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Operator model to control process of obtaining vermicompost

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Abstract

Currently, in the Russian Federation, the amount of contaminated agricultural land is about 2.4 million hectares. The economic damage resulting from the violation of regulations related to the use of bedding manure in animal husbandry is estimated at an average of 150–170 million rubles/year. For the sustainable development of agrolandscapes, integrated biotechnologies should be developed that can fully process the agricultural waste into organic safe fertilizers throughout a year. A technology has been developed for the production of complex fertilizers by mixing waste, and turning it into an organic fertilizer. Integrated biotechnology provides a consistent mixing of pig waste, alcohol production and organic residues in the form of winter crops. It provides processing of the solid phase of pig manure, which is the main component of the liquid fraction of alcohol waste (bard), providing the process of maintaining the moisture content of the substrate and winter wheat straw. The result of complex biotechnology is biohumus (biocompost), obtained from pig pig compost and fugata. A red Californian worm is used as a compost processor in the biocompost. The physicochemical composition of the solid fraction of pig manure and irrigation water has been investigated for the composting process. It is established that components of the technology contains a high level of nutrients, especially macroelements, and do not contain hazardous substances for the nutrition of worms. Therefore, the development of integrated biotechnology is based on processes and parameters of accelerated waste processing and their utilization in the form of organic bio-fertilizers. An operator model has been created to control the process of obtaining vermicompost, , which is based on technological lines for processing waste into organic fertilizers, and their utilization to improve the sustainability of agricultural landscapes. The operator model allows us to manage biocomposing on production lines, each of which completes the process and the output is a complete product to use. On the main line, the organic fertilizer comes ready for utilization on agricultural landscapes. To increase the fertility of agricultural land, additional income from biocomposting is necessary.

Keywords: biotechnology, vermicompost, operating model, land fertility, waste disposal

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INTRODUCTION

It is necessary to restrain the increase of pollution in agricultural land by using the organic waste of enterprises, including livestock farms. In the Russian Federation, the area of contaminated agricultural land is about 2.4 million hectares, of which 20% is highly polluted, 54% is polluted, and 26% is slightly polluted. The economic damage caused by violation of regulations for the use of bedding manure in animal husbandry is estimated at an average of 150–170 million rubles/year. The practice of accumulating livestock waste in manure stores adversely affects the environment. Due to imperfect methods of recycling of wastes, special protective measures are not very effective (Davooabadi and Shahsavari 2013, Van Horn and Hall 1997). In the Krasnodar Territory, only large cattle farms and pig farms annually produce about 6 million tons of manure, and poultry farms produce 50 thousand tons of litter. The technical condition of manure is not reliable and there are open ground and buried lagoon structures that are overloaded. The aging manure and waste are transported to the fields where its liquid part is filtered. Thus, surface and groundwater are polluted due to the leaching character of the soil as well as the atmosphere because of the evaporation of solid waste components. In addition, manure is an important factor in the transmission of various pathogens. Animal waste is significantly different from municipal waste, and therefore, biochemical waste treatment methods are not acceptable (Conkar et al. 2015, Rosa 1997). According

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Table 1. The chemical composition of the solid fraction of pig manure, % (6)

Indicators	Solid fraction	Solid fraction	Solid fraction
Dry matter	22.70	Phosphorus	0.061
Organic matter	8.68	Potassium	0.078
pH	5.7	Calcium	0.159
Carbon	4.180	Magnesium	0.025
Nitrogen	0.217	-	-

Table 2. Composition of straw winter crops, % dry matter

Crop waste	Total ash	Ingredients of straw			
		Water-soluble substances	lignin	pentoses	alpha-pulp
oats	7.2	15.3	17.5	27.1	39.4
winter wheat	6.6	7.4	16.7	28.2	39.9

to the analysis of zonal agrochemical laboratories, manure contains 0.84% nitrogen, 0.15% ammonium, 0.58% phosphorus, 0.62% potassium, 21.9% organic matter (Irshad 2013). The high content of nutrients in the waste should be used to create highly effective organic fertilizers that will not oppress the environment, but create favorable prerequisites for the formation of soil humus (Pavlovskaya 2007).

