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AGRICULTURAL BY-PRODUCT OR EMBEDDED ENERGY?

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Abstract: Nowadays, there is an increasing need for research that seeks answers to complex questions based on generations of knowledge and experience accumulated over thousands of years. Optimizing the utilization opportunities of various cereal straws – as agricultural by-products – is also one such topic. This short synthesis paper presents the research results regarding wheat straw without being exhaustive. The direct objective of this paper is to focus on the boundary and frame conditions for determining utilization rates based on the results of numerous researchers. In particular to determine the amount of straw to keep the carbon to nitrogen ratio (C:N ratio) and the amount of organic C stocks in the soils of arable lands in an acceptable range for crop production. On the other hand, the indirect objective of the paper is to take a looking at the advantages and disadvantages of combustion by knowing the heating value, moisture content, some other physical and chemical parameters of wheat straw, as well as the nutritional values (K content, N content, S content). The utilization possibilities are the so-called "straw trilemma" based on rational usage, which takes into account the ecological aspects as well as the usability of ashes. Regarding the effect of the C:N ratio of wheat straw on the C:N ratio in the soil, it was concluded that after harvest – depending on soil type and soil condition – approximately 30–50% of the wheat straw is needed to ensure the "optimal" C:N ratio in the soil and to ensure healthy soil life (soil biological activity). The rest can be utilised in other ways, however, the agricultural and industrial utilization of 'ash' from direct combustion of straw requires technological development, taking into account the physical and chemical characteristics of "ash".
Keywords: wheat straw, embedded energy, "straw trilemma"

1. INTRODUCTION

Wheat straw is one of the most common by-products of field farming. In terms of utilization possibilities, in addition to meeting agricultural needs (replenishing soil organic matter stock and/or feeding ruminants and/or providing animal bedding), other utilization options (e.g. energy, architecture, art, etc.) might be considered, too. Therefore, wheat straw can be considered as embedded energy, as in terms of crop production it can have a positive effect on soil condition, soil life, soil energy (energy is used here in the sense of "opportunity for activity"). In addition to the amount required for the replenishment of organic matter, and then the amount of energy comes to the fore during energetic utilization (straw combustion).

The amount of wheat straw produced can be determined by knowing the growing area, the crop yield (~5 t/ha) and the grain to straw ratio. Average straw production is 3–5 t/ha annually, but during rainy periods and due to intensive N-fertilization, straw yield can exceed 10 t/ha [Árendás et al. 2013]. The research by Weiser et al. (2014) also provides guidance for determining theoretical, practical (technical) and sustainable straw yields based on statistical data and methods in Germany.

The theoretical straw potential is determined by the grain to straw ratio and the harvested area, the practical (technical) potential is determined by the cutting height (30% remains on the field as non-harvestable short stalks and chaff) and the need for animal husbandry, livestock breeding (approximately 15%), while the sustainable amount of straw is calculated on the basis of humus balance.

The ideal condition for the decomposition of organic matters is the temperature range between 25 and 40°C, fresh soil and pH 6–8.

Soil microorganisms have a C:N ratio near 8:1, they need to acquire energy (C) to maintain their metabolism, and need N to stay alive (maintain that ratio of C and N in their bodies.

Approximately, the decomposition of 24:1 C:N ratio of organic matter is the most favourable [HTTP1]. It is noted, that the C:N ratio of wheat straw is higher than 80:1. It is also important to mention that there is (also) a strong correlation between the amount of C, N and S in soils: the average C:N:S ratio in soils is approximately 140:10:1.3. If the soil respiration is sufficient, organic S is oxidized (mineralized) to sulphate, which most plants can absorb. This occurs when the C:S ratio of specific plant residues is below 200 [Stefanovits 1999; Wallander 2014; Li et al. 2016; Brust 2019].

In the light of the above mentioned, the objective of this short paper is therefore to highlight the determination of C:N ratio and the organic carbon stocks of soils in arable land required for crop production within an acceptable range by using the relevant research findings in the topic, moreover, to take a look at the advantages and disadvantages of combustion, too.

2. MATERIAL AND METHOD

The achievement of the objective is found on the results of short- and long-term experiments and studies of several researchers. These results are revealed and are evaluated in the 'Results' section. Selected publications include writings presenting research results in pedological, energy and socio-economic aspects.

