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Nutrition of black pepper (*Piper nigrum* L.) - a Brazilian experience

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Abstract

Despite investment risk and price variations, among other difficulties, Brazilian farmers are still investing in black pepper (*Piper nigrum*) cultivation due to relative price increment over the years. Action has already been implemented, on improvement of cultivars and diagnosis, fertilization and irrigation, based on technical information for increasing the productivity of the crop. Adequate nutritional diagnosis, based on a proper sample method and regional patterns, will result in efficient input recommendation with a consequent improvement in production with higher sustainability. The DRIS (Diagnosis and Recommendation Integrated System) has been extensively used in Brazil, which contributes to efficient nutrition diagnosis and fertilizer recommendation. The use of simple cultural procedures such as use of cover crops and organic fertilization, among others, has a great potential to control weeds, improve soil quality and mineral nutrition in black pepper, contributing to sustainable production. This review includes information on research work being undertaken in Brazil, on black pepper nutrition (nutrient extraction, foliar patterns, nutritional diagnosis and fertilizer recommendations), including fertilization and diagnosis strategies for increasing the productivity of the crop.

Keywords: black pepper, Brazil, nutrition, *Piper nigrum*.

Introduction

Black pepper (*Piper nigrum* L.) was introduced in Brazil during the 17th century, but commercial utilization of this crop started only in the 20th century, since 1933, when Japanese immigrants introduced the cultivar 'Cingapura' (Kuching) in the State of Pará (Northern Region of Amazon). During the 1950's, Brazil changed from being a black pepper importing country to an exporter of this spice (Albuquerque & Condurú 1971). In 2007, Brazil produced 35,000 tons and exported 36,000 tons (34,000 tons of black-pepper and 2,000 tons of white-pepper), that originated from production during 2007 and from production stocks of preceding years. At present, Brazil has a cultivated area over 30,000 ha, with a mean productivity of 1,200 kg ha^{-1}. Brazil consumes about 6,000 to 8,000 tons of black pepper per year (IPC 2008). During the last few years Brazilian export have been always higher than 30,000 tons, representing about 0.5% of the Brazilian agribusiness export (IBGE 2008).

A large proportion of the black pepper production (80% to 85% of the total production) is produced by small farmers (family growers). In social terms, black pepper is considered to be a work absorbing culture, where each ton of harvested pepper corresponds to one job in the field. Black pepper cultivation generates income of more than 30 million dollars year^{-1} and about 120 thousand jobs during the cultivation season (EMBRAPA 2008). This fact has a social importance, since it reduces rural exodus to bigger urban centres. The rise of price of black pepper during 2007 and 2008 has stimulated Brazilian farmers to invest and renew their plantations.

Cultivation

In Brazil, most of the black pepper plantations occurs in regions up to 200 m altitude and relative humidity of 60% to 85%. The two main producing regions of the country have their particularities: In the State of Pará (Northern Region-Amazon) black pepper plantations are located in areas with precipitation of almost 2,000 mm year^{-1} and mean temperatures between 26 and 28°C; in Espírito Santo State (Southeast Region-Atlantic Forest) black pepper is cultivated in areas with precipitation of 1,200 mm year^{-1} and mean temperature of 23°C. Irrigated plantations represent more than 80% of the cultivated plots (micro-spray, drip-irrigation, conventional spray irrigation). In general, the State of Espírito Santo adopts more technology when compared to the State of Pará, with consequent higher productivity (about 3,000 kg ha^{-1}). A better use of fertilization including fertilization-irrigation is observed in this State (Serrano *et al.* 2006).

Cuttings from orthotropic branches from adult black pepper plants are used as planting materials. Growers purchase planting materials from plantations certified by the Agricultural Ministry. The common spacings used are in single or double row varying from 1,333 to 2,500 plants ha^{-1}. For cultivation of black pepper under open conditions, wooden poles of *Melanoxylon breuna* Schott. or even concrete poles (of 3 m length and 1-15 cm thick) are recommended. For cultivation under shade, the use of live standards is recommended with species such as *Azadiractha indica* A. Juss., *Gliricidia sepium* Jacquin., *Schizolobium parahybum* (Vell.) S. F. Blake or *Erythrina fusca* Lour. Shaded systems allow a reduction in establishment costs of about 21% in comparison with dead standards system, but productivity decreases due to competition for nutrients, water and light.