To create sustainable developing agrolandscapes, it is necessary to develop complex biotechnologies (CBs) that can fully process agricultural waste into organic safe fertilizers throughout a year. Therefore, to create such technologies, it is essential to apply new integrated approaches to the processing and disposal of waste in the form of organic fertilizers. One way to produce safe fertilizers is to obtain complex fertilizers by mixing the waste and turning it into an organic one, where one of the components will be the main, the other will be an accelerator, and the third - ameliorant. Such an approach will provide a solution to several basic tasks including environmental protection (Van Horn and Hall 1997), full and round bottom processing of waste into organic fertilizers, utilization of organic fertilizers to increase agro-resource potential of agrolandscapes (ARP) (Kuznecov 2010, Yüksel et al. 2015); and obtaining environmental and economic efficiency of the CB.

MATERIALS AND METHODS

Integrated biotechnology provides a consistent mixing of pig waste, alcohol production waste and organic residues in the form of winter crops. CB provides processing of the solid phase of pig manure, which is the main component of the liquid fraction of alcohol waste (bard), providing the process of maintaining the moisture content of the substrate and winter wheat straw. The result of CB is biohumus (biocompost) obtained from porcine compost and fugata. As a compost processor, a red Californian worm is used in the biocompost, which has an extraordinary ability to process waste at high speed. The fugat is not only a processing accelerator, but also a component in creating the required process humidity, as well as food for worms.

Waste biotechnology consists of the complex processing of solid fraction (SF) of pig waste, liquid fraction (LF) of alcohol and straw production waste by using Californian worms. SF of pig waste and LF of alcohol waste (fugat) are obtained by separation. The volume of SF in the total mass of pig waste is 80-89% on average, and depending on the content of animals, it contains 92-94% moisture in the fugue (Bondarenko 1980). The technological sequence of the recycling process is given in the patent of the Russian Federation (Patent 2402493 Russian Federation, IPC C02F3 / 00, C05F15 / 00, C02F103 / 20).

In the development of CB, the main component of processing is SF pigs that its chemical composition is given in **Table 1**.

The chemical composition of SF (**Table 1**) consists of nutrients in concentrations not exceeding MACs. The composition contains a high content of nitrogen and calcium, which favorably affects the process of composting the substrate.

Straw winter crops are used as a moisture adsorbent for the processing of SF, which is most preferred for processing into organic fertilizers. Straw supports the structure, and well provide air flow to the substrate during composting. **Table 2** shows the composition of the straw for the preparation of biocompost.

Straw (**Table 2**) contains nutrients and in its raw form is food for worms. For the preparation of organic fertilizers, chopped straw is used with an average particle size of 25 mm, a moisture content of not more than 24% and a moisture absorption capacity of at least 200-300%.

The alcoholic bard is divided into solid and liquid fractions (cake and fugat). When storing bards in the lagoons turn into a substance that itself is pressed, while decomposing for a long time, they release poisons into the environment for many years. After the separation process, the fugate is mixed with lute water, and irrigation water (IW) is obtained, which is used to moisten the substrate and “feed” the worms. The composition of IW contains a high concentration of nutrients (**Table 3**).

Analysis of the components of IW shows that they have a high content of nutrients, especially macronutrients, and do not contain hazardous substances to feed the worms. Consequently, the development of integrated biotechnology, on the use of

Table 3. Composition of irrigation water for the composting process

Indicators	Units of measure	Value
pH	-	5.3
Temperature	^0C	96
Ammonia nitrogen	mg / dm^3	14
Nitrite	mg / dm^3	0,016
Nitrate	mg / dm^3	1.2
Ca	mg / dm^3	72
Mg	mg / dm^3	29
SO-2 sulfates	mg / dm^3	106.7
Chlorides	mg / dm^3	39
BOD	mg / dm^3	355
Chemical	mg / dm^3	410
Weighted	mg / dm^3	80

the above components, will be based on the processes and parameters of accelerated waste processing and their utilization in the form of organic bio-fertilizers.

RESULTS

Production of organic bio-fertilizers is based on a system analysis in the development of an operator model for controlling the processes and parameters of CB. Integrated biotechnology is carried out systematically and includes 3 subsystems and levels; technological operations that provide the final product in the form of increasing the ARP of agrolandscapes and obtaining additional crops on lands degraded from fertility loss (Kuznetsov and Khadzhid 2014). The technological scheme of processing and full utilization of pig-breeding waste is considered as a structural system for managing and controlling the ARP of agrolandscapes, aimed at protecting agricultural lands from degradation caused by loss of soil fertility of agrolandscapes.