The determination of optimal combination(s) of wheat straw utilization based on scientific foundations, as appropriate to the circumstances, can be achieved on the basis of open minded and constructive cooperation between agricultural researchers and practitioners, technical engineers and researchers, economists and other social scientists.

As a common feature of the research, it should be mentioned that the creation of added value and the innovative approach are less taken into account during the examination of the utilization possibilities. Furthermore, besides the advantages of utilization options, it is always essential to draw attention to their disadvantages, too. In numerous cases, the (temporary) economic advantage is the main aspect of straw utilization.

Based on the theses of the selected and processed publications, the "Results" section summarizes such research results, on the basis of which, the best straw utilization option, that the best suits the circumstances, can be selected.

3. RESULTS

A short summary of those papers can be found in this section, they were selected to comprehend the relationship between wheat straw and soil as well as the utilization of wheat straw by combustion in the agricultural context. Figure 1 summarizes the most important characteristics of wheat straw (composition, shear strength, characteristics of "ash" after combustion, etc.) without being exhaustive.

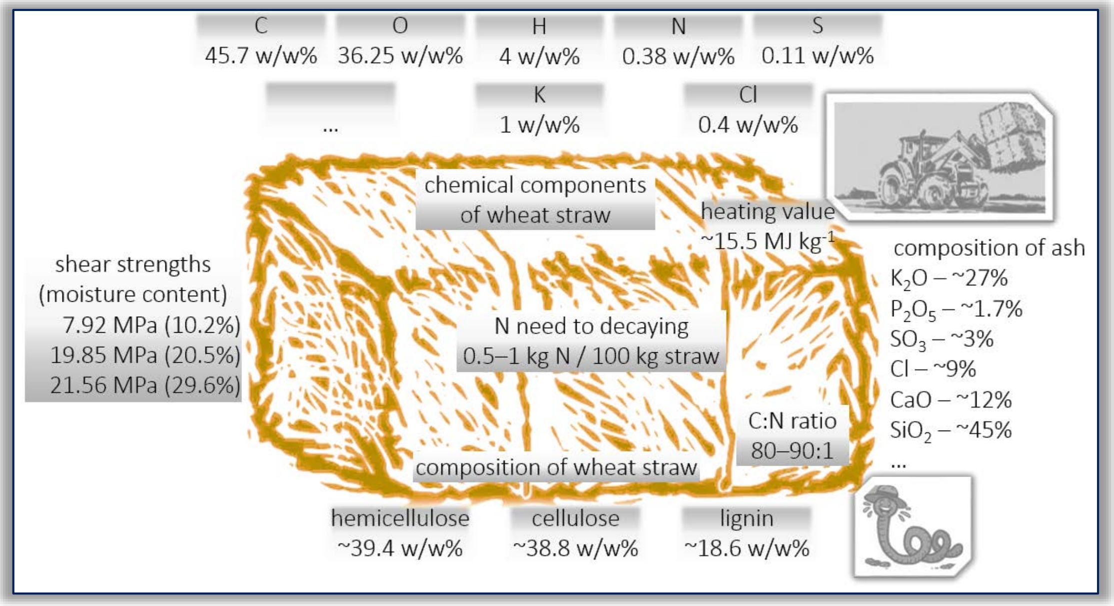

Figure 1: Characteristics of wheat straw based on Fox (1981); Demirbas (2004); Szemmelveisz (2006); Dodson (2011); Monteleone et al. (2015a) and Fang et al. (2016)

Several researchers have calculated how much N is needed to break down wheat straw (0.5–1 kg N / 100 kg of straw) and how much N is released into soil during its decomposition (for example: 4000 kg of wheat straw / ha get ~ 1750 kg of C, ~ 240 kg of N into soil) [Fox 1981; Brust 2019]. Based on the studies of Fox (1981), he also concluded that decomposing straw increases the K content of soil, the water and nutrient retention capacity of straw is an important characteristic, and straw does not represent nutrient competition for crops to be grown.

