Field response of groundnut *Arachis hypogaea* L. inoculated with vermicompost and Arbuscular mycorrizhal fungi

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Abstract

The purpose of this research was to investigate the use of vermicompost (VC) and AMF (Arbuscular mycorrizhal fungi) species (*Glomus intraradices*) on the field response of groundnut (*Arachis hypogaea* L.). Field experiments were carried out at Agricultural Land, Vadakkumangudi, located within 4 km from the Annamalai University, Tamil Nadu. The studies were conducted during January 2009 to May 2009. The incorporation of vermicompost and AM fungi up to 5 tonnes ha⁻¹ VC + AMF inoculation enhanced shoot length, root length, leaf area, fresh weight, dry weight, number of root nodules and pigment content such as chlorophyll ‘a’, chlorophyll ‘b’, total chlorophyll and cortinoid content when compared to control and other treatments. Some of the growth enhancement in these vermicompost to be related to the combined effects of improved porosity, aeration, water holding capacity and uptake of nitrogen by the plant resulting in increased plant growth. The AM fungi increased photosynthetic rates, altered growth regulating substances and altered patterns of the root exudation due to changes in the membrane permeability, nutrient and water uptake. Therefore, it seems likely that the vermicompost and AM fungi provide other biological inputs, such as plant growth regulators, that still need to be identified fully.

Keywords: vermicompost, *Glomus intraradices*, *Arachis hypogaea*, morphological parameters, pigment content

Introduction

Environmental degradation is a major threat confronting the world, the rampant use of chemical fertilizers contributes largely to the deterioration of the environment through depletion of fossil fuels, generation of carbon dioxide (CO₂) and contamination of water resources. It leads to loss of soil fertility due to imbalanced use of fertilizers that has adversely impacted agricultural productivity and has caused soil degradation. Now there is growing realization that adoption of ecological and sustainable farming practices can only reverse the decline trend in the global productivity and environment protection (Jim, 1988; Wani and Lee, 1992; Wani et al., 1995). The plant nutrients are essential for the production of crops and healthy food for the world’s expanding population. Plant nutrients are therefore vital components for sustainable agriculture. Increased crop production largely relies on the type of fertilizers used to supplement essential nutrients for plants. For optimum plant growth, nutrients must be available in sufficient and balanced quantities. Soil contains natural reserves of plant nutrients, largely unavailable to plants, and only a minor portion is released each year through biological activity or chemical processes. This release is too slow to compensate for the removal of nutrients by agricultural production and to meet out the crop requirements. Soil microorganisms play a significant role in regulating the dynamics of organic matter decomposition and the availability of plant nutrients such as N, P and S. It is well-recognized that microbial inoculants constitute an important component of integrated nutrient management that leads to sustainable agriculture.
In addition, microbial inoculants can be used as an economic input to increase crop productivity. Fertilizer dose can be lowered and more nutrients can be harvested from the soil. Biofertilizers is defined as a substance, which contains living microorganisms and is known to help with expansion of the root system and better seed germination. A healthy plant usually has a healthy rhizosphere, which should be dominated by beneficial microbes. Conversely, in unhealthy soil, dominated by pathogenic microbes, optimum plant growth would not be possible. Vermicompost is a hormone like activity and this has been hypothesized to result in greater root initiation, increased root biomass, enhanced plant growth and development and altered morphology of plants grown in vermicompost amended media (Tomati et al., 1988; Arancon et al., 2008). Vermicompost is hormonal in nature together with an “indirect action” on the metabolism of soil microorganisms (Arancon et al., 2006a). Mycorrhizae are mutually beneficial (symbiotic) in establishing relationships between fungi and plant roots. AM fungi infect and spread inside the root. They possess special structures known as vesicles and arbuscules. The plant roots transmit substances (some supplied by exudation) to the fungi and the fungi aid in transmitting nutrients and water to the plant roots. The fungal hyphae may extend the root lengths to 100 fold. The hyphae reach into interior soil areas and help plants absorb plenty of nutrients, particularly the less available mineral nutrients such as phosphorus, zinc, molybdenum and copper. Some AM fungi form a kind of sheath around the root, sometimes giving it a hairy, cottony appearance, providing a protective cover. The AM fungus produces better root systems which combat rooting and soil borne pathogens. The greatest growth response to mycorrhizal fungi is probably in plants highly weathered in tropical acid soils that are low in basic cations (Smith Read, 1997).

