Fluxes of organic matter in harvested biomass and crop residues of energy crops: effects on soil organic matter

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Abstract
C fluxes in crops typical for bioenergy production are compared with conventional crop rotations. We provide indications of soil-crop balances for C and N within each studied system. For the three crops compared in this paper we found a high input of C into the soil by willow SRC and *Miscanthus*. Standing biomass for willow SRC at the end of the 3 year coppice cycle was almost as large as the soil C pool in the upper 30 cm. Yearly C input by leaf fall was higher for *Miscanthus x giganteus* (2160 kg C/ha) than for willow SRC (1785 kg C/ha).

Introduction
Energy crops may negatively affect soil organic C stocks in agricultural soils as maximal aboveground biomass and/or crop residues are removed for bioenergy production. On the other hand, several biomass crop systems are characterised by high input of slowly degrading organic matter [1]. In this study, we collect data on both crop yields and crop residue biomass, and their (bio)chemical composition.

Material and Methods
Field experiment
In 2007 a field trial was initiated at ILVO in Melle with several annual, perennial and lignocellulosic energy crops tested in 3 replicates [2,3]. Annual crops were compared both in monoculture and in crop rotations [2]. Variables in the trial include: crops, varieties and fertilizer input. Data on harvested biomass and its biochemical composition are available for all crops in the trial for all harvest cycles. For energy maize (cropped in monoculture), short rotation coppice (SRC) with *Salix fragilis cv. Belgisch Rood*, and *Miscanthus*, additional data on crop residue biomass and composition were collected in a crop-specific manner. For energy maize, roots and stubble were sampled shortly after harvest in 2012. For willow SRC and *Miscanthus x giganteus*, leaf fall were measured in the 3 replicates between October and December 2012 (willow SRC) and January and March 2013 (*Miscanthus*). In a separate part of the field trial, the rhizomes and remaining stubble of 17 *Miscanthus* varieties were sampled in April 2012, i.e., 5 years after plant establishment.

Analyses and calculations
Plant samples were dried at 70°C and ground, and residual moisture content was determined at 105°C according to ISO 6496. Organic matter and ash content was measured according to ISO 5984. C was determined on at least 3 samples per plant part of each crop dry combustion at 1050 °C with a Skalar Primacs SLC TOC-analyzer. N in harvested energy maize and corn stover was measured according to ISO 5983-2 (Block digestion/steam distillation method). Total N in other plant parts was determined with dry combustion (Dumas principle) with a Thermo flash 4000 according to ISO 16634-1. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) content in the dried compost samples was determined with an Ankom220 Fiber Analyzer extraction unit according to Van Soest et al. [5]. Based on NDF, ADF and ADL content, the biodegradation potential was calculated as (%hemicellulose + %cellulose)/%lignin. All results were expressed on absolute dry matter content taking the residual moisture content into account. The total organic carbon (TOC) content in the soil was measured by dry combustion at 1050 °C with a Skalar Primacs SLC TOC-analyzer according to ISO 10694 in samples of the 0-10 and 10-30 cm soil horizon. Total N content was determined by dry combustion (Dumas principle) with a Thermo flash 4000 according to ISO 13878.

As the *Miscanthus* rhizomes were planted 5 years ago, yearly C input by roots and rhizomes were estimated by dividing the biomass by 5. The root and stubble C biomass for willow short rotation coppice (SRC) was estimated based on data for poplar SRC [4].Biomass of leaf fall was 20% of the harvested biomass for *Miscanthus x giganteus*. The same ratio was applied for calculating the leaf fall biomass for *Miscanthus sinensis*.

Results

Soil organic Carbon (SOC)

A strong gradient in soil OC was observed in the field trial, with values ranging from 0.7% OC in the west part of the field to 1.3% OC in the east part. Differences between top and deeper soil were generally small and no distinct trend was observed (results not shown). Based on the samples of a separate sampling campaign in 2012 focussing on the upper 5 cm of the soil, we observed significantly higher ($p < 0.05$) organic matter contents (determined by ashing) for perennial *Lolium perenne* L. Rebecca than for the other treatments sampled (results not shown).

Biomass C in crop compartments

In this paper we further focus on three crops, i.e., energy maize, SRC with willow, *Miscanthus sinensis* and *Miscanthus x giganteus*. Large differences in C:N ratios in the stubble between both *Miscanthus* varieties were observed (Table 1). *M. x giganteus* had clearly higher C:N ratios in the stubble than the *M. sinensis* varieties. *Miscanthus* is known to translocate N to belowground organs in fall and tot translocate this N back to the aboveground plant parts in spring [6]. This N translocation also affects C:N ratio in the plant compartments: C:N ratio was high for *Miscanthus* leaves and low for willow leaf fall. *Miscanthus* rhizomes and roots had low C:N ratio compared with maize roots (Table 3).

