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EDAPHIC BACTERIAL CONSORTIA AS A USEFUL BIOTECHNOLOGICAL APPROACH TO IMPROVE COCOA FARMING IN AN EXPERIMENTAL AGROFORESTRY SYSTEM

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ABSTRACT

Theobroma cacao L. is a species that extends throughout the humid tropics, where ofttimes it is cultivated in a traditional way in agroforestry systems. Native from South America, cocoa fruit is considered a significant biocultural-resource since its economical importance as well as historical context are related to pre-Hispanic cultures. Nowadays, *Theobroma cacao* is one of the most consumed commodity goods. This research mainly consisted in the establishment of an experimental cultivation plot using four clonal varieties of cocoa treated with edaphic bacterial inoculants as biofertilizers and conventional chemical fertilizers. The work was carried out in an experimental plot located in the community of Cerro Camarón, municipality of San Pedro Ixcatlán Oaxaca, Mexico. The experimental design consisted of two blocks differently oriented (north and south).Under the studied conditions, the cocoa variety that showed a better performance with fertilization treatments was INIFAP 9. Plants subject to bacterial inoculants showed greater growth regarding height and basal diameter. The aim of this study was to determine the ecomorphological response of cocoa plants underagroforestry system conditions, with the application of two different fertilization treatments.

INTRODUCTION

Cocoa, a native species of Central and South America domesticated in Mesoamerica (Zequeira, 2014), is considered one of the most important perennial shade crops on the planet, since it represents the main source of income for millions of people in productive areas located in Africa, Asia and Central and South America. Consumption in Mexico exceeds the capacity of local production, which has diminished due to agro-ecological problems and a low economic performance of the intensive plantations (Hipólito Romero *et al*, 2014). In recent years, the cocoa cultivation area in Mexico has decreased by 30%due to a poor yield and undesirable product quality and, consequently, low sale prices are recurring (Produmedios, 2000). The main causes of the previous are inadequate management conditions (lack of pruning and excessive shade), which in most cases provokes fungal diseases (*e.g.* moniliasis) and poor fruit productivity.

Traditional agroecosystems (agroforestry systems) of some low and humid regions of Mesoamerica, such as Tabasco and Chiapas, show an interesting genetic diversity respect to creole and improved cocoas. Other regions with similar agro-climatic conditions represent a great potential for the development of this crop, in particular using traditional and modern agroforestry approaches capable to improve management conditions, yield, quality and trading prices (Zequeira, 2014). Under these considerations, diversification and establishment of creole cocoa infarming processes are considered to be more vulnerable, since young cultivars must develop support as well as water and nutrients absorption structures, in addition to a growth-related photosynthetic system when they are in early stages of development. In this case, both biotic and abiotic factors interact. Habitat characteristics in traditional agroforestry systems are very dynamic when integrationof the cultural effect of human management into the environment takes place.

The arboreal component is the most determinant factor due to its effect over light conditions, temperature, humidity, nutrients and soil microorganisms; drought and rainy periods, as well as

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interactions with other organisms (bacteria, fungi, plants and animals) are also important, thus, tree species are considered nursery species (Caballero-Mellado, 2006; Hipólito Romero *et al*, 2014). On the other hand, when canopy cover is excessive, thelight availability is limited, thereby; the conditions for the development of phytopathogenic organisms may be promoted. In the case of cocoa, in addition to handling shade, size, shape, as well as fertilization and control of pests and diseases, improved cultivars (clones) have also been developed through grafting techniques that significantly increase production, showing a better resistance to climatic and extreme events. Nevertheless, despitethe potential synergism related to the application of biofertilizers in many agroecosystems (as with the inoculation of beneficial bacterial consortia), cocoa growing in Mexico practically has not been benefited from this practice. Biofertilization, along with integrated control of pests and cocoa diseases, is still a poorly explored field in Latin America, which limits the development of "ecological" products that may explore emerging organic markets.

