Bioenergy Association of Ukraine

OPPORTUNITIES FOR HARVESTING BY-PRODUCTS OF GRAIN CORN FOR ENERGY PRODUCTION IN UKRAINE

UABio Position Paper N 16

Semen Dragnev, Tetiana Zheliezna, Georgii Geletukha

April 06, 2016

Published at www.uabio.org: 06.04.2016
The publication is available at: www.uabio.org/activity/uabio-analytics
Responses and comments: geletukha@uabio.org

Content

Introduction

UABio's Position Paper N 16 covers issues related to the current state of the grain corn production, features of its cultivation and the possibilities of using by-products for energetic use. Corn is the most productive grain culture, by volume of biomass formation. In Ukraine currently only part of it – grain – is sold as commodity products, while plant residues are remained on the field. The information about fuel characteristics of by-products of grain corn and properties of its ash is shown. The technologies and equipment for by-products of grain corn harvesting are reviewed. Particular attention is given to the best practices of the USA. The estimation of costs of by-products of grain corn harvesting is offered. The prospects for its energetic use in Ukraine is estimated.

Current state of the grain corn cultivation in the world and in Ukraine

Corn is the most productive crop, which is widely used as:

- food, pharmaceutical, chemical and other branches of industry feedstock;
- high-energy feed, that is suitable for feeding all kinds of animals and birds;
- first and second generation biofuels feedstock;
- biogas feedstock.

Corn has a huge agrotechnological benefits, such as: corn cleans the soil of weeds and is a good precursor in the crop rotation. Judging by the absorption of carbon dioxide and released oxygen, corn is one of the best crops and is even more effective than a similar forest area [1]. Growing corn allows better use of agricultural machinery, by the later time of planting and harvesting.

Valuable properties of corn cause its consistently high demand on the world market. Corn, in amounts of gross harvest of grain **(Fig. 1**), yield (**Fig. 2**) and growth harvesting area (**Fig. 3**), among other crops, takes first place.

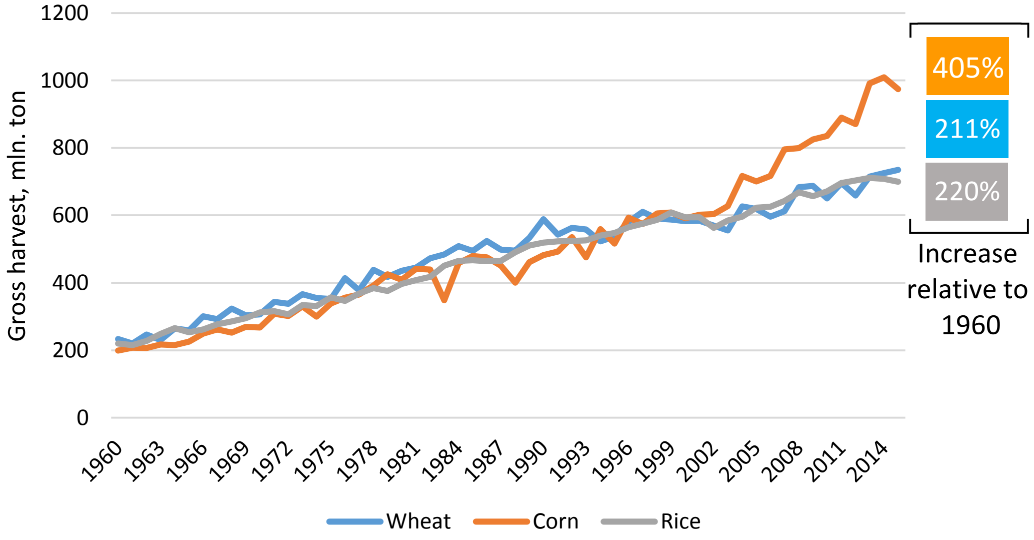


Fig. 1. Gross harvest of the basic crops in the world.

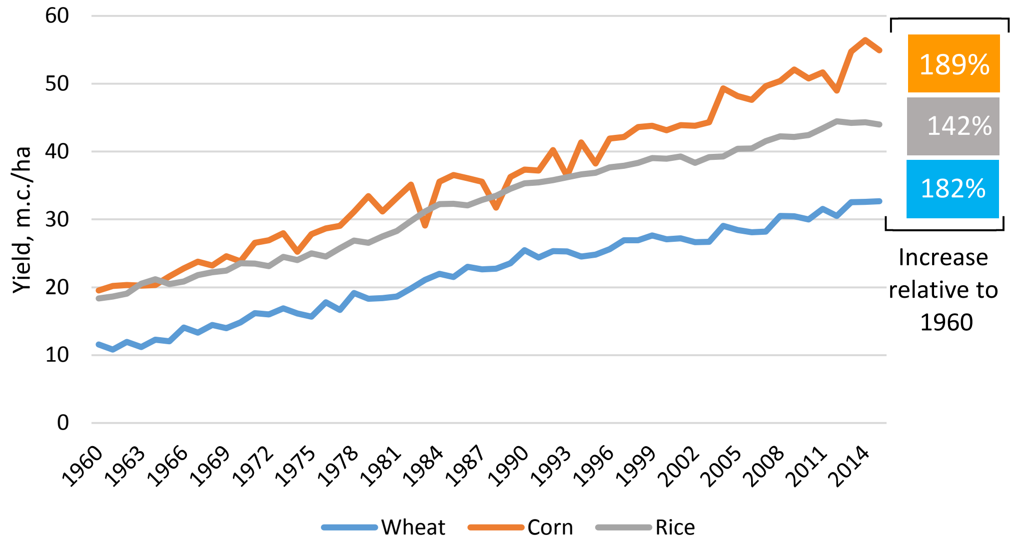


Fig. 2. Yield of the basic crops in the world.

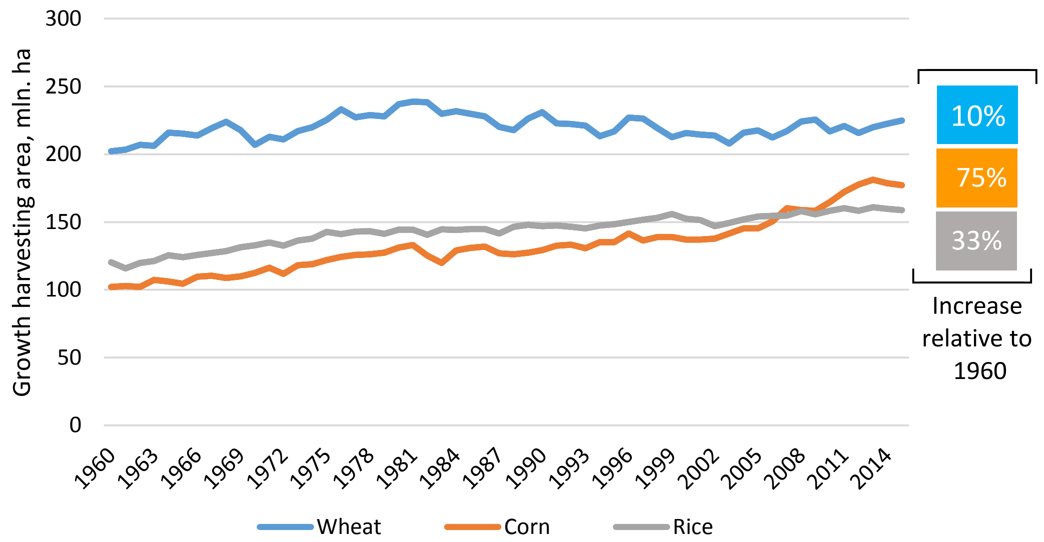


Fig. 3. Growth harvesting area of the basic crops in the world.

USA is the world leader in corn productivity and gross harvest. In the 2014/2015 MY, in the USA, 361 mln. tons of corn (36.4% of the global harvest of this crop) were collected, receiving in the average 107.3 m.c./ha[1] (**Table. 1**). In other countries, in 2014/2015 MY the following amounts of corn were collected: in China – about 216 mln. tons, in Brazil – 85 mln. tons, in the EU – 76 mln. tons, and Ukraine – is on the 5th place with 28.5 mln. tons.

Rising corn yields are associated with the development of agricultural science and with the use of biotechnology for creation of hybrids, that since 2000 have provided yields increasing in the USA at 2% annually (**Fig. 4**). In comparative tests, american farmers had achieved yields of corn more than 250 m.c./ha. In the 2015 the National Association of Corn announced a world record in Virginia – more than 334 m.c./ha of grain corn of Pioneer® P1197AM ™ sort[2].

[1]m. c. – metric centner (m.c. =100 kg)
[2] http://globenewswire.com/news-release/2015/12/18/796991/10158667/en/DuPont-Reports-Virginia-Grower-Breaks-World-Corn-Yield-Record-with-Pioneer-R-Brand-Corn.html

Table 1. The main corn producers in the world

	Country/ region	Growth harvesting area, mln. ha			Yield, m.c./ha			Gross harvest, mln. tons		
		2013/ 2014	2014/ 2015*	2015/ 2016**	2013/ 2014	2014/ 2015*	2015/ 2016**	2013/ 2014	2014/ 2015*	2015/ 2016**
1	USA	35.39	33.64	32.64	9.93	10.73	10.62	351.27	361.09	346.82
2	China	36.32	37.07	37.85	6.02	5.82	5.94	218.49	215.67	225.00
3	Brazil	15.80	15.75	15.80	5.06	5.40	5.16	80.00	85.00	81.50
4	EU	9.66	9.53	9.27	6.69	7.95	6.23	64.63	75.73	57.75
5	**Ukraine**	**4.83**	**4.63**	**4.00**	**6.40**	**6.15**	**5.75**	**30.90**	**28.45**	**23.00**
6	Argentina	3.40	3.20	3.20	7.65	8.28	8.00	26.00	26.50	25.60
7	India	9.07	9.30	9.20	2.68	2.55	2.45	24.26	23.67	22.50
8	Mexico	7.05	7.33	7.0	3.24	3.48	3.36	22.88	25.48	23.50
	World	**181.16**	**178.61**	**177.46**	**5.47**	**5.65**	**5.49**	**991.43**	**1008.79**	**974.87**

*   *Preliminary data*
** *Forecast*
Source: USDA [3]

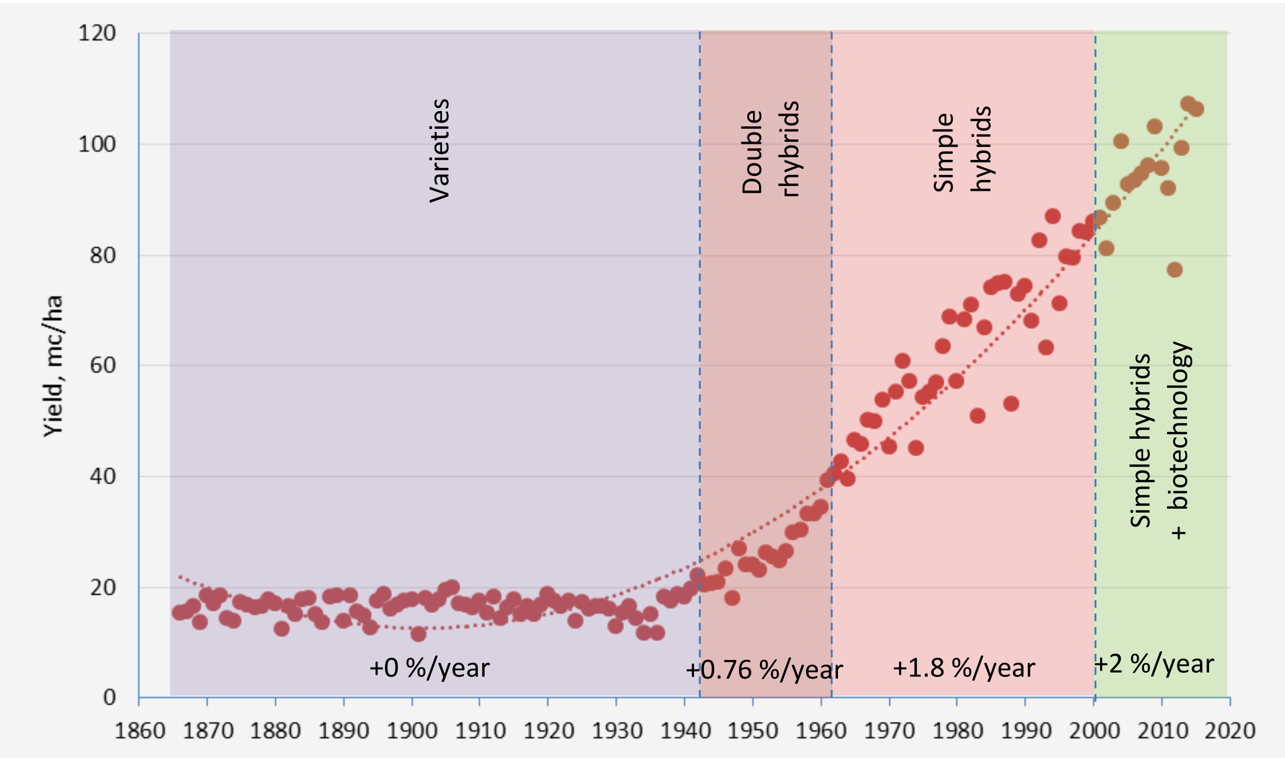


Fig. 4. Increase of corn yield in the USA during the last 150 years[4].
Source: USDA, data treatment AGPM, Arvalis

[3]http://apps.fas.usda.gov/psdonline/psdReport.aspx?hidReportRetrievalName=Table+04+Corn+Area%2c+Yield%2c+and+Production&hidReportRetrievalID=884&hidReportRetrievalTemplateID=1
[4] http://agriculture.by/articles/rastenievodstvo/urozhajnost-kukuruzy-budet-rasti.-pochemu

In the EU grain corn and corn-cob mix (CCM) took a 2nd place in the gross harvest among all grains (**Fig. 5**). There is prevailing in growing grain corn, which was collected in an amount of 75.7 million. tons in 2014, while CCM – 2.4 mln. tons. The biggest amounts of corn are produced in France (18.4 mln. tons), representing 24.3% of the gross harvest in the EU in 2014, Romania – 11.73 mln. tons, Hungary – 9.17 mln. tons and Italy – 8,33 mln. tons. The largest yields in 2014 were in Spain – 112.4 m.c./ha, Austria – 107.9 m.c./ha, Germany – 106.8 m.c./ha and France – 103.8 m.c./ha.

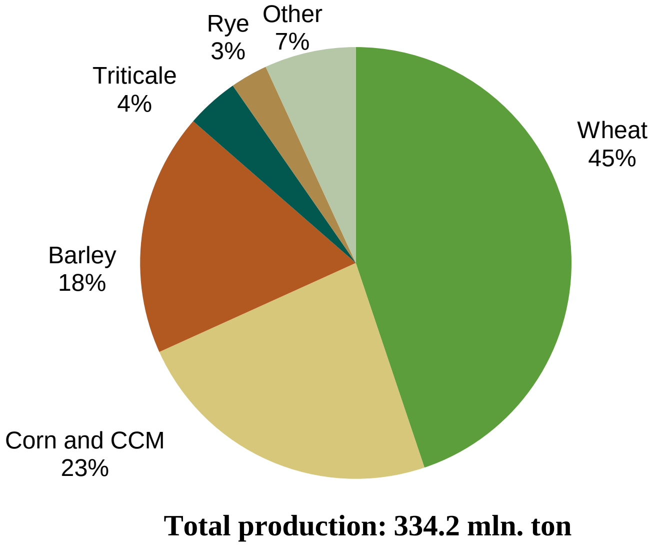


Fig. 5. The structure of cereals production, EU-28, 2014*

** % of the total production of cereals*

Source: Eurostat

Ukraine has the highest gross harvest of grain corn in Europe. In 2011 there were established a European record in corn yielding in the Myronivsky Hliboproduct JSC SPF "Urozhai" company, where from the 91.4 hectares[5] 190 m.c./ha DKS 5143 hybrid breeding were gathered, from "Monsanto" company, with humidity at around 22%. The real achievement in 2013 was the farm "Ladis" Monastyrischensky Cherkasy region harvest, where from 100 hectares 205 m.c./ha grain corn from 3511 BCS hybrid were gathered, with humidity at 22-23%.[6] High yields of corn – 10-12 t/ha – are got in some farms in Forest-Steppe (Lisostep) and Woodlands (Polissya), which far exceed the Ukraine's average in general and for regions in particular. According to the data of Ministry of Agrarian Policy and Food of Ukraine, in 2015 23.2 mln. tons of corn grain was threshed, which is on 9% less in comparison to 2014. The average yield was 57.1 m.c./ha, which is 95.5% relative to 2014 average yield[7]. Data on corn production by regions in 2014 is shown in **Table 2.**

In 2014 the highest gross yield of grain corn was in the Poltava region (3379 kt), although it was only 82.8% of 2013 crop. The average yield in the Poltava region in 2014 was at 58.1 m.c./ha, while in Vinnytsia, Rivne, Sumy and Khmelnytsky it was higher than 80 m.c./ha, and in the Kiev region – 79.4 m.c./ha.

