Corn stover as a feedstock for production of advanced biofuels

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Abstract: *Obligation for biofuels production is clearly defined by the legislation of EU. Using of non food / non feed feedstock has priority and can be eligible for subsidies if defined reduction of greenhouse gases –GHG, at least 60 % after 2018, was obtained and documented. In Danube downstream countries corn is prevailing field crop. The objective was to define possibility of corn stover use as a feedstock for production of lignocellulosic bioethanol –LCB and biomethane. Calculation of potentials and GHG emissions for feedstock procurement was performed.*

During the harvest period, full grain maturity, and years 2011, 2012 and 2014, samples of hybrids were collected at three locations in the province Vojvodina. The average theoretical potentials were 10.4, 5.3 and 12.4 Mg/ha. Technical potentials for analyzed collection technique were 9.2, 6.3 and 8.4 Mg/ha with characteristic relative yield (related to grain yield) ranging between approximately 60 and 80 %. These data can be used, after getting fractions of harvested stover, for the calculation of nutrients and soil organic carbon removal.

Analysis of GHG emission for procurement and pre-processing-feeding of feedstock showed big impact of representative supply radius. For example: procurement results with 20 km supply radius were approximately 70 kg $CO_{2\ eq}$/Mg DM, while those with 100 km were 20 % higher.

Further investigation should be related toward improvement of harvest and storage procedures of corn stover and to consider possible reduction of GHG.

Key Words: *Stover, potentials, GHG emissions.*

INTRODUCTION

In Serbia and especially in province Vojvodina, situated in Pannonia plane, residual corn biomass, stover, represents important potential source for renewable energy due to significant quantities. Corn stover could be especially significant for production of advanced biofuels *i.e.* lignocellulosic bioethanol (LCB) and biomethane. Existence of incentive measures, subsidies, in EU defined by European Directive 2009/28/EC, 98/70/EC and 2009/30/EC, should promote production of these biofuels and increase their share in total fuels consumption in transport. This share should be at least 0.5 %. Every member country is obliged to achieve this goal, but also candidate countries like Serbia as well, which signed a Memorandum of integration into the EU energy market [17], and therewith pledged to follow EU policy in this field.

Possibilities for production of advanced biofuels from corn stover need to be based on acceptable data regarding potentials for stover usage. Estimation of stover potentials is usually estimated in accordance to measured grain yield and determined harvest index (HI). HI of corn was reported in many publications. It is, in average slightly over 0.5, which is similar to many other field crops' HI. Numerous investigations resulted also with definition of stover fractions' share. Stover is mostly divided into stalks+leaves, cobs and husks [12, 13, 14]. Typical ranges of fractions' percentages are: stalks+leaves 69-77 %, cobs 12-20 % and husks 8-14 %.

For consideration of potentials, especially important is technical potential that is based on applied harvest technologies. The majority of reports related to the harvesting technology originate from the USA. Generally, stover harvesting can be divided into single, two and multi-pass procedures. Especially interesting two-pass procedure is mostly related to the harvester with built-in shredder which form windrows, that is known as cornrower [16]. In most of the cases, this technology is adequate for big plots that are more frequent in developed countries. The positive effect is that the out-coming biomass from combine is falling down on formed windrows, which result with considerably lower losses of cobs and husks, as well as reduction of dirt, *i.e.* ash content which is important if stover is considered as substrate for biofuel production.

Another issue that must be considered during evaluation of possibilities for stover utilization as the biofuels substrate is emissions of greenhouse gases (GHG). According to previously mentioned directives, advanced biofuels can be eligible for subsidies if defined reduction of GHG is at least 60 % after 2018, and satisfaction of this sustainability criterion is well documented. Thereby, evaluation of GHG emissions must take into account following phases: substrate procurement, biofuel production and distribution and biofuel utilization. This approach is in line with principles of life cycle assessment (LCA). Some of the undertaken studies based on the principles of LCA have evaluated stover as the substrate for production of LCB. These studies were carried out in order to compare LCB with fossil fuels [10, 15], but at the same time to resolve some methodological issues such as allocation within LCA [6, 8]. General conclusion is that LCB has better results regarding GHG emissions in comparison with fossil fuels, but lacking is sensitivity analysis that can provide answers on how different organization of stover supply chain or seasonal differences for stover yield are influencing GHG emissions.

