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Yacon planting density in intercropping with corn under banana orchard

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ABSTRACT

Yacon is a crop which requires development of strategies for its cultivation. One of the possibilities is to introduce yacon in perennial crops using intercropping system. The aim of this study was to evaluate different planting densities of yacon grown in intercropping with corn under banana orchard, verifying its development and production. At 90 days after planting, morphological and physiological evaluations were done, at 210 days yacon was harvested, and its productivity calculated using the fresh tuberous root production. The Area Equivalence Index (IEA), and the Relative Contribution of Crops (CRC) to IEA were calculated. Yacon development and production were hampered by the corn intercropping (under the banana orchard), regardless of the yacon density used. IEA increased with yacon and corn intercropping in relation to greater CRC of corn to the intercropping and its market value, the system presented higher gross income. Planting yacon under banana orchard optimizes the use of the area and it is profitable for the farmer, especially when yacon is planted in double rows, alternating between banana rows, spacing 0.3 and 0.4 m.

Keywords: *Smallanthus sonchifolius*, spacing, polyculture, shading.

RESUMO

Densidade de plantio de yacon em consórcio com milho sob pomar de bananeira

Yacon é uma cultura que demanda desenvolvimento de estratégias para seu cultivo. Dentre as possibilidades, está a introdução da yacon em lavouras perenes através de consórcios. Objetivou-se com o presente trabalho avaliar diferentes densidades de plantio de yacon cultivada em consórcio com milho, sob pomar de bananeira, verificando seu desenvolvimento e produção. Aos 90 dias após o plantio foram realizadas avaliações morfológicas e fisiológicas, aos 210 dias a colheita da yacon, e sua produtividade calculada a partir da produção de raízes tuberosas frescas. Calculou-se o Índice de Equivalência de Área (IEA), e a Contribuição Relativa das Culturas (CRC) ao IEA. O desenvolvimento e produção da yacon foram prejudicados pelo consórcio com o milho (sob o pomar da bananeira), independente da densidade de yacon utilizada. O consórcio yacon-milho aumentou o IEA e, em função da maior CRC do milho ao consórcio e seu valor de mercado, o sistema apresentou maior renda bruta. O plantio de yacon sob pomar de bananeira otimiza o uso da área sendo rentável ao agricultor, sobretudo quando a yacon é plantada em linhas duplas, alternando nas entrelinhas da bananeira, nos espaçamentos 0,3 e 0,4 m.

Palavras-chave: *Smallanthus sonchifolius*, espaçamento, policultivo, sombreamento.

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Since 80's, yacon has become popular in different countries in South America (Brazil and Paraguay), and also in countries in other continents, such as New Zealand (Oceania), Japan and Korea (Asia), Czech Republic (Europe) and the United States (Seminario *et al.*, 2003).

In Brazil, yacon started to be cultivated in 90's, in São Paulo State, especially in the municipality of Capão Bonito. However, as the vegetable started to be more and more consumed, from the year 2000, yacon was introduced in other states, such as Minas Gerais, Parana, Rio de Janeiro and Espírito Santo (Oliveira *et al*., 2013).

Yacon is a functional food and it has stood out in food technology industry, as it shows prebiotic activities and for its sweet taste of fructans such as inulin and fructooligosaccharides (FOS), promoting positive health outcomes (Sacramento *et al*., 2017). Nevertheless, as it is still an emerging crop, yacon planting areas can be expanded through developing strategies for its cultivation. Among the possibilities, yacon can be intercropped with perennial crops already known, which is an interesting suggestion, since it could mean a diversification of production system, expanding the food supply and generating income for farmers.

In the Andes, where yacon originated, it is also cultivated in edges of corn and vegetable crops, or associated with corn, beans, potatoes, cabbage, parsnips, coffee and fruits (Seminário *et al.*, 2003), considering its potential to be explored as an income-generating alternative for family farming (Villamiza *et al.*, 2014).

According to Teixeira (2018), yacon plants which have been growing under moderate shade levels (30 to 50%) showed greater capacity for total biomass accumulation, part of this accumulation for the tuberous roots, which directly reflects in agronomic productivity gains. According to Tomazini *et al*. (2009), yacon shows to be quite tolerant to variations in light quantity, growing under tree and bush shadows, attributing to these plants important characteristics to compose intercropped production systems, including agroforestry. Thus, it is possible to grow yacon with other larger species, such as fruitful species, constituting intercropped systems.

