field experiment conducted to study the effect of high density planting and seed tuber size on productivity enhancement of lesser yam are discussed in this chapter.

5.1 EFFECT OF SEED SIZE AND SPACING ON GROWTH PARAMETERS

Both spacing and seed tuber size profoundly influenced the growth parameters in lesser yam. The days to emergence were influenced by the size of seed tubers whereas spacing had no effect on the emergence rate. On an average about 60 per cent emergence could be noticed at 10 DAP, and the large seed tubers of 150 g showed a high emergence rate of 74 per cent compared to 47 per cent in 50 g seed tubers. Seed tubers of 100 g weight registered intermediate emergence percentage of 56 per cent. At 30 DAP also superiority of 150 g seed tuber was clear with 98 per cent of emergence whereas in medium and small the corresponding figures were 87 per cent and 89 per cent. In yams there is a dormancy period of 2-4 months and the buds emerge during the storage time itself. However, it was observed that there existed a close relation between bud emergence and size of tubers. Large sized seed tubers showed early sprouting in storage compared to that of relatively small tubers. This relation was reflected in the field emergence also. It is important to note that during the period of 30-40 DAP, irrespective of the size, 100 per cent emergence could be observed. This shows the possibility of utilizing even smaller seed tubers as planting material in lesser yam. The delay in germination or emergence was not considerable enough to result in an appreciable difference in vegetative growth as evidenced from comparable vine length attained among all the plants within 90 DAP. Ferguson *et al.* (1983), in White Lisbon yam (*Dioscorea alata*) observed that the plants from larger setts (355 g) emerged earlier than medium (170 g) and smaller setts (85 g).

As expected, spacing did not influence the emergence percentage. An emergence percentage of 92 per cent was recorded within 30 DAP, as there was no plant to plant competition for space or other crop growth factors. Masarirambi (2012) reported that in potato, the days to emergence was significantly influenced by seed tuber size whereas the population density had no significant effect.

Observations on number of sprouts that emerged from an individual seed tuber was recorded to know whether the seed tuber size affected the plant biomass production in its early growth phase. The number of shoots was more in large seed tubers and significant difference was seen among the three seed sizes. Compared to 50 g tubers the number of sprouts was twice in large tubers (5.44 per tuber), probably due to more number of dormant buds. This also shows a regulatory mechanism within the tuber to adjust to reserve food materials. Spacing did not influence the number of sprouts per seed tuber and on an average four sprouts per tuber was observed in different planting densities. According to Onwueme (1972), formation of higher number of shoots in large seed tubers of *Dioscorea* sp. resulted out of the least dominance of early sprouts over the later formed ones that were relatively remote from the initial sprout. In yams, the primary nodal complex provides a vascular connection between the developing shoot and the stored reserves of the mother tuber, hence large seed tubers by utilizing more reserves have a potential to produce more number of sprouts per tuber (Wikham *et al.*, 1980).

Both the number of leaves and total leaf area were influenced by seed size and planting, whereas vine length was solely influenced by the seed size at 45 DAP. Vines that emerged from large seed tubers produced longer vines. The effect of seed tuber size was pronounced only during the initial vegetative phase of 45 DAP. Later, within three months of growth all plants attained comparable vine length. It might be due to the fact that the initial growth in yams mainly depended on the food reserves from seed tuber and larger corms contributed more food materials for the growing vines. Above all, the plants were given the first dose of fertilizer application at 30 DAP. This resulted in good vegetative growth and development of vines. A second top dressing was also given at 60 DAP, and this further enhanced the vegetative growth of vines irrespective of seed tuber size. Onwueme (1975) reported that larger setts sprouted more readily, emerged more quickly, and produced more vigorous plants with more extensive leaf area. He also opined that large seeds were probably able to transfer a greater quantity of material from the sett to the growing vine.

With respect to effect of spacing, better vine growth was observed in wider spacing when seed tubers were larger and spacing as such had no influence because of the fact that even under closer spacing of 50 x 50 cm, there was no limitation in space or sunlight for individual plants. Hence there was no plant to plant competition even in the initial stage of 90 DAP. In the present study, all the plants were uniformly staked with 2m long poles. This resulted in the limited growth of vines that emerged from larger seed tubers and might have resulted in their performance on par with vines emerged from medium and small sized seed tubers. As staking considerably increase the cost of cultivation, use of longer stakes are not economical from a practical point of view.

Leaf number increased up to 135 DAP, after which there observed a gradual decline by 180 DAP. This was probably due to senescence of older leaves in the later stages of growth. Tuber bulking was at a higher rate during senescence period characterized by low assimilation in leaves and higher translocation of assimilates to the sink. Leaf area showed same trend as that of leaf count. Haynes *et al*. (1967) observed that in greater yam (*Dioscorea alata*) the leaf area declined with the commencement of active tuber formation.

The dry matter production of lesser yam was influenced by seed tuber size and spacing. Due to more vigorous vegetative growth and more space available to individual plants, higher values of dry matter accumulation by both aerial portions and tubers were observed in combination of wider spacing and large seed tuber. This can be explained by the better growth parameters recorded at various growth stages of the crop.

Yield in tuber crops depends directly on the synthesis, transport and accumulation of dry matter content. Dry matter accumulation by aerial portion increased up to 135 DAP and remained almost stagnant, and a marginal decrease could be observed by 225 DAP from 180.07 g to 94.85 g per vine. However, the trend in dry matter accumulation was slightly different in the case of underground portion. Dry matter accumulation showed an increasing trend even during the period from 180 to 225 DAP. This may be due to storage of photosynthates in the tuber and reduction in translocation to aerial vegetative portion. According to Okoli (1980), the total amount of dry matter accumulated in the aerial portions (vines, leaves, and flowers) of the yam plant was observed to be maximum between the 16th and 18th week after planting, after which it decreased as growth progressed. Also he opined that the decrease in dry matter of aerial portions was partly due to the emergence of the sink organ (tuber) in the developmental sequence of the plant and partly due to abscission of leaves following browning and senescence of vines and leaves.

Tuber dry weight per vine was not significantly influenced by spacing and the values ranged from 295.56 g/vine in closer spacing to 323.67 g/vine in wider spacing, indicating that competition for space was not there even at the higher population. The trend in tuber dry matter production and that of total dry matter production was almost the same. Of the total DMP, the underground portion accounted for 24 per cent at 135 DAP whereas the corresponding value at harvest stage was 77 per cent. Melteras *et al.* (2008) observed that in *D. rotundata*, the tubers constituted 87 per cent of total dry matter at 45 weeks after planting. Also, Irizarry and Rivera in 1985 reported that 84 per cent of total dry matter in *D. rotundata* was accounted by the tubers and it exceeded 50-67 per cent in *D. esculenta* according Enyi (1972). It was seen that the plants from seed tubers of 100 g and 150 g weight had comparable dry matter accumulation at harvest. This can be attributed to their early emergence, more number of sprouts per tuber, and better vegetative growth parameters during initial growth phase, which contributed to more photosynthetic area and ultimately more storage in tubers.

In order to obtain the maximum yields, a sufficient balance between shoot, root and tuber growth should be achieved in tuber crops (Osaki *et al*., 1996). Higher productivity in tuber crops like yams is attributed to the balance between shoot and root activity as the photosynthates have to be actively distributed to the underground sink.

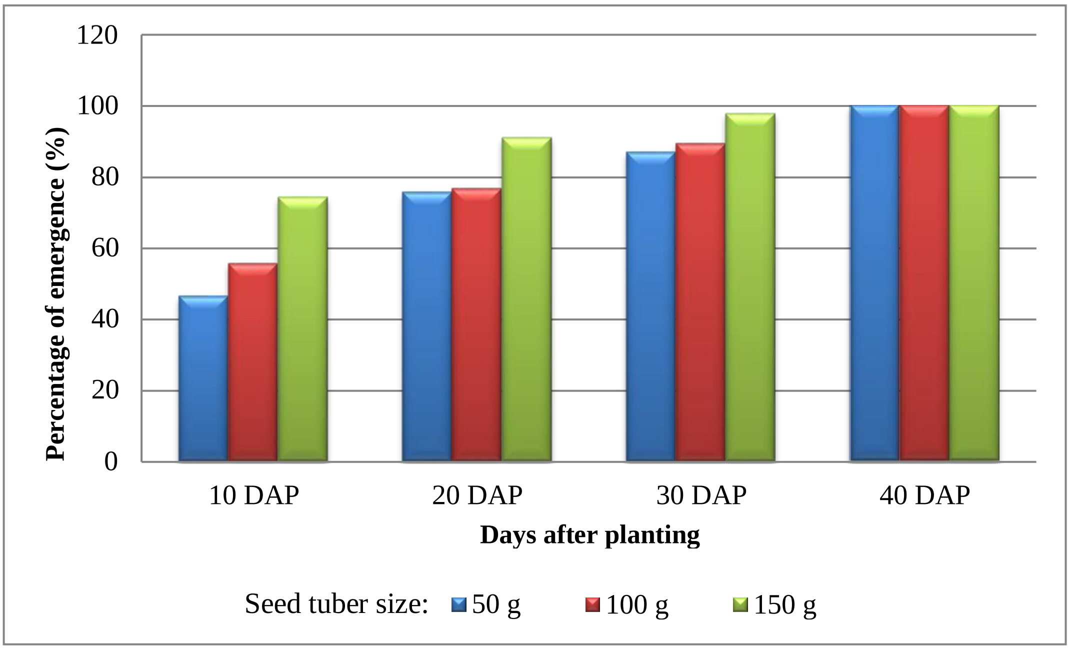


Fig. 2. Effect of seed size and spacing on percentage of plants emerged

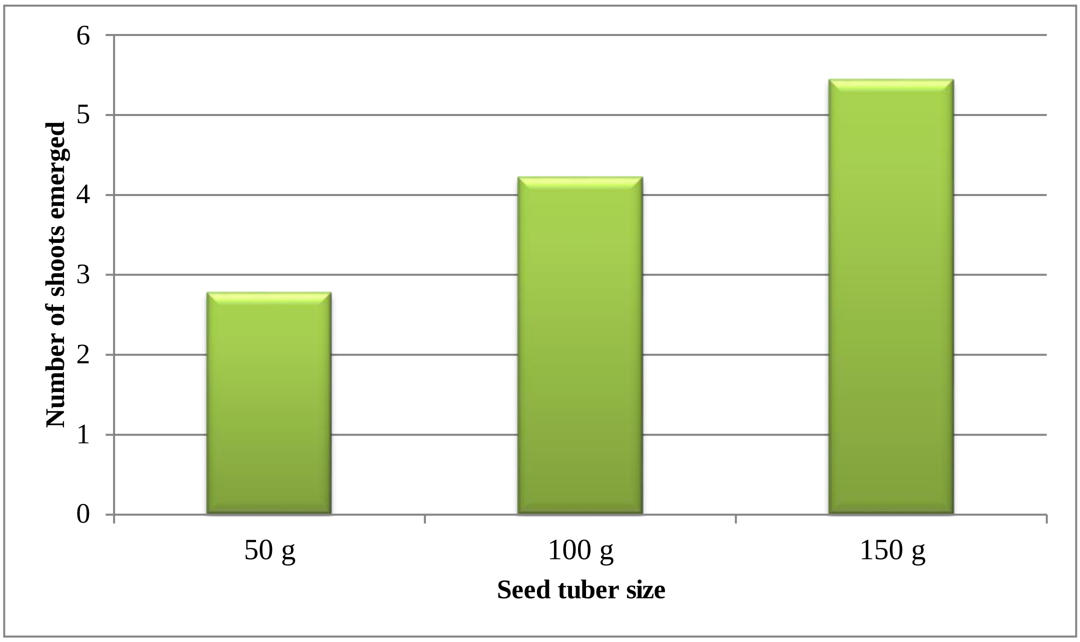


Fig.3. Effect of seed size on number of shoots emerged per tuber (45 DAP)