The objective of the study is to define possibility of corn stover use as a feedstock for production of LCB and biomethane in Serbia. This will be carried on through determination of potentials based on measurements of stover yields and through determination of GHG emissions characteristic for stover procurement.

MATERIAL AND METHOD

Calculation of potentials

During period of three years, 2011, 2012 and 2014, samples of hybrids typical for the region, Table 1, were collected at three locations in the province Vojvodina. The samples were taken on farms that apply high level of agro technology. The row distance for all plots was 0.7 m, and crop density 60,000 to 70,000 plants per ha, which is common in the region.

For each hybrid and location, five samples were taken, from different, randomly selected, plot parts. The samples were taken from two neighboring rows, and one meter length, 1.4 m^2. Corn plants were cut to the ground, packed and transported to the Laboratory of Biosystems Engineering, Faculty of Technical Sciences, Novi Sad.

Each plant was processed as follows: lowest 0.2 m of the stalk was cut off, ears separated, husks were removed and grain threshed manually. Parts of the plant are presented in Fig. 1.

Table 1

The list of tested hybrids

Code	FAO group	Hybrid	Code	FAO group	Hybrid	Code	FAO group	Hybrid
2011/1	400	PR36 R10	2012/1	400	NS 444	2014/1	400	NS 4023
2011/2	490	PAKO	2012/2	480	DKC 5276	2014/2	500	DKC
2011/3	550	LUCE	2012/3	500	ZP 505	2014/3	500	Kitty
2011/4	620	SYCORA	2012/4	550	LUCE	2014/4	600	NS 6010
2011/5	620	DKC 6120	2012/5	600	KORIMBOS	2014/5	600	KORIMBOS
2011/6	700	NS 7070	2012/6	700	GRECALE	2014/6	700	AS 72
2011/7	700	GRECALE						
2011/8	700	VITORINO						

