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Research paper

# Field trial results of straw yield with different harvesting methods, and modelled effects on soil organic carbon. A case study from Southern Finland

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ABSTRACT

We estimated the effects of different cutting heights and harvesting strategies on the amounts of harvestable residue biomasses and allocation of residue biomasses in the soil. A case study on regional straw biomass resources was performed with the different crops cultivated in Varsinais-Suomi (Southern Finland) at present (averages of 2003–2012) and in the predicted future warmer climate (scenario RCP 4.5, year 2055). We also estimated, with the help of the Yasso07 model, the effects of different residue incorporation intensities on soil organic carbon (SOC) at present and in the future warmer climate. The results suggested that cutting height has a significant impact on the amount of straw biomass incorporated in the soil and subsequent change in SOC. The impact depended on crop species and variety. When straw is collected and used e.g. in energy production, harvesting practices leaving greater stubble heights could help to maintain soil fertility. The Yasso07 model suggests that in the predicted future warmer conditions, more straw could be collected without decreasing SOC, as mineralization of SOC in the warmer climate is expected to increase less than organic carbon amendments caused by higher crop and root biomasses. Collection and usage of straw as a renewable energy source always decreases greenhouse gas (GHG) emissions in comparison to fossil fuels. However, collecting straw every second year instead of every year, even with higher stubble, would decrease field traffic and spare the soil from compaction and the farmer from extra work, while still significantly decreasing GHG emissions.



## 1. Introduction

Harvest residues constitute a huge biomass potential all around the world where crops are cultivated. The total energy content of all harvestable crop residues has been estimated to be from 39 to 45 EJ, or up to 12 500 TWh [1] [2]. This corresponds to about 10% of world total primary energy consumption (497 EJ) and about half of total primary energy consumption in the USA (90 EJ) in 2012 (http://www.eia.gov). However, a proportion of crop residues, such as wheat or maize straw and stover, are collected and used for animal feed and bedding, mushroom cultivation and soil cover in horticulture, the amounts depending on country and region [3–7]. Thus, all crop residues are not available for bioenergy generation, despite the huge potential.

Collection of residues, especially straw from cereals, for burning in bioenergy plants or fermenting side streams such as manure, grasses or root crop tops in biogas plants have attracted increasing interest, since countries in EU and elsewhere have started to look for ways to decrease their greenhouse gas (GHG) emissions [2,8]. In addition to the huge potential of bioethanol as a renewable transport fuel [9], the residues could represent a great potential for usage in different valuable products, such as sugars, acids and other water-soluble compounds [10] or nanotechnology products [11]. Producing renewable energy via pyrolysis could also result in end products that can be valuable soil amendments [12]. Having detected the great potential in different agricultural side streams, questions have arisen regarding whether removing these side streams, such as harvesting residues from the field, is environmentally sustainable [1,13–16].

Removal of residues also means removal of nutrients and carbon

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(C) that otherwise would be ploughed into the soil. Thus, soil organic carbon (SOC) content and soil fertility could decrease, leading to decreased production capacity and increased need for fertilizers. SOC content is, indeed, decreasing at present, in many areas globally and even in Finland, where climatic conditions in general favour preservation of SOC [17]. Here the SOC content decreases especially for fields with monocultures of cereals, even when the harvesting residues are ploughed in. On the other hand, it has been found that burning or removal of straw, or whether reduced tilling or conventional tilling were used had no effect on the SOC content in a Finnish field [18]. In accordance with this, it has been evaluated that even within a country areas differ in their residue removal potential: in some areas it would be safe to remove most harvest residues, while in other areas SOC would continue to decrease even without residue removal [19]. Effect of residue collection on SOC depends on soil moisture, temperature and soil texture, as well as yield level: with higher yields also residue and root biomasses are higher and maintain SOC better. According to this research, and in accordance with Heikkinen et al. [17], SOC is prone to decrease between years 2012 and 2020 in some areas in Western Finland (Ostrobothnia), even if no residues would be removed from the fields. On the other hand, with climate change and improving cultivation conditions in Southern Finland, half of the total amount of residues (business as usual scenario) could be collected with no negative effects on SOC [19]. A new initiative of not only conserving, but increasing the SOC, the 4 to 1000 initiative, has recently been launched by France (http://agriculture.gouv.fr/contribution-de-lagriculture-la-lutte-contre-le-changement-climatique-lancement-dun-projet-de). The initiative aims at increasing the quantity of C contained in soils at an annual rate of 4‰ to reduce the $CO_2$ concentration in the atmosphere and mitigate climate change. This initiative may increase the attention on the effects of biomass cropping on SOC and thus constrain biomass cropping for energy in the future.