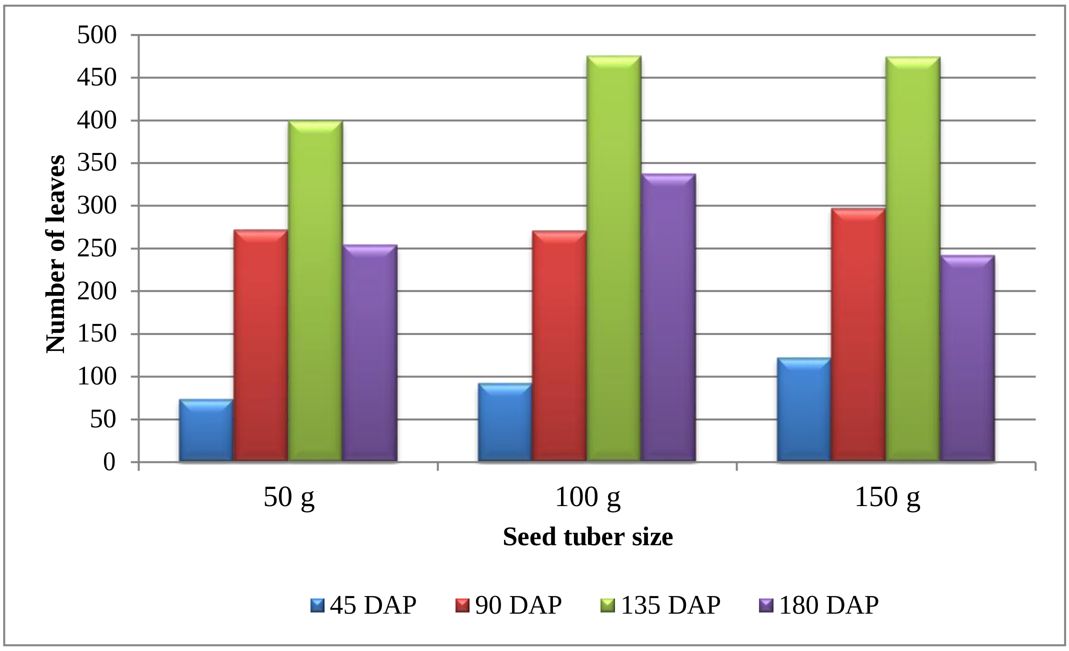


Fig.4. Effect of seed size on number of leaves of lesser yam

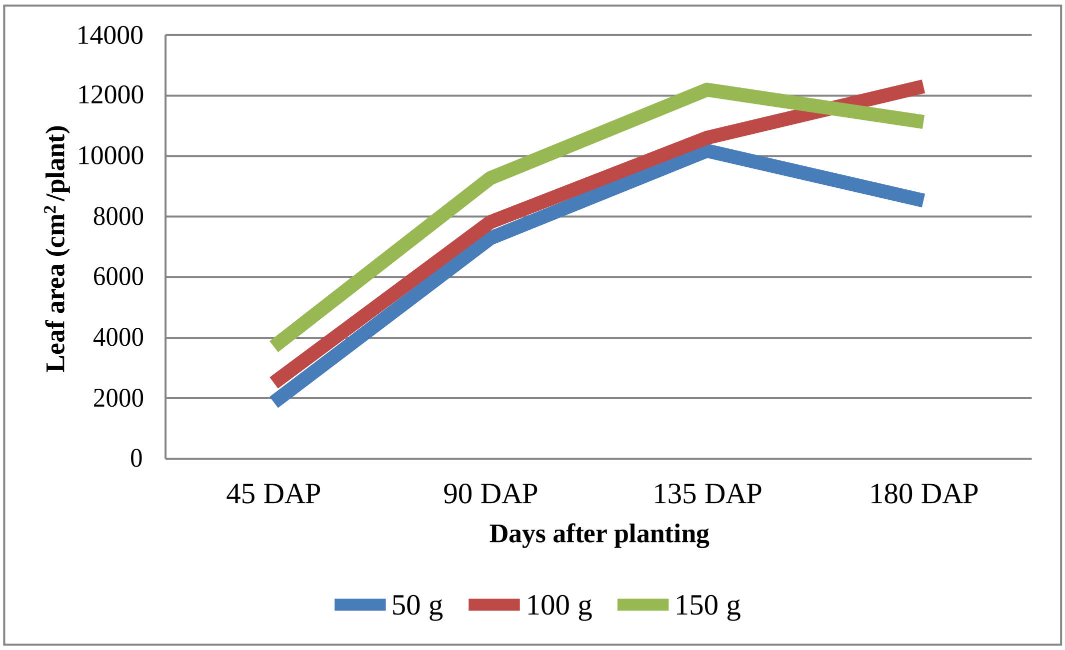


Fig. 5. Effect of seed size on leaf area of lesser yam

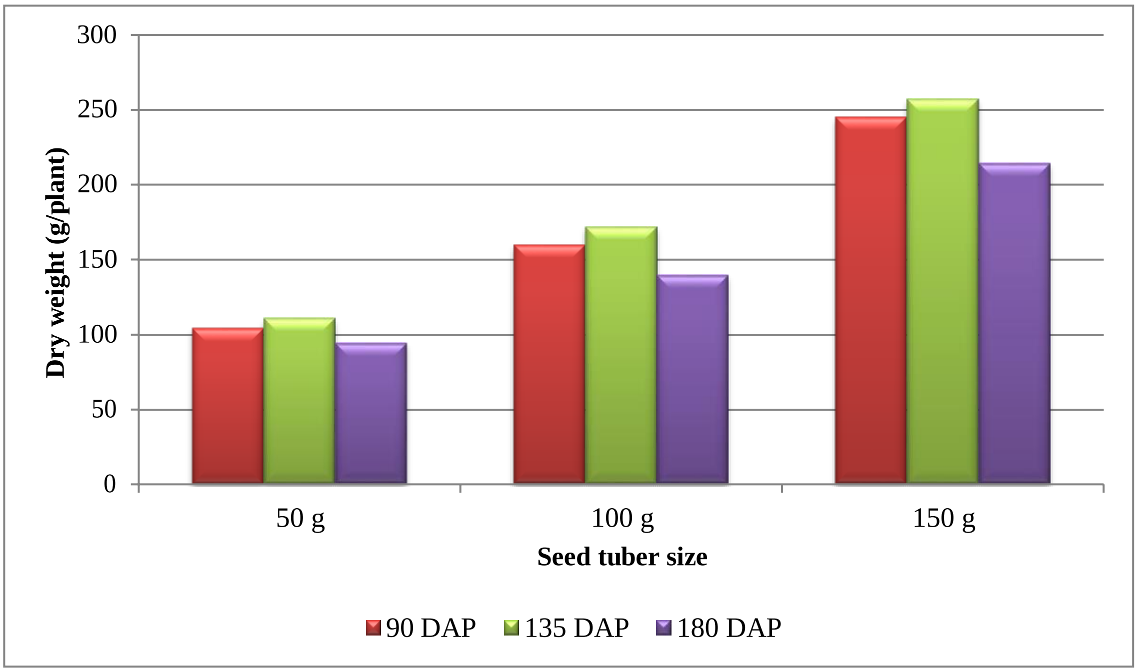


Fig.6. Effect of seed size on dry weight of aerial portion

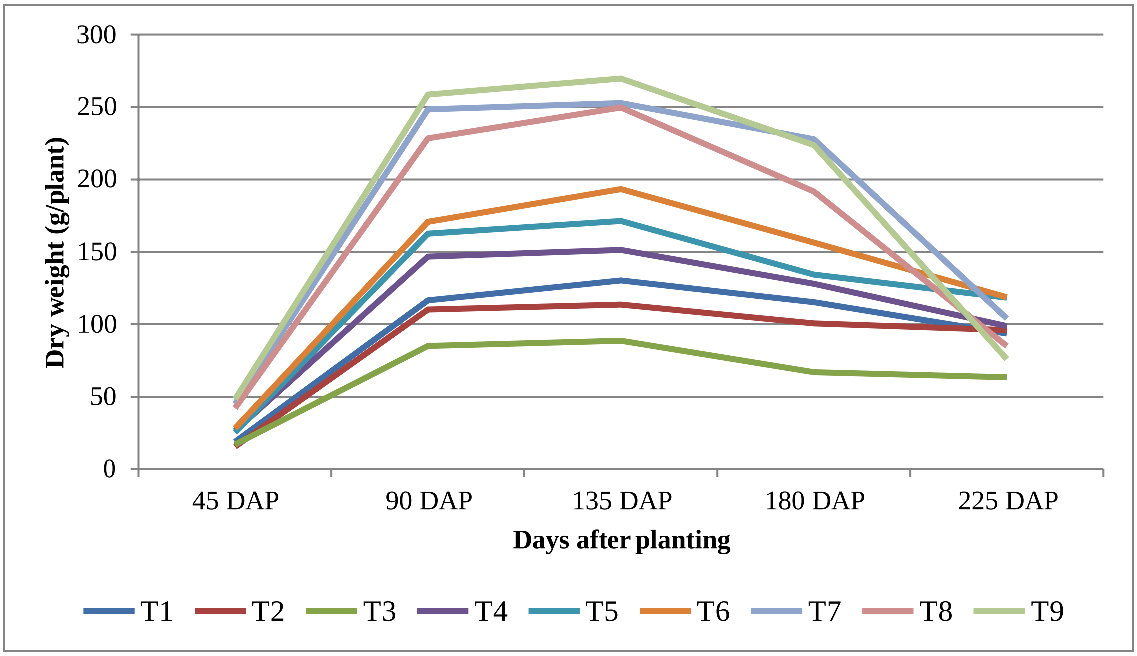


Fig. 7. Interaction effect of spacing and seed size on dry weight of aerial portion

