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Potential Production and Application of Biofertilizers in Sudan

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INTRODUCTION

During the last decades, the increased costs of fertilizer production coupled with the progressively increasing use of chemical fertilizers are adding to the cost of crop cultivation. In addition, chemical fertilizers are harmful when they persist in the soil and enter the food chain. Instead, an approach is adopted to introduce into the soil potential microorganism, a practice known as inoculation. The inoculants are also known as biofertilizers. Several microorganisms and their association with crop plants are being exploited in the production of biofertilizers. The microorganisms which are potential biofertilizers are symbiotic and non-symbiotic nitrogen fixing microorganisms, phosphorous solubilizing microorganisms and silicate bacteria. The potential uses of biofertilizers in agriculture play an important role of providing an economically viable level for achieving the ultimate goal to enhance productivity.

On the other hand, the value of organic materials as a source of plant nutrients is greatly enhanced by composting. Composted materials are also more stable and pleasant to handle.

In this paper the discussion is restricted to a review of the main groups of microbial biofertilizers in addition to fertilizers from the organic origin.

Symbiotic nitrogen fixation

Rhizobium inoculation: In a study of Rhizobial cross inoculation groups of *Faidherbia albida* and *Acacia nilotica*, *Acacia senegal*, *A. tortilis*, *A. seyal* and *A. melifera*, it was found that the frequency of nodulation and total nitrogen content were maximized when each individual plant species was inoculated with its own isolate of *Rhizobium*.In addition of NPK fertilizer benefited *Acacia spp*, as it resulted in more root nodules, when it was combined with inoculation with their own *Rhizobium* isolates (ElAtta and Osman, 1993).

The impact of soil moisture, temperature and soil reaction (pH) on nodulation of six *Acacia spp*, *A. nilotica*, *A. senegal*, *A. seyal*, *A. tortilis*, *A. melifera* and *A. albida* (*Faidherbia albida*) was studied. Increasing the moisture content from 15-35% doubled the frequency of nodulation. The frequency of nodulation increased from 6.5 nodules in winter to 15.3 nodules in summer. Absolutely no nodules were produced by any plant in acidic soil (Osman and ElAtt, 1995).

Alfalfa (*Medicago sativa* L.) was found to respond positively to *Rhizobium* inoculation in three different locations in Khartoum state. Yield of fresh and dry fodder were significantly higher in inoculated plants as compared to uninoculated control plants (Mohamed and Osman, 1996).

The inoculation of faba bean with *rhizobium* strain TAL 1400 constantly resulted in severe increments in the fresh and dry weights of shoot, root, nodules, number of nodules, nodule dry weight, grain yield and N_2 fixation. However, inoculation with *Rhizobium leguminosarum* significantly increased all these parameters (Osman and Mohamed, 1996).

Cultivation of groundnut in Western Sudan is still lacking nitrogen fertilizers. Hence three imported strains were compared to local strains. The results indicate that, the imported *Rhizobium* strain has no benefits for groundnut production in Western Sudan. Hence, the future research on nitrogen fixation by groundnut in this area should be directed to selection and identification of the most effective rhizobia strains from the adapted local population (Ali, 2003). However, inoculation with a compatible strain of rhizobia was found to enhance nodulation, dry weight of nodules, nitrogen fixation and yield of alfalfa (Medicago *sativa*), Fenugreek (*Trigonella foenugraecum*), cluster bean (*Cyamopsis tetragonoloba*), field pea (*Pisum sativum*) and common bean (*Phaseolus vulgaris*) grown in dry land. It was concluded that, the productivity of leguminous crops in dry land could be improved by *Rhizobium* inoculation (Abdelgani *et al*., 2003b).

Bradyrhizobium inoculation to guar significantly improved nodulation and dry matter production particularly by locally isolated bradyrhizobia. Nitrogen fertilization improved dry matter production but depressed nodulation. Phosphate mitigated the depressive effect of nitrogen on nodulation and further enhanced its stimulatory effect on dry matter production (Mahdi and Mustafa, 2005).

Investigation on nodulation of guar and five other species of legumes (*Cajanus cajan*, *Vigna unguiculata*, *Crotalaria saltiana* and *cassia occidentalis*) in the Sudan indicated that although these legumes were naturally nodulated, inoculation by introduced or locally-isolated bacterial strains improved nodulation and dry matter production (Mahdi and Mustafa, 2005).

