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BIOLOGICAL NITROGEN FIXATION AND TUBER YIELD OF YAM BEAN IN CENTRAL MEXICO*

FIJACIÓN BIOLÓGICA DE NITRÓGENO Y RENDIMIENTO DE LA JÍCAMA EN EL CENTRO DE MÉXICO

Javier Zaragoza Castellanos-Ramos[1§], Jorge Alberto Acosta-Gallegos[1], Norberto Rodríguez Orozco[1] y José Jesús Muñoz-Ramos[2]

[1]Plant Nutrition Program, Bajio Experimental Station, INIFAP, A. P. 112, Celaya, Guanajuato, Mexico. C. P. 38110. (jamk@prodigy.net.mx). Tel. 01 461 6 11 53 23 Ext. 200. [2]Universidad Politécnica de Durango. Durango, Durango. Carretera Durango-México, km 9.5 C. P. 34000. Tel. 01 681 15 0 13 00. [§]Autor para correspondencia: castellanos@intagri.com.mx.

ABSTRACT

The Mexican tuber bearing edible *Pachyrhizus erosus* is widely grown and consumed in central Mexico. The aim of this research was to study the relationships between the dynamics of N_2 fixation and biomass accumulation and final tuber yield of two *Phachyrrizus* species, *P. erosus* bred cultivar San Juan EC550 and *P. ahipa* accession 102 introduced from Bolivia. The experiment was established on April 2nd, 2005 at the Bajio Experimental Station located near Celaya, Guanajuato, Mexico. Plant samples from one m^2 were periodically taken from 67 days after planting (DAP) onwards, on those, nodule number and mass, as well as plant biomass and leaf area index (LAI), were recorded. For tuber yield an area of 3.8 m^2 was harvested per plot. *P. erosus* reached the highest number of nodules at 170 DAP, while *P. ahipa* at 123 DAP. *P. ahipa* had a higher number of nodules than *P. erosus*, but of smaller size, thus, nodule dry mass was significantly higher (p<0.05) in *P. erosus* in most sampling dates. Fresh tuber yield of *P. erosus* was significantly (p<0.01) higher than that of *P. ahipa* and *P. ahipa* displayed a larger dry tuber weight that was due to a higher concentration of solids and fiber in the tuber. Higher tuber yield in *P. erosus* was related to a longer growth cycle, higher LAI and biomass accumulation.

Key words: *Phachirizus erosus* and *P. ahipa*, nitrogen harvest index, plant biomass.

RESUMEN

El tubérculo comestible mexicano *Phachirizus erosus* se produce y consume en la región central de México. El objetivo de esta investigación fue estudiar la asociación entre la dinámica de la fijación de N_2, la acumulación de biomasa y el rendimiento de dos especies de *Phachyrrizus*, *P. erosus* cv. San Juan EC550 y *P. ahipa* accesión 102 introducida de Bolivia. El experimento se estableció el 2 de abril 2005 en el Campo Experimental Bajío, de Celaya, Guanajuato. A partir de los 67 días después de la siembra (DDS) se tomaron muestras periódicas de plantas de 1 m^2; en las muestras se determinaron el número y peso de los nódulos, la biomasa y el índice de área foliar (IAF). El rendimiento de tubérculos se determinó en todas las parcelas en una área de 3.8 m^2. *P. erosus* alcanzó el mayor número de nódulos a los 170 DDS, mientras que *P. ahipa* lo hizo a los 123 DDS. *P. ahipa* desarrolló un mayor número de nódulos que *P. erosus*, pero de menor tamaño, por lo tanto, el peso de los nódulos fue significativamente mayor (p<0.05) en *P. erosus* en la mayoría

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de los muestreos. El rendimiento de tubérculos frescos fue significativamente mayor en *P. erosus* (p<0.01) y *P. ahipa* mostró un mayor peso seco, lo que fue debido a una mayor concentración de sólidos solubles y fibra. El mayor rendimiento de *P. erosus* se relacionó a un ciclo de cultivo más largo, mayor IAF y biomasa.

Palabra clave: *Phachirizus erosus* y *P. ahipa*, biomasa de la planta, índice de cosecha de nitrógeno.