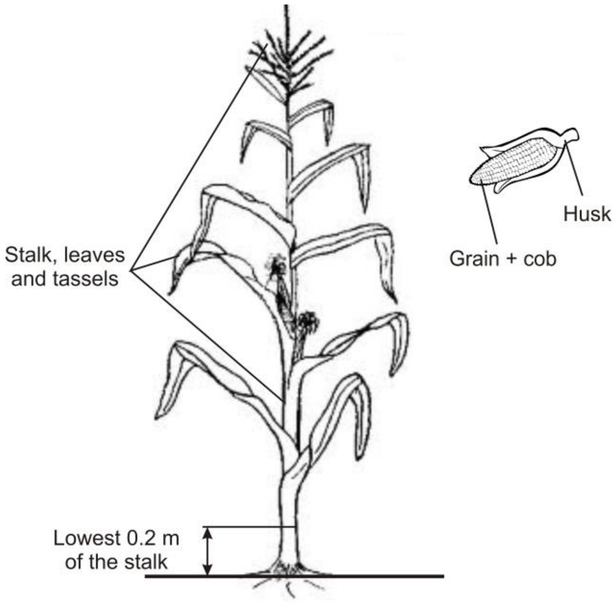


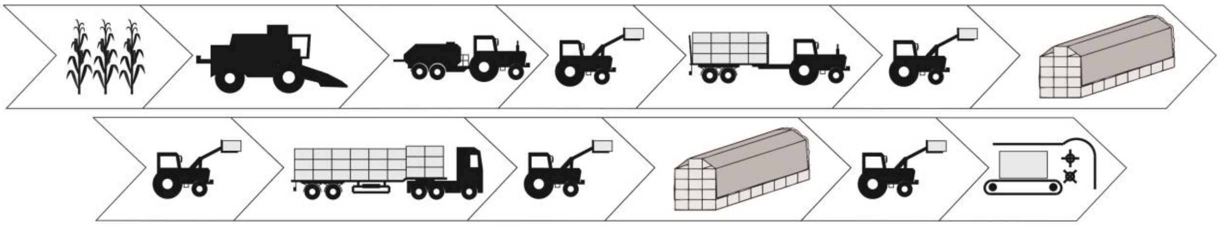
Fig. 1. Classification of corn plant parts

The mass of each part was measured using balance with accuracy of 0.1 g. For the determination of moisture content, grains were dried using procedure defined by ASAE S352.2 [18] and stover fractions according to the procedure defined by ASAE S358.3 [19].

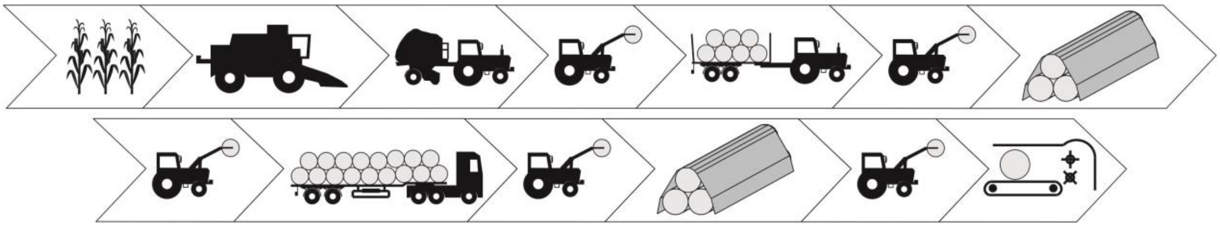
Based on obtained data, yields and moisture contents were calculated for: grain, cobs, husks (shanks included), lowest 0.2 m, stalks+leaves (over 0.2 m height) +tassels (further referred as stalks+leaves). Relative yields of residual parts were calculated by dividing measured values with grain yield, all of dry matter (DM). All above-ground residual parts make total mass and can be considered as theoretical potential of corn stover. Technical potential presents amount of crop residues which can be harvested, harvestable, by applying common or specific harvest procedure. For this investigation, two-pass harvest was analyzed. It includes grain harvest by combine with snapper–head and integrated shredder-cornrower described in [16] and [11]. The stover is picked-up from windrow by round or big rectangular baler. Cutting height is 0.2 m. Percentages of harvested fractions are 70, 90 and 90 %, for stalks+leaves, cobs and husks respectively, with additional baling losses of 10 %.

Calculation of GHG emissions

For determination of GHG emissions, feedstock procurement was seen as the stover supply chain that includes following phases: nutrients removal, windrow forming, stover collection, loading and unloading, transport to the primary storage and to the place of final usage, storage and pre-processing. Organization of the supply chains is mainly influenced by defined two-pass harvest approach and technique for stover collection in forms of big rectangular (BB) and round bales (RB) as it’s presented in Fig. 2.



