SUSTAINABLE AGRICULTURAL BIOGAS PRODUCTION

Tamás János

University of Debrecen, H-4032 Debrecen, Böszörményi 138, Hungary, e-mail address: tamas@gissserver1.date.hu

Abstract

Agriculture is a young member of the energy and waste management sector, thus, it does not have adequate practical experiences to define and manage environmental risks of its activities. Under the conditions of investment and energy politics of Hungary and Central East Europe, biogas plants can be only partial solutions. Critical point is the absences of complex integration of logistics and energy production and consumption related to the centralized biogas production of high capacity, and the by-product recycling. In the new members of the EU countries, the extate and ownership structure includes primary and secondary biomass sources separately, leading to further contradictions in operations. In our study, the first aim was to develop technologies adapted to biomass production specific to the BátorCoop Ltd., Hungary; the second aim was to develop recycling technologies for hazardous materials, such as dead animals and slaughtering wastes as tertiary biomass sources; and the third aim was to develop a unified product tracking system from the supplying to the utilization of the fermentation outlet.

The BátorCoop group started to operate its biogas plant in 2003 in Nyírbátor, in the Northwestern Region of Hungary. In the plant, mainly animal waste (39%) and manure (29%), and crop product (13%) as well as crop waste (19%) are utilized. Crop resources are produced on 3.000 ha own land, and 5.000 ha contracted with cooperations. The cattle breeding produces milk of 9 million liter per year, while broiler breeding includes production of 5 million chickens per year. At the slaughterhouse, 9 million broiler per year is processed. In the biogas plant, homogenized raw materials are loaded every four hours from two homogenizers, 628 m^3 of each, in turn, to 6 mezophil reactors, 628 m^3 of each, for pre-fermentation. Biomass then is loaded to 6 thermophil reactors having 7419 m^3 effective volume. Gas utilization takes place in 4 heat-exchange units of 2600 kWh, by which, 1.000-1.200 kWh electric energy is sold, while hot water is utilized by the chicken slaughterhouse.

As part of our study, the effect and changes of N%, C%, dry and organic material and C/N ratio in raw materials, found in mezophil digester, were examined regarding its biogas quantity. The maximum gas yield was observed in case of 2.76% N content, which suggests that reducing of the input nitrogen increases the biogas yield. Highest biogas yields were found within 33.55-34.3% carbon content. The maximum gas yield was found at 12.2-12.35 C/N ratio. Considering the broiler slaughterhouse, significant amount of feather is produced, the hydrolytic decomposition of which is difficult, thus a preparative step should have been worked out. The high protein content of poultry feather makes it a suitable raw material as amino acid and fatty acid subtrat for biogas production. Experiments made by using Bacillus licheniformis bacteria, however, made possible feather liquefying. For prepared feather content of 1%, ratio of H_2S was found < 300 ppm, while at 5%, it increased to 620 ppm.

For the input logistical system, coordinates of suppliers and distances from the plant were measured with GPS. For the authorized routes, 20 m buffer distance was calculated. When a track is over this distance without permission, the system alarms the the operative of the biogas plant; in this way, illegal discharge of hazardous wastes can be prevented. Discharge of biogas outlet has two alternatives for a biogas plant: A) transport in irrigation pipeline and discharge with water cannon having self-propelled drum; and B) transport on vehicle and surface discharge with using deflector accessories. As part of the work, data sets for GIS mapping for the precision control within the land sections were created for both technologies. During the decision making, basic data can be up-dated and optimized according to the actual nutrient and water content, and cultivation plan. During the planning, several data had to be digitalized to determine the unsutable areas and safety buffer zones. Loading results into the job computer of the discharging vehicle, movement of the vehicle itself can also be planned and monitored during the discharge.

Key words: sustainable agriculture, biogas production

INTRODUCTION

In the Central East European Region of the EU, significant geopolitical conflicts may arise from the dependence on Russian-Ukrainian energy sources, thus, Hungary is also affected. In Hungary, however, in addition to the gas supplying problems, an additional conflict will arise from the technical amortization of the existing power plants, expecting 20-30% of energy absence to 2015. Thus, increase in the ratio of renewable energy sources (4.7% in 2007) would be even more important for Hungary, than for other European countries. At the same time, increasing the use of bioenergy offers significant opportunities for Hungary (as well Europe) to reduce greenhouse gas emissions and improve the security of its energy supply.