Nutrient composition in plant tissues

A detailed composition of the whole black pepper plant dry matter was studied by Veloso & Carvalho (1999) (Table 1). It is evident that in 28 month old plants, fruits and leaves represent the highest dry matter weight percentages with 27.61% and 27.54% of dry matter, respectively, followed by plagiotrophic and orthotrophic branches; the roots represent lesser dry matter percentage in the whole plant. These records are in agreement with results observed by researchers in different countries (Sim 1971).

Table 1. Dry matter content in different parts of black pepper cv. Guajarina, collected in 28 month old plants during the production period

Plant part	Dry matter (g)	% in relation to total plant content
Leaves	368.26	27
Fruits	369.18	28
Plagiotropic branches	272.07	20
Orthotropic branches	222.61	17
Roots	104.92	8
Total	1,337.04	100

Veloso & Carvalho (1999) also quantified the concentration of macronutrient in different parts of the black pepper plant (Table 2). According to these results, the highest concentration of N was found in leaves, fruits and roots. Concentration of P was lower, when compared to other macronutrients

Table 2. Macronutrient concentration in different parts of black pepper cv. Guajarina, collected in 28 month old plants during the production period

Plant part	Macronutrient concentration				
	N	P	K	Ca	Mg
	$g\ kg^{-1}$				
Leaves	23.5	2.10	14.2	21.7	4.3
Fruits	22.8	2.18	12.5	7.8	2.4
Plagiotropic branches	15.2	1.62	11.3	8.9	1.9
Orthotropic branches	18.3	1.63	16.9	11.5	2.9
Roots	22.4	1.34	5.1	20.9	7.6

practically in all plant parts studied. Regarding K concentration, it was higher in plagiothropic branches, while Ca and Mg showed higher values in leaves and roots, with values for Ca always higher than Mg. Similar results were also recorded by Chiba & Terada (1976) and Kato (1978), with the difference of higher concentrations found for Mg. The highest quantities of N were found in leaves and fruits, with 27.78% of N. On the other hand, only 2.52% of P was found, with 31.9% and 30.6% of this content were located in fruits and in leaves, respectively. Relatively high quantities of Ca were contained in leaves. Quantities of Mg contained in black pepper were only higher than P quantities, with higher content in leaves (Veloso & Carvalho 1999) (Table 3).

From the results of Veloso & Carvalho (1999), it is concluded that N is the most extracted nutrient in a black pepper crop (with fruit harvest), followed by K, Ca, Mg and P. Kato (1978) estimated that an adult plant of black pepper requires 90 g of N, 10 g of P, 120 g of K, 80 g of Ca and 11 g of Mg, to grow and produce fruits.

Table 3. Macronutrient distribution and content in different parts of black pepper cv. Guajarina collected in 28 month plants during the production period

Nutrient	Plant part						Total
	Unit	Leaves	Fruits	Orthotropic branches	Plagiotropic branches	Roots	
N	$g\ plant^{-1}$	8.65	8.42	3.38	4.98	2.35	27.78
	$kg\ ha^{-1}$	11.53	11.22	4.51	6.64	3.13	37.03
	%	31.10	30.30	12.20	17.90	8.50	100.00
P	$g\ plant^{-1}$	0.77	0.81	0.36	0.44	0.14	2.52
	$kg\ ha^{-1}$	1.03	1.07	0.48	0.59	0.18	3.35
	%	30.60	31.90	14.30	17.60	5.60	100.00
K	$g\ plant^{-1}$	5.23	4.62	2.52	4.60	0.54	17.51
	$kg\ ha^{-1}$	6.97	6.15	3.35	6.13	0.71	23.31
	%	29.90	26.40	14.40	26.30	3.00	100.00
Ca	$g\ plant^{-1}$	7.99	2.88	1.98	3.13	2.19	18.17
	$kg\ ha^{-1}$	10.65	3.84	2.64	4.17	2.92	24.22
	%	44.00	15.80	10.90	17.20	12.10	100.00
Mg	$g\ plant^{-1}$	1.58	0.89	0.42	0.79	0.80	4.82
	$kg\ ha^{-1}$	2.11	1.18	0.56	1.05	1.06	5.96
	%	35.40	19.80	9.40	17.60	17.80	100.00