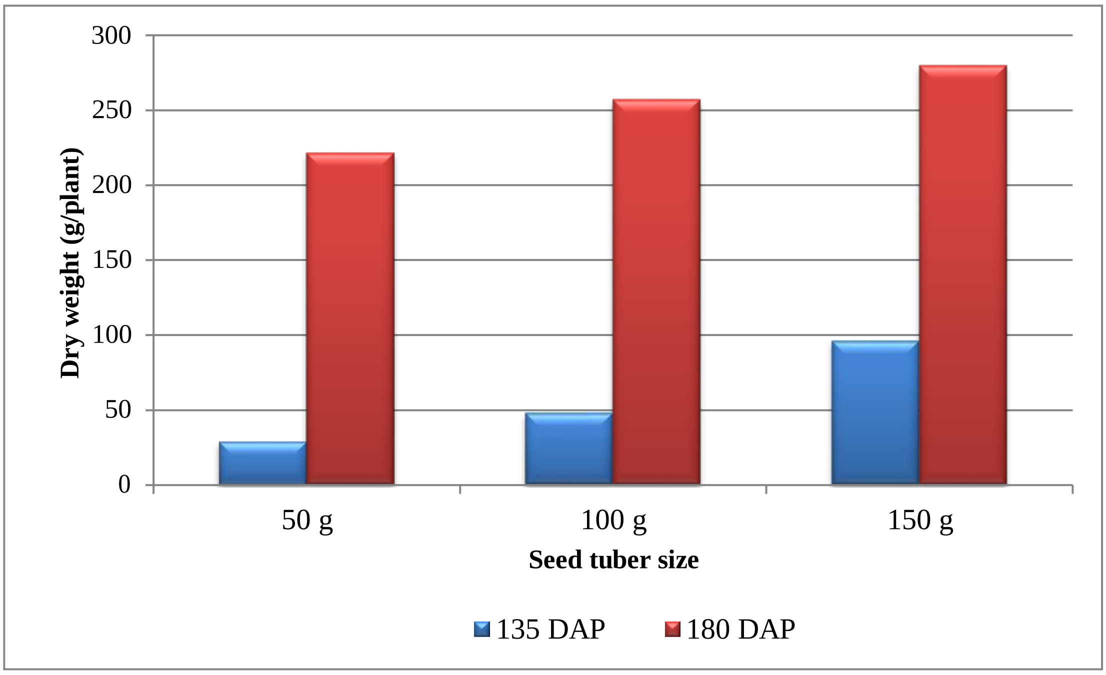


Fig. 8. Effect of seed size on tuber dry weight per plant

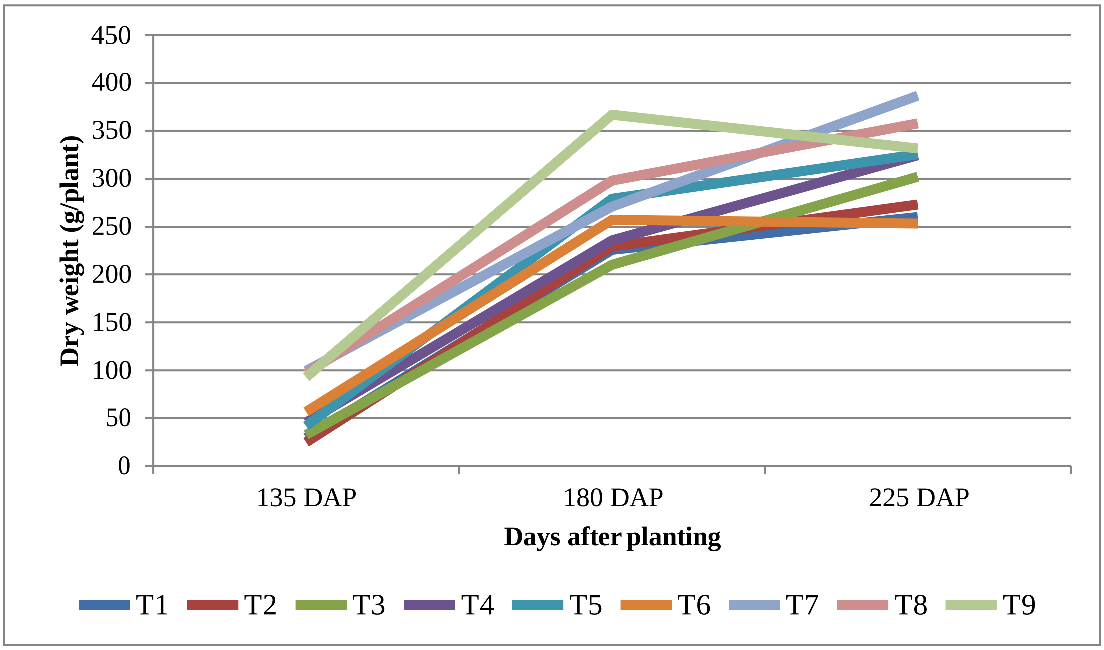


Fig.9. Interaction effect of spacing and seed size on tuber dry weight per plant

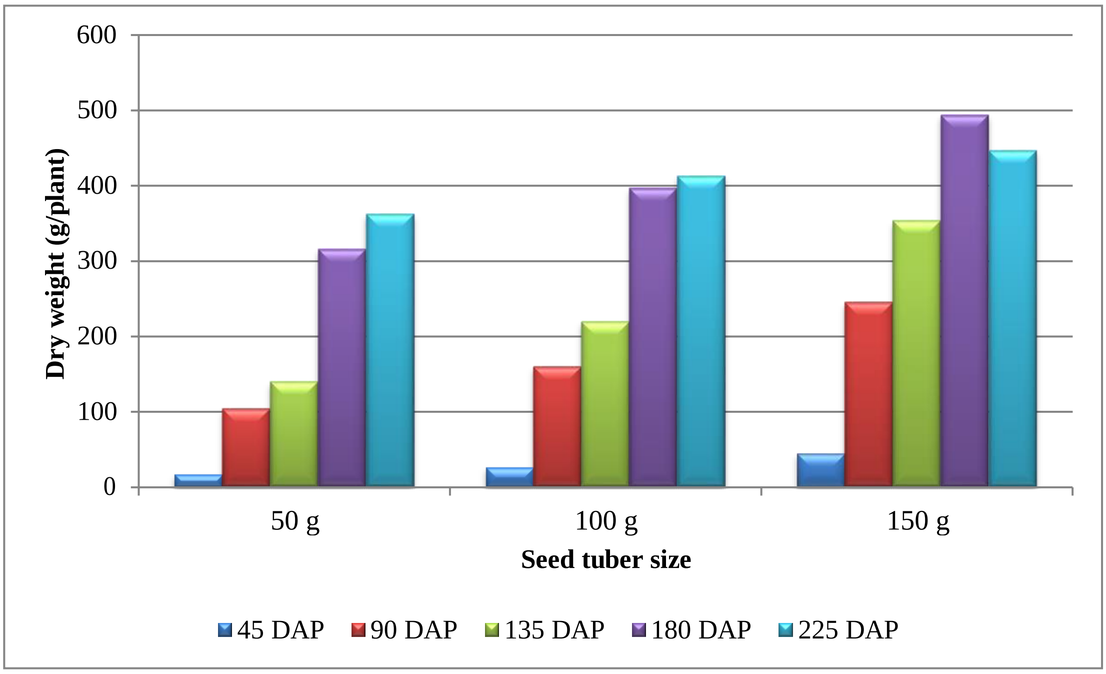


Fig. 10. Effect of seed size on total plant dry weight of lesser yam

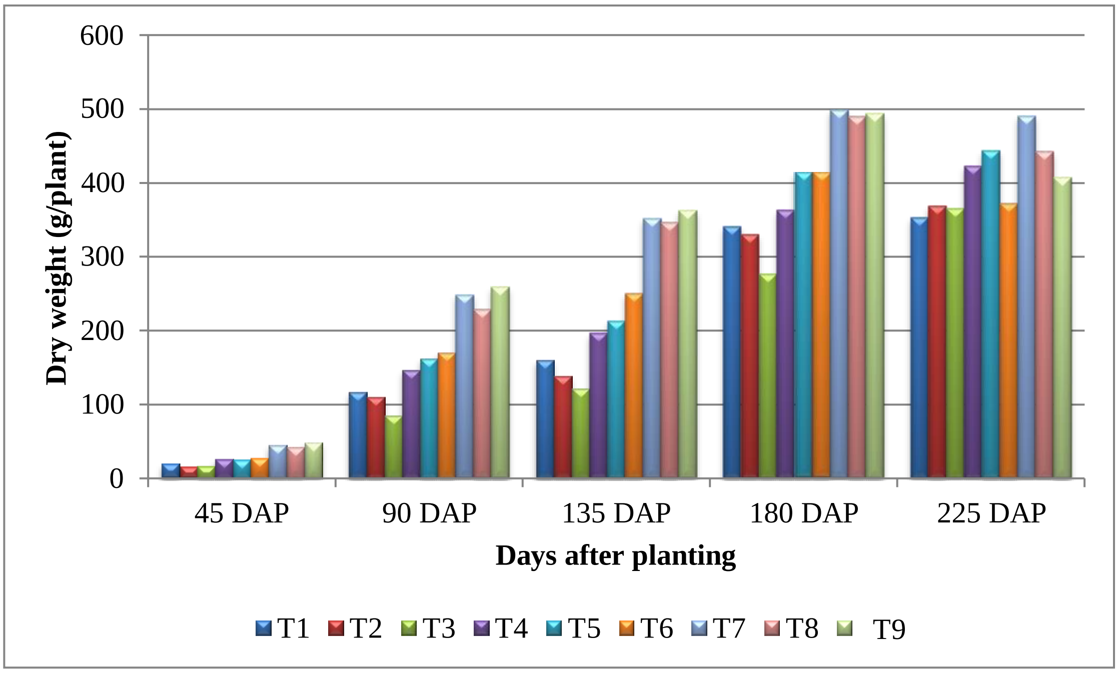


Fig.11. Interaction effect of spacing and seed size on total plant dry weight

5.2 EFFECT OF SEED SIZE AND SPACING ON CROP GROWTH INDICES

LAI is an important parameter in deciding the yield of any crop as optimum LAI is needed to realize maximum yield. In lesser yam LAI increased from 0.76 to 2.88 from 45 DAP to 135 DAP and a decline in LAI was noticed from 135 DAP to 180 DAP. This shows that the plants attained peak vegetative growth by 135 DAP and decline towards later phase is due to leaf fall and plants mobilizing the photosynthates to tuber instead of diverting to aerial portions. This also indicates that peak tuber bulking phase starts after 135 DAP. During crop growth, the extent of leaf area and its display and duration determines the amount of solar energy captured for photosynthetic carbon assimilation. Photosynthetic efficiency of yams is closely related to the effective display of leaf area to ensure maximum light reception (Akoroda, 1993).

Staking also influenced the light interception by leaves in lesser yam. Enyi in 1972 reported that the dry matter accumulation in lesser yam was greater in staked than in unstaked plants. Staking and nitrogen and potassium fertilizer application tended to increase the proportion of dry matter diverted into the tubers.

The effect of both seed tuber size as well as spacing on LAI was evident and the highest LAI of 3.35 was observed when plants were closely planted at a spacing of 50 x 50 cm as LAI is a function of land area available for individual plants. The positive effect of large seed tuber size was due to vigorous vegetative growth and more number of leaves (474.33 leaves per vine) which resulted in more leaf area (12191.37 cm^2/plant). Enyi (1972) reported that LAI increased with increase in seed size from 15 g to 110g and decreased with wider spacing. Nedunchezhiyan *et al.* (2008) opined that large sized seed tubers channelized more food reserves which resulted in increased vine length and higher leaf area development in greater yam. Suja and Nair (2006) also observed a low leaf area index at wider spacing (120 x 120 cm) compared to that of medium (90 x 90 cm) and closer spacing (60 x 60 cm) in greater yam, which is in close agreement with the result.

Growth indices like crop growth rate, relative growth rate and net assimilation rate were studied at different stages of the crop growth. Crop growth rate showed significant differences with respect to seed size and spacing. In all the sampling intervals the large seed tubers generally exhibited higher crop growth rate.

Crop growth rate showed a decreasing trend during the period of 90-135 days after planting compared to the initial growth phase. But it increased during the later growth phase of 135-180 days after planting. This is due to rapid tuber bulking during the later phase of growth (135-180 DAP) at which the leaves were actively photosynthesizing. The decreased rate registered during the active vegetative stage of 90-135 DAP can be attributed to the lag phase of crop growth where the rate of increment in dry matter production is less. Whereas the senescence of aerial portion resulted in a lower or negative crop growth rate values at the late maturity phase. Large seed tubers and closer spacing contributed to higher CGR in lesser yam throughout the growth period. For example; in the active growth phase (90-135 DAP), the values for larger seeds were higher (7.03 g/m^2/day) compared to medium (4.00 g/m^2/day) and small tubers (2.20 g/m^2/day), whereas values were 6.67, 3.88 and 2.59 g/m^2/day for high, medium and low density planting. According to Melteras *et al.* (2008), crop growth rate reflected the photosynthetic capacity of the crop and it followed a similar pattern to vine dry weight, but declined more steeply in the vine senescence period in lesser yam. Also the declining photosynthetic efficiency of the senescing leaves added to the loss of biomass. Spacing substantially affected CGR as it was inversely related to plant spacing. High density planting exhibited highest CGR except at the initial 45-90 DAP. In the senescence phase plants showed negative CGR as the leaf shedding and drying commenced during 180-225 DAP.

Higher relative growth rate was observed at the initial growth phase of lesser yam (45-90 DAP), which could be attributed to rapid vegetative growth during this period that was evident from the recorded biometric parameters and dry matter accumulation. A decrease in RGR after the peak vegetative phase was due to the fact that the dry matter contribution from the tubers were comparatively low at 90-135 DAP. Maduakor *et al.*, (1984) suggested that relative growth rate, as a reflection of the photosynthetic capacity, followed a similar pattern to vine dry weight, but declined more steeply in the vine senescence period, as declining photosynthetic efficiency of the senescing leaves added to loss of leaf biomass. Relative growth rate was fairly steady, around 0.13 g/g/week during the initial vegetative stage, but declined during tuber bulking due to the effect of the unproductive tuber mass. Tuber bulking rate, however, remained high after vine growth had ceased. In lesser yam, Enyi (1972) recorded that the mean RGR for the entire sampling period decreased with the increase in sett size. Law-Ogbomo and Remison (2007) observed high degrees of dry matter accumulation, crop growth rate and net assimilation rate in large sized minisetts of white guinea yam which positively influenced the fresh tuber yield.

