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VEGETATIVE GROWTH OF PEACH TREES [*Prunus persica* (L.) Batsch] ASSOCIATED WITH NATIVE SQUASH (*Cucurbita pepo* ssp. *pepo* L.) AND BAYOCOTE (*Phaseolus coccineus* L.) IN MILPA INTERCROPPED WITH FRUIT TREES (MIAF) SYSTEMS

Eduardo **Muñoz-Ruiz**[1], Horacio **Santiago-Mejía**[1*], Ildefonso **Ronquillo-Cedillo**[1], Rocio **Albino-Garduño**[1], José Isabel **Cortés-Flores**[2], Julie **Grossman**[3]

[1]Universidad Intercultural del Estado de México. Maestría en Gestión de la Innovación Rural Sustentable. Libramiento Francisco Villa S/N, Colonia Centro, San Felipe del Progreso, State of Mexico, Mexico. C. P. 50640.
[2]Colegio de Postgraduados Campus Montecillo. Posgrado en Edafología. Carretera México-Texcoco km 36.5, Montecillo, Texcoco, State of Mexico, Mexico. C. P. 56264.
[3]University of Minnesota. Department of Horticultural Science. 1970 Folwell Ave., Saint Paul, MN, USA. C. P. 55108.
* Author for correspondence: horacio.santiago@uiem.edu.mx

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ABSTRACT

The scarcity of basic foodstuffs in the Mazahua region of the State of Mexico, Mexico, reflects the scarcity of arable land in peasant agriculture. This issue was exacerbated in the early years of the Milpa Intercropped with Fruit Trees system (MIAF, for its Spanish acronym), because the fruit tree strip occupied up to 40 % of the area while producing no food or income during its vegetative growth stage. Native squash (*Cucurbita pepo* L.) and bayocote (*Phaseolus coccineus* L.) are basic species in the Mazahua diet, but it is unknown whether they have an adverse effect on the vegetative growth of the newly planted peach trees [*Prunus persica* (L.) Batsch] when grown in association. The goal of this research was to evaluate the effect of native squash and bayocote, grown in the fruit tree strip of the MIAF system, on the vegetative growth of peach trees for efficient soil intensification during the juvenile period of the tree. The treatments primarily involved associating peach trees with native squash, bayocote, and uncovered soil. The experimental design comprised randomized blocks with three replications. Vegetative growth, shoot biomass, root distribution, and soil moisture content were evaluated 60, 120, and 180 days after planting. Data were subjected to analysis of variance and comparison of means with the Tukey test ($p \leq 0.05$) using the SAS 9.4 program. The native squash decreased the diameter and stem biomass of the peach trees since there was greater root overlap between the two species and less soil moisture. In contrast, with the association of the fruit tree with bayocote, the root distribution of the peach tree was greater, with no decrease in the diameter, height, or biomass of its stem. Local species such as bayocote have the potential to be grown in the fruit tree strip of the MIAF system in their first year of establishment.

Keywords: root distribution, crop association, biomass.

INTRODUCTION

In the Mazahua region of the northwestern State of Mexico, Mexico, traditional agriculture still predominates, practiced by farmers owning less than 5 ha of land (Albino-Garduño *et al*., 2021), who produce basic grains in rainfed and hillside conditions (Vásquez-González *et al*., 2018). In this type of agriculture, maize yields and net incomes are low, and food production is not sufficient for rural families (Martínez-Borrego and Vallejo-Román, 2019).

To address this critical situation, the Milpa Intercropped with Fruit Trees (MIAF) system has been proposed, which is a multi-objective technology for smallholder farmers. MIAF optimizes arable land and increases employment (Cortés *et al*., 2012), pursues food security (Padilla-Fidencio *et al*., 2022), controls water erosion, and increases net income (Ruiz-Mendoza *et al*., 2012), precipitation infiltration (Camas-Gómez *et al*., 2012), and atmospheric carbon sequestration (Arriaga-Vázquez *et al*., 2020).

The MIAF system alternates strips of milpa with strips of fruit trees with high-quality varieties for the fresh fruit market (Cortés *et al*., 2012). On slopes with gradients greater than 20 %, fruit tree strips occupy 40 % of the area; however, they do not provide income during the first years of their establishment because of the formation of the support system and vegetative growth. The limited availability of land makes it necessary to establish annual species in the strip for food production without detriment to the vegetative growth of the fruit trees.

