JUSTIFICATION OF SCIENTIFIC AND PRACTICAL APPROACHES TO RATIONAL USE OF STRAW AND PLANT RESIDUES

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Abstract. *In the paper, the current situation in the production of crop growing by-products in Ukraine is examined. The potential output of crop growing by-products in various regions of Ukraine, part of which could be allocated for energy production, is determined. The fuel properties of the main types of biomass are presented. The state-of-the-art approaches to the use of straw and plant residues in agriculture are analysed. The possible ways of utilising straw and plant residues in crop growing for maintaining and regenerating the fertility of soils, in livestock husbandry as bedding and a supplement to coarse fodders and in heat power industry as an energy source for the production of thermal power are established. The state-of-the-art technologies and machinery for the rational use of straw and plant residues are described. The need for additional research into what plant residues and what quantities of them can be reasonably used for the fertilisation of soils, taking into account the saturation of the crop rotation systems with cereal crops, the limitation of the phytopathogenic load on grain varieties, the development of weeds, the management of the soil's nitrogen status under different soil and climate conditions.*
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1. Introduction

The crop growing production process ends, as a rule, with the harvesting of the main product, while the by-products – the straw of spiked cereals and grain legumes, the stalks of corn, sunflower, rape, the tops of sugar beet etc. – are either gathered as an additional product and used for production purposes or shredded, distributed over the surface of the field and mixed with the upper layer of soil with the use of disk stubble ploughs or ploughed in into the soil to a certain depth during the tilling operations.

The output of crop growing by-products in Ukraine amounts to over 80 million tons per annum, in some years it reaches up to 100 million tons. The bulk of these products is the straw of spiked cereals and grain legumes with an annual production volume of 45…50 million tons. Traditionally, the straw of cereal crops has always been used for heating the houses, feeding the cattle, as bedding and in the construction of houses and household outbuildings. Therefore, it has been carefully collected and stored. The stalks of corn, sunflower, the straw of rape and other plants have been used mostly for heating, the tops of sugar beet – for feeding the animal stock.

It is to be noted that the process of gathering and storing crop growing by-products is rather resource intensive and involves a whole park of agricultural machinery used for various operations. For example, the labour inputs in the gathering and stacking of straw is 2…3 times higher and the fuel consumption is 1.2…1.5 times higher than in the harvesting of grain. That is why farm managers are in constant search for the ways of utilising more efficiently and at less cost the straw and other plant residues.

2. Preconditions and means for resolving the problem

In the worldwide practice, the straw and other residues of agricultural plants are used primarily:

– in crop growing for maintaining and regenerating the fertility of soils,

– in livestock husbandry as bedding and a supplement to coarse fodders,

– in heat power industry as an energy source for the production of thermal power.

On a smaller scale, straw is used for the production of mushroom cultivation substrates, in arts and crafts etc.

Each of the above-listed main areas of utilisation for straw and plant residues has its own advantages and deficiencies, followers and opponents. The majority of scientists, especially those in the domains of soil sciences and agronomy, believe that straw and plant residues must be employed for maintaining and regenerating the fertility of soils. A number scientists and experts take into consideration the problems with hydrocarbon energy products and opine that straw is a promising source of energy and its use for the production of thermal power must be actively promoted. There is a conservative scientific community with ideas about the utilisation of straw in livestock husbandry. The advocates of each of these standpoints bring weighty arguments in favour of their outlook and, under specific real working conditions, it is sometimes difficult to make a right decision about employing one or another of them.

The solution is that each of the proposed approaches is used, where it is most needed and taking into account the specific conditions, in which it will be most efficient. For example, if the farm unit does not work with livestock production or holds a limited number of livestock, the manure output is small or absent, then certainly the straw must for its most part be used for maintaining and regenerating the fertility of soils. Because, in the absence of natural fertilisers, there is virtually no other source of replenishment of the soils' organic component. Meanwhile, if the farm unit under consideration is an animal production unit, which has manure in abundance, the use of straw as a fuel for heat generation is totally justified. Thus, the selection of the approach to the rational use of straw and plant residues has to be based on the principle of economic and operating practicality.

3. Results and discussion

In the following pages, the most widespread approaches to the use of the straw of spiked cereals are given consideration. For example, the use of the straw and plant residues of agricultural plants as a fertiliser is especially popular in the countries with a developed agricultural industry. Recently, this approach has been gaining acceptance in Ukraine as well. The main reason for that is the current situation, when the livestock numbers are significantly reduced and the input of organic and mineral fertilisers into the soil is limited. Thus, the most acceptable way to maintain the humus content at a relatively satisfactory level, prevent the degradation and promote the fertility of soils is to utilise the after-harvesting plant residues of field crops, first of all, the straw of winter crops as organic fertilisers.

