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Sustainable Management of Frutis Orchards Using Organic Matter and Cover Crops: A Case Study from Brazil

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1. Introduction

Few rural productive activities are as diversified and versatile as fruit farming and few countries are deeply engaged as Brazil in the cultivation of all existing species. This is reason enough for the world to keep an eye towards what is happening in the Brazilian plantations, which range from huge modern commercial orchards covering 2.266.791 ha. Fruit farming is scattered throughout all the Brazilian states and as an economic activity, it involves about 5 million people, either directly or indirectly. It comprises 30 organized belts and every year some belts are created. This makes Brazil rank as third global producer, with an annual harvest of 42 million tons, but represents only 2% of the global fruit trade, attesting to heavy domestic consumption (BRAZILIAN FRUIT YEARBOOK, 2010).

The world gets regular supplies of more than a dozen different types of fruit produced in various regions across Brazil. This gave origin to more than 30 fruit belts, each of them benefiting from regional geography, soils and climatic conditions to achieve high yields in orchards that generate thousands of jobs, drive the economy and position Brazil's states to participate in the global economy.

Sustainable agriculture is a keystone for development in Brazil and other parts of the world, as it seeks to preserve environmental quality whilst allowing for economic growth. Integrated fruit production fulfils such purpose as it aims for crop sustainability, balanced nutrient cycles, preservation and improvement of soil fertility and biological diversity as essential components. At the same time, Brazilian fruit producers must consider environmental protection, economical profits, and social and health demands of both farm workers and fruit consumers.

Fertilization using organic materials is complementary to chemical fertilization and especially necessary for integrated fruit production. Reliance on organic fertilizers for fruit production is already a reality in practically all countries in Europe. Brazil has tried to adapt its crops to such system because it has a great potential to supply fruit to countries in the northern hemisphere, mainly during the period between their harvests. However, its

production processes still need to be fitted to the demands of foreigner consumers. There is increasing demand for organic products in the international market and such products obtain better prices than conventional products. Another positive aspect of organic products is the quality control by non-governmental organizations, which guarantees the producer will receive a premium for their organic product. From a technical and scientific point of view, the challenges imposed by organic agriculture are huge. Extensive research is needed to develop appropriate operational technologies to enhance the productivity of organic crops.

As there are few papers describing research with organic fertilization in fruit orchards, the present study aimed to evaluate the effects of organic matter in the form of cattle, goat and green manure, as well as cover crops, on the soil fertility, plant nutrition, growth and yield of some fruit orchards in Brazil. The goal of this work was to obtain nutritionally equilibrated and productive plants. In addition, some quality characteristics of the fruit were also evaluated to determine how organic fertilization would influence such characteristics.

2. Fig tree orchard management using organic fertilization

The fig tree originated from Asia Minor and Syria, in the Mediterranean region, and was first cultured and selected by Arabs and Jews in Southwest Asia. It is one of the oldest plants cultivated in the world – since prehistoric times – and is considered by ancient people as a symbol of honor and fertility. Fig trees are cultivated in approximately 40 countries in the world, predominantly in the Mediterranean region, but is adapted to several climates and can be cultivated in both subtropical and temperate regions. Fig tree cultivation is interesting for Brazil, as it may lead to a market for exported Brazilian figs during the period between fig harvests in Turkey, which is the world's main producer of figs. Brazil produces a large volume of figs (25.500 tonnes per year), and 20 to 30% of the total volume produced in the country is destined for the export market.

Fig trees thrive in several soil types, provided it is deep, well drained and rich in organic matter. According to the experience of producers, the higher the organic fertilizer input, the better the results for both yield and fruit quality. Another reason for the interest in organic fertilization is the growth of the certified organic market, since certified products can be sold for higher prices.

However, scientific research into the fig tree requirements in organic fertilization is scarce and not conclusive. Balanced mineral nutrition during the plant formation phase guarantees good harvests in the plant productive phase. However, Fernandes & Buzetti (2000), emphasized that research recommending the best sources, doses, periods and methods of application of organic fertilizers are scarce.

The use of organic matter in fruit orchards favors the growth and development of plants as well as the soil properties. Organic matter is responsible for maintaining soil life, with benefits observed in the soil physical, chemical and biological properties. According to Kiehl (1985), several published works on the utilization of organic matter from different sources demonstrated the importance of such material as a soil fertilizer and conditioner. Animal manure is an excellent organic fertilizer, due to its content of all essential plant macro- and micro-nutrients, its chemical composition is highly variable depending on the animal species, age and feeding, the bedding material and the methods employed to prepare the fertilizer.

Campo Dall’Orto et al. (1996) noted that organic fertilizers have low and unbalanced nutrient levels, relative to plant requirements, but do possess the necessary nutrients for plant growth, which must be considered when selecting fertilization rates. However, those authors emphasized that special attention should be given to the time lapse for the release of nutrients from organic fertilizers to the plants.

The Minas Gerais Satate Soil Fertility Commitee (1989) and Mielniczuk (1999) reported that the time required for nutrient conversion organic to mineral forms varies with the nutrient. For nitrogen (N), approximately 50%, 20% and 30% of the total N in an organic fertilizer are released in the first, second and third year after application, respectively. The nutrient release from organic fertilizers is slower than that from mineral fertilizers, since the former depends on the mineralization of organic material. Such data must be carefully considered in the calculation of application rates for organic fertilizers, since plant-available N concentration can be different from that obtained with conventional mineral fertilizers, which are generally water soluble and readily release N for absorption.

In this section, we report the results of organic fertilization on the soil fertility, plants nutrition and yield of fig trees (*Ficus carica*, L.) cultivar ‘Roxo de Valinhos’ during four crop cycles.

The experiment was carried out in Botucatu, São Paulo State, Brazil, 22° 52' 47" S and 48° 25' 12" W, 810 m altitude. The local climate is classified as Cwa after Koppen (Curi, 1972), with rainy summers and dry winters, and the highest average temperature is above 22°C (Cunha et al., 1999). The soil is Rhodolic Haplo Udalf, according to the criteria established by United States Soil Conservation Service (1988). The initial chemical characteristics of the 20 cm topsoil, determined based on the methodology of Raij and Quaggio (1983), were: pH (CaCl₂) = 4.2; organic matter (O.M.) = 24 g dm⁻³; P (resin) = 3 mg dm⁻³; H + Al = 84 mmol_c dm⁻³; K = 1.4 mmol_c dm⁻³; Ca = 12 mmol_c dm⁻³; Mg = 5 mmol_c dm⁻³; Sum of bases = 18 mmol_c dm⁻³; cation exchange capacity (CEC) = 102 mmol_c dm⁻³; Percent Base Saturation = 18%.