The first subsystem determines the solid fraction processing of pig waste to produce compost. Additionally, technological operations for preparation of straw wastes are carried out in the scheme to produce a saline mixture that is the initial component for implementation of waste treatment processes.

The second subsystem is the liquid fraction processing of alcohol waste to improve the quality of compost on the content of nutrients. During composting, the irrigation process of waste products from pig breeding is provided. The technological scheme of waste processing CB in the compost includes these technological operations: accumulation of pig waste; separation of manure into fractions; sending SF waste to the bioreactor through quarantine, and entering liquid waste to the drive to prepare for the irrigation of forage crops in the agricultural irrigation fields. Alcohol waste is accumulated and sent to the place of separating fractions; solid alcohol wastes are recycled and disposed of separately; LF waste alcohol is used to maintain the desired moisture content of the compost; Slaked lime is added to maintain a neutral compost environment in bioreactors, and the compost mixture is cooled by aeration when air is supplied to a perforated pipe laid at the bottom of the bioreactor.

The third subsystem is the basis for obtaining the final product, i.e. biocompost. After receiving the compost, it is accumulated in the bioreactors, orderly fit layers of compost; soil, straw, and worms are colonized to obtain vermicompost while maintaining the specified temperature and humidity of the compost. To speed up the vermicomposting process, it is added to the IW substrate, which feeds the worms and maintains the established moisture. Between the layers of compost, there are arranged layers of the soli mixed with straw. The output of the technological scheme of the CB is biocompost.

Levels of the system are the main and intermediate technological operations represented on the technological lines. Technological lines are separate subsystems united by a single technological process - obtaining a biocompost in the form of organic fertilizers. CB includes the following three technological lines.

The first line is pig waste processing, where the main operations include waste averaging and separating into their fractions. For composting pig waste, crop waste is used in the form of straw which is designed to retain moisture in the substrate.

The second technological line consists of averaging the waste of alcohol and dividing it into fractions. LF waste is used for feeding worms and moistening pig waste during composting. Prepared pig waste and alcohol are used in the process of aerobic biofermentation in the preparation of compost and then, in the preparation of biocompost.

The third technological line is the final one in the integrated biotechnology system, where biocompost utilization is carried out to increase the agro-landscaping ARP.

Preparation of the components of biotechnology is carried out directly at the sites of enterprises, and then the prepared components are transported to the place of preparation of biocompost (Kuznetsova et al. 2018). As a rule, the place of preparation of biocompost is a site near pig farms and agricultural irrigation fields, which can significantly reduce the cost of preparing biocompost. Technological lines of the system are united by an operator model, designed to control the processes of composting and the parameters of CB subsystems. The operator model of integrated biotechnology, as how the system allows determining the main processes of preparing the substrate for the production of biocompost and recycling on agricultural landscapes of IW is shown in **Fig. 1**.

The IW results are the technological lines for processing waste into organic fertilizers and their utilization to increase the ARP of agrolandscapes. Technological line A - 1 provides processing of pig waste and straw into compost. Waste pigs are accumulated in containers 1, from where they enter the receiving