---

[5] http://www.mhp.com.ua/uk/media/news/details/52

[6] http://www.agroprofi.com.ua/statti/1041-zernovi-rekordi-cherkaschini-ponad-200-tsga-kukurudzi-virostiv-ladis

[7] http://minagro.gov.ua/uk/node/19858

Table 2. Production of grain corn in Ukraine's regions

	Gross harvest		Harvested area		Yield	
	2014, **kt**	2014 relative to 2013, **%**	2014, **1000 ha**	2014 relative to 2013, **%**	2014, **m.c./ha**	2014 relative to 2013, **+,-**
Vinnytsya	**2702.7**	**97.0**	**345.3**	**94.7**	**82.6**	**+1.9**
Volyn	184.9	105.8	24.6	97.2	77.5	+6.4
Dnipropetrovsk	929.1	70.6	322.7	107.9	26.7	-14.1
Donetsk	366.7	102.3	95.3	106.1	36.3	-1.3
Zhytomyr	1292.9	82.5	199.6	89.6	72.3	-6.2
Zakarpattya	196.4	104.6	41.8	102. 6	45.8	+0.9
Zaporizhzhya	130.7	75.0	53.0	88.7	27.8	-5.0
Ivano-Frankivsk	355.8	102.1	52.5	94.9	71.5	+5.1
Kyiv	**2053.3**	**94.5**	**291.7**	**88.8**	**79.2**	**+4.7**
Kirovohrad	1834.4	85.2	389.6	94.3	49.9	-5.4
Luhansk	316.3	91.5	105.0	85.0	35.4	+2.5
Lviv	434.1	110.4	61.3	101.5	69.7	+5.5
Mykolayiv	499.2	68.1	141.8	94.4	37.3	-14.4
Odesa	546.0	67.7	169.7	95.5	33.7	-13.8
Poltava	**3380.1**	**82.8**	**592.7**	**98.2**	**58.1**	**-10.8**
Rivne	**506.3**	**98.4**	**63.1**	**97.1**	**82.6**	**+1.1**
Sumy	**2672.7**	**110.8**	**317.7**	**102.5**	**82.1**	**+6.2**
Ternopil	1188.1	98.5	159.8	96.0	77.5	+2.0
Kharkiv	1606.8	100.1	319.1	94.3	53.4	+3.1
Kherson	224.5	59.7	59.6	72.7	51.8	-11.3
Khmelnytskiy	**1727.4**	**94.6**	**251.2**	**83.4**	**82.4**	**+9.8**
Cherkasy	2286.8	85.9	339.4	96.0	70.2	-8.2
Chernivtsi	399.7	98.2	66.9	94.2	63.4	+2.6
Chernihiv	2661.9	118.0	353.7	104.5	72.0	+8.2
Ukraine	**28496.8**	**92.3**	**4626.9**	**96.1**	**61.6**	**-2.5**

Source: State Statistics Service of Ukraine

Due to adverse weather conditions (dry and hot summer), 2015 – was the complex year for growing corn in Ukraine. Although the average yield in the Poltava region grew up and reached 73.1 m.c./ha[8], and in the Shishatskiy district even exceed 100 m.c./ha. Another reasons of corn harvest reducing in 2015 – is sown area decreasing on 13% in 2014, down to 4.01 mln. ha, due to the financial difficulties and the reduction in economic attractiveness of corn growing. The graph of the dynamics of changes in domestic purchase prices of corn in 2010-2015 is shown in **Fig. 6**. The maximum price – 261 USD/ton – was in June-August 2011, and the minimum – 115 USD/ton – in November 2014. In January 2016 purchase price of the corn on elevators of LLC JV "NIBULON" was from 3150 to 3350 UAH/ton (from 134 to 142.5 USD/ton).

[8] The data of the major crops, fruits, berries and grapes harvest in 2015 (preliminary data) / Express issue of the State Statistics Service of Ukraine
http://www.ukrstat.gov.ua/express/expr2016/01/11pdf.zip

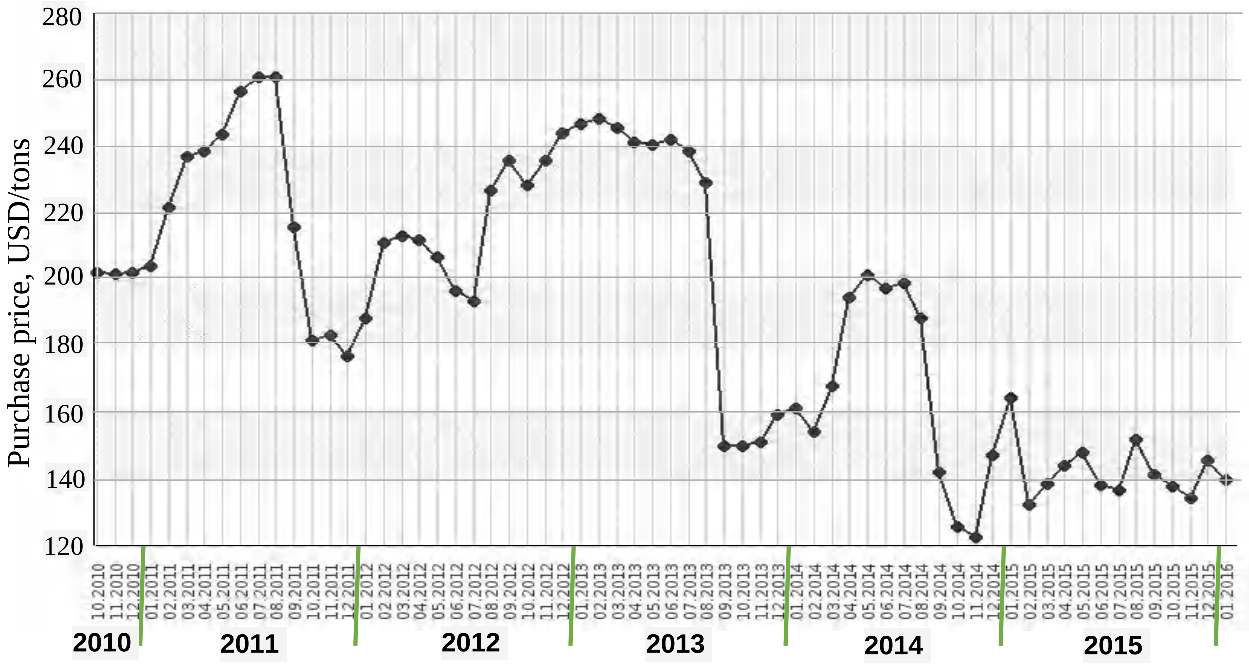


Fig. 6. Dynamics of changes in domestic purchase prices of corn[9].

According to the experts' estimation, low corn prices in the domestic and foreign markets are associated with significant transitional stocks and with the oil prices falling, which also led to price decreasing of bioethanol.[10] It is expected this year, that the decreasing in amounts of world production of grain corn could change the downward prices trend in the market.

Thus, given the large acreage of grain corn in Ukraine, that occupy about 15% of arable lands and high yield over the past 3 years (on average from 57 to 64 m.c./ha), it is evident that this crop forms large amounts of by-products (other than grain), that can be used in the bioenergy sector. It may be noted, that in Ukraine there are reserves to increase yields through better use of achievements of agricultural science. To ensure stable prices for corn, its domestic consumption should be increased, including the processing for producing the products with high added value.

Features of grain corn cultivation in Ukraine

Corn is a highly productive plant with tropical origins. Its birthplace is Central and South America, which explains the need of the heat for its growth and development. In a short time, corn produces more organic matter than other crops. Thanks to progress in the selection, in recent years border areas of corn growing had moved far to the north [1].

Botanical features. Corn (*Zea mays L.*) – annual, monoecious, diclinous,allogamouscereal family plant. The stalk is upright, with height in different hybrids, depending on climatic conditions, farming practices and soil fertility, is from 0.5 to 6.7 m. The bulk of the roots is concentrated at a depth of 30-60 cm, but many viable shallow roots penetrate to a depth of 150-250 cm using moisture and nutrients from lower located soil layers [2].

For the duration of the growing season corn hybrids are divided into seven groups with the growing season period from 85 to 150 days. Each biotype should satisfy growing area's climatic

[9] http://www.apk-inform.com/ru/prices
[10] http://apps.fas.usda.gov/psdonline/psdHome.aspx

conditions requirements, to ensure high yields and robust maturation [3]. The State Register of Plant Varieties of Ukraine in 2015 was recorded more than 750 varieties.

Agro-climatic conditions in Ukraine are heterogeneous, so there are four areas of corn seeding: Steppe, Forest-Steppe and Polissya, Carpathian Mountain and Crimea. Each area has its own soil characteristics, moisture and temperature conditions that significantly affect the yield. The period when corn may develops rapidly and accumulates organic matter, is limited by the date of sustainable transition of daily average temperature through 10°C. An important feature of the thermal regime of corn is its duration, combined with the good provision of moisture [2]. The priority of the corn hybrids for different growing areas according to the groups of maturity: for Steppe – middle-early, Forest-Steppe – early and middle maturing, Polissya – early-maturing form dry corn and usually do not require additional costs for drying (**Tab. 3**).

Table 3. Thermal regime of corn hybrids from different maturity groups [4]

Group of hybrids maturity Group of hybrids maturity	FAO[11]	Total of effective temperatures (above 10 ºC), ºC Total of effective temperatures (above 10 ºC), ºC	Vegetation period, days			The need in total of effective temperatures during the vegetation, ºC FAO
			Vegetation period, days	The need in total of effective temperatures during the vegetation, ºC	Group of hybrids maturity	
Early-maturing	100-199	900-1000	85-99	97-102	101-106	2100
Middle-early	200-299	1100	94-114	107-116	109-119	2200
Middle-maturing	300-399	1150	111-122	120-125	123-126	2400
Middle-late	400-499	1200	115-128	-	-	2500
Late-maturing	500-600	1250-1300	-	-	-	2700

Agro-climatic zones of corn seeding conditions in Ukraine marked a significant variety of hydrothermal indicators, which leads to significant variation in scientifically grounded sowing time as well as duration of the growing season of all corn biotypes and the onset of full grain ripeness (**Tab. 4**) [4].

Corn goes through different stages of growth and development. Dry matter (d.m.) content in the whole plant stems grows until the initial stages of ripening; the content of dry mass in the cob – until the full grain ripening. The maximum content of d.m. in the whole plant – 30-35% (best time for corn silage harvesting). The content of d.m. decreases up to 15-20% until the date of full ripeness. In autumn, when temperatures are below 20°C, dry mass accumulation processes are being finished. The maximum grain yield is achieved with a content in it the 60-64% of the d.m. (physiological maturity) [1].

[11] FAO-number characterizes maturity corn hybrid group on a scale from 100 to 999

Table 4. Zonal scientific-grounded sowing corn hybrids of different maturity groups [4]

Zone	Calendar period of sowing		Vegetation period of biotype hybrids, days			
			Early-maturing	Middle-early	Middle-maturing	Middle-late
Southern Steppe	early	10-17.04	85-90	94-108	111-115	116-125
	optimal	20-30.04				
	later	01.05-08.05				
Northern Steppe	early	15-24.04	94-99	106-114	114-122	123-126
	optimal	25.04-03.05				
	later	04.05-13.05				
Forest-steppe	early	18-30.04	97-102	107-116	120-125	-
	optimal	01.05-09.05				
	later	10-16.05				
Polissya	early	22.04.-02.05	101-106	109-119	-	-
	optimal	03-10.05				
	later	10-15.05				

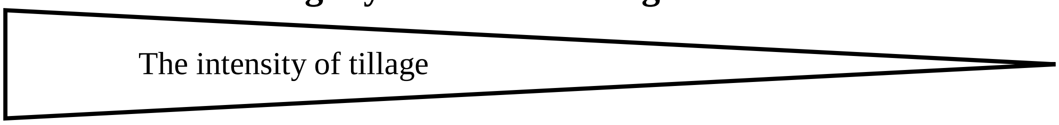
High corn yield is formed on the soils clean of weed, structured, relatively mellow with deep bedding of the humus horizon and high in nutrients. The best corn soils are black earth, chestnut, dark grey and floodplain soils with a neutral reaction (pH 7.0-7.5). Corn is not too fastidious to the predecessors in rotation. In rotation it is placed after winter crops, leguminous crops, potatoes, sugar beets, spiked grains, melons. Corn is capable to withstanding a long growing term on permanent plots. In the areas of inadequate moisture, corn should not be sown after sunflower and sugar beet that dry the soil heavily [5].

Corn is quite demanding on the increased mineral nutrition and as a culture with an extended growing season, is able to absorb nutrients throughout the whole life cycle. To create 1 ton of grain with the appropriate amount of leafy mass, corn uses, approximately, 24-30 kg of nitrogen, 10-12 kg of phosphorus, and 25-30 kg of potassium from soils and fertilizers. To form the 4.5-5.0 t/ha grain harvest corn uses on average of 110-150 kg of nitrogen, phosphorus and 45-60 kg 115-150 kg of potassium from the ground. Soil is unable to provide such nutrients in forms available to plants, even at a high fertility. That’s why fertilizers remain one of the most influential factors in increasing crops yield. The doses of mineral fertilizers used in corn crops, are applied taking into account the content of movable nutrients in the arable soil and average macro elements removal with harvesting main and by-products [4].

The estimated rates of application of the fertilizers are in the Steppe – $N_{60-90}P_{60}K_{35-40}$, Forest-Steppe – $N_{120}P_{90}K_{90}$, Polissya and western regions – $N_{130}P_{100}K_{100}$. Also organic fertilizers are applied, in particular: manure in the Forest-Steppe and Polissya in amount of 30-40 t/ha; in the Steppe – 20-30 t/ha [5]. As well as organic fertilizer, straw stubble and humus are used to improve soil condition [6]. The joint application of mineral and organic fertilizers is the most effective method.

Tillage is one of the key elements in the corn cultivation technology. For tillage it is important to have well-cultivated soil, that is providing well-accommodation of sowing seeds and reception of amicable stairs and also ensure unhindered root development of the plow and subsoil layers. There are three tillage systems: traditional (based on the cultivation plowing) of soil or preserving (minimum) and zero (direct sowing without tillage) (**Fig. 7**) [1].

Tillage systems and sowing



Plow tillage

Continued work with a plow in the main soil tillage in autumn or spring

«Traditional»

Without Plow tillage

Shallow tillage without soil layer rotation, the rejection of autumn plowing, sowing in mulch or residues of interim crops

«Conservation» (Mini-till)

Direct sowing

Disclaimer tillage, sowing in the soil, which it left after harvesting predecessor

«No-till»

Fig. 7. Agricultural practices and working passes at different methods of tillage [1].

Traditional tillage under the corn consists of the main and preplant. The main cultivation begins with stubble peeling or surface cultivation and plowing. After the grain predecessors before plowing vegetable remains should be chop qualitatively, then they should be evenly distribute on the area of the field, and, finally, they should be make in the soil shallowly. Corn has higher requirements for soil aeration. The optimal parameters for soil aeration are provided by traditional deep plowing (at 25-27 cm) or energy-saving chisel plow cultivation with no plough [1-4, 7, 8].