a) Big rectangular bales



b) Round bales

Fig. 2. Organization of analyzed stover supply chains

Only removal of phosphorus and potassium by removed stover is considered in this study and appropriate amount of these nutrients was considered as input to analyzed system in order to compensate removed quantity. The amount of the selected mineral fertilizers, potassium-nitrate and single-superphosphate, was calculated based on the nutrients removal rates: 14.0 and 2.3 g/kg DM respectively for phosphorus pentoxide (P_2O_5) and potassium oxide (K_2O) [2]. For the windrow forming phase of the stover supply chain, it was assumed application of technical solution called *Cornrower* mounted on a harvester which during grain harvest at the same time shreds and creates windrow from stover [11, 16]. Based on the usual bales' size and literature data concerning density of collected stover [9, 13], used values for BB dimensions were 1.6/1.2/0.9 m with density of 110 kg DM/m^3, while these values for RB were ϕ1.5/1.2 m and 90 kg DM/m^3. It is also considered that baled stover is wrapped with special plastic net during baling. Baled stover needs to be loaded and unloaded before and after transportation and these operations are performed by tractor equipped with front loader. The primary storage is usually located in closeness to the fields and transportation distance is up to 5 km [1]. In this study, 5 km is the adopted distance for year 2011, which was considered as the year with usual stover yield. Distances for year 2012 (low yield) and 2014 (high yield) were adjusted with ±20 %. The adopted means of transport was a tractor with trailer. Loading capacity of the trailer allowed loading of 24 BB and 14 RB. Highest analyzed transportation distance between the primary storage and the place of final usage was 100 km. It was assumed that baled stover is transported by the truck (27 Mg of payload capacity) with loading capacity of 48 and 34 bales, respectively for BB and RB. For the storage phase, it was adopted that baled stover is stored beneath special plastic tarpaulin with specific mass of 130 g/m^2 and dimensions 12.5/9 m [20]. For the pre-processing phase, it is assumed that stover bales are transported from the storage to a bale disintegrator. This transportation is carried out by a tractor with front forklift while the disintegrator consumption was 11 kWh/Mg DM of electricity [7].

The analysis was carried on according to principles of standardized LCA methodology [5]. As stated earlier, boundaries of the analyzed system included the entire stover supply chain. Supply chain was analyzed in such a way that stover was considered as a waste material from corn growing, so there was no need for allocation between grain and stover itself. For functional unit (FU), 1 Mg of stover DM was chosen.

Software used to model corn stover supply chain's life cycle and following impact assessment was GaBi 6. Within this software were integrated Ecoinvent 2.2 database [3] and GaBi database with additional database 12. Generic processes, *e.g.* material inputs production or transportation, were selected from stated databases. When it was necessary, some generic processes were modified in such way that realistically represents processes for the region under the scope of analysis. The life-cycle impact was evaluated using CML 2001 (version April 2013) [4]. Chosen impact category was Global Warming Potential without biogenic C (GWP) and unit used for the results of the indicator was kg $CO_{2\ eq}$.

RESULTS

Potentials

Results of measurements are presented in Table 2. In 2011 average grain yield of samples was 10.8 Mg/ha of dry matter (DM). Average theoretical stover yield for this year was 10.4 Mg/ha Harvest index (HI) was 0.51 which is similar to cereals, and is considered as common. The average grain yield was in 2012 considerably lower 5.3 Mg/ha which is, for example, less than half of 2011, as the consequence of extremely dry weather conditions and very high temperatures during reproductive period. Average HI of 0.41 was also result of weather conditions, although average theoretical yield of stover was 7.2 Mg/ha. Year 2014 had the highest yield of both, grain and stover in comparison to two previous analyzed years. Average grain yield was 12.4 Mg/ha and theoretical yield 12.6 Mg/ha that as a result gives HI value of 0.52. Usable stover mass for analyzed years were 9.2, 6.3 and 11.6 Mg/ha, respectively.

Share of stover fractions within usable stover mass for 2011 are 68, 21 and 11 %, for stalks+leaves, cobs and husks, respectively. For year 2012 and 2014, there is a decrease of cobs share within usable mass to the value of 17 % and increase of stalks+leaves fraction to up to 71 %, which is in line with usual values for fractions’ share.

Average yields of stover fractions for 2012 are 29, 42 and 40 % lower than those in 2011, for stalks+leaves, cobs and husks, respectively. In comparison to 2014, reduction of each fraction is approximately 47 %. When years 2011 and 2014 are compared, only stalks+leaves fraction is lower for around 26 % in 2011. Due to grain yield in 2012 the relative yields of stover fractions are higher, with much wider span between min and max values.