Clear differences between energy crops in yearly C input by crop residues were detected (Table 2). Harvested biomass was the largest compartment in the crop C biomass for the 3 crops (Fig. 1). Lower C biomass was observed for *Miscanthus sinensis* than for *Miscanthus x giganteus.* At the end of the 3-year coppice cycle, SRC biomass was more than 32500 kg C, almost as high as the soil C stock in the 0-30 soil horizon on this parcel. The average soil C stock was lowest for maize (34950 kg C/ha) and was highest for *Miscanthus* (36170 and 37290 kg C/ha for *M.x giganteus* and *Miscanthus sinensis*, respectively). Yearly C input by aboveground crop residues or leaves is very low for energy maize as most of the aboveground biomass is harvested. The stubble height determines the amount remaining as aboveground crop residue.

Large differences in yearly N fluxes in aboveground biomass between the 3 crops were found (Table 2). The yearly N flux in aboveground biomass was highest for maize (appr. 200 kg N/ha), intermediate for SRC (appr. 150 kg N/ha) en lowest for *Miscanthus x giganteus* (appr. 95 kg N/ha). Only maize received 150 kg N as fertilizer. No N returned as aboveground crop residue for maize, while at least 1/3th of the N in the aboveground biomass was recycled as crop residue for SRC and *Miscanthus*.

Biochemical composition and OM decomposition

Besides the differences in C fluxes between crops and crop rotations, we found differences in biochemical composition of harvested crops, aboveground and belowground crop residues (Table 3). Based on a comparison of cell wall components for other aboveground and belowground crop residues (Table 3), we estimated the biodegradation potential of the energy crop residues. Leaf fall of *Miscanthus* and stubble of maize have a clearly higher biodegradation potential than leaf fall of SRC and rhizomes and stubbles of *Miscanthus*, which may imply faster decomposition in the soil.

Conclusion and perspectives

In conclusion, the impacts of bioenergy cropping systems on soil C content may be both positive or negative, as large differences in N and C fluxes between crops and crop rotations were observed. Overall, a trend in soil organic C and soil texture over the parcel interfered with the crop effects on soil organic C. Only for the 0-5 cm horizon a difference in soil organic C caused by the energy crops was detected.

For the selected energy crops in the field trial, we found important differences in C input by crop residues into the soil. The supplied organic matter has different biochemical characteristics for

different crops. The effect of crop residues on soil organic matter is affected by C biomass input, biochemical composition, soil tillage application and fertilizer application. Future research should focus on effects of different C input on soil biology and chemistry, e.g. as illustrated by [1].
These results will be used in a study on threats and opportunities of different bioenergy cropping systems for the soil organic C stocks in agricultural soils in Northern Belgium. We determine the effect of the most important (potential) bioenergy production processes in Flanders by modelling the soil organic C cycle in these cultures. Short and long term effects on soil organic matter are assessed and compared with conventional crop rotations.

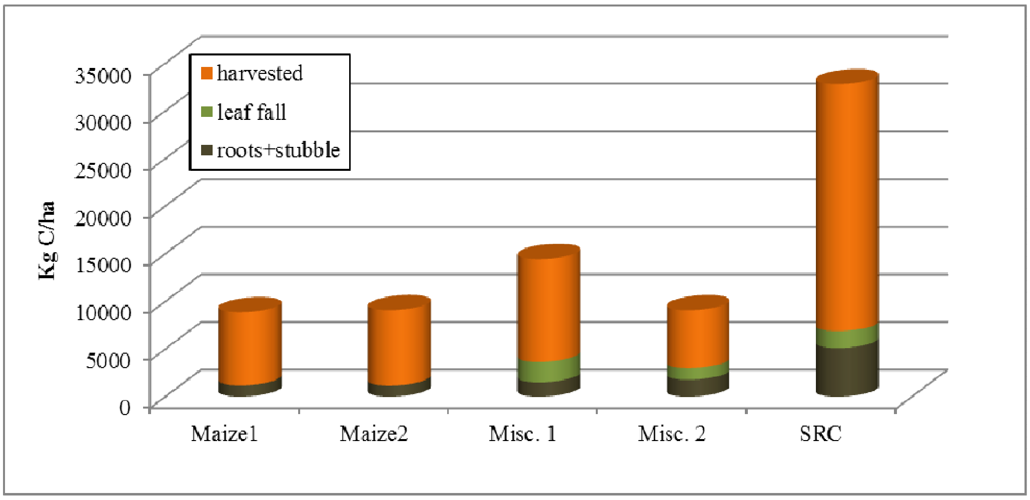

Figure 1. C stocks in aboveground and belowground compartments as measured in the field trial in Melle in the growing season of 2012 for 2 varieties of maize (Maize1, Maize 2), *Miscanthus x giganteus* (Misc. 1), *Miscanthus sinensis* (Misc. 2) and the willow short rotation coppice (SRC). Data are averages of 3 replicates. The root and stubble C biomass for SRC was estimated based on [4].