Treatments consisted of cattle manure rates according to the recommended N level for the fig tree: control (no fertilizer), 25%, 50%, 75%, 100%, 125% and 150% of the recommended N level (Table 1). Since these levels depend on the tree size and as the N content in cattle manure varied (Table 2), the actual quantity of applied manure varied every year (Table 1). Half of the manure level was applied in August and the remainder in September, every year from 2002 to 2005.

Treatment (% crop N requirement)	N levels				Manure levels- dry weight			
	1 st year	2 nd year	3 rd year	4 th year	1 st year	2 nd year	3 rd year	4 th year
	----- (g plant ⁻¹) -----				----- (kg plant ⁻¹) -----			
0 %	0	0	0	0	0	0	0	0
25 %	10	20	30	30	0.8	0.82	1.9	3.6
50 %	20	40	60	60	1.6	1.64	3.8	7.3
75 %	30	60	90	90	2.4	2.46	5.7	11.0
100 %	40	80	120	120	3.2	3.28	7.6	14.3
125 %	50	100	150	150	4.0	4.10	9.5	18.0
150 %	60	120	180	180	4.8	4.92	11.4	22.0

Table 1. Nitrogen levels applied with cattle manure for fig tree fertilizations in four crop cycles (August 2002 to August 2005). The experiment was conducted in Botucatu, São Paulo State, Brazil.

Sample	N	P ₂ O ₅	K ₂ O	humidity	Organic matter	C	Ca	Mg	S
----- (g kg ⁻¹ dry matter) -----									
1	0.13	0.15	0.17	4.1	4.3	2.38	0.15	0.05	0.02
2	0.24	0.21	0.15	3.7	4.1	2.30	0.11	0.04	0.03
3	0.16	0.09	0.09	4.2	3.9	2.17	0.13	0.08	0.02
4	0.11	0.12	0.08	3.0	3.4	1.89	0.84	0.04	0.03

Sample	Fe	Cu	Mn	Na	Zn	pH*	C/N
----- (mg kg ⁻¹ dry matter) -----							
1	11300	120	146	N/D	190	7.60	19
2	7950	302	308	1860	300	7.20	9
3	14300	6	5250	580	286	14.00	14
4	24950	156	278	1460	208	7.97	17

* (in H₂O). Laboratory analyses of chemical fertilizers.

Table 2. Chemical analysis of cattle manure used for fig tree fertilization (Samples were taken as follows - 1: August 2002; 2: June 2003; 3: July 2004; 4: July 2005.). The experiment was conducted in Botucatu, São Paulo State, Brazil.

Values	pH	Organic matter	P	K	Ca	Mg	Sum bases	Effective CEC	Percent Base saturation
CaCl ₂ g dm ⁻³ mgdm ⁻³ ----- mmol _c dm ⁻³ -----									
Mean	5.5	25	34	4.5	43	20	67	96	66
CV (%)	7.22	17.07	55.55	21.47	31.27	29.18	29.17	15.00	18.11

Values	B	Cu	Fe	Mn	Zn
----- mg dm ⁻³ -----					
Mean	0.39	6.2	25	7.7	4.2
¹ CV (%)	36.67	11.96	15.45	26.72	41.19

¹CV = coefficient of variation

Table 3. Macro- and micro-nutrients, pH, organic matter, sum of bases, effective CEC, and percent base saturation (%) of the soil where fig trees were cultivated. Soils were collected after four years of fertilization with cattle manure (December 2005), from an experimental site in Botucatu, São Paulo State, Brazil.

Soil analyses after four applications of cattle manure, compared with the initial soil analysis described in the text, indicated that cattle manure treatments did not influence macro- and micronutrient levels at 0–20cm depth (Table 3); the obtained values were considered appropriate for the fig tree (Raij & Quaggio, 1983). Although N concentration in cattle manure was low (Table 2), the calculation of levels based on the recommended N levels gave a satisfactory input of manure, with no need of readjustment. Besides N, cattle manure contains other macro- and micro-nutrients that are essential to the development of plants, but is necessary to consider that the amount of manure needed to supply the N level was reasonable in this study case, because there was a great quantity of cattle manure for consumption in the experimental farm.

Significant responses to the application of cattle manure were obtained starting in the first crop cycle. On the other hand, plant yield during the orchard formation phase was below the mean values obtained by producers who use conventional fertilizers (about 9 to 20 kg plant⁻¹). One interesting point is that the addition of organic material to the soil aims not only to supply nutrients, but also (and mainly) to improve the soil physical and biological properties which, although not measured herein, may have contributed to the yield increase over three crop cycles (Figure 1). However, the obtained data does not allow the assessment of how such effects occurred and which mechanisms were involved (LEONEL & DAMATTO JÚNIOR, 2008).

