Environmental Aspects of Burning Field Residues for Use as an Alternative Fuel

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Summary: The growing need for energy with concomitant preservation of the environment imposed the need for finding renewable, alternative, environmentally friendly energy sources. Utilization of biomass energy, deriving from residues of field crops, offers numerous advantages. Plant biomass is a renewable source of energy. Its burning does not contribute significantly to the atmosphere CO₂, the contamination with NO_x and SO_x is low, and the amount of ash remaining after combustion is small. Therefore, it is ecologically acceptable. The negative aspects evolve from the fact that organic and mineral matter contained in the harvest residues plays an important role in the cycling of nutrients within agroecosystems. Those nutrients are completely or partly lost when harvested residues are burned. Therefore, regular removal of harvest residues or their burning in the field, without regular application of organic fertilizers which would compensate for lost nutrients and beneficial effect that organic matter has on soil properties, may have long-term negative consequences for soil fertility. Taking into consideration the importance of harvest residues in cycling of nutrients within the agroecosystems and their positive effect on soil properties, it is very wrong to assess their value only on the basis of the value of energy obtained by their burning.

Key words: burning, energy, field residues, nutrients, soils

Introduction

In the history of mankind various types of energy have been used. Today, the most widely used non-renewable energy sources are fossil fuels (coal, oil, natural gas), and still at a small scale renewable energy sources (solar, wind, biomass, etc.). Urbanization, development of transport and various industries, population growth on Earth, increase of living standards, rapid economic development in some, until recently, far less developed countries (China, India, Brazil), have led to an enormous increase in energy consumption and prices. The increasing demand for energy causes a number of technical, technological, economic, social and international problems and in recent decades also environmental problems, for two main reasons. First, stocks of non-renewable energy sources, besides the fact that they are not evenly distributed on Earth, are not infinite

and, second, their massive use threatens to lead to environmental disaster of global proportions, i.e. climate change on our planet. From the standpoint of global climate change, the biggest problem is emission of carbon dioxide, nitrogen oxides and sulphur during combustion of fossil fuels. In Serbia, a significant part of the energy is obtained by coal combustion after which large amounts of ash are left behind. This represents a significant environmental problem. In addition, combustion of coal leads to release of large amounts of sulphur and nitrogen oxides into the atmosphere (Kastori & Milošević, 2011). These data clearly indicate a major environmental benefit of biomass as a renewable source of energy.

The energy crisis of the seventies gave great impetus to study the possibility of using non-conventional, alternative, renewable energy sources, one of which is the biomass (green energy). Using biomass to produce energy has numerous advantages. It reduces dependence on imported fossil fuels for countries that do not have deposits of fossil fuels, which is also of economic and political significance. The use of biomass as an energy source is from an

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environmental point of view much better than the use of fossil fuels, since it is much less polluting the environment (Brkić et al., 1995; Kastori, 1995). In an era of high worldwide unemployment one cannot neglect the fact that the use of biomass as an energy source provides 20 times higher number of jobs (mostly locals) than using coal or oil and the fact that combustion of biomass produces far less ash than combustion of coal. In addition, it is necessary to emphasize the enormous mass of biomass on Earth. Theoretically, the global biomass energy potential of our planet is estimated to be 2900×10^{18} J. The total consumption of biomass energy accounts for 11% (44×10^{18} J) (Track & Michels, 2008). In Serbia the biomass of crop plants per year is 30 million tons (Mihajlović, 2006).

By different technological processes it is possible to produce bioethanol, biogas, biodiesel, and direct burning heat out of biomass (by-products of agriculture, timber and livestock production, algae, energy crops, organic waste, wood, corn and oil crops, etc.) (Bai, 2011). Post-harvest residues of crop plants represent a significant amount of biomass that has a relatively high thermal value and therefore there is the tendency to use them as an energy source (Brkić & Martinov, 2006; Ilic et al., 2004). In addition, it is a renewable and environmentally friendly source of energy. The simplest way of obtaining energy from crop residues (wheat straw, corn, soybean stalks, etc.) is their burning after briquetting or baling (Janjić et al., 2006; Martinov et al., 2005). Recently many affirmative papers were published about the use of crop residues, especially straw, as an alternative fuel (Jovanović & Kiš, 2004; Obernberger et al., 1995; Dinya, 2011). Baling of crop residues and their utilization for energy production has started in Serbia.