The literature reports a wide range of responses when associating fruit trees with annual species, depending on soil and climatic conditions as well as the species itself. On one hand, competition between ground cover species and newly planted peach trees decreases their growth and eventual productivity (Welker and Glenn, 1991). Competition for moisture and nutrients between the roots of newly planted peach trees and clover-grass mixtures reduces root biomass and total tree biomass (Forey *et al*., 2017). With grass, their size, yield (Tworkoski and Glenn, 2010), root depth, root distribution area, and stem diameter are reduced (Parker and Meyer, 1996).

However, other research shows that there is complementarity between peach trees and annual plants. Peach trees (*Prunus persica* (L.) Batsch) associated with native weeds have higher growth due to higher nitrogen availability, higher organic matter and microbial biomass, better nutrient recycling, and lower nutrient loss through leaching and runoff (Zhang *et al*., 2018). With clover, initially, stem diameter decreased, but by the third year, stems were larger than peach trees grown without cover due to greater access to water and nutrients despite root competition (Reeve *et al*., 2017). In addition, the association of peach trees with clover improves pest control because of the increase of generalist predatory arthropods (Wan *et al*., 2014). Similarly, the association of grass with olive trees increases the colonization of arbuscular mycorrhizal fungi (Palla *et al*., 2020).

Local annual species have been studied within the milpa. Native squash (*Cucurbita pepo* ssp. *Pepo* L.) is used for its flowers, vegetable squash, mature squash, and seeds.

From bayocote (*Phaseolus coccineus* L.), the grain is used. These species are consumed and marketed throughout the northern region of the State of Mexico (Vásquez-González *et al*., 2018), which allows for a more sustainable agroecosystem (Acevedo *et al*., 2020). This study set out to evaluate the effects of native squash and bayocote, grown in the fruit tree strip of the MIAF system, on the vegetative growth of peach trees for efficient land intensification during the juvenile cycle of the fruit tree. This was motivated by the scarcity of arable land and research on the association of peach trees, native squash, and bayocote in the MIAF system.

MATERIALS AND METHODS

In the spring-summer cycle of 2020, from May 25 to November 22, an experimental plot of the MIAF system was established with Mr. Manuel Téllez Hernández from the community of San Pablo Tlalchichilpa, municipality of San Felipe del Progreso, located in the Mazahua region in the northwest of the State of Mexico, Mexico (19° 42′ 58.98″ N, 99° 59′ 6.19″ W), at an altitude of 2669 m. The soil of the experimental plot is Andosol, with a temperate sub-humid climate (Cw) and rainfall of 800 to 1100 mm during the crop period (INEGI, 2009).

The result of the soil analysis, which was carried out at the Soil Genesis Laboratory of the Postgraduate College, Mexico, showed a pH of 4.42 and an organic matter content of 2.29 % at a depth of 0 to 30 cm. The bulk density of the soil is clayey, with a sandy clay loam texture, dark brown when wet and brown when dry.

Treatments and experimental design

The treatments evaluated with local species were: peach tree (*Prunus persica* (L.) Batsch) associated with native squash (*Cucurbita pepo* ssp. *pepo* L.), peach tree associated with bayocote (*Phaseolus coccineus* L.), and peach tree in soil without cover as a control. The experimental design consisted of randomized blocks with three replications. The experimental unit was delimited by a strip 4.8 m wide and 10 m long. Each strip of the peach tree is a replica. In the center of the strip, peach trees of the cultivar ‘Azteca de Oro’ were planted 1 m apart, for a total of 10 peach trees per treatment.

Crop management

The experimental plot was established on March 16, 2020, on a slope with a gradient of less than 20 %. The MIAF system modules had a width of 14.4 m, formed by the fruit tree strip of 4.8 m and two flanking strips of milpa of the same size. In the fruit tree strip, the planting of the native squash, bayocote, and peach trees took place on May 26, 2020. The planting of the two annual species was established two furrows (0.8 m each) away from the peach tree row on both contiguous sides (Figure 1).

