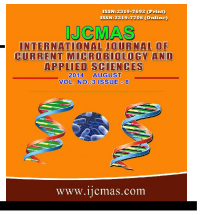
International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 3 Number 8 (2014) pp. 859-879**
http://www.ijcmas.com



Original Research Article

Growth, Yield and Nutrient Uptakes of Sesame (*Sesamum indicum* linn.) as Influenced by Biofertilizer Inoculants

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A B S T R A C T

Two (2) soil treatments (sterile and non-sterile) and six (6) fertilizer inoculations / application (i.e. inoculations with *Mycorrhiza spp., Rhizobuim spp., Azospirillum spp., Azotobacter spp.* and application of urea, and the control), were assayed under green house conditions at two experimental locations (of the derived and southern guinea savanna eco-regions), in the year 2011, to evaluate the potentials of the micro-symbiont inocula as bio-fertilizers as comparable to the chemical fertilizer (urea), for improved sesame production. The trial was arranged in completely randomized design (CRD), replicated three times. Data were collected on growth and yield parameters, and subjected to analysis of variance (ANOVA). Significant means were separated using Duncan multiple range test (DMRT). Soil inoculation with the micro-symbiont inocula significantly ($p < 0.05$) enhanced nutrient uptakes as well as the growth and yield parameters of sesame, irrespective of soil conditions (i.e. either sterile or non-sterile), compared to the control. Sesame responded best to Azospirillum inoculation under sterile and non-sterile soil conditions amongst other microbial inoculants tested. Azospirillum inoculation significantly ($p < 0.05$) increased sesame growth by 160.6 % and 197.0 % (at Ogbomoso), and by 166.2 % and 185.8 % (at Ibadan), under non-sterile and sterile soil conditions respectively. Azospirillum made sesame growth fairly indeterminate by significantly prolonging leaf production and delaying leaf shedding at both locations, under sterile and non-sterile soil. Mycorrhizal inoculation significantly increased sesame root colonization under both sterile and non-sterile soil conditions compared to the control. Mycorrhizal inoculation significantly improved nutrient uptake of sesame particularly N, P, K, Ca, Mg, Na, Fe, Cu, Mn and Zn under both sterile and non-sterile soil conditions. Azotobacter inoculation had the least values of most of the sesame growth and yield parameters tested but the values were significantly higher than the control. Thus, soil inoculation with micro-symbiont inocula (particularly *Azospirilium spp.*), may be suitable for improving sesame performance in the study areas, where soils are mostly very low in essential nutrients (particularly N).

K e y w o r d s

Biofertilizer inoculants, sesame, growth, yield, nutrient uptake and savanna eco-regions.

Introduction

Origin, botany, propagation and utilization of sesame

Sesame (*Sesamum indicum*) is a flowering annual plant in the genus Sesamum. It belongs to the family Pedaliaceae. It is the only cultivated species in the genus sesamum (Zhang *et al.*, 1998; Indu and

Savithri, 2003). Sesame is one of the oldest cultivated oil-rich plants in the world (Langham and Wiermeers, 2001). It was a highly prized oil crop of Babylon and Assyria at least 4,000 years ago (Anonymous, 2000; Anonymous, 2007; Babajide *et al.,* 2012). Although the precise natural origin of the species is unknown, but numerous wild relatives are occurring mostly in Africa and a smaller number found in India (Ashri, 1998).

It is believed to have originated from the tropical Africa where the greatest genetic diversity exists but was believed to have been introduced to India at a very early date, where a secondary center of diversity is well developed (Alegbejo *et al.,* 2003; Anonymous, 2007). Sesame is usually propagated by seeds and matures 70-150 days after sowing (Babajide *et al.,* 2012). It is an erect, flowering self-pollinating annual plant with pubescent branching stem which grows 50 to 250 cm tall. Its growth and development depends on the varieties and soil nutrition / environmental conditions (Sharma, 2005; Leye, 2006).

Flowering starts 38-45 days after sowing and stops at 70-120 days after sowing (Anonymous, 2007). Sesame is well known for its small edible seeds, which are relatively rich in protein (25 %) and 50 % oil (Abdullahi *et al.,* 2013). Another desirable attribute of sesame is that, it is drought-tolerant, although it cannot thrive successfully (and may even die), under prolonged water logging (Ray *et al.,* 2004). It is widely cultivated in the derived, northern and southern guinea, Sudan and Sahel savannas of Nigeria (Alegbejo *et al.,* 2003; Babajide *et al.,* 2012). Utilization includes human consumption, health treatments, beautification, livestock feeding and industrial uses (Jefferson, 2003; El-Habbasa *et al.,* 2007).

Biofertilizer; types and beneficial effects

Microbial inoculants are the micro-symbionts, which are often referred to as biofertilizers. The term 'Biofertilizer' itself denotes that, such fertilizer material is apparently a 'Live Fertilizer' or a fertilizer containing living organisms. Biofertilizers could therefore be regarded as microbial inoculants which contain actively living cells of soil microbes, which are capable of inducing considerable water and nutrient uptakes when inoculated to seeds, seedlings or soils, and thereby enriching the soil with organic nutrients and adequate soil moisture for improved crop performance (Fagbola *et al.,* 2001; Bhaskara *et al.,* 2005; Ananthanaik *et al.,* 2007; Abd El-Gawad, 2008). The main sources of biofertilizers are bacteria, fungi, and cynobacteria particularly the blue-green algae, which had been reported to deliver a number of additional benefits (apart from improved plant nutrition), such as disease resistance and tolerance to adverse soil and climatic conditions (Fagbola *et al.,* 2001; Ananthanaik *et al.,* 2007; Boureima *et al.,* 2007). *Mycorrhiza spp., Azospirillum spp., Azotobacter spp. and Rhizobium spp.* are good examples of beneficial microsymbionts or biofertilizers, which had been reported to improve water and nutrients uptake in many crops found in both tropical and temperate regions of the world (Fagbola *et al.,* 1998; Ghosh and Mohiuddin, 2000; Vessey, 2004; Ananthanaik *et al.,* 2007; Neveen and Amany, 2008).

The significant contributions of mycorrhizae to the nutrition and growth of plants are well established (Smith and Read, 1997; Diallo, 1998; Fagbola *et al.,* 2001; Leye, 2006). The uptake of highly mobile nutrients such as NO_3- can also be enhanced by mycorrhizal association even under drought conditions (Osonubi *et al.,* 1991; Azcon *et al.,* 1996;

Subramanian and Charest, 1999). Several studies have demonstrated the transport of inorganic N by arbuscular mycorrhizal fungi (Johansen *et al.*, 1992; Tobar *et al.*, 1994; Hawkins *et al.*, 2000). Also, the uptake of other macro and micronutrients like K, P, Ca, Mg, S, Cu, Fe, Zn, and B had been reported to be enhanced by mycorhizal inoculation (Clark and Zeto, 2000; Allen *et al.*, 2003; Hodge, 2003).

The beneficial effect of inoculating legumes with rhizobia and bradyrhizobia is well known (Nwoko and Sanginga, 1999; Neveen and Amany, 2008). However, many studies indicated that these nitrogen-fixing bacteria have the potential to be used as plant growth promoting rhizobacteria (PGPR) with the non-leguminous plants (El-Habbasha *et al.*, 2007). Rhizobia can successfully attach themselves to the surface of monocotyledonous plants belonging to different families and species (Wani, 1990; Rademacher, 1994; Bhaskara *et al.*, 2005). Rhizobia grew readily in the presence of germinating seeds and developing root systems in the same manner with both the legumes and non-legumes (Youssef *et al.*, 1997; Fagbola *et al.*, 2001; Bhaskara *et al.*, 2005; Babajide *et al.*, 2008).

