Vermiculture Industry in Circular Economy

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Abstract

This paper reviews the history of vermiculture, indicating it is an important component of macro-agriculture. Earthworms seem to be the missing link of ecological agriculture in China. Earthworms can treat large amounts of organic garbage, livestock manure and poultry droppings and turn them into premium organic fertilizers, and thus could greatly improve the ecological environment in rural areas to restore the fertility of the soil because humus only exists in earthworm feces and castings compared with other fertilizers. Earthworms can supply quality animal protein for feed and even for human consumption, and offer the best raw materials for biochemical and pharmaceutical industries. As industries and agriculture develop and urban construction is booming, the discharge of wastewater and sewage soars and wastewater treatment plants are set up everywhere around cities; stabilizing the sludge presents a big challenge and earthworms could play an important role in facing this challenge. Vermiculture should be oriented to stabilize sludge and organic wastes in circulation economy, for it is an approach to sustainable agriculture and a measure in promoting organic farming so as to break technical barriers of production in international trade. It should be supported by policies under the guidance of scientific development viewpoint and be put into whole circulation economy as a means of protecting the environment, maintaining ecological balance, and fully utilizing resources. However, it should be combined with other technologies such as EC (electro-coagulation), EH (energized hydrolyser), and especially EM (effective microorganisms). We should promote courtyard earthworm composting as well as large-scale vermiculture, which should be mechanized and automated.

Keywords:

Vermiculture, macro-agriculture, sludge stabilization, circular economy, earthworm composting

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Background

3000 years ago written record on earthworms appeared in The Book of Songs. Up to Warring Period (475-221 BC) Xunzi described earthworms, with neither sharp teeth and claw nor strong bone and muscle,□ could however feed on dust at the upper layer and drink from netherworld at the lower in his Article to encourage learning. Earthworms have been introduced into medicines in China for more than a thousand years. In the West, the Greek philosopher Aristotle (384-322 BC) called earthworms the intestines of the earth. He believed that soil was an organic entity and he understood that earthworms played an important role in maintaining the life of soil. But even at the end of 19th Century, some Westerners still thought that earthworms would eat the roots of plants and so hinder the growth of plants and destroy crops, and thus they suggested earthworms be killed. The reputation of earthworms was not rehabilitated until Darwin published his works on **The Formation of Vegetable Mould Through the Action of Worms with Observations on their Habits** in 1881. It indicated that the understanding of earthworms in ancient China was earlier than in

the West, whereas vermiculture (the scientific name for worm farming) in China now lags behind the West.

Since adopting economic reform and open policies China has started to throw away narrow-minded agricultural concepts with grains as its core sector, while promoting the development of macro-agriculture and diversification to develop crop planting, forestry, animal husbandry, side occupation and fisheries simultaneously. The well-known scientist Qian Xuesen says that five sectors are not enough for macro-agriculture, and in addition we should have apiculture, vermiculture, snail culture, edible fungi, fodder grass, etc. He has put forward his concept: the 6th Industrial Revolution---Macro Agriculture Revolution would be launched in China not later than the 2030sâ€. He thinks that once the concept of macro-agriculture is put into practice, it is the beginning of the 6th Industrial Revolution in the world Earthworms are an important part of macro-agriculture.

Necessity to develop vermiculture industry

As agriculture modernization speeds up, the livestock, poultry and fishery sectors are marching on the road of intensive management development. Since 1988 when China put Vegetable Basket Engineering into effect, million-broiler farms, thousand-pig farms, hundred-cow farms and large-sized aquaculture farms have been founded everywhere. Intensive managed sectors are approaching the suburbs of cities and densely populated areas. On the one hand it greatly improves the living standards of the inhabitants of cities and towns; on the other hand there is neither sufficient land to utilize the livestock manure and poultry droppings produced from animal husbandry, nor abundant water resources to self-purify the effluent from aquaculture ponds, resulting in two problems: scarcity of quality feeds, and serious pollution of soil, air and water. Traditional organic manure looks dirty, smells, and is full of pathogenic bacteria. In vast countryside it was labor saving and easy to use that this has promoted the application of large amount of chemical fertilizers for years as a result the fertility degraded, the soil hardened and impervious. This is what would come from fossil fuel agriculture in developed country. Now the UN has proposed the concept of sustainable development and China also proposed the developmental concept of ecological agriculture. No matter what we call it, zero emissions research initiative in recent decades or circular economy at the beginning of this century, vermiculture should be an important part of macro agriculture, an important link in the agricultural circular economy which is internationally called Integrated Biomass Systems (IBS). But in a book which comprehensively described Waste treatment and reuse of wastes in ecological agriculture there is not a single line mentioning earthworms [1]. We have to say that earthworms seem to be a missing link in ecological agriculture in China. Earthworms can treat organic wastes, livestock manure, and poultry droppings, and turn them into quality organic manure and greatly improve the ecological environment in rural areas. Earthworms are also a very good food source, with crude protein in dry weight reaching about 70%, and an excellent industrial raw material as well. Many enzymes and active matter can be extracted from earthworms for pharmaceutical, food, cosmetics and environment protection. Owing to the development of industry and agriculture and the boom in urbanization, the discharge of industrial and agricultural wastewater and sewage effluents has rapidly increased. Thus there are many wastewater treatment plants established around cities. How to stabilize the sludge from those plants is an urgent challenge, and earthworms can play a unique role to stabilize sludge in the circular economy as a whole.