Groundnut (Arachis hypogaea L.) widely distributed, originated from Brazil and has spread, to many tropical and subtropical countries of the world (Patil et al., 2009), it belongs to the leguminaceae family, as annual herb. Its importance lies in the fact that it forms a major raw material for many agro industries. The seeds contain large amount of fats (up to 60%) and proteins (up to 45%). the nuts are eaten raw, boiled or roasted. a favorable dish is prepared from groundnut and both the leaves and nuts are used in soap preparation. groundnut cake containing high protein forms the best feed and an excellent fodder for livestock (Kathirvelan and Kalaiselvan, 2007). The highly economic important groundnut crops the least ten years very low productivity. The main reason such as soil condition, some deficiency of nutrients and imbalanced water irrigation. So the present research works Field response of Groundnut (Arachis hypogaea L.) Inoculated Arbuscular mycorrizhal fungi and Vermicompost.

Materials and methods

Location of experimental site: Field experiments were conducted in Agricultural Land, Vadakumangudi, located within 4 km from the Annamalai University, Tamil Nadu. The studies were conducted during January 2009 to May 2009. The experimental site was situated at 11°24'N latitude and 79°41'E longitude with an altitude of 579 M above Mean Sea Level (MSL).

Seed materials

The seeds of groundnut seeds (Arachis hypogaea (L.) var. VIRGn 7) were obtained from Regional Research Institute, TNAU, Periyar Nagar at Vinudhachalam taluk, Cuddalore district, Tamil Nadu, India. Vermicompost and AM Fungi

Vermicompost were obtained from Tamil Nadu Rice Research Institute, Regional Research Station of Tamil Nadu, Agricultural University, Aduthurai, Thanjavur district, Tamil Nadu. It was ensured that the procured vermicompost was in every way identical to that produced by the farmers in villages. The AM fungi sp. Glomus intraradices cultures were procured from Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. Uniform sized and healthy seeds of groundnut were selected for the field experiments. The seeds were sown in soil mixed with different proportion of vermicompost alone and 500 gram sand mixed with AM fungi application. T1-Control, T2- AMF only, T3- 1 tonne ha⁻¹ vermicompost (VC), T4- 1 tonne ha⁻¹ VC + AMF inoculation T5- 2 tonnes ha⁻¹ VC, T6- 2 tonnes ha⁻¹ VC + AMF inoculation.T7- 3 tonnes ha⁻¹ VC,
T₈ - 3 tonnes ha⁻¹ VC + AMF inoculation, T₉ - 4 tonnes ha⁻¹ VC, T₁₀ - 4 tonnes ha⁻¹ VC + AMF inoculation, T₁₁ - 5 tonnes ha⁻¹ VC, T₁₂ - 5 tonnes ha⁻¹ VC + AMF inoculation. The field was designed as 2.25 × 2.25 m² in split plot design with three replicates. the experimental field was thoroughly ploughed, leveled and then divided into experimental plots as per the lay out. A pre-sowing irrigation was given to ensure sufficient soil moisture.

Morphological Parameters

Five plants were randomly selected for recording the root length and shoot length of crop plants. They were measured by using centimetre scale. The root nodules five plants from each plot with intact roots were removed with the help of digging fork. The root nodules were carefully separated from the soil by gently pinching and washing the soil. And the following characters were recorded. The total leaf area was calculated by using the Kemp’s constant (Kalra and Dhiman, 1977) Total leaf area = L × B × K where, L - length, B - breadth and K - Kemp’s constant (for dicot - 0.66). The fresh weight was taken by using an electrical single pan balance. The photosynthetic pigments such as chlorophyll a, b, (Arnon,1949), total chlorophyll and carotenoid (Kirk and Allen, 1965) were analysis. The fresh plant materials were kept in a hot air oven at 80°C for 24 hr and then their dry weight were also determined.

Fig. 1. Effects of vermicompost and AM fungi on root length (cm plant⁻¹) of groundnut (Arachis hypogaea L.)