Similar to crop growth rate, net assimilation rate was higher during the initial growth stage of lesser yam which was followed by a decreasing trend during the active vegetative phase and further increased towards the tuber bulking period. Net assimilation rates were higher for the plants that emerged from the large seed tubers at 45-90 DAP and 90-135 DAP, whereas during 135-180 DAP, small seed tubers exhibited a higher NAR. The initial stage of growth (45-90 DAP) is solely depended on the food reserves in seed tubers and hence spacing had no significant effect on the NAR. The net assimilation rate showed a decline at active vegetative phase (90-135 DAP) compared to tuber bulking phase (135-180 DAP) even if the vegetative growth was higher during the former phase. It is attributed to the fact that the contribution of tuber dry weight to total dry weight was meager at peak vegetative phase as high moisture content of tubers at this phase resulted in a low tuber dry weight. According to Sobulo (1972), the moisture content in Greater yam tubers was observed to be 70.20 per cent during the active vegetative phase comparing to that of constant lower values towards the end of crop growth phase i.e., 62.80 per cent.

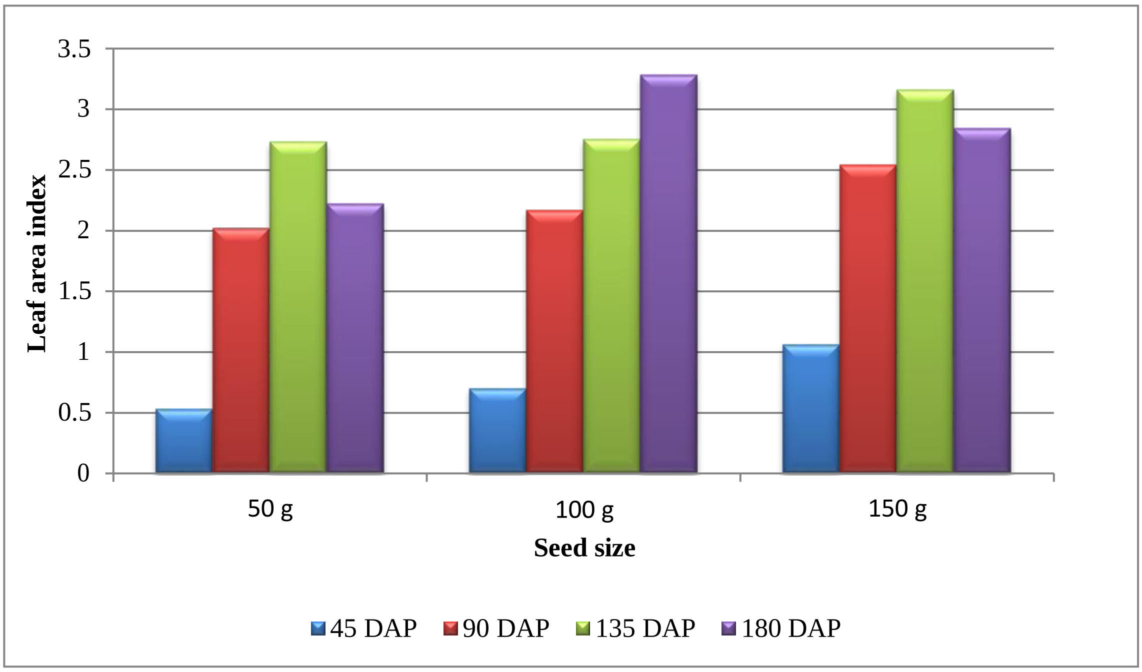


Fig.12. Effect of seed size on leaf area index

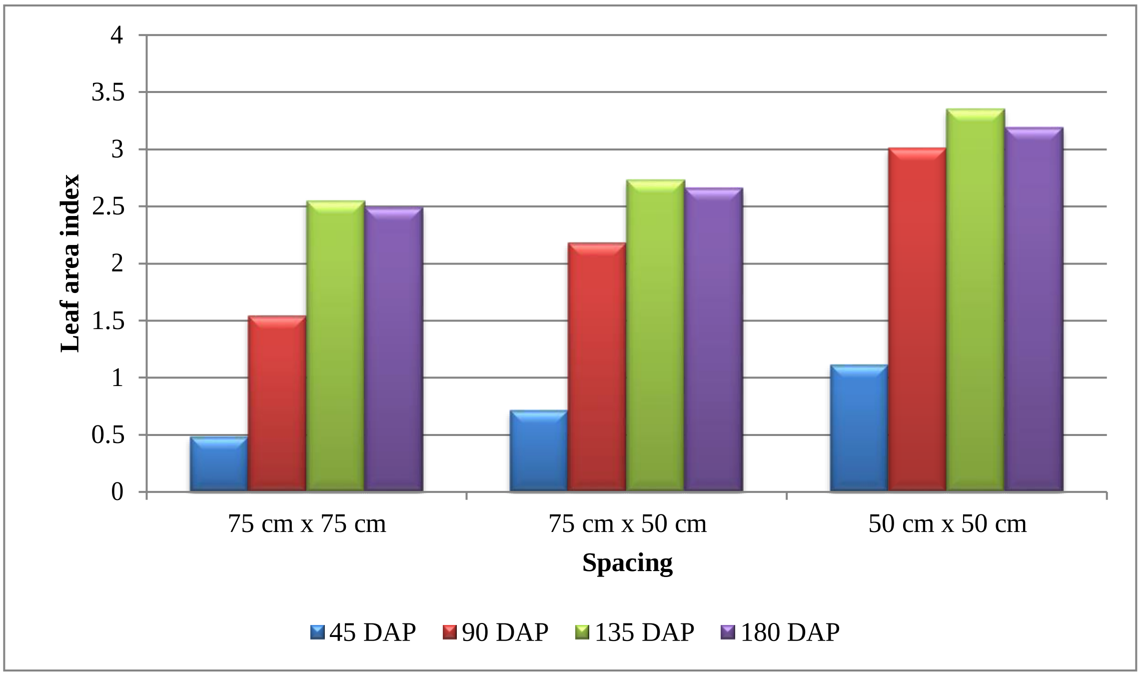


Fig. 13. Effect of spacing on leaf area index

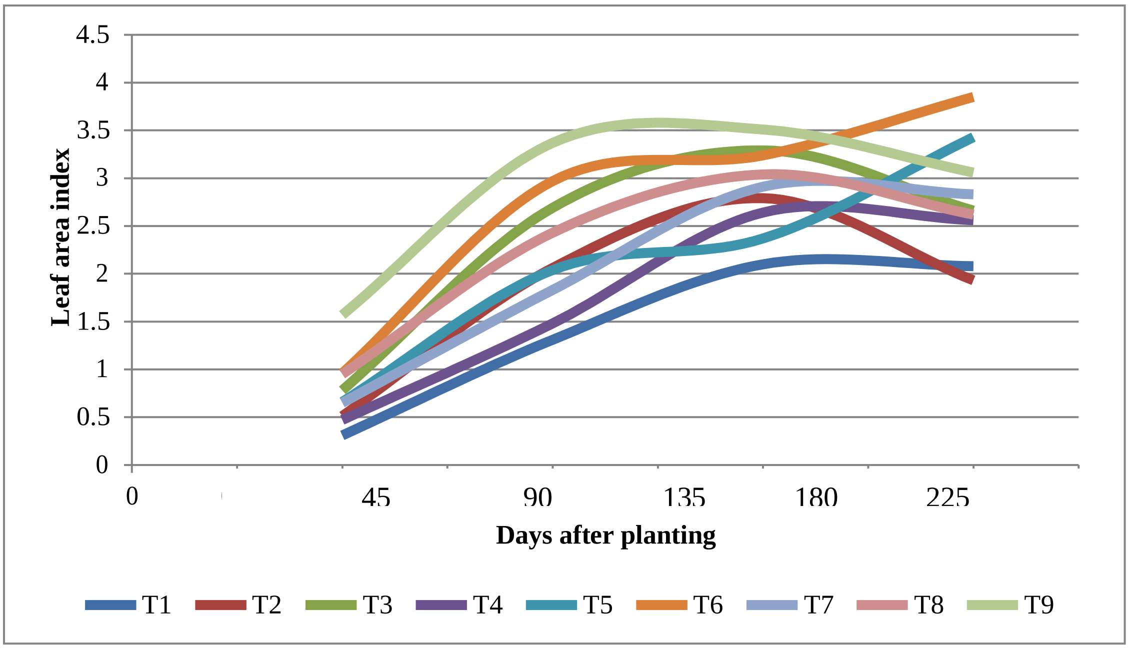


Fig. 14. Interaction effect of seed size and spacing on leaf area index

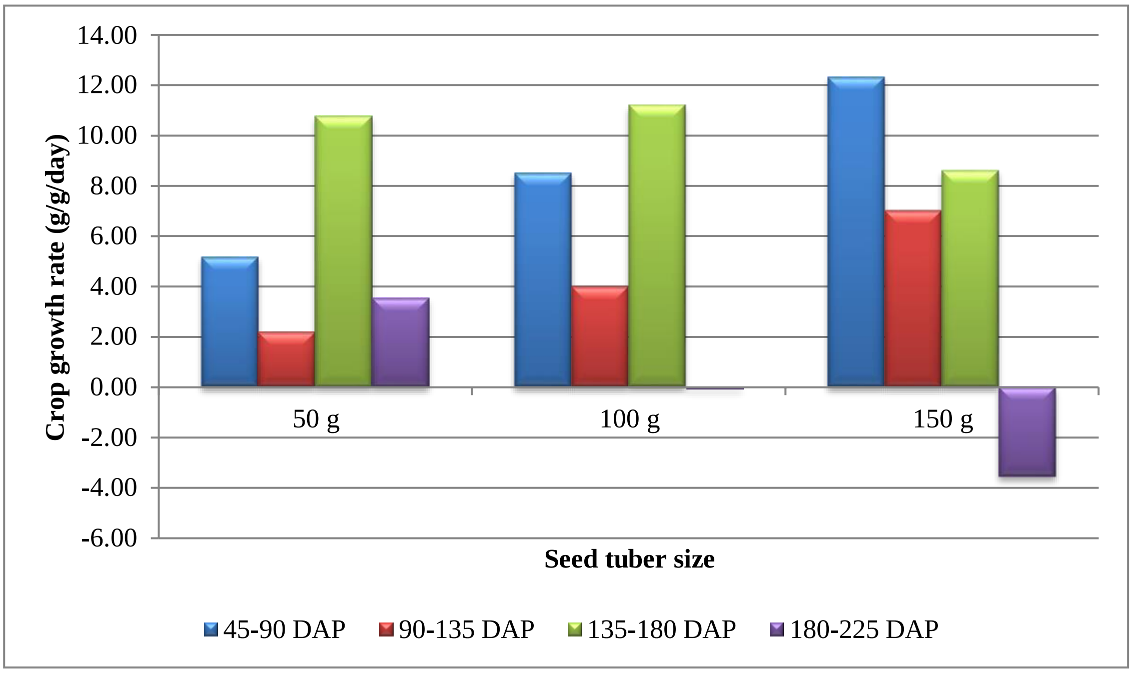


Fig. 16. Effect of seed size on crop growth rate

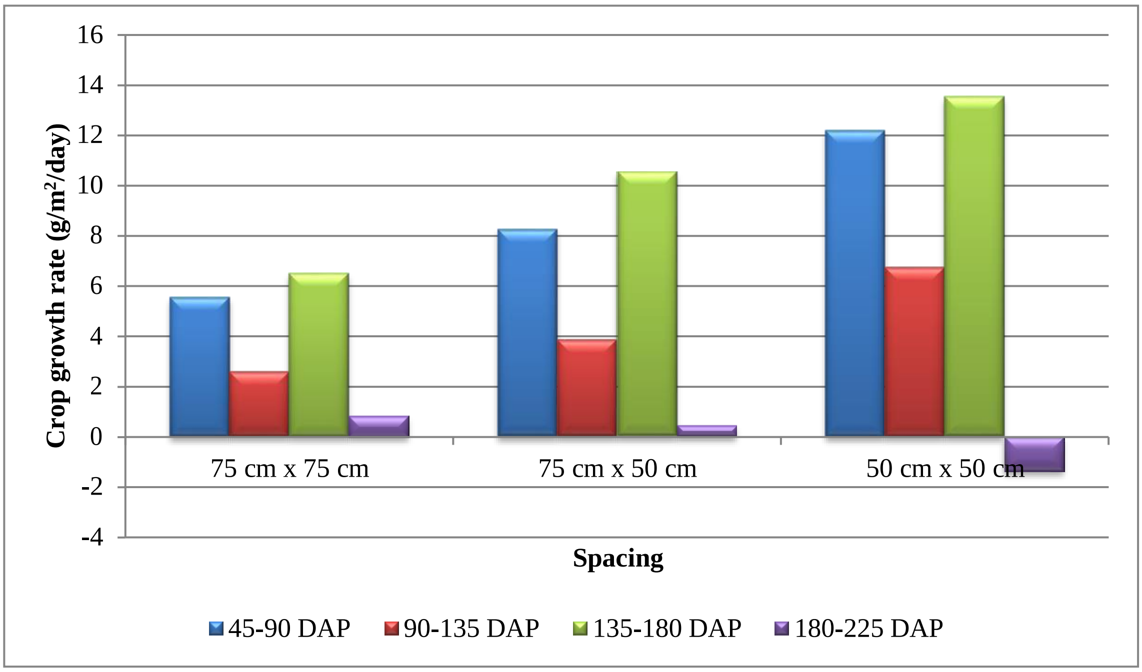


Fig. 17. Effect of spacing on crop growth rate

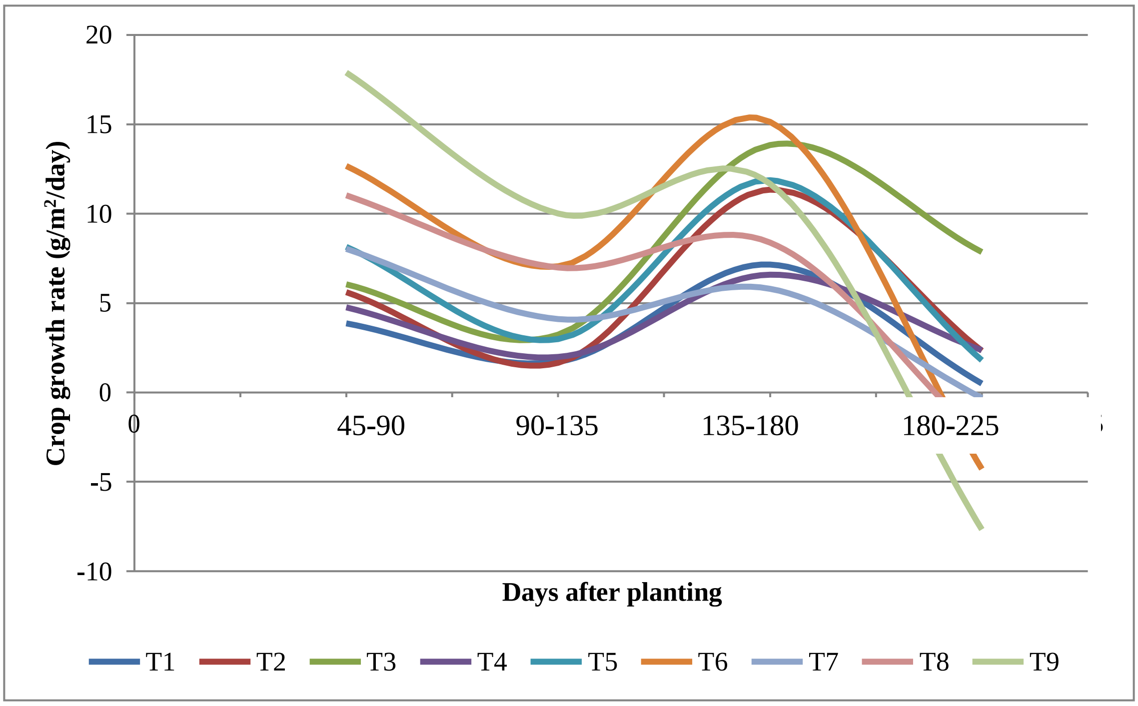


Fig. 18. Effect of seed size and spacing on crop growth rate

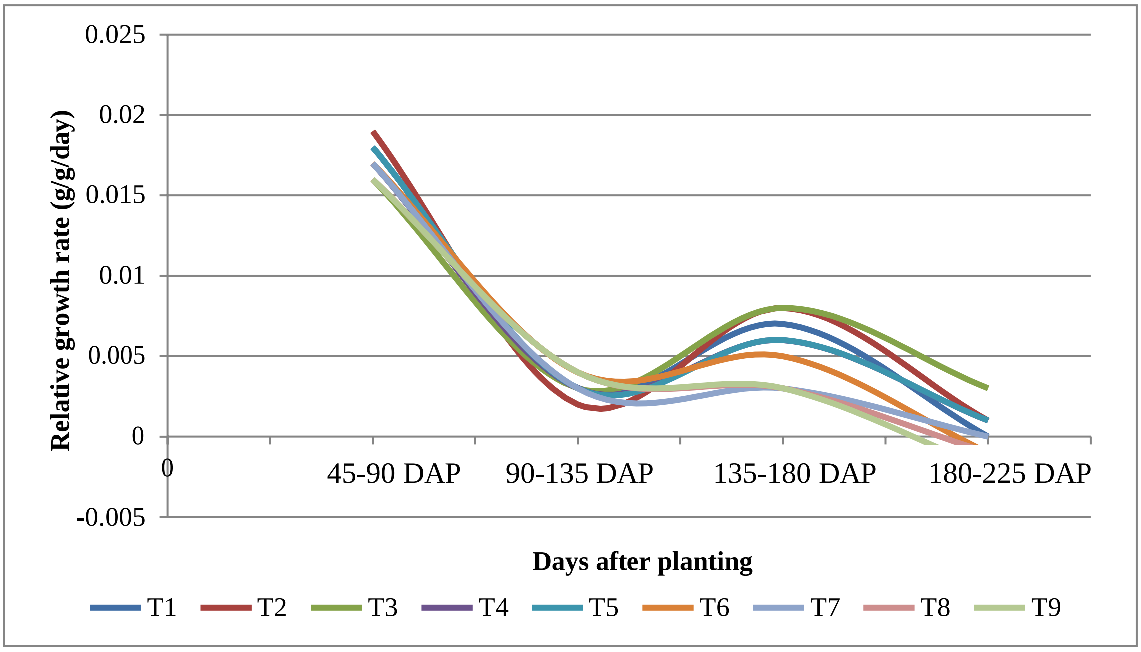


Fig.19. Interaction effect of seed size on relative growth rate

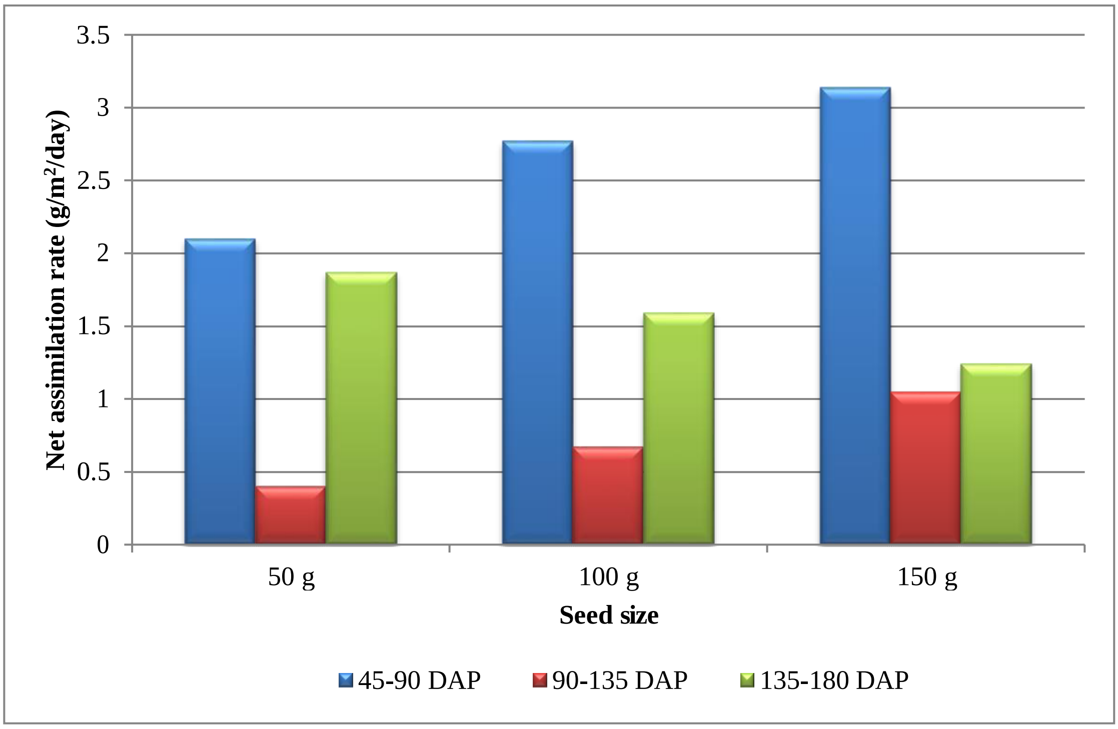


Fig.20. Effect of seed size on net assimilation rate

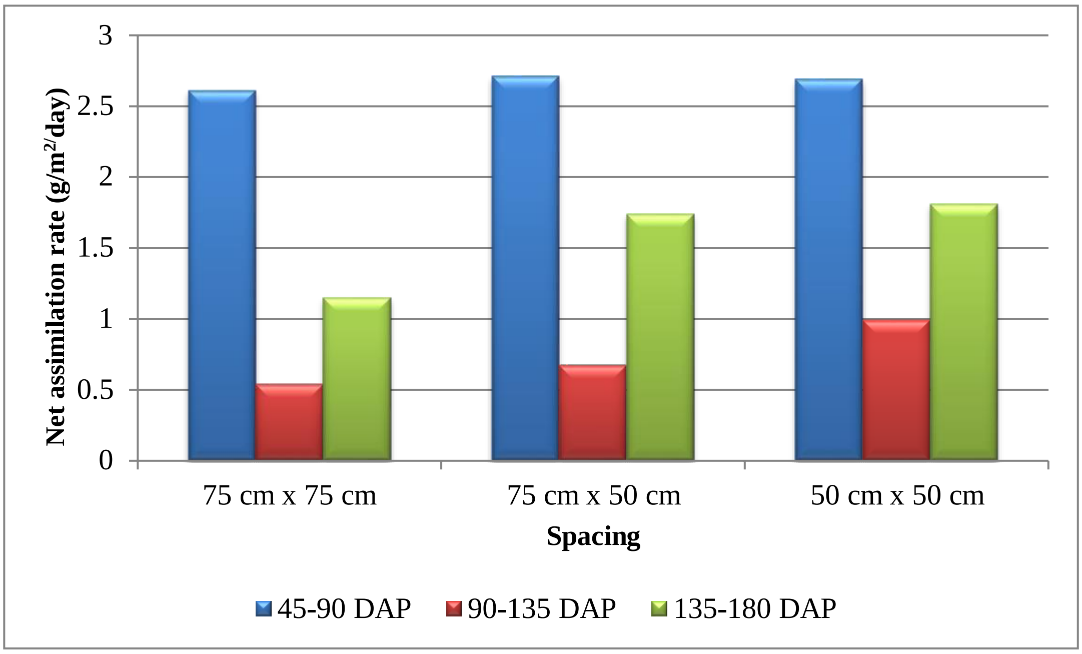


Fig. 21. Effect of spacing on net assimilation rate

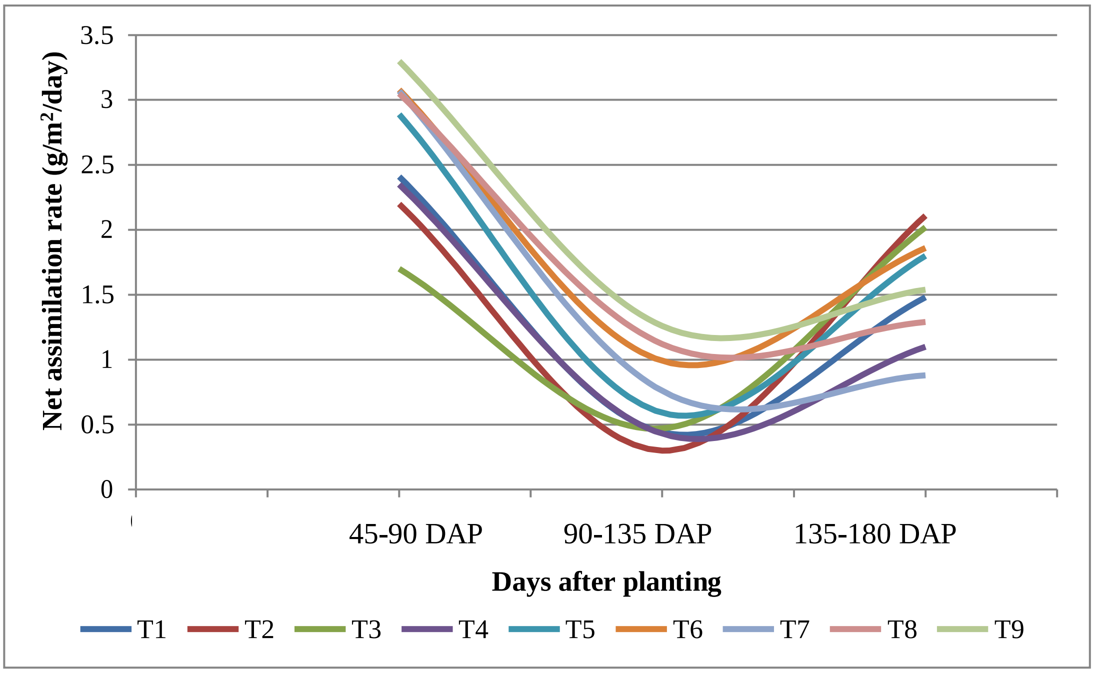


Fig.22. Interaction effect of seed size and spacing on net assimilation rate

5.3. EFFECT OF SEED SIZE AND SPACING ON TUBER FORMATION, BULKING AND YIELD