Status of the vermiculture industry

In the late 1970s, thousands of Americans were victimized by hucksters claiming that backyard worm breeders could easily gross over $14,000 a year by tapping the wrigglers' potential as bait, soil enrichers, and even food. Vermiculture collapsed at the end of 1970s. Up to the environment-friendly 90s, the feeding habits of earthworms which consume large amount of rotten food made them a viablewaste-disposal alternative. The tiny creatures' ability to devour virtually any organic waste--livestock manure, rotten food, even ratty T-shirts--and excrete it as premium organic fertilizer (dubbed "black gold" by organic farmers for its nitrogen richness) is proving profitable for a host of non-squeamish entrepreneurs. Earthworms are the missing link that makes sustainable agriculture a reality. Vermiculture is booming thanks to environmentalism and the demand for organic foods. Vermiculture ventures in America, the biggest of which involve 50 million worms chewing down on almost 90 tons of waste per week, have boomed over the past few years. Nearly 300 large-scale vermi-culturalists formed the International Worm Growers Association in 1997 to help promote the trade. Many outfits are prospering thanks in part to the growing popularity of organic foods, which became a $6.5 billion-a-year business by 2000. With the U.S. Department of Agriculture estimating that 25 percent of Americans purchase organically grown foods at least once a week, organic farmers' demand for worm feces far outstrips supply.

Vermicycle Organics, which harvests worm droppings in high-tech greenhouses, produces 7.5 million pounds of a natural fertilizer a year. The company expects sales of the fertilizer to grow by 500 percent this year. Vermi-technology Unlimited has doubled its business every year since 1991, despite prices that can run twice as high as those of synthetic fertilizers. Vermi-technology founder Larry Martin predicts that "In 5 to 10 years, every commercial fertilizer company will be selling worm castings." With many local and state governments trying to divert waste from clogged landfills, forward-thinking cities are promoting "backyard vermin-composting." Traditional compost piles can take weeks to produce low-quality humus; a pound of worms, on the other hand, needs only 48 hours to convert a pound of waste into nutrient-rich castings. In San Jose, California, where state law has mandated that the amount of garbage going to landfills be cut in half by the year 2000, about 1,200 residents used city-distributed discount vouchers to purchase garbage-eating worms from Chambers's Worm Farms. This small operation sells 4,000 pounds of worms a year--about 4 million of the critters--at around $20 per pound [2].

In the 1970s several species of earthworms were cultured in simulated natural ecological conditions in China, the same as in North America. On the one hand it met the marketâ€™s demand for aquaculture, livestock and animal husbandry as quality protein feeds with high performance-to-price ratio, and also the pharmaceutical industryâ€™s demand for raw materials; on the other hand it was somewhat a profiteering activity as well. Especially after the Japanese premier presented the hybrid of red wiggler and local earthworm as a gift to China, it aroused a small boom in vermiculture in many places, but in a small and scattered scale with low technology, low unit yield (about 3 tons/mu/year), and competitive for land with crop planting. The direction of rearing earthworms fell wrongly on selling earthworm breeding stock to farmers for profit only, not for waste disposal on a large scale and selling earthworm feces and castings to improve the soil. In recent decades vermiculture has experienced ups and downs owing to the fluctuation of market requirements, narrow developmental concepts, and a lack of science and technology support or integrated development capability. In some places there is almost no vermiculture industry except scattered and sporadic farms.