Results

Root length

The data representing the effect of vermicompost and AMF inoculation on the root length of groundnut Arachis hypogaea L. are shown in Fig.1. The figure exhibits that the root length was significantly increased (14.8, 26.4, 28.4 and 30.4 cm plant⁻¹) in 5 tonnes ha⁻¹ Vermicompost (VC) + AMF inoculation at all sampling days. The lower root length (7.8, 13.6, 16.8 and 20.4 cm plant⁻¹) was recorded in control plants. In general the plant root length increased due to the application of vermicompost + AM fungi.

Fig. 2. Effects of vermicompost and AM fungi on shoot length (cm plant⁻¹) of groundnut (Arachis hypogaeaL.)

Shoot length

The highest shoot length (27.6, 33.6, 38.4 and 45.8 cm plant⁻¹) was recorded in 5 tonnes ha⁻¹ vermicompost VC + AMF inoculation at 30, 60, 90 and 120 DAS. Afterwards there was a decrease in the shoot length (16.4, 21.3, 28.4 and 34.6 cm plant⁻¹) was recorded in the control plant at all sampling days (Fig. 2).

Number of leaves

The maximum number of leaves (100.4, 135.6, 158.2 and 171.3) was recorded in 5 tonnes ha⁻¹ VC + AMF application at 30, 60, 90 and 120 DAS. The minimum number of leaves (54.2, 74.6, 98.6 and 115.4) was recorded in control in all sampling days (Fig. 3).
**Total leaf area**

The higher number of total leaf area (13.6, 20.8, 23.4 and 24.8 cm² plant⁻¹) was recorded in 5 tonnes ha⁻¹ VC + AMF application at 30, 60, 90 and 120 DAS. The lower total leaf area (8.5, 11.6, 13.8 and 15.8 cm² plant⁻¹) was recorded in control at all sampling days (30, 60, 90 and 120 DAS) Fig. 4.

**Root nodules**

The figures revealed that the root nodules were significantly influenced by different doses of VC with AMF inoculation on groundnut plants. The higher root nodules (265.8, 318.4, 368.0 and 404.6 nodules plant⁻¹) were recorded in 5 tonnes ha⁻¹ VC + AMF application at 30, 60, 90 and 120 DAS. The lower root nodules (48.5, 91.5, 122.4 and 138.1 nodules plant⁻¹) were recorded in control at all sampling days (Fig. 5).

**Fig. 3.** Effects of vermicompost and AM fungi on number of leaves of groundnut (*Arachis hypogaea* L.)

**Fig. 4.** Effects of vermicompost and AM fungi on total leaf area (cm² plant⁻¹) of groundnut (*Arachis hypogaea* L.)

**Fresh weight**

The higher fresh weight (46.850, 52.115, 85.630 and 117.868 g plant⁻¹) was recorded in 5 tonnes ha⁻¹ VC + AMF application at 30, 60, 90 and 120 DAS. The lower fresh weight (33.765, 41.366, 68.153 and 99.308 g plant⁻¹) was recorded at 30, 60, 90 and 120 DAS. The higher dry weight (25.860, 32.350, 43.450 and 48.630 g plant⁻¹) of groundnut was recorded in 5 tonnes ha⁻¹ VC + AMF application at 30, 60, 90 and 120 DAS. The lower dry weight (13.685, 20.350, 29.633 and 30.285 g plant⁻¹) was recorded in control at all sampling days (Fig. 6).

**Fig. 5.** Effects of vermicompost and AM fungi on root nodules (nodules plant⁻¹) of groundnut (*Arachis hypogaea* L.)

**Fig. 6.** Effects of vermicompost and AM fungi on fresh weight (g plant⁻¹) of groundnut (*Arachis hypogaea* L.)

**Chlorophyll ‘a’ and ‘b’**

The figures exhibit that the chlorophyll content of groundnut plants varied significantly. The higher chlorophyll ‘a’ (0.865, 2.150, 2.850 and 1.750 mg g⁻¹ fr.
wt.) content of groundnut was recorded in 5 tonnes ha\(^{-1}\) VC + AMF application at 30, 60, 90 and 120 DAS. The lower chlorophyll ‘a’ (0.316, 0.748, 0.986 and 0.518 mg g\(^{-1}\) fr. wt.) was recorded in control at all sampling days. The higher chlorophyll ‘b’ (0.513, 1.433, 2.550 and 0.985 mg g\(^{-1}\) fr. wt.) was recorded in 5 tonnes ha\(^{-1}\) VC + AMF application at 30, 60, 90 and 120 DAS. The lower chlorophyll ‘b’ (0.180, 0.315, 0.548 and 0.413 mg g\(^{-1}\) fr. wt.) content was recorded in control at 30, 60, 90 and 120 DAS (Figs. 7 and 8).