In the long run, from the standpoint of preserving the fertility of soil, removal of crop residues from fields and burning them in order to obtain the energy can be very harmful. It is therefore reasonable to point out the environmental consequences that can have a one-sided approach to this problem. It is completely wrong and unacceptable to treat harvest residues of crop plants as useless organic matter or as waste. The value of harvest residues is determined only on the basis of the energy that can be produced by their burning. Therefore, the aim of this paper is to highlight the importance of crop residues and the possible harm that their burning may have on the cycling of matter in the agroecosystem, the preservation of soil fertility and hence on the yield and quality of agricultural products.

The Importance of Crop Residues in the Cycling of Nutrients in the Agroecosystem

Agroecosystems, or agricultural ecosystems, occupy large areas in the world. Their main characteristic is the impact of anthropogenic factors, which is a powerful factor of development of the biosphere. The greatest human impact on the formation of agroecosystems can be seen at the level of producers. The result is a disturbance of the cycling of matter and energy flow (Kastori et al., 1985; Kastori & Tešić, 2006). The main features of development and transformation of agroecosystems are closely associated with the development of agriculture, land use and fate of manufactured goods. In the natural ecosystem, dead parts of plants are returned to the soil where their humification takes place, thus providing continuous cycling of matter. In agroecosystem, the removal of products leads to partial or complete interruption of nutrient cycling, depending on whether it only or main product or by-products as well are removed (Fig. 1). Residual root system is lightweight and has no significant influence on the content of soil organic matter. Root dry weight of corn is only about 2 t/ha (Kastori & Drezgić, 1964).

Figure 1. Cycling of matter in the nature (A) in the agroecosystem (B)

Human activities disturb the circulation of matter in the agroecosystem not only by the removal of biomass from fields, but also by the other unmindfully undertakings such as the burning of crop residues on site, in the field. This procedure is prohibited for the environmental and security reasons, but nevertheless it still happens. In addition to the burning of crop residues in the field, which cause irreparable loss of the organic matter, it leads to the destruction of many beneficial insects and other animals, damage to the soil microflora, and air

pollution. In the European Union, farmers who burn crop residues in the field lose stimulating financial means that the state provides for producers. Lack in nutrients that is provoked by burning or removal of harvest residues may be made up to a certain extent by application of organic fertilizers, manure, green manure, compost, etc. The deficit in the cycling of matter in the agroecosystem, that evolves due to burning or removal of crop residues, to some extent can be made up by application of organic fertilizers, manure, compost, green manure, etc. It is considered that in the ecologically responsible agriculture about one half of the produced biomass should be returned to the soil in the form of crop residues or compensated by organic fertilizers. Farmers burn crop residues (corn, stalks, wheat straw, etc.) because it facilitates tillage. It has to be noted that in some cases it is accompanied by accidents with tragic consequences. The removal of crop residues from fields and their use for production of energy is certainly better solution than burning them in the field. It is economically and environmentally justified and allowed by positive regulations.

The upper layers of soil, from 0 to 30 cm, contain 5-20 t of biomass of microorganisms. These microorganisms are mostly heterotrophic, which meet their need for carbon and energy out of soil organic matter. They decompose and consume significant amount of organic matter. It is considered that the loss of humus in the fields of Vojvodina reaches, depending on the type of soil, 960 to 1350 kg/ha per year. By ploughing of wheat straw, maize residues or sugar beet leaves, 400 to 900 kg of organic matter per hectare is restored, depending on the amount of dry matter ploughed (Vučić, 1992). The humus contents in soils of Vojvodina decreased by an average of about 0.3% during the past decades (Bogdanović et al., 1993). Reasons for the reduction of content of humus, which is one of the main sources of soil fertility, are the following: reduction or long-term omission of use of organic fertilizers, mainly manure, burning of crop residues in the field and disregard of crop rotation. Whereas in the Netherlands on every hectare of arable land there are about 4 animal units, it is estimated that in Vojvodina there are only about 0.3. This clearly indicates that the level of livestock production in our country does not allow regular fertilization of soil with organic fertilizers. If we add more regular and systematic burning of crop residues in order to gain energy over a period of years, it inevitably leads to depletion of soil organic matter and humus, which is very unfavourable effect on his

fertility. Chemical, physical and microbial properties of the soil, which are crucial for its fertility, depend to a large extent on the content of organic matter. Only the soil that contains sufficient amount of organic matter of good quality can have a stable and lasting structure that will enable optimal supply of crops with water and minerals. Favourable soil structure allows the creation and maintenance of compensatory capability of the soil - the ability to buffer the changes of its own properties in the presence of unfavourable climate conditions and in the presence of pollutants.