Among the crops which can be diversified with the introduction of yacon, banana crop stands out since it is of great importance for Brazil (planted area of approximately 477.3 thousand hectares) (Seapa, 2017). It is one of the main crops in Espírito Santo State, with a total planted area of 26,320 hectares and average production around 277 thousand tons (Incaper, 2017), predominantly banana (Prata variety), mostly produced by family-based farmers, which makes it an activity of great social importance.

Moreover, banana plant is considered an ideal component for intercropping in general, since this plant provides several benefits to the systems, such as minimize the incident global solar radiation, adjust the photosynthetic rates in case of an excess of light, minimize high temperatures, and increase the productive capacity of shaded species (Araújo *et al*., 2015), making large amounts of biomass available to the system

The success of the intercropping between plants will depend on some basic aspects such as the choice of species which will compose the system, the choice of the best arrangement, the time of each species planting and the definition of plant population. These aspects are fundamental for reaching desired technological levels, guaranteeing good yields (Oliveira Filho *et al.*, 2016).

Thus, the authors noticed the possibility of yacon planting intercropped with bananas, when its canopy is more open, allowing the insertion of another species. In addition, as yacon has slow initial growth, with an emergency time that can take 30 to 60 days (Silva *et al.*, 2018), it is possible to compose a triple intercropping, based on lines between species, which would further contribute to optimize the use of the area and to increase the farmer's income.

In this context, it is possible to insert another crop which is compatible with yacon and banana, showing fast growth and short cycle, choosing corn, to be harvested in green stage, since its demand for its relevance in Brazilian cuisine and, because of its commercial value, which optimizes the use of the area and would increase the farmer's income (Pereira Filho *et al*., 2015).

Thus, the aim of this study was to evaluate different planting densities of yacon grown intercropped with corn, under banana orchard, verifying its development and production.

MATERIAL AND METHODS

The experiment was carried out from October 2016 to December 2017, in the experimental area of Universidade Federal do Espírito Santo (UFES) in Rive, district of Alegre, Espírito Santo State, Brazil (20°45'49"S, 41°29'59"W, altitude 113 m). The area is located in Rio Itapemirim Valley, a warm tropical micro region (lowlands), with higher temperatures (Pezzopane *et al*., 2012). During the experiment, maximum temperatures ranged from 28 to 36°C and minimum from 15 to 20°C, with accumulated rainfall 1538.2 mm (data obtained from automatic weather station of Instituto Nacional de Meteorologia of Brazil-INMET, Alegre-ES), located near the experiment.

Soil in the area was classified as Red-Yellow Latosol, medium texture (Embrapa, 2014). Soil samples were collected from the 0-20 cm layer, which presented the following chemical and granulometric characteristics (Laboratório de Solos, at Centro de Ciências Agrárias e Engenharias, UFES): pH (water)= 5.73; phosphorus$_{\text{Mehlich1}}$= 34.79 mg dm^{-3}; potassium = 42.0 mg dm^{-3}; calcium = 2.51 cmolc dm^{-3}; magnesium = 1.38 cmolc dm^{-3}; aluminium = 0.00 cmolc dm^{-3}; sum of bases = 2,36 cmolc dm^{-3}; CTC effective = 2,36 cmolc dm^{-3}; base saturation = 57.34%; total organic carbon = 1%; total nitrogen = 0.1%; sand = 60%; silt = 5%; clay = 35%.

The experimental design was completely randomized, with six replicates, arranged in split plot scheme in space, considering the plot the three yacon planting densities (11,111; 8,333 and 6,666 plants ha^{-1}), and split plot factor the presence and absence of corn intercropping.

The densities used in the plots were calculated using the equation: 5m +1m (plot area) x spacing between plants; with plant population of 11,111 plants per hectare, spaced 0.3 m between plants; 8,333 plants per hectare spaced 0.4 m, and 6,666 plants per hectare spaced 0.5 m.