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Rhizobium multi strain inoculation significantly increased dry weight of shoots, roots and nodules and number of nodules of chickpea. Single *Rhizobium* inoculation of *Phaseolus vulgaris* showed significant difference for the studied parameters (Mohamed Ahmed *et al*., 2009).

N^{15} methodology was used to determine the amount of nitrogen fixed by summer legumes guar, pigeon pea and mung bean compared to groundnut. The result showed that pigeon pea and guar could compete well with groundnut as N2-fixers. Levels of fixation were 79, 77, 80 and 12% of the total crops N need for guar, groundnut, pigeon pea and mung bean, respectively (Adlan and Mukhtar, 2004).

Rhizobium inoculation and chicken manure: Inoculation of *Sinorhizobium* and application of chicken manure to alfalfa significantly increased plant density, forage fresh yield and protein content and significantly decreases crude fibre content (Elsheikh *et al*., 2006).

Rhizobium inoculation and phosphorus: Phosphorus application increased plant density of alfalfa, whereas *Rhizobium* inoculation seemed to have a negative effect on plant density. Both treatments (Phosphorus application and *Rhizobium* inoculation) led to increase in seed yield components and seed yield and significantly increased growth parameters and improved nodulation. The introduced cultivar Pioneer 5929 was superior to the local cultivar Hegazi in most studies growth parameters (Abuswar and Mohamed, 1997a,b).

The effect of four doses of phosphorus (0, 100, 200, 300 kg p_2O_5/ha) on the growth and forage yield of clitoria (*Clitoria ternatae*), lablab (*Lablab purpureus*) and phillipesara (*Vigna trilobata*) were studied. Addition of phosphorus significantly increased plant height, number of fruting branches/plant and fresh weight of leaves (Ibrahim *et al*., 1996).

***Rhizobium* inoculation and virus:** Viral infections of faba bean with Broad Bean Mottle Bromovirus (BBMV) and Bean Yellow Mosaic Virus (BYMV) significantly decreased shoot and root dry weight, number of nodules, nodule dry weight, grain yield and N_2 fixation. However, inoculation with *Rhizobium leguminosarum* significantly increased all these parameters (Elsheikh and Osman, 1995). Viral infection had an adverse effect on yield, protein content and IVPD (Babiker *et al*., 1995). Bean Yellow Mosaic Virus (BYMV) inoculum significantly decreased shoot, root, nodule dry weight, nodule number, number of flowers and pods per plant, total plant nitrogen and nitrogen fixation of faba bean, whereas inoculation with *Rhizobium* has significantly increased these parameters. The results also indicated that *Rhizobium* strain TAL 1397 is effective in fixing nitrogen in normal and in virus infected faba bean plants (Osman and Elsheikh, 1994).

***Rhizobium* co-inoculation:** Inoculation of groundnut with *Bradyrhizobium* and *Azospirillum* could be a promising technology for improving groundnut production giving 8% increase in yield which was almost similar to the 90% increase caused by 86 kg N/ha. The nitrogen derived from the air was calculated to be about 79-80% indicating that groundnut fixed more than 70% of its N need from the air (Ahmed *et al*., 2005).

Inoculation with the PSB *Bacillus megatherium* var. *phosphatcum* (Osman *et al*., 2007) increased nodulation, nodule dry weight, nitrogen and phosphorus content in shoot and fresh and dry fodder. Co-inoculation with *Rhizobium* and PSB had a synergetic effect manifested in increased nodulation, nodule dry weight, shoot dry weight and shoot nitrogen and phosphorus content, compared to uninoculated control (Hassan and Abdelgani, 2009).

Rugheim and Abdelgani (2009) assessed the effect of inoculation by different *Rhizobium* and phosphate solubilizing bacterial strains and their interaction on yield and seed quality of faba bean at EL-Hudeiba Research Station farm in north Sudan. *Rhizobium* inoculation individually significantly increased yield, seed moisture, ash, crude fiber and crude protein. Phosphate solubilizing bacteria individually significantly increased yield, seed moisture, ash and fat in faba bean. A synergetic effect was observed when the two types of microorganisms were combined, they significantly increased yield and seed quality (moisture, crude protein, fat, crude fiber and ash content) of faba bean plants.