In addition, cocoa growing in traditional agroforestry systems maintains an ecological and social resilience due to an equilibrium that is maintained among the soil´s microbiotic components and those related to the growth of aerial structures of agroecosystems (Ahmad *et al*, 2008). Thus, bacterial fertilizers (*e.g.Rhizobium*, *Pseudomonas*, *Azospirillum*, *Acinetobacter* or *Chromobacterium*) are capable to produce elicitor secondary metabolites (*e.g.* indole compounds and chelator agents) and they represent a systemic biotechnological tool. Likewise, plant growth promoting bacteria are usually able to fix atmospheric nitrogen and solubilize insoluble phosphorus, and they have proved to be an easy handle economic alternative (Paredes-Mendoza, 2010). On the other hand, since these processes are usuallyenvironmentally friendly, they favor the consumer´shealth as a result of a reduced interaction with toxic substances, for example: heterocyclic nitrogen compounds such as benzonitrile and bromoxynil (Ricaño, 2014).

It is important to mention that these microorganisms are capable to promote the plant nutrition as well as their vigor and systemic resistance to several pests and diseases (Aguirre-Medina *et al*, 2004), given their interaction with the host´smetabolism and as a consequence, adetection of molecular patterns related to pathogenicity that finally release resistance-like proteins and as a result, the activation of an induced immunity (Jones and Dangl, 2006). Based on the above considerations, the aim of this work was to attend the current problematic of cocoa plantations byanalyzeimproved cultivars on a traditional agroforestry system in synergy with the inoculation of mixed edaphic bacterial consortia.

MATERIALS AND METHODS

Study zone

This study was conducted in the community of Cerro Camarón, Municipality of San Pedro Ixcatlán Oaxaca, Mexico, in the catchment area of the Papaloapan River.

Experimental Design

The experimental design took place in a traditional agroforestry plot, configured by arboreal and fruit tree species in the upper canopy; the lower canopy consisted of creole varieties of cocoa, banana, camedora palm, coffee and vanilla. A two-block (A and B) design was established, each one with five repetitions (for every cultivar) per fertilization treatment; treatments were applied in each block. Fourcultivars of improved cocoa were planted; the plants were provided in plastic bags of 20 × 30 cm by the Nestlé Cacao Plan of Mexico:*i.e.* Inifap 1, Inifap 9, Inifap 8 and creole cocoa. All plants showed a very similar size and age: 50-70 cm height and 12-15 months after grafting; in addition, a creole variety was planted which it was called "local". The plantation was established in a quincunx system (3 × 3 m distance among specimens occupying each of the vertices of an equilateral triangle in the ground). Three different treatments were applied: a) biofertilization (bacterial consortia), b) control (water), and c) chemical fertilization (N-P-K: 20-30-10) (Fig 1). The response variables were morphological parameters of cocoa plants growth:*i.e.,* height, basal diameter, number of leaves and secondary branches; physicochemical and microbiological characteristics of the soil were also determined.

Two block experimental design of the traditional agroforestry plot used to conduct this work

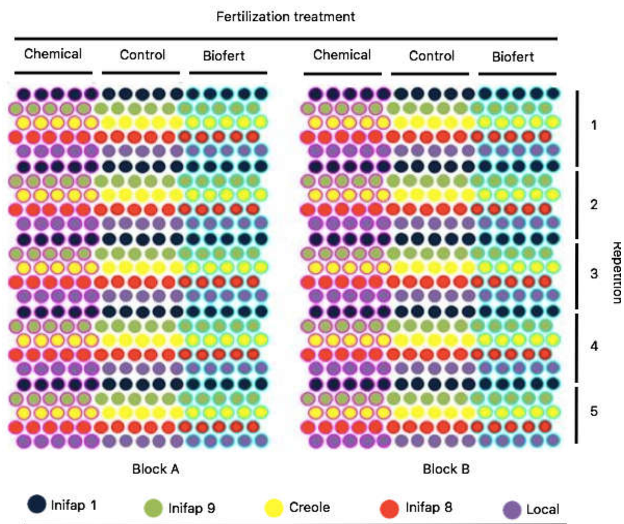


Fig 1 The block design was established with five repetitions per fertilization treatment and block. Different colors mean each cocoa variety subject to fertilization treatment (chemical, control and biofertilization).