In lesser yam, tubers initiate from the hypocotyl region of the plant with the formation of stolon like structures. Number of tuber forming roots was counted at 45 days interval. When sample plants were uprooted at 45 DAP, tuber producing roots could be differentiated from normal roots by their thickness and characteristic white colour. It has been reported that tuber initiation in *D. rotundata* occurred from the time of sprouting to 84 days after sprouting (Okezie *et al*., 1981). The timing of tuber initiation and the duration of tuber formation vary within and between species, and are highly influenced by environmental factors. Tuber bulking was identified around 90 DAP, especially in the large and medium sized seed tubers planted at wider spacing. In yams, an excess of assimilates is necessary for tuber initiation to occur, and this excess might have been present in plants that developed from large seed tubers earlier than smaller plants. Generally, in all treatments tuber number increased up to 180 DAP, and a reduction was observed towards the senescence phase. At wider spacing, tuber number steadily increased compared to closer spacing, where little or no increase in tuber number occurred. The number of tubers recorded at harvest showed that some of the tubers initiated during the later phase did not undergo bulking due to the senescence of aerial portion due to dry climatic condition and physiological maturity of the vine and hence not contributed to yield. Ferguson (1983) in White Lisbon yam, observed an increase in tuber number up to six months after planting followed by a reduction in number of productive tubers due to senescence of vines.

Enyi (1972) indicated that when many tubers were initiated from a single plant, the size of individual tubers is small and proportion of initiated tubers that never reach the harvestable size is greater. He also reported that in lesser yam, there was no difference in duration of tuber bulking between the large and small tubers, even though the vegetative parameters like leaf area and higher bulking rates were observed in larger setts.

In the experiment, in all the treatments tubers were initiated at similar time, and the tuber initiation continued during 45- 90 DAP. The tuber development was highly influenced by the shoot dry matter content. After the active vegetative phase of 135 DAP, the plants showed an increasing trend of tuber bulking, correspondingly reducing the further development of leaves, and photosynthates were channelized towards the sink after this period. There was a relation between the shoot dry matter and final yield among treatments as the highest yields were secured from 150 g planted at 75 x 75 cm wider spacing (1511.67 g/vine) which also registered a higher shoot dry weight (257.33 g/vine).