Deficiency symptoms

Deficiency symptoms in black pepper have been described by Veloso & Muraoka (1993) and Veloso *et al*. (1998a,b), based on experiments using nutritive solution (Table 4). Analogous symptoms have been described by Serrano *et al*. (2006) in adult plantations. Veloso *et al*. (1998a,b), concluded that with the absence of any nutrient, a significant limitation to the total dry matter of plants occurs, when compared to treatments that received all nutrients in sufficient quantities. Thus, black pepper's dry matter production gets limited under nutrition restricted conditions, as follows: N (60%), Fe (59%), Zn (57%), Cu (49%), B (48%), S (44%), P (41%), Mn (38%), K (36%), Ca (27%) and Mg (21%).

Table 4. Nutritional deficiency symptoms in black pepper seedlings of cv. Bragantina, cultivated in nutritive solution

Nutrient	Days	Deficiency symptoms
Nitrogen	30	Green leaves showing green-yellowish colour homogeneously distributed over the blade, petiole and veins; later on the yellowish colour gets more accentuated with a generalized chlorosis. Plant growth with thin and chlorotic stems.
Phosphorus	140	Thin stems with upside curved younger leaves and later older leaves. Older leaves become small and narrow. Green-bluish colour with purple tones in the upside blade. Lower development.
Potassium	122	Deformation in older leaves, with an initial chlorosis at the leaves plant apex that evolves towards the base. With the intensification of deficiency, necrosis occurs at the leaf margin in older leaves and then in younger leaves. Leaves are of a cracking consistence.
Calcium	120	Initially, a small yellowing of younger leaves is observed, with small necrotic spots in the upside blade of older laves. Later, necrotic spots occur at the leaf borders. The basal parts show a pale-yellowish colour with small necrotic spots.
Magnesium	104	Older leaves with yellowish colouring and inter-vein chlorosis, with a narrow strip of green tissue in the blade along leaf veins. Parts of the margins are necrotic. During advanced deficiency stage, some young leaves also show yellowing and inter-vein chlorosis.
Sulphur	150	Reduction in growth and lower number of leaves, with a gradual yellowing all over the area, later on showing necrosis of the extremities, especially in younger leaves.
Boron	130	Yellowing starting from the centre to the extremities in younger leaves. Formation of terminal buds with reduced development and showing dark spots between veins and leaf margins. Some younger leaves are curved downside with a rosette aspect.
Copper	92	Yellowing of the younger leaves with a pale green colour between leaf veins. Later, leaves show a little distortion, turning narrowed, smaller and curved with necrotic spots in the edges.
Iron	70	Generalized chlorosis in younger leaves. Later, leaves are pale-yellow and whitish. Reduction in plant growth.
Manganese	89	Yellowing of younger leaves with bands of green tissue around median vein and secondary leaf veins. With the intensification of deficiency, leaves turn yellow and whitish, with necrosis at the apex or in the edges and with a small reduction is size.
Zinc	95	Younger leaves narrowed and longer than normal. Generalized chlorosis of leaves and plants. Reduction of inter-knots.

Days=Number of days when the seedlings showed first visual symptoms of deficiency, after exclusion of the nutrient.

Nutritional diagnosis based on foliar analysis

Foliar diagnosis is very efficient, since it allows a direct and accurate nutritional diagnosis while considering the plant as the soil nutrient extractor (Beaufils 1973); however it does not replace soil analysis. Proper interpretation of foliar analysis results generates information that helps in the rational use of supplies, plant nutritional equilibrium and consequently in productivity increment. Thus, the use of methods that favours an efficient and practical nutritional diagnosis, from analytical results of a crop or plant leaves, are to be stimulated, for a correct use of fertilizers. These will result in a more economical and even environmental conditions (avoiding contamination through the rational use of supplies, thus preventing excess).

The Diagnosis and Recommendation Integrated System (DRIS) (Beaufils 1973), integrates the concept of nutritional balance, or equilibrium between minerals in the plant tissue (Baldock & Schulte 1996; Lucena 1997), thus being an efficient tool for nutritional diagnosis. This technique is based on DRIS index calculation, for each nutrient, evaluated by the ratio between the content of each element in relation to the others, obtained from a sample with standard ratios with a mineral composition originated from a high productive plant population. It is well known that DRIS norms and even sufficiency ranges must have a regional character (Dara *et al*. 1992; Reis & Monnerat 2003), and even be related with the cultivation method (Partelli *et al*. 2006) and period of the year (Partelli *et al*. 2007). Thus, specific foliar standards for black pepper, in different regions and countries are fundamental, avoiding incorrect diagnosis and therefore inadequate recommendations.