Chisel plow[12] tillage – provides better energy and soil protective effect, during which fuel is saved in amounts of 10-12 kg/ha, maintenance costs are reduced by nearly half, labor costs – by 31%, energy consumption is reduced by 1.4 times. In households with high farming culture, where integrated weeds control system is used, shallow tilling to a depth of 12-14 cm are provided [4].

Also in recent years in Ukraine technology *"No-till"* acquires distribution [9]. According to the NSC "ISSAR named after O.N. Sokolovsky"[13] (Kharkov city), Ukraine has a great potential for the introduction the minimum tillage methods. There are following barriers for providing technology *"No-till"*: low agriculture culture, excess in weeds and the forced use of plowing and other numerous preplant and between the row tillage as a mean to combat them. [10]

The use of soil-protecting tillage technologies prevents water and wind erosion (**Tab. 5**), increases water-soil infiltration capacity, preserves favorable soil conditions for the implementation technology processes. At the same time the use of soil-protecting technologies, including the use of the mulch from a plant residues, has the following negative characteristics: after heating the soil, field germination of corn is lower; the growth of corn is slower; mineralization of nitrogen is lower;

[12] *Chisel plow* – a soil tillage device pulled by a tractor or animal, used to break up and stir soil a foot or more beneath the surface without turning it.

[13] National Science Centre "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky" http://www.issar.com.ua/

clogging weeds is increased; damage crops from the mice is increasing. To solve these problems, constant crops developing control must be done and appropriate measures must be carried out [1].

Table 5. Effect of mulch on the runoff and soil removal [1]

Soil covering with mulch, %	Crop residues, t d.m./ha	Runoff, %	Soil removal, %
0	0	45	100
less 20	0.5	40	25
20-30	1	25	8
50	2	0.5	3
70	4	0.1	< 1
> 90	8	not measured	< 1

In spring pre-tillage is making in the way to reduce to a minimum the mechanical impact of the machinery on the soil, to preserve the existing structure and to process only seeding areas and to protect the soil from much consolidation, drying and spraying. For this purpose harrowing, sweeping and cultivation are carrying out [1, 4].

Today, the main method of planting corn in Ukraine is the wide row method – with a 70 cm width between rows, while in the USA – 76.2 cm. The distance between plants in the row depends on the seed rate. Since in the No-till farming systems it is not necessary to carry out between row loosening during the growing season, row spacing can be reduced down to 50 cm, which enhances the crops competitiveness to weeds and can increase the standing plants corn density. But to harvesting crops reaper that is used is needed to be adapted to the width between rows. For No-till tillage the typical is slower soil warming in the spring compared to the traditional system of agriculture, in particular due to its plant remains coating [9]. Usually corn planting is being started with the soil warming at a depth of seeds laying of 8-10°C. Density of grain corn sowing in the harvesting period should be: 70-80 thous. pcs./ha (20-25 kg/ha) for the area of Polissya, Forest-Steppe, Western Ukraine regions; 50-70 thous. pcs./ha (15-20 kg/ha) for the Steppe zone[5].

Due to caring about crops should be created favorable conditions for obtaining unanimous corn stairs, enabled to maintain crops in a pure of weeds state and retained moisture in sowing and plow soil layer. For this purpose, harrowing and cultivation between rows are being introduced. Intensive technology of growing corn on a background of soil and post-risen herbicides involves reducing the number of mechanical methods of care; and on the clean fields - involves their complete exclusion. However, the high potential of the soil infestation with the different terms germination seeds and certain types of weeds resistance to a chemicals requires a combination of mechanical and chemical crops care measures. To combat pests and diseases of corn chemical or biological protection is being used [1, 4].

Grain corn harvesting technologies

Harvesting grain corn is a complex and laborious process. There are several technological schemes to do this (**Fig. 8**):

1. Harvesting grain corn with corn harvesters with the further cobs refining in the other stationary place:

1.1. with no cleaning cobs from cornhusk (item 1.1 in **Fig. 8**);

1.2. with simultaneously cleaning cobs from cornhusk (item 1.2 in **Fig. 8**);

2. Harvesting grain corn with combine harvesters with corn reapers (item 2 in **Fig. 8**);

3. Harvesting CCM with combines (item 3 in **Fig. 8**).

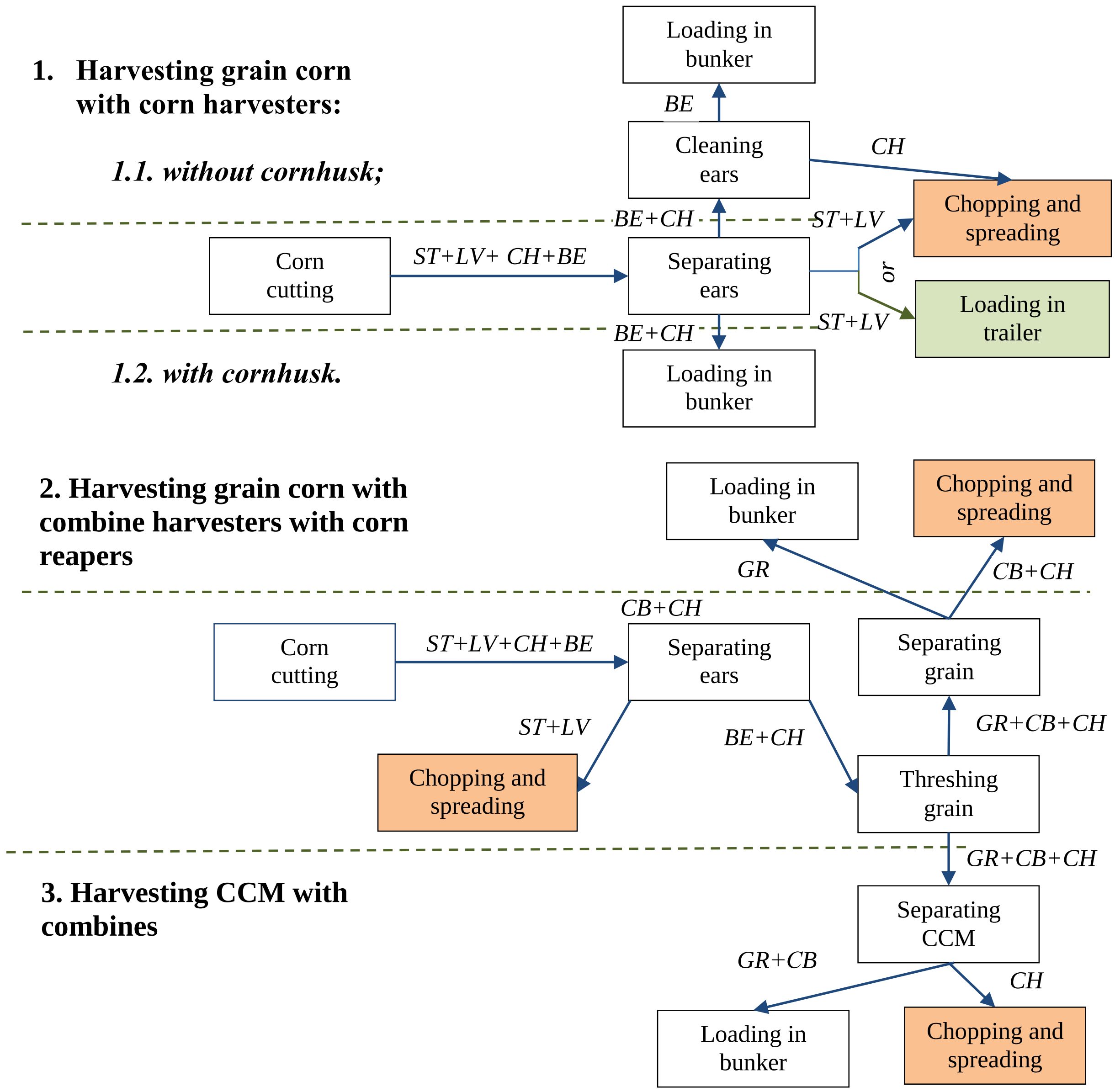
Grain corn should be harvested with grain moisture content from 20 to 35-40%, and CCM harvest – with grain moisture content 40-50%. Corn harvest without cobs thrashing starts when grain humidity is less than 40%; with cobs threshing – with less than 30%. With bigger humidity threshing worsens, corn injures, harvesters productivity reduces. The best quality thrashing occurs when grain moisture is 20-22% [5].

In 1980s-1990s in Ukraine was popular grain corn harvesting technology, which included collection of all biological crop through the use of grain harvesters SK-5M, Enisei-1200, Don-1500 and KZS-9-1 with special headers PPK-4, KMD-6, PZKS-6 that produced by "Hersonmash" plant and are directing chopped by-products to the trailer.

Currently, the main method of commodity grain corn harvesting is the ***cobs threshing by combine in the field, shredding and spreading truncated mass*** using combine harvesters with corn reapers. This method of corn harvesting is the most economically feasible method. In comparison with corn with cobs harvesting it provides in 1.8-2 times lower labor costs and in 20-25% lower fuel consumption [4]. Only a few farms are harvested corn with cobs with following stationary threshing that *enables to collect the cobs*. This is grain plants that grows corn for the getting hybrid corn seeds as a planting material. CCM collection in Ukraine is still not widely spread.

Due to the dates of the corn sowing period in the corn sowing areas and the average length of the vegetation period of the biotypes corn hybrids with different maturity groups, the expected term of biological ripeness, depending on hydrothermal growing conditions comes usually: [4]

- In the South Steppe zone – during august 1-5 (Early hybrids) – September 10-15 (Medium hybrids);
- In the North Steppe zone, respectively, – during August 15-20 – September 15-20;
- In the Forest Steppe zone – during August 25-30 – September 20-25;
- Polissya - 1-5 September – during September 25-30.



GR – grain; *ST* – stalk; *LV* – leaves; *CB* – cob; *CH* – cornhusk; *BE – bald ear (BE = CB+GR)*

Fig. 8. Grain corn harvesting technologies.

The duration of a one hybrid harvesting should not exceed 5-7 days, otherwise delay causes significant yield losses. Thus, according to the Institute of agriculture of the Steppe zone[14] (Dnipropetrovsk city), the losses of corn after 10 days from start picking up are only 4%, after 20 days – are increasing up to 10%; after 30 days – up to 17% and in 35th day the losses are 23% of the formed yield level [4]. In a lot of regions of Ukraine the corn is harvested usually in a period that is far exceeding the permissible limits of optimal period. Typically, grain corn is harvested in October-November. To provide the basic humidity – 14% – corn is dried in grain dryers that is required additional costs. So, often due to the high humidity of the basic products, even when it reaches the full maturity, in a number of a households, the harvesting of culture is deliberately delaying, in order to reduce the moisture content in the grain. The plants are leaving for a long time on the vine, causing irreversible crop losses. In the dry freezing weather, the grain moisture

[14] http://www.institut-zerna.com/

decreases, but other main product indicators become worst. But despite this, in a number of a households, corn is harvested in December-January, or even later.

The use of grain corn by-products

There are several components of the by-products of grain corn (BPGC): *stalk, leaves, cob core* and *cornhusk*. BPGC **mass ratio to grain** depends on many factors, primarily on hybrid, but in general, it can take **1.3** according to recommendations [11]. General view of the relationship and the main parts of corn [12] is shown in **Fig. 9.**

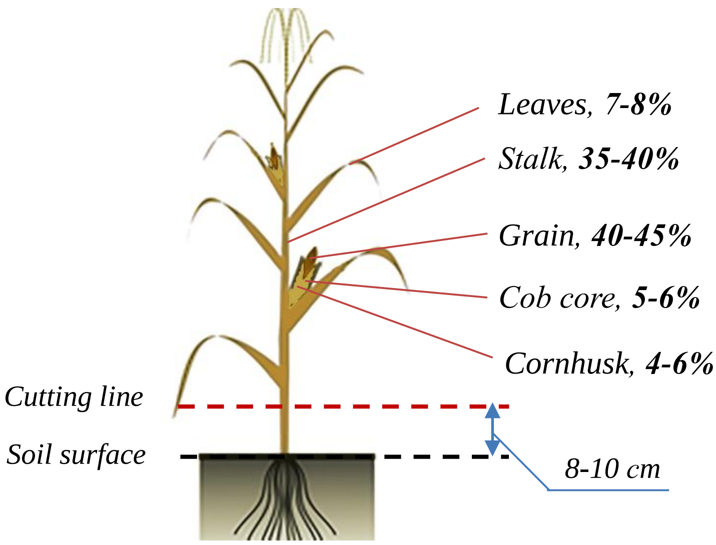


Fig. 9. The mass ratio of the main corn parts.

In the modern corn harvesting technologies, sideline products are mainly shredded and are scattered on the plot. If harvesters are not equipped with shredders, the mulchers are used. Mulchers are aggregated with tractors and are enabled a good quality chopping and evenly distribution the plant remains on the surface of the field. For further calculations, we accept the average value of corn parts and calculate the potential of the BPGC (**Tab. 6**). BPGC potential in Ukraine in 2014, as a whole, amounted to 37 046 kt, with the largest part – 4394 kt – in Poltava region (**Fig. 13**).

Table 6. Potential of BPGC parts in Ukraine (2014)

Name	Symbol	Average ratio, %	Mass (average), kt
Stalk	ST	37.5	25259
Leaves	LV	7.5	5052
Cob	CB	5.5	3704
Cornhusk	CH	4.5	3031
Total			**37046**

Corn is a valuable raw material not only for agriculture, but also for other sectors of the economy, because with the complete and complex corn processing more than 500 different kinds of products are receiving [3]. The main uses of BPGC is shown in **Fig. 11**. In the US and some EU countries, a significant amounts of BPGC are harvested and used industrially for the production a wide range of products. In Ukraine BPGC are used mainly as a fertilizer, animal feed and litter and in some regions – as a solid biofuel.

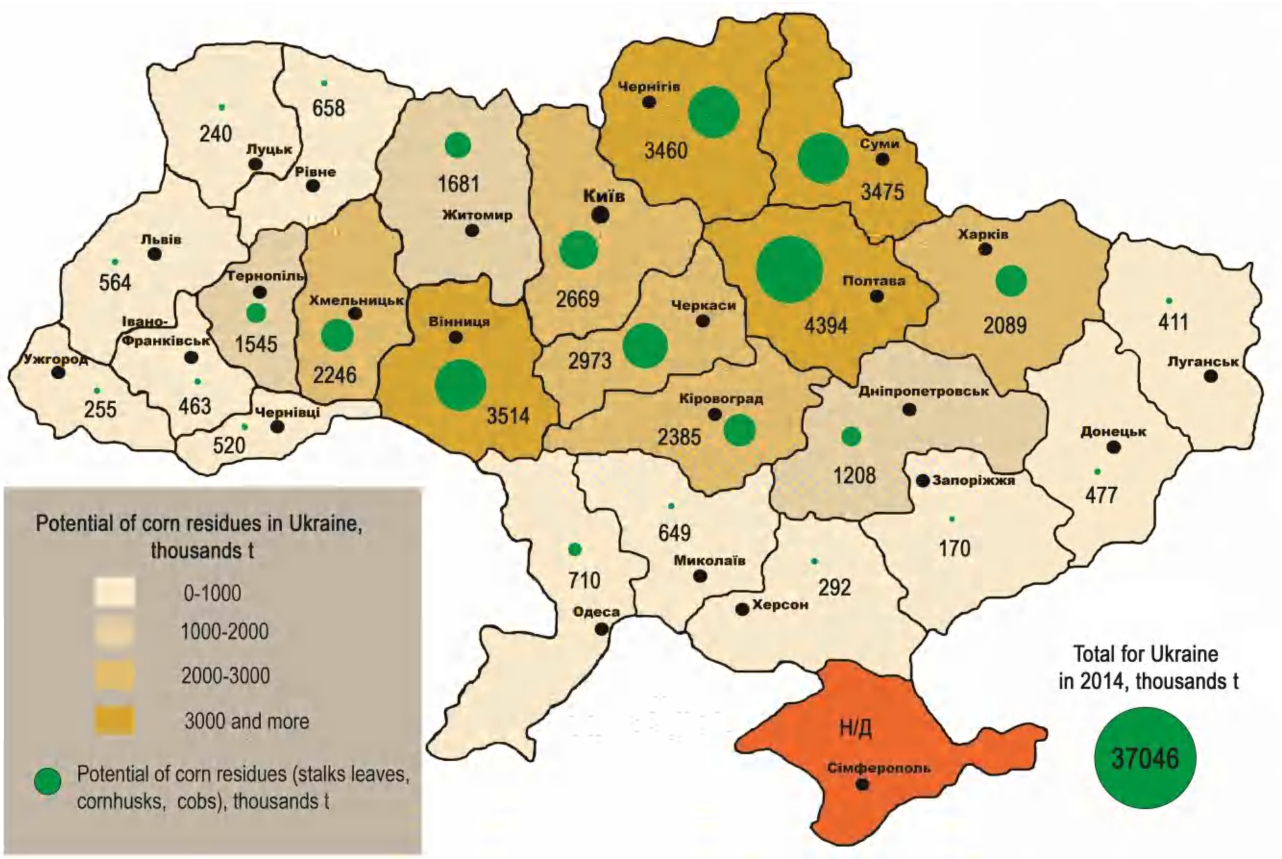


Fig. 10. By-products of grain corn potential in Ukraine (2014).

