

MICROBIAL FERTILIZERS IN JAPAN

Michinori Nishio
National Institute of Agro-Environmental Sciences
Kannondai 3-1-1, Tsukuba, Ibaraki 305 Japan

ABSTRACT

This Bulletin discusses microbial products in Japan, where they are used on many farms, particularly by organic farmers who hope that these products will improve nutrient uptake by plants and the quality of their products. It discusses the use of charcoal and rhizobia to stimulate nutrient uptake, and the use of arbuscular mycorrhizal fungi (AMF) to help establish vegetation on barren land. The range of commercial AMF products available in Japan is briefly described, and their use and effectiveness in Japanese agriculture.

INTRODUCTION

In 1961, Japan enacted the “Fundamental Law of Agriculture”, which encouraged farmers to selectively produce vegetables, fruits, forage crops and livestock as well as rice, instead of staple foods such as wheat, barley and corn. The aim of the law was to raise farmers’ incomes in response to the rapid growth of the Japanese economy. Consumption of vegetables, fruits, milk, eggs and meats increased with economic growth. Farmers adopted the strategy of increasing crop yields by applying large amounts of chemical fertilizers and pesticides. During the 1960s and 1970s, the yield of many crops per unit area increased dramatically as the result of intensive use of chemical inputs and various soil amendments.

At present, however, the yield of many crops in Japan has reached a plateau. Moreover, the negative effects of heavy applications of chemical inputs are becoming apparent, in terms of both production and the environment, especially in the case of vegetables. Physiological disturbance of plant metabolism is common, due to the accumulation of excess plant nutrients in the soil. The spread of soil-borne diseases is a threat to vegetable production, especially where monoculture is prevailing. Pollution of underground and surface water by nitrates is sometimes reported from vegetable producing areas. Quality deterioration, in terms of a decrease in the content of vitamins and sugars, is becoming a subject of concern. All these factors are

giving farmers an interest in the function and utilization of soil microorganisms, as a way of repairing the damage from the overuse of chemical inputs.

Many farmers in Japan are showing a strong interest in the utilization of microorganisms to help:

- Stimulate plant nutrient uptake;
- Provide biological control of soil-borne diseases;
- Hasten the decomposition of straw and other organic wastes;
- Improve soil structure; *and*
- Promote the production of physiologically active substances in the rhizosphere or in organic matter.

The main incentive for farmers to use microorganisms seems to be that they hope to increase the yield or quality of their crops at a relatively low cost, without a large investment of money and labor. Although many microbial materials are sold commercially, most of them are not microbiologically defined, i.e. the microorganisms contained in the products are not identified, and the microbial composition is not fixed. Many of these commercial products are advertised as if they could solve any problem a farmer is likely to encounter. Because most extension advisors lack any knowledge of microbial products, confusion and trouble frequently occur.

In this report I would like to describe the present situation of microbial technologies in Japan, focusing on the practical use of various products and their potential.

Keywords: Bokashi, charcoal, microbial products, organic farming, vesicular-arbuscular mycorrhizal (VAM) fungi

UTILIZATION OF ARBUSCULAR MYCORRHIZAL FUNGI

More than 50% of upland and grassland soils in Japan are volcanic ash soils (Andosols), which transform phosphate into unavailable forms by chemical bonding with aluminum ions. Phosphate availability is therefore one of the strongest limiting factors on Japanese upland and grassland farms. At present, this problem is being overcome by a heavy basal dressing of a mixture of superphosphate and fused phosphate. Although these heavy applications have contributed to a remarkable increase in yields of many crops, many vegetable fields have accumulated phosphate at levels which inhibit plant growth. On the other hand, most grasslands are still deficient in phosphate, because enough chemical phosphate is being applied only when they are reclaimed. Therefore, there are two types of Andosols in Japan; one contains a sufficient amount of phosphate, and one does not. In both cases, there have been attempts to use arbuscular mycorrhizal fungi (AMF) or vesicular-arbuscular mycorrhizal fungi (VAM) for soil amelioration.

Utilization of Indigenous AMF by the Application of Charcoal

The idea that the application of charcoal stimulates indigenous AMF in soil and thus promotes plant growth is relatively well-known in Japan, although the actual application of charcoal is limited due to its high cost. The concept originated in the work of M. Ogawa, a former soil microbiologist in the Forestry and Forest Products Research Institute in Tsukuba. He and his colleagues applied charcoal around the roots of pine trees growing by the seashore, and found that Japanese truffles became plentiful. He also tested the application of charcoal to soybean with a small quantity of applied fertilizer, and demonstrated the stimulation of plant growth and nodule formation (Ogawa 1983). His findings with regard to legumes were taken up for further study by the National Grassland Research Institute (Nishio and Okano 1991).

Stimulation of Alfalfa Growth by Charcoal Application

Table 1 shows the results obtained with alfalfa in pot experiments. The soil used was a volcanic ash soil with very low phosphate availability. Although alfalfa growth was very poor without applied fertilizer, it was improved by the application

of small amounts of fertilizer, and even more by the application of charcoal with the fertilizer.

Four sets of pots were prepared. Each set received the same amount of fertilizer (2 g N, 4.4 g P and 8.3 g K/m²). Set [F] received only fertilizer. The others received fertilizer and also rhizobia [F+R], 1,000g/m of charcoal [F+C], and rhizobia plus charcoal [F+R+C]. The charcoal used was a commercial product made of bark from several kinds of deciduous broad-leaved trees. Particle composition was >2mm, 24%; 1-2mm, 18%, and <1mm; 58%.