**Fig. 7.** Effects of vermicompost and AM fungi on dry weight (g plant\(^{-1}\)) of groundnut (*Arachis hypogaea* L.)

**Fig. 8.** Effects of vermicompost and AM fungi on chlorophyll ‘a’ (mg g\(^{-1}\) fr. wt.) content of groundnut (*Arachis hypogaea* L.)

**Total chlorophyll**

Fig. 9 represented the effects of VC + AMF inoculation on the total chlorophyll content of groundnut. The higher total chlorophyll (1.378, 3.583, 5.400 and 2.735 mg g\(^{-1}\) fr. wt.) was recorded in 5 tonnes ha\(^{-1}\) VC + AMF application at 30, 60, 90 and 120 DAS. The lower total chlorophyll (0.496, 1.063, 1.534 and 0.931 mg g\(^{-1}\) fr. wt.) was recorded in control at all sampling days.

**Carotenoid**

The higher carotenoid content (0.964, 1.663, 2.785 and 1.963 mg g\(^{-1}\) fr. wt.) was recorded in 5 tonnes ha\(^{-1}\) VC + AMF application at 30, 60, 90 and 120 DAS. The lower carotenoid content (0.218, 0.563, 0.718 and 0.615 mg g\(^{-1}\) fr. wt.) was recorded in control at 30, 60, 90 and 120 DAS (Fig. 10).

**Fig. 9.** Effects of vermicompost and AM fungi on chlorophyll ‘b’ (mg g\(^{-1}\) fr. wt.) content of groundnut (*Arachis hypogaea* L.)

**Fig. 10.** Effects of vermicompost and AM fungi on total chlorophyll content (mg g\(^{-1}\) fr. wt.) of groundnut (*Arachis hypogaea* L.)

**Discussion**

In the field experiments, the highest shoot length and root length of groundnut were observed in the vermicompost + AM fungi application when compared with control. Among the treatments the highest plant growth was recorded at the 5 tonnes ha\(^{-1}\) vermicompost + AM fungi...
application. The vermicompost is applied in the ratio of 1 tonne ha\(^{-1}\) VC, 2 tonnes ha\(^{-1}\) VC, 3 tonnes ha\(^{-1}\) VC, 4 tonnes ha\(^{-1}\) VC and 5 tonnes ha\(^{-1}\) VC alone and combination with AM fungi. The sampling days increased, the root length and shoot length also increased. Highest plant growth was recorded at 120 DAS. The similar results were recorded earlier in various fertilizers and various crops such as chickpea (Singh, 2003), Barley (Waller et al., 2005; Erashin et al., 2009), potato (Alam et al., 2007), Arachis hypogaea L. (Azouni et al., 2008), rice (Prajapati et al., 2008), Allium sativum (Suthar, 2009) and sorghum (Ahmed et al., 2010). Enhancement of growth might be attributed to the role of vermicompost in greater the nutrient availability, and increase in beneficial enzymatic activities, increased population of beneficial microorganisms or the presence of biologically active plant growth influencing substances such as plant growth regulators or plant hormones in the vermicompost and humic acids (Arancon et al., 2006a).

**Fig. 11.** Effects of vermicompost and AM fungi on carotenoid content (mg g\(^{-1}\) fr.wt.) of groundnut (*Arachis hypogaea* L.)

When the compost was added to the soil in adequate quantity there was increase in the nutrient status, which resulted in better growth of crops and culminated in higher yields (Hameeda et al., 2007; Sahni et al., 2008; Padnavathamma et al., 2008; Uma and Malathi, 2009; Indira et al., 2010). Phosphorus and Nitrogen are the two major plant growth nutrients among the nutrients to enhance synthesis and accumulation of protein, amino acid and enzymes, which are responsible for cell division, cell elongation of plant growth (Dudi et al., 2003). The plant growth hormones can become absorbed to the complex structure of humic acid that are produced very rapidly in vermicompost (Canellas et al., 2000) and may act in conjunction with them to influence plant growth. Since humates (humic acids) have also been shown to increase plant growth (Arancon et al., 2008) important symbiotic microorganisms play a remarkable role in nutrients such as nitrogen, phosphorus, potassium and microelements of plants (Rabie, 2005).