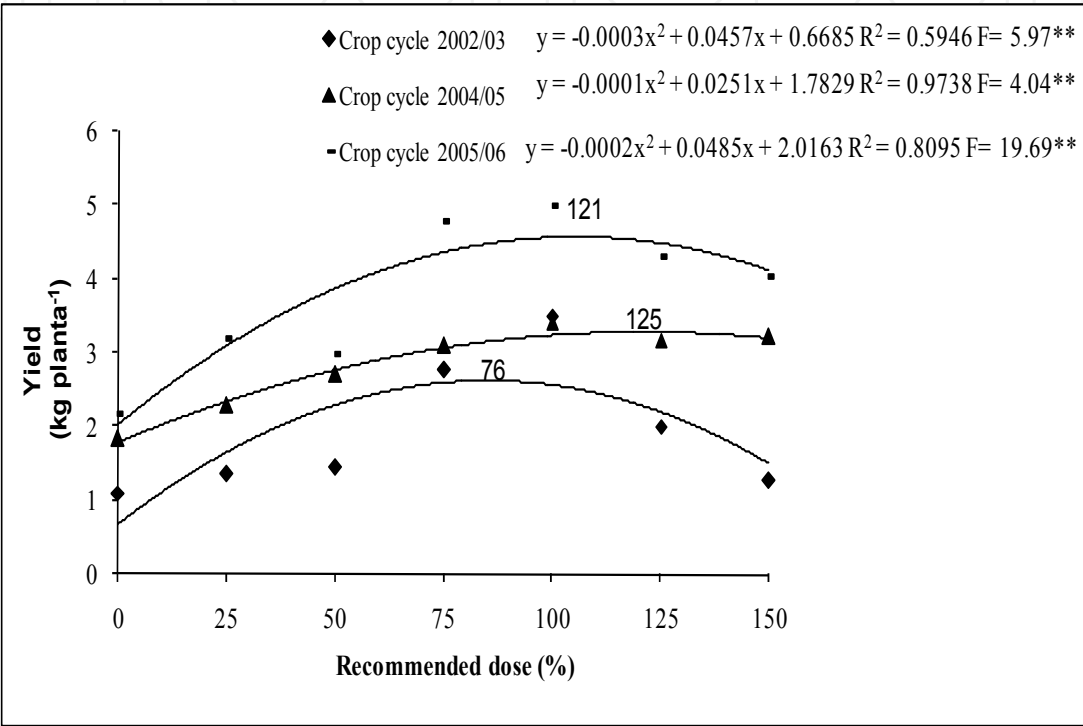


Fig. 1. Yield (kg plant⁻¹) of fig tree fertilized with cattle manure at different nitrogen levels corresponding to 0 to 150% of the recommended N dose (%). Data were from three crop cycles and the experiment was conducted at Botucatu, São Paulo State, Brazil.

In Small Meander Valley, Aegean Region of Turkey, where dried fig production is concentrated, Eryuce et al. (1995) selected an orchard in a lowland area where the trees were ten-year-old, cultivar Calyrmina receiving conventional chemical fertilization, and did not observe any effect of fertilization on fruit length, width and weight. In Jiangsu Province, situated in eastern China, where the annual average temperature ranges from 13°C to 16°C, the climate is semi-humid and subtropical, and the annual average rainfall is 800 to 1200 mm, Jinseng et al. (1997) studied the effects of supplementary fertilization with nitrogen, phosphorus and potassium on fig trees in one crop cycle. These authors did not report differences among treatments or positive effects on the yield due to fertilizer application. In the present experiment, the effects on fruit diameter and weight were slighter and the main increases were due to more fruits per plant, rather than a change in fruit size. The fig tree has continuous growth; thus, increased yield is due to fruit production along an elongated stem rather than an increase in fruit size.

Caetano et al. (2006) studied the effects of organic fertilization on fig yield using treatments without (0 kg plant^{-1}) and with (10 kg plant^{-1}) cattle manure. There were significant differences among the evaluated levels and the yield was $6597 \text{ g plant}^{-1}$ for the treatment without fertilizer and $7517 \text{ g plant}^{-1}$ for the treatment receiving 10 kg manure. Such results indicate a 13.9% increase in the yield due to the addition of organic matter, besides the benefits to the soil, which were not assessed. However, similar to the present work, the economical viability of this application was not investigated. In the current experiment, the yield increased in each evaluated crop cycle when comparing the 0% recommended dose (control) to the 100% recommended dose, and the average increase was 45.1% considering all four cycles.

3. Use of organic fertilizer for bananas

The banana is one of the most consumed fruits in the world, exploited in most tropical countries, reaching a world production of 70.7 million tons in 2009; Brazil is responsible for approximately 10% of this total. Brazil has around 500 thousand hectares planted with bananas and an annual production of around seven million tons, nearly all of which is destined for the internal market (Brazilian Institute for Geographical Statistics – IBGE 2009). Producing bananas under an organic system has appeared as an alternative so the final product can reach a whole segment of specific consumers with greater purchasing powers (BRAZILIAN FRUIT YEARBOOK, 2010), as well as being a means to reduce costs, as chemical fertilizers have incurred high cost increases over the last few years. In addition, organic fertilization is a more sustainable method of cultivation, creating less impact on the environment.

Even though banana cultivation of great importance at present to generate income and employment for the country, there is still a shortage of studies related to the use of organic fertilizer for banana nutrition. Since the banana tree demands high nutrient inputs and this factor has not always been given due attention, many of the banana producing locations have historically been under fertilized, which has led to low production and susceptibility to disease.

Although it is cultivated in various types of soil, the banana plant prefers soils rich in organic matter, well drained, and with a loamy soil that has a good water retention capacity and favorable topography (Rangel, 1997). In reality, many of the producing regions are located on soil poor in nutrients and also with a low organic matter index; the inadequate supply of nutrients is one of the main causes for low yields in banana cultivation. According to Lahav & Turner (1983), only a part of the necessary nutrients for banana plants can be supplied through natural soil reserves, the rest has to be incorporated into the soil-plant system, which should be made through crop waste matter or fertilizers.

Therefore it is necessary to use fertilizers to meet the demands of cultivating this crop and, according to Teixeira (2000) the recommendations for using N and K based fertilizers vary greatly, depending on the location of the banana plantation. This is because recommendations for using fertilizers should take into consideration the soil/climatic conditions, plant variety, production ceilings, local banana cultivation management practices, available resources and the plant's response to the application of nutrients.

Moreira (1987) points out that fertilization should be carried out during periods of greatest demand for nutrients, for example; during the vegetative growth phase and when the fruit first appears, which is when the greatest demand for N occurs, whilst the period of fattening and fruit ripening is when the greatest demand for K occurs.

Organic fertilizers are excellent source of nutrients for the banana plant, and common types available are animal manure, agro-industrial waste, straw and organic composts. These fertilizers contain all the necessary nutrients for the plants, such as nitrogen, phosphorus, potassium, calcium, manganese, sulfur, apart from micronutrients (Kiehl, 1985). Another benefit of adding organic material to the soil is in improving its physical attributes, helping to maintain humidity, as well as being responsible for assisting in some beneficial chemical reactions, such as in the concatenation interaction of toxic elements and micronutrients, increasing the cation exchange capacity and buffering pH levels, apart from increasing biological diversity. All these benefits created by the application of organic fertilizers come about through trying to meet the real needs of our soil, because tropical soils have their limitations in respect to chemical properties, with low levels of nutrients and little organic matter, which hinders the effective development of plants.