In Hungary, solar, wind and water energies have low and basically regional potential, based on the characteristics. However, within the next 5 years, infrastructural developments in the energetic sector using geothermal and biomass sources are expected to be significant. In the European Union, the ratio of renewable energy sources are planned to be increased to 12% in 2010. Based on the investigations made by the European Environmental Agency (EEA), the available biomass energy potential is 145.5 PJ, for Hungary, which is 50-55% if the theoretical value. In 2007, biogas provided 43.55 PJ, which, by 2020, are planned to be increased to 37% (Szerdahelyi, 2009).

Background

In Hungary, situated in the Carpatian Region, 72% of the area has agricultural utilization, which is high comparing to the european average. The traditionally good agricultural technology is able supply adequate materials, inspite of low governmental or EU financial support. Thus, increase in energy production based on biomass will not generated food shortage, it may be rather a solution for the excesses on food market. However, the EU-compatible agri-environment regulation 2078/92/EEC and Regulation 1257/1999 on rural development provide for programmes to encourage farmers to carry out environmentally beneficial activities on their land.

In 2009, the Hungarian Agricultural Ministry provided financial support for the construction of 35 biogas plants, each of 0.2-1 MW capacity operated with by-products of animal origin primarily, to solve the problems of slurry treatment and utilization.

The agriculture has no enough practical experiences to define and manage environmental risks of its activities in the energy and waste management sector. Biogas plants started to operate after the year 2005. Considering their volume, small farm-scale and centralized biogas plants were also built. The farm-scale biogas plants use basically primary biomasses (green vegetal parts, silage, and straw) as lignocellulose sources, with some added secondary biomass. The centrelized biogasplants use significant amount of secondary biomass generated by the livestock-farming and also important tertiery biomasses wich come from diverse soures.

Most part of them are wastes of food industry, though municipal wastes of selective garbage gathering and waste water treatment by product sewage sludge origins will be used increasingly in the future. However, lack of experiences in the field of biomass production on farmland for energy purposes carries significant environmental risks.

In Hungary, biogas production in the agriculture has shown significant development for the last 10 years. However, lack of systematic development leaded to similar problems what was experienced in other more developped European countries. These are discussed by Ravena and Gregersen, (2007), based on experiences of 3 decades in the Netherlands and Denmark, focusing on the role of the economical and social environment.

According to Petis (2007), under the conditions of the Hungarian and Central Eastern European investment and energy politics given today, there are several shortcomings in the

utilization of a biogas plant. As for him, complex integration of logistics, energy production and utilization, and by-product recycling is missing. In case of the new members of the EU, the extate and ownership structure includes primary and secondary biomass sources separately, leading to further contradictions in operations.
In this study, the experiences of the biggest Hungarian agricultural integrated centralized biogas plant owned by the BátorCoop Ltd. are assessed, and solutions are provided to the problems arisen.

Research objectives

Procedure of the biogas production is well-known and several technologies have been worked out (Kacz, 2008). However, efficiency of the biological processes is negatively affected by the quantity and quality of the fermentation raw materials, as well as the actual technological parameters. When, considering the environmental aspects, biomass volume should be decreased primarily, variation in intensity of methane production is not a critical factor. This is characteristic of farm-land biogas plants utilizing by-products of stock farms. In a centralized biogas plant, to increase the efficiency, variable biomass types are used, in most cases. In this case, technology, biomass formula, dosing, and optimation of fermentation conditions should be given always site specifically. As a result of the agro-biological cycles, quantity and quality of agricultural biomass sources are much more variable comparing to other technologies such as sewage from urban waste water treatment plants.
In our study, the first aim was to *develop technologies adapted to biomass production* specific to the BátorCoop Ltd., Hungary. The second aim was to *develop recycling technologies for hazardous materials*, such as dead animals and slaughtering wastes (i.e. fat, blood, and feather) as tertiary biomass sources. Supplying and discharging processes being variable in time and space, require complex development of PC-supported controlling, which, as a system, should be integrated to the logistical and technological systems of the biogas plant, to provide a unified information techology environment for a life cycle tracking from the input raw materials to the utilization. Thus, the third, last aim was to *develop a unified product tracking system* from the supplying to the utilization of the fermentation outlet.