Where is the orientation of vermiculture ?

l Organic waste disposal

In other countries vermiculture has been promoted to stabilize sludge and other organic wastes for 50 years, while vermiculture in China is still a side occupation of households. There is no large earthworm farming facility to treat large amounts of organic wastes. This is due mainly to a lack of scientific guidance and of awareness that earthworms can play an important role in a circular economy. Certainly the constraints of commercial application come from many factors such as engineering, investment, risks in the process of production, high cost, and lack of policy support.

Many cities in the world are surrounded by garbage; for example, the world garbage capital New York City produces 11,000 tons of garbage each day[3]. The cost of landfill is higher and the land is less available for garbage. Thus many countries seek to avoid sending organic waste to landfills through legislative measures. In order to control water pollution and to use wastewater as resources China brings forward its clear requirements of wastewater treatment for cities: by 2005 the wastewater disposal rate from cities with a population of 500,000 should reach 60%; by 2010 the wastewater disposal rate from all cities should not be less than 60%; for cities under direct jurisdiction, provincial capitals, independent cities out of planning, and tourist cities the wastewater disposal rate should not be less than 70%. How to deal with huge amounts of sludge is a challenge faced by many big cities.

In general we call the stabilization and dehydration (reduced to the moisture 70-80%) of sludge the treatment of sludge; we call compost, landfill, drying and heating and final treatment the disposal of sludge. There are two methods to stabilize sludge, one aerobic and the other anaerobic. Aerobic treatment has many advantages but consumes a great deal of energy. Anaerobic treatment adopts anaerobic digest methods at medium temperatures (35â„ƒ). After the sludge has been digested, organic matter will be reduced and performance stabilized, and total volume reduced. During the digestion the large amount of biogas which are produced (1kg COD can produce 350L biogas) can be recovered for use [4]. Stabilizing sludge by earthworms is considered the most attractive option [5] [6] [7]. The method is to mix sludge with solid garbage from cities, bark, and sawdust, and to feed this mixture to earthworms [8]. The development and application of earthworm technologies are most often performed in temperate climates, but Vermibloc in Russia developed year-around vermiculture methods in the northern harsh and temperate climatic conditions.

Tests predict that building an earthworm culture farm which can treat 55,000 tons of garbage a year can produce 2,500 tons earthworms and 18,000 tons of earthworm feces a year. It can reimburse the investment in construction of the farm in about one year, saving the energy otherwise consumed to burn garbage in incinerators and avoiding secondary pollution to air and water. Every wastewater treatment plant should have its own earthworm culture farm. An earthworm culture farm in Los Angeles in America rears 1,000,000 earthworms and can treat 7.5 tons of garbage each month. Each earthworm can usually treat 0.3 g of garbage a day. If one wants to treat 1 ton of sludge from a paper mill per day he needs to culture more than 3,000,000 earthworms. Some countries use earthworms to collect heavy metals because their capability to collect heavy metals such as cadmium, lead, and mercury is 2.5-7.2 times greater than that of soil alone [9].

Australia uses dehydrated sludge direct from a water plant without compost to feed earthworms. Earthworm treatment systems are installed in many sites. Redland in Brisbane, Queensland, is the largest installation in

Australia, which has a capacity of 400 m^3 per week. They first analyze the input contaminants of sludge, mix it with clean organic material so as to reduce the ultimate level, and then to feed earthworms, thus making earthworm castings to meet the stabilization standards Grade A or B for permission to be sold. Vermiculture in large scale provides an ecological, commercial and sustainable stabilization method to replace compost and limestone stabilization. This has several advantages: no pollution, no odor, and no leaching; low cost; installation set up near the wastewater treatment plant; transportation of sludge is avoided; it is possible to treat organic wastes from other regions; and the production of quality products to supply new markets.

