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Interaction between Coffee (*Coffea arabica* L.) and Intercropped Herbs under Field Conditions in the Sierra Norte of Puebla, Mexico

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Abstract

Caffeine released from decaying seeds and leaves accumulates in a soluble form in the soil. The compound is known to inhibit mitosis, reduce the access of nutrients and water to surrounding plants which is one of limiting problems in intercropped coffee plantations. The allelopathic interactions between coffee (*Coffea arabica* L.) and mint (*Mentha piperita* L.), basil (*Ocimum basilicum* L.), oregano (*Origanum vulgare* L.) and sage (*Salvia officinalis* L.) could be a diversification alternative and extra income activity for coffee growers outside the harvest period that could cope with high levels of caffeine in the soil. We tested the interaction of the proposed system (2004 – 2005) in rural area of Puebla State, Mexico. The results demonstrate that intercropping sage, spearmint, basil and oregano stimulate the plagiotropic growth of *Coffea arabica* plants most effectively in young production systems, through volatile essential oils. Intercropping basil, sage, spearmint and oregano in coffee plantations seems to be a promising approach for higher income and increasing yield and quality production in coffee farms.

Keywords: Allelopathy, herbs, caffeine uptake, intercropping systems, mint, oregano, sage, basil

1 Introduction

Coffee production and industry is a significant source of revenue and a source of job in rural communities for many countries. The coffee price crisis like present day, create social unbalances, instability and migration accelerated to urban areas (Cardenas, 2003; Pohlan, 2002, p. 386). If crisis continues, coffee growers in Latin America will be forced to abandon their cultivations and to look for alternative activities, like illegal crops (Torrico *et al.*, 2005; Pohlan, 2001). Some coffee growers, that confront the crisis, have begun to diversify with cultivation of medicinal and aromatic plants as intercrops. Intercropped aromatic plants provide some advantages like control of weeds, recycling of nutrients, use of unproductive areas and extra income.

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Wide arrays of natural products that cause allelopathy are secondary compounds synthesized by plants and microorganisms. The compounds belong to different chemical classes such as, phenolic acids, tannins, flavonoids, terpenoids, alkaloids, steroids, and quinons (Duke *et al.*, 2000; Phippen and Simon, 2000; Einhellig and Leather, 1988; Chou and Waller, 1980b). Phenolics and other secondary products, including flavonoids and antocyanins are common constituents of aromatic plants.

On the other hand, caffeine is a biologically active compound found in members of the Rubiaceae family, e.g. *Coffea arabica* that contribute to allelopathic and auto toxic effects appearing in coffee plantations (Anaya *et al.*, 2002). Friedman and Waller (1983) showed that caffeine inhibits mitosis in lettuce (*Lactuca sativa* L.) roots. As a consequence of restricted development of young roots the access of nutrients and water is reduced. The inhibitory effect is thought to be finally due to the ability of caffeine to destabilize nucleic acids by intercalation. The researchers indicated that caffeine released from decaying seeds and leaves accumulates in a soluble form in the soil and is the major reason of auto-toxicity, one of the principal problems in coffee plantations. Only 150-200 g of coffee dry matter has the potential to liberate 1-2 g caffeine/m^2/year in addition to other components, originating limitations in production. Waller *et al.* (1986) demonstrated that caffeine applied externally was absorbed and translocated by the root system of coffee (*Coffea arabica*, Bourbon variety).

The interest in aromatic plants has been generated in the last years among the planter's community and the actual demand of these profitable products in the international market. Aromatic plants are profitable crops and the possibility to introduce them to environmental conditions under coffee systems is high. In order to appraise this new alternative and this possible interrelation with coffee, must be consider that allopathic effects are produced by both crops and plant-plant interaction need to be defined.

The investigation included the following objectives:

- Establishment of suitable species for intercropping in a commercial production under different seasons and determines if caffeine and other compounds released by coffee may have a negative effect on aromatic plants.

- To evaluate if factors like long period of establishment, density, moisture, nutrients availability, management of coffee plantations, age of the production system, seasonality affect the plant- plant relationship when aromatic plants and coffee are intercropped.

- To evaluate the participation of volatile essential oils in plant-plant relationships and possible targets in plant physiology as growth stimulant.

2 Materials and Methods

Four species of aromatic plants and one control without herbs were tested as intercrops in three different age coffee systems at two ecological conditions. The first named "Providencia", located at 20° 16' 295 N and 97° 50' 456 W with an altitude of 900 m above sea level and the second named "Orquidea" located at 20° 16', 887 N and 97°

45' 600 W with an altitude of 550 m above sea level, both in rural area from Xicotepec de Juarez, Puebla, Mexico.