Statistical analyzes

Final ecomorphological data were averaged (all records were made by triplicate) and analyzedusing STAT 2 software(Lorch *et al*, 1995; Camelo-Rusinque *et al*, 2011).To determine significant effects of fertilization treatments as well as bacterial counts, variance analyzes and Tukey mean comparisons (α= 0.05) were performed.

Bacterial inoculants

The bacterial consortium consisted of standard nitrogen-fixing strains (*Azospirillum brasiliensis* UAP-151 and UAP-154) and two phosphorous solubilizing strains: *Chromobacterium violaceum* (BUAP 35) and *Acinetobacter calcoaceticus* (BUAP 40) (strain collection from theLaboratory of Soil Microbiology of the Center for Research in Microbiological Sciences of the Institute of Sciences of the Benemérita Autonomous University of Puebla, Mexico [ICUAP]). The application of biofertilization treatments consisted in the inoculation of 200 mL of a liquid suspension of the bacterial consortium (3×10^8UFC / g of *A. brasilense* and $1,7 \times 10^9$UCF / g of *C. violaceum* and *A. calcoaceticus*) on two different events: (a) before planting and on the plastic bags, and (b) four months after planting (when plants were already established and competition among native bacterial populations of the soil had started), placing them around the plant, about 10-20 cm from the stem.

Chemical fertilization

The application of chemical fertilization (N-P-K: 20-30-10) was carried out only at the time of planting (50 g / plant, distributed around the stem, 10-20 cm).

Control treatment

Two hundred mL of sterile water with no fertilizer was applied to each selected plant with this treatment.

Evaluation of soil physical and chemical characteristics

Electrical conductivity, pH, texture, organic matter (OM) and amounts of nitrogen and phosphorus in the soil; were measured from 45 samples taken around the stem, under the crown of the cocoa plants, about 15 cm distance from the base and two months after planting, according to the Official Mexican Norm (NOM-021-SEMARNAT-2000).

Microbiological evaluation around the steam of the cocoa plants

The population of microorganisms was evaluated in 45 samples taken around the stem, under the crown of the cocoa plants and at root level, at two and 12 months after field planting. Serial dilutions were made from 10^{-1} to 10^{-6} and they were cultured on Goldstein® agar medium (Sigma-Aldrich) for the determination of phosphorus solubilizing bacteria (PSB); soy agar and trypticase for total aerobic mesophilic bacteria; as well as semi-solid NFB (Nitrogen Fixing Bacteria) agar for nitrogen fixing microorganisms. Agar plates and NFB vials were incubated at 30 °C for 48-72 h(Lorch *et al*, 1995). All the bacterial colonies observed in solid and liquidmedium were counted. For the case of NFB the method of most probable number was applied, and in the case of semi-solid media, colonies countwas performed by obtaining the CFU (Colony Forming Units) number by taking the record in triplicate and using its average as the final count.

Evaluation of morphological variables

The evaluation of growth indicators was performed twice (different moments), by measuring the plants height and stem radius (cm), foliage and lateral branches development (number of leaves and lateral branches; number of primary branches is maintained between four and five by pruning molding) at two and 12 months after planting.

RESULTS

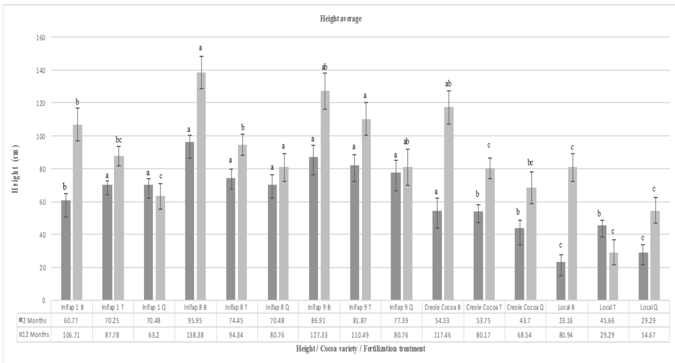
Soil physical and chemical characteristics