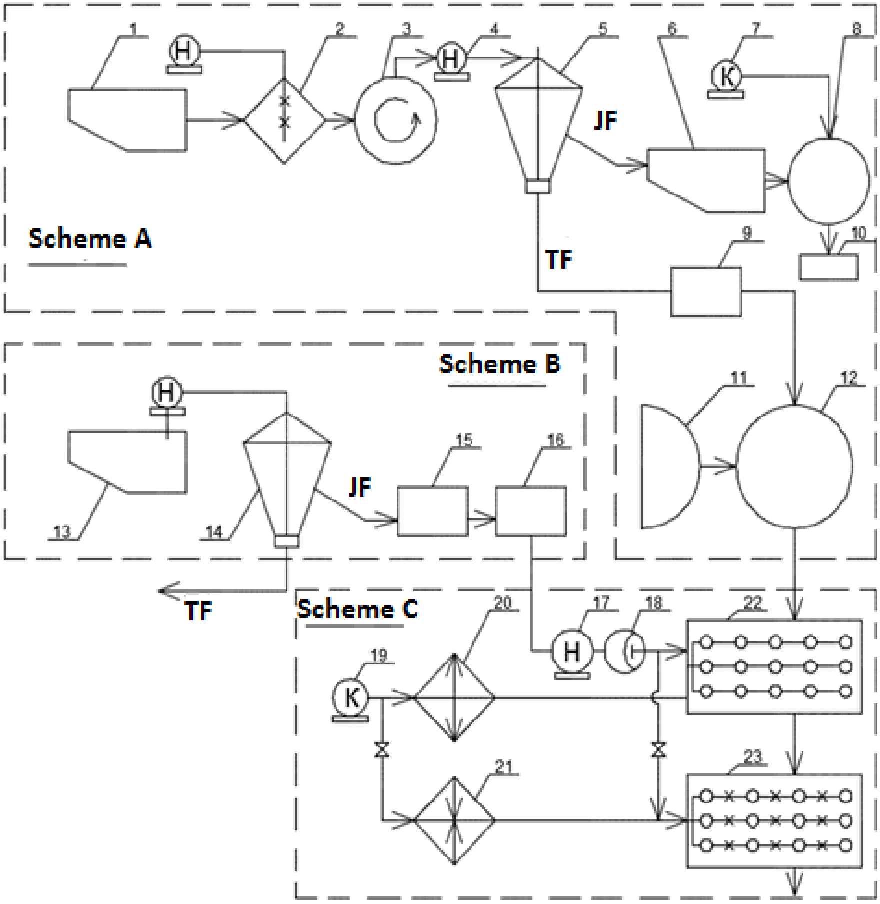

Fig. 1. A - 1 subsystem – technological line for processing pig waste and straw into compost. The technology includes: 1 manure storage tank and averager; 2 - manure wetting for the homogenization process; 3- homogenizer; 4 - pump; 5 separator for the separation of pig waste into fractions; 6- drive and quarantine zhf; 7 - compressor for aeration of railways; 8 storage and aerobic biofermentation; 9- a plaSForm for receiving, quarantine and mixing of manure with straw; 10- JF utilization; 11 - storage of centrate and irrigation of compost; 12 - composting, aerobic fermentation.
B - 2 subsystem - technological line for production of liquid waste of alcohol for feeding worms and moistening pig waste during composting. The technology includes: 13 bards collector and averager; 14-screw separator for separating bards into fractions; 15 - storage zhf - fugata; 16- a container with hydrated lime and lute water, quarantine for a centrate.
B - 3 subsystem - technological line of integrated biotechnology utilization of biocompost. The technology includes: 17 - pump; 18- dispenser fugata; 19 - compressor; 20 and 21 - heating and cooling air, respectively; 22 - aerobic biofermentation of compost; 22 - the process of composting vermicomposting (irrigation, maintaining temperature and pH).

chamber 2, where homogenization of waste occurs. To accelerate the process of homogenization, add the IW in the amount necessary to ensure 90-95% moisture content of manure. The mixture is fed to the separator 3 through pumping units. The liquid fraction from the separator enters the reservoir 6 through the pipe, and then, after being prepared for utilization by aerobic biofermentation 8, it is fed to the agricultural irrigation fields 10. Waste SF is fed to site 9, where it is diluted with organic matter at a ratio of 1:10 to substrate moisture of 75% and is fed to composting. The technological line provides the required quality of the HF with a moisture content of at least 75%, which is convenient to transport to the composting sites, to dose and mix with the crushed straw waste at the site 9.

Technological line B - 2 is intended for the production of fertilizer of alcohol, which provides the feed for worms and moistens the substrate. Alcohol waste products are bard and lute water. Barda has a water content of 85-90%, and lute water is 7-9%. After sublimation processes, bard enters the averager 13, where it is accumulated. In the process of cooking, fugate bard is pressed on the separator 14, separating the fugate from SF bards, which accumulates in the tank 15. The cake is sent to the drive, where it can also be used for composting or additives for the preparation of premixes. The centrate has an acidic environment, therefore it is deacidified by slaked lime, which is supplied from the tank 16 through the dispenser 18. The quarantine of the centrate is executed in the tank 16.