***Rhizobium* inoculation and micronutrients:** Studies were conducted to investigate the effects of *Bradyrhizobium* inoculation, molybdenum and zinc application on growth and yield of groundnut. Leaf N content was positively related to rhizobia effectiveness, and leaf MO content was negatively related to rhizobia effectiveness. Increase in applied MO and Zn levels increased their contents in leaves. The highest pod and seed yields were obtained from the interaction of the lowest soil Zn application and the indigenous strains-subjected plants (Hassan *et al*., 2006 a,b).

Micronutrient fertilizers consistently gave a considerable increase in the number of pods and consequently higher yield. *Rhizobium* inoculation had no significant effect on the parameters measured. A significant interaction was found between cultivars and fertilizers only in leaf nitrogen content (Elballa *et al*., 2004).

***Rhizobium* inoculation and salinity:** Elsheikh (1998a) reported that *Rhizobium* inoculation has a great potential for improving fertility in saline soils.

The effect of chemical (nitrogen and phosphorus) and biological fertilizers (*Rhizobium* and Vesicular Arbuscular Mycorrhizae (VAM) (*Glomus sp*) on growth and symbiotic properties of faba bean under saline conditions were investigated. salinity significantly reduced the shoot fresh and dry weight, number of nodules and percentage of mycorrhizal infection. Both VAM inoculation and phosphorus fertilization significantly increased the shoot and root fresh weight and number and dry weight of nodules. Inoculation with *Rhizobium* significantly increased shoot and root fresh weight and number and dry weight of nodule under saline and non-saline conditions (Ahmed and Elsheikh, 1998).

According to Abdelgani *et al*. (2003a,b), Salinity of > 4 dsm^{-1} significantly reduced growth of TAL 169 and two local isolates: ENRRI 16A and ENRRI 16C. However, average number of viable cells per ml tended to higher in TAL 169 up to EC8 than in the total isolates In laboratory experiments. However, the salinity level of $6dsm^{-1}$ significantly reduced nodulation, nodule dry weight and shoot nitrogen content of guar plant. The locally isolates strain ENRRI 16A was found to be more tolerant to salinity compare to stain TAL169.

Eight Fenugreek, (*Trigonella foenumgraecum*) cultivars and four *Rhizobium* strains were screened for their salt tolerance in three types of soils. *Rhizobium* meliloti strains were more salt-tolerant than fenugreek cultivars. Several pot experiments were designed to study the effect of salinity, chicken manure and nitrogen on nodulation. Application of chicken manure significantly increased all measured parameters. Salinity significantly reduced all measured parameters (Elsheikh and Forawi, 1995).

***Rhizobium* inoculation and fungicides:** Laboratory experiments were conducted to study the effect of different concentrations (0, 10, 20, 50, 100, 200, 500 and 1000 µg/l) of the fungicides captan, thiram, luxan, fernasan-d and milcurb on inhibition of growth and colony size of seven *Rhizobium* strains (4 introduced and 3 locally isolated). The effects were determined by measuring the colony size and the diameter of the zone of inhibited growth. Fungicides differed in their effects on *Rhizobium* and *Bradyrhizobium* strains. Captan at the concentration of 100 and 1000 µg/l was the most toxic. All strains tolerated low fungicide concentrations ($\leq$100 µg/l) but they were sensitive to high concentrations ($\geq$500 µg/l) with varying degrees of sensitivity. *Rhizobium* strains were more tolerant than *Bradyrhizobium* strains and no clear differences were observed between the introduced and locally isolated strains (Mohamed Ahmed *et al*., 2009).

A study was conducted to investigate the effect of fungicide Bayleton in some nitrogen fixing bacteria (*Rhizobium, Pseudomonas, Flavobacteria*). *Pseudomonas putida* was the most resistant to the fungicide in comparison to the other species. LD_{50} of these microbes were greater than the field dose therefore these microbes can be used as biofertilizers with bayleton (Osman and Abdelgani, 2005).

Rhizobium inoculation and seed composition: Elshiekh (2001) reported that positive results were found on physical and chemical properties of legume seeds.

Afield experiment was conducted to study the response of four faba bean (*Vicia faba* L.) genotypes to *Rhizobium* inoculation, nitrogen and chicken manure fertilization. With the exception of one genotype, all treatments significantly increased protein content and the *in vitro* protein digestibility. The *Rhizobium* inoculation and chicken manure fertilization significantly increased the crude fibre and significantly decreased the carbohydrate content (Elsheikh, 1998b).