INTRODUCTION

The Mesoamerican yam bean crop *Phachyrizus erosu*s is native to Mexico, Guatemala and Northern Nicaragua, where it is known as "jicama". This crop is widely grown in the Bajio region of central Mexico under irrigated plus rainfall conditions. Edible tuber production is best suited to sandy, light textured soils with moderate to favorable fertility and high soil organic matter content (Lind and Purcino, 1987). The yam bean is a crop of low nitrogen requirements (Tamez, 1987), since it has a high capacity to fix atmospheric N_2 in symbiosis with nitrogen-fixing Rhizobium and Bradyrhizobium bacteria (Hafini *et al*., 1994; Badillo and Castellanos, 1996) and for biomass and tuber production (Sorensen, 1996).

In contrast with many of the grain legumes, a substantial amount of the fixed nitrogen is returned to the soil if the vegetative above ground parts are left in the field (Badillo and Castellanos, 1996; Sorensen, 1996). Therefore, the crop can be an important component in any agronomic rotation and of a sustainable land use, from both an ecological and socioeconomic standpoint (Hafini *et al*., 1994). This crop is particularly interesting to be used in crop rotations under organic farming. Adequate available soil P favorably influences Yam bean tuber growth and atmospheric N_2 fixation, being P a first limiting factor for high tuber yields. Nodulation occurs in clusters of sparse fibrous roots closely proximate to the developing tuber. Nitrogen content of the tuber is from three to five times greater than potatoes, cassava, taro and sweet potato (Lind and Purcino, 1987).

Castellanos *et al*. (1997) conducted a field test in the central region of Mexico to assess the nitrogen fixation of two *P. ahipa* accessions (58 to 80 kg N ha^{-1}) and three *P. erosus* bred cultivars (162 to 215 kg N ha^{-1}). The amount of nitrogen recorded in the residues of *P. erosus* was from 120 to 150 kg ha^{-1} twice the amount recorded in *P. ahipa* residue and is higher than the quantity recorded in practically all grain legumes (Sorensen, 1996). Following that line of research, an experiment was conducted to determine if there is an association between the dynamics of N_2 fixation and biomass accumulation and tuber yield in *P. erosus* bred cultivar San Juan EC550 and *P. ahipa* accession 102, introduced from Bolivia.

MATERIALS AND METHODS

Plant culture

San Juan EC550 and AC-102 seeds, along with the reference crop maize hybrid H 358, were planted on April 2nd, 2005 in the field at the Bajio Experimental Station of National Research Institute for Forestry, Agriculture and Livestock (INIFAP) in Celaya, Guanajuato, Mexico (20° 34' N, 100° 46' W and 1750 masl). The soil is a Typic Pellusterts (pH 7.6, 1.8% organic matter and clay in texture) that during the previous season was planted with oat (*Avena sativa*) without the addition of chemical fertilizer. Plots 3.68 X 10 m were used in the experiment. Each plot contained four rows spaced 0.92 m apart. Plant stand for the yam bean species was of 170 000 plants ha^{-1} and 110 000 for the maize hybrid. Eighty kg ha^{-1} of P_2O_5 was applied to all treatments. Since there is abundant natural Rhyzobium and Bradyrhyzobium N_2 fixing bacteria in the experimental soil (Badillo and Castellanos, 1997), none inoculants were applied to the seed.

The weather was typical for the region, hot in spring and rainy during the summer (Figure 1). All plots were furrow-irrigated as needed with about 5 cm of water every month. In addition, during the growing season a total rainfall of 584 mm was registered near the experimental plots from June onwards.

After the onset of flowering, at 70 and 80 days after planting (DAP) in *P. ahipa* and *P. erosus*, respectively, flowers and young pods were removed from all plants in each plot every week to avoid the formation of pods and seeds. This is a common practice for yam bean production in the region since it allows for high tuber yields (Heredia, 1996). The removal of reproductive structures was suspended at 199 and 226 DAP for each species, respectively.

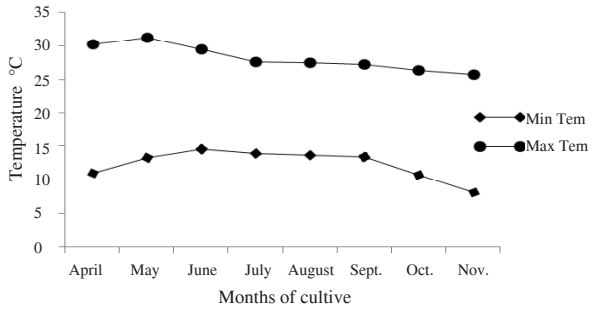

Figure 1. Average maximum and minimum temperatures during the growing season in the Bajio Experimental Station, Celaya, Guanajuato.