The result of soil´s physicochemical evaluation was recorded at two and 12 months after planting (data not shown). The rank of electrical conductivity of the treatments showed a low salinity effect for all cases; texture was clayey and a slight increase of pHaverage valueswas recorded, with the highest data corresponding to the chemical fertilization (5,50 and 5,12). In regard to OM percentage, low and moderate values were observed for all treatments at two months after planting; however, 12 months later, the OM in soils with the biofertilization treatment went from low to moderate (4,66 to 7,10%), while the amount of OM with the chemical fertilizer and control decreased between two and 12 months. Total average of nitrogen content increased considerably in all treatments from two to 12 months after planting (*i.e.* 0, 29 to 0,57%). Highest values corresponded to the biofertilization treatment (0,74%) followed by the control (0,53%). The amount of extractable phosphorus declined in all treatments between two and 12 months after planting, and it was noticed that the lowest final values corresponded to the control treatment, followed by the biofertilization.

Effects of fertilization on height development

After two months of planting, cultivarInifap 8 showed a better response to the biofertilization treatment (95,95 cm) in comparison (statistically significant differences) with the control and chemical treatments (74,45 and 69,00 cm respectively). The local variety on control treatment (45,66 cm) exceeded in height the chemical treatment (29,29 cm) as well as the biofertilization treatment (23.16 cm), while cultivars Inifap 1, Inifap 9 and creole showed no differences among them (Graph 1).

Effects of fertilization on the height development of cocoa plants



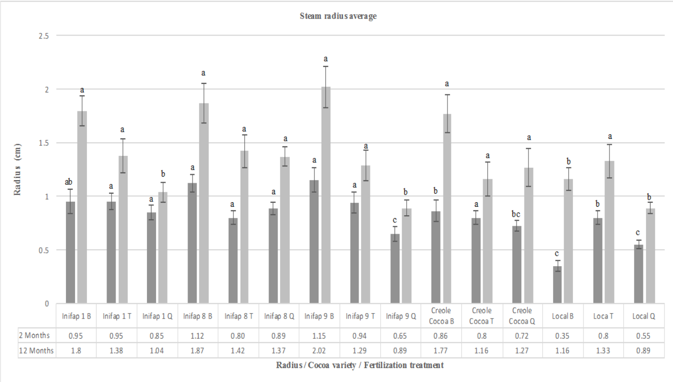
Graph 1 Cultivars Inifap were exposed to three different treatments: B) Biofertilization, T) Control; Q) Chemical. Bars represent the average values (cm) of two and 12 months after inoculation. Different letters mean significant differences.

At 12 months after the inoculation, it was observed that the height of most of cultivars was higher with the biofertilization treatment, followed by the control, and interesting the lowest values were found with the chemical fertilization. When comparing cultivars, it was observed that the biofertilization treatment showed greater positive effects on Inifap 8 (138,38 cm), Inifap 9 (127,33 cm) and creole cocoa (117,46 cm) compared to Inifap 1 (106,71 cm) and with that of local variety (80,94 cm) (Graph 1). Respect to control treatment, Inifap 9 significantly exceeded in height (110,49 cm) Inifap8 (94,34 cm), Inifap 1 (87,78 cm), creole cocoa (80,17 cm) and the local variety (77, 29 cm). The chemical treatment showed higher height in cultivar Inifap 8 (92,38 cm) and Inifap 9 (80,76 cm); those differences were statistically significant when compared to cultivars Inifap 1 (63,02 cm), creole cacao (68,54 cm) and local variety (54,67 cm).

Effects of fertilization on stem radius development

At two months after inoculation, cultivars Inifap 8 and 9 showed the highest values of basal diameter of the steam (BDS) in the biofertilization treatment; 1,14 and 1,15 cm respectively(Graph 2).