Azospirillum lipoferum is a very useful soil and root bacterium. It is found in the soil around plant roots and root surfaces (Indu and Savithri, 2003). When *Azospirillum lipoferum* is added to the soil, it multiplies in millions and can supply up to 20-40 kg of nitrogen per hectare per season. It also produces growth-promoting substances like Indole acetic acid (IAA), gibberellins, and promotes root proliferation (Bhaskara *et al.*, 2005; Ananthanaik, 2006). It increases the rootlet density and root branching resulting in the increased uptake of mineral and water. Plant growth promoting substance like pantothenic acid, thiamine and niacin are produced by *Azospirillum lipoferum* in large quantities. These substances improve the plant growth and yield (Ananthanaik, 2006; Ananthanaik *et al.*, 2007).

Significance of nitrogen to crop performance

Amongst all the inputs required to be applied in order to enhance soil productivity, application of nitrogenous fertilizer materials is ranked first (Kathiresan and Dharmalingam, 1999; Loiseau *et al.*, 2001; Akanbi *et al.*, 2005). Nitrogen is indispensable because the base element of all the biological cells starts with nitrogen and its role can't be substituted (Subramanian and Kulandaiveiv, 1997). Nitrogen contributes up to 50 % of all the nutrients inputs. This makes nitrogen a great determinant of farmers' crop yield (Hansen *et al.*, 2000; Akanbi, 2002). Growth ceases and new cells fail to form, in the absence of nitrogen (Enwezor, *et al.*, 1989; Stout *et al.*, 2000). However, nitrogen is one of the most critical elements needed to be carefully managed under modern and sustainable crop production. This is very necessary because of its significant roles in crop production as well as the high level volatilization and leaching losses from farmlands, particularly in the tropics where rainfall is torrential and solar radiation is very high. Nitrogen is the most dynamic nutrient element and becomes the first limiting nutrient as land use intensifies (Tiessen *et al.*, 2003; Lafond *et al.*, 2003; Akanbi *et al.*, 2005). It is taken up in the highest amount by crops and its role in plants cannot be easily substituted (Olaniyi and Akanbi, 2008). Its supply in the soil is the most important factor limiting growth and yield (Akanbi, 2002). Increases in N supply within limits are associated with increase in leaf area and weight, carboxylases and chlorophyll content, all of which determine the photosynthetic

activities of leaf and ultimately dry matter production and allocation to the various organs of a plant (Akanbi, 2002). Photosynthetic rate and leaf surface area increase with increase in nitrogen levels (Tiessen *et al.,* 2003; Akanbi *et al.,* 2005).

Justification of the research

Under a system of intensive cropping, the use of chemical fertilizers for crop production had been reported to be undesirably doubled (Gunarto *et al.,* 1999; Allen and Gretchen, 2002; Bhaskara *et al.,* 2005). However, productivity can only be maintained through the use of chemical fertilizer or organic manure such as compost. While the use of organic manure is limited by the huge quantities needed to meet crop nutritional needs in view of its low nutrient content, the use of chemical fertilizers is limited by residual effects, cost and scarcity. Thus, supplementary application of organic manures and biofertilizers is frequently recommended for improving soil productivity, biological, physical and chemical properties of soil and to get agricultural products with good quality which are free of pollutants (Indu and Savithri, 2003). Although organic compounds are excreted by the growing roots to sustain the community, competition in this environment must be intense in view of size, diversity and biochemical activity of the community.

More so, effective biofertilizer potentials of some soil-borne symbionts had been reported, but concurrent comparative studies of the effects of several symbiotic microbial inoculants on versatile and highly adaptive crops such as sesame, had not been adequately investigated and reported (particularly under low fertile tropical soil conditions).

Materials and Methods

Locations, sites history and land clearing / preparation

The experiments were carried out at two distinctive locations: Ladoke Akintola University of Technology (LAUTECH), Ogbomoso (latitude 8° 10' N and longitude 4° 10' E) which falls under southern guinea savanna vegetation zone of Nigeria, and the Institute of Agricultural Research and Training (I.A.R&T), Ibadan (latitude 7^{0} 30' N and longitude 3^{0} 45' E) which falls under derived guinea savanna vegetation zone of Nigeria. These two vegetation zones are located in the south-western part of Nigeria. They are similarly characterized by bimodal rainfall distribution (whereby the early rainy season starts in late March and ends in late July/early August, followed by a short dry spell in August and finally the late rainy season from August to November). The annual mean rainfall is usually ranging between 1150 mm and 1250 mm**.** The soil samples used at Ibadan and Ogbomoso were Alfisols belonging to Egbeda and Olorunda soil series respectively (Smyth and Montgomery, 1962).

The experimental sites had been under cultivation of arable crops for several years, before the experiments were set up. At Ogbomoso (LAUTECH), the site was under regular mixed-cropping of okra and maize. At the I.A.R &T, Ibadan, cassava and maize were previously inter-planted and harvested before the research. The amount and distribution of rainfall during the period of study at the locations were presented in Table 2. Land clearing and preparation were carried out manually, following farmers' conventional practice, using hoe, cutlass, mattock, rake, e.t.c.

Source of mineral fertilizer materials used

Urea fertilizer (46% N), was used as the only inorganic nitrogen (N) fertilizer material used. It was obtained from the Oyo State Agricultural Development Programme (OYSADEP), Ogbomoso. Split application of the fertilizer was done at four weeks after sowing (4 WAS) and seven weeks after sowing (7 WAS).

Source of propagating materials used

Sesame seeds of variety E8 (early maturing type), were obtained from the National Cereal Research Institute (NCRI) at Badeggi in Niger State, Nigeria.

Soil sampling and analyses

During land preparation at each site, pre-planting collection of soil samples was carried out using soil auger at a depth of 0-15 cm, for laboratory analyses of the soil physical and chemical properties. Samples were bulked into a composite sample. The sample was then air-dried, crushed and sieved through 2mm and 0.5mm meshes for the determination of particle size, pH (H_2O), total nitrogen (N), organic carbon, available phosphorus (P), iron (Fe), copper (Cu), zinc (Zn), the exchangeable cations (Ca, Na, Mg, and K) and exchangeable acidity. The particle size analysis was carried out according to the Bouyoucos (1951) hydrometer method using sodium hexamataphosphate as the dispersant. Soil pH was determined in a 1:1 soil: water ratio and 2:1 soil: KCl ratio (IITA, 1982). Total N was determined by the macro-Kjedahl method (Bremmer, 1965) and colorimetric determination by Technicon Autoanalyser. Phosphorus and exchangeable cations were determined by Mehlich 3 extraction (Mehlich, 1984). Phosphorus was determined colorimetrically using the Technicon AAII Auto-analyser, while the cations were determined using Atomic Absorption Spectrophotometer (Model Buck 200A). Olsen P was determined by extraction with sodium bicarbonate (Olsen *et al.,* 1954). Organic carbon was determined by chromic acid digestion (Heanes, 1984).

Filling of pots with soil

Each pot was filled with 10 kg soil. About 5cm to the brim of each pot was left unfilled, to prevent undesirable washing away of the soil particles and fertilizer materials which may occur during watering. Also, four perforations were carefully made at the bottom of each pot, using hot-red 4 inches nail, prior to pot filling. The perforations made were plugged with cotton wool to regulate drainage and encourage proper aeration.