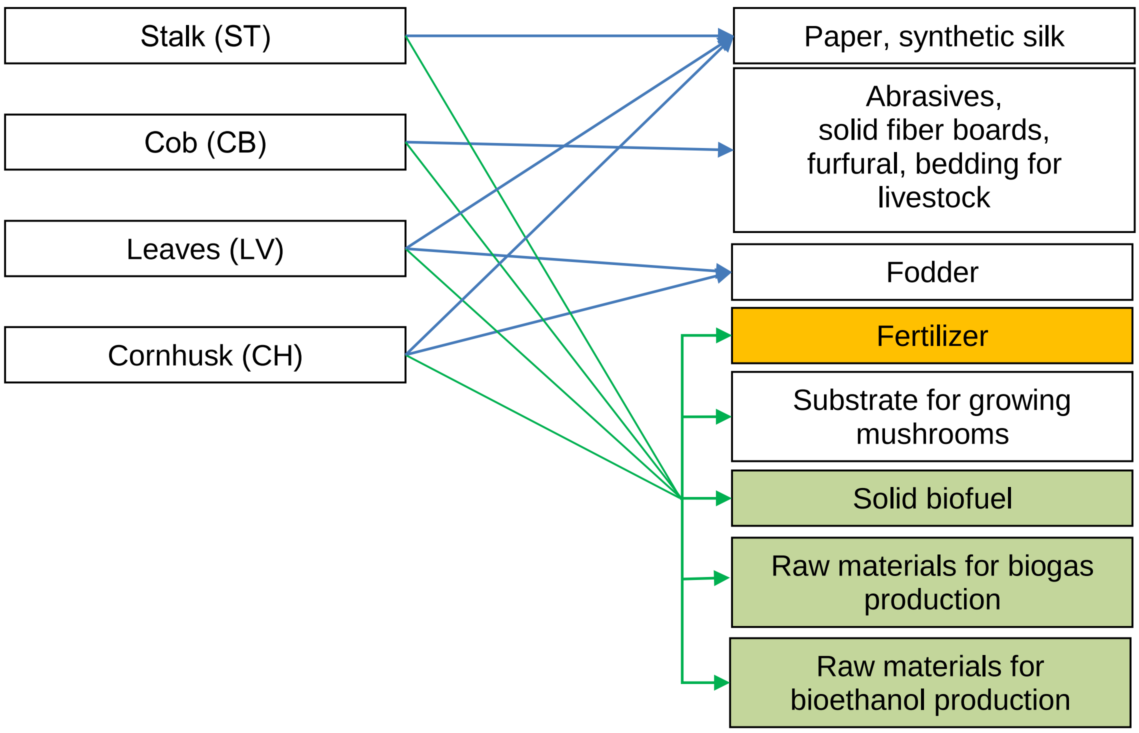


Fig. 11. Area of use of grain corn by-products.

In livestock straw, including corn straw, because of the low nutritional value is used in limited quantities: as a ballast feed and if other roughages are lacked. Corn leaves and cornhusks nutritional value is higher compared with corn stalks and cob cores. For example, in southern Odessa region, in villages, after corn harvesting locals have for decades harvested corn stalks with leaves to feed livestock during the winter. Livestock eat the leaves and stems are burned in stoves for heating.

Examples of use of grain corn by-products for energy production

In Ukraine, the by-products of grain corn (BPGC) is primarily used for producing ***solid biofuels: square and round bales, pellets and briquettes***. There were also attempts to use this biomass as a substrate for ***biogas plants*** in the test mode. Significant amounts of BPGC processed in the United States, in particular, modern technology allows to get ***bioethanol*** from such lignocellulosic biomass.

In the stationary points, when corn cobs are threshing, cob cores are collected for producing pellets. The characteristics of pellets that are realized in Ukraine's market, are following: the diameter – 6-8 mm, operating humidity – 7.3%, ash content – of 2.6%, lower calorific value – 4168 kcal/kg (17.4 MJ/kg). The cost of pellets, at the end of 2015, amounted to 1900 UAH/ton with VAT[15]. Also, granulated and briquetted biofuels are derived from other parts of corn that should be collected from the field and delivered to the place of processing. Some agricultural producers are modernized dryers for using straw bales as a fuel, including corn straw. Characteristics of *corn straw*, that consists of the stalks and leaves that are remained after corn cob separation, is shown in **Table 7**.

Ash content in BPGC depends on the harvesting technology, as if biomass contact with the soil, the biomass ash increases. Considering this, it is being identified two types of ash: structural and nonstructural [13]. Structural ash consists of inorganic chemicals substances that remain after the burning. The normal corn straw ash content is 3.5%. Unstructured ash consists of inorganic substances (mainly soil), which fall into the straw during the harvesting, in particular during the swathing and baling. A typical full ash content, if multiple passes by agricultural machines, during the collection, is 8-10%.

Looking at the fusibility characteristics of ash, corn straw is close to the wood biomass (to compared: the wood ash fusion temperature is about 1200°C), that is providing better conditions for combustion in comparison with cereal straw.

Also corn straw contains less chlorine (0.2% of d.m. weight) in comparison with fresh ("yellow") cereals straw (0.75% of d.m. weight) (**Tab. 8**). This is a positive factor for using corn straw as a fuel, due to the fact that chlorine causes corrosion of steel energy equipment elements.

Over the elementary composition, the corn straw is just like cereals straw, because they are comparable calorific value. Properties of the straw are heavily dependent on the place of growing, harvesting period and weather, soil and fertilizers [15]. The most influence on a calorific value of the corn biomass is by moisture (**Fig. 12**).

[15] http://energy-group.com.ua/p59420521-toplivnye-pellety-pochatkov.html

Table 7. Fuel properties of corn straw [16]

Property	Sample value		
	№704	№889	№241
Moisture content, W^r, %	6.06	5.00	–
Ash content, A^d, %	5.06	7.35	3.7
Volatile matter, V^{daf}, %	85.17	84.30	–
Carbon, C^d, %	46.82	50.19	51.40
Hydrogen, H^d, %	5.74	6.27	5.61
Nitrogen, N^d, %	0.66	0.60	0.62
Sulphur, S^d, %	0.11	0.12	–
Oxygen, O^d, %	41.36	42.82	43.41
Chlorine, Cl^d, mg/kg	2661.3	0.0	–
Net calorific value, Q^r, MJ/kg	15.68	16.72	–
Gross calorific value, Q^{daf}, MJ/kg	19.06	20.50	18.48
Ash composition, %:			
P_2O_5	8.68	–	–
SiO_2	54.04	–	–
Al_2O_3	1.99	–	–
CaO	8.66	–	–
MgO	6.11	–	–
Na_2O	0.15	–	–
K_2O	20.67	–	–
Ash melting behavior, ^{0}C:			
Initial deformation temperature, IDT	–	1232	–
Hemispherical temperature, HT	–	1500	–
Fluid temperature, FT	–	1500	–
Biochemical composition, %			
Cellulose	–	36.80	51.20
Hemicellulose	–	25.40	30.70
Lignin	–	16.90	14.40

Notation:
^{r} – fuel as received; ^{d} – dry matter; ^{daf} – dry and ash free basis.

The humidity of the different corn parts is not homogeneous and rapidly decreases after 120 days from the date of sowing (**Fig. 13**). Corn stalks are always wetter (W 35-45%), than grain (W 22-35%), but during the drying corn stalks are evaporated moisture intensively. Immediately after harvesting the stems humidity is in the range 45-60% (calorific value is 5.8 MJ/kg) [16]. But due to the proper technology, which creates conditions for biomass wind blowing, W is reducing to 30% during 10 hours in the field. [12] Also BPGC humidity is highly dependent on the time of collection

[16] https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis

and weather conditions, that's why heavy rainfalls during the harvesting can lead to irrationality of harvesting biomass for the production of solid biofuels.

Table 8. Chemical composition and some properties of different types of biomass [14]

Property	Yellow straw	Gray straw	Winter wheat straw	Corn stover*	Sunflower stover*	Wood chips
Moisture content, %	10-20	10-20	11.2	45-60 (after harvesting) 15-18 (dried in air)	60-70% (after harvesting) ~20 (dried in air)	40
Net calorific value, MJ/kg	14.4	15	14.96	16.7 (d.m.) 5-8 (W 45-60%) 15-17 (W 15-18%)	16 (W<16%)	10.4
Volatile matter, %	>70	>70	80.2	67	73	>70
Ash content, %	4	3	6.59	6-9	10-12	0.6-1.5
Elemental composition, %:						
Carbon	42	43	45.64	45.5	44.1	50
Hydrogen	5	5.2	5.97	5.5	5.0	6
Oxygen	37	38	41.36	41.5	39.4	43
Chlorine	0.75	0.2	0.392	0.2	0.7-0.8	0.02
Potassium (alkali metal)	1.18	0.22	–	cobs: 6.1 mg/kg d.m.	5.0	0.13-0.35
Nitrogen	0.35	0.41	0.37	0.69; 0.3	0.7	0.3
Sulphur	0.16	0.13	0.08	0.04	0.1	0.05
Ash melting behavior, °C	800-1000	950-1100	1150	1050-1200	800-1270	1000-1400

Notation:
d.m. – dry matter; W – moisture content.
* Data on the content of volatile matter, ash content, elemental composition – in % of d.m. mass

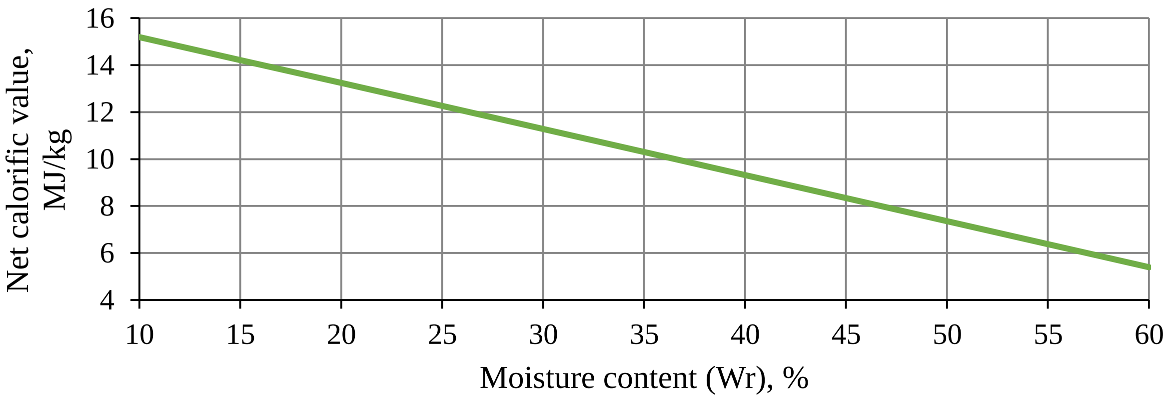


Fig. 12. Graph of net calorific value dependence from moisture content of corn stover.

Thus, BPGC harvesting for energy use should be done at a time when biomass moisture decreases to 20%, that is approximately 150 days from the date of sowing. The important factors to ensure the quality of biomass are properly selected technology and equipment. It is also necessary to coordinate the working plans of harvesting campaign with the weather forecast.

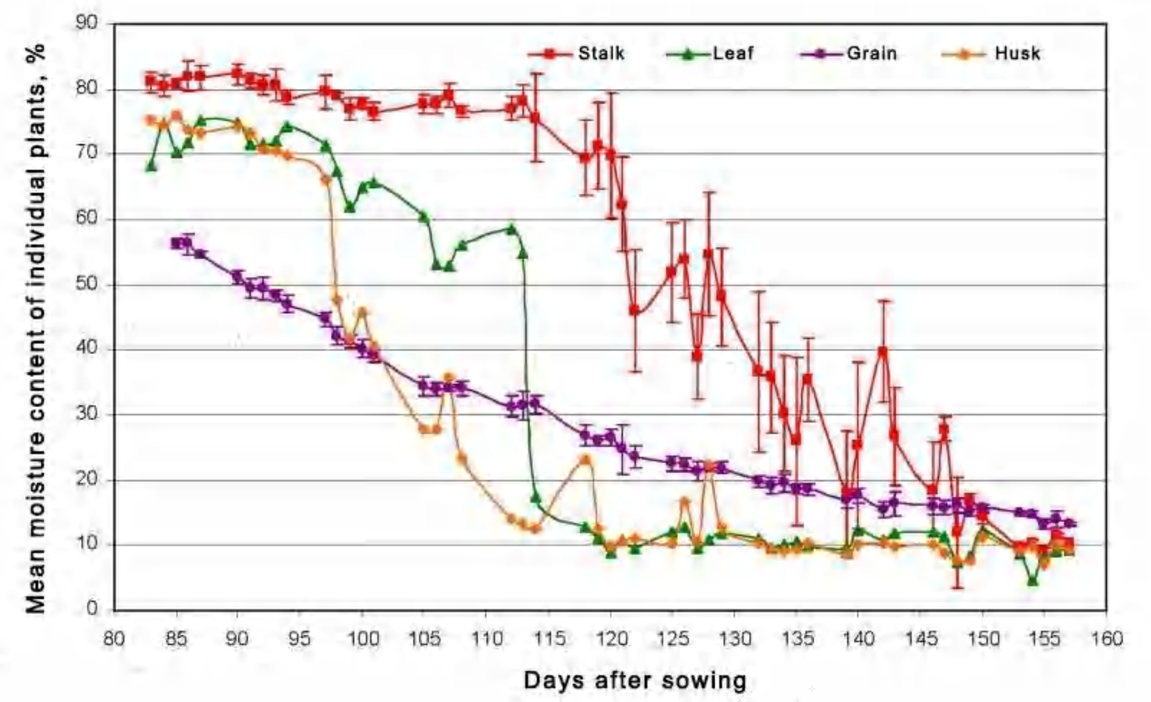


Fig. 13. Moisture distribution in overground part of a standing corn [17].

Studies [18] shows the possibility of successful bales of corn stalks burning in a Farm 2000 pot (UK) with a capacity of 176 kW (**Fig. 14**), that is intended for a bales of cereals straw. One of the differences was the formation of larger amounts of ash – 9.2% for corn stalks, against 2.6% for cereals straw. The average level of CO emissions by corn stalks burning was higher than by the cereals straw (2725 mg/m^3 to 2210 mg/m^3), and NO_x and SO_2 – is lower (mg/m^3): 9.8 against 40.4 and 2.1 against 3.7, respectively.