Based on defined harvest procedures, the harvested mass and that remaining on field have been calculated and presented in Table 3. Percentage of harvested stover was between 60 and 67 % related to theoretical yield. For years with highest quantity of available stover, technical potential was approximately 8.4 Mg/ha in contrast to 4.3 Mg/ha for year 2012. This high fluctuation of yield should be basis for supply security program, for any big user of corn stover, and must be considered as a risk aspect.

Table 2

General data of grain, yields of residual biomass and stover fractions

Code	Grain		Residual biomass											
	Y, Mg ha	HI	Total		Usable		Stalk, lowest		Stalk+leaves		Cobs		Husks	
			Y, Mg/ha	RY, %	Y, Mg/ha	RY, %	Y, Mg/ha	RY, %	Y, Mg/ha	RY, %	Y, Mg/ha	RY, %	Y, Mg/ha	RY, %
2011/1	11.2	0.52	10.4	92.8	9.3	83.4	1.1	9.5	6.1	54.1	2.4	21.8	0.8	7.4
2011/2	8.0	0.53	7.1	88.7	6.5	81.2	0.6	7.5	4.4	55.0	1.4	17.3	0.7	8.9
2011/3	12.0	0.51	11.3	94.5	10.0	83.2	1.3	11.3	6.5	54.0	2.3	19.4	1.2	9.8
2011/4	10.3	0.48	11.0	106.7	9.0	87.4	2.0	19.3	6.1	59.5	1.9	18.9	0.9	8.9
2011/5	10.5	0.53	9.4	90.0	8.6	81.6	0.9	8.4	6.3	60.5	1.4	13.1	0.8	7.9
2011/6	11.5	0.50	11.7	101.3	10.7	92.3	1.0	9.0	7.5	65.0	1.9	16.4	1.3	10.9
2011/7	13,6	0.51	13.0	95.9	11.6	85.0	1.5	10.9	8.3	60.9	2.1	15.7	1.1	8.5
2011/8	9.0	0.50	8.9	99.2	8.0	89.2	0.9	10.0	5.1	57.1	1.9	21.2	1.0	11.0
Mean	10.8	0.51	10.4	96.1	9.2	85.4	1.2	10.7	6.3	58.3	1.9	18.0	1.0	9.2
SD	1.6	0.02	1.7	5.6	1.5	3.7	0.4	3.5	1.1	3.6	0.4	2.7	0.2	1.2
2012/1	5.8	0.45	7.7	122.9	6.7	110.8	1.0	16.2	4.3	69.8	1.4	22.2	1.0	16.6
2012/2	3.9	0.35	5.6	188.7	4.8	163.5	0.8	35.3	4.1	174.2	0.3	13.0	0.4	14.7
2012/3	6.7	0.46	7.2	115.9	6.5	104.7	0.7	12.1	4.5	77.2	1.2	21.4	0.7	12.3
2012/4	6.6	0.47	7.4	111.3	6.6	99.3	0.8	12.0	4.3	65.3	1.5	23.2	0.7	10.8
2012/5	2.3	0.30	7.8	237.2	7.0	201.9	0.8	11.2	5.2	77.0	1.3	19.9	0.5	7.8
2012/6	6.1	0.44	7.4	124.7	6.4	108.6	1.0	25.1	4.9	124.3	1.1	27.3	0.5	12.0
Mean	5.3	0.41	7.2	136.1	6.3	120.	0.8	16.1	4.5	86.3	1.1	21.7	0.6	12.0
SD	1.6	0.07	0.7	46.8	0.7	38.1	0.1	8.8	0.4	39.2	0.4	4.3	0.2	2.8
2014/1	9.8	0.49	11.5	117.1	10.3	104.9	1.2	12.2	7.9	79.9	1.6	16.3	0.9	8.8
2014/2	12.4	0.55	11.1	89.5	10.2	93.7	0.9	7.6	7.1	56.9	2.0	15.1	1.1	8.8
2014/3	12.7	0.54	11.9	93.8	10.9	85.7	1.0	8.2	7.9	62.0	1.9	15.3	1.1	8.5
2014/4	13.5	0.49	15.6	116.1	14.3	106.1	1.3	10.0	10.9	81.1	2.2	16.3	1.2	8.8
2014/5	12.8	0.55	11.4	89.0	10.7	83.2	0.7	5.8	7.7	60.2	1.9	15.1	1.0	7.9
2014/6	13.3	0.50	14.4	108.0	13.1	98.8	1.2	9.1	9.8	73.8	2.2	16.3	1.2	8.8
Mean	12.4	0.52	12.6	102.2	11.6	95.4	1.1	8.8	8.5	69.0	2.0	15.7	1.1	8.6
SD	1.2	0.03	1.7	11.9	1.6	8.8	0.2	2.0	1.4	9.7	0.2	1.6	0.1	1.3