Various studies on the use of organic fertilizer demonstrated improvements in the physical, chemical and biological characteristics of the soil, as well as encouraging the growth of the plant, in addition to increasing the yield. Lahav & Turner (1983) reported that applying up to 80 t.ha⁻¹.year⁻¹ of stable waste on the soil encouraged growth and advanced flowering and fruiting of the banana plant. In a study using different top soils, in a partnership with a banana farm, Espindola et al. (2006) found that peanut waste fodder (*Arachis pintoi*) showed an increased speed in its decomposition, while spontaneous vegetation such as predominant guinea grass (*Panicum maximum*), demonstrated a slower rate, indicating that legumes liberated N, Ca and Mg rapidly, while spontaneous vegetation liberated P.

According to Borges (2008) the application of nitrogen can be accomplished through incorporating green fertilizers, especially legumes, which permits the production of organic matter and the supply of nitrogen, so that during the formation phase of the banana plant, it is recommended to plant legumes between the lines of plants, leaving it as green manure mulch. In the semi-arid region of North East Brazil, Silva et al. (2008) found that a mixture of legumes, grasses and oilseed in the understory of a banana plantation, to be chopped and left on the soil surface as a mulch and green manure, was a beneficial practice that contributed to the diversity of species, both above and below the soil, giving greater protection for the soil and a greater diversity of nutrients within the system.

Damatto Junior et al. (2006a) found that applying organic compost (sawdust and bovine manure) to banana plants (Prata anã) led to increases in pH, organic matter, phosphorous, calcium, CEC, and the soil saturation base level. However, it did not affect K and Mg levels (Table 4). The nutritional assessment of the Prata anã banana leaves, fertilized with different doses of organic compost indicated average levels of 30 mg N kg⁻¹; 2.0 mg kg⁻¹ of P; 31 mg kg⁻¹ of K; 9 mg kg⁻¹ of Ca; 3.2 mg kg⁻¹ of Mg and 2.5 mg kg⁻¹ of S, during the flowering season (Damatto Junior et al., 2006 b).

Treatments	pH	O.M.	P	K	Ca	Mg	SB	CEC	Percent Base Saturation
	CaCl ₂	g/dm ³	mg/dm ³	----- mmol/dm ³ -----					
T1: 0 kg compost/plant	5.4 c	32 b	54 b	1.2 a	59 b	17 a	77 d	108 d	69 c
T2: 43 kg compost/plant	5.6 bc	33 b	85 ab	1.3 a	74 b	19 a	93 cd	124 cd	73 bc
T3: 86 kg compost/plant	5.7 abc	35 ab	93 ab	1.3 a	90 ab	22 a	113 bc	141 bc	79 ab
T4: 129 kg compost/plant	6.0 a	43 a	153 a	1.4 a	114 a	22 a	137 ab	161 ab	85 a
T5: 172 kg compost/plant	5.9 ab	40 ab	135 ab	1.3 a	119 a	19 a	151 a	178 a	84 a
Averages	5,7	37	104	1,3	91	20	114	142	78
Coefficient of variation (%)	3	12	41	19	20	18	15	9	5

Averages followed by different letters in the columns differ by Tukey test at 5% of probability.

Table 4. Macronutrient concentrations, pH, organic matter (O.M.), sum of bases (SB), effective CEC, and percent base saturation values of an Alfisol cultivated with banana plants fertilized with different compost rates in Botucatu, Sao Paulo, Brazil from November 2002 to May 2004.

Other studies on the use of organic fertilizers with banana cultivation proved to be efficient. Borges et al. (2002) found that during the first cycle of Banana de Terra, when 267 kg of N/ha/year had been applied in the form of farmyard manure, an increase in the number of fruit per bunch was achieved, as well as increasing the average length of the fruit, in relation to an equivalent input of chemical N fertilizer.

A farmer growing the Prata anã banana, fertilized with organic compost, in the town of Botucatu, Sao Paulo obtained an average yield of 26.2 t/ha during the first harvest, producing bunches with an average weight of 16.4 kg, and 9 stalks on each bunch (DAMATTO JÚNIOR, 2005), this yield is higher than the national average, which was 19.8 t ha⁻¹ in the year 2008 (FAO, 2011). While studying the effect of the residual levels of the organic compost during the Prata anã plant’s second cycle, Damatto Junior et al. (2006 c) found that there was no residual effect with increasing levels of organic compost, although the average productivity was satisfactory at 27.3 t/ha.

In the State of Mato Grosso, Marílio et al. (2006) applied bovine manure, natural phosphate and leaf bio-fertilizer and using a covering of bean chaff mulch on five genotypes of banana plants, confirmed the viability of the banana production within an organic system.

Another important aspect to be taken into consideration when using organic fertilizer is the time taken for the organic residue to decompose and consequently liberate the nutrients contained within it. According to Campo Dall’Orto et al., (1996) the liberation of nutrients from organic fertilizer is much slower than from mineral fertilizers, as this is dependent on the mineralization of the organic matter. Bartz et al. (1995) reported that 50% of the applied N was mineralized in the first cultivation cycle and 20% in the second cycle, while P mineralization was 60% in the first cultivation cycle and 20% in the second.

When calculating the amount of fertilizer to use for banana plants, producers should consider the cultivated waste from the previous harvest, as the cultivated organic waste is considerable. This includes pseudo stem, leaves, husks and raques, which are an important source of nutrients. Various writers stress the importance of this sort of maintenance. In Vale do Ribeira in the state of São Paulo, Moreira (1987) estimated that a banana plantation can produce up to 200 t/ha/year by using the cultivated waste from the banana plants as a source of organic material for plants under development. Cintra (1998) pointed out that by using the cultivated waste from the banana plants as a form of mulch coverage; this represented a substantial source of organic material. Rodriguez et al. (2006), in Mexico, found that working the waste from the harvest between the banana plant rows was an excellent practice for increasing levels of organic matter in the soil by up to 1.0 to 1.5%. In addition, this practice reduced production costs and preserved productive top soil in that region.

Besides its nutritional aspect and in improving soil conditions, positive results were noted by using organic fertilizer for the banana plants in pest control and diseases, as it was observed that plants under the organic system presented a greater tolerance against attack from pests and mainly from diseases, which favors a longer productive period for the banana plant in the field. According to observations made by Penteado (2006), the cultivated plants within the organic system tend to be healthier and more resistant to diseases and insect pests than the plants grown using chemical fertilizers.