Compared to the sets which received fertilizer alone, or fertilizer plus rhizobia, the charcoal application stimulated plant growth by 1.7 - 1.8 times [F+C] and 1.4 - 1.8 times [F+R+C], measured at 38 days after sowing. At this stage the stimulatory effect of rhizobia on plant growth was not marked, because the plants had met most of their requirements by absorbing the applied nitrogen fertilizer, and nodule development was still at an early stage. At 58 days, when the nitrate added had been completely exhausted, plants not inoculated with rhizobia ([F] and [F + C]) ceased to grow, and their leaves turned yellow due to nitrogen deficiency. The soil used did not contain any indigenous rhizobia effective on alfalfa, so that roots not inoculated with *R. meliloti* did not show any acetylene reduction activity. At this stage, the stimulatory effect of charcoal on growth was observed only in the plants inoculated with rhizobia. The shoot weight of the [F + R + C] plants was 1.7 times greater than that of the [F + R] plants.

Stimulation of Nutrient Uptake by Charcoal Application

The amount of nutrients (N, P, K) absorbed by the shoots showed a trend similar to that of the shoot fresh weight (Table 1). The amount of N fixed by the nodules and transported to the shoots was calculated by subtracting the N content of the shoots of the plants not inoculated with rhizobia from the N content of the inoculated plants ([F+R]-[F], [F+R+C] - [F+C]). The addition of charcoal increased this amount of N 2.8-4.0 times, and the ARA by 6.2 times (Table 2). Added charcoal also increased the nodule weight by 2.3 times.

Fig. 1 shows the relationship between the increment of P and N associated with rhizobial inoculation in comparison with the non-inoculated alfalfa ([F+R] - [F] and [+R+C] - [F+C]). A significant correlation was observed between the increments of P and N, suggesting that the stimulation of nitrogen fixation by charcoal addition may be due to

the stimulation of P uptake.

Relationship between Charcoal Application and AMP

The relative values of the shoot fresh weight and the degree of AMF infection were determined on the basis of the values of [F+R]. A significant correlation was observed between the shoot weight and AMF infection (Fig. 2).

When the soil was sterilized by chloropicrin, alfalfa growth was greatly reduced, even with the application of the same amount of fertilizer shown in Table 1. The stimulatory effect of charcoal on plant growth also diminished. On the other hand, vigorous plant growth and the stimulatory effects of charcoal addition were clearly observed when the sterilized soil was mixed with a large amount of

native soil (Fig. 3). This clearly indicates that the stimulatory effect of added charcoal may appear only when a certain level of indigenous AMF are present.

MECHANISM WHEREBY CHARCOAL STIMULATES THE GROWTH OF AMF

Charcoal may stimulate the growth of AMF by the following mechanism. Charcoal particles have a large number of continuous pores with a diameter of more than 100 μ m. They do not contain any organic nutrients, because of the carbonization process. The large pores in the charcoal may offer a new microhabitat to the AMF, which can obtain organic nutrients through mycelia extended from roots. This may enable the AMF to extend their mycelia far out from the roots, thus collecting a larger amount of available phosphate.

Table 1. Effect of *Rhizobium* inoculation and charcoal application on the growth of alfalfa, root infection with VAM fungi and nutrient uptake by the plant

	Fresh weight of shoots (mg/plant)		Root area infected with VAM fungi (%)		Nutrients absorbed in shoots (mg/plant)					
	38 days*	58 days	38 days	58 days	N		P		K	
					38 days	58 days	38 days	58 days	38 days	58 days
F	227±27a	1,250±60c	22	38	1.91	4.16	.091	.544	1.37	5.67
F + R	249±41a	1,400±60c	32	44	2.06	6.48	.105	.639	1.61	7.02
F + C	396±29b	1,360±30c	39	47	2.70	4.08	.143	.692	2.35	5.83
F + R + C	447±27b	2,390±70d	45	54	3.12	13.32	.168	.989	2.72	12.41

* Days after seeding. \pm S.E. of triplicate means.

F: Fertilizer alone, F + R: F + *Rhizobium*, F + C: F + charcoal, F + R + C: F + *Rhizobium* + charcoal. Different letters refer to the values which were significantly different at P = 0.01 by Duncan's multiple range test

Source: Nishio and Okano 1991

Table 2. Stimulation of nitrogen fixation by alfalfa through charcoal application

	N fixed in shoot (difference method) mg/plant		ARA n mole C ₂ H ₄ / (h • plant)	Nodule dry weight mg/plant
	38 days*	58 days	38 days	58 days
F + R	0.15	2.32	3.6±1.0	8.9±5.5
F + R + C	0.42	9.24	22.2±7.2	20.6±2.0

* Days after seeding. \pm S.E. of triplicate means

F + R: Fertilizer + *Rhizobium*, F + R + C: Fertilizer + *Rhizobium* + charcoal

UTILIZATION OF AMF FOR ESTABLISHMENT OF GREEN COVER ON BARREN LAND

Barren land with poor vegetation cover, such as bare slopes beside roads and on mountains, or large fresh deposits of volcanic debris, are subject to serious soil erosion. The ordinary method of

establishing plant cover on sloping barren land is to seed grass or transplant tree seedlings, together with fertilization of the soil. At the early stages of plant development, however, when plant cover is not yet well established, heavy rainfall can cause soil erosion and leach out fertilizers. This retards plant establishment. To overcome the problem, a new technology