Technological line provides the required quality of LF with pH = 6.8-7.2, which is conveniently transported to the composting sites, dispensed and mixed with the crushed straw waste at the site 9. The centrate from the

Table 4. Averaged composition of biocompost, %

Components of biocompost	experiment 1	experiment 2
Humus, mass fraction in terms of dry substance, not less	23.9	25.0
Total N (N)	3.01	3.03
Phosphorus (P)	2.35	2.41
Potassium (K)	2.64	2.63
Calcium (Ca)	7.29	7.38
Magnesium (Mg)	2.55	2.52
Humidity	22	23
Dry organic matter	78	77

tank 15 is mixed with Luther water in the tank 16. With the help of a pump, LF gets into the drive 17, where there is aeration of waste blower from the compressor (aerobic biofermentation). Volume of the averager 15 is consistent with the volume of the dispenser 18. This is justified by the fact that the incoming volume of IW must be in the averager 16 for some time to raise the pH to 6.8-7.2. 2. A fan is used to mix the IW.

Technological line B - 3 is intended for complete waste disposal and the production of valuable organic fertilizer, i.e. biocompost. From site 12, the compost is transported to site 22 for the biocomposing process, where bioreactors are placed to perform the compost utilization process using aerobic biofermentation. The compost is moistened with organic matter from accumulator 16. To speed up the process of fermentation, a compressor with perforated pipes at the bottom of bioreactors is used. The ripe compost is sent to site 22 for preparation and changing to vermicompost. Compost layers fitting into the bioreactors are inhabited by worms. When worms are growing, a soil with chopped straw is used, which is placed between the compost layers as the substrate and processed and the worms are multiplied. Moistening of vermicompost is carried out with irrigation water. Raw biohumus is transported to the site for drying and further utilization on the fields, where it is brought into the arable horizon of the soil to increase the ARP of agricultural landscapes.

The operator model (**Fig. 1**) has passed an experimental test for the processing of substrate components (**Table 1-3**) into a biocompost. Using the IW and technological lines of CB for the processing and disposal of waste, biocompost is obtained, and the results of the experiments are presented in **Table 4** (Poltorak 2011).

The creation and implementation of closed production systems and non-waste integrated biotechnology are one of the areas of environmental activities. Biotechnology provides conditions for preserving the environment from degradation; it allows the use of waste and transforming it from a type of pollutant into valuable organic fertilizer to ensure a continuous increase in the ARP of agricultural landscapes.

Table 5. The main parameters of the process of vermicomposting waste

Options	Quantitative values
C: N ratio	From 25: 1 or more
Straw particle size	12.5mm for compost rows with natural aeration. For systems with mixing and forced aeration - 50 mm
Substrate Humidity	70-75%
pH	6.5-8.5
Free volume	Not less than 30%
Aeration	Supply of 5.5 m3 of air per day for 1 kg of compost.
	Ammonium nitrate, phosphoric flour, an admixture of clay. Additives are calculated depending on the volume of the substrate and the number of worms.
Nutrient Supplements	21-23 ° C
Temperature	The minimum size is 0.5 x 0.5 x 1.0 m with natural aeration. In the case of large sizes - forced aeration is used.

DISCUSSION

Processing the organic waste using worms occurs in IW bioreactors, where the main process, i.e. vermicomposting, happens (Kuznecov 2018). Nurturing worms in artificial conditions where waste is used as a source of feed, provides a number of advantages:

- transformation of indigestible components of manure into easily digestible substances for plant development: ammonia nitrogen, easily digestible phosphorus and potassium (Irshad et al. 2013);
- reproduction of worms contributes to the transformation of waste into a biocompost - a product obtained from organic waste subjected to physicochemical, biochemical and microbiological transformation in the intestines of earthworms (Kuz'mina 2003);
- biotechnology of composting affects the composition and characteristics of the substrate. Compost as a substrate for worms should be considered in a double sense: first, it is the environment in which worms live and all their vital functions are carried out; secondly, it is food that provides their livelihoods and the process of obtaining biohumus is carried out;
- compost as a habitat manifests a multifaceted impact on worms. First of all, the decisive importance of the physical structure and chemical characteristics of the compost should be noted (Adler and Sikora 2004). Compost provides good aeration, creates optimal conditions for the worms to breathe and the necessary microflora to exist. Most worms are required in the habitat; environmental acidity, temperature, and humidity are among the main vital factors for worms (Bondarenko 1980).