Plant samples and harvest

In addition to the final harvest, during the growing cycle seven plant samples were taken in *P. erosus* and six in *P. ahipa* and in the maize crop at monthly intervals, starting at 67 DAP and finishing near physiological maturity. All samples were taken from 1.0 m^2 per plot in eight replicates for the two yam beam species and in four replicates for the H 358 maize hybrid.

Plant samples were dissected to record leaf area, biomass components and number and weight of nodules. Samples were air dried first in a greenhouse and subsequently oven dried at 70 °C until constant weight was reached. After recording the weight in all plant samples, they were grounded and N content determined by the microkjeldhal method (Bremmer and Mulvaney, 1982). The amount of nitrogen fixed by the two yam species was calculated by the difference method (Weaber, 1986) utilizing maize as the reference crop. With the tuber and total biomass and nitrogen content data, the harvest index (HI) and nitrogen harvest index (NHI) were calculated as follows: HI= tuber yield/total biomass (100) and NHI= tuber nitrogen content/biomass nitrogen content (100).

Tuber harvest of *P. ahipa* and H 358 was on October 18th and November 15th for *P. erosus*. For tuber yield determination, an area of 3.8 m^2 was harvested per plot. Tuber production was recorded as fresh and dry weight.

RESULTS AND DISCUSION

Plant nodulation

In both species fixing nodules were present since the first sampling date (67 DAP) and its number and mass increased in subsequent samplings (Table 1). During the growing cycle, *P. erosus* reached the highest number of nodules at 170 DAP and its number was similar to the observed in previous reports (Tamez, 1987; Castellanos *et al*., 1997), while in *P. ahipa* it was observed at 123 DAP. *P. ahipa* had a higher number of nodules than *P. erosus*, but of smaller size, therefore, the dry weight of nodule mass was significantly higher (p>0.01) in *P. erosus* from 123 DAP onwards.

Table 1. Number and dry weight of nodules per m^2 of two yam bean species grown under irrigation plus rainfall conditions in Celaya, Guanajuato, Mexico.

Days after planting	Nodules m^2		Dry weigh g m^2	
	P. ahipa	*P. erosus*	*P. ahipa*	*P. erosus*
67	20	20	0.28	0.28
97	89	39	0.98	0.84
123	326	230	1.99	7.42
143	293	85	0.81	3.86
170 (183)[1]	515	128	1.61	6.31
199 (210)	144	146	2.08	8.24
(226)	-	86	-	5.82

[1] (#)= number of DAP for *P. erosus*.

From the third and fifth sampling onwards, 123 and 170 DAP in *P. erosus* and *P. ahipa*, respectively, nodules were senescent, decreased in number and weighted less than in previous sampling dates, although there was some variation in this response across sampling dates. Since the reproductive structures were weekly removed, thus senescence was

probably due to a high demand for assimilates exerted mainly by the tubers and some by the vegetative growth. The yam beam is an indeterminate plant with overlap of vegetative and reproductive growth (Sorensen, 1996).

Biological nitrogen fixation, plant nitrogen content and NHI

The amount of nitrogen fixed, after removing the maize nitrogen content from the total nitrogen in the yam bean species, was higher in *P. erosus* (199 kg ha^{-1}) than in *P. ahipa* (134 kg ha^{-1}) (Table 2), similar results as those previously reported by Castellanos *et al*. (1997). This result was probably due to a larger nodule mass and longer growing cycle of *P. erosus* that allowed for a prolonged time for fixation. Since the straw is usually left in the field for incorporation during plowing, the contribution of nitrogen by the yam bean crop to the subsequent crop in the agronomic rotation is quite important (Sorensen, 1996; Castellanos *et al*., 1997).

Table 2. Tuber and straw N content of two yam bean species and maize hybrid H 358 grown under irrigation plus rainfall conditions in Celaya, Guanajuato, Mexico.

Species	Tuber N kg ha $^{-1}$	Straw N kg ha $^{-1}$	Total N kg ha $^{-1}$	N fixed kg ha $^{-1}$
P. erosus	149 a	127 a	276 a	199 a
P. ahipa	116 a	94 a	210 b	134 b
Z mays L.	50 (grain)	27	77	-

Data obtained from the total N in tuber (Table 2) and fresh yield (Table 3), shows that protein content of *P erosus* was 0.9% as compared with 1.5% for *P. ahipa*. Regarding NHI both species were similar in this characteristic (Table 4). Figures 2 and 3 shows the data on N accumulation in the different parts of the plant along the season. It is particularly interesting that the crop show a very low acquisition of N during the first 100 days, but after that stage, it increases significantly. Nitrogen remobilization to tuber becomes important until the end of the season, after 150 to 180 days.