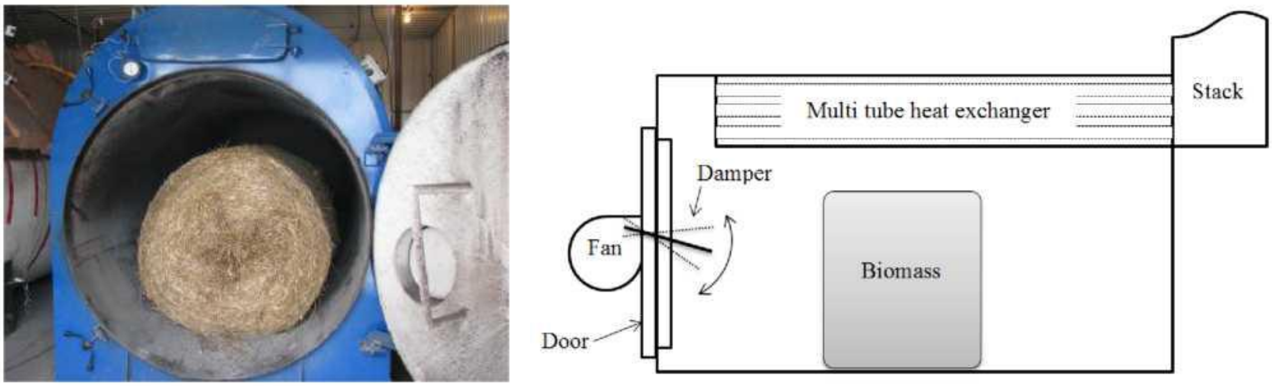


Fig. 14. General view of the Farm 2000 boiler [18].

Using a BPGC for energy in Ukraine has been introduced for a long time, but in a very limited amounts, mainly for heat energy producing for household needs, although BPGC has a significant source of a raw materials for large-scale development. In addition, it is necessary to determine the conditions under which it is possible to dispose by-products (BP) **with maintaining**

soil fertility and criterion for their evaluation. Ash from burning BPGC can be used as a fertilizer. National Academy of Agrarian Sciences of Ukraine has developed recommendation for agriculture about the use and applying a straw and stubble residues as an *organic fertilizer* [6, 30], while specialized recommendations of determination the possibility of alienation BPGC have not been developed yet. This is the reason why domestic agricultural producers determine directions to use the BPGC by themselves, which is often not rational, or burn it along with stubble on the fields, which causes significant environmental damage.

U.S. experience in harvesting biomass for bioethanol production from lignocellulosic raw materials

To assess the impact of the alienation of BP there are a lot of plant residues Managements. In particular, the protection of natural resources Service USDA published a White Paper "Crop Residue Removal for Biomass Energy Production: Effects on Soils and Recommendations " [19].

The document stipulated that specific guidelines for residue harvest need to be developed in an effort to prevent soil degradation resulting from over-harvest, among them:

- ***Soil Erosion.*** Surface residues protect soil from water and wind erosion. Residues also increase soil resistance to runoff events, unless soil infiltration is already impaired. Studies predict that up to 30% of surface residue can be removed from some No-till systems without increased erosion or runoff.
- ***Organic Matter and Nutrients.*** With added nitrogen fertilizers, residues can increase soil organic matter (SOM). However, roots appear to be the largest contributor to new SOM, making residues less important for carbon accrual. Residue removal leading to higher erosion and runoff rates would greatly decrease SOM and nutrients. Residue harvest would also require increased fertilizer inputs to make up for nutrients removed in the plant material.
- ***Beneficial and Deleterious Soil Organisms.*** Residue removal can result in detrimental changes in many biological soil quality indicators including soil carbon, microbial activity, fungal biomass and earthworm populations, indicating reduced soil function. Some disease-producing organisms are enhanced by residue removal, others by residue retention, depending on crop and region.
- ***Available Water and Drought Resistance.*** Residue cover can reduce evaporation from the soil surface, thereby conserving moisture and increasing the number of days a crop can survive in drought conditions. Improved soil physical properties related to crop residues, such as reduced bulk density and greater aggregate stability, also lead to better water infiltration and retention.
- ***Soil Temperature and Crop Yield.*** In colder climates, residues are linked to reduced yields due to lower soil temperatures resulting in poor germination. Stubble mulching, as opposed to residue chopping, can overcome this problem. Residue-associated yield reductions have also been found on poorly drained, fine–textured soils. Since these soils often have low erosion risk, residues might safely be removed.

Recommendations:

- ***Residue Removal Rates.*** Sustainable crop residue removal rates for biofuel production will vary by factors such as management, yield, and soil type. Tools like RUSLE, WEQ, and the Soil

Conditioning Index are likely to be the most practical ways to predict safe removal rates. Removal rates are not the same as percent soil cover: appropriate conversion is necessary and will vary by crop and region. While areas with low slopes and high yields may support residue harvest, in many areas the residue amounts required for maintaining soil quality will be higher than current soil cover practices.

- ***Additional Conservation Practices.*** Conservation practices such as contour cropping or conservation tillage must be used to compensate for the loss of erosion protection and SOM reductions seen with residue removal. In many regions, cover crops are another viable alternative.
- ***Periodic Monitoring and Assessment.*** Regardless of the residue removal practice chosen, fields should be carefully monitored for visual signs of erosion or crusting. Periodic checks of soil carbon as part of fertility testing are also recommended. Removal rates should be adjusted in response to adverse changes: if erosion increases or carbon decreases, removal rates must be reduced to maintain soil quality.

A study by American scientists [20] shows that the major limiting factor in calculation of amounts of BPGC removal is *a humus balance*, that must be constant, and that is characterized by amounts of organic carbon in the soil (**Fig. 15**). If continuous corn cultivation and with traditional tillage technology – should be leaved about 8.5 ton/ha corn straw; with conservation or No-till tillage technology – should be leaved about 6 ton/ha. If corn-soybean crop rotation with plowing – should be leaved about 14 ton/ha; with conservation or No-till – 8.75 ton/ha.

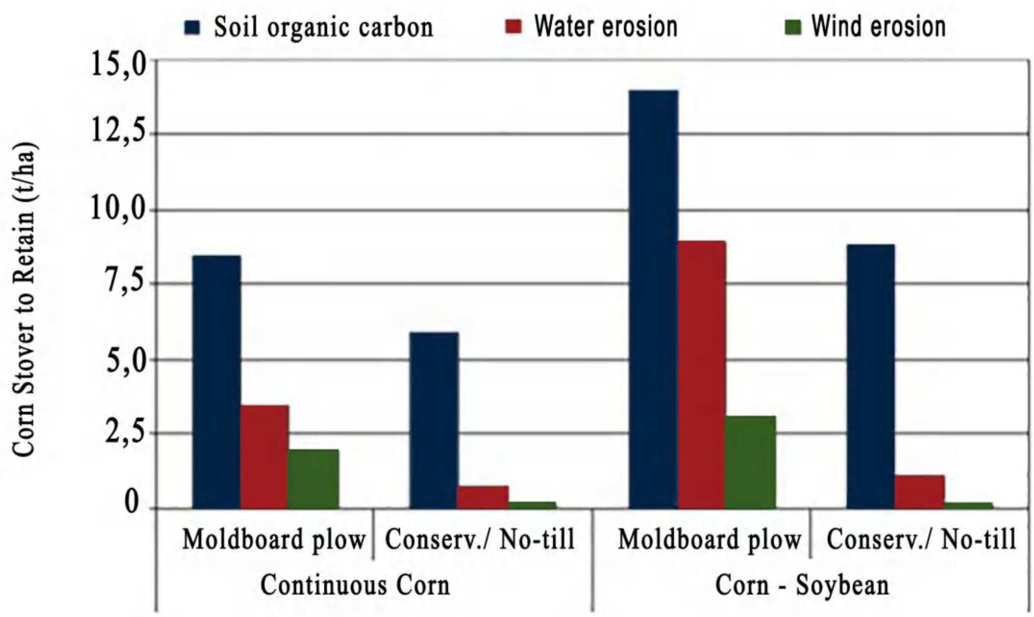


Fig. 15. Average amounts of corn residue needed to maintain soil organic carbon and manage water and wind erosion across multiple sites [20].

Practical experience of harvesting a significant amounts of BPGC gained in the USA by the DuPont company, which in October 30, 2015 in the Nevada city, Iowa state, has opened one of the first and largest advanced biorefineries in the world for the cellulosic ethanol production. [21] It is planned to produce more than 110 mln. liters of cellulosic ethanol per year (**Fig. 16**).

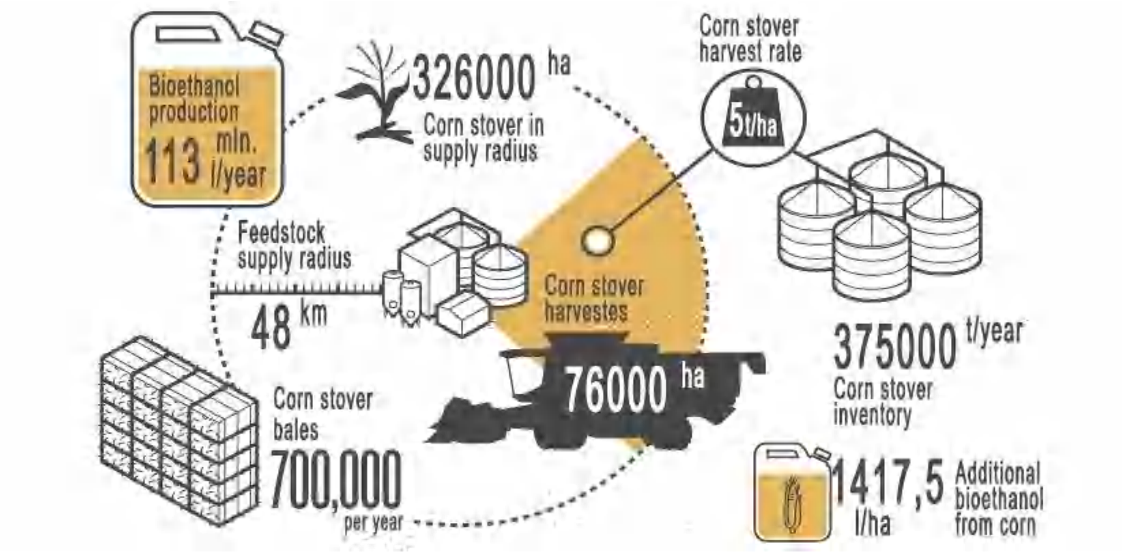


Fig. 16. Operation program of DuPont cellulosic bioethanol plant[17].

DuPont cellulosic ethanol plant pays growers for the permission to harvest corn stover and manage the costs on harvesting, storage and transportation. Growers get costs for giving access to the field and for the amounts of nutrients that are removed together with the BP. Corn stover is harvested from the 500 nearest farms. There are 85 permanent jobs at the plant, 150 individuals involved in collection, transportation and storage of seasonal feedstock collection.

Due to the DuPont cellulosic ethanol corn stover harvest program, DuPont is contracting with growers to harvest, store and deliver corn stover to the DuPont cellulosic ethanol plant in Nevada, Iowa. Qualified growers must meet the following criteria[18]:

- Located within a 48 km radius of Nevada, Iowa;
- Corn acres must be grown in a no-till or conservation tillage system;
- Yield of 12.2 tons per ha or higher;
- Relatively flat land (with a slope of 4% or less).

Higher corn yields have resulted in a higher level of residue, which can pose a challenge for growers. Excess residue harbors disease, interferes with planting, impedes stand establishment and monopolizes nitrogen. Removing a portion of corn stover from high-productivity fields before planting can improve establishment, growth and yield.

On-farm research in Iowa showed an additional 0.35 tons/ha on average for fields replanted to corn after partial stover harvest the preceding fall.

The amount of BPGC that can be sustainably harvested, due to DuPont's recommendations, depends on field characteristics, including productivity, soil type, slope, tillage practices and crop rotation. (**Table. 9**).

Table 9. Effects of yield level and crop rotation on quantity of corn stover available for continual harvest while maintaining soil organic carbon [20]

[17] http://www.dupont.com/products-and-services/industrial-biotechnology/advanced-biofuels/articles/nevada-cellulosic-ethanol-by-the-numbers.html

[18] http://www.dupont.com/products-and-services/industrial-biotechnology/advanced-biofuels/articles/nevada-corn-stover-harvest-program.html

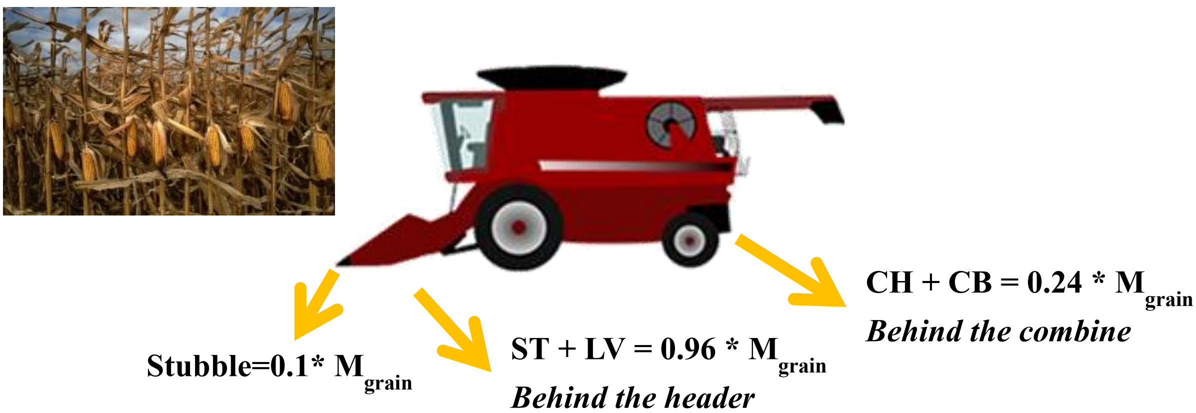
Grain yield	Stover production[1]	Stover available for harvest			
		Continuous corn[2]	Corn-Soybean[3]	Continuous corn[2]	Corn-Soybean[3]
t/ha	dry matter tons/ha			%	
9.4	8.6	3.0	0.0	34	0
10.0	9.4	3.7	0.7	39	8
10.7	9.9	4.2	1.2	43	13
11.3	10.6	4.9	2.0	47	19
11.9	11.1	5.4	2.5	49	22
12.5	11.6	5.9	3.0	51	26
13.2	12.3	6.7	3.7	54	30
13.8	12.8	7.2	4.2	56	33
14.4	13.3	7.7	4.7	57	35
15.1	14.1	8.4	5.4	60	39
15.7	14.6	8.9	5.9	61	41

Notation:

1. Based on harvest index IB=0,5 (IB = corn yield/{corn yield + stover yield});
2. Estimated 5.75 t/ha dry corn stover needed to maintain soil organic carbon under continuous corn with conservation or No-tillage;
3. Estimated 8.75 t/ha dry corn stover needed to maintain soil organic carbon under corn soybean rotation with conservation or No-tillage.

Harvesting of grain corn by-products

When harvesting corn with a combine harvester with corn header, plant residues redistributed as follows (**Fig. 17**): in the stubble, behind the header and behind combine harvester. The greatest amount of biomass of stalks and leaves is formed behind the header that in the wet is weight 0.96 of the grain mass.



ST – stalk, LV – leaves, CH – cornhusk, CB – cob, M_{grain} – mass of grain

Fig. 17. Directions and amount of formed corn residues of the combine harvester.

Technological harvesting operations generally involve: shredding, separation and compacting biomass. According to the methods of BPGC harvesting, *five* basic technologies (**Tab. 10**) can be classified. In addition, distributed after the combine harvester BPGC *can be baled*, but the low efficiency of residues matching (25-30% [22]) with the high cost of fuel as a result of baler going through an entire area of the field makes the method *economically unattractive*. By using a combination of core technologies can be provided a certain amount of biomass harvesting, which is difficult to achieve in the harvesting straw of cereals, soya and rapeseed, due to the fact that BPGC is concentrated behind the combine. The first four technologies compacted BPGC in rectangular or round bales rolls, and the fifth – harvested it in the crushed form. Depending on the final commodity production form of biomass, there are: harvesting technology, loading/unloading and transportation, and, accordingly, may be used different technical facilities.

For harvest maximum amounts of BPGC, shredders and rakes should be used. Shredders should allow plant residues crushing up to 40-70 mm and rakes should form the rolls. It should be noted that with increasing contact with the soil, biomass ash content increases (**Fig. 18).** To determine the list of necessary manufacturing operations and equipment it is also important to take into account losses and plant residues remains in the field.