Rhizobium inoculation and/or intercropping treatments significantly increased the ash, crude fibre, fat, protein content, moisture and tannin contents compared to the uninoculated monocrop control (Elsheikh and Ahmed, 2000).

On the other hand, study was conducted to investigate the effect of *Bradyrhizobium* inoculation and chicken manure and sulphur fertilization on minerals composition of soybean (*Glycine max* L). The results showed that inoculation, chicken manure, sulphur and their interactions significantly improved both major and trace minerals composition of the seeds. The highest value of each mineral was observed with either 10 ton/fed chicken manure or 100 kg/fed sulphur with or without *Bradyrhizobium* inoculation (Ibrahim *et al*., 2008a). In addition to that, a study was carried out to investigate the effect of two *Bradyrhizobium* strains (local and imported), chicken manure fertilization (7 t/ha) and intercropping with sorghum on the chemical composition and physical characteristics of soybean seed. For both monocropping and intercropping systems, moisture, protein, tannin, 100 seeds weight, hydration coefficient, cookability and mineral composition of the seeds were increased for all treatments while ash, fibre and carbohydrate contents were fluctuated for both systems and treatments (Elsheikh *et al*., 2009).

More over, a study was conducted to investigate the effect of *Bradyrhizobium* inoculation, chicken manure or sulphur fertilization on physical characteristics and chemical composition of hyacinth bean seeds. The results indicated that hydration coefficient, cookability, moisture, ash, fat, fiber, protein, carbohydrates, major and trace elements were increased with increasing level of amendments (manure or sulphur) in the presence or absence of *Bradyrhizobium* and the highest value of each parameter was observed with either 10 t/fed chicken manure or 100 kg/fed sulphur (Ibrahim *et al*., 2008b).

Financial studies: Results from two faba bean cultivars showed that *Rhizobium* inoculation and nitrogen fertilization significantly increased yield. However, *Rhizobium* inoculation gave significantly higher yield than nitrogen fertilization. The financial analysis showed that both treatments were financially feasible, but the net returns obtained from *Rizobium* inoculation were by far greater than those of nitrogen fertilization for the two cultivars, Silaim and Agabat (Osman *et al*., 1996).

Rhizobium carrier materials: A study was carried out to assess the suitability of locally available materials as carriers for rhizobia. It also aimed at evaluating the effect of carrier sterilization on the shelf life of inoculants. Sterilization of the carrier material enhanced growth of rhizobia and prolonged the shelf life of the inoculum. Charcoal powder was found to be the best among the tested materials with a storage ability of 60 days at room temperature. Sterilized groundnut shells were better than sterilized Nile silt and bagasse mixture (1:1 by weight) for storage for 40 days. The combination of Nile silt with bagasse (1:1) was better than the mixture of (3:1). Sterilized bagasse carrier could be used for storage for 40 days while sterilized rice residues could be used for storage for 20 days. Nile silt alone was found to be the least suitable material to be used as carrier for rhizobia (Abdelrahim *et al*., 2005).

In another study (Elsharif and Abdelgani, 2007), filter mud from 2 local sources was tested for its efficiency as a carrier for rhizobia, compared to charcoal. The results showed that filter mud from ElGenaid Sugar Factory maintained the highest numbers of rhizobia and was the best to be used as a carrier. Sterilization of carrier material showed better results compared to the non-sterilized carrier. The shelf life of the inoculants was 7 weeks when kept at room temperature (with maximum limit of 32°C).

Commercial production of elokadin biofertilzer: The commercial production of Elokadin biofertilizer was started in 1992 by the Biofertilization Department of the environment and natural resources research institute of the National Center for Research (NCR) (Table 1 and 2 and Fig. 1)

Cyanobacteria: Very little work has been devoted to investigate the biofertilizer role of cyanobacteria in Sudanese agriculture (Mahdi, 1993). Eco-physiological studies, it was found that all cyanobacterial orders including nitrogen fixers were represented in soil and water samples taken from Khartoum and North Kordofan states. Cyanobacterial plasticity enables them to live in a wide range of temperature, light intensity.pH and salinity. In addition, they have considerable crusting potentials (Ali, 2010).

Mycorrhizal association: Mycorrhizae are a group of fungi that include a number of types based on the different structures formed inside or outside the root. These fungi grow on the roots of these plants. Seedlings that have mycorrhizal fungi growing on their roots survive better after transplantation and grow faster. The fungal symbiont gets shelter and food from the plant which, in turn, acquires an array of benefits such as better uptake of phosphorus, salinity and drought tolerance, maintenance of water balance, and overall increase in plant growth and development.