We used this way to calculate densities since yacon was planted in two rows (spaced 1.0 m between rows, and spacing between plants following the treatment mentioned above), alternating the rows of banana plants. The spacing used in banana plants was 3x2 m. We used cultivar BRS Vitória, group Prata, for banana orchard, at the stage which corresponds to the end of the juvenile phase and the beginning of the reproductive phase at 180 days; the shoot emission was at 90 and 120 days, conducted with management practices (fertilization, sprout thinning) based on the manual of recommendation for bananas (Embrapa, 2012).

In split plots, the one with corn intercropping, three rows were sown in order to involve the two rows of yacon (equidistant 0.5 m from the rows), spaced 0.2 m between plants.

The insertion of corn crop between rows of yacon was due to its low growth characteristic in the initial phase presented, with emergence from 30 to 60 days after planting, combined with a banana orchard in formation stage.

The soil to cultivate yacon and corn was prepared using a rotary hoe (two passes). Then, in April, rhizophores weighing approximately 35 g were planted in furrows at 10 cm depth. The fertilization of yacon was adapted according to the recommendation of Amaya Robles (2002), providing nitrogen (N), at equivalent dose of 104.37 kg ha^{-1}. The authors used tanned bovine manure, which presented: 15.054 g kg^{-1} nitrogen, 5.996 g kg^{-1} phosphorus, 8.746 g kg^{-1} magnesium, 9.098 g kg^{-1} calcium and 30.069 g kg^{-1} potassium. Bovine manure, 160 g, was applied per plant at planting and 70 g was applied top dressing, after 90 days. Corn planting was performed on the same day yacon was planted (April, 5) using seeds of conventional variety Alvareli, with two fertilizations, one at planting and another at 20 days after emergence, with 50 g m^{-2} of formulation 04-14-08.

Three manual hoeings were done throughout yacon cycle in order to control spontaneous plants. Sprinkler irrigations were performed in order to supplement monthly rainfall, via climate management, and irrigation shift every three days, in order to approach 600 mm required by yacon crop (Grau & Rea, 1997). There was no need for pest and disease control for any of the crops.

Solar radiation measurements were performed 90 days after yacon planting, with the aid of a radiometer LI-191R Line Quantum Sensor, at the top of yacon canopy, in both environments (with or without corn intercropping).

At 90 days after planting (DAP), we performed some evaluations in the four central plants of the yacon plots. The following morphological and physiological characteristics were measured: plant height, number of leaves, leaf area, contents of chlorophyll a, b and total, net CO_2 assimilation rate, stomatal conductance and transpiration rate.

Leaf area was obtained with the aid of rulers, measuring the length along the main leaf vein, from the base to the leaf apex, disregarding the petiole; and the width measured perpendicular to the main rib, obtained from one end to the other of the leaf. The leaf area was calculated using the equation ÂƒCL= -27.7418+ (3.9812CL/lnCL), in which C is the length and L the width of the leaf, developed by Erlacher *et al*. (2016).

Chlorophylls contents were determined with the aid of ClorofiLogFalker model FL103, at 8 a.m., using the last pair of fully expanded leaves.

Net CO_2 assimilation rate, stomatal conductance and transpiration rate were determined using an infrared gas reader (IRGA Licor 6800XT). The measurements were carried out at 1 p.m., on clear sky days, again using the last pair of fully expanded leaves, and without any visual abnormalities. Photosynthetically active radiation was standardized in artificial saturating light of 1000 μmol photons m^{-2} s^{-1} and CO_2 in concentration in a 420 ppm chamber.

After evaluating yacon, corn was harvested (90 DAP) at green corn stage. Corn biomass was cut and left on the soil, to be used as mulching. We evaluated diameter, length and weight of the ears (husked and unhusked), and total productivity (t ha^{-1}). Productivity was calculated using fresh mass of husked ears, and productivity in monocrop was estimated based on the data obtained from Embrapa (2016).

At 210 days, yacon was harvested and its productivity calculated using the production of tuberous roots per area, according to planting density in each treatment. For productivity in yacon monocrop, we calculated IEA considering 39.9 t ha^{-1} found by Carvalho (2018), in density of 20,000 plants per hectare, under the same climatic conditions.

Banana productivity was calculated using tier weight and cluster emission at the end of the first production cycle. The authors considered the intercropping in the two rows along with yacon, and monocrops for the lines with no yacon planting.