Some regions in Brazil have already established sufficiency ranges (Table 5) and DRIS norms, even a CD-ROM is available to make easy the interpretation using DRIS in black pepper (Costa 2005). This work has helped to achieve higher productivities, as in the case of Espírito Santo state, where productivity increased from about 1,300 kg ha^{-1} in 1981 to 3,636 kg ha^{-1} in 2006 (Serrano *et al*. 2008). It is recommended to sample vegetal tissues during the period of fast fruit growth (between two and three months after flowering), sampling the first adult complete leaf (blade + petiole) from the terminal bud of productive branches localized in the middle and external portion of the canopy; 4 leaves per plant must be sampled (each one corresponding to a cardinal point), at a minimum of 30 plants per plot (Serrano *et al*. 2006).

Fertilization recommendation based on soil analysis

In Brazil, the majority of soils where black pepper is cultivated has a low natural fertility, with an elevated acidity, low saturation of bases and frequently possessing exchangeable aluminum and manganese and iron in high quantities to limit plant development (Falesi 1972). This fact, associated with the elevated nutritional demand of the species, results in a constant necessity of fertilization application to guarantee a vigorous growth with high productivity. Thus, it is

Table 5. Recommended adequate foliar contents of nutrients for black pepper in Brazil

Macronutrient (dag kg^{-1})					
N	P	K	Ca	Mg	S
2.5 - 2.8	0.13 - 0.14	1.9 - 2.6	1.0 - 1.4	0.2 - 0.3	0.12 - 0.2
Micronutrient (mg kg^{-1})					
Fe	Zn	Cu	Mn	B	-
60 - 200	20 - 30	8 - 11	60 - 240	25 - 42	-

Veloso *et al*. 1998a,b; Costa 2005

recommended to perform soil and foliar chemical analysis each year, in order to supply all nutrients needed by the plant appropriately.

Soil samples must be collected all over the area before planting. If the culture is already implemented, samples must be collected within fertilized soil rows under the canopy. It is recommended to collect at least 12 to 20 soil samples within an area considered as homogeneous (maximum of 10 ha), to make a compound sample (Serrano *et al*. 2006). Samples may be collected from the superficial (0 to 20 cm) and sub-superficial (21 to 40 cm) soil layer, aiming at the identification of possible chemical limitations, such as aluminum toxicity and low availability of Ca and Mg, among others.

Soil liming

A general recommendation is to increase the base saturation value to 70%, fulfill Ca and Mg demand and maintain soil pH between 6.0 and 6.5, promoting the availability of most nutrients. The estimates for soil liming among the main black pepper producing regions in Brazil considers the criteria of bases saturation. If Ca content is lower than 0.4 cmol kg^{-1} and/or Al content is higher than 0.5 cmol kg^{-1} in the soil analysis of the sub-superficial layer (21-40 cm), it is recommended to use agricultural gypsum. If this application is needed, 25% of the recommended liming necessity for the superficial layer is used (Serrano *et al*. 2006).

Fertilization recommendation for planting, growth and production

Soil chemical and physical analysis are considered for developing fertilizer recommendations. During planting it is recommended to use 3 to 15 l of bovine manure $plant^{-1}$, phosphate and potassium fertilizers and micro-nutrients. In general, if soil analysis detects low contents of micro-nutrients, application of 25 g of zinc sulphate, 2 g of copper sulphate, 5 g of boric acid, 8 g of ferrous sulphate and 6 g of manganese sulphate $plant^{-1}$, is recommended.

The soil test nutrients may be used as base during planting, growth and production stages of crops as fertilizers may be recommended by the use of an approximation table (Table 6). Nitrogen and potassium must be divided along the agricultural year. Mineral fertilization for production begins the third year after planting, according to results of the foliar and chemical and physical soil analysis (Table 7), performed each year.