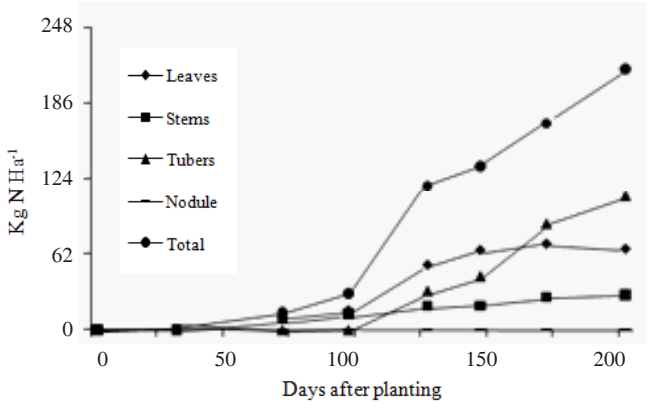

Figure 2. N accumulated in *P. ahipa* at different stages of the crop.

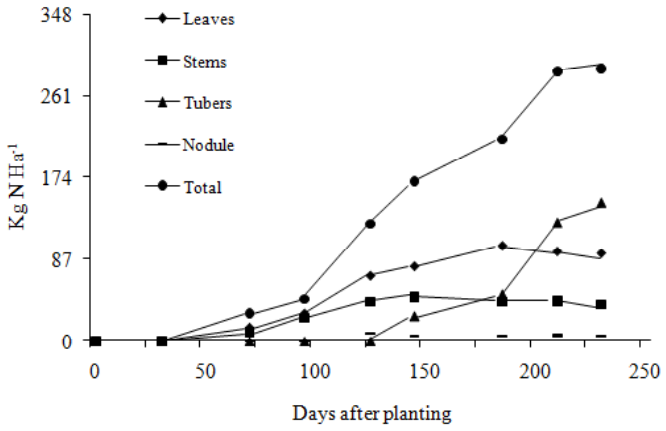

Figure 3. N accumulated in *P. erosus* at different stages of the crop.

Table 3. Tuber yield[1] and dry weight of two yam bean species and grain yield of maize grown under irrigation plus rainfall conditions in Celaya, Guanajuato, Mexico.

Species	Yield	Dry weight	Above ground biomass	Above ground/tuber biomass[2]
			t ha^{-1}	
P. ahipa	48.3 b	9.00 a	2.75 b	0.305
P. erosus	105.3 a	7.96 a	4.33 a	0.544
Z mays L.	5.0 (grain)	4.33	10.44	-

[1] fresh weight; [2] on a dry weight basis.

Biomass and LAI

Early during the cycle, in a similar way as for biomass, the LAI was greater in *P. ahipa* and from 65 DAP onwards *P. erosus* displayed a significantly larger LAI (Figure 4). This was in part due to a larger growing cycle in *P. erosus, which* initiated the reproductive period ten days after *P. ahipa* (Figure 5). This difference in the duration of the vegetative period between the two species might be due to differences in photoperiod sensitivity, being *P. ahipa* less sensitive.

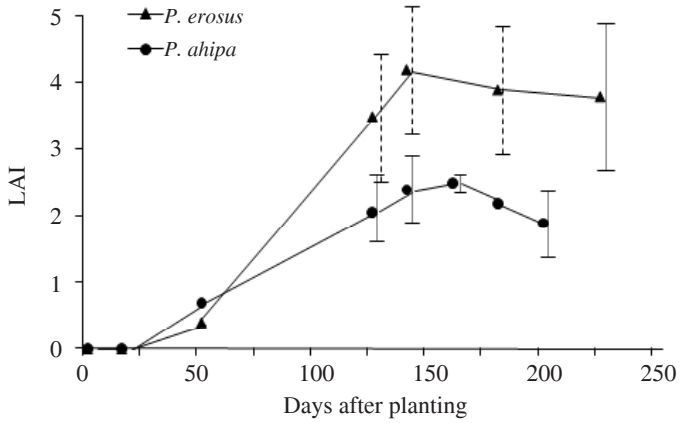

Figure 4. Leaf area index of two yam bean genotypes during the growing cycle at Celaya, Guanajuato, Mexico.

