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Effect of Planting Density and Prunings on Yam Bean Tuber Yields and Quality

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Abstract: In an effort to elevate yam bean (*Pachyrhizus erosus* (L.) Urban) from a garden crop to a commercial crop the optimal planting density and pruning management were studied in relation to yield and tuber quality under field conditions at CATIE, Turrialba, Costa Rica for varying accessions. For each accession the number of tubers decreased with decreasing plant density, the average weight of the tubers increased and the total fresh weight yields were maintained. This confirms that by manipulating the plant density the tuber quality can be targeted to a specific consumer demand. Reproductive pruning did in contrast not affect the total number of tubers ha^{-1} but accessions differed ($p<0.05$) in their total yield responses although in all cases did the tubers increase in weight on average. This positive yield effect of reproductive pruning may potentially be used to increase yield and in areas where smaller sized tubers are preferred, to obtain the desirable tuber size at high plant densities at an earlier date thereby advancing the onset of the marketing season.

Key words: Plant density, tuber quality, yam bean

INTRODUCTION

Tuber crops contribute significantly to the world food supply and 70% of the production is harvested in developing countries (FAO, 2005). Many of the developing world's poorest producers and most undernourished households depend on roots and tubers as a contributing food source (Alexandratos, 1995). This situation arises because roots and tubers ensure a high degree of food security as they are very productive, also compared to cereals, under relatively poor agroecological conditions (Scott .., 2000). Roots and tubers are frequently grouped together because they are bulky, perishable and vegetatively propagated. At the same time they are highly differentiated in terms of origin, production, use and nutritional qualities. Of global importance are potato, manioc, sweet potato and yam. Of more regional importance is cocoyam, taro and the seed propagated legume yam bean. However, these crops do also differ significantly in both their genetics and their agroecological requirements.

The cultivated species of the yam bean genus (*Pachyrhizus* DC.-Fabaceae) produce tuberous roots which are mainly consumed fresh as a snack or in salads; the roots are often regarded more as fruits than vegetables (Kay, 1973; Sørensen, 1990). The species with the widest production area is the Mexican yam bean (*P. erosus*) which is widely cultivated in Meso-America, South East Asia and China (Hoof and Sørensen, 1989; Sørensen, 1996) as a backyard crop while having diversified niches in the diets.

However, yam bean as a commercial crop is still very much in its infant stage. In Costa Rica the crop was unknown to most farmers a decade ago (Mora and Morera, 1994; Morera, 1994). Nevertheless, initial field evaluations have demonstrate that attractive yields can be obtained. Despite this potential, knowledge is lacking regarding the cultivation practices leading to optimization of yields. Like in other root and tuber crops, a maximum economic plant density should exist above which yield may still be large but leading to reduced size and reduced

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quality of the product. The recommended planting distances for yam bean vary considerably depending on the length of the growth period, the tuberous root size desired and the day length at the time of planting (Heredia, 1998; Sahadevan, 1987).

Further, during the growth cycle when the growth of the reproductive shoots (inflorescences) is initiated these shoots must be removed, i.e., reproductively pruned, in order to favour the continued growth of the tuberous roots and ensuring optimum yields (Pinto Cortes, 1970), i.e. with the exception of plants grown for propagation. Such pruning may multiply the tuber yield from 2 (Díaz, 1979) by as much as ten times (Noda and Kerr, 1983; Noda *et al*., 1991). The cause for this effect is due to the source-sink competition for assimilates allocation between reproductive growth, i.e. flowering and production of leguminous pods and tuberisation (Caro and Casillas, 1998; Noda and Kerr, 1983; Sinha *et al*., 1977a, b; Sørensen *et al*., 1993; Zinsou, 1994). There is a lack of knowledge to what extent management practices may ensure optimisation of yields.

The aim of the current study was to examine the relation between yield and tuber size for different planting densities on 3 accessions of yam bean and, further, to determine the effect of reproductive pruning on fresh tuber yield on 5 accessions.

MATERIALS AND METHODS

Experimental site and setup: The study comprised 2 experiments conducted at Cabiria, CATIE (Turrialba, Costa Rica; Latitude: 9° 38′ N, Longitude: 83° 38′ W, Altitude: 602 m a.s.l.) on a well structured clay loam. The first trial was planted on 6th June 1993 and harvested on 24th November 1993 (≈ 171 days) to evaluate the accession-planting density relation. The second was conducted during the period between 20th April (planting) and 20th September (harvest) 1994 (≈ 153 days) to evaluate the accession-pruning relation. In all cases no fertiliser was applied.