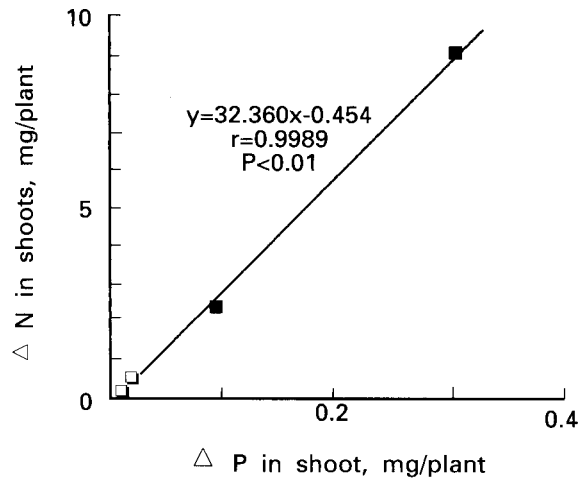


Fig. 1. Relationship between the increments of N and P uptake in shoots of alfalfa by the inoculation of *Rhizobium*

The plants were grown in pots for □ 38 days or ■ 58 days after sowing.

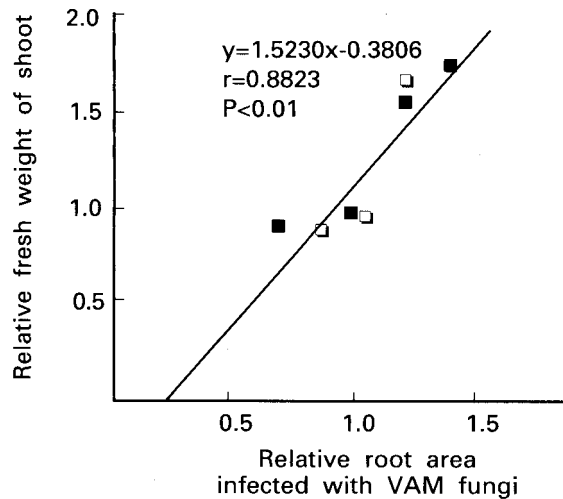


Fig. 2. Relationship between the relative fresh weight of alfalfa and relative root area infected with VAM fungi

The plants were grown in pots for □ 38 days or ■ 58 days after sowing.

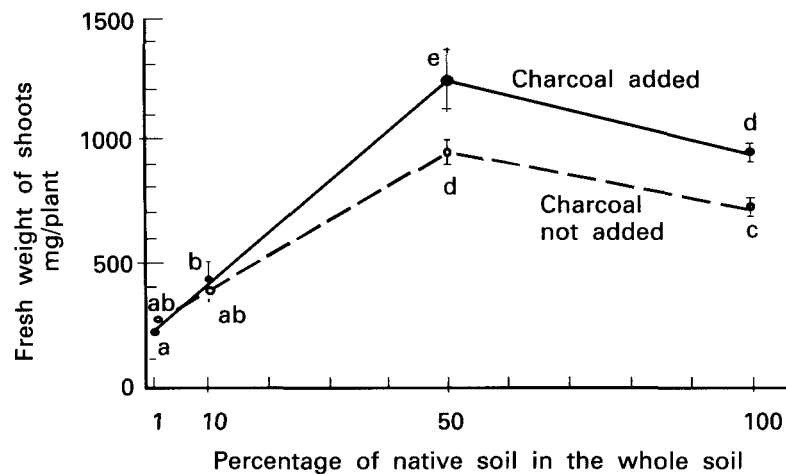


Fig. 3. Effect of dilution of native soil by sterilized soil on the growth of alfalfa in the presence or absence of charcoal (42 days after sowing)

1. Standard error of the triplicate means

Different letters refer to the values which were significantly different at $P=0.05$ by Duncan's multiple range test

is now being developed.

T. Marumoto of Yamaguchi University and his colleagues have developed a new soil mulching sheet made of a plastic random-fiber sheet of webbing. It contains plant seeds, fertilizer (including a coated nitrogen fertilizer and culture media composed of organic materials (peat soil + bark manure), zeolite and bentonite (Marumoto 1996). The sheet is stretched out over the soil surface, and helps prevent soil erosion at the early stages of vegetation growth. Shoots and roots of seedlings can easily push through the sheet and develop further. Marumoto also attempted to stimulate the growth of grasses and trees by inoculating the sheet with AMF and ectomycorrhizal fungi. Table 3 shows one of their experiments, in which a commercial product of AMF (*Gigarospora margarita*) was inoculated on the soil surface beneath a sheet containing mixed grass seeds. After six months, the dry weight of the grass increased by 1.4-1.6 times compared to the control, and the level of infection by AMF was clearly enhanced by the inoculation.

Marumoto *et al.* demonstrated the effectiveness of their sheet by applying it to more than 50 field sites, including bare slopes of building construction sites, sites where golf courses were being developed, road construction sites and fresh deposits of volcanic debris. They are now attempting to improve their technology by utilizing mycorrhizal fungi. Their experiments show that the selection of plant species suited to the targeted soil, and also of species of endo-

and ecto-mycorrhizal fungi suited to the host plant, are very important.