(1) Y– yield
(2) RY– relative yield to the grain
(3) SD– standard deviation

Table 3
Harvestable and remained corn residues for analyzed harvest procedure

Season	Grain yield	Theoretical yield	Technical yield			Remained mass
	M, Mg/ha	M, Mg/ha	M, Mg/ ha	RY, %	PTM, %	M, Mg/ha
2011	10.8	10.4	6.3	59	61	4.1
2012	5.3	7.2	4.3	82	60	2.9
2014	12.4	12.6	8.4	68	67	4.2

(1) M– mass calculated based on average grain
(2) RY– relative yield to the grain
(3) PTM– percentage of total mass

GHG emissions

In Fig. 3 are presented results of impact on GWP for both methods of stover collection and for all three analyzed years. Presented results are characteristic for 20 km transport distance between primary storage and site of final treatment. It can be seen that total impact for all scenarios and every year is approximately 70 kg $CO_{2\ eq}$/Mg DM. Phases with the largest impact on GWP are nutrients removal and collection of stover. Their influences on GWP are around 28 % of total. Impact for collection of stover in the form of RB is slightly lower than collection in the form of BB, but this difference is practically negligible since difference is around 0.05 kg $CO_{2\ eq}$/Mg DM. For shredding of baled stover, electricity is consumed and significant impact is consequence of using electricity from Serbian electricity-mix based on utilization of coal. This pre-processing is responsible for around 21 % of total impact. Another significant phase is load and unloads of bales with around 12 % of impact. Storage and windrow forming phases are insignificant with combined impact of around 2 %. Due to efficient transport in the form of BB, it can be seen that impact of transport phases is lower in case of scenarios with BB than RB. If both transports are considered, transport of BB is responsible for 8 % of total impact on GWP in comparison to 11 % for RB.