The distance from the furrows to the peach tree trunks was 0.8 and 1.6 m. The distances between bushes of native squash and bayocote were 1 and 0.5 m, respectively; the number of plants per bush was one and two, respectively. The native squash

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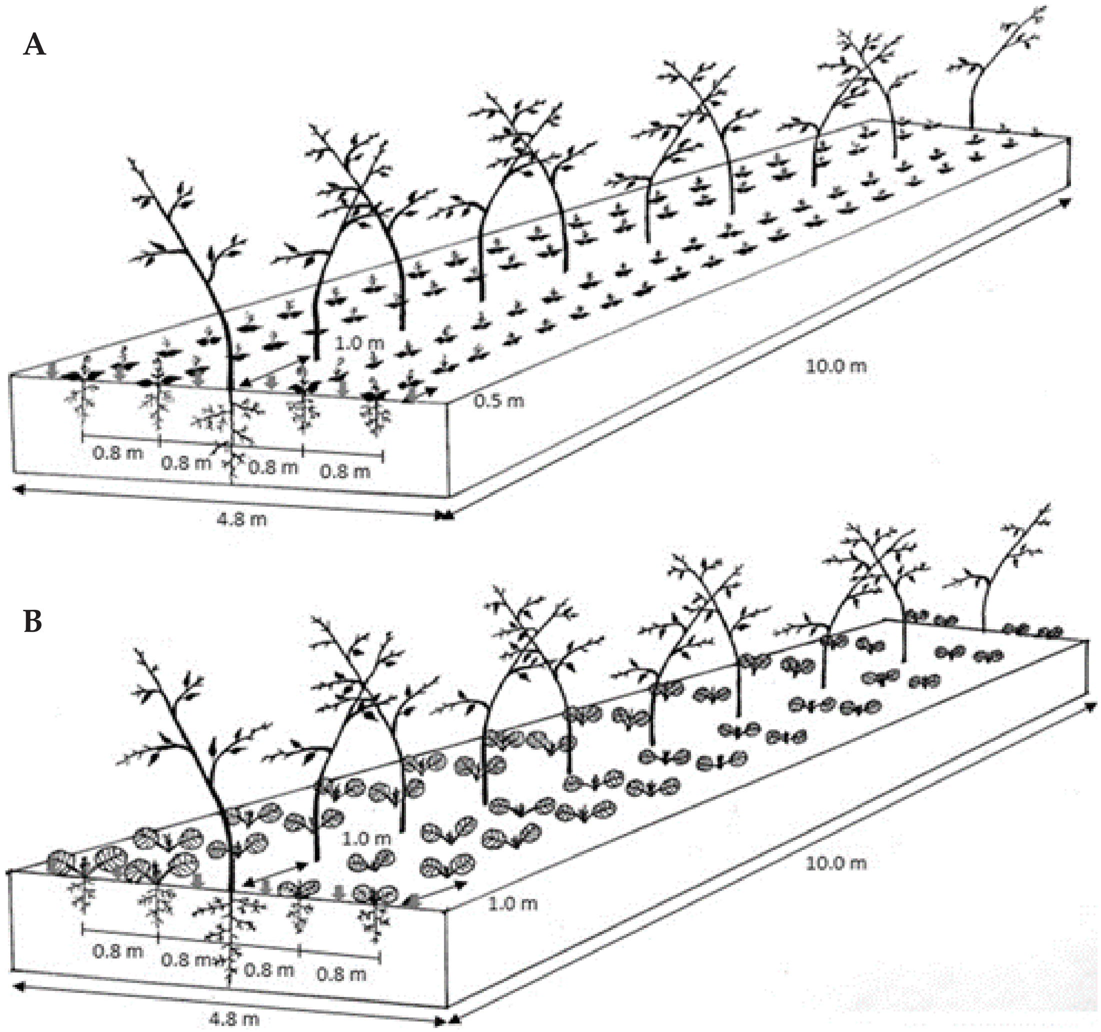

Figure 1. Experimental unit design of the fruit tree strip of the Milpa Intercropped with Fruit Trees (MIAF) system. A: Peach trees (*Prunus persica* (L.) Batsch) intercropped with bayocote (*Phaseolus coccineus* L.); B: peach trees intercropped with native squash (*Cucurbita pepo* ssp. *pepo* L.).

and bayocote were fertilized with 120-140-40 kg ha^{-1} of N-P-K and 10 Mg ha^{-1} of precomposted manure. Stocking density was 0.83 and 3.33 plants m^{-2}, respectively. At planting, all P, K, manure, and one-third of the N were applied; the remainder was placed 86 days after planting. Peach tree fertilization was done with the 20-20-20 g dose of N, P_2O_5, and K_2O_5, in combination with 1 kg of precomposted sheep manure per peach tree. The local species and peach trees were maintained with auxiliary irrigation for the first 60 days after establishment. Weed control was manual and permanent.