UTILIZATION OF THE COMMERCIAL AMF PRODUCTS IN VEGETABLE PRODUCTION

A number of AMF products for inoculation are sold commercially in Japan. In May 1994, Idemitsu Industry, one of the biggest oil companies in Japan, launched its AMF product (Yorifuji and Suzuki 1955). The Central Glass Company then began to sell its AMF products through Tosho Central Trading Company. Before these two companies, Kyowa Fermentation Industry had been the first company in Japan to produce an AMF product and subject it to marketing tests, but abandoned actual marketing since it judged there would be little profit, in the context of Japanese intensive agriculture. Several other companies are now investigating the application of AMF to agriculture, and intend to market new products in the near future. As the sales of chemical fertilizers fall, affected by the environmental conservation movement and by the increasing costs of production, fertilizer companies are searching for alternative added-value technologies, of which AMF is one. In addition to stimulating the nutrient uptake by plants, it is hoped that AMF will prevent the infection by pathogens of roots. If they are found in fact to do this, a very large market demand might be expected, because soil-borne plant diseases are the most

Table 3. Stimulation of grass growth by inoculation with AMF

	Seed type	Dry weight (g/plot)		Infection %	
		Not inoculated	Inoculated	Not inoculated	Inoculated
I	Mugwort	45.67	50.74	10.9	49.2
	White clover	1.44	1.05		
	Mixed clovers	155.26	169.39	23.2	58.7
	Kentucky bluegrass	64.56	75.57	66.1	76.4
	Wind-borne weed species	100.78	287.36	30.2	76.1
	Total/mean	367.71 (100)	584.11 (159)	32.6	65.1
II	Bush-clover	127.30	147.52	28.7	85.4
	White clover	1.74	8.40		
	Mixed clovers	139.85	197.29	10.3	87.7
	Kentucky bluegrass	7.52	19.34	24.4	57.1
	Wind-borne weed species	117.05	182.80	39.3	78.7
	Total/mean	393.46 (100)	555.35 (141)	25.7	77.2

Plot size: 2 x 1.9 m. Bush-clover: Mixture of *Lespedeza cuneata* and *L. bicolor*

Source: Marumoto et al. 1996

serious limiting factor in Japan's vegetable production, where continuous cropping is widespread. Since the microbiological industry generally needs a relatively small investment, at least at the start, companies other than fertilizer producers are also competing to develop and sell AMF products.

Brief Description of Commercial AMF Products

Idemitsu Industry uses mainly strains of *Glomus*, with complementary strains of *Gigaspora* and *Scutellospora*. Central Glass uses strains of *Gigaspora*. Although the specificity of AMF is generally said not to be high, researchers at these companies have demonstrated that different strains may sometimes vary greatly in their ability to infect the roots of certain plants. Therefore, AMF products are composed of multiple strains, all with confirmed infection abilities. Spores and mycelia produced by the cultivation of host plants are packed with mineral carriers or peat moss. One AMF product sold by Idemitsu Industry has a water content of 15%, and should be stored at temperatures lower than 20°C. Activity can be maintained for at least two years if the product is stored at 5°C.

Effectiveness of Commercial AMF Products

AMF products are used mainly on vegetables such as eggplant, tomato, strawberry, sweet pepper, leek, asparagus and lettuce. They are not used much on flowers or fruit trees, although they probably will be in future. They will probably not be used on low-value crops such as cereals, soybean and pasture, because of the cost-benefit relationship.

In most cases, nursery beds are inoculated with AMF products, and the inoculated seedlings are planted out in the field. Usually nursery beds also receive 150-205 kg/ha of P₂O₅ fertilizer. Although this amount of phosphate seems to be excessive in terms of producing full AMF activity, the growth of seedlings has been reported to be increased significantly, by 20% or more, by AMF inoculation. Final yields of marketable produce were reported to be increased by 20-50%.

Vegetable farmers regard large, healthy seedlings as important in achieving higher yields and preventing soilborne diseases. A more noticeable stimulation of seedling growth could be expected if phosphate applications were reduced to a lower level. Even so, farmers might not be satisfied if lower

phosphate applications resulted in smaller seedlings. In intensive agriculture, the objective is not a reduction in chemical fertilizers, but a higher yield of better quality. Organic farming using reduced inputs might be able to utilize AMF products more effectively.

UTILIZATION OF PHOSPHATE SOLUBILIZING MICROORGANISMS

Japan has only very small amounts of rock phosphate, and most of its soils immobilize phosphate ions into unavailable forms. Rock phosphate which can be mined by current technology is predicted to become exhausted in about 100 years' time. Therefore, there is a strong interest in developing alternative sources of phosphate fertilizer. Many countries are studying the direct utilization of rock phosphate. Australia has developed "biosuper", i.e. pellets composed of rock phosphate, sulfur and sulfur-oxidizing bacteria. Japanese scientists are very interested in the solubilization of bound phosphate in soil which has accumulated phosphate from repeated, heavy applications of phosphate fertilizer.