According to the experience of BPGC harvesting in Hungary by the 4th technology (Combine + tractor with shredder + tractor with rake + tractor with baler) the best consolidation of such biomass is: with 24-30% moisture – into rolls; with 22 -30% – into bales. After shredding and compacting, in bales and rolls it is harvested only 35-50% of the dry weight of the plant. The most of the losses (about 66.6%) is from the biomass that remains in the field after rolls forming. [12]

Table 10. Classification of corn residues harvesting technology after combine harvester

<table>
<tr><th>№</th><th>Harvesting technology</th><th>Types of harvesting biomass</th><th>Collection / transportation to local storage *</th><th>Loading operation*</th><th>Transportation to central storage*</th></tr>
<tr><td>1</td><td>Single pass system: combine with baler</td><td>CH+CB</td><td rowspan="4">Tractor with pickup trailer (auto-stacker or loader + tractor with trailer (truck))</td><td rowspan="4">Telehandler (frontal loader or tractor with frontal loader)</td><td rowspan="4">Truck with trailer (truck with semi-trailer)</td></tr>
<tr><td>2</td><td>Combine with windrowing header + tractor with baler</td><td>CH+CB + ST+LV</td></tr>
<tr><td>3</td><td>Combine + tractor with flail windrower + tractor with baler</td><td>CH+CB + ST+LV + Stubble</td></tr>
<tr><td>4</td><td>Combine + tractor with shredder + tractor with rake + tractor with baler</td><td>CH+CB + ST+LV + Stubble</td></tr>
<tr><td>5</td><td>Combine with cob and cornhusk collection</td><td>CH+CB</td><td>Tractor with trailer</td><td>Loader</td><td>Truck with trailer</td></tr>
</table>

** The options are specified in brackets.*

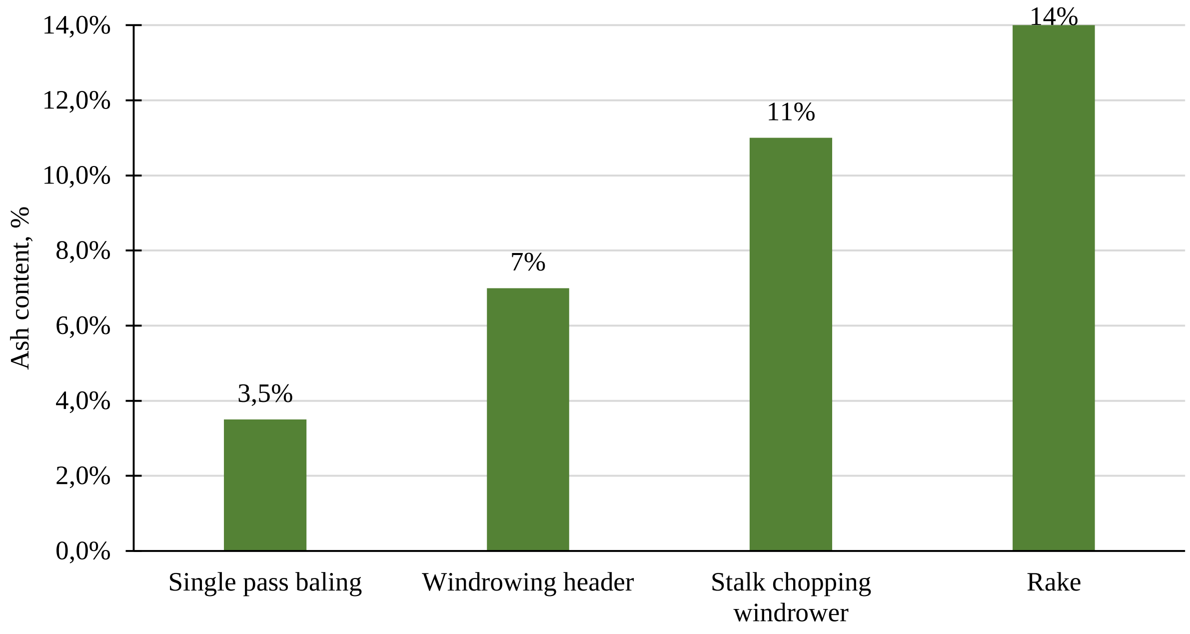


Fig. 18. Typical corn stover ash content by collection method.

Source: M.J. Darr Machinery Innovations to Meet Industrial Biomass Harvesting Demands in Expanding United States Markets – 71st International Conference on Agricultural Engineering LAND TECHNIK AgEng 2013 (November 8–9, 2013 Hannover, Germany)

Based on the estimated d.m. of BPGC harvesting efficiency [12, 22, 23, 24] it is defined plant residues losses per technological operations during the biomass harvesting **(Table 11)**.

Table 11. Estimated d.m. losses during various field operations

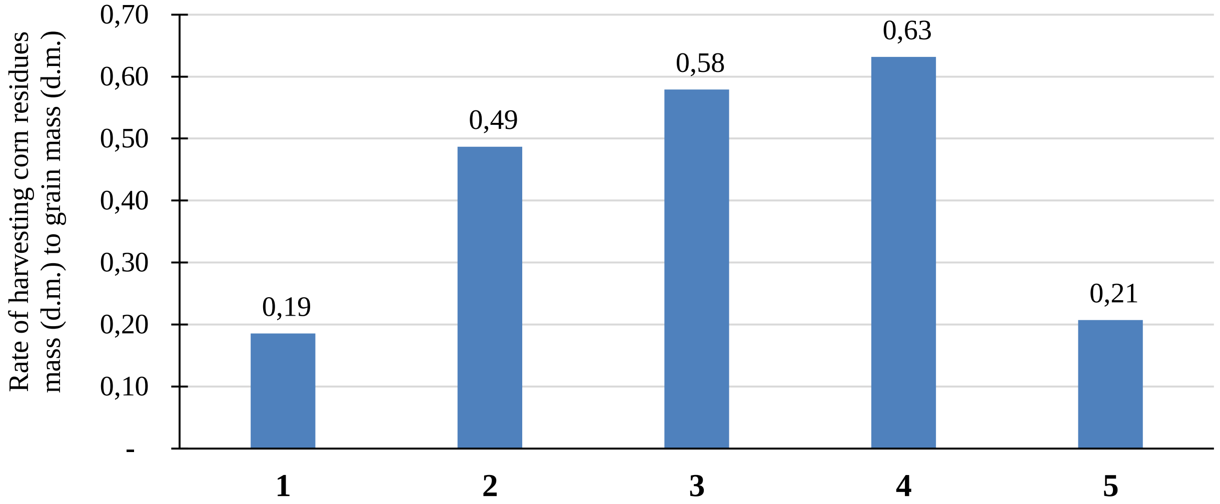
Technological operation	Maximum d.m. loss during machine operations and remains in the field, %
Corn header:	
- cutting	5
- chopping	5
- windrowing	5
Combine harvester:	
- threshing	3
- chopping and windrowing	10
Shredder:	
- chopping	5
- windrowing	10
Baler:	
- biomass pickup from ground	20
- biomass from combine	5
Rake	5
Pickup and stacking bales	2

To calculate the mass of d.m. in plant residues, a typical moisture value of dried in the field BPGC is being used (**Table 12**).

Table 12. Moisture content in corn residues [22]

Corn part	Moisture content, % (dried in field)
Grain	15
Cob	19
Cornhusk	24
Stover and leaves	33

So, based on assumptions about the volume of BPGC (**Fig. 17, Table 10**), humidity (**Tab. 12**) and possible losses (**Tab. 11**), we can determine the approximate amounts of biomass for each of the five core harvesting technologies that is shown in **Fig. 19**. Thus, when corn yield is 80 m.c./ha with 15% humidity, it is technically possible to prepare from 13 to 43 m.c./ha of BPGC, while the rest of the plant residues are remained on the field and are used as organic fertilizer. However it should be noted that these indicatives are value and depend on many factors, primarily on the parts ratio of the specific hybrid plant, the period of harvesting, biomass moisture, weather conditions, the characteristics of specific models of technical facilities, qualifications of machine operators, and so on.



1 – single pass system: combine with baler; 2 – combine with windrowing header + tractor with baler; 3 – combine + tractor with flail windrower + tractor with baler; 4 – combine + tractor with shredder + tractor with rake + tractor with baler; 5 – combine with cob and cornhusk collection

Fig. 19. Estimation ratio of corn residues harvesting mass (d.m.) to grain mass (d.m.) depending on harvesting technology.

Today, for BPGC industrial harvesting, special technical facilities are being used. Thus, in the harvesting and logistics systems include seven basic technological operations (**Fig. 20**). Corn is harvested by farmers, while other operations are carried out by DuPont custom crews.

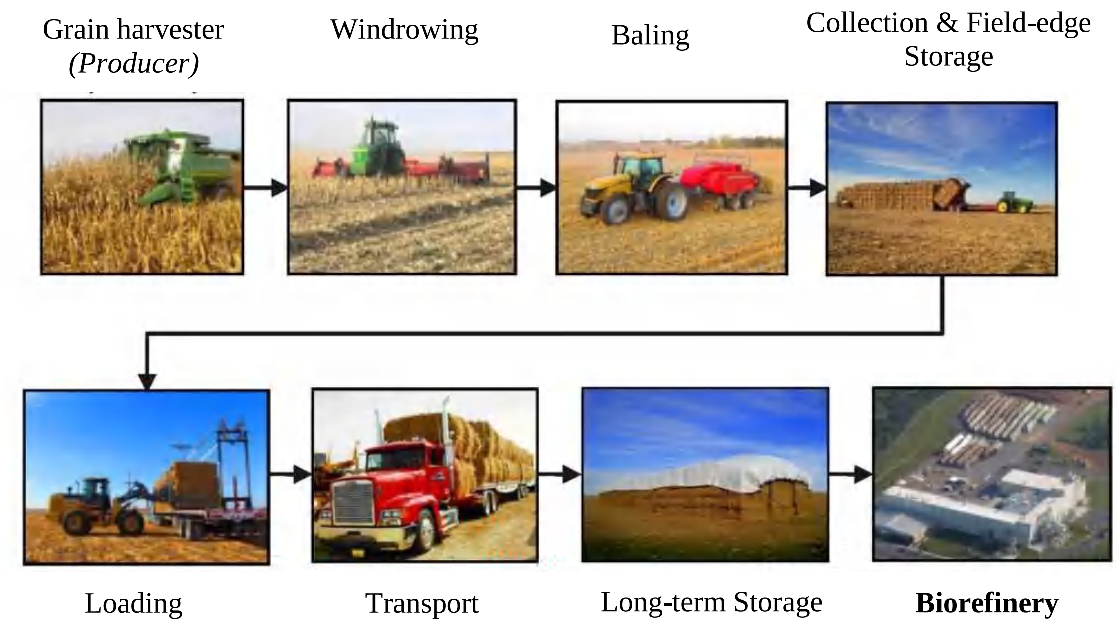


Fig. 20. DuPont's cellulosic ethanol plant corn stover supply chain model [25].

For *shredding and windrowing* of BPGC after grain harvester, shredders are used (**Fig. 21 a**). The USA company, Hiniker, produces for crop residues shredding and windrowing 5600 series machines with width of 15, 20 and 30 feet. To ensure high linear roll mass and reducing the number of machinery passes, Hiniker 5610 and 5620 are connected two passes in a single swath (**Fig. 21 b**). For shredder, with width of 30 feet, mount on a tractor with 200 hp engine power is required.

a) general view *б) usage*

Fig. 21. Machine for crop residues shredding and windrowing Hiniker 5620.

For BPGC *baling* large square baler is used (**Fig. 22 a**). By baling, biomass compacts from 51 kg/m^3 to 272 kg/m^3 [12], which significantly improves logistics efficiency and reduces logistics costs. Also round balers are widely used (**Fig. 22 b**). They are cheaper and they are needed less powerful tractor, but they are characterized by lower throughput compared to the large square baler. Also, round balers provide lower compaction density and need grid to be used, which is slightly more expensive compared with twine. It is therefore important to carefully analyze the costs while selecting a method of biomass baling. It should also be noted, that presses needed to be adapted to corn stalks baling because of the bigger faction size and strength compared to hay, cereals straw, canola and soybeans. It is necessary to consider the possibility of equipment working during adverse weather conditions.

a *b*

a – large square baler Massey Ferguson 2270XD;
б – round baler 605 Super M Cornstalk Special Baler

Fig. 22. Equipment for BPGC baling.

To prevent losses of dry matter and worsening of biomass quality, bales and rolls must be quickly taken off the field and put in pile for storage. For example, DuPont cellulosic ethanol plant for this purpose, uses special machinery and trailers which can be loaded and unloaded independently (**Fig. 23**). Stinger Stacker 6500 machine has an engine capacity of 305 hp, 6-speed automatic transmission and can, during 1 hour, – pick up, take out and put in a pile 80-120 large rectangular bales. Self-downloaded trailer 16K Plus Bale Runner collects in one pass 12 large bales with 1.2 m width and 0.9 m height and is mounted on a tractor with 180 hp power.

a *б*

a – truck Stinger Stacker 6500; b – large square bale picker/stacker 16K Plus Bale Runner

Fig. 23. Equipment for bales pickup and stacking.

Then, for truck operations in warehouses, frontal loaders and telehandlers are used. For transportation from the local to the central warehouse, cars-tractors with semitrailers platforms are used. Such equipment is traditionally used for logistic operations with bales of straw and hay. But bales from BPGC are generally have a higher moisture content and therefore are heavier compared to cereals straw and oilseed rape, so this should be considered when choosing machines for bales pickup and stacking. Considering the smaller volume efficiency of transportation and storage, logistics operations of the round bales compared to rectangular bales are more complex and more expensive.

Examined above equipment enables to harvest BPGC for DuPont cellulosic ethanol plant, but DuPont realizes only technology **№3** (combine + tractor with flail windrower + tractor with baler (**Tab. 10**). For other technologies the following equipment is being used.

To windrowing with corn straw, special reapers with windrowers are used (**Fig. 24**) in technology **№2** (**Tab. 10**). BPGC in bales can be drying and thus biomass fuel characteristics become better. Geringhoff Mais Star Collect reaper can shred and scatter the leaves and stalks of the corn or put them in the roll. On the top of this roll also can be entered shredded cob cores and cornhusks, that are formed after combine shredder. New Holland company produces devices – Cornrower, for forming rolls, that can be attached to corn harvesters. This technical solution has received a silver medal at Agritechnica 2013 exhibition. For windrowing the BPGC, except balers, sometimes are used self-propelled foragers and crushed biomass in the form of embankment are transported to livestock farms or biogas plants.

a

b

a – Geringhoff Mais Star Collect; b – New Holland's Cornrower

Fig. 24. Reapers with windrowing for corn harvesting.

Modern combine harvesters shred and scatter straw on the surface of the field. But sometimes when using combine harvesters with conventional reapers for corn harvesting, may be needed additional BPGC shredding. Then, the standard shredders are applied, mounted on a tractor that are also shredding stubble and scattering biomass on a field, according to the corn harvesting technology **№4** (**Tab. 10**). To windrowing, rake mounted on a tractor are used (**Fig. 25**). They can also geminate rolls. To work with corn stalks, rake must be equipped with stronger fingers compared to hay rake.

Examined above technology of BPGC harvesting are performed consistently and therefore are required some additional equipment passes through the field, that is compacting the soil. Therefore, in recent years, a new system of collecting biomass – single pass system, is introduced (technology **№1**, **Table 10**). In accordance to this technology baler is mounted on combine (**Fig. 26**). The square and round bales are formed from the plant matter (mostly cob cores and cornhusks), which went through shredding-separation combine system. Despite the numerical advantages, single pass system has a significant limitation – moisture of the biomass, under which the baler can perform baling. Considering less grain corn moisture compared to other parts of the plant, BPGC may be unsuitable for baling, while biomass in bales with favorable weather can be drying.

Fig. 25. Biomass windrowing with Vermeer VR2040 rake.

a

B

Fig. 26. Single pass system:

a – Hillco for round bales; b – AGCO Challenger for large square bales.