Toxicity of nutrients

According Veloso *et al*. (1995a), the main production areas of black pepper in Brazil are located in regions with acid soils, with low base saturation and fertility and frequently having Al and Mn in enough quantities to

Table 6. Fertilization recommendation for planting and develpment of black pepper in Brazil

Nutrient	Planting	1st year	2nd year
Nitrogen (N) g/N $plant^{-1}$	0	50	100
Phosphorus (P)* g/P_2O_5 $plant^{-1}$			
Low	70	30	60
Medium	60	15	40
High	50	0	20
Potassium (K)* g/K_2O $plant^{-1}$			
Low	30	100	150
Medium	15	80	100
High	0	50	80

* Content showed in soil analysis.

Table 7. Mineral fertilization recommendation for black pepper production in Brazil

	N		P		K	
Foliar content	< 2.8 dag kg^{-1}	> 2.8 dag kg^{-1}	< 0.14 dag kg^{-1}	> 0.14 dag kg^{-1}	< 2.0 dag kg^{-1}	> 2.0 dag kg^{-1}
	g/N $plant^{-1}$		g/P_2O_5 $plant^{-1}$		g/K_2O $plant^{-1}$	
	200	120	80	50	250	180

limit the normal development of plants. The researchers concluded that the addition of 20 mg l^{-1} in the substrate, reduces dry matter weight and nutrient absorption, which was associated with the toxicity effect. The initial toxicity symptom of Al was characterized by a delay in root growth, with an increase in root diameter. Black pepper accumulates and tolerates the presence of Al concentrations below 20 mgl^{-1} in the substrate, however higher doses promote nutritional disturbances in the plant.

Manganese, in high acidity soils, may produce plant toxicity. Veloso *et al*. (1995b) studied the effect of this nutrient in black pepper, cv. Guajarina, in nutrient solution. In the absence of Mn, deficiency symptoms and reduction in growth were observed. Toxicity was observed starting at the concentration of 20 mgl^{-1}, with yellowing and necrotic lesions (necrotic spots) in younger leaves that extended to older leaves with increase of Mn in the aerial parts. Excessive content of manganese (30 mgl^{-1}), reduced plant development and absorption of P, K, Ca, Mg, Cu, Fe and Zn.

The effects of calcium nutrition on Al toxicity in back pepper seedlings, studied by Veloso *et al*. (2000a), showed that Al resulted in delayed plant growth and induced symptoms of Al toxicity in the aerial part of the seedlings, causing increased root diameter. The accumulation of Ca increased with the increment of the nutrient concentrations in the solution, in the absence of Al. In roots, the content of Ca decreased with the increase of Al concentration in the solution. Absorption of Al was reduced with the increase of Ca concentration in the solution.

Nutrient response studies

Chiba & Terada (1976) determined the uptake of macronutients in the field in the Amazon region of Brazil, concluding that N was absorbed in small quantities by young plants and uptake increased with plant growth. Nutrients absorbed in higher quantities by black pepper plants were K and N, followed by Ca > Mg > S > P in a decreasing order. The absence of N affected plant development the most, followed by absence of Ca and K. Nutrient contents in leaves under complete treatment and in the absence of nutrient treatment were: N=1.89% and 1.39%, P=0.12% and 0.06%, K=2.19% and 1.22%, Ca=1.04% and 0.73%, Mg=0.35% and 0.14%, S=0.18% and 0.12% (Veloso & Muraoka 1993).

In the Amazon region, Veloso *et al*. (2000 b) observed a positive response to nitrogen application with black pepper berry production at 72 and 78 kg ha^{-1} of N, in cvs. Cingapura and Bragantina, respectively. Only cv. Guajarina responded to phosphorus application. The addition of K favoured the increase of berry production at 42, 13 and 22 kg ha^{-1} of K_2O, for cvs. Cingapura, Bragantina and Guajarina, respectively.

A study performed in the State of Paraiba (north east region) showed that black pepper plants respond positively to bovine manure application. Maximum green pepper productivity $plant^{-1}$, from cvs. Bragantina (1,012 g), Iacara (11,269) and Cingapura (627 g), were obtained with doses of 7.3, 8.6 and 7.0 kg of manure $plant^{-1}$ respectively. For dry pepper production, doses of 6.5, 8.9 and 7.8 kg of manure $plant^{-1}$ resulted in maximum production of 358, 793 and 204 g $plant^{-1}$ in cvs. Bragantina, Iacara and Cingapura, respectively (Oliveira *et al*. 2007). These authors also observed that higher quantities of manure may be detrimental to growth and development of these cultivars.