METHODOLOGY

The BátorCoop group started to operate its biogas plant in 2003 in Nyírbátor, in the Northwestern Region of Hungary. In the plant, mainly animal waste (39%) and manure (29%), and crop product (13%) as well as crop waste (19%) are utilized. Crop resources are produced on 3.000 ha own land, and 5.000 ha contracted with cooperations. The cattle breeding produces milk of 9 million liter per year, while broiler breeding includes production of 5 million chickens per year. At the slaughterhouse, 9 million broilers per year are processed.
In the biogas plant the inner transport tasks are as follows: 7000 T/y cattle manure, 557 T/y poultry manure, 5000 T/y cropping product, 40000 T/y outlet water from slaughterhouses, 24500 T/y offal, and 1500 T/y carcass; in all 78557 T/y organic material transportation into the system. The average retention time of the mean 360 m3 daily amount of the substratum is 18 days in the mezophil fermentor and 22 days in the thermophil fermentor (40 days in total). In the case of 6 % organic material content the daily load of the mezophil fermentor is 18000 kg organic material, this means 2,8 kg organic material per m^3. The homogenized

raw materials are loaded every 15 minutes from two agitators, 628 m3 of each, in turn, to 6 mezophil reactors (38 °C), 628 m^3 of each, for pre-fermentation. Biomass then is loaded to 6 thermophil reactors (55 °C) having 7419 m^3 effective volume, where the methanogenic processes are taken place. The inner tallness of the fermentors is 5 m, from which 4,2 m is the high of the liquid material and 0,8 m is the gas place. The authorized gas pressure is 10 bar in the fermentors and 5 bar in the gas tank, consequently the gas is loaded under the one's own pressure across the refrigerant condensing the water vapour. The cleaned biogas is stored in two gas tank having 2000 m^3 volume. In the plant the CO_2, CH_4, H_2S and NH_3 content of the biogas is examined by Chemec BC-20 precious gas analyst working with absorption principle. Gas utilization takes place in 4 heat-exchange units of 2600 kWh, by which, 1.000-1.200 kWh electric energy is sold, while hot water is utilized by the chicken slaughterhouse. All of the above mentioned parameters make it obvious that the biogas plant can be effective and profitable being with significant technological experiment. The raw materials come into the works and loaded are recorded in every day, while the analysis of the inner content value is taken place in the accredited laboratory in the central company seat (Petis, 2007).

The regulation No. 1774/2002 of EC declares that the dangerous slaughterhouse by-product has to be collected and disposed. If the storage is necessary the dangerous wastes have to be cooled in closed chambers and special delivering vehicle has to be provided too. Before sterilization, dangerous waste has to be bruised to max. 5 mm pieces. Bruised wastes have to be heated with 3 bar saturated steam up to 133 °C in autoclaves. Food leftovers are sterilized for 1 hour on temperature 70 °C and then it has to be cooled down at 55 °C. After that the wastes can only be fed into the biogas equipment. In the case of the BátorCoop Biogas Plant, the raw materials are collected with special vehicles from the distance of 150 km zone.

The reactors were integrated with the Tycoon batch experimental reactor, which was a 6 m3 double-walled tank with stirring-shovels and aeration-system. The pressure, the temperature, the time of the air circulation and unloading were controlled by centrally. The temperature was measured by built-in searcher and the data were recorded with a computer-software developed for the aims of the experiments. In the case of the secondary and thirdly analysis of biomass the final control measures were taken place in this reactor before the working operation.

The remained "bio fertilizer" in the working fermentor is used as nutrient supply on its own arable lands. However, according to the EU Nitrates Directive the fields of the works where the liquid fertilizers are settled are tended to nitrate leaching mainly sand and sandy-loam soil type. Consequently it's difficult to observe and to control the authorized amount of the 170 kg/hectare nutrient (Makádi et al. 2007).

In 2004, the Regional Biogas Plant of Nyírbátor entered into a research and developing contract with the Department of Water- and Environmental Management, University of Debrecen, within the frame of this the research work has performed in the environmental-technology laboratory of the department.