Blanco-Canqui et al. (2007) performed long-term (10 years) experiments in areas without tillage: on plots without straw retention and on plots with straw retention on the top of the soil (8 t/ha per year) treated with 244 kg/ha N fertilization. As a result of larger straw and combined N fertilization, significant earthworm activity (158±52 piece/m2) was observed in the vicinity of soil surface (it should be noted that their role in the exploration of slowly decomposing organic matter is indisputable), as well as improved soil hydraulic features, water retention and porosity as well.

While the soil surface without straw retention did not actually show biological activity. The experiments by Varga et al. (2018) also confirmed the beneficial effect of earthworms on soil compaction. Since earthworms are sensitive to the physical parameters of soil, thus they are excellent bioindicators of soil microclimate and the physical condition of soil.

NPK fertilization can promote the decomposition of straw, but also increases the rate of decomposition. For soils with a low C:N ratio (11.0–12.3), the high C:N ratio of straw also promotes soil microbial growth [Zhao et al. 2019].

Long-term (10 years) winter wheat experiments prove that the organic C content is also higher in plots with tillage and straw retention (13.1 g/kg) than in plots without conventional tillage and straw retention. Furthermore, it was observed that the yield increased by 20% and the yield stability was also satisfactory [Xu et al. 2019a; Xu et al. 2019b].

Based on the above mentioned, it can be concluded that wheat straw plays a critical role in maintaining the soil organic matter content. Thus, the amount of wheat straw that must be left on stubble to maintain the cultivable condition of soil depends on several factors: it is influenced by geographical location, soil type, crop production system, existing soil organic content levels [Searle & Bitnere 2017; Townsend et al. 2018], nutrient turnover, and the risk of nitrate leach [Huang et al. 2017].

Some other research groups have drawn attention to that the presence of straw induces changes in the soil shear properties (Fig. 1) [Fang et al. 2016], which results in a significant increase in draught force during tillage process, so it requires further studies on energy use of agricultural machines [Eltom et al. 2015]. These results suggest that total straw abandonment retention in arable land can be considered excessive and can lead to tillage difficulties, and any cultivation (rotation into the ground) will demand additional energy input.

After describing the relationship between soil and wheat straw, we also need to look at the advantages and disadvantages of utilization by combustion (in connection with agriculture). It should be noted here that in terms of climate change mitigation, some studies suggest that straw must be harvested (rather than left in fields to increase the C content of soil) and must be used for energy purposes, hence "displacing" fossil fuels [Gabrielle et al. 2008; Powlson et al. 2008; Monteleone et al. 2015b].

However, the use of straw as an energy source is in competition with the humus balance. Furthermore, the texture of soil, the moisture content of soil and the organic C dynamics influenced by the soil temperature must be always taken into account when selecting the utilising opportunity and determining the utilisation rate. According to surveys, the removal rate of cereal crop residues (straw), for instance in Germany, Hungary, Romania is less than 40% [Kluts et al. 2017].

Agricultural crop residues can be considered a reliable resource for energy use, however, there are concerns among farmers about the potential depletion of soil organic C stocks. The latter is also influenced by climate, soil type, current farming practices and cultivation histories [Monforti et al. 2015].

If wheat straw is still considered a fuel source, then the primary information is the energy content of wheat straw, which practically means its heating value (Figure 1). The release of energy present in chemically bound form in wheat straw is aided by the creation of an optimal system of combustion.

In terms of combustion technology it is important to keep the moisture content ~10%, which is significantly influenced by the "time window" of harvest and storage, and to organize storage / transport for the continuous fuel supply, and to increase energy density by compaction (baling). At the same time, due to the by-products / waste of combustion, the K, N and S content must also be taken into account. K appears in solid combustion product, while N and S might also appear in flue gas in a modified form.

Based on the composition of the ash (Figure 1) – in connection with soil – it can be stated that it is rich in K and its P content is also significant [Dodson 2011]. When utilising "ash", it is important that less ash ought to be taken to landfills. It is also possible to place it on forest soils, or to utilize it as fuel due to its unburned carbon content, or to use it as an additive of building materials [James et al. 2012].

With regard to agriculture, it is possible to place "ash" as a by-product of straw burning on arable land, however the use of "ash" for such a purpose is only possible if it does not endanger soil ecology, plants and human health [Bradna et al. 2016] as well as efficient and safe spreading can also be solved. Moreover, it improves soil strength, increases moisture content and also stabilizes it [Kalyane & Patil 2020].