Variables evaluated

The variables studied were measured at 60, 120, and 180 days after sowing (DAS) in the case of native squash and bayocote, and days after planting (DAP) in the case of peach trees. The useful area sampled was 8 m long and 4.8 m wide, as the ends of each experimental unit were not evaluated.

Vegetative growth of peach tree

To measure the vegetative growth of the peach shoot, six peach trees per treatment were measured in all replications. Height was measured from the branch insertion to the trunk to the apex of the main branch using a tape measure. Diameter was measured with a digital vernier (electronic digital caliper, 0–300 mm) 2 cm above the graft. With the data obtained, the cumulative growth rate was calculated, in millimeters for diameter and centimeters for height, at 60, 120, and 180 days, using the following equation (Poorter and Lewis, 1986):

$$TA = \frac{(ln\, W_2 - lnW_1)}{(t_2 - t_1)}$$

where TA is the cumulative growth rate; W_1 and W_2 are diameter 1 and 2; and t_1 and t_2 are times 1 and 2.

Peach tree stem biomass

On each sampling date, one tree was cut at ground level for each replicate and dehydrated in a drying oven (Lumiteell MR HTP-42, Mexico) at 72 °C to a constant weight (Díaz-Ríos *et al*., 2016). Subsequently, it was weighed on a digital balance (Torrey L-EQ 5/10, Mexico) and recorded in g plant^{-1}.

Root distribution

The destructive profile wall method (Atkinson and Wilson, 1980) was used, in which a trench was dug in the soil perpendicular to the peach tree strip in the MIAF system at the point of soil insertion with the peach tree stems, native squash, and bayocote. The dimensions of the trench were: 4.8 m long, corresponding to the width of the strip of fruit trees in the MIAF system, and 0.9 m wide; the depth of the trench varied according to the depth of the roots at the time of sampling.

Root exposure and measurement were done according to Albino-Garduño *et al*. (2015). The root distribution of peach trees, native squash, and bayocote was recorded on a millimeter sheet, indicating in each quadrant the presence or absence of roots. Color-based root differentiation was used, with the peach tree's roots being dark brown and the native squash and bayocote being light brown. Root distribution was calculated using the total area occupied by the root in the trench profile and the overlapping areas of each species. Results were plotted in Excel and reported in cm^2.

Soil moisture content

Soil was sampled between the native squash rows and bayocote at 0.4, 1.2, and 2 m on both contiguous sides of the peach tree row, at depths of 0–20, 20–40, 40–60, and 60–80 cm, for a total of 24 subsamples per experimental unit. Soil samples were obtained with a T-type auger (Oakfield, USA). The time of sampling was standardized within each treatment, from 8:00 to 14:00 h. The samples were placed in aluminum cans and weighed in the field with a digital scale (Torrey L-EQ 5/10, Mexico). They were then placed in a drying oven (Lumiteell HTP-42, Mexico) at 105 °C until they reached constant weight. Soil moisture content (% w/w) was calculated with the following formula (Xylogiannis *et al*., 2020):

$$\frac{Wet\ weight - Constant\ dry\ weight}{Constant\ dry\ weight} * 100$$

Statistical analysis

The data were tested for normality of errors (Shapiro-Wilks) and homogeneity of variances (Bartlett) prior to performing other analyses. The variables vegetative growth and peach shoot biomass were analyzed as a one-factorial design (three treatments: peach tree and native squash, bayocote, or soil without cover as a control). Soil moisture content was analyzed in a 3 x 6 x 4 factorial design (the three treatments evaluated, six depths, and four furrows of the experimental unit).

The data of the measured variables were analyzed through an analysis of variance and comparison of means with the Tukey test ($p \leq 0.05$) with the SAS 9.4 program. In the case of root distribution, data were analyzed descriptively; quadrants with root presence were summed to calculate the area and its overlap (peach tree, native squash, and bayocote) and plotted to scale using the Excel program (Albino-Garduño *et al*., 2015).