In the stationary long-term field trials which have been lasting since 1966, it was found that multi-year incorporation of by-products of crop production (wheat and maize straw) increases the proportion of organic matter in the soil. The increase is reflected both in comparison to the control, and in comparison to the plot to which mineral fertilizers were applied. In the layer of 0 to 15 cm of the plot to which harvest residues were incorporated, the increase in organic matter is 0.28% compared to the control, whereas in the layer from 15 to 30 cm it is much higher, 0.46%. In comparison with long-term application of mineral fertilizers, increase in organic matter in the soil to which harvest residues were incorporated is 0.25% and 0.32% for the 0 to 15 cm and 15 to 30 cm, respectively (Stevanović, 1978). After Vasin (2008), 41.2% of plowed fields, 54.4% of orchards, 57.9% of vineyards and 37.5% of soils under greenhouses in Vojvodina are low in humus. To increase humus content in those soils, the authors recommend, among the other measures, ploughing under of harvest residues of preceding crop.

Importance of organic matter that constitutes crop residues is not limited only to carbon cycling in the agroecosystem. Crop residues are important for the cycling of the other essential elements, with special emphasis on nitrogen. During combustion of biomass the entire amount of carbon is lost, in the form of carbon dioxide. A very important intermediate product is carbon monoxide, which in the presence of oxygen quickly oxidizes into carbon dioxide. Combustion of biomass leads also to the loss of the entire amount of nitrogen present in biomass. Emission of nitrogen oxides (NO_x) takes place during burning of crop residues. During the combustion, about 90% of the nitrogen forms NO and about 10% NO_2 . Depending on the presence of oxygen and temperature, other nitrogen compounds such as N_2O or N_2 may arise. Dry matter of crop plants contains most often between 2 and 5% nitrogen (Vukadinović & Vukadinović, 2011),

and depending on the level of nitrogen provision, crop species, genotype, organ, etc. nitrogen content may significantly deviate from the average (Kastori & Maksimović, 2008). Especially high nitrogen content has soybean straw. Because of its relatively high calorie value (15.500 kJ/kg) it is recommended as an alternative fuel (Brkić, 2012). Therefore, the burning of crop residues leads to the loss of a significant amount of this, for plants very important biogenic element, which has direct negative environmental and economic consequences. Combustion of biomass is accompanied by the loss of a part of the biogenic elements sulphur, which is of little ecological significance for two reasons: 1) the sulphur content is low in most plants, and 2) on the soil surface accumulate significant amounts of sulphur from the atmosphere (even more of 20 kg of sulphur per hectare per year), depending on the level of pollution of the atmosphere by sulphur oxides.

Biomass is important for cycling of phosphorus as well. After burning, most of the phosphorus remains in the ashes. Combustion leads to emissions of one part of potassium, chlorine and sodium – these elements are components of flying ash or salt (KCl, NaCl, and K₂SO₄). Salts are formed in the reaction between potassium and sodium with chlorine or sulphur (Loo & Koppejan, 2002). From an ecological point of view, the fate of biogenic trace elements and elements with predominantly toxic effects, such as Cd, Hg, Pb and As, to name several of them, is of high importance (Sander & Andren, 1997).

The composition and solubility of some elements in the ash deriving from biomass are different and depend on several factors, especially on its origin or plant species. Ash deriving from by-products of cereals is characterized by a higher content of potassium oxide, calcium, magnesium and phosphorus. In the wheat straw ash, about 30% of potassium is water soluble which means that that potassium is available to plants. Only part of the phosphorus is soluble, while the residual chlorine and sulphur are soluble in water (Loo & Koppejan, 2002).

Crop Residues and Soil Fertility

Each unit of the biological yield is a great gift of nature, in which solar energy is transformed into chemical energy. There are many examples where the ploughing of crop residues gave the same or nearly the same results as application of manure to the soil, with respect to improvement of soil properties, yield and its quality. Incorporating crop residues

partly resolves the problem of soil organic matter. Moreover, costs of collection and shipment to the field and field trampling (due to transport, which causes soil compaction) are absent. Humification of crop residues lasts about the same as the processes of decomposition of manure, and the products of these processes have similar effects on the structure, adsorptive capacity, the water regime, and formation of humus. It was found that three years after ploughing of soybean hay, the organic mass of soil retained 20% carbon, about 70% mineral matters, and cation exchange capacity of soil increased by 10% (Shaw & Robinson, 1990). Positive effects of application of millet crop residues on symbiotic nitrogen fixation, accumulation of nitrogen, potassium and molybdenum on acid sandy soil was found and in groundnut grown there had higher yield, and concentrations of manganese and aluminium in its tissues declined (Rebafka et al., 1993). In the same edaphic conditions, application of crop residues diminished the toxicity of aluminium and increased availability of phosphorus (Kretschmar et al., 1991). On heavy soils, harvest residues improve internal drainage in the layer in which they are incorporated and protect the soil from water erosion (Dimitrov et al., 2011). Ploughing of crop residues favourably affected the growth and yield of millet (Bationo & Mokwunye, 1991).