The treatments were planted in-between the coffee rows. Randomized complete block design with four repetitions of treatment per plot were established. An area of $12m^2$ ($6m \times 2m$) were demarked as experimental units leaving a free space among treatments of $8m^2$ ($4m \times 2m$) without influence of aromatic herbs. Four weeks old plants of the proposed species sown and propagated under homogeneous conditions were planted with a density of 4 plants per m^2, as treatments. For sampling growth variables on coffee, four plants per treatment were marked. Two primary plagiotropic branches (10^{th} and 20^{th}) from the upper third of the plant canopies were tagged in each treatment unit for periodical length measurements and number of leaves evaluation. Physiological variables on coffee were evaluated every 2 months. Samples of coffee beans from experimental units were collected separately and after processed dried to 10 to 12% moisture content. No specific agronomical management was required for the herbs. Five fertilizations were applied, the first with 500g/plant of compost (no nutritional data available) when transplanting and after every harvest 50 g/plant of soluble commercial fertilizer (18-18-18 Hydro). No controls on pest or diseases were made on the treatments. The coffee plants were pruned after the first harvest (as traditional management) and fertilized two times per year with soluble commercial product (46-15-15 Hydro). No agronomical management was made and the control of *Hypothenemus hampei* Ferr., was made by using pheromones tramps wit a density of 17 tramps/ ha.

Two factors were analyzed in the experiment:
Factor A: Influence of aromatic plants in physiological development of coffee

The following treatments were evaluated:
A1: coffee without aromatic plants
A2: coffee with Genovese basil
A3: coffee with spearmint
A4: coffee with sage
A5: coffee with oregano

Factor B: Effects of different age coffee systems on yield of aromatic plants

B1: New plot (5 years of establishment)
B2: Medium plot (10 years of establishment)
B3: Old plot (over 20 year of establishment)
Variables analyzed:
Plagiotropic growth (cm)
Vegetative growth (cm)
Appearance of new leaves

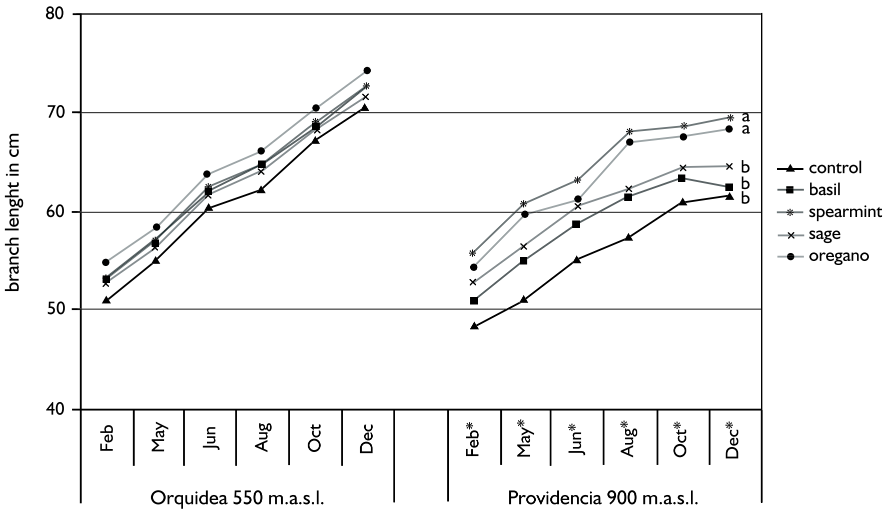
For the statistical analysis of data, SPSS, 11.0 was used. The data were subjected to ANOVA and, when test F is significant, the means were compared using Tukey's test at 95% probability.

3 Results and Discussion

In every allelopathic relation exists a plant (donor) that frees to the environment (atmosphere or rhizosphere) by a specific way, volatilization, leaching, decomposition of residues, and root exudation (Chou, 1986) chemical compounds which are absorbed by another plant (receptor) causing a damage or beneficial effect. The growth habit and physiological properties of plants can differ markedly under different influence of neighbour plants, in this case of study, growth stimulation in coffee due to volatilization of essential oils of intercropped aromatic plants.

For the variables of plagiotropic growth in coffee under different ecological conditions an increase in branch length when aromatics plants were intercropped was found (Figure 1).

Figure 1: Increasing of branch length in coffee (*Coffea arabica* L.) when intercropping aromatic herbs.