Banana in the Ribeira Valley region is susceptible to Sigatoka-negra (a disease caused by the *Mycosphaerella* fungus), but disease levels were no different in the organic system than conventionally managed plantations. The best performing species were IAC 2001 (19.9 kg per bunch) and Tropical (10.6 kg per bunch).

According to Pereira et al. (1996), organic composts can act on soil phytopathogens because they can produce inhibitory chemicals such as antibiotics or indirectly by encouraging the antagonist population, which will favor an increase in the useful life of the plant. This biological control is important, as banana plantations suffer big losses from the “Mal-do-Panama”, (*Panama disease*), a fungal disease caused by *Fusarium oxysporum*, which reduces the useful productive life of the banana plant, and can only be combated by the antagonistic micro-organisms present within organic materials.

4. The influence of organic fertilizer on production and quality of citrus fruits

According to Melarato (1989) most soil cultivated with citrus plants in South East Brazil demonstrated high soil acidity and toxic aluminum concentrations, low cation retention levels and low levels of saturated bases. These constraints are, due to a high degree of soil instability, because the parent materials are poor in base cations and need to be understood and overcome to optimize yields of citrus fruit.

Alva & Paramasivam (1998) mentioned that the production of citrus fruit is largely influenced by the supply of N, due to the fact that this nutrient regulates the rate of photosynthesis and the synthesis of carbohydrates (Kato, 1986), the specific weight of the leaves (Syvertsen & Smith, 1984); the total bio-mass production and the allocation of carbon in plant organs (Lea-Cox et al., 2001). Due to these reasons, N is considered as the most important nutrient in citrus plants and is instrumental in growth, yield and quality of the

fruit (Quaggio et al., 2005). Within this context, the use of organic N sources seems to be useful in the pursuit of sustainable and productive systems that will incorporate locally-available resources, satisfying human needs while maintaining or improving the environmental quality and conserving natural resources.

According to Pereira Neto (2007) the amounts of organic fertilizers to be applied vary according to the characteristics of the final product, the soil, the climate, type of cultivation, agricultural activity, method of fertilization, among other aspects. Considering these factors, researchers can perform fertilization experiments within representative orchards that test the levels of nutrients in soils and plants, the fertilizer source and the timing of application in orchards in a precise manner for assessing the nutrient requirements and responses of the citrus plants (Koller, 2009).

As a result of these needs, Ramos et al. (2010) assessed the effects of organic compost treatment on soil fertility, relative to the yield and quality of the 'Poncã' (*Citrus reticulata* Blanco) tangerine, cultivated in São Manuel-SP, where N treatments of 0, 50, 100, 150 and 200% the recommended dose were tested, corresponding to 0, 41.5, 83, 124.5 and 166 kg compost /plant respectively. Their findings confirmed that in the case of applying 200% nitrogen treatment, there was an increase in soil pH and greater concentrations of phosphorus, calcium, total basic cations, effective CEC, percent base saturation, manganese and zinc were observed in the soil. The (0%N) treatment reduced pH (and consequently a smaller H+A1 value), organic matter, phosphorus, potassium, calcium, total basic cations, CEC, Percent Base Saturation, sulphur, copper and zinc levels, indicating that applying organic compost alters the soil fertility (Table 5 and 6). The same authors observed that after fertilization there was an increase in pH, phosphorus, potassium, manganese, V%, sulphur, copper and zinc levels and a decrease in H+A1, boron, iron and manganese for practically all compost-amended treatments.

Treatments	pH	MO	P	S	Al ³⁺	H+A1	K	Ca	Mg	SB	CEC	Percent Base Saturation
	CaCl ₂	g/dm ³	mg/dm ³					---mmol _c /dm ³ ---				
Before fertilization (September 2009)												
T1	5,7	9,7	43,7	3,7	0	14,0	1,4	21,3	8,3	31,3	45,0	69,3
T2	6,1	7,5	20,5	3,0	0	11,5	1,7	17,5	5,7	25,0	36,7	68,2
T3	6,1	8,0	34,5	3,2	0	12,2	1,8	29,0	7,5	38,2	50,2	75,2
T4	6,4	9,5	45,5	4,2	0	11,5	1,7	40,2	8,5	50,7	62,7	80,0
T5	6,1	10,7	44,0	4,0	0	13,0	1,4	35,0	7,7	44,2	57,0	75,7
After fertilization (February 2010)												
T1	5,8	6,7	17,5	5,7	0	10,5	1,3	16,5	7,5	25,0	35,5	70,2
T2	6,3	10,5	22,7	6,5	0	9,7	1,8	24,5	7,0	33,2	42,5	77,0
T3	6,1	11,7	34,2	6,0	0	9,5	2,4	26,5	9,0	38,2	47,7	78,0
T4	6,5	11,7	48,2	7,7	0	9,0	2,7	37,0	9,7	49,5	58,5	82,5
T5	6,5	9,7	50,5	7,2	0	9,0	2,5	49,7	9,5	61,7	70,7	83,7

Table 5. Average concentrations of macronutrient, pH, organic matter (O.M.), sum of bases (SB), effective CEC, and base saturation values (V) in the soil cultivated with the 'Poncã' tangerine before and after fertilization using organic compost (moisture of the horse, cattle and bird manure) treatment (São Manuel/SP, 2009).

Treatments	B	Cu	Fe	Mn	Zn
	-----mg/dm3-----				
Before fertilization (September 2009)					
T1	0,24	0,75	23,00	10,07	1,52
T2	0,20	0,62	15,75	10,42	2,50
T3	0,17	0,95	19,75	8,75	3,27
T4	0,24	1,30	17,50	10,27	4,70
T5	0,20	1,20	20,75	10,12	4,30
After fertilization (February 2010)					
T1	0,17	0,90	9,75	6,52	2,30
T2	0,12	1,00	9,25	5,85	3,27
T3	0,16	1,42	10,5	6,17	4,92
T4	0,16	1,97	12,0	6,00	8,12
T5	0,15	1,87	11,0	7,25	8,97

T1: 0%N; T2: 50%N; T3: 100%N; T4: 150%N; T5: 200%N

Table 6. Average concentrations of micronutrients in the soil cultivated with the ‘Poncã’ before and after fertilization using organic compost (moisture of calcareous sugarcane bagace and birds manure) treatments (São Manuel/SP, 2009).