The climatic conditions prevailing in the area during the 2 trial periods are presented in Table 1. Before each trial, the soils in the experimental plots were sampled to a depth of 0.30 m, bulked and kept frozen (-20°C) until analysis. The soil had a low content of nitrogen (<0.6%) and a particular high content of carbon (>9.7%). Extraction of cations took place with 1 M NH_4-OAc (10 g dry soil in 100 mL 0.5M NH_4OAc + 3 mL LiCl, shaken for 30 min (Page *et al*., 1982) and determined by atomic absorption. The P content was determined by $NaHCO_3$ extraction (5 g dry soil in 100 mL 0.5M $NaHCO_3$, shaken for 30 min (Olsen *et al*., 1954) and estimated by spectrophotometry using the molybdate-blue method. The copper, zinc and manganese content were extracted with a solution of 0.005 mol L^{-1} DTPA (diethylenetriaminepentaacetic acid), 0.01 mol L^{-1} $CaCl_2$, 0.1 mol L^{-1} TEA (triethylamine) (pH 7.3) for 2 h at 20°C (Lindsay and Norvell, 1978). Soil texture was determined by the hydrometer method (Gee and Bauder, 1986) (Table 2).

Experimental design and management: The first trial followed a randomized factorial plot design with 3 replications. The evaluated factors were as follows: accessions (3 levels) in the main plots and distances (3 levels) in the sub-plots. The following accessions were used: EC032, EC509 and EC534 (Table 3) all originating from lowland tropics.

The planting used the traditional Mexican design with double rows on ridges and the distances used were 0.75 m between the ridges with double rows 0.25 apart and 0.10, 0.15 and 0.20 m between plants. This resulted in planting densities of 266, 700 plants ha^{-1} at a distance of 0.10 m within row, 177, 800 plants ha^{-1} at 0.15 m and 133, 300 plants ha^{-1} at a distance of 0.20 m. In order to control leaf damaging insect pest, i.e., genus *Diabrotica* Chevrolat, insecticide (pyrethrines) was applied only once. The trial plots were weeded at 22 days intervals until 75 days after planting when the plant cover was sufficient to control further weed growth.

The second trial followed a complete randomised plot design with 4 replications. The factors evaluated were as follows: Reproductively pruned (removal of flowers) and non-pruned in the main plots and with 5 accessions as sub-plots. The accessions used were: EC114, EC509, EC511, EC523 and EC536 (Table 3). Each experimental plot consisted of 4 double rows 0.50 m apart and 5 m long. The distance between the double rows was 0.25 and 0.20 m between plants within rows. Thus, the distance between centres of the double rows was 0.75 m. The planting density corresponds to 133, 300 plants ha^{-1}.

The reproductive pruning involving the removal of the entire inflorescences was conducted using pruning shears. This operation was carried out twice during the crop growth period, the first during the first week of July and the second during the first week of August.

Sampling and analysis: In the non-pruned plots of the second trial, the number of days after sowing (DAS) till first flowering was registered when >50% of the plants had fully opened flowers. Furthermore, the number of flower buds per inflorescence was calculated from replicate test samples of 10 inflorescences.

Harvest of tuberous roots took place 75 days after planting. At harvest the fresh weight of the tubers was in

Table 1: Climatic data for the experimental period, from May 1993 to December 1994

	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Temperature, max averages (°C)	30.6	29.2	29.2	30.7	30.6	31.1	30.4	29.0	28.4	28.1	19.3	28.8	29.3	28.1	27.9	28.3	29.4	29.1	28.2	27.7
Temperature, min averages (°C)	19.4	19.2	19.1	19.8	19.3	19.4	19.0	17.9	21.8	21.2	22.2	22.2	23.0	22.7	21.9	22.1	22.8	22.5	21.8	21.3
Temperature, averages (°C)	23.4	22.9	22.7	23.6	23.3	23.9	23.1	22.5	16.6	17.2	16.2	17.9	19.1	18.7	19.2	19.0	19.9	19.1	19.1	17.9
Precipitation, monthly total (mm)	269	321	362	293	271	138	146	517	96	32	41	111	206	353	333	246	292	271	202	424
Solar radiation, daily averages (MJ m^{-2} d^{-1})	18.7	15.1	14.6	16.3	16.2	17.7	14.7	13.4	16.9	17.1	21.3	17.0	16.9	15.3	16.9	16.9	16.3	18.8	13.7	18.8
Relative humidity, averages (%)	88.1	89.3	89.8	89.6	89.5	88.5	87.5	88.5	85.4	85.3	82.2	85.6	88.7	87.6	92.4	90.0	90.1	88.4	89.9	90.1