While more than 70% of total phosphate is present in organic forms, such as inositol phosphate in volcanic ash soils, there are very few indigenous microorganisms with a strong ability to decompose inositol phosphate in the soil. On the contrary, Japanese soils contain many indigenous heterotrophic microorganisms which solubilize mineral bound phosphates by the excretion of chelating organic acids. In grassland soils, phosphate solubilizing microorganisms made up 1% of bacterial populations and 10% of fungal populations (Nishio 1985). Tinker (1980) raised doubts on the utilization of heterotrophic phosphate solubilizing microorganisms, because they need a large amount of organic matter before they can excrete organic acids. Even if phosphate is solubilized, phosphate ions are incorporated into the microbial biomass, so roots cannot absorb enough of them. Thus, we adopted the following strategy: a) The addition of a large amount of organic matter makes phosphate solubilizing (PS) microorganisms proliferate and these solubilize bound phosphate. b) Solubilized phosphates are incorporated into the microbial biomass during other microbial multiplication, using organic matter. c) Once the organic matter becomes exhausted, the microbial biomass decreases and releases phosphate into the soil. d) The death of the microbial biomass can be accelerated by various soil treatments, including tillage, drying, liming and sterilization. e) Plants can absorb phosphate after microbial proliferation has ceased. f) The absorption of phosphate by plants can be

accelerated by inoculation with AMF.

Experimental Evidence

Each step described above has been experimentally confirmed (Kimura and Nishio 1989). Fig. 4 shows the difference in biomass P (P retained in biomass) between the soils with and without compound phosphate. When the soil was incubated for 7 days by adding sucrose and ammonium sulfate, the biomass P significantly increased, utilizing Ca-, Al-, and Fe-phosphates and low-quality rock phosphate. However, no significant increase was observed with varicite (crystallized aluminum phosphate) over this short period. This indicates that insoluble phosphates which are not crystallized can be solubilized by indigenous microorganisms when abundant carbon sources are supplied.

The rate of increase in soil biomass P fell, and available phosphate increased, after the depletion of carbon sources, or after soil treatments such as chloropicrin fumigation, air-drying or grinding (Fig. 5). This indicates that after the exhaustion of organic matter, microbial biomass falls, releasing phosphate into the soil, and that the release of available phosphate can be accelerated by soil treatments.

To demonstrate the stimulatory effect of AMF on plant absorption of phosphate released from soil biomass, an experiment was conducted using dry yeast as an alternative to dead soil biomass. Fig. 6 shows that the simultaneous addition of dry yeast and AMF had a marked effect on both the growth of alfalfa and phosphate absorption by the plant.

Implications

Although this experimental evidence merely shows the principles underlying the technology, this is very useful when we attempt to utilize heterotrophic phosphate-solubilizing (PS) microorganisms in soil. It indicates that

- PS microorganisms need the addition of a large amount of organic matter as a substrate (excretes from roots are not sufficient);
- Phosphate solubilized by PS microorganisms is seldom absorbed directly by the plant as long as a large amount of organic matter remains, because other heterotrophs incorporate phosphate into biomass; thus,
- Growth retardation of the plant may be a possibility just after the application of

organic matter.

- To avoid growth retardation, seeding or transplanting should be delayed.
- If rock phosphate, basic sludge or other low-grade phosphate is added, pre-solubilization of bound phosphate in the compost is one way of avoiding growth retardation.

UTILIZATION OF MICROBIAL MATERIALS IN ORGANIC FARMING

The number of farmers following organic farming is increasing each year in Japan. The Ministry of Agriculture, Forestry and Fisheries adopted guidelines for organic commodities in 1993. These define organic produce as being produced in fields to which no chemically synthesized inputs, except for those permitted, have been applied for at least three years. Since crop production with no chemical inputs at all is very difficult in Japan, many farmers instead try to make minimal use of chemical fertilizer

and pesticides. Produce grown in this way is regarded as being related to organic food.

In terms of the plant nutrient supply, there are two types of organic farming. One provides plant nutrients from local resources, and the other uses commercial organic fertilizers. Most organic farmers in Japan use the latter type, i.e. commercial organic fertilizers, made from rape seed meal or soybean meal (both residues of oil extraction), meat and fish meal, bone meal etc. These supply sufficient plant nutrients to give relatively high yields. Local resources include green manures, composted livestock manure etc.

Utilization of Microbial Materials to Make "Bokashi"

Most Japanese organic farmers utilize what is known as 'bokashi', in addition to compost. 'Bokashi' is organic fertilizer which is briefly composted, to make it less attractive to pests. If rape seed or soybean meal is directly applied to soil, a

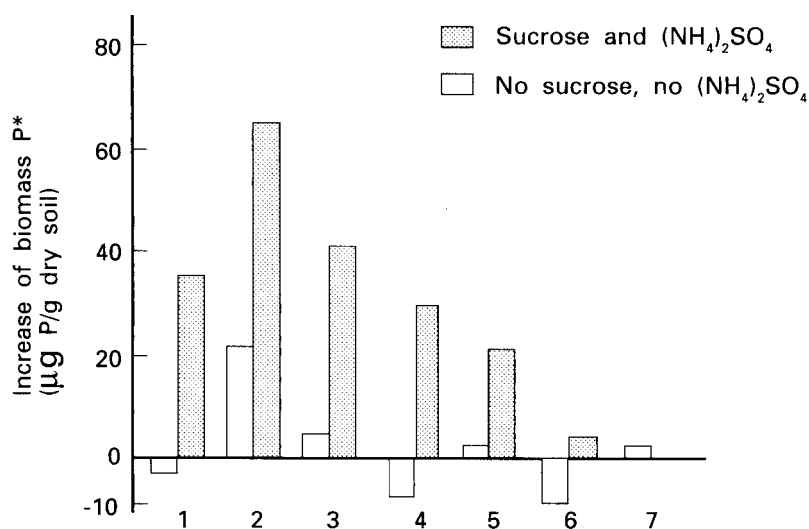


Fig. 4. Increase of biomass P after addition of sucrose to soil containing various forms of phosphate

Wet soil equivalent to 1 g of dry soil was supplied with 400 µgP phosphates except treatment 1, 30 mg organic matter and 0.1 mgN (NH₄)₂SO₄ and incubated for 7 days.