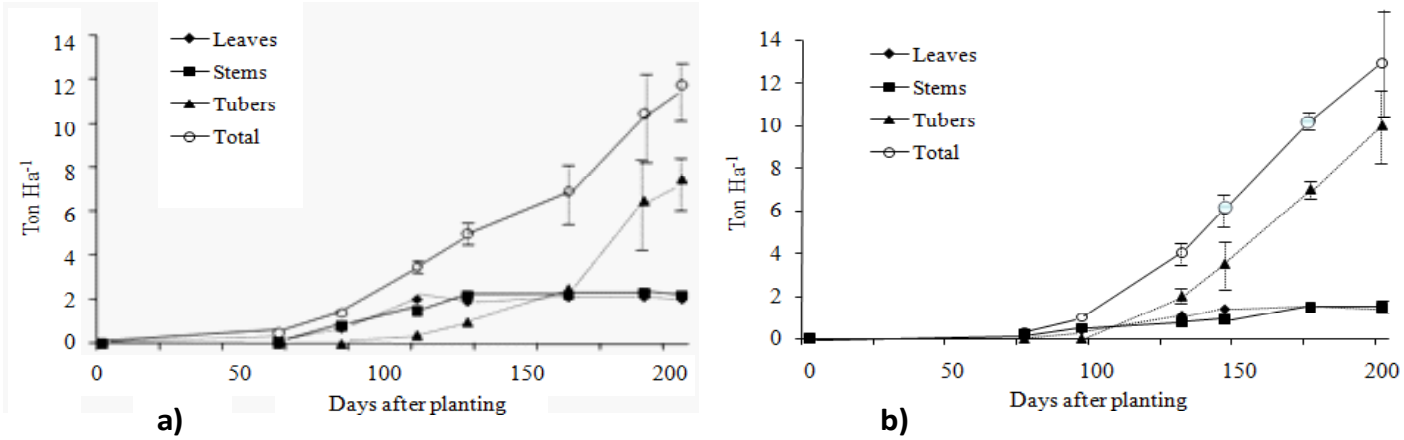

Figure 5. Biomass of plant parts along of the growing cycle of *P. erosus* a) y *P. ahipa* b) grown at Celaya, Guanajuato, Mexico.

Tuber yield and HI

Tuber yield of *P. erosus* was significantly higher than that of *P. ahipa* (Table 4) and the dry matter was similar; thus the water content of *P. erosus* was higher and that may be the reason for its vernacular name 'jicama de agua' in Mexico, in contrast to other yam bean cultivars with less water called 'jicama de leche', *P. ahipa* belongs to the later vernacular classification. The higher water content of *P. erosus* makes it suitable for fresh consumption rather than processed (Sorensen, 1996). *P. ahipa* displayed a larger dry tuber weight and this was due to a higher concentration of solids in the tuber.

Table 4. Tuber harvest index and nitrogen harvest index of two yam bean species and maize hybrid H 358 grown under irrigated plus rainfall conditions in Celaya, Guanajuato, Mexico.

Species	Harvest index	Nitrogen Harvest index
P. erosus	0.65 b	0.54 a
P. ahipa	0.76 a	0.55 a
Z. mays	0.48	0.65

In contrast to the NHI that was similar between species, the tuber HI was significantly higher in *P. erosus* as compared to *P. ahipa*. In spite of its lower yield potential, the introduction of *P. ahipa* into central Mexico might have been due to other desirable traits, such as longer shelf life.

CONCLUSIONS

The dynamics of nitrogen fixation of the species *P. ahipa* and *P. erosus* was similar up to 170 DAP, from that date onwards the amount fixed was greater *in P. erosus* due to a longer growing cycle.

The number of nodules was larger in *P. ahipa* than in *P. erosus*, but the nodular mass was greater in the last species due to a larger nodule size.

Early during the cycle the LAI was greater in *P. ahipa* and from 65 DAP *P. erosus* displayed a significantly larger LAI. This was in part due to a longer growing cycle in *P. erosus*.

Fresh tuber yield in *P. erosus* was superior to *P. ahipa*; however, this last species displayed a larger dry tuber weight and this was due to a higher concentration of solids in the tuber.

The straw of the yam bean crop left in the field contained 127 kg of N ha^{-1} in *P. erosus* and 97 kg of N in *P. ahipa*. Therefore, this crop can be an excellent component in agronomic rotations.

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