RESULTS AND DISCUSSION

Vegetative growth of peach tree

Native squash (*Cucurbita pepo* ssp. *pepo.* L.) and bayocote (*Phaseolus coccineus* L.) had no effect on tree height compared to the treatment without soil cover ($p = 0.0487$) on the three sampling dates (60, 120, and 180 DAP) (Table 1); however, stem diameter was affected. From 120 DAP onwards, peach trees associated with native squash had a smaller diameter than those grown in uncovered soil.

Peach tree shoot biomass at 60 and 120 DAP was similar in all treatments, but at 180 DAP it was lower in peach trees associated with native squash (Table 2).

The diameter, height, and biomass of peach tree stems associated with bayocote were unaffected, unlike those of soil without vegetative cover. However, there was a positive

Table 1. Cumulative rate of growth in height and diameter of peach trees (*Prunus persica* (L.) Batsch) in the strip of the Milpa Intercropped with Fruit Trees (MIAF) system associated with native squash (*Cucurbita pepo* ssp. *pepo* L.) and bayocote (*Phaseolus coccineus* L.).

Treatment	Days after planting					
	60		120		180	
	Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)
Native squash	8.17 a	1.67 a	23.39 a	3.71 a	30.66 a	5.05 a
Bayocote	9.00 a	2.66 a	18.16 a	5.86 ab	24.10 a	6.99 ab
Uncovered soil	10.15 a	3.43 a	23.62 a	7.55 b	32.38 a	9.87 b

Means with a common letter are not significantly different ($p > 0.05$).

Table 2. Stem biomass of peach trees (*Prunus persica* (L.) Batsch) associated with native squash (*Cucurbita pepo* ssp. pepo L.) and bayocote (*Phaseolus coccineus* L.) in the fruit tree strip of the Milpa Intercropped with Fruit Trees (MIAF) system.

Treatment	Days after planting		
	60 (g plant^{-1})	120 (g plant^{-1})	180 (g plant^{-1})
Native squash	6.50 a	11.91 a	13.83 a
Bayocote	3.29 a	11.78 a	81.28 b
Uncovered squash	4.28 a	21.78 a	69.61 b

Means with a common letter are not significantly different ($p > 0.05$).

effect on root distribution, since at the end of the sampling period (180 DAP), the roots of peach trees associated with bayocote had a greater distribution of 36.4 and 37.5 % in comparison to the soil without mulch and with native squash, respectively (Table 3). The root distribution area of peach trees was similar when grown with native squash as in soil without cover.

The effect on stem diameter, biomass, and root distribution of peach trees associated with native squash or bayocote is related to the area of overlap between peach tree roots and annual species. In all sampling dates, the root overlap area was greater in peach trees associated with native squash than with bayocote (Figures 2 and 3). At 180 DAP, the highest value was found; peach tree roots had an overlap of 74.57 % of their total area with native squash roots, compared to 28.96 % with bayocote roots (Figures 2 and 3). This greater overlap was because native squash has a greater root distribution than bayocote (Table 4). In addition, less competition between peach tree and bayocote roots favored the growth of peach tree roots.

Table 3. Root distribution and root overlap area of peach trees (*Prunus persica* (L.) Batsch) associated with native squash (*Cucurbita pepo* ssp. pepo L.) and bayocote (*Phaseolus coccineus* L.) in the fruit tree strip of the Milpa Intercropped with Fruit Trees (MIAF) system.

Treatment	Days after planting					
	60		120		180	
	Root distribution (cm^2)	Overlap (cm^2)	Root distribution (cm^2)	Overlap (cm^2)	Root distribution (cm^2)	Overlap (cm^2)
Native squash	468	88	1648	904	1356	1012
Bayocote	800	4	892	528	2168	628
Uncovered	412	-*	1192	-*	1380	-*

*Uncovered soil. The overlap area of the root distribution corresponds to the total sum of the sampled rows 2 and 3 (contiguous to the peach trees).