Higher tuber yields were registered for the treatment combinations of 150 g seed tubers at 75 x 75 cm spacing (1511.67 g/vine) followed by 150 g at medium (1192.33 g/vine) and high densities (1105 g/vine) and 100 g tubers at low (1145.67 g/vine) and medium densities (1084.67 g). It indicated that a higher seed sett size and wider spacing are important in better tuber production. All the small seed tubers irrespective of spacing resulted in lower yields on a per plant basis compared to that of larger seed tubers.

Tuber fresh weight per hectare was influenced significantly by plant population. At higher planting densities, all the treatments showed high values of tuber yield. This was due to the fact that tuber yield is a function of number of plants per unit area. The maximum yields were registered for larger seed tubers planted at 50 x 50 cm spacing (44.20 t/ha). It was followed by 100 g (37.09 t/ha) and 50 g tubers (35.36 t/ha) at high density planting.

It is important to note that the number of tubers per vine was not influenced by seed tuber size and on an average 25-26 tubers were produced per plant. However, vines under wider spacing produced more tubers per vine and at 75 x 75 cm, 29 tubers were produced per plant whereas it was 24 tubers at 50 x 50 cm. This resulted from better growth attributes and dry matter accumulation at wider spacing. But this increase could not compensate for the number of plants per unit area and hence more yields were realized at closer spacing.

A maximum tuber count of 31.67 was observed with that of larger seed tubers planted at 75 x 75 cm. This might be due to the better root system development and further tuber growth in the initial stages of the vines from 150 g seed tuber at wider spacing. On a contrary, in *Dioscorea rotundata* while increasing the plant populations from 9000 to 36,000 plants/ha, greatly increased yield but decreased average tuber weight, but plant density did not affect the average number of tubers per plant. An increase in yield was observed with heavier setts, which positively influenced the number of tubers per plant but not their weight. (Gurnah, 1974).

The harvested tubers were graded into small medium and large sizes based on weight of individual tubers. Grade of tubers was not significantly affected by the seed size. Length and girth of tubers exhibited no significant variations with respect to seed size or spacing. It was found that the proportion of small, medium and large tubers per vine was more or less same in lesser yam irrespective of seed tuber size and spacing.