Area equivalence index (IEA) was calculated using the relationship between the productivity in the cultivated area using the intercropping system and in monocrop (Vandermeer, 1990), using the following formula: IEA = (productivity of Crop A in intercropping / productivity of Crop A in monocrop) + (productivity of Crop B in intercropping / productivity of Crop A in monocrop). According to Vandermeer (1990), intercropping is considered efficient, in relation to monocrop, when the value of IEA is superior to 1.00.

We also calculated the Relative Contribution of Crops (CRC) to IEA, which is a derivative of the ratio between Individual Relative Productivity (IA and IB) and the total IEA of the system, showing the percentage of participation of each crop in obtaining the total index, using the formula: CRCA = (IA x 100) / IEA and CRCB = (IB x 100) / IEA. In addition to these agronomic indicators, gross income was calculated (RB = quantity produced x selling price), taking into consideration the average marketing cost of the kilogram of yacon roots, husked ears and banana tier, from January to July, 2018, at the Supply Centers in the state of Espírito Santo (Ceasa-ES).

Data were submitted to variance analysis (ANOVA) in a scheme of subdivided plots. The averages for corn intercropping were compared using the F test ($p<0.05$) and effect of planting densities were compared using Tukey test ($p<0.05$), by SISVAR software (Ferreira, 2011).

RESULTS AND DISCUSSION

No interaction between densities of yacon cultivation and intercropping with corn was observed, for morphological and physiological variables at 90 DAP. However, significant effect using intercropping was verified, considering that yacon plants presented a decrease in height, number of leaves and leaf area, when intercropped with corn up to 90 DAT (Table 1). We also verified significant effect on density only for productivity (Table 2).

Changes in height, leaf area and number of flowers of yacon plant occurred due to light restrictions caused by the intercropping with corn (on the first 90 days of yacon cycle), which retarded the growth. The same was observed in yacon cultivated with corn in Peru, where yacon grew slowly in the first three months. Nevertheless, after corn harvest, greater plant development was observed; which coincided with the vegetative stage and beginning of tuberization of rapid growth roots of yacon (Seminário *et al*., 2003).

Morphological characters also vary according to environmental (water, light, temperature) and cultural factors (such as planting density) (Amaya Robles, 2002).

Most of the time shaded plants are higher than non-shaded ones (Han *et al*., 2015), almost always due to etiolation;

no response for yacon in intercropping was verified, though. However, a decrease in growth in relation to less radiation incident on the plant was noticed.

Generally the small amount of light provides lower levels of chlorophyll "a", "b" and total in plants in relation to the plant in full sun (Yang *et al*., 2018). However, these responses depend on each plant, as well as restriction intensity in which it is exposed, since some plants can adapt to conditions with some light restrictions, such as taro (*Colocasia esculenta*), which produces better under 30% light restriction (Oliveira *et al*., 2011). For sweet potato, the ability to develop under light restriction depends on the genetic material, considering that some cultivars are more adapted to low light intensity conditions (Zhang *et al.*, 2018).

Some reports state that yacon is benefited by a certain level of shading, according to Teixeira (2018), 30% to 50% light restriction promote better growth and development of yacon plant.

The decrease in photosynthetically active radiation also affected other physiological processes, since net CO_2 assimilation rate, stomatal conductance and transpiration rate were lower in yacon intercropped with corn (Table 1). Lower stomatal conductance resulted in the lower rate of transpiration, demonstrating that the plants would be in an unfavorable condition, which would limit the opening of stomata, resulting in less conductance of these plants and making it difficult to maintain the continuous soil-plant-atmosphere. This may lead to inefficiency of electron transporters and in the activity of ribulose-1.5-bisphosphate carboxylase / oxygenase, and decrease in the rate of liquid assimilation (Li *et al*., 2014).

The results may be related to the lower efficiency of yacon in increasing the total dry mass under greater light restriction conditions, which is directly related to a lower efficiency in the use of light, CO_2, water and nutrient resources (Pinzón-Torres & Schiavinato, 2008), resulting in a lower development up to 90 DAP, when intercropped with corn, under banana orchard.

Corn was harvested at 90 DAP showing corns with 4.2 cm average diameter (husked ear) and 3.8 cm (unhusked ear), 17.3 cm average length (husked ear) and 10.9 cm (unhusked ear), 4.6 t ha^{-1} average productivity (husked ear) and 7.6 t ha^{-1} (unhusked ear). Despite the values of ear length being below those observed in monocrops, with averages from 16.71 to 19 cm (Pereira Filho *et al*., 2015), diameters were superior to 3 cm, showing that no produced ear quality was lost.