The content of soil organic matter does not change quickly. This helps to explain the fact that effects of faulty management of soil organic matter, on the soil of good chemical and physical properties, become observed only after several years or decades. This is well illustrated by the results of long-term field trials which showed that yields on surfaces from which crop residues were removed each year yield decreases in comparison with surfaces where each three years 5 t/ha of straw were ploughed. The effect of long-term ploughing under of wheat straw on grain yield of corn ranged from only 360 kg/ha of grain in the case of the hybrid NS 6010 to a significant amount of 1310 kg/ha in the case of the hybrid NS 510 (Latković et al., 2009). Average wheat grain yield after ploughing under of straw for three cultivars amounted to 640 kg/ha, or 15.3%, and it was 750 kg in cultivar Pobeda, 680 kg in cultivar Sofija and 460 kg/ha in cultivar Sremica (Jaćimović et al., 2009). At the same time ploughing of crop residues increased the content of proteins and some amino acids in wheat and maize grain (Kastori et al., 1985). In the same experiments the beneficial effect of ploughing of crop residues on soil microbiological activity was

demonstrated (Milošević, 1985). In addition it was found that ploughing of crop residues reduces the leaching of nitrate in the deeper layers of soil which is very important from an economic and ecological point of view as this improves plant nutrition while reducing the pollution of groundwater with nitrates (Marinković et al., 1993).

Incorporation of crop residues enriches the soil in nutrient elements as well. On average, dry matter of plants contains 45% carbon, 42% oxygen, 6.5% hydrogen, 1.5% nitrogen and 0.5% of the other minerals. Average yield of wheat is accompanied with about 6 t/ha of straw. This amount of straw contains (kg) N 24 P 3, K 42, Ca 12, Mg and S 6, and biogenic trace elements (mg) Fe 420, Mn 240, Zn 60, Cu 30, B 24 and Mo 2. The average yield of corn straw is 9 t/ha and it contains in average (kg) N 80, P 18, K 72, Ca 36, Mg 18, S 9, and biogenic trace elements (mg) Fe 360, Mn 270, Zn 180, Cu 36, B 38 and Mo 2 (Kastori & Tešić, 2006). The corn stalk contains about 45% of nitrogen, 30% of phosphorus and 71% of potassium taken up during vegetation period, which means that by ploughing the corn stalk significant amounts of these very important elements is returned to the soil. It should be noted that the amounts of nitrogen, phosphorus and especially potassium contained in crop residues are sometimes greater than the amounts of the same elements commonly given to the soil in the form of mineral and other types of fertilizers.

On the one hand, incorporation of crop residues in crop production partially solves the problem of compensation of mineral and organic matter to the soil, and on the other reduces costs of their collecting after harvest and their transport, which is also accompanied by additional trampling and soil compaction. In Hungary in 1985, the total biomass (not just agricultural) contained 1.1 million tons of nitrogen, phosphorus and potassium. If that the amount of biomass was used for fertilization, in total 229 kg of nitrogen, phosphorus and potassium would have been added per hectare of arable land. That amount of nutrients corresponds to the amount of nutrients taken up by winter wheat that has final yield of 4.1 t/ha (Lång et al., 1985).

There are agricultural by-products that are not of high significance in the nutrient cycling in the soil due to unfavourable C:N ratio and a low content of biogenic elements, such as by-products of ears of corn or hemp, which decompose and mineralize in the soil very slowly. Their use as a fuel can be considered as a good option.

There is none technical/technological solution in any area which is characterized by only positive traits. Summing up the positive and negative characteristics of burning of crop residue for energy production leads to the following conclusion:

There are other possibilities for the use of biomass to obtain energy, besides burning of crop

Advantages and disadvantages of burning of crop residues for energy production

Advantages:	Disadvantages:
- Large mass	- Interrupts nutrient cycling in the agroecosystem
- Renewable source of energy	- Soil compaction
- Does not affect the concentration of atmospheric CO ₂	- Baling expenses
- Minimal emission of SO _x and NO _x	- Transportation expenses
- Combustion generates little ash	- Loss of nutrients (C, N, S, etc.)