The results indicate that the inoculation of AM fungi increase the shoot length, root length, when compared to uninoculated plants. The increase in plant growth may be attributed to increase the uptake of phosphorus by AM fungi (Linderman and Davis, 2004). The high rate of substitutions of vermicompost was a response to higher concentrations of plant growth hormones such as auxins and humic acids produced by microorganisms in vermicompost (Arancon et al., 2006b). When auxins are applied at high concentrations they reduce the rates of growth and development of plants as well as increasing growth at lower concentration of auxins (Hopkins and Huner, 2004). Reduced growth with high doses of vermicompost has also been reported elsewhere, (Roberts et al., 2007) and it has been attributed to the establishment of adverse physical and/or chemical conditions in the media due to vermicompost addition.

**Total leaf area**

Leaf area is a major factor which determines the amount of light interception by crop (Mandal and Sinha, 2004), more leaf area of crop can intercept more solar radiation and thus help in the production of more dry matter crops having higher yield. Wright et al. (1998) also showed that mycorrhiza exhibited a higher specific leaf area of the plants and increased rate of photosynthesis compared with non-inoculated plants. The data regarding leaf area show that the significant difference between the AMF inoculated and AMF uninoculated groundnut plants. The highest total leaf area was recorded in 5 tonnes ha\(^{-1}\) vermicompost + AMF application of groundnut plants. The lowest total leaf area was recorded in control plants. Similar results were recorded in various crops due to the different compost and
different soil microorganisms such as groundnut (Ravindran et al., 2007) tomato, marigold, pepper and cornflower (Bachman and Metzger, 2008), tomato (Zaller, 2007), pepper (Malgorzata and Georgios, 2008), strawberry (Singh et al., 2008) and amaranthus (Uma and Malathi, 2009).

The earlier reports in various crops and different biofertilizers such as sorghum (Vikram Reddy and Ohkura, 2004; Amujoyegbe et al., 2007; Ahmed et al., 2010), wheat (Abo-Ghalia and Khalafallah, 2008), kalmegh (Arpana and Bagyaraj, 2007), soybean (Maheshbabu et al., 2008), \textit{Allium sativum} (Borde et al., 2010) and Pakchoi (Pant et al., 2009). Allen et al. (1980) and Dixon (1990) observed an increase in leaf area of AM associated plants. It is probable that an increase in leaf area may result from a higher nutrient availability or combined effect of both nutrients and hormone increase due to the AMF association. The increase in leaf area can elevate photosynthetic rates in AM treated plants. It may be due to higher nutrients provided by the application of vermicompost that increased the number of leaves and the AM fungi properly colonized root increased mineral and water uptake from the soil and biological nitrogen fixation. As demonstrated scientifically the microbes like fungi, bacteria, yeasts, actinomycetes, algae are capable of producing auxins, gibberlins in appreciable quantity during the application of vermicompost (Arancon et al., 2004; Singh, 2008). The favourable effect of macro and micronutrients in promoting length of the leaf might be due to the fact that nitrogen application increased more metabolism and transport for growth and enhanced the cell division, cell elongation and concomitant increase in metabolic activity (Tomati et al., 1988; Kalyanasundaram et al., 2008).

**Root nodules**

Root nodules are granular structures, which contain leghaemoglobin and fix the atmospheric nitrogen in soil with the help of symbiotic organisms. In the experiment a higher number root nodules were recorded at treatment 5 tonnes ha$^{-1}$ VC + AMF than in other treatments and control. The nodule growth and number also increases with the increase in age of the plants. A similar work in various organic manure and crops plants peanut (Radwon and Awad, 2002; Ravindran et al., 2007) and chickpea (Saini et al., 2004; Akhtar and Siddiqui, 2010). They are known to enhance nodulation and the nitrogen fixing ability of symbiotic nitrogen fixers of legumes (Patreze and Cordeiro, 2004; Kuster et al., 2007). Increased P nutrition in AMF associated legumes (Carling et al., 1978) is one of the reasons for increased nodulation in such plants. AMF increases the amount of N availability of legumes by stimulating nodule development (Harris et al., 1985). The mycorrhiza formation is known to enhance nodulation and \(\text{N}_2\) fixation by legumes. The positive fungal effect on plant ‘P’ uptake is beneficial for the functioning of nitrogenase enzyme of the rhizobial symbiont leading to a higher \(\text{N}_2\) fixation and consequently to a better root nodules growth and mycorrhizal development. IAA plays an important role in nodulation and may induce a localized re-orientation of plant cell wall synthesis, to give infection threads for initiation of new nodules, which in turn might have helped in more growth of plants (Johansson et al., 2004). Further, vermicompost is a carrier of beneficial soil microorganisms particularly Rhizobium which is a nodule forming bacteria in legumes (Bono et al., 1987).