Table 2: Chemical and physical soil properties of the experimental plots

Parameter	'Distance trial'	'Pruning trial'
$pH_{(H2O)}$	5.00	4.60
Potassium (cmol (+) kg^{-1})	0.24	0.25
Calcium (cmol (+) kg^{-1})	1.80	0.83
Magnesium (cmol (+)kg^{-1})	0.44	0.27
Sodium (cmol (+) kg^{-1})	0.00	0.00
Extractable acid (cmol (+) kg^{-1})	0.35	0.70
Phosphorus (mg kg^{-1})	9.35	6.30
Copper (mg kg^{-1})	5.06	4.70
Zinc (mg kg^{-1})	0.80	1.00
Manganese (mg kg^{-1})	9.46	8.0
Cation Exchange Capacity (cmol (+) kg^{-1})	2.83	2.05
Sand (%)	33.8	46.4
Silt (%)	35.6	31.2
Clay (%)	30.6	22.4

Table 3: Origin of the *Pachyrhizus erosus* accessions used in the experiments

Accession	Country	Province/ Institution	Position	Status
EC032	Mexico	Yucatan	20°48'N, 89°02'W	Landrace
EC114	Brazil	Pará	3°23'S, 51.51'W	Landrace
EC509	Costa Rica	Cartago	9°56'N, 83.40'W	Landrace
EC511	Mexico	Chiapas	14°54'N, 92°15'W	Landrace
EC523	Nigeria	I.I.T.A.	7°23'N, 3°56' E	Cultivar
EC534	Mexico	Nayarit	21°50'N, 105°04'W	Landrace
EC536	Mexico	Guanajuato	20°31'N, 100°53'W	Commercial line

all cases measured and the tubers were classified according to size classes: small sized weighing below 300 g, medium sized between 300 and 600 g and large sized weighing above 600 g. As only very few were observed in the large group, this was included in the medium sized group. Furthermore, the number of cracked or split tubers was recorded as was the number of tubers unmarketable due to other defects, e.g., multiple/double and deformed.

Analyses of variance were conducted using the SAS statistical program (SAS Institute Inc., 1993) and for the analyses of differences of averages the Duncan's Multiple Range Test were applied.

RESULTS

Planting density and tuber size interactions: Increasing the planting distances and thus reducing the plant densities from 266, 700 to 133, 300 plants ha^{-1} reduced ($p<0.05$) the total number of tubers by 32-40% in the 3 accession (Fig. 1A). This reduction in plant density caused an increase in the amount of medium sized tubers from 13, 96 and 73% in EC032, EG509 and EG534, respectively.

The total yields of tuberous roots in terms of amount fresh material were not affected ($p>0.05$) by planting density (Fig. 1B) whereas the yield of medium sized tubers increased by 37, 154 and 32% in EC032, EG509 and EG534, respectively, by decreasing the plant density from 133.300-266.700 plants ha^{-1}.

There was found no interaction between accessions and plant densities in the variables for tubers sizes and number of tubers. Regarding the small tuber size, the accession with the highest average number of tubers was EC032 (132, 400 tubers ha^{-1}), followed by accession EC509 with a similar quantity (131, 300 tuber ha^{-1}). EC534 had a lower number of tubers per hectare, i.e., 117, 900, but the highest tuber yield (17.7 Mg ha^{-1}) although not significantly different from the 2 other accessions. For each accession, it was observed that the number of tubers and the fresh weight yield increased with plant density per area unit, e.g., the accession number EC509 at the 0.10 m distance between plants had the highest average number of tubers per hectare, i.e., 207, 800 tubers ha^{-1} (Fig. 1).

Accessions and tuber size interactions: The average total yields for all 3 accessions were very similar, regardless of planting distance. Conversely the total number of tuberous roots per hectare as a result of different planting distance differed significantly between accessions and between distances (Fig. 1).

It was apparent that accessions with equal fresh weight yield per hectare may vary considerably in tuber size, i.e., an important characteristic when breeding towards a specific ideotype. Similarly, as demonstrated for the small sized tubers, the total number of tubers harvested per hectare tends to decrease with increasing sowing distance, i.e., lower plant density (Fig. 1).