According to the data of the NSC "O.N. Sokolovsky Institute of Soil Sciences and Agricultural Chemistry", the current rate of the annual loss of humus in Ukraine is up to 0.5 tons per hectare of plough land. At the same time, it is possible to return to soil through the use of straw and plant residues 15…20 kg of nitrogen, 8…10 kg of phosphorus and 30…40 kg of potassium per hectare as well as some important secondary fertilizer components, such as boron, copper, manganese, molybdenum, zinc and cobalt.

By using 17…20 million tons of straw as organic fertiliser, it is possible to achieve annual savings of over 100 thousand tons of nitrogen, 70 thousand tons of phosphorus and 250 thousand tons of potassium. The listed figures prove that straw is a valuable organic amendment; indeed, in humus equivalent one ton of straw can replace 2.5…2.8 tons of bedding manure.

That said, it is worthwhile to say that the straw just introduced into the soil is not yet an organic fertiliser in a literal sense, it will become such only later, after the humification process is complete and the straw has lost its ability to produce a depressive effect on the subsequent agricultural crop. For that to happen, it is necessary to create certain conditions, as the microorganisms that decompose organic compounds belong to the aerobic group, therefore, the straw humification process can be intensified by the sufficient aeration and moistening of the soil. Thus, it is better to plough in the shredded straw into broken humid soil. The length of a straw shred may not exceed 10 cm. This requirement is applicable also to the other plant residues allocated for the use as organic fertilisers. In order to cancel the depressive effect of straw on the growth and development of the plants of the subsequent crop, it is necessary to input at least 10…12 kg of the primary nutrient of ammonium-based nitrogen fertilisers in each ton of straw prior to ploughing it in into the soil. If the above-mentioned conditions are met, in 6…8 months 40…50% of the straw deposited in the soil will undergo humification and become an organic fertiliser. The remainder of the straw will turn into a fertiliser a little later.

Taking into account the described situation, straw is usually introduced into the soil as a fertiliser for spring crops, because the sowing is preferably carried out only in 6…8 months after ploughing in the straw into the soil.

Technically and economically, the most rational process layout for the use of straw as a fertiliser comprises its shredding during the main product harvesting followed by the introduction of a nitrogen fertiliser and the ploughing in of the straw into the soil. For that purpose, the grain harvesters have to be equipped with multi-purpose shredding machines, which will shred the straw and uniformly spread it over the surface of the field within the working width of the header. Other layouts are less efficient, but in real working conditions their implementation as often as not is stipulated by the specific circumstances.

In summer 2016, it so happened that the rains caused delays in the grain harvesting operations, the standing crop was beaten down, weeds came up, which led to the growing loss of the harvest. Taking into account these circumstances as well as the high price of fuel and high rate of wear-and-tear in the complete harvester fleet, part of the grain producers were bound to gather only the grain component of the harvest, while the straw was left in the field in windrows. In addition, the imported grain harvesters operated in many farm units were not equipped with straw shredders.

As a result, the condition of many fields after the harvesting of early cereal crops virtually prohibited the ploughing in of the straw into the soil and the performance of the main soil cultivation without undertaking additional operations.

The question was raised: how can the straw lying in the fields in windrows be shredded, uniformly spread over the surface of the field, mixed with soil with the following main soil cultivation in those fields? In the case under consideration, the most reasonable way to shred the straw was to apply the plant residue shredder PR-4.5 and IRP-5.4 with the vertical line of rotation of the tools and the shredders PP-2, PN-2.0 and PN-4.0 with the horizontal line of rotation, or shredders manufactured by the foreign companies "KUHN", "SHULTE" and other.

Sometimes farmers use heavy disk harrows of the BPRR-4.2 and BPRR-6.5 types instead of plant residue shredders for shredding straw in windrows, after which the surface of the field is cultivated with the use of heavy cultivators of the KPE-3.8 type. But in that case, it is to be taken into account that the quality of straw shredding will be much lower, not to mention the uneven distribution of the straw over the area.

For the shredding of the stalks of the corn harvested for grain, OAO "Kherson Machine-Building Plant" offer the KMS-6 header for the KZS-9-1 "Slavutich", Don-1500, "Yenisey-960" grain harvesters and the KKP-2S trailing corn harvester, for the shredding of the stalks of sunflower simultaneously with the harvesting of the seeds they offer the PZS-8 header that can be ganged up with all models of grain harvesters available in the Ukrainian market.

The straw or other plant residues shredded and spread over the surface of the field must be ploughed in into the soil not later than two days after the addition of nitrogen fertilisers. In order to mix the shredded straw and plant residues with the soil and plough them in into the soil, heavy disk harrows of domestic or foreign manufacturers are generally used. The best results are provided by the disk harrows with the combined operation of disc tools and cylindrical compactors.