Citrus yields in treatments 1, 2, 3 and 4 (Table 7) were hardly different, ranging from 24.2 to 26.2 t/ha. However, using the recommended nitrogen treatment of 200% there was a yield of 43 t/ha (104 kg/plant), a significant increase of 16 t/ha. As a result of this high productivity in the 200% N treatment, a system of classification of the fruit was performed to see if this greater productivity affected the size of the fruit. Therefore, the fruit was classified: small ($\leq 69\text{mm}$), medium (70-81mm) and large ($\geq 82\text{ mm}$) and according to the results presented in Table 7, it was noted that treatments 3 and 5 presented the greater percentage of the large and medium sized fruit and a smaller percentage of the small sized fruit. This demonstrates that the greater yields achieved with treatment 5 did not affect the fruit size.

Treatments	Yield (kg/plant)	Productivity (t/ha)	Big ($\geq 82\text{ mm}$)	Medium (70-81mm)	Small ($\leq 69\text{mm}$)
T1	59	24,6	7%	25%	68%
T2	62	25,8	5%	26%	69%
T3	58	24,2	14%	30%	56%
T4	63	26,2	7%	23%	70%
T5	104	43	11%	27%	62%

T1: 0%N; T2: 50%N; T3: 100%N; T4: 150%N; T5: 200%N.

Table 7. Yield, productivity and size classification (big, medium and small) of the ‘Poncã’ tangerine fruit (*Citrus reticulata*, Blanco), with organic compost (moisture of calcareous, sugarcane bagace and birds manure) treatments (São Manuel/SP, 2009).

However, Panzenhagen et al. (1999) observed that the treatments achieved a greater fruit yield in the third category (diameters less than 5,7 cm), which would indicate that the greater total fruit yield was attributed to the sharp increase in the yield of the smaller sized

fruit, of poor quality and commercially undesirable. This leads to the conclusion that higher levels of N are positively related to an increase in fruit yield and with a decrease in their average weight.

With respect to the quality of the fruit, little difference was observed on the average weight, juice yield, technological index, pH, acidity, soluble solids and Vitamin C ratio. However, some authors claim that the quality of citric fruit is also influenced by fertilizing. Pozzan and Tribone (2005) claimed that studies such as those by Chapman (1968), Embleton and Jones (1973), Reese and Koo (1975) and Koo and Reese (1976) concluded that the greatest effect from nutrition in the quality of the fruit, is related to the supply of nitrogen and potassium; the former (N), tends to reduce the size of the fruit and increase the quantity of juice, soluble solids and acidity. On the other hand, high levels of potassium (K) proportionally decrease the concentration of soluble solids and increase the acidity of the juice by significantly increasing the size of the fruit and the thickness of the skin.

Through these various studies we can see that there still exists some controversy regarding the influence of fertilization on soil fertility, yield and quality of fruit. Although Ramos et al. (2010) compiled data on fertilization practices for a productive cycle of citrus orchards, it is possible to achieve good results with organic fertilizer, which influences the soil fertility and the yield, although does not interfere with the size or quality of the fruit.

5. Alternative management of intercropping in citrus

The greatest challenge for citriculturists is to obtain a product that fulfills the needs of consumers (which can be either the fresh fruit market or the processing industry) at a price that allows a profit, relative to the investment and the annual expenses demanded by the crop.

Citriculture in São Paulo State, Brazil is concentrated in regions with low fertility soils. Demattê & Vitti (1992) summarized soil characteristics in this area and found that 65% of the evaluated areas presented medium-texture soils (clay content of 15%–35% at the soil surface); 30% had sandy-texture soils (clay content of up to 15%); and about 5% were clayish soils. This forces the producer to use external inputs to achieve good yields, increasing thus the costs of citrus production.

Considering the above-mentioned factors – reducing production costs, maintaining soil chemical and physical properties with fewer inputs, and increasing competitiveness in the global market, assuring the citriculturist's profit – suggests that the use of green manure, catch crop or cover crop could be beneficial for citrus production in São Paulo, Brazil.

Green manuring consists in incorporating into the soil the non-decomposed biomass of plants locally cultivated or imported to preserve and/or improve the productivity of cultivable lands. According to scientific studies and practical evidence, green manure acts on diverse soil fertility aspects by: protecting against the rain impact and the direct incidence of sun rays; rupturing soil layers that were compacted over the years; increasing organic matter content; increasing water infiltration and retention capacity; decreasing Al and Mn toxicity due to complexation of these compounds with organic matter and pH buffering capacity of organic residues; promoting nutrient recycling; extracting and mobilizing nutrients from the deepest layers of the soil and subsoil including Ca, Mg, K, P and micronutrients; extracting fixed phosphorus; fixing atmospheric N in a symbiotic

manner with plants of the Leguminosae; and inhibiting germination and growth of invasive plants either by allelopathic effects or by competition for light (Von Osterroht, 2002).

There is little information on the response of soil chemistry and fertility following the introduction of green manure in *Citrus* orchards in Brazil. The following research aimed to evaluate soil chemistry following the introduction of green manure in an orchard of orange trees ‘Pêra’ (*Citrus sinensis* Osbeck).

The soil at the studied farm had a texture as Oxic Quartzipsamments. Orange trees were budded on ‘Rangpur’ lime trees and planted in a space of 7 x 4 m in 1996. Four different treatments corresponding to the evaluated green manure types were employed: jack bean (JB) (*Canavalia ensiformis* DC), lablab (LL) (*Dolichos lablab* L.), pigeon pea (PP) (*Cajanus cajan* L. Millsp), and brachiaria (BQ) (*Brachiaria brizantha* Hochst ex A. Rich. Stapf) as a control. They were sown in December of both 2003 and 2004 and were mowed and transferred to the plant rows during full flowering. The tests included chemical analysis of the soil in and between plant rows (Tables 8, 9, 10 and 11), macro and micronutrient levels in green manure and control (Table 12), dry matter accumulation in orange trees (Table 13) and assessment of the productivity (Table 14).