l Call for castings to improve soil

Macro agriculture must have earthworms. It is imperative that all of us reach a unanimous conclusion: society must return to nature and human beings and nature should develop in harmony in co-evolution, and we should return badly needed organic matter back to the soil. Farmers have now realized they should change their production practices and reverse the degradation of soil, and they must use earthworm castings to replace chemical fertilizers or crop yields and quality will both fall further, with fruits and melons no sweet. Darwin wrote in â€œEarthworms and plant loamâ€ in 1837 that â€œearthworms as a plough is one of the most ancient valuable inventions of human being. Long before human society emerged soil had been ploughed, have been now ploughed and will be continuously ploughed by earthworms afterwardsâ€. Earthworms are called â€˜living ploughsâ€™ by virtue of their excellent ability to loosen soil, gather nutrients and increase fertility. In general the land ploughed by earthworms for 3 years will become high yielding land. Healthy soil is rich in minerals, soil microorganisms, earthworms and humus. Earthworms loosen the soil as they move through it. Air and water can penetrate soil through earthworm tunnels. Earthworms climb up to the surface of soil to grab remnants of plants and feed in tunnels and thus fertilize all strata of soil. One square meter of healthy soil contains 1,000 earthworms. According to the estimate of an American researcher, 1,000,000 earthworms in a garden plot provide the same benefit as three gardeners working 8 hours in shifts all year round, and moreover having 10 tons of manure applied in the plot [8].

But what soil needs is not only manure, but more importantly humates, the salts of humic acids. Compared with other manures, only earthworm feces contain humic acid [Table 1]. Without humus and humic acids plants cannot grow and survive. Humic acids are found in humus, and humus is formed by the decomposition of vegetable and animal matter. The humic acids (humic, ulmic and fulvic) are essential to plants in three basic ways: humic acid enables plants to extract nutrients from the soil; ulmic acid stimulates and increases root growth: and fulvic acid helps plants overcome stress and helps dissolve unsolved minerals to make organic matter ready for plants to use. Humates help aerate the soil and increase moisture retention. As any vegetable and animal matter decomposes it produces humus. Often people confuse organic fertilizers such as manure or sludge with humates. Manure, sludge and other waste products require a period of time to further decompose so as to become active and available to benefit the soil and plants. Time makes humus. The Romans were aware of humus, but it was not until the 18th century that scientists discovered the humic acids, and not until the early 1960â€™s was science able to find a way to analyze humus and humates to determine their humic acid content. For mankind and the environment, unfortunately, research grants to agricultural universities abroad have come primarily form the commercial fertilizer companies, many of who considered humates a competitor. Therefore, the effectiveness of humic acids has not been widely published. Humates time has now arrived. More and more people are aware of the Earth's environment. More and more people are aware of the effects of chemicals and fertilizers on the soil and the fact that our soil has become depleted and worn out. Research has shown that humates can restore the vitality of the soil and increase the soils capacity to retain moisture, and even help chemical fertilizers become more effective. Earthworm feces are also better than other organic fertilizers in other ways: they generate no mold or odor, they conform with hygiene requirements, and can be preserved for a long time. The value of earthworm castings is much better. The result recently achieved by Lunt and Jacobson of the experimental station in Connecticut indicates that

compound nitrogen, available phosphorus and potash in earthworm castings are 5 times, 7 times and 11 times upper soil respectively. China Agriculture University further hydrolyzed earthworm protein to extract compound amino acids and has developed a new generation of amino acid fertilizers and amino acid insecticides.

Table 1 Comparison between nutrient contents of earthworms and manure (%)

	TN	TP	TK	C	Humus	Organic matter	Moisture
Worm feces	0.82	0.80	0.44	16.51	7.34	29.93	37.06
Cow dung	0.32	0.25	0.16	-	-	14.50	83.03
Pig manure	0.60	0.40	0.44	-	-	15.00	81.50
Horse manure	0.58	0.30	0.24	-	-	21.00	75.80
Sheep drops	0.65	0.47	0.23	-	-	31.40	65.50

l **Source of animal protein feed**

It is an ancient practice in China to feed earthworms to livestock and poultry, i.e. to dig earthworms from fields to feed chickens and ducks or to graze chicken and ducks to feed on earthworms at ease. Earthworms are rich in nutrients with high protein. According to measurements, the crude protein in dry earthworms reaches about 70%, while in wet earthworms about 10-20%. The amino acids of earthworm protein are complete, especially the contents of Glutamic acid, Leucine and Lysine, among which Arginine is higher than fish meal, and Tryptophan is 4 times higher than in blood powder, and 7 times higher than in cow liver. Earthworms are rich in Vitamin A and Vitamin B. There is 0.25 mg of Vitamin B_1 and 2.3 mg of Vitamin B_2 in each 100 g of earthworms. Vitamin D accounts for 0.04%-0.073% of earthworms wet weight. In view of the great effects of El NiÃ±o, fish meal from Peru cannot meet the market demand in the world. Thus earthworms are the best substitute with the functions of supplements, anti-diseases and allurement. Earthworms are used as additive to produce pellet feeds in the USA, Canada and Japan, which account for 50% of the pellet feed market [9]. However, when earthworms are used as feeds one must note that earthworms degrade quickly and should be processed within several hours by hot wind or freeze drying. In general earthworms contain more pollutants than fish meal because it is hard to clean residues from the epidermis and seta of earthworms. Some people realize that it is better to feed earthworms in wet. For fowls the earthworm amount could reach 50% and for swamp eel 100%.