The BPGC harvesting technology **№5** (**Tab. 10**) involves the use of corn harvester combine with corn reapers and stalks and cornhusks harvester (**Fig. 27**). Then biomass is overloaded into a car or tractor trailer and is transported in embankment storage.

Fig. 27. Grain corn harvester with cobs harvester – COBS HARVESTER Lafargue Bio Energy.

Today in Ukraine can be implemented all five BPGC harvesting technologies, but now *single pass systems* with harvesters and balers in the domestic market of agricultural equipment ***are not provided.*** *S*talks and cornhusks harvesters, shredders and windrowing reapers ***are provided in a little quantities***. However, a lot of local households have already have agricultural technic, which allows to harvest the BPGC on a technology №4 (***combine + tractor with shredder + tractor with rake + tractor with baler*** (**Tab. 10**).

Pricing conditions in crop residues market in Ukraine

An important aspect of sustainable functioning of bioenergy, is pricing conditions in biomass market. For BP of biomass, there are several possible pricing options:

- the purchase price is determined by processing plant;
- price is determined by feeding value;
- price is determined by the cost of equivalent doses of mineral fertilizers to replace the nutrients in biomass, and by savings, by the agricultural producer, on technology operations during the plant residues management [26].

In Ukraine, the current price on BPGC is formed individually by agreement between the seller and the buyer. To ensure the sustainable crop development, when determining the base price, it is useful to take into account the cost of fertilizers for equivalent nutrients replacement in plants residues that alienated [14]. For example, in the **Table 13** is shown the results of the value calculation of d.m. of the BPGC, by the equivalent costs of fertilizers (simple and complex); also included the possibility of returning ash, which is a valuable potassium and phosphate fertilizer, to the field.

Table 13. Value calculation of d.m. of the by-products of grain corn

Nutrient	Nutrient content in corn residues (d.m.) [27], %	Nutrient cost in mineral fertilizers, UAH/kg	Nutrient cost in corn residues (d.m.), UAH/t	Nutrient content in ash[4,5], %	Nutrient cost in corn residues ash, UAH/t	Total cost (d.m.), UAH/t	
						without ash returning	with ash returning on field
Variant 1. Usage of simple fertilizers							
N	0.7	17.61[1]	132.07	–	–	–	–
P_2O_5	0.3	28.87[2]	86.62	4.88	71.29	86.62	15.32
K_2O	1.6	15.81[3]	259.23	11.84	94.70	259.23	164.53
ВСЬОГО			**477.91**		**165.99**	**345.85**	**179.85**
Variant 2. Usage of complex fertilizers							
1 д.р.	**2.69**	**21.25**[6]	**571.63**	**16.72**	**179.78**	**448.36**	**232.47**

Notation:
[1] – carbamide (N-46%);
[2] – double superphosphate (NP (S) 10:32 (20));
[3] – potassium chloride (K-62%);
[4] – chemical composition of straw ash, which was burned in boiler with moving grate (bottom ash)[19];
[5] – ash content in d.m. 5.06% (**Table 10**);
[6] – nitroamophoska (NPK 16:16:16).

It should be noted, that the content of nutrients in BPGC depends on many factors and can vary over a wide range. Thus, according to the work [17], it can be: 0.32-1.67% N, 0.045-0.36%

[19] http://www.ieabcc.nl

P_2O_5 and 0.54-1.45% K_2O. And, according to the research of Monsanto and ADM companies: the average N content is 0.73%, P_2O_5 – 0.24%; and K_2O – 0.82%, which is lower than the national directory data [27], that is used in the calculation (**Tab. 13**).

During estimation it is desirable to consider the types of fertilizers that are applied by agricultural producers. If using ordinary fertilizers (option 1: carbamide, double superphosphate and potassium chloride), the estimated value of nutrients in BPGC in January 2016 is 179.85 UAH/ton This is 22.5% less compared to the case of complex fertilizers (option 2: nitroamophoska) in which the value of nutrients in BPGC is 232.47 UAH/ton. Also it should be noted, that BPGC are decomposed for a long time, which slows the plants nutrients absorption. For 2.5-4 months straw is decomposed up to 46%; for 1.5-2 years – up to 80%, others – decomposed later. For faster BP decomposition additional doses of nitrogen fertilizers must be entered. When wrapping the straw into the soil it is recommended to enter to the soil 10-12 kg of active nitrogen ingredient per ton. [6] These doses of nitrogen exceeds the plant residues nitrogen content, that's why, in the generalized value of BP, according to recommendations [28], the content of nitrogen is not considered.

Graphic dependence of costs of BP from corn moisture content for both versions is shown in **Fig. 28**. With increasing humidity (W), dry matter weight of 1 ton of biomass reduces, and therefore its price reduces.

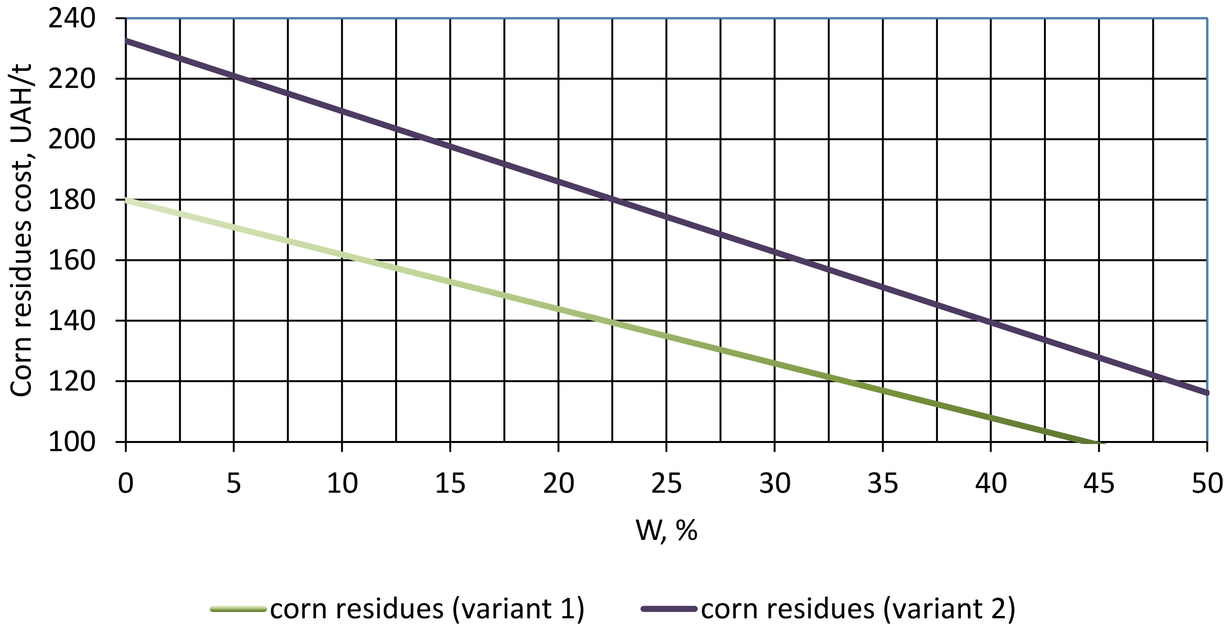


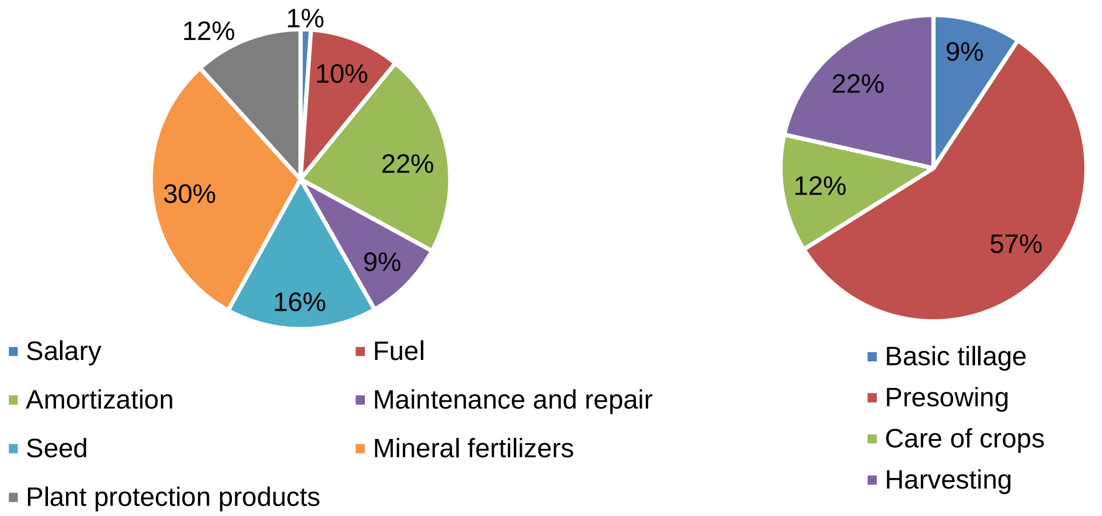
Fig. 28. Graph of dependence costs of corn residues from its moisture content.

Thus, when BPGC harvesting with 20% moisture, its estimated cost is: 143.88 UAH/ton – if fertilizers uses according to variant 1; 185.97 UAH/ton – for option 2. When the humidity is 30%: 125.90 and 162.73 UAH/ton, respectively.

Expenditures for growing and harvesting of grain corn

To estimate the costs, technology map of corn growing for agricultural enterprise in Kyiv region in the Forest-Steppe zone in 2015 is drafted. Primary data: 119 ha of sowing area; standards of mineral fertilizers: nitroamophoska – 200 kg/ha; ammonium nitrate – 200 kg/ha; organic fertilizers – 30 t/ha of cattle manure; plant protection products: Harness – 3 l/ha and Master – 0.15 kg/ha. Predecessor culture – soy. The main cultivation – plowing.

The structure of the cost per hectare by expense items with the planned corn yield of 70 m.c./ha is shown in **Fig. 29a**, and the structure by agricultural technological operation groups – in **Fig. 29b**. The most of the funds should be spent for the purchase of mineral fertilizers – 30% of total costs (by items). The main cultivation occupies 9% in the structure of the cost (by agricultural operations), and use of minimum tillage technology compared to traditional plowing can reduce the cost of corn on 2.6-4.5%.



a) **Total: 12393 UAH/ha** б)

Fig. 29. Structure of the cost per unit for corn growing by yield 70 m.c./ha:

a – by expense items; б – by technological operation groups.

Cost per unit and net profit (per ha) of corn growing, depending on the yield is shown in **Fig. 30**. Adopted purchase price of corn – 3180 UAH/ton. Thus, reducing grain yield from 70 to 40 m.c./ha reduces producer's revenue in the implementation of the main products from 9867 UAH/ha to 1338 UAH/ha. In 2015, preliminary data on the average yield of corn in the Kiev region is 60 m.c./ha[20], which corresponds to 54% profitability for the considered technological map.

Meanwhile, corn growing allows agricultural producers, beside selling basic products (grain), to receive additional income from selling by-products.

[20] http://latifundist.com/urojai

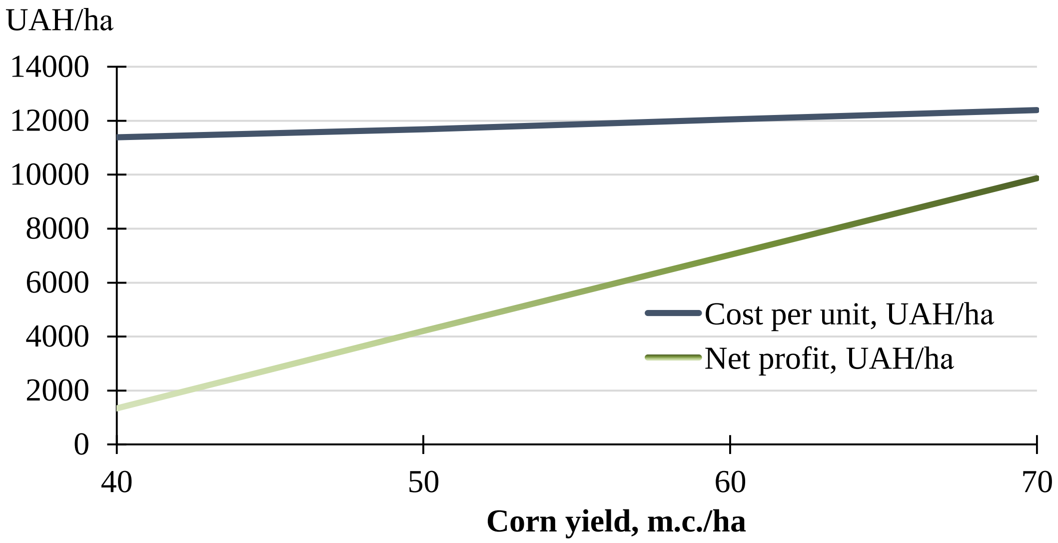


Fig. 30. Dependence of costs per unit and net profits for growing grain corn from yield.

Determining allowable share of corn residues alienation for Ukraine's conditions

In UABio Position Paper №7 «Prospects for the use of agricultural residues for energy production in Ukraine» the analysis of European countries practical experience for the share of plant agricultural residues, which are available for energy production, and studies carried out by Ukrainian specialists is shown [16]. According to this analysis, the following UABio position is created:

1. *The share* of straw and other crop residues that can be used for energy or biofuels production issue should be solved *independently* for every household. At the same time, all relevant agro-economic factors should be taken into account.

2. For Ukraine in general only *general* recommendations about the share of straw and other crop residues available for utilization as fuel, considering agricultural needs, can be offered: to *use* ***up to 30%*** *of the theoretical potential of cereal straw and* ***up to 40%*** *of the theoretical potential of waste from grain corn production and sunflower production.*

Consider in more detail differentiated approach for estimation the share of corn residues that can be alienated for energetic use on example of agricultural enterprise in Kiev region in the Forest-steppe area that is viewed above.

For sustainable agriculture development it is important to follow the nutrients return agrochemical law, according to which the nutrients that are alienated from the crops harvests should be returned to the soil. One of the major control measures is determining the balances of humus and nutrients in agriculture. This takes into account and compares the items of nutrients earning into soil and alienating them with harvest and also losses from soil. The calculations use components of these items, based on experimental reference data. Most items revenues include organic and mineral fertilizers, meliorant[21], crop residues, root, seed, biological nitrogen fixation, ingress of precipitation. Losses item formed by the harvest nutrients removal, erosion losses, leaching, weathering to the atmosphere [10, 29]. The calculation of the essential nutrients and humus balances carried out with methodological guidelines for the protection of soil [30].

[21] Meliorants are substances used for the improvement of the soil with unfavorable chemical and physical properties.

The calculation of the essential nutrients balance (N, P_2O_5, K_2O)

Items of nutrients supply

- with mineral fertilizers (Q_1):

The technological map of the farm is planned to use nitroamophoska (N16P16K16) – 200 kg/ha, ammonium nitrate (N34.4) – 200 kg/ha. Consequently, the supply of nutrients in kg a.m. ***N, P_2O_5, K_2O*** per hectare are:

$$Q_{1(N)} = 100.8 \text{ kg/ha},\ Q_{1(P2O5)} = 32 \text{ kg/ha},\ Q_{1(K2O)} = 32 \text{ kg/ha};$$

- with organic fertilizers (Q_2):

With an average nutrient content of manure ***N* – 0.5 %, *P_2O_5* – 0.25 %** and ***K_2O* – 0.6** %, spreading 30 t/ha manure of cattle provides ingress:

$$Q_{2(N)} = 150 \text{ kg/ha},\ Q_{2(P2O5)} = 75 \text{ kg/ha},\ Q_{2(K2O)} = 180 \text{ kg/ha};$$

- with precipitation (Q_3):

Conventionally count that in Forest-steppe through the rain comes *N* 10 kg/ha (**$Q_{3(N)}$ = 10 kg/ha**), and the value of revenues $Q_{3(P2O5)}$ and $Q_{3(K2O)}$ take into account if the data is present. We assume that near fields no industrial enterprises that emit the appropriate substances, and there are no data on the penetration of phosphorus in the soil with precipitation;

- with seed (Q_4):

At norm of seeding 24 kg/ha and average conten in the grain corn ***N* – 1.9 %. *P_2O_5* – 0.57 %** and ***K_2O* – 0.37 %.** supply of nutrients constitute:

$$Q_{4(N)} = 0.46 \text{ kg/ha}.\ Q_{4(P2O5)} = 0.14 \text{ kg/ha}.\ Q_{4(K2O)} = 0.09 \text{ kg/ha};$$

- symbiotic nitrogen fixation[22] (Q_5):

Whereas predecessor soybean belong to leguminous plants which are nitrogen retainer crops, for 1 m.c. primary products are fixed 2.5 kg *N*. Given that the average yield of soybean in was 21.9 m.c./ha Kyiv oblast in 2014, appropriate ingress of nitrogen is **$Q_{5(N)}$ = 55 кг/га**;

- non-symbiotic nitrogen fixation[23] (Q_6):

Conventionally considered that the absorption of atmospheric nitrogen and converting it into organic form by soil microorganisms in Forest-steppe is 10 kg *N*/ha (**$Q_{6(N)}$ = 10 kg/ha**).