Effects of fertilization on the stem radius development on cocoa plants

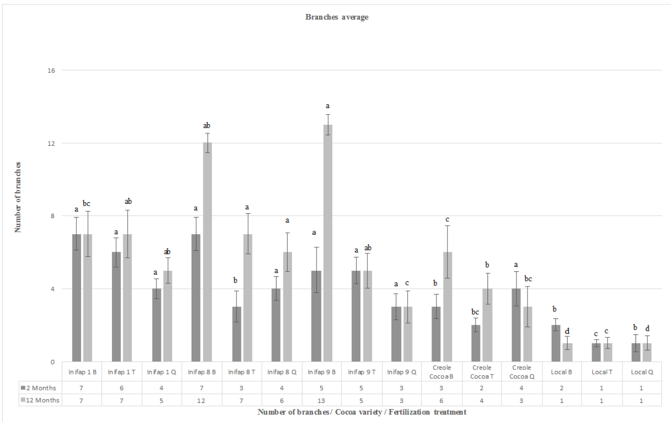


Graph 2 Cultivars Inifap were exposed to three different treatments: B) Biofertilization, T) Control; Q) Chemical. Bars represent the average values (cm) of two and 12 months after inoculation. Different letters mean significant differences.

It was also found that the local variety showed the highest values when this was exposed to chemical and control treatments (0,60 and 0,55 cm respectively), surpassing the biofertilization treatment (0,35 cm). Cultivars Inifap 1 and creole showed no significant differences. In relation to height,12 months after inoculation BDS of most of cultivars was higher with the biofertilization treatment, followed by the control, and once again the lowest values were found with the chemical fertilization. Inifap 9 was highlighted, followed by Inifap 8, while local variety showed lowest records (Graph 2).

Effects of fertilization on lateral branches development

Effects of fertilization on the lateral branches development of cocoa plants



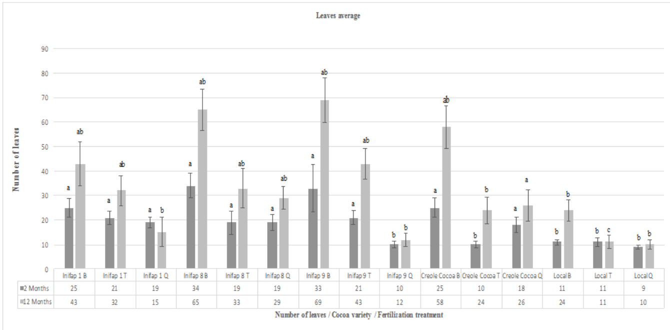
Graph 3 Cultivars Inifap were exposed to three different treatments: B) Biofertilization, T) Control; Q) Chemical. Bars represent the average values (number of branches) of two and 12 months after inoculation. Different letters mean significant differences.

At two months after inoculation, most of the cultivars showed a high number of secondary branches with the biofertilization treatment, followed by the control although the chemical treatment showed lower results, a trend that was accentuated after 12 months (Graph 3).In this sense the highest values were found in Inifap 9 and creole cultivars with the biofertilization treatment, while the lowest were observed in the local variety with all treatments.

Effects of fertilization on foliage development

Similar to the number of branches, at two months after the inoculation most of the cultivars showed a high number of leaves with the biofertilization treatment, followed by the control, whereas a smaller number was observed with the chemical treatment. As mentioned above, these results were accentuated 12 months later. The highest values were found in Inifap 9 and creole cacao with the biofertilization treatment at 12 months, while the lowest values behooved to local variety for all treatments (Graph 4).

Effects of fertilization on the foliage development of cocoa plants

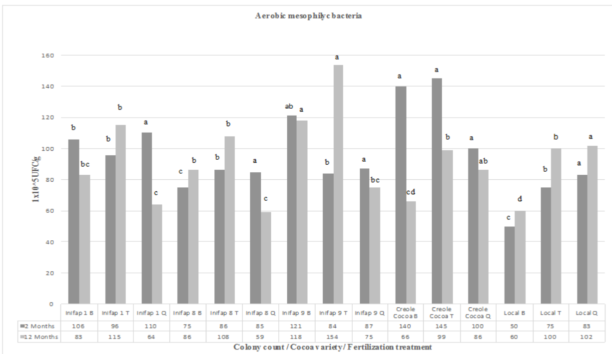


Graph 4 Cultivars Inifap were exposed to three different treatments: B) Biofertilization, T) Control; Q) Chemical. Bars represent the average values (number of leaves) of two and 12 months after inoculation. Different letters mean significant differences.