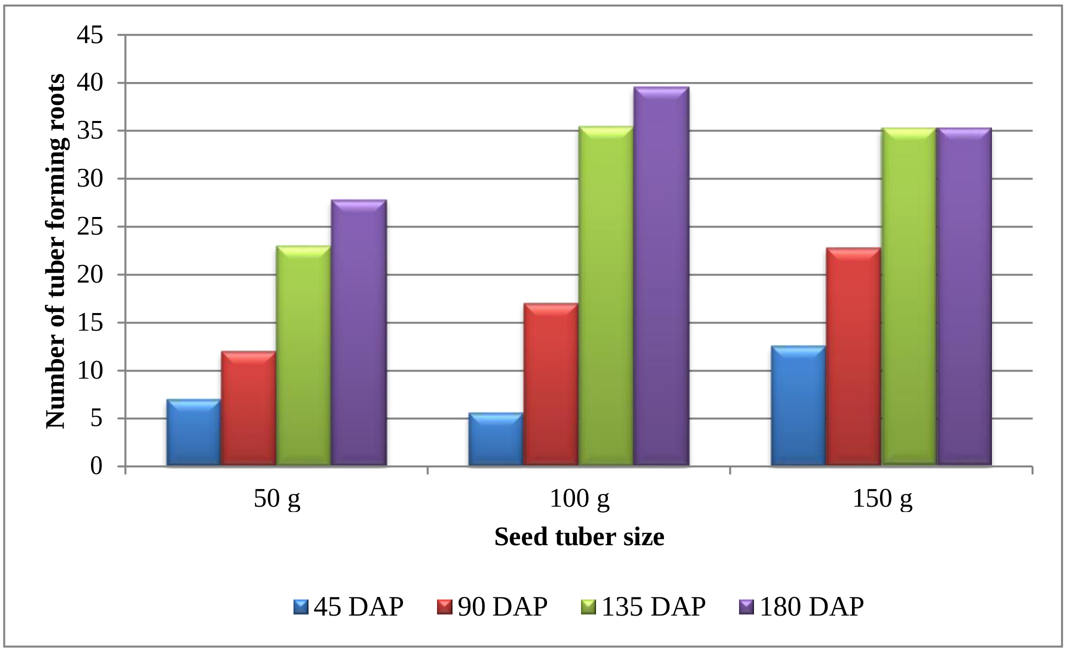


Fig.22. Effect of seed size on number of tuber forming roots

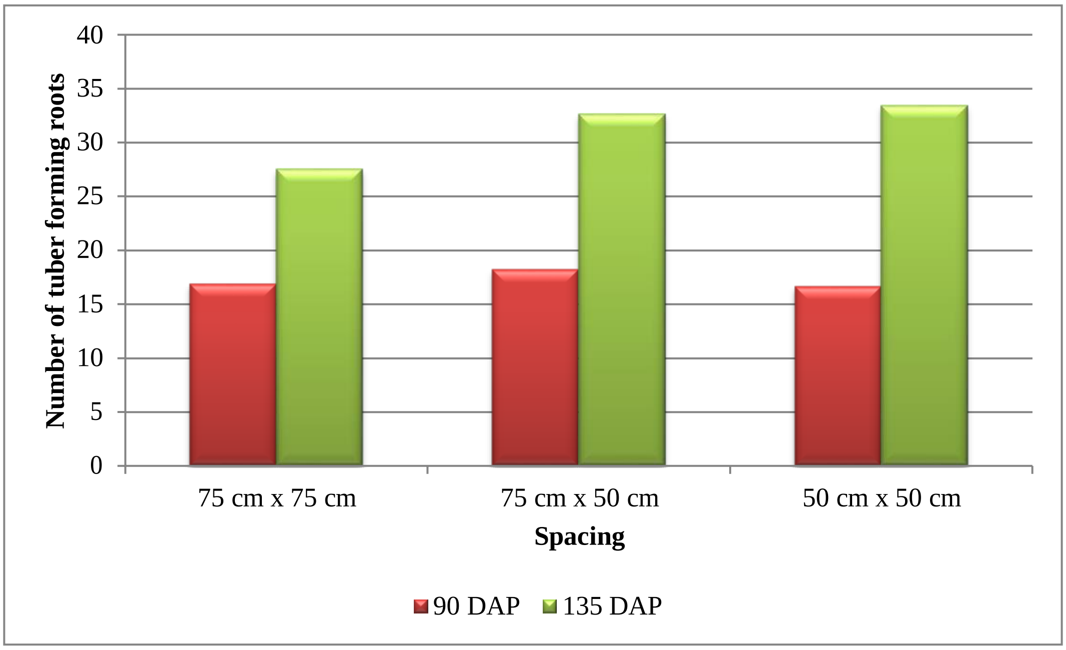


Fig.23. Effect of spacing on number of tuber forming roots

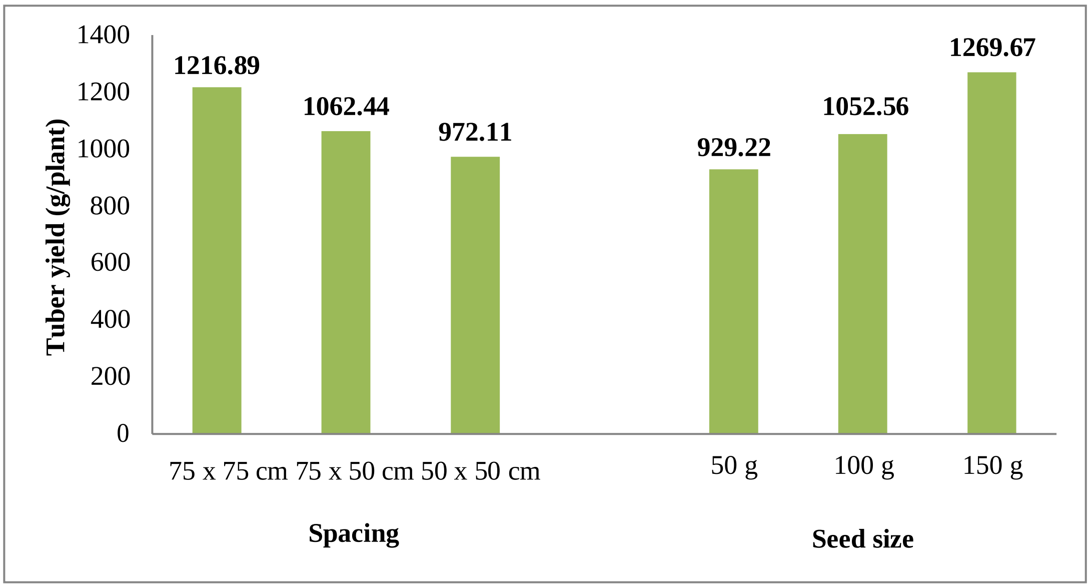


Fig. 24. Effect of seed size and spacing on tuber yield per plant of lesser yam

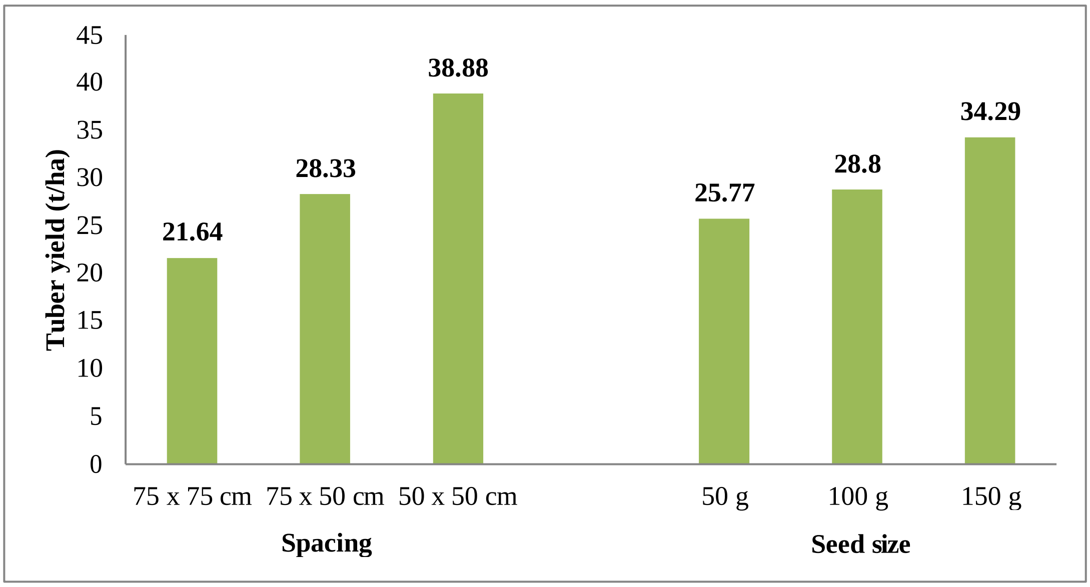


Fig. 25. Effect of seed size and spacing on productivity of lesser yam

5.4. EFFECT OF SEED SIZE AND SPACING ON WEED INCIDENCE

Observations were recorded only during 30 and 60 DAP. Weed competition in the first four months of growth reduced yam yield by as much as 43 % (Orkwor, 1990). Weed population per square meter did not vary significantly and ranged from 69.36 to 128 (30 DAP) and 61 to 157 (60 DAP) in various plots. However, significant influence of spacing and seed tuber size was observed on weed dry matter production at 60 DAP. Wider spacing favored more weed dry matter production as compared to closer spacing at 30 and 60 DAP. This can be attributed to better resource utilization by weeds facilitated by wider spacing. It indicates the potential of reducing the weed population at the active growth stages of lesser yam. Weeding alone consumes approximately 30-50 per cent of total labour budget depending on the crop and the level of other available resources (Agboola, 2000). It has been shown that the most damaging effect on cassava yield was from weed competition experienced by the crop during canopy formation and early tuberization period (three months after planting) and less from the fourth month until harvest (Onochie, 1974).

Tuber growth in yams was influenced by weeding at the initial stages of the crop. The crop requires a minimum of three weedings during the first 16 weeks after planting according to Akobundu (1987). Unamma (1989) reported that highest LAI values were observed in the weed-free plots while the lowest values were recorded in plots with full weed interference in *Dioscorea rotundata*. A reduced LAI considerably lowered crop's capacity to produce assimilates necessary for food storage during tuber bulking and directly affected the tuber yield. Competitive weed interference reduced shoot biomass significantly.

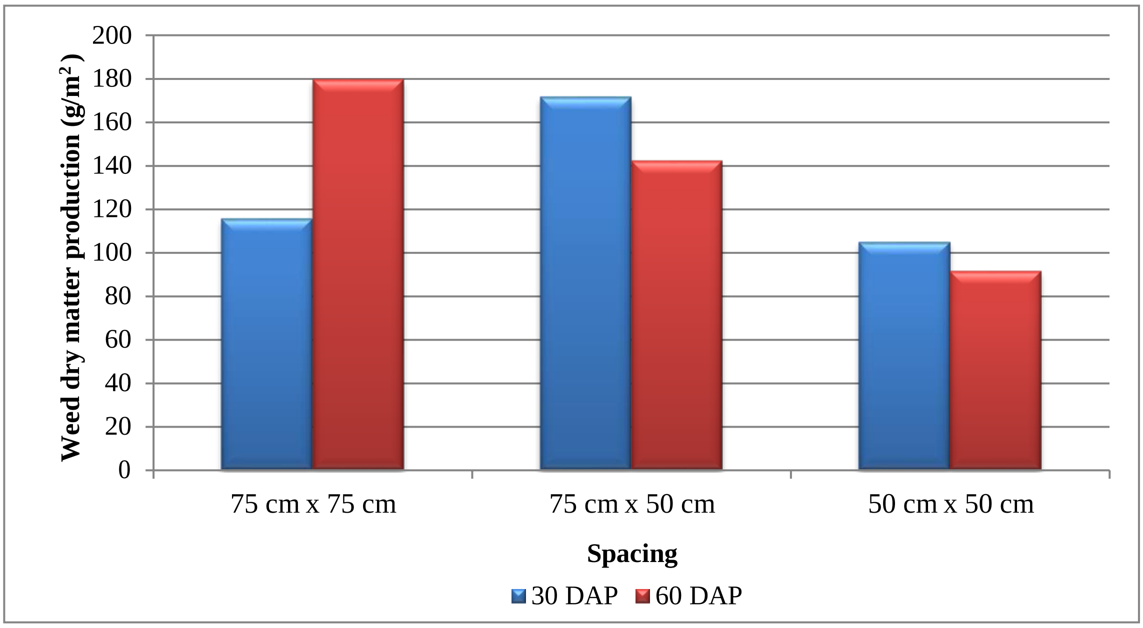


Fig.26. Effect of spacing on weed dry matter production

5.5. SOIL NUTRIENT STATUS AND PLANT UPTAKE OF PRIMARY NUTRIENTS

Though varying planting densities were tried, manures and fertilizers were applied on a per plant basis. Cowdung was applied at the rate of 1 kg per plant. Fertilizer recommendation followed for normal spacing and seed tuber size was 80:60:80 kg N, P_2O_5 and K_2O per ha. Hence each plant was supplied with 7.5 g urea, 5 g MOP and 7.5 g rock phosphate. At both medium and high density planting the expected fertilizer recommendations were 120:90:120 kg N, P_2O_5 and K_2O per ha and 180:135:180 kg N, P_2O_5 and K_2O per ha.

Post-harvest soil nutrient status shows an increase in soil organic carbon content from 1.1 per cent to 1.86 per cent. The available nitrogen increased from 155 kg/ha to 188 kg/ha and phosphorus showed a marginal increase from 26 to 29 kg/ha. However, a substantial decrease in available potassium (from 283 to 247 kg/ha) could be observed probably due to higher K removal by the crop. Potassium is a nutrient that plays a major role in starch synthesis and translocation and it is reported that K requirement of tuber crops are higher compared to other crops. Obigbesan (1976) observed that nitrogen and potassium constituted the major nutrients removed by *Dioscorea* spp. during its growth phase and the average nutrient removal of potassium was recorded to be 155-184 kg/ha.

It is reported that the continuous cultivation of lesser yam in field requires a high level of natural soil fertility (Carsky *et al.*, 2010). Reports on fertilizer response studies reveal that the effectiveness of NPK fertilizers in yam production is clearly not understood, with the yield remaining unchanged under different rates of application (Legapsi and Beatriz, 2013).

Nutrient content in plant leaves and tubers exhibited variations. At harvest, the nitrogen (0.23 %) and phosphorus content (0.25 %) were comparable in leaves while potassium content was registered to be thrice (0.81 %). Whereas in tubers a higher nutrient content was registered at harvest (0.41 % N, 0.51 % P, 1.30 % K). The NPK contents in plant leaves showed a reducing trend towards harvest whereas the content increased in tubers with maturation. Both nitrogen and phosphorus uptake of yams were comparable during the growth phase, whereas potassium uptake was twice compared to that of both nitrogen and phosphorus. Among all the treatments the highest nutrient uptake from unit area was more in high density planting due to increased demand for nutrients for a large population compared to that of medium and low density planting. On an average nutrient uptake by plants at harvest was estimated at 72.44 kg/ha nitrogen, 86 kg/ha phosphorus and 237.44 kg/ha potassium. Nitrogen and phosphorus uptake by lesser yam was found to be comparable, whereas potassium uptake registered more than twice to that of nitrogen or phosphorus uptake by plants. A similar trend can be seen in N, P and K content of aerial and underground portions of vines. A high requirement of potassium for carbohydrate synthesis in tuber crops have already been reported by Ward (1959).

5.6. EFFECT OF SEED SIZE AND SPACING ON ECONOMICS OF PRODUCTION

The ideal management practices in crop production can be recommended only after a cost- benefit analysis. Yam production is basically undertaken in a low external input system as in the case of homestead cultivation where production is not market oriented. However, under intensive production systems, the cost of production and returns are important.

The cost of cultivation ranged from ₹ 1, 99,588 to ₹5, 73,660/ha for different treatments under closer spacing. Under high density planting increased cost of cultivation was mainly for staking and seed tubers; along with more man days for the intercultural operations. Lowest cost of cultivation was for small seed tubers under wider spacing. The highest cost of cultivation and net returns was for 150 g seed tubers planted at closer spacing of 50 x 50 cm with gross returns of ₹11 lakhs/ ha and net returns of ₹ 5.31 lakhs/ ha. Net returns was the lowest when small seed tubers were planted at a wider spacing (₹2.42 lakhs/ ha) and this resulted in lowest tuber yield even though a low cost of cultivation and high B-C ratio of 2.21 could be attained.

The three best spacings with respect to net profit were high density planting (50 x 50 cm) irrespective of the seed tuber size i.e., ₹ 11 lakhs, ₹ 9.27 lakhs, and ₹ 8.84 lakhs/ha respectively for 150 g, 100 g and 50 g seed tubers. With respect to B-C ratio, the values ranged from 1.88 to 2.48. The treatment which realized the highest BC ratio was

150 g tubers under recommended spacing of 75 x 75 cm. However, this treatment was inferior in terms of net returns as the productivity was low due to less plant population.

A close analysis reveals that it is advisable to go for 50 g seed tubers at high density planting (50 x 50 cm) as it showed a high returns with good B-C ratio of 2.14 and a net profit of ₹4.70 lakhs per hectare. Also from a practical point of view, this would be superior as the availability of small sized tubers for planting is not a constraint in yam production. Thus a farmer can market large and medium sized tubers and set apart the small sized unmarketable tubers for planting. The data on different grades of tubers produced per vine shows that on an average a plant produces 13 small, seven medium and only four or five large tubers irrespective of seed tuber size. Even when 100 g seed tubers are used as planting materials, a farmer has to go for closer spacing of 50 x 50 cm or 75 x 50 cm instead of wider spacing of 75 x 75 cm as these treatments resulted in an additional profit of ₹1.60 lakhs/ ha and 1.₹10 lakhs/ ha respectively over the recommended spacing 75 x 75 cm.

Hence, from the current study it is suggested to go for planting 50-100 g seed tubers at a spacing of 50 x 50 cm or 75 x 50 cm in order to enhance the productivity and profitability in lesser yam cultivation.