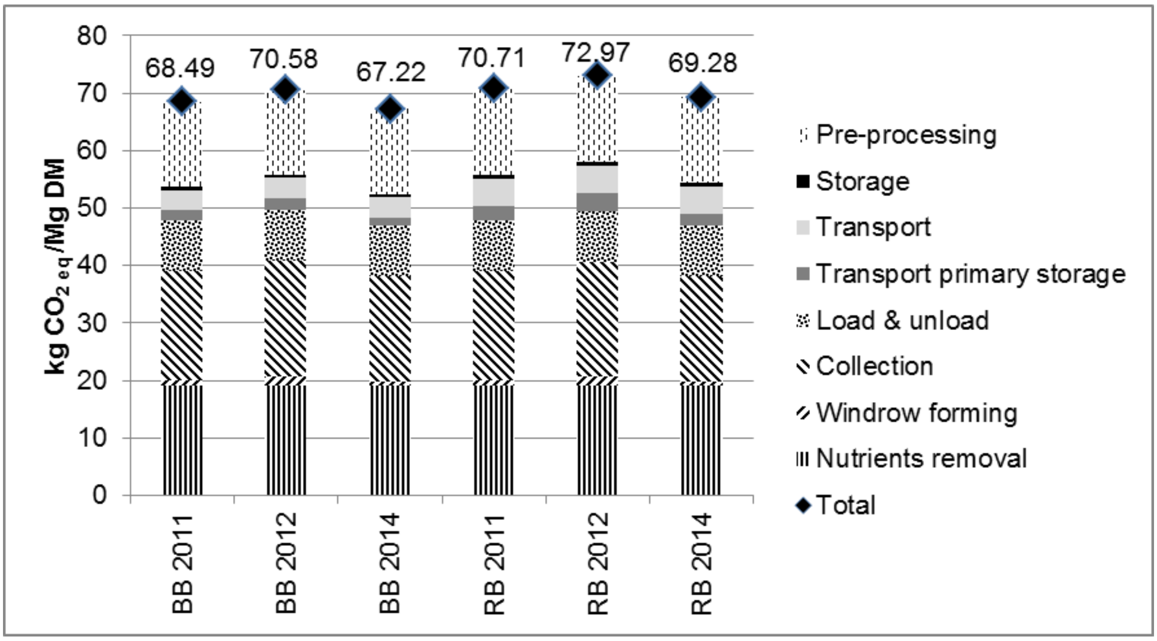
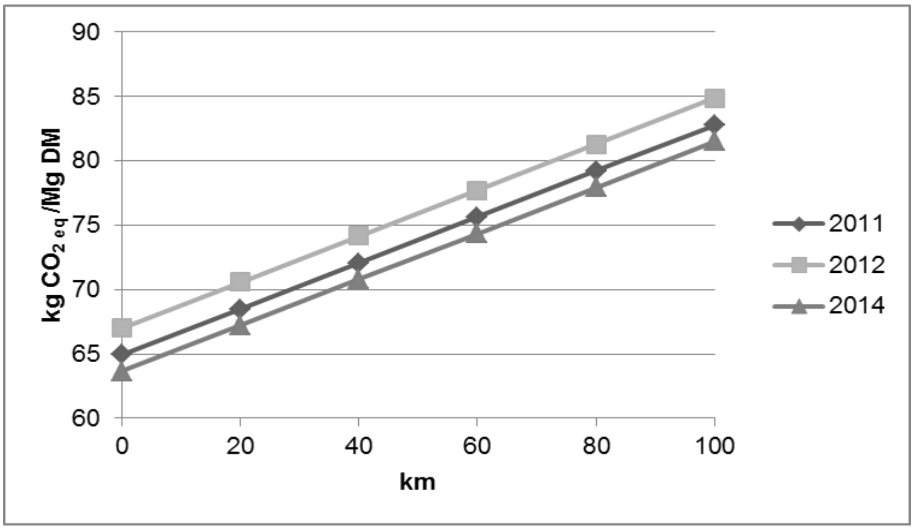


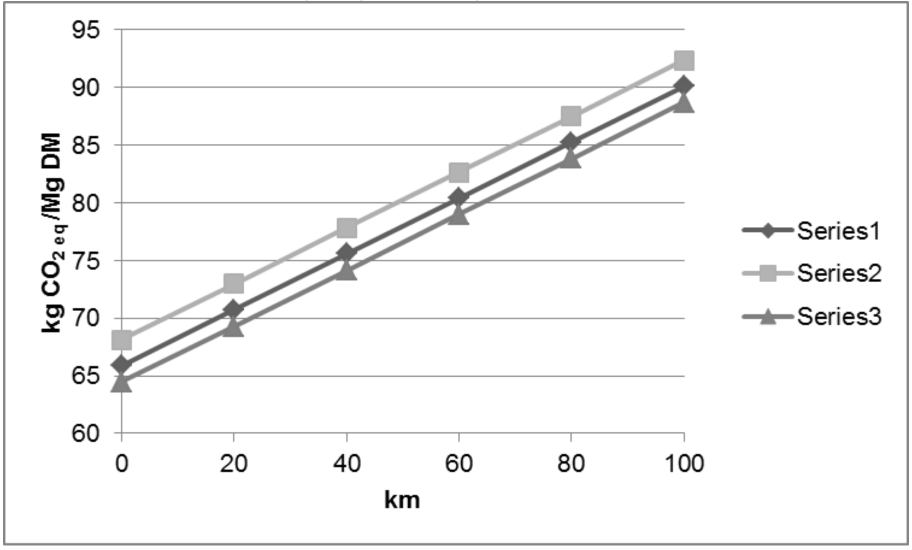
Fig. 3. Comparison of results for impact on GWP (transport distance 20 km)