The four rustproof steal fermentors, 6 l volume of each, were settled in the insulated incubator-cabinets in this laboratory. The absorption of the possible organic acid content of the escaping gas-mixture from the reactor was used by the gas-washer bottle pouring with water. The gases are conducted to the two and two magnetic valves from the four isolated reactors. Before the detector the gas-mixture passes through a carbon-filter then safety gas-washer bottle. The following refrigerant serves as a dewatering instrument. After this to examine the composition of the gas-mixture the Fisher-Rosemount NGA 2000 Multi-Component Gas Analysers was used. The Advantech – Genie acquisition provided the measuring of the O_2, CO_2, CO, methane, sulphur-hydrogen and ammonia gasses at every 2 minutes. The system automatically controls the cooling fan in the incubator-cabinet by the data of the thermometer and pH meter. The C, N and C/N ratio of the input material and the final product were measured with the help of the Vario El universal analyser (Bíró et al., 2008). The biogas capacity of the different organic materials is significantly affected by the volume of the experimental bioreactor moreover the mixing and homogeneous conditions. The working conditions were tested with the help of the gas analyser instruments and in a double-wall experimental bath fermentor of 100 l volume with external heating. The scoops in two lines supply the adjustable mechanical mixing intensity, the upper part of it brills the scum in. During the hydrolityc degradation of the poultry feather the cell numbers were determined by turbidimetric method, after the extinction samples were taking in every hour during 2 days. The extinction of the samples was determined and then the cell number (item/deciliter) in the bacterium culture was determined with a Bürker-cell/chamber. Then based on the extinction of the solutions the calibration curve was determined from the cell numbers. Filterphotometer PF-10 type of photometer was used to measure extinction. For the experiments 1,6 x 10^9 item/cm^3 cell-numbered bacteria-vegetation with 1,5 extinction was used.

RESULTS AND DISCUSSION

As the first experimental task we examined the composition, the quality and the quantity of the organic material uploaded into the fermentor in every day. The raw material can be put into the fermentor in two ways, on the one hand after homogenization from the agitators, on the other hand directly. The quantity and the quality of the uploaded organic materials are changing each day. To follow up these changes the data have to be recorded and analysed continuously. This is not only important to comparison the biogas-proceed with inner content value, but also to follow the changes in the quality taken place during the fermentation process. The effect of the combination of the different recipes was examined in laboratory experiments then in industrial conditions. According to the working experiments increasing mixing ratios were set during the laboratory research. We evaluated statistically the results of laboratory experiment and the industrial measurements for 3 years. In the course of the first research, when animal by-product was not used, the aim was to reduce the retention time in the reactors during the fermentation process and to produce high amount of methane.

The two processes have reverse effects, because the highest amount of methane production needs long retention time, but it's harmful the specific effectiveness of the reactors during a given time interval.

A biogas firm's fundamental interest is to increase the capacity utilization through enhancing of the velocity of circulation to exploit the possible fermentable gas content and to stabilise end product corresponding to official limit value. During the storage, transportation and getting out the higher VOC content and significant odour problem blocks the agricultural recycle.

The optimization of retention time is complicated by the fermentation split into two sections. Based on the results, the pre-treated easily digestible input materials can be added directly in the thermophil phase. It can reduce rotation time. From the daily amounts of raw materials fed in the fermentor we could calculate mean retention time. After the adding of the mezophil and the thermophil hydraulic retention time we get the full hydraulic retention time (t) of the system and we compared it with the biogas yields (m^3/day). In case of the mezophil fermentors the largest yields were observed at 18 days retention time, while in the thermophil fermentors this value varied between 16-18 days. This relationship was not defined enough in case of the thermophil digesters.

The quantity of produced biogas depends basically on the retention time given from the raw material combination. The composition of input organic materials were various on spring and autumn period, which it could be detected in the gas production of the beginning period also. In the winter time the C/N ratio of the output material were less significantly, than in summer. Because of the external temperature, the degradation process in the bioreactors is kept on a little causing carbon loss moreover the fresh green plant-material is also decreasing so glycerine and maize-silo are added to the recipe in limited value during winter. As part of our study, the effect and changes of N%, C%, dry and organic material and C/N ratio in raw materials, found in mezophil digester, were examined regarding its biogas quantity. The maximum gas yield was observed in case of 2.76% N content, which suggests that reducing of the input nitrogen increases the biogas yield. Highest biogas yields were found within 33.55-34.3% carbon content. The maximum gas yield was found at 12.2-12.35 C/N ratio. Comparing C% and C/N ratio of raw materials to biogas production resulted weak correlation (r= 0,32). The relationships were medium strong (r= 0.65) between the dry matter content of input substances and its gas output values. Based on results, 8% dry-matter content is found to be appropriate concerning the biogas yield. Above this value the gas quantity was reduced significantly (Bíró et. al., 2008).