Soil sterilization and inoculation with microsymbionts

Soil was sterilized by autoclaving at 120 ^{0}C, for 1 hour for two consecutive days. Chopped root fragments of maize plant containing mycorrhizal propagules of *Glomus clarum* were used as mycorrhizal inocula. Each inoculum of a root-soil-fungal spore mixture weighing 20g obtained from the Microbiological Laboratory of Agronomy Department, University of Ibadan, Nigeria, was placed at about 3cm depth of the soil (Carling *et al.,* 1978). Also, Inocula for the *Rhizobia spp.* (R25B) were obtained from the International Institute of Tropical Agriculture (IITA), Ibadan. One ml each of inoculum containing approximately 10^8 cfu/ ml of R25B rhizobial strain was applied to the soil at one week after sowing, by using a sterile pipette (Babajide, 2002; Indu and Savithri, 2003). Fresh liquid

culture medium containing approximately 10^8 cfu/ ml of pure local strain *Azotobacter chroococcum* isolated from arable crop unit of the Teaching and Research Farms, LAUTECH, Ogbomoso, purified and identified was also used as biofertilizer inoculum applied to the soil at planting (Abd EL-Gawad, 2008). *Azospirillum lipoferum* strain was isolated from the rhizosphere of a millet (*Pennisetum typhoides*) experimental plot located at the Teaching and Research Farms, LAUTECH, Ogbomoso. Pure culture of the strain of *Azospirillum lipoferum* was grown in malate broth (Dobereiner and Day, 1976) supplemented with NH_4Cl (Okon, 1985). The log phase culture was used for inoculation. The cells were harvested by centrifugation at 5,000g at 4^0C for 20 min. The supernatant was discarded and the pellet was washed two times with saline (5g NaCl and 0.12g $MgSO_4.7H_2O$ in distilled water) and re-suspended in saline at a concentration of 10^8 colony forming units (CFU) per ml. Each plant per pot was inoculated with 10ml of the material culture.

Determination of mycorrhizal root colonization

After harvesting, root samples were cut into 1cm length and stored in 50% ethanol. Root samples were then carefully rinsed with slow running tap water (before the commencement of the root staining procedure). Mycorrhizal staining commenced by heating the roots in 10% KOH for 40 minutes at 80^0C (Phillip and Hayman, 1970). Roots were bleached in alkaline H_2O_2 for 10 minutes, after which they were rinsed in water and soaked in 1% HCl for 10 minutes. The staining solution chlorazol black E (Brundrett, *et al.,* 1984) was used on the roots containing 0.03% chlorazol black E, lactic acid (400 ml), and water (200 ml). Stained roots were later destained with 50% glycerol. The degree of mycorrhizal colonization was assessed by spreading the root samples evenly on a grid plate and observing them under the dissecting microscope at low magnification. The total number of roots and the infected roots intersecting the grids were counted using the gridline intersect method (Giovanetti and Mosse, 1980). The percentage mycorrhizal root colonization was calculated by the ratio between the number of intersects with infection and the total number of intersects multiplied by 100 (Fagbola *et al.,* 2001).

Treatments and experimental design

Two (2) soil treatments (sterile and non-sterile) and six (6) fertilizer inoculations / application (i.e. inoculations with *Mycorrhiza spp., Rhizobuim spp., Azospirillum spp., Azotobacter spp.* and application of urea, and the control), were assayed under green house conditions at two experimental locations. The twelve (12) treatment combinations were; S-T0=unsterilized soil without inoculation of any microbe / biofertilizer, S-T1= unsterilized soil with urea application, S-T2= unsterilized soil inoculated with azospirillum, S-T3= unsterilized soil inoculated with rhizobium. S-T4= unsterilized soil inoculated with mycorrhiza, S-T5= unsterilized soil inoculated with azotobacter, S+T0=sterilized soil without inoculation of any microbe/ biofertilizer, S+T1= sterilized soil with urea application, S+T2= sterilized soil inoculated with azospirillum, S+T3= sterilized soil inoculated with rhizobium, S+T4= sterilized soil inoculated with mycorrhiza, S+T5= sterilized soil inoculated with azotobacter. The trial was arranged in completely randomized design (CRD), replicated three (3) times.

Sowing, fertilizer application and maintenance of sesame under green house conditions

Sesame seeds of variety E8 were surface sterilized by using 95% ethanol for 10 seconds and later rinsed six times with sterile water after shaking for three to five minutes in 3% hydrogen peroxide (H_2O_2). Six seeds were sown in each pot. Emerged seedlings were later thinned to one per pot, at one week after sowing (WAS). The sowing dates at Ogbomoso and Ibadan respectively were April 10th and 13th, 2011. Plant residues found on the farm site were applied as basal manure application. Urea fertilizer (46% N), was used as the only inorganic nitrogen (N) source (where applicable, two split applications of urea fertilizer were done at four weeks after sowing (4 WAS) and seven weeks after sowing (7 WAS). Regular watering was maintained when necessary. Pots were manually weeded by careful hand pulling of all the emerging weed seedlings from the pots on weekly basis.

Data collection on sesame under green house conditions

Data were collected on growth and yield parameters. The growth parameters determination commenced at 6 WAS. The growth parameters measured were plant height using measuring tape placed at the base of the main stem of the plant to the tip, stem girth by using calipers, the value obtained was later converted to stem girth using a fomular πD (where $\pi = 3.142$ and D = diameter), number of branches was determined at 10 WAS by direct counting of all developed branches per plant and the number of leaves was also determined by direct counting of all fully opened leaves per plant. Fully ripe capsules were carefully plucked. Number of capsules per plant was then determined by direct counting. Weight of 1000 seeds per treatment was also determined by direct counting and weighing of randomly selected 1000 seeds per treatment, followed by total seed yield converted from the seed yield obtained (from 2.5 by 2.0 m^2) at spacing of 50 cm by 25cm (Fathy and Mohammed, 2009). After harvesting, all shoots and roots were oven-dried at a temperature of 80 ^{0}C to a constant weight for five days, for dry weight determination of the total biomass yield and to determine the nutrient concentration (Akanbi *et al.,* 2005).

Harvesting of sesame under green house conditions

Each of the experiments was terminated at 14 weeks after sowing (WAS) i.e. on July 17th and 20th, 2011 at Ogbomoso and Ibadan respectively. Plants were harvested by cutting the stem at the ground level and the roots were carefully uprooted, washed and air-dried. All the shoots and roots were then carefully packed into corresponding envelopes (65 cm by 30 cm) and oven-dried at a temperature of 80^{0}C to a constant weight for five days.