Earthworms are the best bait for anglers. Pay attention to the palatability of various species of earthworms. It is said that **Eisenia foetida** can produce a substance fish do not like. In Australia they culture 3-4 species of earthworms: red wiggler **Lumbricus rubellus,** Indian blue **Perionyx excavatus**, African earthworm **Eudrilus eugeniae**, and **Eisenia foetida.** Different fish prefer different species of earthworms as bait, but according to Rodriquez et al. from Colombia, the palatability of earthworms is out of question [10]**.**

The protein content of earthworms is complete, containing 8-9 essential amino acids for human beings, including 9%-10% tasty glutamic acid. Compared with other meat, the protein of earthworms is higher than

meat and the lipid, 2% lower than meat. From the view point of health, earthworms might be one of ideal food with high protein and low lipid for human beings. In southern China and Taiwan people used to eat earthworms. There are many dishes of earthworms: mincemeat of earthworm as stuffing for dumplings to increase delicacy and prevent it from going bad. It is said that spiced sauce from ROK has a big market in SEA. For human consumption a worm farm should use beer spent grains or mushroom spent substrate to feed earthworms. The Edible Fungi Scientific Center in Qingyuan Zhejiang as well as Shanghai Academy of Agriculture has developed artificial logs which do not require pure hardwood chips. Each year Qingyuan produces some 50,000 tons of used logs. This substrate of shiitake **Lentinus edodes** could also generate as much as 5,000 tons of earthworms and in turn can be processed to quality human food. It is said that there are 200 kinds of food from earthworms in the U.S.A.

l **Raw materials for pharmaceutical biological medicines fracture healing**

The earthworms called â€œearth dragonâ€ in China have been used as an important ingredient in traditional Chinese medicine recipes. â€œCompendium of Materia Medicaâ€ by Li Shizhen (1518-1593) listed 40 usages, such as allaying a fever, alleviating pain, smoothing asthma, lowering hypertension, anti-bacteria, anti-convulsions, dilating blood vessels, expediting child delivery, relieving impotence, promoting lactation, tonic, and protecting the skin. As biochemical technology develops some effective medicinal compounds can be extracted from earthworms such as Lumbritin, Lumbrofebrin, and Terrestrolumbrolysin and several enzymes such as Lumbrokinase (Milhara et al. 1983).

CAS Biophysics Research Institute developed Lumbrokinase in 1984; it was appraised by specialists in 1987 and also gained a medicine license in 1992 from the Health Department. This technology was transferred to Jiangzhong Pharmaceutical Co. and Double Dragon Pharmaceutical Corp. Ltd. in 1992 and 1995, respectively. Slovak and Holland scientists adopted Contifocuser, a novel continuous flow iso-electric focusing apparatus to extract five enzymes on a medium-sized industrial scale: eisenase, fellulase, fetilase, fetipase and wormase [11]. Fibrinolysin is an enzyme extracted from earthworms which has high cellulolytic activity as well as proteolytic activity. It can reduce the viscosity of blood and apparently has beneficial effects on paralysis of limbs or aphasia caused by cerebro-vascular disease. The main function index of this type of fibrinolysin is better than urikase, streptokinase and other types of fibrinolysin. It has been predicted in medical circles that the man who found collagenase would succeed in curing thrombus-type diseases. The researchers of Zhongyuanwei Pharmaceutical Company have found highly active collagenase in earthworms, which cleaves peptide bonds in timeworn, triple-helical collagen. Because of its unique ability to hydrolyze timeworn collagen, it can be used to cut the strong outer cover of an old thrombus. It enables the other two enzymesâ€”fibrinolysin and fibrinokinaseâ€”to enter into the thrombus, and dissolve the thrombus. Then, the plugged blood vessel is once again opened up and the oxygen supply restored. Qinghua University has recently obtained a patent for the extraction of four medicinal compounds from earthworms using modern biotechnology methods: a large molecular compound, which has some anti-carcinogen functions; a medium molecular compound, which has some active efficacy in anti-thrombosis & thrombus dissolution; a small molecular compound, which contains 17 kinds of amino acids, polymers, trace elements and vitamins; and a 4th product which can cure burns and scalds [12]. According to the statistics of the World Health Organization (WHO), about 12 million people die of cardiopathy and cerebro-vascular diseases each year. As reported, 2 million people die of cardio-vascular disease each year, and 900,000 people die of cerebro-vascular disease. In large cities, the incidence of these diseases reached more than 20% of the population. The forecast indicates demand for 199.8 million capsules. Medicines and health products extracted from earthworms include anti-carcinogen â€œfunaikangâ€, â€œxuezhikangâ€ (Beijing University), thrombus dissolving capsule (Shanxi), â€œlongjing capsuleâ€ (Nanjing), Qinghua No. 2 (Qinghua University), â€œlongmaikangâ€ (Wuxi Jinchang), etc. Moreover there are earth dragon syrup, wine, and bone connecting powder, etc.