Soil moisture content was related to the areas of overlap between peach and native squash and bayocote roots. At 120 DAP ($p < 0.0001$), less overlap or competition between peach and bayocote roots maintained higher soil moisture content in the fruit tree strip compared to that grown with peach tree and native squash or no cover crop (Table 5). At 180 DAP ($p < 0.0001$), when it had stopped raining, moisture content was similar in the strip cultivated with peach trees and bayocote or native squash; however, moisture use was more efficient when there was greater peach tree root distribution and less overlap area in association with bayocote, without reducing stem diameter growth or peach tree biomass production.

During the rainfall period, at 60 and 180 DAS, native squash had a larger root distribution area than bayocote. A larger overlap area with peach tree roots resulted in lower peach stem biomass. This root competition increased moisture levels in the fruit tree strip planted with native squash rather than bayocote. Young peach trees are very sensitive to moisture competition when associated with grass and legume mixtures (Forey *et al*., 2017), limiting deep root (Gómez and Gómez, 2011) and aerial growth (Welker and Glenn, 1991). Competition for soil moisture affects stem elongation (Sharma *et al*., 2018) and interferes with peach tree root architecture and penetration (Colombi *et al*., 2018).

In contrast, the smaller distribution and overlapping area of bayocote roots with those of peach trees and the greater availability of soil moisture (120 DAP) favored a larger distribution area of its roots at 180 DAS, even though the values for uncovered soil were similar to native squash. The compact root morphology of legumes (Reeve *et al*., 2017) and some native species (Zhang *et al*., 2018) makes them less competitive for moisture and nutrients. Mulinge *et al*. (2017) mention that the legumes dolichos (*Lablab purpureus*), mucuna (*Mucuna pruriens*), and cowpea (*Vigna unguiculata*), used as cover crops, do not compete for soil moisture and improve root distribution of orange fruit