Advantages and disadvantages of plowing crop residues

Advantages:	Disadvantages:
- A positive effect on the yield and product quality	- Ploughing of crop residues makes tillage more difficult
- Increases the amount of organic and inorganic matter in the soil	- Unfavourable C:N ratio (wheat straw and corn stalk)
- Increases the activity of soil microflora	
- Reduces the washing away of nitrate in the deeper layers of soil	
- Increases availability of P and Mo, and decreases availability of Al and Mn in acidic soils	
- Decrease of erosion	

residues, such as for production of biogas (Jäkel et al., 2002). This procedure has more advantages for the environment also because the residues after fermentation contain significant amount of biogenic elements. Therefore, those residues can be used as fertilizers.

Conclusions

Reserves of conventional sources of energy are very limited, and their prices are increasing together with the increased demand for them. Therefore, replacement of conventional sources of energy, at least in part, with the renewable and sustainable sources, such as biomass, wind, solar, hydro and geothermal energy, is becoming more and more important.

In Serbia, biomass represents an important renewable energy source (crop plants, crop residues, remains after processing of plant material and wood, etc.). There are different technological procedures for obtaining energy from biomass and only one of them is biomass combustion. Summing up the positive and negative characteristics of that way of the use of biomass, especially with regard to its ecological impact, the following conclusions can be made:

- Advantage is that biomass is present in large quantities, its combustion does not further burden the atmosphere with carbon dioxide, it burdens it only a little by nitrogen and sulphur oxides, and the amount of ash that remains after combustion is relatively small.
- Crop residues (straw of wheat, soybeans, corn, etc.) contain a significant amount of organic and mineral matter and therefore their ploughing contributes to the maintenance of soil fertility. Ploughing of crop residues affect yield and quality of crops, increases the activity of soil microflora, reduces rinsing of nitrate in the soil profile, etc.
- Burning of crop residues leads to loss of the entire organic matter and nitrogen, and partly of sulphur and therefore removal of crop residues from fields and their combustion leads to the interruption of circulation of substances in the agroecosystem, and their baling and transport further contribute to soil compaction.
- When crop residues are regularly removed from the field, it is necessary to fertilize with organic fertilizers, especially manure, every three or four years, in order to preserve soil fertility

- There are other technological possibilities of using biomass to obtain energy, such as the production of biogas, which is agroecologically a much more suitable procedure.

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Ekološki aspekti spaljivanja žetvenih ostataka kao alternativnog goriva

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Izvod: Sve veća potreba za energijom i očuvanjem životne sredine nametnula je potrebu za iznalaženjem obnovljivih, alternativnih, ekološki prihvatljivih izvora energije. S tim u vezi u žiži interesovanja našla se i biomasa njivskih biljaka. Korišćenje biomase njivskih biljaka u energetske svrhe ima niz prednosti. Biomasa spada u obnovljive izvore energije, prisutna je u velikim količinama, njeno sagorevanje ne opterećuje dodatno atmosferu ugljen-dioksidom i samo neznatno oksidima sumpora i azota, a količina pepela koji ostaje nakon sagorevanja je mala. Negativni efekti proističu iz činjenice da organska materija žetvenih ostataka ima važnu ulogu u kruženju materije u agroekosistemu. Pored toga što predstavljaju organsku masu, žetveni ostaci se odlikuju i relativno velikim sadržajem biogenih elemenata koji se sagorevanjem potpuno ili delimično gube. Odnosenje žetvenih ostataka sa njiva (baliranje, transport i sl.) povezano je sa dodatnim gaženjem i sabijanjem zemljišta. Stoga redovno odnošenje žetvenih ostataka sa njiva bez redovne primene organskih đubriva, sa stanovišta očuvanja plodnosti zemljišta, može da bude dugoročno veoma štetno. U slučaju da se biomasa redovno odnosi sa njive, u cilju očuvanja plodnosti zemljišta potrebno bi bilo svake treće ili četvrt godinu đubriti organskim đubrivima, pre svega stajnjakom. Imajući u vidu značaj žetvenih ostataka u kruženju materija u agroekosistemu i sa tim u vezi povoljnog dejstva na plodnost zemljišta, pogrešno je njihovu vrednost proceniti samo na osnovu vrednosti energije koja se dobija njihovim sagorevanjem. Postoje i druga tehnološka rešenja za dobijanje energije iz biomase, npr. proizvodnjom biogasa što je ekološki mnogo prihvatljivije.

Ključne reči: energija, hranljivi elementi, spaljivanje, zemljište, žetveni ostaci