In addition to the environmental challenges, the development of technological solutions for storage, baling techniques, transport, technological development of use/disposal are challenges, and their cost is not negligible either. Pintér (2012) concluded in the course of his research on the economic analysis of the energy utilization of certain agricultural by-products that the value of utilizing straw as a nutrient may exceed the income from energy sales therefore it is not profitable to utilize the entire amount of straw on a farm for energy purposes in the long run.

Another research team also carried out extended life cycle analysis for three farm models (conventional cultivation technology – with tillage and straw retention; conventional cultivation technology – with tillage and straw removal; "innovative" cultivation technology – without tillage and partial straw removal).

They came to the conclusion that the environmental performance of the optimized agriculture-energy value chain is satisfactory. To put in another way, in the case of agricultural systems without tillage and based on partial straw retention (0.3–0.5 kg/m2), straw retention (abandonment) contributes to maintaining soil organic C content and reducing CO2 emissions, while minimum tillage results in less greenhouse gas emissions [Monteleone et al. 2015a; Monteleone et al. 2015b;]. Thus, it is necessary to examine the sustainability regarding straw utilization as well, but this should be done for the entire logistic process, in particular with regard to resource and energy potentials [Weiser et al. 2014]. Thus, various agronomical methods can and must be implemented primarily with the preservation of good soil condition [Monteleone et al. 2015b]. One way to do this "mentoring the environment" [Barczi et al. 2019].

Researchers in countries at the forefront of straw utilization also provide strong examples of straw utilization for energy purposes in the context of straw availability, economic considerations and political support, emphasizing the need for complex analysis prior to the utilization of straw for energy purposes that rely on scientific, political and governmental documents and considerations. Field farming conditions, climate, and landscape type should also be considered at all times [Bentsen et al. 2014; Bentsen et al. 2018]. Previously, Scarlat et al. (2010) suggested that straw-based energy production capacity should be determined by taking into account the minimum amount of raw materials available in the area.

Interesting results were found in a questionnaire carried out in England, which also analysed the relationship of straw utilization in terms of farmers' age and farm size: farms up to 300 ha are more likely to bale all straws (i.e. they do not chop and rotate it into the soil) than farms over 300 ha.

On farms, which are larger than 300 ha, 50–99% of straw is chopped and rotated into soil. The form of straw utilization was also determined by the age of farmers: from the age of 35–44, the proportion of chopped and straw rotated into soil increased with age, while the proportion of straw baled, sold or used on farms began to decrease.

For some farmers, maintaining and increasing soil organic matter is more important for the sustainability of their own farms than the shorter-term financial benefits of additional straw sales [Townsend et al. 2018].

4. CONCLUSIONS

Although agriculture is an anthropogenic activity, where the environmental sensitivity of soil in relation to the soil-environment means its tolerance and vulnerability to the effects of intense anthropogenic stress factors [Várallyay 2003], however, the presented research results show that the bioinspired existence of human activity pervaded (also) with ecological approach might contribute to the preservation of soil competencies. In other words, cereal production can be optimally combined with energy production based on straw utilization without detrimental affect soil fertility. The content characteristics of wheat straw carry the complex possibility of utilization, however, according to the given condition, the choice of the combinations of optimal wheat straw utilization requires prudence.

Based on the presented results, regarding the effect of the C:N ratio of wheat straw on the C:N ratio in the soil, it was concluded that the amount of wheat straw produced after harvest, depending on the soil type and soil condition, was approximately 30–50% which is needed to ensure the "optimal" C:N ratio in the soil, the others can be utilised in other ways (for example by direct combustion).

However, with regard to the "ash" generated after direct combustion, technological development is needed for storage, transport and utilisation: therefore, "ash manager" research is urgent in the near future. The results also show that wheat straw can indeed be considered as embedded energy – "energy" for soil and energy for society.

This paper also confirms that engineering in the context of the environment, agricultural landscapes and energy landscapes is challenging, creative and, at the same time, innovative: in the future, our decisions must be made in cooperation with nature (in symbiosis) in order to avoid the need to adapt to the changed environment caused by our activities.

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