Accessions and flowering: The number of days till first flowering and number of flower buds per inflorescences showed highly significant variations between accessions.

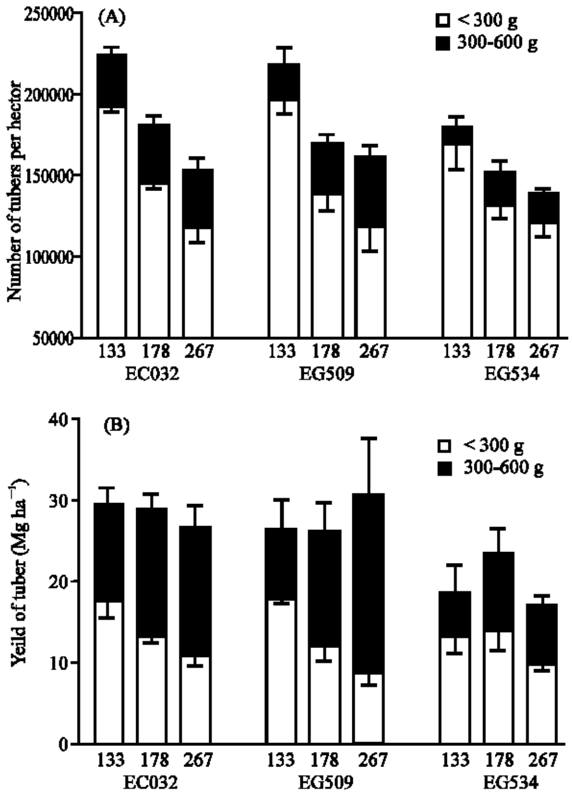

Fig. 1: Tuber yields of 3 yam bean accessions in terms of numbers (A) and in terms of weight per area unit (B) for the tuber sizes <300 g and 300-600 g per tuber under different plant densities (133 ≈ 133.300 plants ha^{-1}; 178 ≈ 177.800 plants ha^{-1}; 267 ≈ 266.700 plants ha^{-1}). Mean±SE (n = 4)

According to the length of the period from sowing to flower initiation the accessions may be divided into 3 groups: A late group with the accessions EC114 (108 DAS) and EC509 (99 DAS); a medium group including EC511 and EC523 (both 87 DAS) and with the accession EC536 (78 DAS) forming a third group with very early flowering (Fig. 2). In Fig. 2, a tendency towards an increase in the number of flower buds per inflorescence, as a result of early flower initiation, is observed, with the exception of EC536. In this way, EC114, being latest flowering accession, had the lowest number of flower buds per inflorescence.

Pruning versus tuber yield and quality: On average, the total weight of tubers in the reproductively pruned treatment (19, 100 Mg ha^{-1}) surpassed the average tuber yield of the non-pruned treatment (8, 400 Mg ha^{-1}) (Fig. 3).

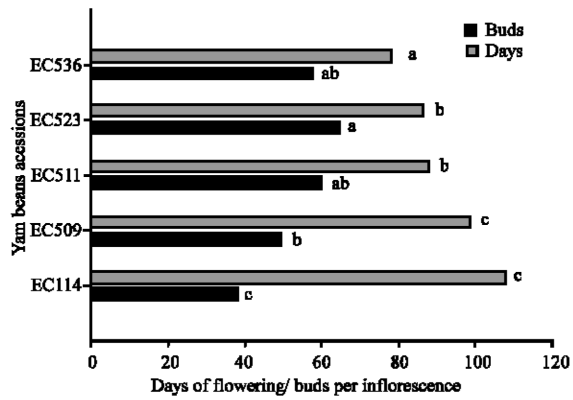

Fig. 2: Intervals in days from sowing until flowering and buds per inflorescence of 5 yam bean accessions (n = 4). Differences according to Duncan's multiple range tests with significances on 5% levels are indicated by different letters