Table 1. C Biomass and C:N ratio in belowground (rhizomes + roots) and aboveground stubble of 17 *Miscanthus* varieties in the field trial at ILVO in Melle.

Variety	Rhizomes/roots		Stubble	
	kg C/ha	C:N	kg C/ha	C:N
M. purpurascens	879	42.3	<25	NA
M. sacchariflorus	535	61.9	35.0	78.3
M. sinensis Cosmopolitan	2446	48.2	304.0	98.9
M. sinensis ferner osten	954	37.0	348.3	82.0
M. sinensis Goliath	1380	33.3	386.1	78.9
M. sinensis gracillimus	4192	54.8	657.0	138.2
M. sinensis Grosse Fontane	3244	39.6	631.0	92.0
M. sinensis Herman Müssel	2208	38.4	669.8	82.8
M. sinensis Morning Light	792	45.1	243.4	101.5
M. sinensis Poseidon	1197	31.2	371.3	91.3
M. sinensis Punktchen	799	54.1	236.9	92.1
M. sinensis Richard Hansen	1804	38.5	427.4	100.1
M. sinensis Roland	4754	40.1	787.2	128.8
M. sinensis Silberfeder	3211	36.3	396.6	68.4
M. sinensis Silbertum	1215	42.6	168.1	78.1
M. x giganteus floridulus	2113	41.2	75.7	179.1
M. x giganteus (the Netherlands)	1152	31.4	342.1	166.6

Table 2. Yearly fluxes of C and N in belowground and aboveground compartments of 3 crops in the field trial in Melle in the growing season of 2012. Data are averages of 3 replicates. The root and stubble C biomass for willow short rotation coppice (SRC) was estimated based on [4].

Crop	Variety	Fertigation	kg C/ha.year			kg N/ha.year		
		kg N/ha.year	harvested	leaves	roots + stubble	harvested	leaves	roots + stubble
maize	variety 1	150	7681	0	1177	206	0	22
	variety 2	150	7913	0	1160	203	0	22
Miscanthus	xgiganteus	0	10793	2160	299	61	34	7
	sinensis	0	6084	1217	353	50	28	8
willow SRC		0	8640	1774	1020	83	64	NA

Table 3. Biochemical composition and biodegradation potential (OM: organic matter, adm: absolute dry matter, biodegr.: biodegradation potential). Values are averages of n samples.

Crop	Part	n	OM (% /adm)	C (% /adm)	C/N	hemicellulose (% /adm)	cellulose (% /adm)	lignin (% /adm)	biodegr.
willow SRC	leaf fall, leaves	3	82.5	45.6	25.5	16.1	16.0	27.2	1.2
willow SRC	leaf fall, branches	3	92.0	48.7	61.9	13.4	37.7	27.6	1.9
willow SRC	harvested	3	98.3	47.5	99.8	39.1	14.7	13.4	4.0
Miscanthus x giganteus	stubble	3	96.6	45.8	166.6	28.0	47.5	14.2	5.3
Miscanthus sinensis	rhizome	3	82.8	39.3	33.3	28.6	25.6	9.9	5.5
Miscanthus x giganteus	rhizome	3	86.1	40.8	31.4	28.9	33.0	10.6	5.8
Miscanthus x giganteus	harvested	3	98.0	48.0	196.5	49.3	27.0	12.0	6.4
Miscanthus sinensis	stubble	3	95.6	45.3	78.9	32.0	43.2	11.6	6.5
reed canarygrass	harvested	3	88.2	NA	NA	42.4	31.5	9.2	8.0
switchgrass	harvested	3	88.8	NA	NA	44.0	32.5	9.1	8.4
reed	harvested	3	NA	NA	NA	33.1	34.9	7.9	8.6
Miscanthus sinensis	harvested	3	96.9	47.5	134.4	46.4	32.8	8.7	9.1
energy maize	stubble + roots	18	76.1	39.4	56.6	29.1	33.1	6.8	9.2
Miscanthus x giganteus	leaf fall	3	93.2	45.7	60.4	35.8	37.7	6.6	11.1
energy sorghum	harvested	6	94.3	NA	NA	27.2	31.7	4.4	13.4
energy maize	harvested	6	93.7	45.1	41.0	24.4	23.3	2.3	20.5

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