A significant difference between control and treatments was found in Providencia farm, during the whole year, with higher growth rate when mint, oregano, sage and basil were intercropped. No significance difference in Orquidea farm for this variable was observed but higher means of branch growth in coffee when oregano was intercropped elucidated a positive stimulation of this treatment.

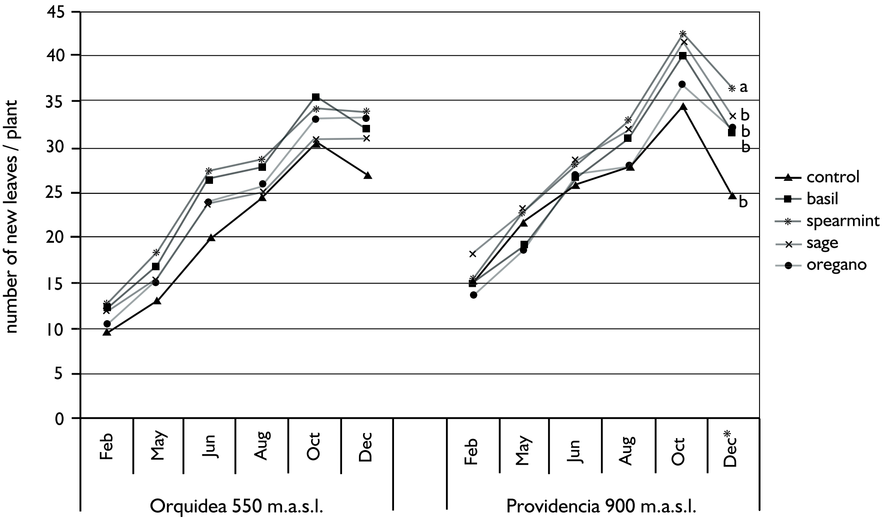
Stress in plants causes various physiological and biological changes, one of which is the accumulation of reactive oxygen species in the cell. The reactive oxygen radicals are toxic and may result in a series of injuries to plant metabolism. It damages photosynthetic components, inactivates protein and enzymes, destroys cell membrane structure and permeability by causing lipid peroxidation (Price and Hendry, 1989, 1991; Winston, 1990). Other authors suggest that many environmental stresses such as drought, salinity, low temperature, herbicide application and cultural management (pruning), damage plants directly or indirectly and suppress their vegetative growth (Larson, 1988; Price and Hendry, 1989; Smirnoff, 1995; Thompson *et al.*, 1987).

The effect on growth stimulation in *C. arabica* close to the intercropped herbs could be related to the important role of volatilization of monoterpens from herb oils into the environment and its effects on neighbour plants.

The importance of aromatic plants as natural antioxidants is well established (Dapkevicious *et al.*, 1998). As reported by Aruoma *et al.* (1992) rosemary and sage have highly antioxidant properties due to the carnosic acid in their leaves. Carnosic acid is lipophilic antioxidant that scavenges singlet oxygen, hydroxyl radicals, and lipid peroxyl radicals, thus preventing lipid peroxidation and disruption on biological membranes. Antioxidant activities of polyphenols from sage (*Salvia officinalis* L.) have been reported by Lu and Foo (2001). In herbs like rosemary, thyme, and basil similar concentrations of phenolic compounds were found (Zheng and Wang, 2001) supporting the hypothesis that aromatic plants are good sources of natural antioxidants. Preliminary results clearly indicate that antioxidant capacity of volatile essential oils and plants extracts are closely related to the total growth of the coffee and the vegetative stage of the plants.

A significant difference for the number of new leaf was found in December 2005 in Providencia farm for the treatments with basil, sage and oregano (Figure 2).

Figure 2: Increasing of leaf number in coffee (*Coffea arabica* L.) when intercropping aromatic herbs.