Plant sampling and analyses

After harvesting, all shoots and roots were oven-dried at a temperature of 80 ^{0}C to a constant weight for five days, for determination of dry weight and total biomass production. The plant samples were milled in Wiley mill to pass through 1mm sieve and subjected to Kjeldah digestion at 360^{0}C for 4 hours with concentrated sulphuric acid using selenium and Sodium sulphate as catalyst. Total N was determined from the digest by steam distillation with excess NaOH. Plant contents of P, K, Ca, Mg, Mn, Na, Zn and Cu were determined by ashing plant samples in muffle furnace at

600^0C for 2 hours; the ash was cooled and dissolved in 1N Hydrochloric acid and the solution passed through filter paper into 5ml volumetric flask and made up to the mark with distilled water. From the digest, P concentration was determined by the vanadomolybdate yellow colorimetric method using spectrophotometer (Spectronic 20). The K and Ca were determined by using flame photometer (Cornin Model 400) while Mg, Fe, Zn and Cu were determined with atomic absorption spectrophotometer (AAS) of the Bulk Scientific Model (Akanbi *et al.,* 2005). The nutrients accumulated in plant parts were calculated as; Nutrient uptake = % Nutrient content x sample dry weight according to Ombo (1994) and Gungunla (1999). Random selection of 1000 dried seeds of sesame per treatment was done for determination of oil content using soxhlet apparatus and n-Hexane (60^0C) as an extraction solvent according to A.O.A.C. (1980).

Statistical analysis

All the data collected were subjected to analysis of variance (ANOVA) and the significant means were separated using Duncan Multiple Range Test (DMRT), according to SAS, (2011).

Results and Discussion

Soil characteristics

The followings results were obtained from the pre-cropping chemical and physical analyses of the soil samples used at both experimental sites: The soils were both slightly acidic (Table 1) with pH (H_20) values of 6.10 (at Ibadan) and 6.30 (Ogbomoso). The soils were texturally sandy-loam, with sand (80.71% and 79.12%), silt (10.92% and 11.16%) and clay (8.37% and 9.72%) at Ibadan and Ogbomoso respectively (Table1). Also, they were grossly low in concentrations of essential nutrients e.g. total N (0.14% and 0.08%), extractable P Bray 1 (3.12 $mgkg^{-1}$ and 2.42 $mgkg^{-1}$), Organic carbon (3.72% and 3.83%), while the exchangeable bases (in cmol kg^{-1}) were; K^+ (0.31 and 0.25), Ca^{2+} (9.23 and 8.17), Mg^{2+} (3.47 and 3.12) and Na^+ (0.28 and 0.36) at Ibadan and Ogbomoso respectively (Table 1). Also, the values of micro nutrient levels were: Fe (11.41 and 11.20 mg kg^{-1}), Cu (3.10 and 2.42 mg kg^{-1}) and 2.46 and 2.82 mg kg^{-1} for Zn at Ibadan and Ogbomoso respectively (Table1). All these were in line with the findings of earlier researchers such as Makinde *et al.,* (2007), Babajide *et al.,* (2008) and Babajide *et al.,* (2012), who reported that soils in the study areas were slightly acidic and grossly low in essential nutrient concentrations, and therefore required better nutrient management approaches, for efficient crop production.

Microsymbionts and growth parameters of sesame

Soil inoculation with microbial inoculants significantly ($p < 0.05$) enhanced growth parameters of sesame, irrespective of soil conditions (i.e. either sterile or non-sterile), compared to the control. Sesame responded best to Azospirillum inoculation under sterile and non-sterile soil conditions amongst other microbial inoculants tested. Azospirillum inoculation significantly ($p < 0.05$) increased sesame growth by 160.6 % and 197.0 % (at Ogbomoso), and by 166.2 % and 185.8 % (at Ibadan), under non-sterile and sterile soil conditions respectively (Table 2). Mycorrhizal and rhizobial inoculations resulted in similar plant height of sesame but were ($p < 0.05$) significantly higher than those obtained from Azotobacter inoculum and the control under sterile and non-sterile soil conditions

at the two experimental locations. Azotobacter inoculation had the least values of plant height under sterile and non-sterile soil conditions at both locations but, the values were significantly higher than the control (Table 2).

Improvement of sesame growth by Azospirillum agreed with earlier reports on biofertilizers, particularly Azospirillum which had been reported to be good alternative sources to chemical fertilizers in order to increase soil fertility and crop production in sustainable farming (Gunarto *et al.,* 1999; Itzigsohn *et al.,* 1995; Boureima *et al.,* 2007).

Microbial inoculations significantly ($p < 0.05$) enhanced leaf production of sesame, compared to the control. Azospirillum inoculation significantly ($p < 0.05$) enhanced leaf production and delayed leaf shedding at both locations and soil conditions, compared to other inoculants and the control (Table 3). The reasons for such prolonged leaf production and delay leaf shedding in Azospirillum inoculated plants, may be due to production of phytohormones like indole acetic acid, gibberellins and cytokinnins as reported under in vitro conditions by Hartmann *et al* (1994); Rademacher, (1994) and Bhaskara *et al.,* (2005). These hormones were also reported to enhance nitrogen fixing capacity of the diazotrophs (Christiansen Weniger, 1988; Bhaskara *et al.,* 2005).

Also, soil inoculation with Azospirillum significantly ($p < 0.05$) enhanced stem circumference of sesame by 812.5 % and 952.8 % at Ogbomoso under non-sterile and sterile soil conditions (Table 4). At Ibadan, there were 288.9 % and 337.5 % increment in stem circumference when plants were inoculated with Azospirillum, under non-sterile and sterile soils respectively (Table 4). Mycorrhizal inoculation significantly ($p < 0.05$) increased sesame stem circumference compared to the control, under sterile and non-sterile soil conditions (Table 4). The values obtained from mycorrhizal plants under both soil conditions were significantly ($p < 0.05$) higher than those of Rhizobial and Azotobacter inoculations but lower than those obtained from Azospirillum inoculated plants. The control had the least values at both locations and soil conditions (Table 4). Azospirillum inoculated plants under sterile soil conditions had the significantly ($p < 0.05$) higher number of branches i.e. 9.0 and 9.6 at Ogbomoso and Ibadan respectively (Fig. 1). The values of number of branches obtained from most of the treatments under non-sterile soil conditions were not significantly different from one another but significantly ($p < 0.05$) higher than the control. At Ogbomoso, mycorrhizal inoculation significantly enhanced number of branches of sesame under sterile soil conditions (Fig. 1). The values of number of branches obtained from mycorrhizal inoculated plants were significantly ($p < 0.05$) higher than other treatments (except for Azospirillum inoculated plants).

These results are in line with the findings reported by Gunarto *et al.,* (1999) and Boureima *et al.,* (2007), who reported improved crop performance by Azospirillum. Also, Kothari *et al.* (1990); Tobar *et al.* (1994) and Subramanian *et al.* (1995), who respectively reported enhanced growth and yield of mycorrhizal inoculated corn, lettuce and maize.

Mycorrhizal root colonization

Mycorrhizal inoculation significantly increased sesame root colonization under both sterile and non-sterile soil conditions compared to the control. This may be due to lack of abundant indigenous mycorrhizal

species (or may be available, but not very effective), at the two experimental locations. These reports agree with the research reports of Li and Zhao, (2005); Muthukumar and Udaiyan, (2002) and Singh, (2005), who reported that mycorrhizal root colonization is influenced by climatic and edaphic factors such as temperature, rainfall, light, atmospheric CO_2, soil pH, soil moisture content, fertility level and density of inoculum, which can be positive or negative and vary with plant species. The percentage mycorrhizal root colonization or infection of sesame ranged from 2.9 % to 57.8 % and 2.2 % to 56.0 % at Ogbomoso and Ibadan respectively (Table 5). Inoculation of soil with *Glomus clarum* significantly increased sesame root colonization by 48.6 % and 55.3 % at Ogbomoso and Ibadan respectively (Table 5).