6. Summary

6. SUMMARY

The experiment entitled "High density planting and seed tuber size on productivity enhancement of lesser yam [*Dioscorea esculenta* (Lour.) Burkill]" was conducted with the objectives to enhance yield of lesser yam by adjusting the plant geometry, to optimize seed rate for high density planting and to work out the economics of production. The study was conducted during the period from May 2018 to December 2018 at Agronomy Farm, College of Horticulture, Vellanikkara, Thrissur. The salient findings from the experiment are summarized below.

1. The parameters such as emergence percentage, number of shoots per tuber, length of vine, number of tuber forming roots, number of leaves, leaf area, and total dry matter accumulation per plant were significantly influenced by the seed tuber size and spacings. Generally large sized seed tubers (150 g) showed higher values for most of these parameters compared to that of medium or small seed tubers while the effect of spacing varied.
2. The shoot emergence in lesser yam was completed within 40 DAP and was significantly higher in 150 g seed tubers compared to that of 100 g or 50 g seed tubers. Spacing had no significant effect on the emergence percentage.
3. In the initial growth stage of 45 days after planting (DAP), length of vine was significantly higher for large seed tubers. However, by 90 DAP, all vines exhibited comparable length irrespective of seed size or spacing.
4. The number of shoots were recorded at 45 DAP and maximum number of shoots were observed to be emerged from large seed tubers followed by medium and small seed tubers.
5. Tuber forming roots were observed as early as within one month after planting, found to be thick, white and swollen compared to the normal feeder roots. The number of potential tuber forming roots gradually increased up to active tuber

bulking stage (180 DAP), whereas their number attained stability without a further increase towards the senescence phase. Large seed size and closer spacing realized higher number of potential tuber forming roots at 180 DAP.

6. There was significant effect of seed size and spacing on number of leaves per plant. At 45 and 90 DAP, the maximum and significantly higher number of leaves was observed in vines that emerged from large seed tubers at wider spacing (121.84 and 296.78 leaves). Peak vegetative phase in lesser yam was observed at four months after planting when the number of leaves were maximum (135 DAP). A gradual decline in the number of leaves was found towards 180 days of planting. Spacing had a significant effect on the number of leaves except at the initial stage of growth (45 DAP).
7. Leaf area also exhibited similar trend to that of leaf count. Superior values with respect to leaf area were observed for plants that emerged from large seed tubers up to 135 DAP compared to medium or small seed tubers. Spacing had significant effect on leaf area only at 135 and 180 DAP, at which the wider spacing showed superior values followed by medium and high density planting.
8. Leaf area index was found to be higher for large seed tubers and closer planting density. Leaf area index tend to increase up to 135 DAP, after which it declined towards the senescence phase. The crop growth rate, relative growth rate as well as net assimilation rate were influenced by seed tuber size and spacing. Plants from larger seed tubers and closer spacing had higher crop growth rate and net assimilation rate. Relative growth rate was less affected by different treatments.
9. A significant effect of seed size was found among the treatments attributing to a higher total plant dry weight among the larger seed tubers up to 180 DAP. Whereas spacing had no effect on total dry matter production among the treatments. The interaction effect showed that 150 g tubers at all planting densities exhibited higher total dry matter accumulation at both 135 and 180 DAP. The results on dry weight of aerial portions revealed higher values at 135 DAP which marked the peak vegetative phase.

10. The highest tuber yield was recorded from larger seed tubers of 150 g size (1270 g/vine), followed by 100 g (1053 g/vine) and 50g seed tubers (929 g/vine), which differed significantly from each other. Spacing also had influence on tuber yield per plant and wider spacing resulted in significantly higher yield (1217 g), compared to 75 x 50 cm (1062 g) and 50 x 50 cm (972 g) spacings. Interaction effect revealed that the performance of 150 g seed tuber at 75 cm x 75 cm was significantly superior (1511.67 g) to others. Neither the seed tuber size nor the spacing influenced the number of small, medium or large sized tubers per plant or the length and girth of individual tubers.
11. On an average, the number of small, medium and large seed tubers was observed to be 3.71, 6.66 and 13.48 at harvest. The mean length of small, medium and large tubers was recorded as 5.33, 8.64, and 13.33 respectively, whereas the average tuber girth was registered to be 8.62, 10.62, and 13.26 for small, medium and large tubers.
12. The highest productivity of 44.20 t/ha was realized when 150 g seed tubers were planted at a closer spacing of 50 x 50 cm. The combination of small seed tuber and wider spacing led to lower productivity in lesser yam (17.66 t/ha).
13. The weed dry matter production per square meter was higher under wider spacing at 60 DAP. Whereas, weed dry matter production was not affected by seed size.
14. Soil nitrogen and phosphorus contents were found to be increased after harvest whereas potassium content decreased.
15. Higher potassium uptake compared to that of nitrogen and phosphorus was observed in lesser yam.
16. Economic analysis revealed that closer spacing resulted in higher cost of cultivation, but correspondingly yield per hectare was also high. The highest net profit of ₹ 5.31 lakhs per ha was realized when 150 g seed tubers were planted at 50 cm x 50 cm spacing, compared to ₹4.70 lakhs in the case of 50 g seed tubers and ₹ 4.34 lakhs from 100 g seed tubers at 50 cm x 50 cm.
17. The present research work implies that, considering the easy availability of small seed tubers and higher net profit and B-C ratio, for realizing maximum productivity, it is advisable to go for medium and high density planting in lesser yam with seed tubers of 50 g and 100 g size.

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Appendices

Appendix 1. Monthly weather data during experimental period

(May 2018-December 2018)

Month	**Maximum temperature (^{0}C)**	**Minimum temperature (^{0}C)**	**Relative Humidity (%)**	**Rainfall (mm)**	**Rainy days**	**Evaporation (mm)**	**Sunshine hours**
May	36.7	24.0	79	483.6	14	102.9	149.0
June	29.8	23.2	89	730.0	23	65.7	51.2
July	29.6	22.5	88	793.2	22	79.6	58.0
Aug	29.2	22.2	87	928.0	21	70.7	68.4
Sep	32.2	22.5	75	29.0	1	99.6	216.2
Oct	32.8	22.9	76	393.0	13	94.4	176.0
Nov	32.7	23.3	68	66.6	5	102.3	207.5
Dec	33.0	22.5	63	0.0	0	109.5	215.7

Appendix 2. Cost of cultivation

Cost of seed tubers: Rs 40/ kg

Cost of FYM: Rs 1.5 / kg

Cost of fertilizers: Urea -7 Rs/ kg, Rajphos-7 Rs/ kg, MOP- 20 Rs/ kg

Cost of rope: Rs 5 / 10 m, Cost of poles: Rs 15 /pole

Cost of labour: Rs 600/ man days

Seed size	**Yield (kg/ha)**	**No. of plants**	**Cost of tubers (Rs)**	**Cost of poles (Rs)**	**Cost of FYM (Rs)**	**Cost of rope (Rs)**	**Cost of fertilizers (Rs)**	**Labour cost (Rs)**	**Total Cost (Rs)**	**Total returns (Rs)**	**B: C**	**Net returns (Rs)**
50 g												
75 x 75 cm	17.66	17778	35556	66667	26667	17778	7922	45000	199588	441500	2.21	241912
75 x 50 cm	24.28	26667	53333	100000	40000	26667	11773	54000	285773	607000	2.12	321227
50 x 50 cm	35.36	40000	80000	150000	60000	40000	17660	66000	413660	884000	2.14	470340
100 g												
75 x 75 cm	20.37	17778	71111	66667	26667	17778	7922	45000	235144	509250	2.17	274106
75 x 50 cm	28.92	26667	106667	100000	40000	26667	11773	54000	339107	723000	2.13	383893
50 x 50 cm	37.09	40000	160000	150000	60000	40000	17660	66000	493660	927250	1.88	433590
150 g												
75 x 75 cm	26.88	17778	106667	66667	26667	17778	7922	45000	270699	672000	2.48	401301
75 x 50 cm	31.8	26667	160000	100000	40000	26667	11773	54000	392440	795000	2.03	402560
50 x 50 cm	44.2	40000	240000	150000	60000	40000	17660	66000	573660	1105000	1.93	531340

HIGH DENSITY PLANTING AND SEED TUBER SIZE ON PRODUCTIVITY ENHANCEMENT OF LESSER YAM [*Dioscorea esculenta* (LOUR.) BURKILL]

By
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(2017-11-019)

ABSTRACT OF THE THESIS

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(Agronomy)

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ABSTRACT

The experiment was conducted during the period from May 2018 to December 2018 at Agronomy Farm, College of Horticulture, Vellanikkara, Thrissur to study the effect of planting density and seed tuber size on productivity of lesser yam. Seed tubers of 50 g, 100 g, and 150 g were planted at spacings of 50 x 50 cm (high density planting), 75 x 50 cm (medium density planting) and 75 x 75 cm (low density planting-recommended spacing), adopting factorial RBD. The treatments consisted of nine combinations of seed tuber size and spacing.

Growth characteristics like emergence percentage, number of sprouts per tuber, length of vine, number of tuber forming roots, number of leaves, leaf area, and total drymatter accumulation per plant were significantly influenced by seed tuber size. Large sized seed tubers (150 g) showed higher values for these parameters compared to that of medium or small sized tubers. In the initial growth stage of 45 days after planting (DAP), length of vine was significantly higher for large seed tubers. However by 90 DAP, all vines exhibited comparable length irrespective of seed size or spacing.

Spacing significantly influenced the leaf area index (LAI) as well as number of leaves per vine, and at peak vegetative growth (135 DAP), the highest leaf count of 591 leaves per vine was noticed in 150 g tubers planted at wider spacing of 75 x 75 cm. Total dry matter accumulation per plant was not significantly influenced by spacing.

Tuber forming roots could be observed even at 45 days after planting indicating early tuber initiation in lesser yam. The number of tuber forming roots increased upto 180 DAP, after which tuber bulking was noticed. Plants that emerged from large seed tubers produced more number of tuberous roots in the initial growth stage of upto 90 DAP. However at 135 DAP, plants from both 100 g and 150 g tubers were on par with respect to number of tuber forming roots. Plants at closer spacing of 50 x 50 cm produced higher number of tuber forming roots compared to wider spacing at 180 DAP. The crop growth rate (CGR), relative growth rate (RGR) as well as net assimilation rate

(NAR) were influenced by seed tuber size and spacing. Plants from larger seed tubers and closer spacing had higher CGR, RGR and NAR. Higher RGR was observed during the period from 135 to 180 DAP. Spacing had no influence on NAR at initial growth phase. However at later stages of observations, high density planting resulted in higher NAR. The highest NAR was observed at 45-90 DAP, after which a declining trend was observed.

The highest tuber yield was recorded from larger seed tubers of 150 g size (1270 g/vine), followed by 100 g (1053 g/ vine) and 50g seed tubers (929 g/vine), which differed significantly from each other. Spacing also had influence on tuber yield per plant and wider spacing resulted in significantly higher yield (1217 g), compared to 75 x 50 cm (1062 g) and 50 x 50 cm (972 g) spacings. Interaction effect also could be observed and performance of 150 g seed tuber at 75 x 75 cm was superior to others. It was also clear that neither the seed tuber size nor the spacing had influence on the number of small, medium or large sized tubers per plant or the length and girth of individual tubers. The trend in tuber yield per hectare was different as the yield is a function of number of plants per unit area. The highest productivity of 44.20 t/ha was realized when 150 g seed tubers were planted at a closer spacing of 50 x 50 cm. The combination of small seed tuber and wider spacing led to lower productivity in lesser yam (17.66 t/ha).Closer spacing resulted in higher cost of cultivation, but correspondingly yield per hectare was also high. The highest net profit of ₹ 5.31 lakhs per ha was realized when 150 g seed tubers were planted at 50 x 50 cm spacing, compared to ₹4.70 lakhs in the case of 50 g seed tubers and ₹4.34 lakhs from 100 g seed tubers at 50 x 50 cm.

Considering the easy availability of small seed tubers and higher net profit and B:C ratio, for realizing maximum productivity per unit area, it is advisable to go for high density planting in lesser yam with seed tubers of about 50 g or 100 g weight. This is especially important in a state like Kerala where availability of land is a major constraint in crop production.