Depth	pH	OM	P	H+Al	K	Ca	Mg	SB	CEC	V%
(cm)	CaCl ₂	g dm ⁻³	mg dm ⁻³	-----mmol _c dm ⁻³ -----						
0-20	7.4	12	18	14	0.4	40	32	72	86	84
20-40	5.0	11	6	21	0.3	16	8	25	46	54

V = Percent base saturation. OM = organic matter. SB = sum of bases. CEC = effective cation exchange capacity (CEC)

Table 8. Results of soil chemical analysis in plant rows before treatment with green manure (collected in 0-20 and 20-40 cm depth). The experiment was conducted in a citrus orchard at the FCA/UNESP site in Botucatu, Sao Paulo, Brazil.

Depth	B	Cu	Fe	Mn	Zn
(cm)	-----mg dm ⁻³ -----				
0-20	0.20	0.7	20	1.3	0.8
20-40	0.13	0.6	31	1.3	0.8

Table 9. Soil micronutrient concentrations in plant rows before treatment with green manure. The experiment was conducted in a citrus orchard at the FCA/UNESP site in Botucatu, São Paulo, Brazil.

The values of pH slightly varied among treatments, ranging between 5.0 and 5.8 in the first experimental year and between 5.0 and 5.4 in the second year (Table 11), which lower than the ideal values for such plants (about 6.0-6.5). The decline in soil pH, relative to the initial soil analysis (Table 8), can be attributed to the soil acidification caused nitrification, considering that two H⁺ ions are released for every molecule of ammonium that is nitrified (Silva et al. 1999). Another possibility is that decaying plant residues release organic acids, which also promote soil acidification. Another possibility is that it was stimulated uptake of cations by the citrus trees and cation uptake is accompanied by H⁺ release from the root surface to maintain electrical neutrality in the plant.

Year	Treatment	Depth (cm)	B	Cu	Fe	Mn	Zn
			-----mg dm ⁻³ -----				
1 st	JB	0 - 20	0.16	1.2	34	3.4	1.5
		20-40	0.12	1.0	33	2.5	1.2
1 st	PP	0 - 20	0.15	2.1	35	3.5	1.5
		20-40	0.10	1.6	32	2.5	1.6
1 st	LL	0 - 20	0.17	1.4	38	4.2	1.9
		20-40	0.16	1.1	40	3.1	1.5
1 st	BQ	0 - 20	0.19	2.0	49	3.7	1.8
		20-40	0.19	1.8	42	3.5	2.1
2 nd	JB	0 - 20	0.18	1.3	59	2.8	1.3
		20-40	0.14	0.8	44	1.3	0.7
2 nd	PP	0 - 20	0.21	1.6	48	3.3	1.4
		20-40	0.16	0.6	39	0.8	0.4
2 nd	LL	0 - 20	0.21	0.9	49	2.4	0.7
		20-40	0.18	0.6	35	0.9	0.5
2 nd	BQ	0 - 20	0.20	1.3	49	2.5	1.1
		20-40	0.15	0.6	35	1.0	0.6

*jack bean (JB) (*Canavalia ensiformis* DC), lablab (LL) (*Dolichos lablab* L.), pigeon pea (PP) (*Cajanus cajan* L. Millsp), and brachiaria (BQ) (*Brachiaria brizantha* Hochst ex A. Rich. Stapf).

Table 10. Soil micronutrient concentrations at the layers 0-20 and 20-40 cm in plant rows after treatment with green manure* in the first (2003) and the second (2004) experimental years. The experiment was conducted in a citrus orchard at the FCA/UNESP site in Botucatu, Sao Paulo, Brazil.

Phosphorus levels at the layer 0–20 cm for JB, PP and LL treatments were considered high and those for BQ treatment were considered medium, according to GPACC (1994), compared with the initial soil chemical analysis; therefore, there was a considerable increase, 2-3 times greater, in P levels in the first experimental year (Table 11). In the following year, P concentrations declined to a similar level as the initial soil chemical analysis, i.e. medium P levels for JB, PP and BQ and low P levels for LL treatment. This indicates that maybe it had something to do with the time needed for P uptake or P fixation reactions to reduce the P concentration in soil solution in the first experimental year, altering thus the analysis results.

Potassium concentrations in the 0-20 cm layer were very low to low for all treatments during the evaluated years, which was consistent with the low fertility of the Oxic Quartzipsamments studied. It appeared that green manure did not provide sufficient K to increase the soil K concentration and highlights the need for additional fertilization to obtain high productivity and consequently high-quality citrus fruit.

According to Vitti et al. (1996), normal values for Ca/Mg ratio in the soil for citrus plants cultivation are about 4/1, which was not achieved with the treatments; the mean value obtained was around 1.4/1, mainly due to the utilization of dolomitic limestone for liming. Ca levels at the layer 20–40 cm should not be lower than 5 mmol_c dm⁻³, which did not occur with any treatment. Mg levels were within the suitable limits for such plants which correspond to 4 and 8 mmol_c dm⁻³ considering the layers 0–20 cm and 20–40 cm,

respectively. Data in Table 8 show that the applied limestone had a noticeable mobility with considerably higher levels than the initial ones at the layer 20–40 cm. As the soil is extremely sandy and consequently excessively drained, limestone probably moved considerably, surpassing the 40 cm sampling depth. Other research works (Quaggio et al., 1982; Anjos & Rowell, 1983 and Wong, 1999) have demonstrated significant loss of Ca and Mg by leaching, even in soils that received limestone at suitable doses. Under laboratory conditions, Büll et al. (1991) observed that Ca and Mg loss by leaching increased proportionally to the limestone dose in soils with X, Y and Z textures.

Year	Treatment	Depth (cm)	pH CaCl ₂	P mg dm ⁻³	K -----mmolc dm ⁻³ -----	Ca	Mg
1 st	JB	0 - 20	5.8	48	1.0	29	23
		20-40	5.5	11	0.5	13	14
1 st	PP	0 - 20	5.7	34	0.7	19	18
		20-40	5.6	18	0.6	14	12
1 st	LL	0 - 20	5.4	36	0.5	16	12
		20-40	5.2	19	0.1	7	5
1 st	BQ	0 - 20	5.0	28	0.7	11	9
		20-40	5.3	34	0.6	14	12
2 nd	JB	0 - 20	5.3	16	0.9	16	11
		20-40	5.1	4	0.4	9	6
2 nd	PP	0 - 20	5.4	16	0.8	16	11
		20-40	5.2	3	0.7	9	7
2 nd	LL	0 - 20	4.9	11	1.0	11	6
		20-40	5.2	3	1.7	9	8
2 nd	BQ	0 - 20	5.0	17	0.8	13	8
		20-40	4.9	4	0.3	8	6

*jack bean (JB) (*Canavalia ensiformis* DC), lablab (LL) (*Dolichos lablab* L.), pigeon pea (PP) (*Cajanus cajan* L. Millsp), and brachiaria (BQ) (*Brachiaria brizantha* Hochst ex A. Rich. Stapf).