Table 1: Area and major crops in Sudan that fertilized by *Rhizobium* inoculant (Elokadin)

Area	Major Crops
Khartoum State	Alfalfa, Broad bean, Lubia, Bean, Garden pea
Northern State	Broad bean, Chickpea
River Nile State	Lentils, Broad bean, Alfalfa
Blue Nile State	Guar
ElGadaref State	Guar, Groundnut
Northern Kordofan	Guar, Groundnut
Northern Darfur	Alfalfa, Broad bean

Table 2: Production area from 1992-2009

Year	Area (Feddan)
1992	240
1994	355
1995	1750
1996	2805
1997	1183
1998	890
2000	2249
2001	1484
2002	400
2003	1953
2004	518
2005	2000
2006	736
2007	2220
2008	2498
2009	1361

Source: ENRRI annual scientific reports

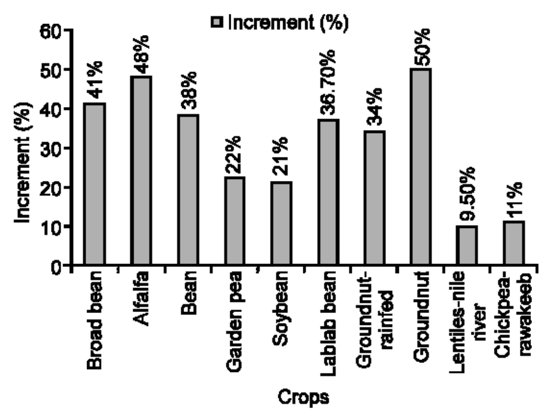

Fig. 1: Increase in production in some corps fertilized by Elokadin biofartilizer

Mycorrhizal research in the Sudan: Atabani (1988) studied the effect of four mycorrhizal fungi, namely *Glomus mossae, Gigaspora margarita, Gigasporea calospora and Acaulospora sp* on hyacinth bean (*Lablab* *purpureus*) and soybean *(Glycine max*). Inoculation with any of the four mycorrhizal fungi established successful symbiotic association between these fungi and the crops and resulted in improved plant performance which was further enhanced in the presence of phosphate fertilization. According to Galal (1993), inoculation of cowpea with local and introduced *Glomus sp* VAM fungi significantly enhanced plant nodulation, dry matter yield and tissue N&P contents in silt and sandy soils. No significant differences were reported between the efficiency of the introduced and the local VAM fungi. Mahdi (1993) reviewed the use of VAM fungi as a biofertilizer in Sudan. He suggested that VAM fungi have a great potentiality for using as a biofertilizer. Shoots and roots dry weight and phosphorus content of Dolichos bean plants increased with *Glomus sp* inoculation. *Glomus sp* significantly reduced the number of galls induced by the root-knot nematode *M. incognita* and hence reduced the infestation effect of the nematodes (Ahmed *et al*., 2009).

A study was conducted to investigate the effects of mycorrhizal inoculation and phosphorus application on infection, symbiotic activity and yield of faba bean. Mycorrhizal infection occurred with low P concentration. Mycorrhizal inoculation significantly increased nodule number, nodule dry weight, flower set, pod production and seed yield compared to non-mycorrhizal plants. The stimulation of faba bean symbiotic activity and seed yield by mycorrhizal inoculation was suppressed by the application of phosphorus (Ahmed *et al*., 2000).

Mycorrhizal inoculation and/or superphosphate significantly increased both oil and protein content of groundnut seeds. *Bradyrhizobium* and/or mycorrhizal inoculation significantly increased the ash, crude fibre, IVPD and tannin content (Elsheikh and Mohamedzein, 1998).

Nodulation and plant growth of soybean were significantly enhanced by mycorrhization and P fertilization, but the effect was greater in presence of both treatments. Increase in mycorrhizal colonization was associated with a corresponding increase in plant N and P contents (Mahdi *et al*., 2004).

A study was conducted to evaluate the efficiency of *Tricoderma viride*, VA mycorrhiza and dry yeast, separately and in combination as an integrated strategy of Rhizctonia disease management in potato crop. VA mycorrhiza enhanced both the growth and yield of measurements of *Rhizoctonia* inoculated potato plants and significantly reduced the efficacious biocontrol agent to *Rhizoctonia* compared to the other two organisms, yet it also significantly improved the situation of the infected plants (Mohamed *et al*., 2008).