Significantly ($p < 0.05$) higher values of 57.8 % and 56.0 % root colonization obtained from sesame plants grown on sterilized soils at Ogbomoso and Ibadan respectively (Table 5). It was also observed that plants grown under sterile soil conditions at both locations generally had significantly ($p < 0.05$) higher mycorrhizal root colonization than those grown under non-sterile soil conditions irrespective of other microsymbionts involved (Table 5).

These results agreed with the findings of Dare (2008), who reported high mycorrhizal root colonizations of yam cultivars after soil inoculation with mycorrhizal species at different experimental locations, even at Onne where acidity was relatively high. However, the results contradicted Fagbola *et al* (2001) who reported that inoculation of *Glomus clarum* mycorrhizal species did not significantly influence mycorrhizal root colonization of tree species.

Microsymbionts and yield parameters of sesame

At Ibadan, Azospirillum inoculated plants had significantly ($p < 0.05$) higher number of capsules per plant under sterile and non-sterile soil conditions (Table 5), compared to other microsymbionts tested. There were no significant differences in the weight of 1000 seeds under non-sterile soil conditions across the microsymbionts (Table 5). Also, at Ibadan, plants inoculated with mycorrhiza under sterile soil conditions were significantly lower in weight of 1000 seeds than other tested inocula, except for plants inoculated with Azotobacter and the control which were significantly ($p < 0.05$) lower (Table 5). Azospirillum inoculation significantly improved the seed oil content of sesame under both sterile and non-sterile soil conditions. At Ogbomoso, inoculated plants with Azospirillum had significantly higher oil contents of 52.63 % and 52.87 % under sterile and non-sterile soil conditions respectively (Table 5). However, it was observed at Ibadan that Azospirillum inoculated sesame plants produced significantly higher oil content of 54.97 % under non-sterile soil conditions (Table 5).

Azospirillum inoculation significantly improved total seed yield of sesame irrespective of soil conditions (Fig. 2). The highest total seed yield of 1.05 tons ha^{-1} and 0.9 tons ha^{-1} were obtained under sterile and non-sterile conditions respectively at Ogbomoso when the soil was inoculated with Azospirillum. At Ibadan, Azospirillum inoculated plants had significantly ($p < 0.05$) higher total seed yields (1.01 tons ha^{-1} and 1.04 tons ha^{-1}) under sterile and non-sterile soil conditions respectively (Fig. 2). The control had the least values of total seed yield at the two locations.

Table.1 Pre-cropping chemical and physical properties of the soil sample used

PROPERTIES	VALUES OGBOMOSO	IBADAN
pH (H_20)	6.32	6.13
Organic C (%)	3.82	3.72
Total N (%)	0.08	0.14
Extractable P Bray 1(mg kg^{-1})	2.42	3.12
Fe (mg kg^{-1})	11.20	11.41
Cu (mg kg^{-1})	2.42	3.10
Zn (mg kg^{-1})	2.82	2.46
Exchangeable K^+ ($cmolKg^{-1}$)	0.25	0.31
Exchangeable Na^+ ($cmolKg^{-1}$)	0.32	0.28
Exchangeable Ca^{2+} ($cmolkg^{-1}$)	8.17	9.23
Exchangeable Mg^{2+} ($cmolkg^{-1}$)	3.12	3.47
Sand (%)	79.12	80.71
Silt (%)	11.16	10.92
Clay (%)	9.72	8.37
Textural class	Sandy loam	Sandy loam

Table.2 Plant height (cm) of sesame as influenced by biofertilizers under sterile and non-sterile soil conditions at different weeks after sowing (WAS) at Ogbomoso and Ibadan

	Ogbomoso					Ibadan				
Treatment	6	8	10	12	14	6	8	10	12	14
S¯T0	21.2ef	25.2e	33.4d	39.2c	43.4d	23.4f	31.8f	32.9h	36.0e	39.6e
S¯T1	24.6e	56.6bc	64.4bc	80.9b	92.0bc	29.1e	57.3c	68.3cde	75.3bc	83.3bc
S¯T2	39.8ab	62.0ab	82.9a	97.3a	113.1a	37.8c	65.0b	76.0ab	85.0a	105.4a
S¯T3	33.5d	50.7cd	65.0bc	76.2b	90.3bc	32.1de	51.0d	61.8f	71.4cd	86.4b
S¯T4	34.3cd	46.5d	62.6bc	73.8b	82.2c	32.3de	47.8de	67.6def	76.7bc	86.0b
S¯T5	33.9d	45.3d	60.0c	71.8b	81.4c	32.6d	42.7e	55.4g	65.8d	75.5d
S+T0	17.4f	23.2e	27.0d	31.9c	39.9d	20.1g	26.6f	30.2h	34.3e	38.0e
S+T1	38.1bc	62.5ab	69.5b	82.6b	95.8b	35.9c	65.1b	74.0abc	78.3b	85.4b
S+T2	43.3a	68.8a	86.3a	104.1a	118.5a	46.9a	73.7a	79.0a	84.1a	108.6a
S+T3	40.8ab	57.6bc	69.8b	81.8b	89.9bc	42.6b	58.4c	65.4def	73.5bc	87.3b
S+T4	31.6d	49.7cd	62.9bc	75.1b	83.0c	42.5b	50.8d	65.4bcd	76.8bc	88.6b
S+T5	33.5d	51.2cd	62.7bc	73.1b	81.9c	41.5b	52.7cd	62.9ef	72.2bc	77.9cd

Means followed by the same letters within the same column are not significantly different at $p \leq 0.05$, using DMRT. S-T0=unsterilized soil without inoculation of any microbe/ biofertilizer, S-T1= unsterilized soil with urea application, S-T2= unsterilized soil inoculated with azospirillum, S-T3= unsterilized soil inoculated with rhizobium. S-T4= unsterilized soil inoculated with mycorrhiza, S-T5= unsterilized soil inoculated with azotobacter, S+T0=sterilized soil without inoculation of any microbe/ biofertilizer, S+T1= sterilized soil with urea application, S+T2= sterilized soil inoculated with azospirillum, S+T3= sterilized soil inoculated with rhizobium, S+T4= sterilized soil inoculated with mycorrhiza, S+T5= sterilized soil inoculated with azotobacter.

Table.3 Number of leaves of sesame as influenced by biofertilizers under sterile and non-sterile soil conditions at different ages at Ogbomoso and Ibadan

	Ogbomoso					Ibadan				
Treatments	6	8	10	12	14	6	8	10	12	14
S¯T0	12.8g	17.4g	23.6e	20.8d	10.8e	12.1f	16.5h	22.0f	23.4g	17.7f
S¯T1	29.0cdef	35.8def	42.9cd	40.3b	29.8bc	27.9e	34.4ef	41.1e	39.5f	28.8e
S¯T2	31.1bc	43.3b	51.3b	60.6a	49.6a	31.8c	44.3b	58.8b	66.3a	66.5b
S¯T3	27.5def	32.9f	40.7d	39.7b	28.3c	28.2e	32.9f	40.0e	40.9ef	32.4e
S¯T4	30.7bcd	38.4cd	45.8c	43.1b	34.7b	31.4c	40.7c	48.3c	49.3c	42.4d
S¯T5	27.4def	32.9f	40.9d	38.3bc	28.2c	27.8e	36.5de	45.1d	44.9d	37.6d
S+T0	15.4g	19.8g	23.8e	21.0d	10.8e	13.8f	20.5g	24.4f	21.0g	16.1f
S+T1	29.7bcde	35.7def	43.8cd	38.8bc	30.1bc	31.1cd	38.0cd	45.8cd	43.8de	38.4d
S+T2	38.1a	48.9a	60.1a	62.5a	51.4a	40.2a	52.6a	66.0a	68.3a	71.6a
S+T3	26.0f	36.2de	42.1d	40.2b	28.4c	28.5de	38.6cd	45.3d	44.1de	39.2d
S+T4	32.4b	40.6c	49.2b	43.6b	33.2bc	35.3b	39.5c	56.2b	56.1b	49.6c
S+T5	26.4ef	34.1ef	41.6d	32.6c	22.7d	27.7e	34.1ef	44.8d	44.7d	38.9d