Use of cover crops

The adoption of soil and environment conservational practices such as the use of cover crops are prominent feasible practices that favours the density and diversity of soil microorganism, especially P-solubilizing microorganisms (Carneiro *et al*. 2004), thus improving soil structure (Carvalho *et al*. 2004) and promoting nutrient recycling. Besides that, the use of legumes as cover crops promotes biological fixation of atmospheric nitrogen in association with specific bacteria (Oliveira *et al*. 2002a; Perin *et al*. 2004; Ricci *et al*. 2005; Alves *et al*. 2006; Partelli 2008). Thus, the use of cover crops contributes positively to soil N and P balance (Bayer *et al*. 2000) and consequently leads to increase in crop productivity (Oliveira *et al*. 2002b).

The cover crops commonly used in Brazil are: *Canavalia ensiformis* L., *Crotalaria* sp., *Cajanus* sp. and *Mucuna deeringeana* (Bort) Merr. which promote nutrient recycling, increase soil carbon and reduce erosion. Cover crops for areas cultivated with black pepper, must be free of any allelopathic effect, neither be parasitic itself nor a disease or pest host, should not be a vine, have small size or be amenable for pruning. Cover crops must be correctly managed in order to aid the sustainable management of economically important crops such as black pepper.

Cover plants may also reduce infestation by weed plants in crops (Silva *et al*. 2006; Partelli, 2008). Nevertheless, if inadequately managed, these cover plants may promote reduction in productivity (Paulo *et al*. 2006). For this reason, it is necessary to choose cover plants with high biomass production capability and well adapted to specific soil and climatic conditions. Among the desired characteristics for these cover crop species, a good tolerance to drought, low nutritional requirements, rapid growth and good soil cover capacity may be important.

Organic fertilization

Under organic crop management, solid or liquid animal manures may be used as well as green fertilizers, stillage, sugarcane filter cake and other sources of organic matter. The origin of these materials must be verified and in many cases composting such materials before use is recommended. The main phosphorous sources allowed are the natural phosphates, Thomas' phosphates, bone meal and thermo-phosphates. Among the potassium sources, coffee straw, vegetal ashes, black oat, potassium sulphate and potassium magnesium double sulphate are accepted for use. Micro-nutrients may be supplied with basalts (slow liberation), algae, salts (zinc and copper sulphate, boric acid and others), bio-fertilizers and other sources of organic materials.

The utilization of organic matter is a widely accepted practice among organic farmers and may substitute conventional fertilization. (Damatto Júnior *et al*. 2005). The need for fertilization may vary according to the crop, expected productivity and soil chemical and physical conditions. Thus, it is suggested to proceed as follows to calculate the recommended doses for organic fertilization:

$X = A/(B/100) \times (C/100) \times (D/100)$

Where: X=Quantity of organic fertilizer to be applied (kg); A=Crop's nutrient necessity; B=Percentage of dry matter of the fertilizer; C=Nutrient's concentration in the dry matter (in percentage); D=Conversion index in percentage (it may very from 80% to 100%)

Conclusion

Despite investment risks and variation in prices, Brazilian growers are returning again to invest in cultivation of black pepper, due to price increment. It is also important to make available new management techniques like pruning techniques, fertilization, use of denser spacement plantations, use of live stacking, new systems of stacking, associating plantations with forest and other agricultural species, etc.

Regardless of difficulties and limitations in black pepper production, Brazil shows a great potential to increase its production and competitivity in the international market. To achieve this, some actions have already been implemented, as the creation and strengthening of cooperatives and research groups, higher quality control in plantations and promoting nurseries, execution of scientific and informative events and meetings, higher agricultural bank credits, etc. A strategic area that has deserved a special focus is cultivar breeding and genetic improvement, especially aiming at resistance and tolerance to diseases, use of alternate stacking and irrigation. It is clear that an adequate nutritional diagnosis, based on proper sampling, regional patterns and efficient diagnosis methods will lead to an efficient input recommendation and consequently better productivity in a more economic and sustainable way. Uilization of simple cultural measures such as the use of cover plants, organic fertilization, etc. have an enormous potential to control weed plants, improve soil quality and mineral nutrition and productivity of cultivated crops including black pepper, thus contributing to sustainable agriculture.

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