Non-symbiotic nitrogen fixers: Different micro-organisms were isolated characterized and identified from six peat based inoculants (Biogen, microbin, Bioplant-K pseudomin, flavobacterin and mobilin) that are world wide used. The results revealed that Biogin inoculant contain *Azotobacter vienlandi*, Bioplant-K contained *Kelbsiella planticola* and Microbin contains four bacterial species -*Azospirillum brasiliense Azotobacter vienlandi, Bacillus megatherium var phosphaticum* and *Pseudomonas aurantiaca*. (Osman *et al*., 2007), mobilin contain *Azomonas, flavobacterin* contain *flavobacterium*, Pseudomin contain *Pseudomons putida* (Osman, 2003).

Suitability of charcoal, groundnut shells, nilesilt filtermud and bagasse as carries for *flavobacterium* and *Azomonas* was studied by Osman and Mohamed Ahmed (2005). The results revealed that the best carrier for *flavobacterium* was Nile silt and for *Azomans* charcoal was the best. Nitrogen fertilization at 60 and 90 kg/ha and the combined inoculation of *Azospirillum brazilense* and *Bacillus polymyxa* +30 kg N/ha significantly increased plant height, yield per plant, number of seeds/plant and seed yield. It is recommended to use the composite inoculum +30 kg N/ha since 60 kg N/ha can be spared off (Mohammed *et al*., 2010).

IAEA funded a programme to increase the productivity of new varities of sugarcane, tomatoes, wheat and banana through introduction of new production packages. Non-symbiotic nitrogen fixing bacteria for banana and tomatoes were isolated by ARC, Medani. The biofertilization department started now the study of some local meterials as carries for these bacteria, in addition to the shelf life of the inoculants for mass production.

Phosphorous solubilizing bacteria: Thirty nine local isolates of phoshorus solubilizing bacteria were isolated from different Sudanese soil types. The isolates were characterized and identified as *Bacillus megatherim var phosphaticum*. The efficiency of those isolates under laboratory condition revealed that all of them can solubilize different quantities of $Ca_3 (PO_4)_2$ in 48 h. The maximum solubilizing quantity was 66.6 ppm.

Charcoal, filter mud, Nile silt, Bagass and groundnut shells were used as carries for two phosphorus solubilizing bacteria, *streptomyces albus* and *Bacillus megatherium var phosphaticum*. The results showed that the four materials can be used as carriers. However, Charcoal was found to be the most efficient carrier (Osman and Mohamed, 2006).

Silicate bacteria: Biological potassium fertilizer is efficient and non polluting biological fertilizer that is manufactured by advanced production technology under strict quality control. It can activate Mg, Fe. Mo, P etc, releasing balanced nutrients from soil, increase fertility of soil and also facilitates secretion of gibberellins, IAA, cytokinin and other hormones. It can improve the structure of soil, enhance rooting of seeds and enlarge the shoot and branches. It is widely used in many plants, food crops, economic crop, fruits and vegetables with varied impact on yield between 10-50% over the untreated.

Some microscopical and biochemical characteristics of two isolates of silicate bacteria isolated from peat-based silicate bacteria inoculant were carried out. The results revealed that the inoculants contained two strains of silicate bacteria. These isolates were found to be close to *Bacillus circulans* and *Bacillus mucilaginous* (Osman, 2009).

Compost production in Sudan: There are 2 factories which produce compost in Sudan: Elkhaseeb factory with production capacity of 8000 ton/year and Elkhierat factory with production capacity of 6000 ton/year.

Elkhierat compost production

Production rate: In 2007 the factory started producing small quantities (1 t/month) applied in nurseries and house gardens. In 2008 the factory was established in an area of 5.5 feddans at Elselate scheme and the average production was 5t/month. The average production rate in 2009 reached 150 t/month.