The second main trend in the efficient utilisation of straw is its application in livestock husbandry. In the previous years the straw of cereal crops was used in this sector as a coarse fodder and for bedding. Mechanical, chemical, thermal, thermochemical, biological, barothermal and other methods of improving the nutritional value of straw were used in the preparation of it for feeding. For that purpose, various straw choppers, metering bins, mixing machines, steamers etc. had been developed, but the desired effect from feeding straw to animals had not been achieved. The main conclusion from that is that for high-performance animals straw is a fodder of little value and it is only reasonable to use it as a supplement, which in certain feeding diets can satisfy the demand of the livestock for fibre. In livestock farming, it is practical to use straw first of all as the bedding that is most suitable for providing the comfortable housing conditions for the animals and production of organic fertilisers.

According to the data of the Institute of Livestock Husbandry of the NAAS, the daily demand for bedding straw varies from 2 to 8 kg per cow, depending on the type of housing and the livestock production rate. At such straw consumption rates, in dairy farms it is possible to obtain daily 40…50 kg of organic fertilisers per capita; high-performance farms can have even higher outputs.

Lately, in developed economy countries the use of straw and plant residues for energy production purposes has been gaining popularity. This trend in energy industry is developing most actively in Denmark, Sweden and the majority of the Central European countries. In their economies, 5 to 20 per cent of all straw is used for energy-related purposes every year.

Considering the growing prices of fossil fuels and the dependency of our country on their import, the utilisation of crop growing by-products, in particular, straw for energy production purposes is a promising trend. Ukraine already has certain experience in the utilisation of straw for thermal power production. Thus, at the moment, 16 heat-generating systems operate in rural areas, which consume about 10.5 thousand tons of straw and generate over 1.5 million kWh of thermal energy.

According to the preliminary estimates, there are possibilities in Ukraine to utilise annually up to 10 million tons of the straw of cereals and about 7 million tons of the straw of rape, which can reduce the demand for fossil fuels in the heating energy generation sector by almost 4 million tons.

Nevertheless, it is worth mentioning that the agricultural biomass used as a fuel has a number of distinctive features, which make it different from the energy resources conventionally used for heating. The most important fuel technology property of the biomass used as a solid biofuel is its heat generation capacity, which depends on many factors, such as: genetic traits of the energy plants, environmental effects, storage conditions, moisture content etc. Table 1 lists the average heat generation capacities of various agricultural energy feedstocks (which previously were classified as the waste products of the agricultural industry) at a moisture content of 20%.

The present-day consumers of fuels tend to favour, as regards the technology and engineering, concentrated non-renewable sources of energy. Raising the level of the energy self-sufficiency of the agricultural industry through the use of straw will require considerable capital investments.

Table 1. *Average heat generation capacity of energy feedstocks*

Description of feedstock	Heat generation capacity ($MJ \cdot kg^{-1}$)
Straw of cereal crops	10.5
Stalks of corn	12.5
Branches of fruit trees	10.5
Stalks of sunflower	12.5
Grapevine	14.2

In Ukraine, straw burning heat generators with air as the heat transfer medium are produced. They can be ganged up with drying installations and used for heating greenhouses and industrial premises (heat generators of the TGS type manufactured by OAO "BRIG", Nikolayev Region). The range of heat generating units includes also hot-water boilers for heating industrial premises and social and cultural facilities (boilers of the RAU type manufactured by OAO "PIVDENTEPLOENERGOMASH", Rovno Region, under the licence the Danish "PASSOT ENERGI"), waste heat boilers for burning the woodworking waste (waste heat boilers of the TGU type manufactured by AO "MACKAGROTEKH", Kiev Region, and of the "DRAKON" type manufactured by OOO "UKRAINIAN TECHNOLOGICAL SYSTEMS", Ternopol Region). Another trend in the utilisation of straw as an energy vector is its burning in the compacted form of pellets and bricks, which makes the combustion process slower (5-6 times comparing to the pulverised non-compacted bulk) and more controlled with respect to the emission of volatile compounds and combustion gas into the atmosphere. Moreover, with this approach positive preconditions arise for the improvement of the specific energy content of the plant feedstock through its mixing with more calorific waste products generated during the processing of agricultural stock, for example, extraction cakes, press cakes, ballast products from the production of vegetable oils as well as peat and coal dust. In view of the fact that the Ukrainian industry has opened up the production of press and special process equipment ("PRESMASH" Works, Ivano-Frankovsk, ZAO "CHERKASELEVATORMASH", Cherkassy), it becomes possible to initiate the pilot projects of mini-plants for the production of bricks or pellets of enriched biomass fuel with a heat generation capacity of 18 to 30 $MJ \cdot kg^{-1}$ right at the place of stock storage and its sale with insignificant transport costs.