Table 11. Soil macronutrient concentrations and pH at the layers 0-20 and 20-40 cm in plant rows after treatment with green manure* in the first (2003) and the second (2004) experimental years. The experiment was conducted in a citrus orchard at the FCA/UNESP site in Botucatu, Sao Paulo, Brazil.

B levels were considered low for all treatments in the first experimental year, and in the second year, JB kept showing low levels although increased of 0.02 mmolc dm⁻³. The remaining treatments then presented medium levels although B was not applied via soil. Such situation can be explained by the relationship between pH and B availability, once B levels tend to be stable when pH is close to 5.0.

Cu levels were considered high in the first year and remained high in the second year for all treatments, except for LL which returned to medium levels. Mn levels were medium throughout the two experimental years, and increased compared to the initial soil chemical

analysis. Similarly, the Zn concentration was initially at a medium level and remained medium or increased for the LL and BQ treatments (first year only). The Fe concentrations tended to increase throughout the experiment. The stability and, in some situations, the increase in the levels of micronutrients (Cu, Mn, Zn and Fe) were attributed to the soil acidification, as this reduced the pH and consequently increased their availability in the soil solution.

Green manure treatments presented higher levels of nutrients N, Ca, B, Fe and Zn, compared with BQ treatment (Table 12), corroborating the results of Weber & Passos (1991) and San Martin Mateis (2008), who reported that brachiaria, among other natural Gramineae of citrus orchard, have lower nutrient concentrations than Leguminosae.

Table 13. shows the dry matter yield of citrus trees, expressed as percentage and macro and micronutrient levels for green manure and control treatments over two years. Dry matter content at 20 cm deep had a slight increase of 3 g dm⁻³ in the first experimental year, compared with the chemical analysis of the soil before treatments, and a little decrease of 6 g dm⁻³ in the subsequent year. At the layer 20–40 cm, it also had an increase of up to 5 g dm⁻³ followed by a decrease of up to 10 g dm⁻³.

There was a significant difference among treatments (Table 13); PP showed higher dry matter content (34.3%). In the second year, it was statistically different from JB and LL, but equal to BQ. In the first year, PP treatment showed the highest dry matter content, which significantly differed from the other treatments; in the second year, it was different from JB and LL (Ragoso et al., 2006).

	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	g/kg						mg/kg				
JB	27	1.9	8	13	6	2	26	7	289	33	25
PP	21	1.7	7	6	4	2	24	9	364	30	26
LL	22	2	8	12	6	2	33	8	625	53	40
BQ	13	2	12	5	7	2	12	6	225	34	21

*jack bean (JB) (*Canavalia ensiformis* DC), lablab (LL) (*Dolichos lablab* L.), pigeon pea (PP) (*Cajanus cajan* L. Millsp), and brachiaria (BQ) (*Brachiaria brizantha* Hochst ex A. Rich. Stapf).

Table 12. Macro and micronutrient concentrations in four green manures*, averaged over two experimental years (2003 and 2004). The experimental treatments were applied to a citrus orchard at the FCA/UNESP site in Botucatu, Sao Paulo, Brazil

Treatments				
Year	JB	PP	LL	BQ
2004	25.7Aa	34.3Ba	21.7Aa	18.6Aa
2005	19.8Ab	32.0Ba	22.9Aa	27.2ABb
Coefficient of Variation = 22.2%	Minimum Significant Difference Treat.= 87		Minimum Significant Difference Year= 6.57	

Table 13. Dry matter means (%) of orange trees subjected to four different treatments over two experimental years.

There was no difference in citrus productivity with green manure treatments in 2003 or 2004 (Table 14), although yields were up to 20% greater from trees receiving the legume-based green manures, compared to the grass-based control (BQ), by the second year of the study. This was attributed to the gradual decomposition and nutrient uptake from the nutrient-rich legume residues, compared to the control..

Green manure can provide the crop with a better nutrition, even though the soil macro and micronutrient content was slightly reduced in the second year. It would be beneficial to continue evaluating the experiment over a longer period of time, and analyze additional soil characteristics, such as density, water retention, texture, structure, porosity and thermal conductivity, in response to green manure application..

Treatments				
Year	JB	PP	LL	BQ
2003	79.8Aa	83.9Aa	82.6Aa	81.7Aa
2004	102.2Ab	103.2Ab	103.0Ab	86.5Aa

CV = 21% DMS Treat.= 29.60 DMS Year = 22.30

Means followed by the same letter in the same line and column are not statistically different by the Tukey at 5% significance. Uppercase letters = treatments; Lowercase letters = years.
Adapted from RAGOSO et al. (2006).

Table 14. Productivity (kg plant⁻¹) of orange trees receiving four green manure treatments in two years. The experimental treatments were applied to a citrus orchard at the FCA/UNESP site in Botucatu, Sao Paulo, Brazil

6. Final considerations

Based on the premise that organic fertilizers, including green manureare fundamental to rural sustainability, i.e. that locally produced compost and cultivation waste should be to their maximum potential, studies were conducted to evaluate their use in orchard production. Considering that the composition of organic materials available is variable, it is hard to provide general recommendations for organic fertilization and the use for diverse orchard crops.

One approach is to devise recommendations based on the N requirements of the crop, calculating the application rates based on the percentage of N present in the organic fertilizer. However, this method frequently suggests such high levels of organic fertilizer that it becomes too costly for producers to consider this option. One can consider organic fertilizer to be more than a simple N source, in that it possesses an entire suite of macro and micro nutrients required for nutrition of orchard crops; in addition, the high organic matter content of most organic fertilizers is beneficial for improving soil physical, chemical and biological properties, which can indirectly or directly improve tree growth i.e., improved rooting, warmer soil temperature, buffer pH, increase reaction surface for cation exchange, promote the growth of soil microorganisms including biocontrol organisms.

There still exist very few studies on managing orchards in Brazil with organic fertilizers only, without employing any chemical fertilizers. The experiments done until now show promising results, and these studies must be continued.

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