Elkhaseeb organic fertilizer: Elkhaseeb organic fertilizer is manufactured locally in El Bagair industrial area. It is a mixture of sheep manure, farmyord manure and chicken in 1:2:1 ratio. It is heated up to 70°C for 30 min and then beletted (2.5, 4 millimeter), it is free from plastic materials, weeds seeds, insects, warms, nematode and pathogenic microorganisms (*shigella*, *salmonella* and *E. coli*). The analysis of this fertilizer proved that, heavy metals, micronutrients, sodium, potassium chlorine, total nitrogen, C.N ratio, EC, pH, bulk density, strange materials were within the range compared to finished compost. However, calcium carbonate, phosphorus lignin, cellulose, hemicellulose and fiber were all over the standard range compared to finished compost. CEC and magnesium were lower than the standard range. The preliminary results of the effect of this fertilizer on growth, yield and quality of onion, tomatoes, potatoes and wheat showed increments in crop yields and qualities in Khartoum state (Osman *et al*., 2009).

Imported biofertilizers: Although there are some restrictions to import microorganisms in any formulation, there are some imported biofertilizers that contain (foreign) microorganisms are found in Sudan.

a) Effective microorganisms (EM): It is a liquid microbial consortium based on diluted molass. The analyses of the EM were conducted at Biofertilization Department .ENRRI, NCR it contains yeast: *saccharomyces cerevisiae*, bacteria: lactic acid bacteria, photosynthetic bacteria (*Rhodopseudomonas palustris*, and *Rhodobacter sphaeroides*). It is free from pathogenic bacteria, *E. coli*, *shigella* and *salmonella*.

b) Zander mycohorriza: It contains six strains of VAM, nitrogen fixing bacteria and other benefical microorganisms in pelleted form with different additives e.g. organic fertilizer, humic acids, cortenoides and Gibberellin. Those strains were isolated from aquatic environment in Eastern Europe. It is packed in 10 kg to fertilize one feddan. The shelf life is 8 month at 50°C. The efficiency is for 15 year. It was manufactured in Arab Emirates licensed by British Company. The above informations are mentioned in Zander Company brochure.

c) Granular rhizobia inoculant: It was imported from Australia. It contains 3.9×10^7 cfu/g. The moisure content was 5%, Ash 73.20%, pH 8.74, total carbon 26.88% P 2.2 ppm and N 0.37&.

The analysis of the inoculant was condcuted by biofertiliztion department, ENRRI, NCR.

Future research in biofertilizers

Future Research Areas in biofertilizers in Sudan should include the following:

Rhizobium inoculation: Further researches are required to study the response of *Cicer aritenum, Cajanus cajan, Arachis hypogaea and Phaseolus vulgaris* in Gazira scheme and rainfed areas, to Rhizobium inoculation.

Non-symbiotic nitrogen fixers: Researches are required to investigate the effect of non-symbiotic N fixing bacteria with different non-leguminous crops, in addition to co-inoculation with Rhizobium, Mycorrhiza, Phosphorus Solubilizing Bacteria (PSB), Mineral fertilizers and Organic fertilizers.

Table 3: Elkhierat compost use in Sudan

					Average yield	
Crop	Location	Area	Season	Rate of application	Control plots	Compost fertilized
Okra	Selate scheme	4 fed	2008/2009	1t/fed	2t/fed	3t/fed
Wheat	Selate scheme	6 fed	2008/2009	1t/fed	4 sac/fed	12 sac/fed
Cotton	Gezira scheme	351 fed	2009/2010	½ t/fed	4-5 kontar/fed	15-20 kontar/fed

PSB, silicate bacteria and mycorrhiza: Researches are required to investigate the effects of PSB, silicate bacteria and mycorrhiza on cereals and vegetables growth and yield.

ElKhaseeb and ElKhierat: More studies are required to investigate the effects of those organic fertilizers on different crops.

Cyanobacteria: Researches are required to study the response of rice grown in White Nile schemes to inoculation with nitrogen fixing cyanobacteria.

Effect of inoculation: The effect of inoculation with the above mentioned microorganisms on seed quality of different crops must be studied.

Suggestions: To promote adoption of biofertilizer production and use in Sudan the following suggestions should be taken into consideration:

- Support of applied research in the field of biofertilizer through financial support, training of personnel and providing logistics.
- Continuous improvement of skills and capacity building of the agricultural extensionists in the areas of biofertilizer use.
- Strengthen collaboration between the different research institutions, the fedral and state ministries of agriculture.
- Establishment of technical committees for development of production and use of biofertilizers technology.
- Adoption of international quality control standards for production of microbial inoculants.
- Establishment of extension programmes among farmers and agricultural companies for dissemination of biofertilizers.
- Encouragement of bioferilizers commercial production in Sudan.
- Close supervision from the government authorities to the imported biofertilizers is highly needed.

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