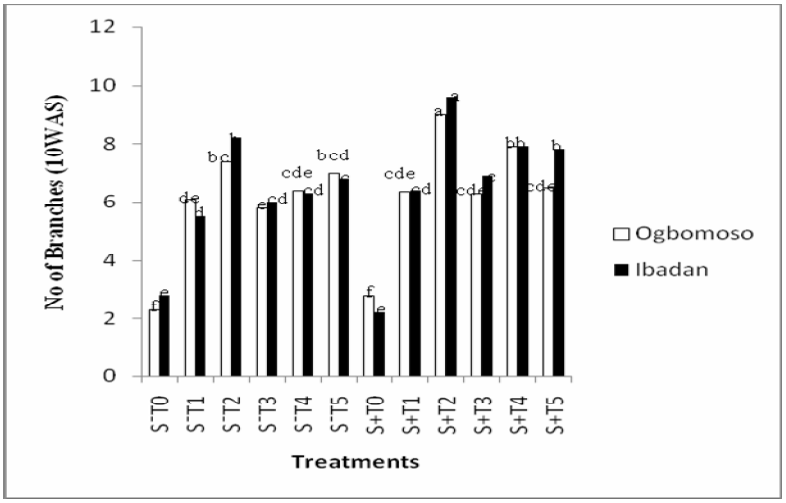
Means followed by the same letters within the same column are not significantly different at $p \leq 0.05$, using DMRT.S-T0=unsterilized soil without inoculation of any microbe/ biofertilizer, S-T1= unsterilized soil with urea application, S-T2= unsterilized soil inoculated with azospirillum, S-T3= unsterilized soil inoculated with rhizobium. S-T4= unsterilized soil inoculated with mycorrhiza, S-T5= unsterilized soil inoculated with azotobacter, S+T0=sterilized soil without inoculation of any microbe/ biofertilizer, S+T1= sterilized soil with urea application, S+T2= sterilized soil inoculated with azospirillum, S+T3= sterilized soil inoculated with rhizobium, S+T4= sterilized soil inoculated with mycorrhiza, S+T5= sterilized soil inoculated with azotobacter.

Table.4 Stem circumference (cm) of sesame as influenced by microbial inocula under sterile and non-sterile soil conditions at different WAS at Ogbomoso and Ibadan

	Ogbomoso					Ibadan				
Treatments	6	8	10	12	14	6	8	10	12	14
S¯T0	0.30e	0.29e	0.26e	1.36f	0.40e	0.26f	0.29g	0.4f	0.9d	1.8e
S¯T1	0.40bc	0.86bc	0.40bc	5.62b	3.26bcd	0.39cde	0.43f	3.3cde	6.5a	6.4b
S¯T2	0.42b	1.08a	0.42b	5.81ab	3.65ab	0.48a	1.14b	3.7ab	6.0a	7.0a
S¯T3	0.41b	0.78d	0.41b	4.26de	3.00d	0.41bcde	0.81e	3.0de	4.3c	4.9d
S¯T4	0.42b	0.86bc	0.42b	4.69c	3.26bcd	0.42bc	0.90d	3.4bc	4.7bc	5.8c
S¯T5	0.38cd	0.79cd	0.38cd	4.02de	3.07cd	0.38e	0.81e	3.0e	4.0c	4.8d
S+T0	0.22f	0.26e	0.22f	0.96g	0.36e	0.21g	0.24g	0.4f	0.8d	1.6e
S+T1	0.40bcd	0.93b	0.40bcd	5.98a	3.58ab	0.40bcde	0.98c	3.7ab	5.5ab	6.5b
S+T2	0.48a	1.06a	0.48a	6.13a	3.79a	0.48a	1.21a	3.9a	6.0a	7.0a
S+T3	0.43b	0.82cd	0.43b	4.33d	3.02d	0.43b	0.86de	3.3cd	4.4bc	5.0d
S+T4	0.37d	0.83cd	0.37d	4.79c	3.42abc	0.39de	0.97c	3.5bc	4.8bc	5.9c
S+T5	0.41b	0.83d	0.41b	3.94e	2.97d	0.42bcd	0.88d	3.0e	4.0c	4.9d

Means followed by the same letters within the same column are not significantly different at $p \leq 0.05$, using DMRT.S-T0=unsterilized soil without inoculation of any microbe/ biofertilizer, S-T1= unsterilized soil with urea application, S-T2= unsterilized soil inoculated with azospirillum, S-T3= unsterilized soil inoculated with rhizobium. S-T4= unsterilized soil inoculated with mycorrhiza, S-T5= unsterilized soil inoculated with azotobacter, S+T0=sterilized soil without inoculation of any microbe/ biofertilizer, S+T1= sterilized soil with urea application, S+T2= sterilized soil inoculated with azospirillum, S+T3= sterilized soil inoculated with rhizobium, S+T4= sterilized soil inoculated with mycorrhiza, S+T5= sterilized soil inoculated with azotobacter.

Fig.1 Effect of inoculation of different microsymbionts on number of branches of sesame under sterile and non-sterile soil conditions at Ogbomoso and Ibadan



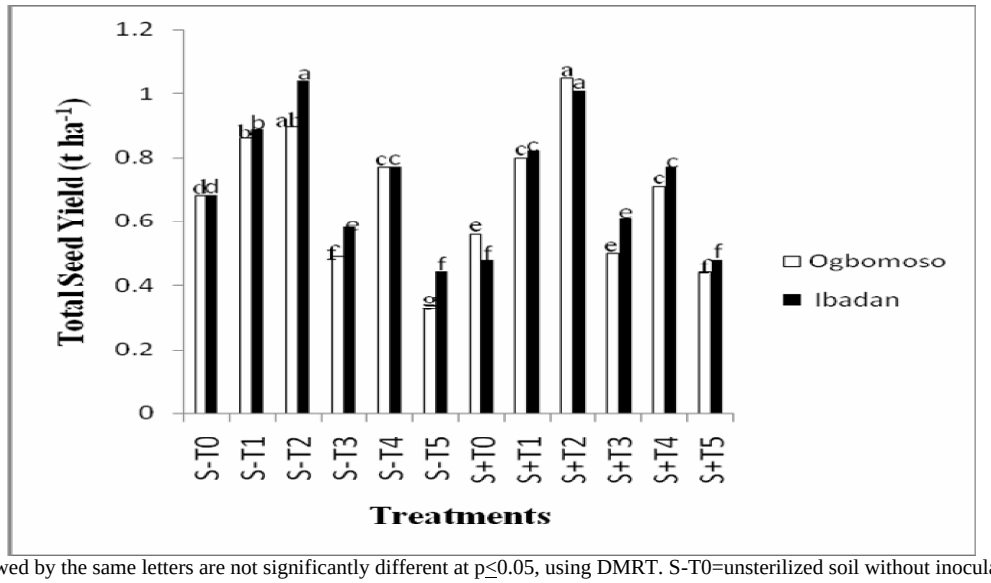
Means followed by the same letters are not significantly different at p≤0.05, using DMRT. S-T0=unsterilized soil without inoculation of any microbe/biofertilizer, S-T1= unsterilized soil with urea application, S-T2= unsterilized soil inoculated with azospirillum, S-T3= unsterilized soil inoculated with rhizobium. S-T4= unsterilized soil inoculated with mycorrhiza, S-T5= unsterilized soil inoculated with azotobacter, S+T0=sterilized soil without inoculation of any microbe/biofertilizer, S^{+}T1= sterilized soil with urea application, S+T2= sterilized soil inoculated with azospirillum, S+T3= sterilized soil inoculated with rhizobium, S+T4= sterilized soil inoculated with mycorrhiza, S+T5= sterilized soil inoculated with azotobacter.