The second aim was to develop recycling technologies for tertiary biomass sources, such as dead animals and slaughtering wastes (animal fat, blood and poultry feather). Before using of the sterilized slaughterhouse by-product different N% and C% ratio were examined in laboratory. We set the N% content of the input biogas in an increasing order as follows: 3-3,9-5,4-6,5-7,3-8-8,3, while the C/N ratio were in a decreasing order as follows: 16,5-13-9,5-8-7,1-6,5-6,3. The gas-production capacity of the animal wastes from slaughterhouses is well-known, at the same time the higher nitrogen content can block the fermentation processes. Taken as a function of C/N ratio the upper limit of the nitrogen-input was determined with the help of the analysis of the developing biogas. The optimal C/N ratio was estimated at 10-16. The lack of nitrogen causes the multiplication of the micro-organisms to stop under this ratio; otherwise ammonia can form because of the surplus of nitrogen, so the organ becomes alkaline limiting the growing of the bacteria.

Considering the broiler slaughterhouse, significant amount of feather is produced, the hydrolytic decomposition of which is difficult, thus a preparative step should have been worked out.

The high protein content of poultry feather makes it a suitable raw material as amino acid and fatty acid subtract for biogas production (Bagi, 2008). The digestion by fermentation of this difficultly disintegrating material produced in large quantities in poultry slaughterhouses provides an environmentally-friendly way of reutilization. Our objective was to determine the timing of application and the maximal amount of pre-processed feather for hydrolytic digestion, to optimize the concentration of disintegrating micro-organisms and examine their reproduction and to elaborate a biomass recipe with optimal C/N ratio for maximal efficiency of methane production.

Bálint and his colleagues (2005) isolated the feather digesting *Bacillus licheniformis* KK1 bacteria from the soil, which originally was used to produce bio-hydrogen. Based on these results of the examinations we used it to digest boiler poultry feather. Some Bacillus species are aerobe bacteria and proliferate well on high temperature (40-60°C) with having a wide substrate spectrum.

In the first step the heat treatment of the feather was carried out in a cooker at a temperature of 70, 100 and 140°C, then the optimal feather : water ratio was determined by examining feather: water ratios of 1:1, 1:2 and 1:3. The ratio of 1:1 (1kg feather: 1 liter of water) proved unsuitable for mechanical mixing, so its application under industrial-scale operation is not recommended. At the ratio of 1:2 0,67 kg of feather was mixed with 1,33 liters of water., while at the ratio of 1:3 0,5 kg of feather was interspersed with 1,5 liters of water. The optimal digestion temperature of 42°C and a pH between 6,5-8 in the solution was ensured by adding 5-5 milliliters of phosphate-buffer to each treatment coupled with the application of a thermostat. The ratio of feather: *Bacillus licheniformis* (%) was ensured by inoculating 1, 3 and 5% of Bacillus licheniformis culture to the feather. During the first experiment the cell number in the bacterium culture was determined with a Bürker-cell/chamber before inoculation, as well as the extinction in the range of 605 nm with a photometer. In the further experiments the cell numbers were determined with the calculated calibration curve by turbidimetric method based on the extinction of the solutions. The stabilization of pH could be resolved by adding a maximum of 5-15 milliliters of phosphate buffer. Based on the measured extinction values, the highest rate of digestion was observed in the experimental group with pre-treatment at 70°C, 1% bacillus: feather rate, 1:2 or 1:3 feather: water ratio (Bíró et al. 2007). The hydrolyzed material with the keratin content can be added to the reactor as an amino-acid and fatty acid substratum.