A major part of field crop production and especially cereal cultivation in Finland is situated in the climatically most favourable Southern and Western Finland. In less favourable climatic areas, such as Eastern and Northern Finland, grasslands and animal husbandry are the main sources of agricultural income (agricultural statistics of Luke, http://stat.luke.fi/en/maatalous). Cereal production is the highest in the county Varsinais-Suomi in Southern Finland (see map in Appendix Fig. A1), where there is little grassland cultivation and bovine husbandry, but a high amount of pig husbandry. Some harvest residue is at present used in pig houses as bedding, but a major part is ploughed into the soil [7].

The objective of the present study was to find out whether, and with which methodology, it would be environmentally sustainable to use the straw and other residues of field crops for energy and other purposes, in addition to the need for animal husbandry, in the main cereal cultivation area in Finland, Varsinais-Suomi. We studied the effect of different methods of harvesting (cutting height and method of residue collection) on the amount of harvestable straw biomass, amount of residues incorporated in the soil, and conservation of SOC in the present climate and for predicted future climate.

## 2. Materials and methods

### 2.1. Field experiment

Spring wheat (*Triticum aestivum* L.), winter wheat, spring barley (*Hordeum vulgare* L.), winter rye (*Secale cereale* L.), spring oats (*Avena sativa* L.), spring turnip rape (*Brassica rapa* L.) and spring oilseed rape (*Brassica napus* L.) were sown in different fields parcels (one parcel per crop) at Natural Resources Institute Finland, Jokioinen (60°49′N, 23°29′E). Winter crops were sown on 29–30 August 2007, and spring crops in 2–8 May 2008. The sowing and fertilization were done according to present EU regulations, and yields of all crops were normal or higher than normal, demonstrating sufficient water and nutrient levels. For cultivation details, see Appendix, Table A1.

At maturity (Appendix, Table A1), samples were taken from 5 replicate 2 m × 10 m areas adjacent to each other, with a total sampling area of 100 $m^2$ per crop. The samples consisted of 50 (cereals) or 20 (oilseed) randomly chosen plants/replicate area. The plants were pulled from the ground with roots to harvest the total above ground growth, including the root collar, after which the roots were cut at the root collar and the whole above-ground biomass of plants was packed in a plastic tube or film for transport and further treatment in the laboratory.

Immediately after transfer to the laboratory the samples were treated as follows: The ears and siliques were removed, dried at 100 °C overnight and threshed, and the dry weight of the seed was measured. The straw (stem) was cut into 5 cm segments beginning from the root collar, and ending at the ear or pod set (Fig. 1). The segment groups of the 50 (cereals) or 20 (oilseed) plants in a sample were dried at 100 °C overnight, and the dry weight of each segment group was measured. Because of different heights of individual plants, the weights of the 5 cm segments varied the more the higher the cut was done. The coefficient of variation (CV) of the replicate segments remained below 10%, when the cut was done below the plant height of 50 cm in winter wheat, 65 cm of spring oats and barley, 75 cm in winter rye, 80 cm of spring wheat and spring turnip rape and 90 cm of spring oilseed rape. With segments cut above these heights, the CV increased to higher than 10%, as the weight of the segments decreased and variation between plants increased with plant height. After the weighing of the segments, the percentage of each 5 cm segment weight of the whole plant straw (or stem) weight was calculated for each replicate sample and the average of the five replicate samples was calculated. The cumulative straw percentage weight of the whole straw weight at each cutting height was calculated per replicate and the results were averaged over the five replicates. Plant density (number of stubbles per 3 randomly selected 50 cm lengths of row per plot) was counted after harvest in each replicate plot and averaged to give the plant density per $m^2$ of each crop.

### 2.2. Estimation of residue biomass now and in the future in Varsinais-Suomi

For estimation of the harvestable straw biomass as well as biomass remaining in the field at different stubble heights in Varsinais-Suomi, yield averages of the studied crops from 2003 to 2012 were calculated based on the average yields per crop reported yearly for the area (agricultural statistics of Luke, http://stat.luke.fi/en/maatalous). The CV of the yield was 14% in winter wheat and spring oats, 15% in spring barley, 16% in spring oilseed rape and spring wheat and 17% in spring turnip rape and rye. The total amount of straw biomass was estimated according to the average harvest indices (HI) of the different crops [2]. After this, the cumulated dry weight of straw either harvested or remaining in the field at present climatic conditions was calculated at different stubble heights, according to the cumulated percentage of straw biomass at each cutting height, according to the results of the field experiment reported here (Chapter 2.1). Estimated root biomass was added to the calculated stubble straw biomass to give the total crop biomass left in the field using different harvesting techniques. The estimate of root biomass was based on published data on the proportion of roots in a crop total biomass (Table 1).

Future climatic conditions were estimated according to scenario group "Representative Concentration Pathway 4.5" (RCP 4.5) [20] for a 30-year period 2040–2070, centred on year 2055.