Therefore, during vermicomposting, it is necessary to use high-quality compost, which can only be obtained by controlling the basic parameters of the IW biocomposing process (Van Horn and Hall 1997).

The main parameters of the vermicomposting process are determined and listed in **Table 5**.

Data in **Table 5** are used to determine the parameters of the ordered stacking of components in layers, heat loss, air supply, humidity and the rate of irrigation of the organic substances of the substrate for performing the processes of vermicomposting in bioreactors. The biocompost for disposal (**Table 4**) was obtained in bioreactors of 0.7x0.7x1.0 m with forced air supply through a capillary-porous mixture (substrate), and recommendations (**Table 5**) for managing the main parameters of composting were maintained (Bolan et al. 2004).

To prepare a high-quality substrate, it is necessary to analyze components of CB compost, which significantly affect the composting speed of a mixture of straw and pig manure. Composting speed is the main parameter in the process of preparing vermicompost and determines the effectiveness of biotechnology.

The main components include dispersion of particles; nutrients; humidity; free volume; aeration; mixing; heat dissipation and stack sizes.

Particle dispersion: The smaller the particle size of organic waste, the greater the specific surface area that is open to microorganisms, which theoretically should ensure higher speed of the process. However, small particles are packaged very closely, forming a material with high density and narrow pores, which limits the diffusion of oxygen into the volume and diffusion of carbon dioxide from the volume, which reduces the speed of the process. The size of grinding is accepted within 12.5-25.0 mm.

Nutrients: The composting process depends on the activity of microorganisms that need a source of carbon for energy, a substance to form new cells, and a source of nitrogen for the synthesis of cellular proteins. To a lesser extent, microorganisms need phosphorus, potassium, calcium, sodium, and magnesium — these needs are met by the initial composition of organic waste.

Analysis of macro-elements of nitrogen, phosphorus, and potassium in the process of biocomposing: the lack of nitrogen inhibits the process of biotechnological oxidation of organic matter. Phosphorus in manure is in an undissolved state — it is not suitable for feeding microorganisms and plants. In addition, with a small amount of phosphorus, a reduction in the intensity of biochemical oxidation is observed, which leads to the formation of bacteria. Composting phosphorites with an organic mass have a positive effect on the conversion of indigestible calcium phosphate into a phosphoric compound digestible by plants. Scientists note that the admixture of clay with manure helps reduce the loss of dry matter and nitrogen (Bubina 2004). The loss of nitrogen and potassium has significantly decreased as a result of the improvement of the absorbing complex, less water permeability and some changes in the direction of biological processes in manure piles.,

Humidity: water is necessary in the composting process since nutrients must be dissolved in water before they become available for consumption. When the humidity is less than 30%, the rate of biological processes drops sharply, and at a humidity of 20%, they may stop altogether. When humidity is too high, voids in the compost structure are filled with water, which limits the accessibility of oxygen for microorganisms. Optimum humidity is in the range of 70-75%.

When composting a mixture of pig manure with straw, it can be assumed that moistening the substrate centrate to the required humidity of 70-75% speeds up the process of preparing vermicompost by 5-10%.

After the production of alcohol, waste is formed in the form of bards and lute water. Barda separation is divided into a solid fraction (cake) and a liquid fraction (fugat). The composting process uses a liquid consisting of a fugate and lute water.

Free volume: Compostable mass-the substrate can be simply considered as a three-phase system, which includes the solid, liquid and gas phases. The structure of the substrate is a mixture of solid particles, which contain voids of various sizes. The voids between the particles are filled with gas (oxygen, nitrogen, carbon dioxide), a centrate, or a gas-fugate mixture. The minimum accepted free gas space is 30%.

Thus, the operator model allows us to manage biocomposing on production lines, each of which completes the process, where the output from each line turns the finished product into use. The organic fertilizer for agricultural landscapes comes ready on the main 3 lines. Economically, CB does not require large costs for its implementation. It is necessary to consider the additional income of biocomposting for increasing the fertility of agricultural land.

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