Effects of fertilization on aerobic mesophilyc bacteria colonization

The largest population of mesophilic bacteria found with the control treatment in the creole cultivar ($1,45 \times 10^7$ UFC / g) showed no significant differences between treatments after two months of inoculation. In a contrary way, cultivars Inifap 1, 8, 9 and local varieties showed opposite results (Graph 5).

Effects of fertilization on the colonization of aerobic mesophylic bacteria around the stem of cocoa plants in the field



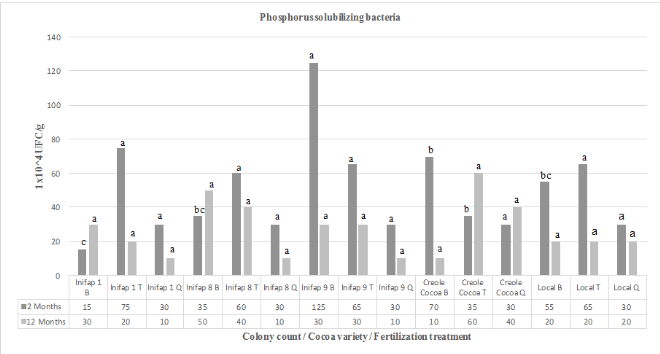
Graph 5 Cultivars Inifap were exposed to three different treatments: B) Biofertilization, T) Control; Q) Chemical. Individual values of two and 12 months after inoculation are expressed in UFC / g of soil. Different letters mean significant differences.

Regarding the biofertilization treatment, the largest populations of aerobic mesophilic bacteria were observed in creole cultivars

($1,4 \times 10^7$ UFC / g) and Inifap 9 ($1,21 \times 10^7$ UFC / g) and no significant differences among treatments were observed. With the same treatment, cultivars Inifap 8 and local variety evidenced the lowest values: $7,5 \times 10^6$ UFC / g and 5×10^6 UFC / g.

Effects of fertilization on phosphorus solubilizing bacteria colonization

Effects of fertilization on the colonization of phosphorus solubilizing bacteria around the stem of cocoa plants in the field



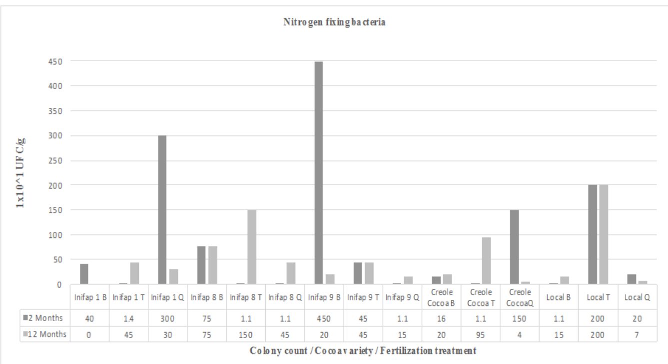
Graph 6 Cultivars Inifap were exposed to three different treatments: B) Biofertilization, T) Control; Q) Chemical. Individual values of two and 12 months after inoculation are expressed in UFC / g of soil. Different letters mean significant differences.

The highest PSB count was recorded with the biofertilization treatment in Inifap 9 ($1,25 \times 10^6$ UFC / g), showing significant differences respect to the rest of the cultivars (Graph 6).

Effects of fertilization on nitrogen fixing bacteria colonization

In the case of NFB, highest populations were found in Inifap 1 ($1,4 \times 10^3$ UFC / g), Inifap 8 ($1,1 \times 10^3$ UFC / g) and creole cacao ($1,1 \times 10^3$ UFC / g). On the other hand, chemical fertilization exhibited the highest values in Inifap 8 and 9 ($1,1 \times 10^3$ UFC / g), and regarding to the biofertilization treatment, the highest results were observed in the local variety ($1,1 \times 10^3$ UFC / g) (Graph 7).