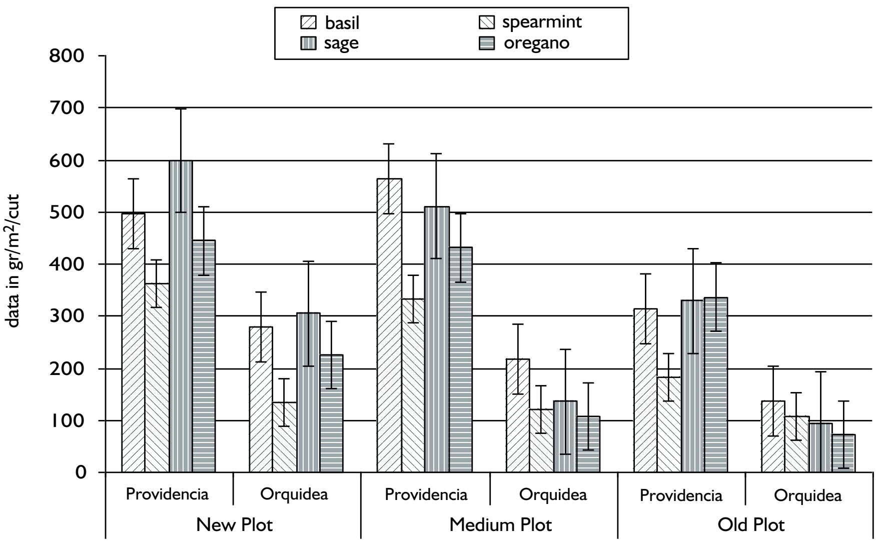


Thus no difference were found in the other experimental unit, the average of new leaf appearance in coffee were better for the treatments with aromatic herbs intercalated in comparison with the control. A decrease in the development of new leaves was observed in October in both experimental units, it coincides with the start of fructification and constrain of nutrient availability for the vegetative growth.

The relationships between vegetative and reproductive growth in coffee are rather complex and poorly understood. In most regions, rapid vegetative growth and fruit development appear to take place at different times. Nevertheless, the positive effect on appearance of new coffee leaves and an increase in branch length when intercropped with aromatic species is of considerable relevance because flower buds in *Arabica* coffee are initiated on the same wood only once (RENA *et al.*, 1994), thus the amount of growth produced in the current season will determine the crop yield of the following growing season. Therefore, additional studies have to be performed to compare the yield of coffee plants intercropped with aromatic species to that of control plants growing in the absence of aromatic plants.

Experiment results and field observations show negative influence of caffeine accumulation in soil on the production yield of basil, oregano, spearmint and sage. Sage, oregano and basil revealed to be the less affected species in the three production systems evaluated and high altitude conditions. Under plots of 10 year of coffee establishment, basil and sage show better average of yield production in comparison with the other two crops, thus demonstrating that they can adapt well to coffee plantations by the means of a tolerance mechanism to the potentiality toxic effects of caffeine (Figure 3).

Figure 3: Yield production of herbs under different age coffee systems in Puebla, Mexico



The negative interaction in soils with more than ten years of coffee monoculture has been previously reported by Weinberg and Bealer (2001), due to accumulation of soluble form of caffeine in the soil. Under old coffee system the yield production of all species decrease and demonstrate that thus a involved mechanism to tolerate certain levels of caffeine, higher amounts of the alkaloid in the soil can be toxic, limiting the tested crops development. A notorious general result for all species is that they grow better on younger fields and at higher altitudes.

Data demonstrates that caffeine acts as a negative allelochemical to aromatic plants. Although there is a high potential of intercropping basil, sage, spearmint and oregano between coffees rows in order to obtain extra income for the idle area, evidence on this study indicates that age of the plots and accumulation of caffeine in the soil are limiting factors in the yield of aromatic plants.

According to the available data, an estimation of production for the three different systems shows a decrease in yield with increasing age of the plot. Low altitude conditions are not suitable for sage, oregano, basil and mint. A possible ability of the aromatic plants to grow better under high altitude conditions may be associated with the temperature and water availability.

For coffee production systems between 5 and 10 years of establishment, an extra income of 400-500 kg of basil, sage and oregano can be obtained per cut. Three cuts during no harvest period can be done, obtaining 1500 kg/ ha^{-1} as extra income for coffee growers in crisis. The production of spearmint is not significant, and cannot compete with commercial production, but competition with weeds and coverage in between coffee rows open an interesting sustainable alternative for weed management in coffee production systems.

4 Conclusions

Intercropping sage, spearmint, basil and oregano stimulate the plagiotropic growth of *Coffea arabica* plants most effectively in young production systems. Coffee growers can stabilize their income and their social condition by offering aromatic plants produced during the no-harvest period of coffee to the local markets and using idle space of their farms. Therefore, additional studies have to be performed to compare yields of aromatic species under different coffee production systems. There are indications that these herbs cope with high caffeine levels and are even able to stimulate coffee growth. Further research of the biochemical nature of this interaction is promising and needed.

On the basis that stimulatory effect of the constituents of the evaluated volatile essential oils acts as growth stimulants, it might be necessary to define from the qualitative and quantitative composition the effect of each compound.

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