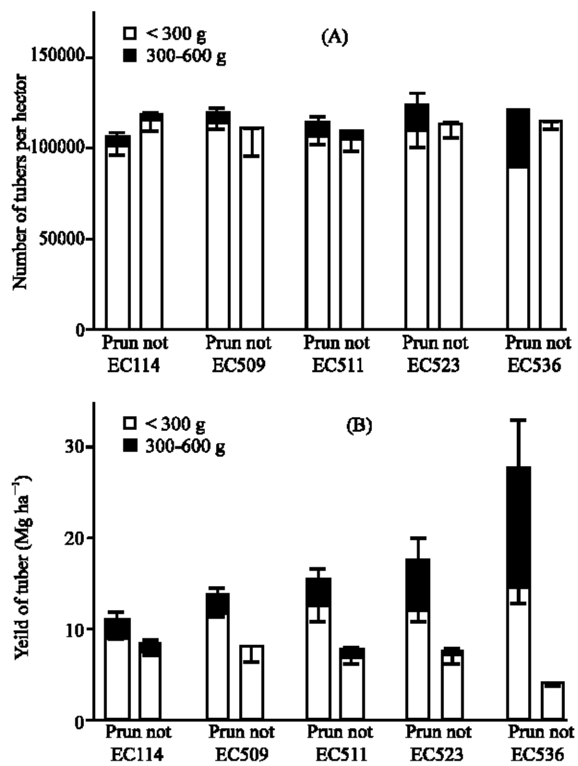

Fig. 3: Tuber yields of 5 yam bean accessions in terms of numbers (A) and in terms of weight per area unit (B) for the tuber sizes < 300 g and 300-600 gram per tuber under a density of 133.300 plants ha^{-1} under pruned (prun) or non-pruned (non) conditions. Mean±SE (n= 4)

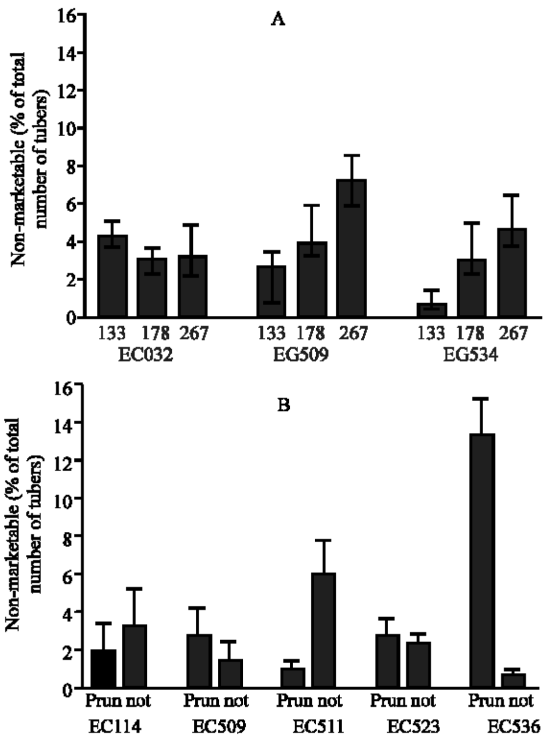

Fig. 4: Proportion (%) of non-marketable tubers of yam bean accessions under different plant densities (133 ≈ 133.300 plants ha^{-1}; 178 ≈ 177.800 plants ha^{-1}; 267 ≈ 266.700 plants ha^{-1}) (A) or at a density of 133.300 plants ha^{-1} under pruned (prun) or non-pruned (non) conditions (B). Mean±SE (n = 4)

Reproductive prunings increased the weight of small tubers (p = 0.002) and average weight per tuber of small size (p = 0.004). Also the total tuber weight differed ($p<0.05$) as well as the average weight of medium sized tubers ($p<0.05$) and the number of tubers with defects ($p<0.05$). Differences ($p<0.05$) was recorded between accessions in number of small and medium sized tubers and in weight of medium tubers (p = 0.007) and total weights (p = 0.0001) (Fig. 3).

Non-marketable tuber yields: The non-marketable tubers were largely cracked tubers. Increasing plant densities increased as described above the individual tuber sizes. This relation, however, also caused an increase in the amount of non-marketable tubers (Fig. 4A) with the exception of the Mexican landrace EC032. The increased tuber sizes caused by reproduction prunings were related to a substantial growth in the proportion of non-marketable tubers, the commercial Mexican landrace EG536 in particular (Fig. 4B). Across both data sets, a general positive correlation (r^2 = 0.50) was found between the yield of larger sized tubers and the proportion of non-marketable tubers.

DISCUSSION

The current studies demonstrate the direct influence of management in terms of planting density and reproductive pruning on yam bean crops. Consequently, despite being mainly a garden crop it possesses large potentials for commercial exploitation. Such exploitation must consider local consumer preferences regarding desirable tuber size without the risk of reduced yield. This consideration is reflected in the cultivation practices observed in e.g. Thailand with high planting densities where an onion sized tuber of approx. Two hundred gram where tubers of 600-800 g are considered optimal.