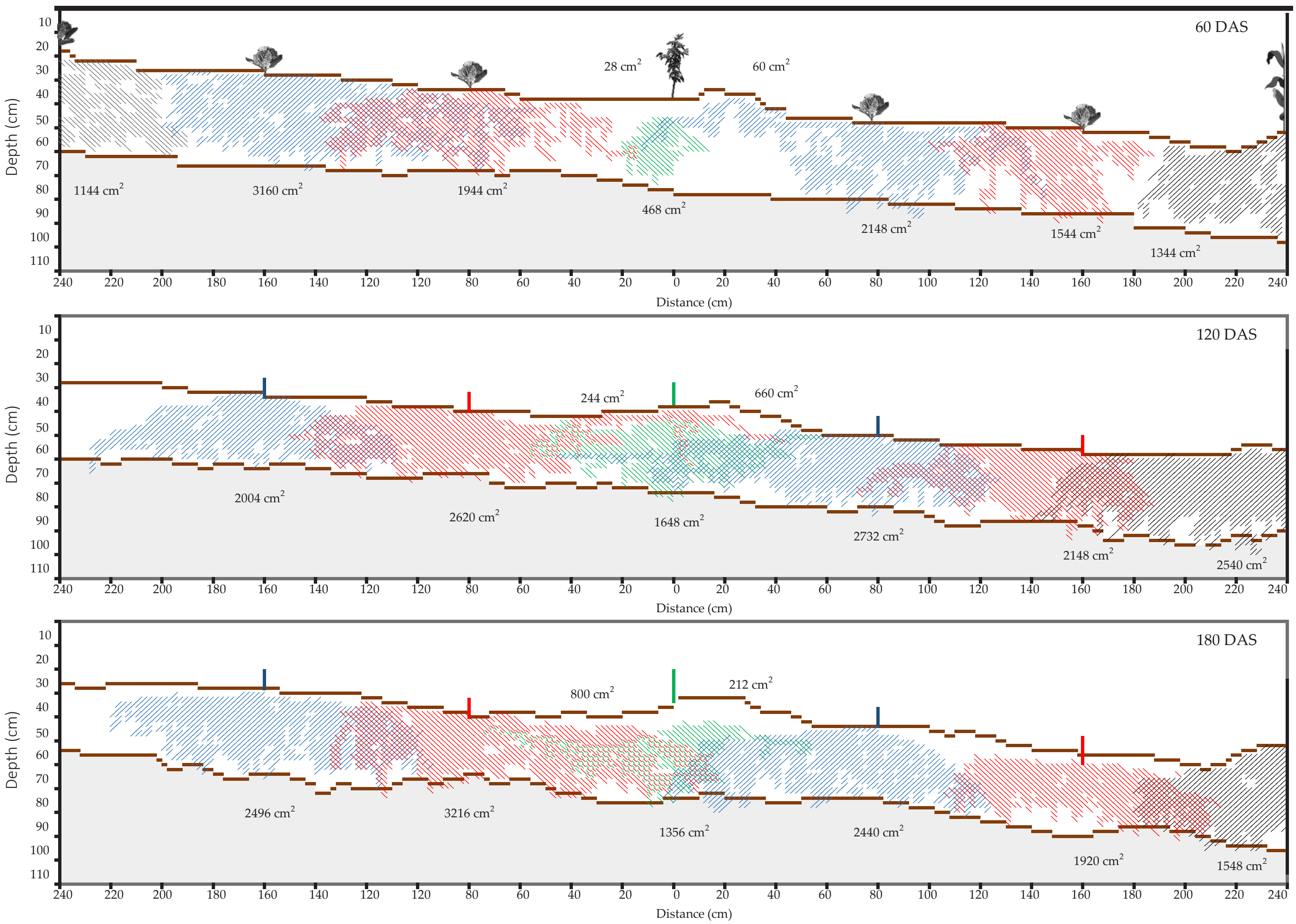

Figure 2. Root distribution area of peach trees (*Prunus persica* (L.) Batsch) (green) associated with native squash (*Cucurbita pepo* ssp. *pepo* L.) (blue and red) in two contiguous rows at 60, 120, and 180 days after sowing (DAS). The numbers on top of the peach tree represent the area where the tree roots overlap with those of native squash. The numbers at the bottom of each root correspond to the root distribution area of each plant.