Carbon dioxide (CO_2) represents dominant gas whose emissions make around 93 % of total impact on GWP. Emissions of methane (CH_4) contribute with around 6 %, while emissions of nitrous oxide (N_2O) with approximately 1 %. Other GHG are negligible. If emissions are considered in the context of the generic processes, GHG emissions from mineral fertilizers production are dominant and represent around 28 % of total emissions. Agricultural equipment production is responsible for 12 % of GHG emissions, electricity production 15 %, plastic (dominantly net used for bale wrapping) production 16 %. Carrying of agricultural operations within the supply chains, or more precisely diesel consumption, is responsible for approximately 12 % and diesel production for 4 %. Contribution of transport is for scenario with BB 12 % and for scenario with RB 14 %. Lowest contribution to emission of GHG, approximately 1 %, can be assigned to buildings (a shed used for the equipment storage).

For results presented in Fig. 3, transport distance was 20 km. In Fig. 4, are presented results of impact on GWP for whole range of analyzed transport distance, from 0 to 100 km. For both analyzed collection techniques, every 20 km causes approximately additional 5 % increase of GHG impact.



a) Big rectangular bales



b) Round bales

Fig. 4. Impact on GWP characteristic for supply chains in dependency from applied transport distance

CONCLUSIONS

Possibilities for stover usage as source for advanced biofuels is evaluated through measurements of stover yields with special emphasize to yields of different stover fractions and through evaluation of impacts of GHG characteristic for stover supply chain.

The performed measurement of stover fractions yield and relative yield to grain, results with data usable for determination of expected harvestable potential and remained stover mass. These data can be also used for defining of impact on soil as the result of stover removal and offtake of nutrients and soil organic carbon. Obviously, for the exact calculation of corn stover potentials as energy source the reductions of yield caused by drought, but also other yield reductions (extreme diseases and insects' infestation, flood, etc.), have to be analyzed and included in planning.

The supply chain that incorporates baling in the forms of BB has certain advantage in comparison to baling in the form of RB. However, the difference is very small and it can be said that a choice of balling technique has no significant influence on the assessment of the impact of GHG emissions. If imperative is to lower GHG emissions, potential improvement in organization of supply chain can be increase of the dimensions of bales, e.g. length of big rectangular bales could generate additional savings in emissions for around 5 %. Another possible improvement could be change of plastic nets used for wrapping whose characteristic emissions are assigned to collection phase of stover supply chain. If it is possible, they should be changed with materials with better characteristic in terms of GHG emissions. In this way, potential saving is another 10-15 %.

Variations of the stover yield have impact only on emission values for collection phase, but in general, these differences in overall impact of GHG are less than 3 % which can also be seen as insignificant. Transport distance has potential to significantly affect results of GHG impact. If for example 60 km is seen as maximum transport distance when trucks are used as means of transport, potential differences between supplied stover from different locations can be up to 15 % for BB and around 20 % for RB. For higher transport distances, more suitable way of transport could be by river, which would have positive impact to GHG emission.

Further investigation should be related toward improvement of harvest and storage procedures of corn stover and to consider possible reduction of GHG. Also, it is necessary that sustainable and potentials for biofuels be determined. Sustainable should be related to the amount of residual biomass which can be removed without negative impact on soil while biofuel potential shall represent amount that is obtained after subtraction of crop residues used for other purposes.

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