1. KH₂PO₄ (100 µgP/g dry soil). 2. KH₂PO₄ µgP/g dry soil. 3. Ca₃(PO₄)₂. 4. AlPO₄. 5. FePO₄. 6. Low-quality rock phosphate. 7. Variscite.

* Difference between soils with and without added phosphate.

certain fly (“tanebae”) lays eggs in it. The maggots feed on young seedlings just after germination and cause serious damage. Fishmeal also attracts field mice, which dig tunnels under the seed beds. To avoid damage of this kind, farmers developed on their own initiative a technique of composting organic fertilizers for a short period. Typical ingredients are shown in Table 4. These are mixed, and inoculated with microorganisms. Water is added to give a moisture content of 50-55%, and the compost is heaped into a pile. When the temperature of the pile reaches 50-55°C, the pile is mixed and spread out. After the compost has cooled down, it is again heaped in a pile. This microbial decomposition and cooling is repeated three or four times. The materials are then spread out to dry, and finally packed in bags for storage. The name of the product, ‘bokashi’, means in Japanese “obscuring the direct effectiveness”. The concentration of nitrogen in bokashi is much lower than in chemical fertilizer, ranging from 2 to 5% total nitrogen.

Since the original ingredients are dried materials, there are not enough microorganisms present to begin immediate decomposition of the organic matter. To avoid anaerobic fermentation, with its unpleasant odor, the compost is inoculated

with aerobic microorganisms which multiply rapidly. Because these microorganisms need oxygen and have no heat-tolerance, the pile is mixed and spread every one or two days. During the process of composting, easily decomposable organic matter is decomposed through the production of microbial biomass, liberating ammonium ions. The ammonium is retained on soil particles. The microbial biomass contributes to the slower release of nutrients with the residual ingredients. Overall, the aim of the process seems to be, firstly, to decompose substances which attract pests, and secondly, to create a slower-acting organic fertilizer.

The production of bokashi in Japan seems to be increasing. Many organic farmers engaged in vegetable production use bokashi when they limit the water supply to plants. Plants under water stress increase the osmotic pressure in their fluid by increasing concentrations of mono- and oligo-saccharides instead of starch. This results in a higher level of sugars and vitamins in the vegetables, as well as a longer post-harvest storage life. These attributes raise the quality of the produce. When vegetables are being cultivated in a state of water stress, the application of ordinary chemical fertilizers is very difficult, because a rapid increase in the concentration of

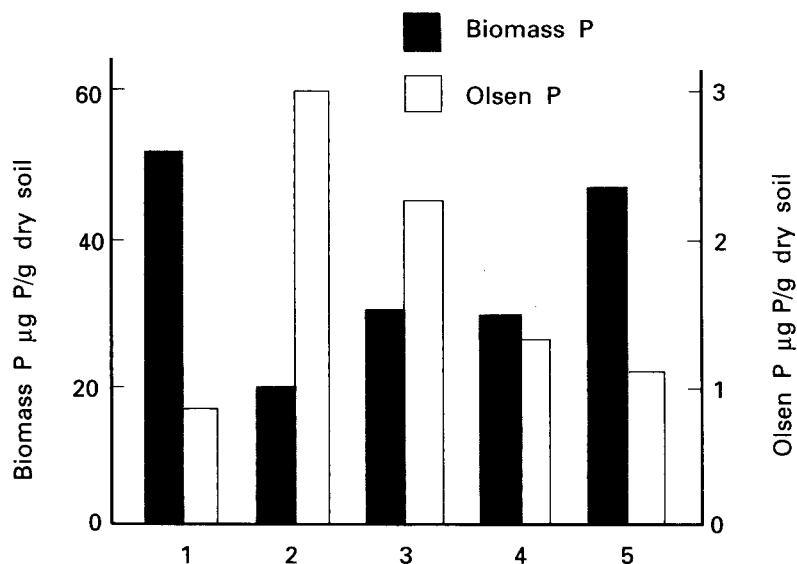


Fig. 5. Effects of various treatments of soil on biomass P and available P (Olsen P) in soil

Measurements were made after incubation for 24 h following the treatments. 1. No treatment. 2. Chloropicrin fumigation. 3. Addition of Ca(OH)₂. 4. Grinding. 5. Freezing and thawing.