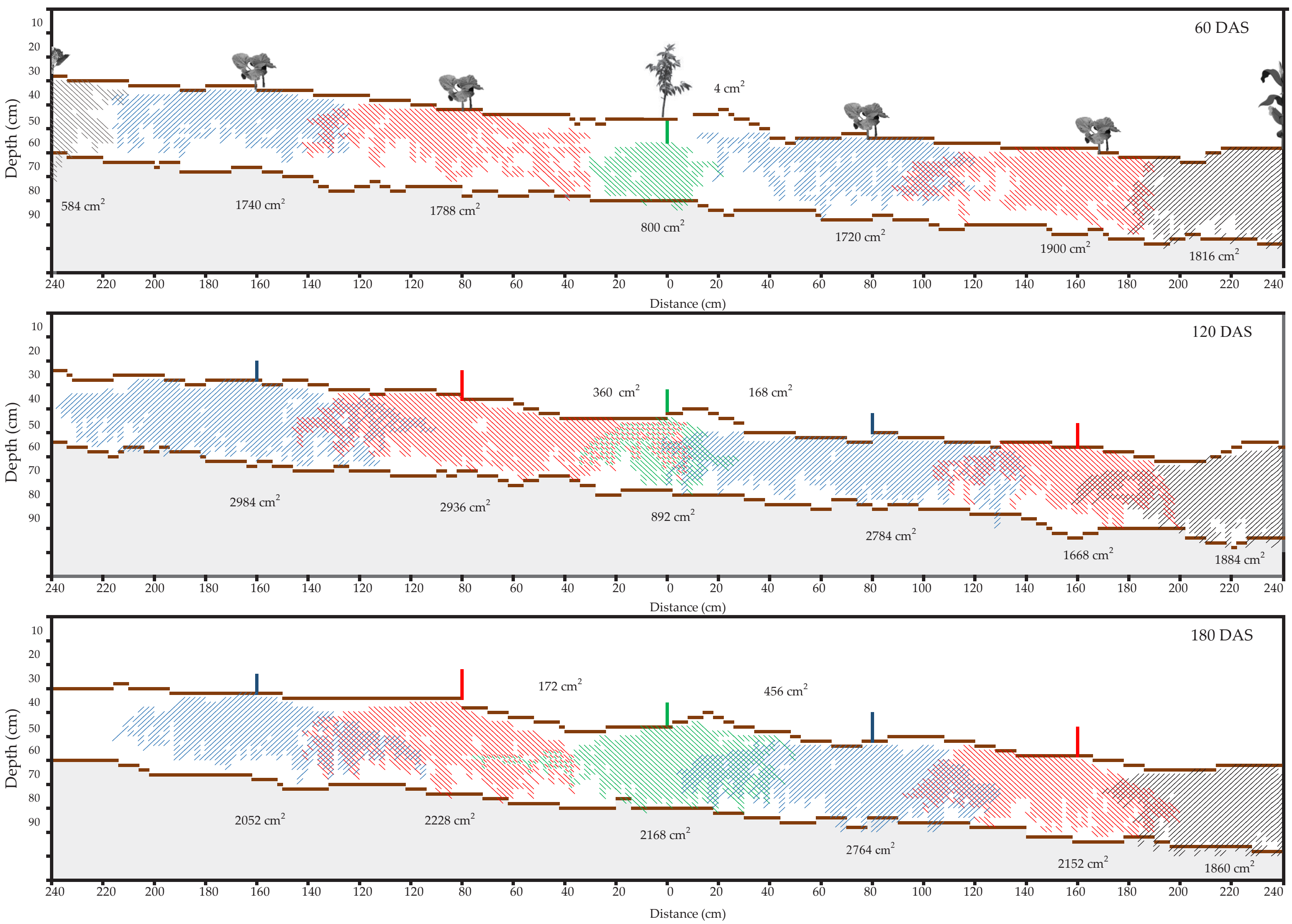

Figure 3. Root distribution area of peach trees (*Prunus persica* (L.) Batsch) (green) associated with bayocote (*Phaseolus coccineus* L.) (blue and red) in two contiguous rows at 60, 120, and 180 days after sowing (DAS). The numbers on top of the peach tree represent the area where the tree roots overlap with those of bayocote. The numbers at the bottom of each root correspond to the root distribution area of each plant.

Table 4. Root distribution area of native squash (*Cucurbita pepo* ssp. pepo L.) and bayocote (*Phaseolus coccineus* L.) associated with peach trees (*Prunus persica* (L.) Batsch) in the fruit tree strip of the Milpa Intercropped with Fruit Trees (MIAF) system, corresponding to the average of the four sampled rows.

Treatment	Days after sowing		
	60 (cm^2)	120 (cm^2)	180 (cm^2)
Native squash	2199	2376	2518
Bayocote	1787	2593	2299

Table 5. Soil moisture content (% w/w) in the strip cultivated with peach trees (*Prunus persica* (L.) Batsch) associated with native squash (*Cucurbita pepo* ssp. pepo L.) or bayocote (*Phaseolus coccineus* L.).

Treatment	Days after sowing		
	60	120	180
Native squash	20.86 b	25.06 b	16.72 a
Bayocote	19.81 a	25.47 c	16.64 a
Uncovered soil	19.78 a	23.88 a	17.82 b

Means with a common letter are not significantly different ($p > 0.05$).

trees. Vegetative growth of fruit trees is positively correlated to soil moisture and root development (Abrisqueta *et al*., 2017). Likewise, van Noordwijk *et al*. (2015) mention that the roots of fruit trees and annual crops are distributed differently in their early stages of development to avoid competition for moisture.

At the end of the rainy season (180 DAS), moisture was higher in the uncovered fruit tree strip than in the strips cultivated with native squash or bayocote, but this no longer modified the vegetative growth of the peach trees. The stem diameter of peach trees grown with native squash was smaller than with uncovered soil. González *et al*. (2012) found a similar response in peach trees grown without weed control in the strip, as it restricted the surface growth of tree roots.

CONCLUSIONS

In the first year of establishment of the experimental plot, using the Milpa Intercropped with Fruit Trees system (MIAF) with peach tree (*Prunus persica* (L.) Batsch) strips associated with native squash (*Cucurbita pepo* ssp. *pepo* L.) and bayocote (*Phaseolus* *coccineus* L.), vegetative growth (height and diameter) and biomass of peach trees with bayocote were the same as in the uncovered fruit tree strip. This suggests that bayocote does not inhibit the vegetative growth of peach trees. In addition, bayocote increased the root distribution area of the peach tree compared to the association with native squash or uncovered soil. The greater root distribution of the peach tree favored the utilization of the limited moisture at 180 days after sowing, without detracting from its growth and biomass production. The native squash restricted vegetative growth of peach trees, reflected in a lower stem diameter and biomass compared to peach trees grown without cover, due to greater root competition and lower moisture availability.

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