Table.5 Effect of inoculation of different microsymbionts on number of capsules, weight of 1000 seeds, oil content and mycorrhizal root colonization of sesame under sterile and non-sterile soil conditions at Ogbomoso and Ibadan

Treatments	Ogbomoso				Ibadan			
	No of Capsules Plant^{-1}	Weight of 1000 Seeds (g)	Oil content (%)	Mycorrhizal root colonization (%)	No of Capsules Plant^{-1}	Weight of 1000 Seeds (g)	Oil content (%)	Mycorrhizal root colonization (%)
S^{-}T0	18.1f	2.2d	41.33c	33.1c	19.3g	2.3c	41.80c	29.1c
S^{-}T1	73.9b	2.5a	45.53bc	34.5c	77.3ab	2.4bc	45.10c	31.3c
S^{-}T2	74.0b	2.4bc	52.87a	30.9cd	79.3a	2.4abc	54.97a	29.1c
S^{-}T3	56.1d	2.4bc	42.20c	26.1d	61.7de	2.5abc	45.20bc	28.5c
S^{-}T4	71.8bc	2.4bc	44.97bc	49.2b	69.4c	2.5abc	45.53bc	45.2b
S^{-}T5	45.2e	2.4abc	45.70bc	29.3cd	55.8ef	2.5abc	46.23bc	27.8c
S+T0	14.6f	2.1e	44.53bc	4.1e	19.6g	2.5ab	45.63bc	2.3d
S+T1	71.8bc	2.4bc	45.93bc	2.9e	71.6bc	2.4abc	45.80bc	2.2d
S+T2	81.1a	2.5a	52.63a	3.7e	81.1a	2.4abc	47.73bc	2.7d
S+T3	57.0d	2.3bc	47.00b	3e	60.6ef	2.5ab	51.83ab	2.6d
S+T4	66.8c	2.4bc	45.50bc	57.8a	2.5a	2.3c	45.90bc	56a
S+T5	2.4bc	2.3bc	45.07bc	3.2e	2.5ab	483.6h	45.77bc	2.9d

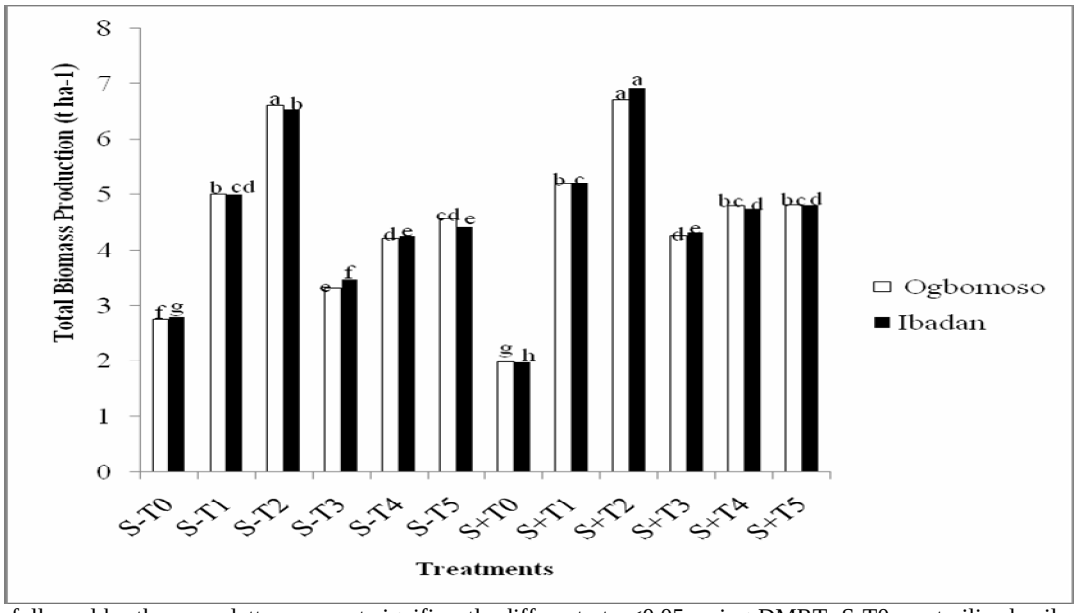
Means followed by the same letters are not significantly different at p≤0.05, using DMRT. S-T0=unsterilized soil without inoculation of any microbe/biofertilizer, S-T1= unsterilized soil with urea application, S-T2= unsterilized soil inoculated with azospirillum, S-T3= unsterilized soil inoculated with rhizobium. S-T4= unsterilized soil inoculated with mycorrhiza, S-T5= unsterilized soil inoculated with azotobacter, S+T0=sterilized soil without inoculation of any microbe/biofertilizer, S^{+}T1= sterilized soil with urea application, S+T2= sterilized soil inoculated with azospirillum, S+T3= sterilized soil inoculated with rhizobium, S+T4= sterilized soil inoculated with mycorrhiza, S+T5= sterilized soil inoculated with azotobacter.

Fig.2 Effect of inoculation of different microsymbionts on total seed yield of sesame under sterile and non-sterile soil conditions at Ogbomoso and Ibadan



Means followed by the same letters are not significantly different at $p \leq 0.05$, using DMRT. S-T0=unsterilized soil without inoculation of any microbe/biofertilizer, S-T1= unsterilized soil with urea application, S-T2= unsterilized soil inoculated with azospirillum, S-T3= unsterilized soil inoculated with rhizobium. S-T4= unsterilized soil inoculated with mycorrhiza, S-T5= unsterilized soil inoculated with azotobacter, S+T0=sterilized soil without inoculation of any microbe/biofertilizer, S+T1= sterilized soil with urea application, S+T2= sterilized soil inoculated with azospirillum, S+T3= sterilized soil inoculated with rhizobium, S+T4= sterilized soil inoculated with mycorrhiza, S+T5= sterilized soil inoculated with azotobacter.

Fig.3 Effect of inoculation of different microsymbionts on total biomass production of sesame under sterile and non-sterile soil conditions at Ogbomoso and Ibadan



Means followed by the same letters are not significantly different at $p \leq 0.05$, using DMRT. S-T0=unsterilized soil without inoculation of any microbe/biofertilizer, S-T1= unsterilized soil with urea application, S-T2= unsterilized soil inoculated with azospirillum, S-T3= unsterilized soil inoculated with rhizobium. S-T4= unsterilized soil inoculated with mycorrhiza, S-T5= unsterilized soil inoculated with azotobacter, S+T0=sterilized soil without inoculation of any microbe/biofertilizer, S+T1= sterilized soil with urea application, S+T2= sterilized soil inoculated with azospirillum, S+T3= sterilized soil inoculated with rhizobium, S+T4= sterilized soil inoculated with mycorrhiza, S+T5= sterilized soil inoculated with azotobacter.