Light restriction condition decreases the leaf photosynthetic rates (Yang *et al*., 2018), promoting lower net photosynthesis rates, which may affect the development and production of some plants. For yacon/corn intercropping, a competition for nutrients may probably have happened when yacon would be mobilizing its reserves for the tuberous roots, as it was reported by Silva *et al*. (2018): yacon shows increasing investment in the fraction of tuberous roots, especially after 60 days after planting, and peak investment at 120 days.

This possible competition must have been supported by the characteristics of corn which is a rapid-growth plant, with an aggressive root system, and great nutrient extractor (mainly nitrogen), which could have harmed yacon, despite management conditions and cultural treatment (mainly fertilizations) have been done according to the needs for each plant. It has to be considered that the corn crop received top dressing fertilization earlier (at 20 days), which could have allowed the possible competition between crops, after 60 days.

Thus, this fact should be observed when planning an intercropping system to achieve success. Some crops are affected by light restriction caused by other crops, when intercropped, which results in a decrease in growth and production (Zhang *et al*., 2018). However, adaptations of these crops to intercropping need to be studied case by case, since management used in the system also influences. Taro plants, for instance, were benefited from intercropping with crotolaria, during the first 120 days in the cycle; permanent intercropping with crotolaria was harmful to this plant, though (Oliveira *et al*., 2007).

Thus, we should observe that the performance of yacon/corn intercropping, under banana orchard, is efficient for income generation to the farmer. The area equivalence index (IEA) was 1.23 (value from which intercropping system is considered

Table 1. Averages of plant height, leaf area and number of leaves, chlorophyll a, b and total, net assimilation rate, transpiratory rates and stomatal conductance in yacon plants cultivated in intercropping in the absence and presence of corn, under banana orchard, at 90 days after planting. UFES, Alegre, 2017.

Corn intercropping	Height (cm)	Leaf area (cm^2)	Number of leaves
Absence	35.5 a*	252.05 a	15.72a
Presence	30.5 b	163.61 b	11.61b
CV (%)	5.89	11.43	5.20
	Chlorophyll "*a*"	**Chlorophyll "*b*"**	**Total chlorophyll**
	28.64a	8.41a	37.41a
	24.70b	6.52b	31.58b
CV (%)	4.71	11.96	5.20
	A **(μmol CO_2 m^{-2} s^{-1})**	***E*** **(mmol H_2O $m^{-2}s^{-1}$)**	**g_s(mol H_2O m^{-2} s^{-1})**
	8.63a	4.67a	0.400a
	5.62b	3.12b	0.267b
CV (%)	32.82	15.00	25.03

Averages followed by same letters did not differ significantly by F test, 5% probability; *A*= net assimilation rate; transpiratory rates (*E*) and stomatal conductance (g_s).

Table 2. Area equivalence index, relative contribution of crops and gross income of yacon cultivation under banana orchard. UFES, Alegre, 2017.

Spacings	Productivity (t ha $^{-1}$)	IEA[2]	CRC[3] (%)		Gross income (R$)[4]		
			Yacon	Banana	Yacon	Banana	Total
0.3 m	6.47a[1]	1.16	13.7	86.3	8,057.50	27,400.00[4]	35,457.50
0.4 m	6.09a	1.15	13.4	86.6	7,612.00	27,400.00	35,012.00
0.5 m	2.79b	1.07	6.5	93.5	3,487.50	27,400.00	30,885.50
CV (%)	30.08						

[1]Averages followed by same letters in the column did not differ significantly by F test, 5% probability. [2]Area equivalence index (IEA); [3]Relative contribution of crops (CRC). [4]Calculus based on R$1.25 kg^{-1} of yacon roots and on R$1.37 kg^{-1} of banana tier, which were the average values commercialized from January to July, 2018 at Centrais de Abastecimento do Espírito Santo (Ceasa-ES).

efficient to be used), it means, superior to 1.0 showing that yacon/corn intercropping increase the efficiency in using the area, despite the decrease in yacon productivity 3.91 t ha^{-1} in the presence of corn, less than in the absence of 6.25 t ha^{-1}.