Measures taken in vermiculture industry

l First of all we must deepen our understanding that vermiculture industry is an important part of developing macro-agriculture, an approach to sustainable agriculture getting away from the side effects of fossil fuel agriculture, and a measure to cope with the technical barriers from other countries in developing organic farming.

l We must work out correct policies to help develop the earthworm industry under the guidance of scientific development concepts.

Vermiculture industry must be put into the whole circular economy so as to make it an important means to protect the environment, maintain ecological balance, utilize resources, and stabilize sewage sludge. Worm farms should be an indispensable part of every wastewater treatment plant and urban garbage treatment facility. Vermiculture must combine with EC (electro-coagulation), EH (energized hydrolyser), and EM (effective micro-organisms) [13]. The installation of the former two technologies is readily supplied at home and abroad. EC technology is used to absorb heavy metals to decompose the residues of agricultural chemicals. EH technology is used to sterilize bacteria, to eliminate toxins, to deodorize, and to turn large molecules into small molecules which can be easily absorbed by plants. EM contains more than 80 probiotics including photosynthetic bacteria, lactic acid bacteria, yeast, actinomycetes, fermenting fungi such as Aspergillus and Penicillium, nitrogen fixing, phosphorus dissolving, and potassium dissolving micro-organisms, sillico bacteria, mainly aerobic bacteria as well as anaerobic bacteria and facultative bacteria. EM developed by Professor Teruo Higa at the University of the Ryukyus in Okinawa, Japan was introduced into China at the end of 1980â€™s, and was tested in the 1990s. The result proved that it could increase yields and could be widely used in various aspects. After application of EM in animal husbandry it can raise the feed conversion rate, eliminate odor in livestock barns and poultry houses, improve the environments of animals, strengthen the health of animals; promote their growth, raise their propagation and survival rates; improve the quality of products; manure and excreta could be used as quality fertilizers; and reduce or even eliminate the need for antibiotics so as to produce green food. Applied in environment protection it can promote dissolution of organic pollutants, reduce BOD and COD so as to purify water; raise the purifying capacity of wastewater treatment systems so as to reduce the amount of sludge and cost; eliminate odors in the environment, restrain the growth of pathogenic bacteria; and dehydrate sewage sludge with no breeding of flies and mosquitoes. The degradation of EM strains in many places is serious after its introduction into China. In recent years only Fengben Brand is the most effective. If earthworms are used to treat manure it is better to use EM technology during animal raising and it will greatly increase the efficiency of vermiculture and improve its quality.

l Vermiculture industry should be done on a large scale so as to permit mechanization and automation. Simultaneously we should promote courtyard earthworm compost if the conditions permit. There are many earthworm bins on sale and the local government should give some subsidy for household to buy them, among which multi-tray worm bins are better (see Fig. 2).

l For different earthworm products we could use different wastes, e.g. for earthworm products such as animal feeds or for human consumption, the wastes fed to the earthworms might include used mushroom substrate, residues from citric acid plant, sawdust, crude bran, fruit peel and vegetable peel, etc. For earthworm products such as medicines and health foods, clean feed is used, such as wastes from potato processing and food factories. For sludge stabilization the known methods suggest mixing sludge with bulking materials such as solid urban wastes, peat, straw, bark and sawdust to feed to earthworms.

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