**Fresh weight and dry weight**

The fresh weight and dry weight are mainly based on their growth performance of a particular crop. In the present study the vermicompost (5 tonnes ha$^{-1}$ VC) and AM fungi application increased the fresh and dry weight of the groundnut plant when compared to control. The highest fresh and dry weights were recorded in 120 days old plants. Similar reports were documented in different organic amendments and various crop plants, \textit{Gymnema sylvestre} (Padmapriya et al., 2010); sweet marjoram (Gharib et al., 2008); wheat (Abo-Ghalia and Khalatallah, 2008); chickpea (Akhtar and Siddiqui, 2010); This may be due to better synchrony of nutrient release and uptake as evidenced by the significant positive correlation between the biomass accumulation and N-mineralization pattern and negative correlation with available mineral N in the soil in most of the cases (Roy et al., 2010). The increase in activity of plant growth substances like Gibberellic acid and IAA in vermicompost inoculated plants might have been responsible for the increased vegetative growth as well as dry weight (Kalyanasundaram et al., 2008; Erashin...
The earthworm casts and vermicompost influenced the development of the plants and promoted stem elongation, root initiation and root biomass which suggest the linkage between biological metabolites that influence the plant growth and development (Tomati et al., 1983; Atiyeh et al., 2002; Saniz et al., 2004; Vikram Reddy and Ohkura, 2004; Kalantari et al., 2010). The unexpected low biomass of plants grown in the organic manure could also to attributed to the disappearance of indigenous microbes. It may be essential to increase nutrient bioavailability and uptake in the rhizospheric soil (Wu et al., 2005).

**Pigment content**

Chlorophyll is one of the important pigment content which is used as an index of plant production capacity. The pigment content is an indication of photosynthetic and metabolic activity. The chlorophyll is an integral component of plant pigments and play important role in the process of photosynthesis. The highest chlorophyll content was recorded in the vermicompost at 5 tonnes ha$^{-1}$ and AM fungi applied plants when compared to control and other treatments. The increasing chlorophyll content was due to the presence of microorganisms in the organic manure that colonize in the rhizosphere and stimulate the plant growth and biochemical contents (Varma and Schuepp, 1995). Santos (2004) stated that the higher chlorophyll in AMF inoculated plants due to increase in nitrogen and magnesium contents (major components of chlorophyll molecules in mycorrhalzal plants) and the depletion of chlorophyll content in leaves may be due to a decrease in chlorophyll synthesis or to an increase in chlorophyll degradation. Carotenoid is an accessory pigment in photosynthetic assimilation of plants. A high value of carotenoid content is registered in vermicompost (5 tonnes ha$^{-1}$) and AM fungi application. The lowest content was recorded in control plants. A possible mechanism is well known that carotenoids are involved in the protection of the photosynthetic apparatus against photoinhibiting damage by single oxygen (O$_2$). So, carotenoid can directly deactivate (O$_2$) and can also quench the excited triple state chlorophyll (Foyer and Harbinson, 1994). It conclusion the VC and AM fungi application have positive effects on plant growth. The morphological parameters such as root length and shoot length, fresh weight, dry weight, total number of leaves, total leaf area, and number of root nodules. The pigment content such as chlorophyll ‘a’, ‘b’ and total chlorophyll was increased in 5 tonnes VC + AMF inoculated plots. The vermicompost could promote the production of the phytohormones, auxins, IAA and cytokinins. The AM fungi uptake of phosphorus and other nutrients were absorbed in the substrate very dramatically. These plant hormones and nutrients are play a fundamental role in plant metabolisms, and improved the soil fertility.

**References**


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