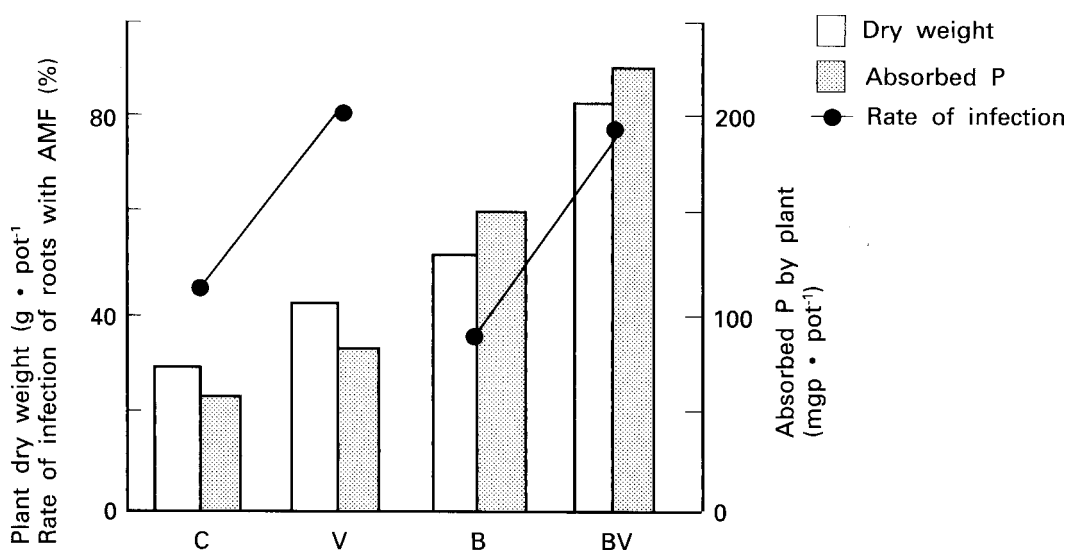


Fig. 6. Influence of addition of dry yeast to soil and inoculation of soil with arbuscular mycorrhizal fungi (AMF) on growth of alfalfa, absorption of P by alfalfa and infection of roots with AMF

C: control; V: inoculation of spores of AMF; B: addition of dry yeast which simulates dead soil biomass

mineral nutrients in a small amount of soil water frequently damages plant growth. Although slow-acting fertilizers can avoid these difficulties, organic farmers prefer bokashi because it is organic.

Although many microbial products are sold in Japan, except in a few special cases, they are not microbiologically defined, i.e. the microorganisms they contain are not identified, and merely described in terms of their hoped-for results. Products which not only identify the microorganisms, but quantify them, are very rare. Fortunately, the microorganisms effective in bokashi production are not restricted to a special group, but are very common species which can multiply rapidly in ordinary composting materials. No serious problems have occurred in bokashi production, with one interesting exception.

Is “EM” Really an Effective Microorganism?

What is “EM”?

This exception is “EM”, standing for “effective microorganisms”. EM products were developed by T. Higa of Ryukyu University, Okinawa. They contain abundant anaerobic lactic acid bacteria and yeasts, as well as other microorganisms. The

utilization of these anaerobic microorganisms is a distinctive feature which distinguishes EM from other microbial products. EM first attracted notice in garbage treatment by local governments that were struggling to cope with the increasing amount of garbage. The EM manufacturer claimed that individual households could make “compost” of good quality in one or two weeks using a sealed plastic bag or container containing cooking refuse mixed with an EM product. Although anaerobic fermentation usually generates an unpleasant odor, EM products were claimed to suppress any bad smells by producing lactic acid. Higa claimed that the “compost” thus prepared could be used in a home garden or distributed to farmers. This idea attracted local governments, who hoped it would cut down on the cost of garbage treatment, as well as citizens who appreciated the importance of recycling. The “compost” thus prepared, however, has a very high water content, because water vapor cannot escape from a sealed bag. It also contains a large amount of available organic matter, because the decomposition of organic matter is incomplete, as with the making of silage or pickles. Incorporating available organic matter into the soil causes an explosive proliferation of pathogenic “sugar fungi” such as *Physium* and *Rhizoctonia*. Therefore, many crop failures have occurred when seeds were sown just after applica-

Table 4. Typical ingredients in 'bokashi'

	Weight	N	P ₂ O ₅	K ₂ O
Subsoil from mountain	500			
Rapeseed meal	200	10.0	5.0	2.2
Chicken manure	170	6.4	4.6	2.2
Fishmeal	50	4.7	2.1	0.3
Bonemeal	50	2.0	11.5	0.3
Rice bran	30	0.5	1.1	0.4
Total	1,000	23.6	24.3	5.4

tion of the "compost". Some farmers' groups are now making bokashi from this garbage compost by drying it, mixing it with other materials, and composting this mixture further.

"EM Bokashi"

Apart from compost made from household wastes, farmers are also making bokashi, using EM products under anaerobic conditions, from other ordinary organic materials. Higa claims in his book that a revolution in agriculture is possible, since the use of EM products increases greatly the yield of crops. For example, rice fertilized with EM bokashi produced brown rice yields of more than 12 mt/ha.