Having evaluate the effect of the pre-treated poultry feather, it can be lay down a fact, that the biogas-production can be observed in case of mezophil fermentor after 20 days retention time, it is necessary to start the micro-biology processes and to explore raw materials. It can also be 18-20 days by the thermophil fermentors. It could be observed the increasing of the maximum gas-yield (2,6%) completing with pre-treated feather (5%) under 42 retention times. The pre-treated material with 2% additional feather resulted increasing methane gas-yield on average 1,4%, while the mixture with 1% feather content caused 1,22% rate growth. The quantity of evolving sulphur-hydrogen from amino-acid having sulphur have to be kept under 2-300 ppm to protect the gas-engines from the damages. When 5% pre-treated feather was added to substratum, the H_2S content of the biogas exceeded 620 ppm, which can lead to corrosion. However, using 2% feather ratio it was only produced H_2S of 345 ppm, which needs gas-cleaning in a long term. In case of using 1% pre-treated feather the H_2S value was under 300 ppm, which is suitable for biogas production without gas-cleaning.

The third aim was to develop a unified product tracking system from the supplying to the utilization of the fermentation outlet. While the factory applied mixed content raw materials, its quality assurance system were expanded to the supplier-net and the setting out to arable lands in order to reduce working risk. Therefore a common geographical information system was established with the help of the researchers of the University of Debrecen having environmental-technology, informatics and corporate management experiences. As a result of this work such a restricted logistical system was established that can be minimizing the environmental risk of the utilization of raw materials. For the input logistical system, coordinates of suppliers and distances from the plant were measured with GPS. For the authorized routes, 20 m buffer distance was calculated. When a track is over this distance without permission, the system alarms the operative of the biogas plant; in this way, illegal discharge of wastes can be prevented. Continuous, digital recording of the transportation data and identification of the truck driver is also managed by this system. Thus, the transportation of supplier vehicle can be monitored real time from the biomass sources to the biogas plant and can be archived and searched. The incoming shipment is sampled, which provides sample with unique identification. The outlet material of the biogas fermentation is also continuously sampled.

Discharge of biogas outlet has two alternatives for a biogas plant: A) transport in irrigation pipeline and discharge with water cannon having self-propelled drum; and B) transport on vehicle and surface discharge with using deflector accessories. As part of the work, data sets for GIS mapping for the precision control within the land sections were created for both technologies. During the decision making, basic data can be up-dated and optimized

according to the actual nutrient and water content, and cultivation plan. In the case of the discharge with water cannon, the main control point is the retraction speed of self-propelled drum, minor changes can be set with changing nozzle size and pressure. In practise the cross inhomogenity factor is lower than 15% at the borders of the neighbouring tracks in the case of the discharge of liquid phase of fermentation with BAUER Rainstar T61 typed irrigation system. In case of an asymmetrical parcel it can be used the irrigation pipeline and discharge with water cannon having self-propelled drum, but the disadvantages of this methods are hardly changeable so it can cause higher charging on several fields. The transportation on vehicle has higher cost, but it can be adapted to different soil properties.
In this instance, the transportation on vehicle and surface discharge with using deflector accessories we have tested the digital map data by Trimble AgGPS FM 550 job computer. The computer is controlling the autopilot system continuously on the bases of applied digital maps. It controls the getting out of the liquid phase on the defined routes and enables to place out the nitrogen of max. 170 kg/ha consider the EU Nitrate Directive. During the planning, several data had to be digitalized (for example: relief, surface waters, ground waters, settlements, roads etc.) to determine the unsuitable areas and safety buffer zones. We have defined the useful quantity of the liquid phase of fermented material after the examinations of the soil parameters, agro-chemical, cropping and water management. Loading results into the job computer of the discharging vehicle, movement of the vehicle itself can also be planned and monitored during the discharge.

CONCLUSIONS

The biogas plants working with high capacity mixed material have several working risks, because of changing of the components of raw materials. The bio-fermentation processes can be disturbed for a long time by fewer breakdowns and stalling causing a decrease in capacity and losing the profit. Getting out the enormous amount of digested outlet materials originated form centralized industries is also hazardous, while the unsuitable disposing leads to damage the soil or causes odour. Because of the hard agro-environmental rules farmers consider that the disposal of the material having higher nutrient is risky. To reduce risks we have carried out examinations above mentioned in laboratory. The combinations of the optimal recipes could reduce the harmful gas outlet (ammonia, sulphur-hydrogen). The GIS logistical system controls the input transportations and the precocious agricultural system based on GIS/GPS ensures the disposal of output material in an environmental way. In this closed controlling system the life cycle of the bio-fermented materials can be followable from the hazardous wastes, through the biogas production, to disposal. Archiving of the GPS and the real time coordinates guarantees the correspondence to the hard agro-environmental rules.

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