Effects of fertilization on the colonization of nitrogen fixing bacteria around the stem of cocoa plants in the field



Graph 7 Cultivars Inifap were exposed to three different treatments: B) Biofertilization, T) Control; Q) Chemical. Individual values of two and 12 months after inoculation are expressed in UFC / g of soil. Different letters mean significant differences.

The soil sampling that was carried out 12 months after inoculation also showed interesting data, since largest populations of aerobic mesophilic bacteria were perceived with the control treatment, followed by the biofertilization and finally by the chemical treatment. Cultivars Inifap 9 and 1 showed the highest values with the control ($1,54 \times 10^7$ UFC / g and $1,15 \times 10^7$UFC / g) and biofertilization treatments ($1,18 \times 10^7$UFC / g). In the case of PSB, the highest values were also observed with the control treatment followed by the biofertilization. Creole and Inifap 8 cultivars exceeded the results of the other varieties. A similar trend was observed in relation to NFBs: control treatment showed the highest values followed by those obtained with the chemical fertilization. These results were associated with cultivars Inifap8 and 9.

DISCUSSION

The plant variety and type of cultivar are important factors that contribute to the complexity of vegetal responses as well as the effects of different types of fertilization treatments, and in particular, to the inoculation response of nitrogenfixing and phosphorus solubilizers bacteria into the soil. Edaphic microbiological characteristics and their interactions, synergies and antagonisms as well as the kind of used fertilizer are also considerable features(Mohandas *et al*, 2013; Pedraza *et al*, 2010). Although improved cocoa cultivars were used in this work that theoretically showed well response in forest soils and, in particular to chemical fertilizers due to their fast readiness, not all plants responded as expected. This was clearly observed in the diversity of soil responses and cocoa cultivars.

Generally, some soil characteristics showed meaningful changes after two months of planting, however, changes were more remarkable at the twelfth month, when the proportions of OM and available nitrogen in the soil with biofertilization treatment increased. This could be due to an indirect effect on leaf production that consequently increases the OM proportion in the soil, which represents a naccessible source of carbon and nitrogen for microorganisms (Graetz, 1997; Harris, 1991). Nevertheless, this phenomenon does not correspond to the amount of NFB found in the soil after 12 months of planting, whose highest value corresponds to the control treatment. In this sense, there is an imminent need to continue with field trials to improve a higher frequency of biofertilizer application and an increase in sampling frequency and soil analysis.

The amount of phosphorus found in the soil after two months of inoculation was consistent with the expected results: the greatest amount was recorded with the chemical treatment, followed by the biofertilization, and the lowest values were registered with the control. However, 12 months after the inoculation the amounts of phosphorous drastically decrease for all treatments, demonstrating that the effects of chemical and biological fertilization on available phosphorus in the soil may be considered short-term. Also, the application of the bacterial consortia in dose and frequencies mentioned above was not reflected in the amount of PSB obtained around the stem under the crown of the cocoa plants, where control showed the largest bacterial population.

While native bacteria in the soil mean a natural competition, they can also facilitate the establishment of new consortia through direct inoculation, improving soil fertility by regulating biogeochemical cycles and influencing the kinetics of nutrients and water inflow (Vessey and Heisinger, 2001). Increase of available chemical elements is also noteworthy (Soil Science

Society of America, 1994) as well as the activation or inhibition of microbial enzymes related to biodegradation processes (Camelo-Rusinque *et al*, 2011; Reyes *et al*, 2006). In this context, PSB are of vital importance in the management of tropical acid soils since phosphates are found to be insoluble, (Fusconi, 2014) fixed to aluminum or iron, as well as being part of organic compounds in humus (Vassilev *et al*, 2006). It is important to mention that 12 months after planting, cocoa plants increased their size, height, BDS, number of branches and leaves, when biofertilization treatment was applied.