Table.6 Effect of microsymbiont inoculations on nutrient uptake of sesame under sterile and non-sterile soil conditions at Ogbomoso and Ibadan

	Ogbomoso										Ibadan									
Treatments	N	P	K	Ca	Mg	Na	Fe	Cu	Mn	Zn	N	P	K	Ca	Mg	Na	Fe	Cu	Mn	Zn
				(g kg-^{1}dw)					(mgkg-^{1}dw)					(g kg-^{1}dw)					(mgkg-^{1}dw)	
S¯T0	3.27g	1.60e	0.47e	0.47f	0.57f	0.33d	83.87c	0.90d	28.03e	12.43e	3.80f	1..90c	0.50c	0.45d	0.55d	0.40d	85.50c	0.80c.	29.00c	13.25b
S¯T1	23.30c	4.77a	12.70a	1.10a	1.37b	0.93ab	166.73a	4.60ab	53.30b	19.93a	17.03bcdef	3.70b	9.00ab	0.93abc	1.23abc	0.97a	144.90a	3.60ab	43.90abc	17.80ab
S¯T2	27.53b	4.23b	10.57bc	0.87b	1.40b	0.70bc	116.87b	4.10b	48.70c	14.60c	28.00abc	4.90a	12.00a	1.07ab	1.37abc	0.80ab	127.30abc	4.37a	52.30ab	17.70ab
S¯T3	20.33d	4.23b	9.60c	0.60ed	1.03de	1.03c	88.80c	2.20c	40.97d	15.30c	23.73abcd	4.57a	10.20a	0.73bcd	1.37abc	0.77abc	99.23bc	2.63bc	45.17abc	15.13ab
S¯T4	17.40e	4.17b	10.00c	0.53ef	1.30bc	0.53cd	110.60b	4.17ab	45.03cd	17.43b	20.57abcd	4.50a	11.00a	0.73bcd	1.20abc	0.70abcd	100.60abc	3.93ab	42.90abc	17.10ab
S¯T5	9.43f	3.70c	7.50d	0.37f	0.80f	0.67bc	94.27c	2.53c	43.43d	14.67c	12.97def	4.33ab	9.70a	0.60cd	1.03bcd	0.80ab	103.30abc	3.00abc	43.27abc	15.13ab
S+T0	3.17g	2.27d	0.90e	0.47ef	0.67f	0.60cd	65.73d	0.63d	28.70e	12.70e	5.80ef	2.77bc	2.97bc	0.67bcd	0.83cd	0.57bcd	75.13c	1.43c	33.20bc	13.80ab
S+T1	23.70c	4.83a	12.90a	1.16a	1.40b	1.00a	167.30a	4.73a	73.53a	20.23a	17.63bcde	4.17ab	9.47ab	0.87abcd	1.27abc	0.97a	136.43ab	3.47ab	60.50a	18.70a
S+T2	32.97a	4.07bc	11.47b	1.20a	1.73a	0.93ab	124.93b	4.60ab	48.57c	15.47c	34.30a	4.50a	12.20a	1.30a	1.77a	1.00a	144.43a	4.50a	57.30a	15.30ab
S+T3	22.43c	4.27b	9.80c	0.67cd	1.23cd	0.77abc	89.60c	2.37c	41.30d	17.53b	30.73ab	4.70a	10.70a	0.93abc	1.53ab	0.93a	100.70abc	3.23abc	44.83abc	17.43ab
S+T4	20.23d	4.27b	9.93c	0.70c	1.30bc	0.50cd	111.57b	4.23ab	45.07cd	14.83c	23.30abcd	4.43a	10.87a	0.77bcd	1.37abc	0.73abc	104.23abc	3.83ab	45.17abc	15.63ab
S+T5	10.50f	3.93c	6.73d	0.43f	0.97e	0.50cd	91.60c	2.23c	44.13d	14.00cd	16.20cdef	3.93ab	7.93ab	0.47d	1.06bcd	0.47cd	110.27abc	2.97abc	45.27abc	14.23ab

Means followed by the same letters are not significantly different at $p \leq 0.05$, using DMRT. S-T0=unsterilized soil without inoculation of any microbe/biofertilizer, S-T1= unsterilized soil with urea application, S-T2= unsterilized soil inoculated with azospirillum, S-T3= unsterilized soil inoculated with rhizobium. S-T4= unsterilized soil inoculated with mycorrhiza, S-T5= unsterilized soil inoculated with azotobacter, S+T0=sterilized soil without inoculation of any microbe/biofertilizer, S+T1= sterilized soil with urea application, S+T2= sterilized soil inoculated with azospirillum, S+T3= sterilized soil inoculated with rhizobium, S+T4= sterilized soil inoculated with mycorrhiza, S+T5= sterilized soil inoculated with azotobacter.

Other inoculants significantly improved total seed yield under sterile and non-sterile soil conditions at both locations but the values obtained were significantly ($p < 0.05$) lower than those of Azospirillum inoculated plants (Fig. 2). Azospirillum inoculation significantly ($p < 0.05$) enhanced total biomass yield of sesame under sterile and non-sterile soil conditions respectively (Fig. 3). Inoculation with Azospirillum under sterile and non-sterile soil conditions resulted in similar values of total biomass production. At Ogbomoso, inoculation of Azospirillum significantly ($p < 0.05$) increased the total biomass production (6.71 tons ha^{-1} and 6.61 tons ha^{-1}) under sterile and non-sterile soil conditions respectively (Fig. 3). Similarly, at Ibadan, the total biomass production of 6.92 tons ha^{-1} and 6.55 tons ha^{-1} under sterile and non-sterile soil conditions respectively were observed (Fig. 3). Other microbial inoculations significantly improved total biomass production of sesame at both locations, under sterile and non-sterile soil conditions compared to those plants without application of microsymbionts, at Ogbomoso and Ibadan (Fig. 3). These results are in line with the findings reported by Gunarto *et al.*, (1999) and Boureima *et al.*, (2007), who reported improved crop performance by Azospirillum. Also, Kothari *et al.* (1990); Tobar *et al.* (1994); Subramanian *et al.* (1995) and Dare (2008), who reported enhanced growth and yield of different crops by microbial inoculants.

Microsymbionts and nutrient uptake of sesame

At the two locations, microbial inoculations generally enhanced nutrient uptakes significantly under both soil conditions, compared to the control (Table 6). Mycorrhizal inoculation significantly ($p < 0.05$) improved nutrient uptakes of sesame particularly N, P, K, Ca, Mg, under both sterile and non-sterile soil conditions at Ibadan, compared to the control (Table 6). Inoculation of sterile soil with Azospirillum significantly enhanced nutrient uptakes at both locations (Table 6). Many of the essential nutrients determined were significantly higher in terms of uptakes in sesame plants which received Azospirillum inocula. Sole application of urea at recommended N-rate for sesame significantly ($p < 0.05$) increased uptakes of Mn, Zn, Cu, Fe and Na at both locations irrespective of the soil conditions (i.e. sterile or non-sterile). These results also corroborated the research findings reported by Gunarto *et al.*, (1999) and Boureima *et al.*, (2007), Dare (2008) and Babajide (2012) who reported improved nutrient uptakes in different crop plants, as resulted from inoculation of microsymbionts.

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