We calculated the Relative Contribution of Crops (CRC) in yacon/corn intercropping based on R$1.25 kg^{-1} of yacon roots and R$1,33 kg^{-1} of husked ear, which were the average values commercialized from January to July (2018) at Centrais de Abastecimento do Espírito Santo (the main supply center in the state of Espírito Santo, Ceasa-ES). The authors noticed that corn contributes in 51.3% more than yacon, with 48.7%, due to a good crop yield in the intercropping (7.6 t ha^{-1}). This greater contribution of corn will reflect in the gross income obtained in the intercropping system, compensating for decrease in productivity noted with yacon. That is why, the intercropped areas showed better gross incomes, R$8060.00, in relation to areas without intercropping, R$4885.00, showing that although intercropping is detrimental to yacon productivity, corn yield can financially compensate.

Considering this fact, for a farmer who aims to grow yacon, this intercropping is not interesting, since yacon shows a decrease in productivity when intercropped with corn. However, for a farmer who aims to grow corn, corn intercropping in the initial phase of yacon cycle (90 first days of cycle) can be convenient, as the extra income offered by corn makes intercropping more profitable.

Observing the effect of yacon planting densities under banana orchard, the authors noticed that spacings 0.3 and 0.4 m were the ones which promoted higher productivities (6.47 and 6.09 t ha^{-1}, respectively), this is related to greater number of plants per area (Table 2).

Generally, yacon productivity obtained under banana orchard can be considered lower than expected, since the higher density of the plant tested in this system (11,111 plants ha^{-1}) was around 50% in relation to density usually used in monocrop (20,000 plants ha^{-1}) and presented around 21% of the productivity observed in monocrops (30 t ha^{-1}) (Silva *et al.*, 2018).

Using these values of productivity of yacon and banana, IEA was estimated in the three spacings of yacon cultivation, considering that all the values were higher than 1.0 (reference value), showing that yacon planting system under banana orchard was efficient in use of the area, in all used spacings (Table 2). IEA results showed that intercropping with yacon grown in double rows (between alternating banana plant rows) optimizes the use of the area in 16, 15 and 7%, in yacon spacing of 0.3 m; 0.4 m and 0.5 m, respectively.

Also, Relative Contribution of Crops (CRC) to IEA in yacon intercropping under banana orchard (in each density) was calculated. The authors noticed that banana is the crop which most contributes, which was expected, since it is the main crop; yacon also generates contributions for intercropping, around 13%, when planted in spacings 0.3 and 0.4 m, though (Table 2).

Observing monetary income of the intercropping (gross income, R$), we noticed that higher productivity, with higher CRC, was obtained using yacon in spacings 0.3 and 0.4 m, provided higher gross income using intercropping in these densities. Thus, for a banana farmer who also aims yacon market, the intercropping is also interesting, considering using double rows to plant yacon, alternating between the rows of banana, mainly in 0.3 and 0.4 m spacings.

The authors highlight that banana crop was not affected by yacon crop, presenting an average productivity of 20 t ha^{-1} (in first generation plants, mother plants), 12.42 kg cluster weight, 1.6 kg tier weight, 144 g fruit weight, 8.73 tiers/cluster, 14.05 fruits/tier, and 14-cm length and 40-mm diameter fruits. These characteristics are within market classification standard (HorteBrasil, 2018). Moreover, banana productivity, in general, was above average in Espírito Santo (7.8 t ha^{-1}) (Incaper, 2017).

Taking into consideration that banana crop is one of Capixaba agribusiness activities, showing great social and economic importance, generating over 25 thousand jobs mostly family-based farmers, yacon insertion intercropped with banana orchard can be a viable strategy, extra income for family farmers, contributing to their food and financial sovereignty.

Yacon development and production were harmed by corn intercropping (under banana orchard), regardless yacon spacing used. Yacon-corn intercropping increased area use efficiency and, in relation to a greater relative contribution of crop to intercropping and its market value, the system generated higher gross income, showing that despite harming yacon productivity, it is still profitable for the farmer.

Yacon planting, under banana orchard, optimizes the use of the area (around 15%), being profitable to the farmer, especially when the yacon is planted in double rows, alternating between the rows of the banana tree, in 0.3 and 0.4m spacings.

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