The relation between density and total yield: The experiment testing the influence of plant density per hectare on yield did not succeed in determining a possible maximum density as an increasing seeding density in all cases caused similar yields for all 3 accessions tested (Fig. 1B). This underlines the large phenological plasticity of this specie. However, for accession EC534 (Table 3) the maximum yield was recorded at a plant density of 177, 800 plants ha^{-1} and with a significant reduction in yield at the highest density of 266, 700 plants ha^{-1}.

Albeit the number of tubers per area unit decreased with decreasing plant population density, this decrease took place entirely among the small tubers as the number of medium size tubers remained the same (Fig. 1A). Planting density does have a strong influence on the number of unmarketable tubers (Fig. 4A and 4B) as a below optimum density may cause an increase in the number of multiple-tubered plants. Selection has traditionally been made for mono-tuberous habits at a well defined traditional plant population. Some accessions may at densities lower than those in the current studies 'revert' to a multi-tuberous habit.

The relation between density and marketable quality tubers: The lowest density gave in all cases the highest ratio medium: small tuber yields (partly shown in Fig. 1B). The lowest density also unambiguously gave the lowest proportion of non-marketable tubers (Fig. 4A). Hence, a positive correlation (r^2= 0.50) between the yield of larger sized tubers and the proportion of non-marketable tubers could be established.

For accession EC032, a landraces from Yucatan in Mexico, this correlation does not apply and the only apparent explanation must be genetic difference as a result of different selection criteria. In the Yucatan peninsula, the yam bean is traditionally inter-cropped with maize and common bean and thus the yam bean is adapted to intensified competition from non-specific neighbour plants.

The inverse relation between the densities of the crops and the yield of larger tubers agrees with the observed inverse coupling of sucrose and amino acid transport in other species (Schobert and Komor, 1989). As the experimental areas were of relatively low soil fertility, these processes may give the lower density plants an improved nutritional status which may cause a concomitant increase in tuber size (Fig. 3A and 3B) due to an increase in photosynthates transport to the tubers (Robin *et al*., 1990).

Reproductive pruning improve both tuber yields and tuber quality: The positive effects of reproductive pruning on yields were confirmed for all 5 accessions (Fig. 3B) in agreement with Arévalo-Tello (1998), Caro and Casillas (1998), Castellanos *et al.* (1997), Nielsen and Sørensen (1998), Nielsen *et al.* (1999) and Noda and Kerr (1983). For other tuberous crops, the tubers are considered the dominant sink (Kooman and Rabbinge, 1996) which will lead to an increase in harvest index (tuber: other organ ratio) when increasing the nutrient supply (Mohammad *et al*., 1999). However, the current data clearly demonstrate that this view does not hold for seed propagated yam beans; on the contrary it may well be the developing seeds that are the dominant sink (Fig. 3B). This suggestion is further supported by the fact that the number of tubers is not affected by pruning (Fig. 3A). It is thus concluded that the changes in quality, i.e. tuber size and marketable yields (Fig. 3B and 4B), are directly related to sink strength, i.e. the metabolic activity of the sink organ (Marschner, 1995) in agreement with observations by Lamaze *et al.* (1985).

The sink strength is largely controlled by phytohormons and obviously these hormones are affected when a reproductive pruning is conducted. Accordingly the largest proportion of non-marketable tubers was found in the Mexican EC536 which is an advanced commercial line (Table 3). This is also the accession with an outstanding positive response to reproductive pruning is terms of yield. It is assumed that the breeding criterion has been tuber yields and selection has thus been made for improved assimilation allocation to the tubers. For accession EC114, the response is a moderate yield increase when reproductively pruned but with an apparent decrease in number of non-marketable tubers. This may possibly be a result of the near equatorial origin of this accession, i.e. from Brazil which also has been found to have reduced photo-thermal sensitivity thus possibly more efficient during the shorter day-length and reduced difference in day/night temperature at the test site in Costa Rica as compared to the conditions of the highlands of Guanajuato, Mexico. Hence, effect of reproductive pruning under different photo-thermal regimes should be included in future studies of different accessions.

CONCLUSION

The current studies demonstrated that the overall tuber yield remain remarkably uniform regardless of plant density as the accessions tested did compensate by increased tuber weight per plant at lower densities. Further, the direct influence of management in terms of planting density and reproductive pruning on yam bean crops was demonstrated. These crop management practices may be utilized in a commercial situation to target local consumer preferences. Reproductive pruning may be used to increase yield and to obtain the desirable tuber size at higher plant densities at an earlier date.

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