In the NSC "IMESKH" of the NAAS, four main patterns of combining the machinery and equipment for the procurement of plant residues and production of biomass fuel from them have been determined.

Pattern I follows the sequence developed earlier in "IMESKH" and most widely used in its time: from the harvester with a shredding attachment, the shredded straw is unloaded into trailing bogies of the 2PTS-887A type (its Ukrainian equivalent, mod. 8545-45) and transferred by a 1.4 Class tractor (MTZ, PMZ) to the place of storage, where it is disintegrated in the disintegrator of the IGK-30B type (Ukrainian equivalent IUF-10) before feeding it into the heat generating unit.

Pattern II suggests compacting the whole or partially shredded straw arranged in large stacks by a baling machine of the PRF or PT type (manufactured by OAO "IRPINMASH") into square or round bales, which are loaded by a PF-0.5 loader in the carrier vehicles (a heavy trailer or a truck with a trailer of the KAMAZ-53208 or MAZ-Super type) and transported to the place of storage or combustion. It is also reasonable to utilise in the carriage of round bales the 1PTSM-9 trailer retrofitted in DPDG "STEPNOYE", Poltava Region, which is capable of transporting simultaneously 9 round bales of straw and unloading them with own means at the place of storage or combustion.

Pattern III is applicable mainly to the procurement of after-harvesting residues (stalks) of corn, sunflower, sorghum: the stalk mass is shredded with the use of the grass-mowing machine of the "ROS-2" type (manufactured by "BILOTCERKIVSILMASH"), arranged in windrows, compacted with the use of the above-mentioned baling machines and delivered to the place of combustion following Pattern II.

Pattern IV for compacting plant residues into bricks or pellets can involve Pattern I, where the initially shredded biomass is transferred by heavy trailers to the place of combustion, finally disintegrated, finally dried and compacted with the use of ram, ring-roll or screw press.

It is to be noted that the use of straw is economically viable with the short distances of carriage from the production site to the utilisation site. Thus, the economically rational distance for the carriage of shredded straw at a haulage rate of about 1 $dollar \cdot (t \cdot km)^{-1}$ may not exceed 100 km. Under the same conditions, the economically viable distance for the carriage of straw in round bales can be 2…2.5 times greater, the carriage of straw in bricks – 5…6 times greater. The said difference between the economically acceptable carriage distances results from the different costs of carriage. Thus, the cost of carriage of loose shredded straw under current economic conditions can be around 7.5 hryvnias a ton to a distance of 1 km, straw in round bales – 0.3 $dollar \cdot (t \cdot km)^{-1}$, straw in bricks – 0.1…0.2 $dollar \cdot (t \cdot km)^{-1}$. The mentioned limit values are based on the fact that the cost of the heat generated by burning straw is within a range of 20…23 $UAH \cdot ha^{-1}$ and is equal to the cost of the heat generated by burning own natural gas.

As is obvious from the data on the production and utilisation of straw obtained in the scientific establishments and research and development farm units of the National Academy of Agricultural Sciences of Ukraine (Table 2) in the last three years, considerable amounts of straw can be used for energy production purposes. If the stalks of corn, sunflower and rape are added, it becomes apparent that there are reserves for thermal energy generation.

Table 2. *Data on production and utilisation of straw of early cereal crops in different years from scientific establishments and research and development farm units under NAAS*

Production and utilisation of straw (thousand tons)	2007	2010	2017
Production	420.0	675.0	524.0
Demand for fodder and bedding for livestock	86.0	85.0	84.0
Utilisation as organic fertiliser	126.0	203.0	157.0
Free balance	208.0	387.0	283.0

Hence, it is possible to state that the machinery of the domestic and foreign manufacture available in the Ukrainian market is quite sufficient for the gathering, storage and preparation of straw in round bales, packs, bricks, pellets or unprocessed form. At the same time, the equipment for the preparation of biomass for combustion and heat generation needs improvement with due with provision for the specific factors in the consumption of thermal energy produced from biomass.

4. Conclusions

With reference to the above-said, taking into account the current trends in the utilisation of straw and other plant residues, there is urgent necessity of additional research into what plant residues and what quantities of them can be reasonably used for the fertilisation of soils, taking into account the saturation of the crop rotation systems with cereal crops, the limitation of the phytopathogenic load on grain varieties, the development of weeds, the management of the soil's nitrogen status under different soil and climate conditions. The accumulated knowledge and field experience in the utilisation of crop growing by-products as organic fertilisers have to be taken into account under specific farming conditions.

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