In particular, BDS is related to water and nutrients transport, and it reflects the size and efficiency of the plant root system in the soil(Hernández-Rodríguez *et al*, 2008; Welbaum *et al*, 2004). Although there is an obvious relationship between height and the biofertilization treatment after two months of planting, differences among treatments were even greater after 12 months under experimental conditions (Rodríguez, 2008). Other authors have reported favorable effects when bacterial consortia were applied in different vegetable crops, for example when Díaz-Medina *et al* (2004) used *A. chroococcum* and PSB, and they observed a favorable effect on the growth and development of coffee seedlings (*i.e.* up to 33%). On the other hand, Galindo *et al* (2006) noticed an increase in the height of *Avicennia germinans* when applying a mixture of NFB (*Azotobacter vinelandii*) and phosphorus solubilizers (*Aquaspirillum* sp.).

According to Acosta-Echeverría *et al* (2000) the response of specific organs (bud, apex, stem, root) depends on the concentration of hormone receptors and the efficacy of the receptor-hormone binding. This factor explains the specific morphological changes observed in different cocoa varieties, which showed the largest increase in any of their organs due to the inoculation of beneficial bacteria (Paredes-Cardona *et al*, 1988).In regard to the effect of chemical fertilization on plants, no significant differences were observed with control treatments. The amount and frequency of NPK application could have been abridged, although an interaction with the soil´s characteristics (clayey texture, high acidity and poor drainage) (Sánchez *et al*, 2005; Sánchez-Hernández *et al*, 2005) as well as the high amount of shade could also have been implicated.

Several authors reported similar effects in field studies, in which the response of cocoa cultivars to chemical fertilization is not always homogeneous(INIFAP, 2012; Orozco and Thienhaus, 1997; Uribe *et al*, 2001). In a large study that included ten localities of a Colombian region where different doses of fertilizer were evaluated (the highest was 368 g of N / plant per year, 90 g of P_2O_5 and 600 g of K_2O), no significant differences were observed in relation to a control without fertilizer (Produmedios, 2000). It should also be considered that cocoa is a shade growing crop, and therefore growth variations may be influenced by the ecological conditions where the sun exposure is primordial, since it affects some other factors such as temperature, relative humidity, evaporation and water availability in the soil, as well as other features that affect soil´s fertility as the incorporation speed and leaf litter decomposition.

Finally, it is very important to highlight some positive effects in the development of cocoa fruits regarding biofertilization treatments compared to chemical fertilization: a) since these microorganisms are symbiotic to plants, they support their nutrition and soil regeneration; b) because of their ecological and sustainable nature, they are a clean alternative inasmuch as they do not harm the environment; c)they take advantage of organic residues and recover OM from the soil, besides allowing nitrogen and carbon fixing, which improves the capacity of water absorption of plants; d) in comparison with chemical fertilizers, they usually require less energy and the bacterial strains are obtained from autochthonous microbiota surrounding the crops subject to biofertilization, so the specificity is extremely high; e) symbiotic microorganisms are cable to activate the plant immune response as well as systemic molecular responses, which help them to fight viral, fungal and bacterial infections (Jones and Dangl, 2006; Mohandas *et al*, 2013; Acuña *et al*, 2006). In addition to the above, it will always be necessary to validate the obtained results with the production of fruits and seeds, adjusting the amount and frequency of the biological and chemical fertilizers application. In this sense, soil analyzes need to be done in more detail. These actions would enable a better guidance for cocoa farmers under traditional agroforestry systems operation, while contributing to a better work of biodiversity conservation and promotion of other crops farming with significant commercial value.

CONCLUSIONS

Nowadays, *Theobroma cacao* is considered a species of economic importance and biocultural interest due to its nutrimental and organoleptic characteristics, as well as its Mesoamerican natural history, which dates back to pre-Columbian times. In addition to conventional chemical fertilizers that are commonly used to improve the production of this type of crops, there are highly efficient bio-products made based on edaphic bacterial consortia that offer excellent yield and confer systemic benefits to the plants such as immune system enhancing and growth promotion. In addition to the implementation of traditional agroforestry systems, the application of plant biofertilizers are usually an ecological alternative, easy to apply and cheaper, that is increasingly used around the world. In this work, we have found that a bacterial consortium provides remarkable benefits in cocoa plants harvested under a traditional agroforestry system.

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