I. Goto and a colleague of Tokyo Agricultural University carried out some field experiments in cooperation with the EM company. They analyzed EM bokashi supplied by the company and also bokashi supplied by farmers, and showed that the samples contained on average 40 kg N, 30 Kg P₂O₅ and 13 kg K₂O per 1000 kg, much the same as ordinary bokashi (Goto and Muramoto 1995). EM recommends the application of 1000 kg/ha of EM bokashi, but the input of 40 kg of nitrogen contained in this amount is not sufficient for the full growth of vegetables. Goto examined the crops of farmers who use EM bokashi, and found that the yield of lettuce from 1000 kg of EM bokashi was much the same as that from ordinary commercial organic fertilizer, when the nitrogen levels were adjusted. He also found that farmers generally applied 30 mt/ha of cattle manure in addition to the EM bokashi, and pointed out that the yields obtained by the farmers may have been greatly supported by the manure. When in fact vegetables were cultivated with only 1000 kg/ha EM bokashi alone in the fields of the University, he found that the yields of many veg-

etables were only half those obtained by ordinary practices (Muramoto and Goto 1995). Later, researchers of EM reported that when the nitrogen level was adjusted to 100 kg/ha, EM bokashi (2500 kg/ha) yielded the same quantity of lettuce as chemical fertilizer (Iwahori *et al.* 1996). Therefore, they insisted that the standard amount of EM bokashi which should be applied was 2500 kg/ha for lettuce, and criticized Goto for using an insufficient amount. These experiments seem to show that EM bokashi is no revolutionary step forward, because when it is used, vegetables need the same level of nitrogen as when they are given chemical fertilizers. Goto claims that EM bokashi is nothing but ordinary bokashi, and has no special qualities (Goto *et al.* 1996).

UTILIZATION OF AZOLLA IN ORGANIC PADDY FIELDS

Although *Azolla* has seldom been utilized by Japanese farmers, regardless of experimental results in research institutes, the recent trend towards organic farming shows signs of changing the situation. A common practice in organic rice production is to release ducklings, usually hybrids of domestic ducks and wild ones, into paddy fields. The webs of their feet disturb the soil surface in the shallow water, and remove the young seedlings of weeds, thus controlling weeds without herbicides. I. Watanabe, who studied *Azolla* at the International Rice Research Institute, speculated that this soil disturbance would suspend soil particles in the water, thus increasing the availability of phosphate adsorbed on soil particles to *Azolla* floating on the water surface. He made contact with a farmer and proposed his idea. They carried out experiments in 1995 in the farmer's paddy field, inoculating *Azolla*

in early May without fertilizer. The *Azolla* increased very rapidly, and covered the whole field just like a carpet. The *Azolla* biomass was estimated to be 28 mt/ha on June 25. Subsequently, some of the *Azolla* was eaten by birds, and was reduced by about 30% by July 14. Since the *Azolla* supplied too much nitrogen to the rice, some of the plants collapsed, and the yield of brown rice was only 4.36-4.5 mt/ha (Huruno 1995). This experiment is likely to trigger off widespread utilization of *Azolla* in Japan.

REFERENCES

- Goto, I. and J. Muramoto. 1995. Chemical properties of EM bokashi. *Proceedings of the Japanese Society of Soil Science and Plant Nutrition* 41: 158. (In Japanese).
- Goto, I. *et al.* 1996. Cultivation of vegetables in the field with EM bokashi. *Proceedings of the Japanese Journal of Soil Science and Plant Nutrition* 42: 171. (In Japanese).
- Higa, T. 1993. The revolutionary change that will save the earth. *Sunmark, Tokyo*, p. 222. (In Japanese).
- Huruno, T. 1995. Simultaneous production of rice and hybrid ducks (3). *Gendai Nogyo* 9: 188-191. (In Japanese).
- Huruno, T. 1995. Simultaneous production of rice and hybrid ducks (4). *Gendai Nogyo* 11: 192-195. (In Japanese).
- Huruno, T. 1995. Simultaneous production of rice and hybrid ducks. *Gendai Nogyo* 12: 202-205. (In Japanese).
- Iwahori, H. *et al.* 1996. Utilizing method of EM bokashi for vegetable production. *Proceedings of the Japanese Society of Soil Science and Plant Nutrition* 42: 171. (In Japanese).
- Kimura, R. and M. Nishio. 1989. Contribution of soil microorganisms to utilization of insoluble soil phosphorus by plants in grasslands. *Proceedings of the Third Grassland Ecology Conference, Czechoslovakia*, pp. 10-17.
- Marumoto, T., H. Okabe, T. Ezaki, M. Nishiyama and K. Yamamoto. 1996. Application of symbiotic microorganisms to soil conservation and reforestation. *Proceedings of International Symposium, Bio-Japan, Tokyo*, pp. 242-250.
- Muramoto, J. and Goto, I. 1995. Field cultivation of vegetables with EM bokashi. *Proceedings of the Japanese Society of Soil Science and Plant Nutrition* 41: 159. (In Japanese).
- Nishio, M. 1985. Some ecological features of phosphate-solubilizing microorganisms in grassland soils. *Proceedings of the XV International Grassland Congress, Kyoto, Japan*, pp. 483-485.
- Nishio, M. and S. Okano. 1991. Stimulation of the growth of alfalfa and infection of roots with indigenous vesicular-arbuscular mycorrhizal fungi by the application of charcoal. *Bulletin of the National Grassland Research Institute* 45: 61-71.
- Ogawa, M., Y. Yambe and G. Sugiura. 1983. Effect of charcoal on the root nodule and VA mycorrhizal formation of soybean. *Proceedings of the Third International Mycology Congress, Tokyo, Japan*, p. 578.
- Tinker, P.B. 1984. The role of microorganisms in mediating and facilitating the uptake of plant nutrients from soil. *Plant and Soil* 76: 77-91.
- Yorifuji, T. and M. Suzuki. 1995. *Practical Use of Mycorrhizal Fungi: Effectiveness and utilization of Dr. Kinkon (Kinkonkin No Ikasi Kata)*. Nobunkyo, Tokyo, Japan. 167 pp. (In Japanese).