<u>*The total ingress nitrogen, phosphorus and potassium are:*</u>

$$Q_{(N)} = Q_{1(N)} + Q_{2(N)} + Q_{3(N)} + Q_{4(N)} + Q_{5(N)} + Q_{6(N)} = 100.8+150+10+0.46+55+10 = 326.26 \text{ kg/ha};$$

$$Q_{(P2O5)} = Q_{1(P2O5)} + Q_{2(P2O5)} + Q_{4(P2O5)} = 32+75+0.14 = 107.14 \text{ kg/ha};$$

$$Q_{(K2O)} = Q_{1(K2O)} + Q_{2(K2O)} + Q_{4(K2O)} = 32+180+0.09 = 212.09 \text{ kg/ha}.$$

Items of nutrients losses

- with crops harvest (V_1):

In order to determine the losses of nutrients by crops we use average removal rate with corn harvest for 1 m.c. primary product and byproducts [30, table 2.2]. The calculation results depending on the yield given in **Table 14**.

[22] Symbiotic nitrogen fixation is absorption of atmospheric nitrogen by microorganisms that live in symbiosis with legume and some non-legume plants.

[23] Non-symbiotic nitrogen fixation is absorption of atmospheric nitrogen by free-living soil microorganisms.

Table 14. Removing of nutrients with primary product and byproducts of corn, kg

	On 1 m.c. of grain	**Corn yield, m.c./ha**						
		40	50	60	**70**	80	90	100
$V_{1(N)}$	2.41	96.4	120.5	144.6	***168.7***	192.8	216.9	241
$V_{1(P2O5)}$	0.86	34.4	43	51.6	***60.2***	68.8	77.4	86
$V_{1(K2O)}$	2.24	89.6	112	134.4	***156.8***	179.2	201.6	224

- with weeds (V_2):

Based on the fact that the cultivation of corn used intensive agricultural technologies, losses of nutrients from the removal of weeds are neglected;

- with irrigation water (V_3) nutrients are lost through leaching, but these losses are only on irrigated lands, so the calculations will not take them into account for conditions of Kiev oblast;

- due to erosion (V_4):

Average losses of nutrients on heavily eroded soils are:

$V_{4(N)}$ **= 18 kg/ha,** $V_{4(P2O5)}$ **= 5 kg/ha** та $V_{4(K2O)}$ **= 12 kg/ha**;

- through denitrification (V_5):

The losses of nitrogen through nitrification at norm more than 60 kg N/ha are 20%, so $V_{5(N)}$ **= 20.16 kg/ha**.

Total losses of nitrogen, phosphorus and potassium in the planned corn yield 70 m.c./ha are:

$V_{(N)} = V_{1(N)} + V_{4(N)} + V_{5(N)} = 168.7+18+20.16 = 206.86$ **kg/ha;**

$V_{(P2O5)} = V_{1(P2O5)} + V_{4(P2O5)} = 60.2+5 = 65.2$ **kg/ha;**

$V_{(K2O)} = V_{1(K2O)} + V_{4(K2O)} = 156.8 + 12 = 168.8$ **kg/ha.**

Thus, the calculated balances of nitrogen, phosphorus and potassium in planned corn yield of 70 m.c./ha are:

$B_{(N)} = Q_{(N)} - V_{(N)} = 326.26 - 206.86 = 119.4$ **kg/ha;**

$B_{(P2O5)} = Q_{(P2O5)} - V_{(P2O5)} = 107.14 - 65.2 = 41.94$ **kg/ha;**

$B_{(K2O)} = Q_{(K2O)} - V_{(K2O)} = 212.09 - 168.8 = 43.29$ **kg/ha.**

Positive balance of main nutrients indicates the possibility of alienation the part of by-products. Given the removal of nutrients are N – 0.69 kg/m.c., P_2O_5 – 0.21 kg/m.c., K_2O – 1.42 kg/m.c. with corn residues harvest, we determined the amount of biomass that can alienate provided that nutrients balances are deficit free:

- 119.4/0.69 = 173 m.c./ha;
- 41.94/0.21 = 200 m.c./ha;
- 43.29/1.42 = 30.5 m.c./ha.

So, for conditions can be considered it is allowed to take off **30.5 m.c./ha** corn residues, representing **33.5%** of the total mass of corn residues. Increase the share of corn residues alienation can be up to 100% by increasing the application rate of potash. The main items of nutrients ingress are application of mineral (15-31%) and organic (46-85%) fertilizers, and losses items are losses of nutrients by primary product and by-products of corn (82-93%).

Humus balance calculation

Calculation of humus takings

- humification of crops residues (***Q_1***):

Amount of formed humus in t/ha is calculated by formula:

$\boldsymbol{Q_1} = U \cdot k_p \cdot k_g = 7 \cdot 1.3 \cdot 0.2 =$ **1.82 t/ha**,

where U = 7 t/ha – corn yield;

k_p = 1.3 – coefficient of corn residues accumulation in reference to corn grain;

k_g = 0.2 – coefficient of corn residues humification in Forest-Steppe.

- humification of organic fertilizers (***Q_2***):

Given that the coefficient of bedding manure humification in Forest-steppe is 0.054, at the norm of manure 30 t/ha, the amount of humus, which is formed from manure is:

Q_2 = 0.054 · 30 = 1.62 t/ha.

The total ingress of humus is:

$Q = Q_1 + Q_2$ = 1.82 + 1.62 = 3.44 t/ha.

Calculation of humus losses

- humus mineralization (***V_1***):

The value of the humus mineralization (t/ha) is determined by the total amount of humus in the plow layer, the degree of its stability under different tillage systems and climatic conditions. The calculation formula is:

$\boldsymbol{V_1} = G \cdot h \cdot d_v \cdot k_M \cdot k_k = 3.2 \cdot 30 \cdot 1.1 \cdot 0.0108 \cdot 1.065 =$ **1.21 t/ha**,

where G = 3.2 % – humus content in the soil;

h = 30 cm – depth of plow layer;

d_v = 1.1 g/cm^3 – soil density;

k_m = 0.0108 – coefficient of humus mineralization;

k_k = 1.065 – the relative index of biological productivity.

- the humus losses from erosion (***V_2***):

Loss of humus due to erosion (t/ha) determined by the equation:

$\boldsymbol{V_2} = B_e \cdot \frac{G}{100} = 10 \cdot \frac{3.2}{100} =$ **0.32 t/ha**,

where B_e = 10 t/ha –humus losses under the influence of erosion in Forest-steppe at steep slopes to 2^0.

Total humus losses:

$V = V_1 + V_2$ = 1.21 + 0.32 = 1.53 t/ha.

Consequently. the humus balance is:

***Bg* = *Q* – *V* = 3.44 – 1.53 = 1.91 t/ha**.

Humus balance is *positive*, and considering that the humus loss less than its ingress from manure humification, it can be alienated of all corn residues under the planned corn yield of 70 m.c./ha. If *manure is not* applied, the loss of humus 1.53 t/ha should be exceed through the use of corn residues as organic fertilizers. In this case, it is necessary to leave 7.65 t/ha corn residues, representing 83% of their total mass. And it can be taken off, respectively, only ***17%***. For more accurate results should be calculated balances of nutrients and humus for the entire crop rotation.

It should be noted that in Ukraine in agriculture predominant crop production, and the amount of organic fertilizers, including manure, in recent years significantly *decreased*. Thus, according to the State Statistics Service of Ukraine in 2014 per hectare of sown area is applied 1.7 t/ha[24] of organic fertilizer in Kiev oblast, while in 1985 was applied 12 tons/ha [10]. Recommended norm for deficit free humus balance is 6-8 t manure per ha [30]. Many farmers do not apply manure, and humus stocks replenish only by the crop residues. As shown above, in this case, if the use of compensatory doses of mineral fertilizers on relatively flat fields with slopes up to 2^0, which is slightly eroded, that are necessary to leave 7.65 t/ha corn residues for the humus balance maintain and the remaining biomass can alienate.

When using conservation tillage or No-till, and erosion control actions, losses from erosion are significantly reduced near to zero. In the absence of humus losses from erosion **6.05 tons** of corn residues should be retained and used as organic fertilizer that will provide humus ingress 1.21 t/ha and **3.05 t** of corn residues can alienate (**33.5%**).

With the increase of corn yield increasing amount of corn residues for alienation in the considered agricultural enterprise (**Fig. 31**). Thus, if the organic fertilizers are used only crop residues, **40%** CR can pick from the fields with corn yield more than **80 m.c./ha** for conservation technology and No-till and **100 m.c./ha** while plowing.

According to the data of National scientific center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky"[25], actual humus balance in case the 0.4-0.5 t/ha of organic fertilizer per 1 hectare of cultivated area, which is observed in Ukraine in recent years, without making a crop of non-tradable harvest is **-1.22 t/ha**. In order to ensure non-deficit balance of humus it should be retained and used as organic fertilizer 6.1 t/ha corn residues, which is formed by the main production yield 47 m.c./ha. Thus, the corn yield 47 m.c./ha is the minimum to evaluate the alienation CR. With increasing corn yields amounts of by-products that can alienate for energy increased.

Thus, the factual average yield of corn in 2014 in Ukraine was 61,6 m.c./ha, so it was produced 8.0 t corn residues per ha. From this amount it can be alienated to the energy needs of **up to 24%**, which the whole country is *8891 kt* of biomass (about ***4 million tons of coal equivalent***). It is rough estimate because of significant deviations in yield, different rules applying fertilizers, agrotechnological techniques, economically grounded corn residues harvesting amount and other features in crop production.

Consequently, the share of corn residues to further alienation and energy usage is determined mainly by *yield*, but it is possible to *adjust* it by making reasonable standards of mineral and organic fertilizers and the application of appropriate agrotechnological actions.

[24] The Statistical Bulletin "Adding mineral and organic fertilizers to agricultural crop harvest in 2014" // K: State Statistics Service of Ukraine, 2015 – 52 p.
[25] http://www.bakertilly.ua/media/pdf/Biogas%20Institute.pdf

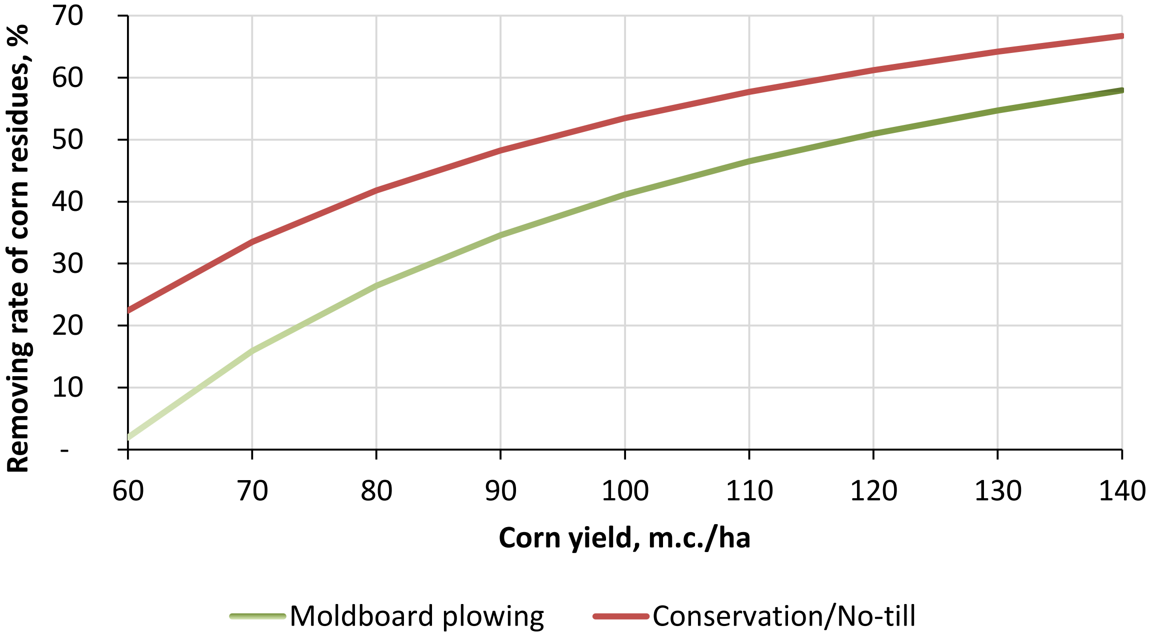


Fig. 31. Dependence of corn residues removing rate from corn yield in agricultural enterprise in Kyiv oblast (under using only plant residues as organic fertilizers)

Estimation of costs of harvesting grain corn by-products in Ukraine's conditions

The costs for BPGC harvesting are identified for technology **№4 *combine* + *tractor with shredder* + *tractor with rake* + *tractor with baler*** (see. **Table 10**), that can be implemented using the existing in the Ukrainian farms technique. In the calculations the research results of corn stover harvesting is applied, according to [12]. The list and the technical and economic characteristics of machines are given in **Table. 15**.

Table 15. Technical and economic characteristics of machines for corn residues harvesting [12]

Name	Operating characteristics	Unit	Machines of the technologies		
			Shredder	Rake	Baling
Variant 1			MTZ-82 + RZ 1.5	MTZ-82 + ПЗК 5	MTZ-82 + Claas Rollant 66
	Field performance	ha/hour	1.3	3.59	–
	Mass performance	t/hour piece/hour	– –	– –	10.0 21
	Fuel consumption	l/hour	13.6	10.09	16.09
Variant 2			Krone BIG M + Perfect	McCormick CX 90 XL + ПЗК 5	Atles 936 RZ + Claas Quadrant 2200 RC
	Field performance	ha/hour	4.09	3.59	–
	Mass performance	t/hour piece/hour	– –	– –	37 74
	Fuel consumption	l/hour	36.0	10.09	61.28

In *variant 1* corn yield is *9.0* t/ha with 24.2-27.6% moisture; in *variant 2* – 8.5 t/ha at 22-23% moisture. Has been achieved pressing density of round bale – 163.13 kg/m^3 with 25.8% biomass moisture (variant 1); in square bale – 266.42 kg/m^3 with 28.4% biomass moisture (variant 2). The average weight of round bale in variant 1is from 1.18 to 2.84 kg/m and in variant 2 – from 3.56 to 4.62 kg/m [12]. In the 1st variant 3.3 t/ha of BPGC is alienated with 26.7% moisture; in the 2nd variant – 7.1 t/ha with 28.7% moisture.

It should be noted that ready square/round bales under two variants are harvesting by telescopic handlers and are loaded in vehicles [31], that are transported biofuel to the storage on the distance up to 30 km. Unloading the vehicles and stacking square/round bales is also making by telescopic handlers.

Estimated cost structure of BPGC harvesting and logistic on storage facility is shown in **Fig. 31**. The most funds are spent on baling – 152 UAH/ton for round bales (32% of total expenditure, variant 1) and 186 UAH/ton for square bale (42%, variant 2). The total costs of compression, storage and transportation of biomass in variant 1 is ***472 UAH/ton***, in variant 2 – ***445 UAH/ton***.

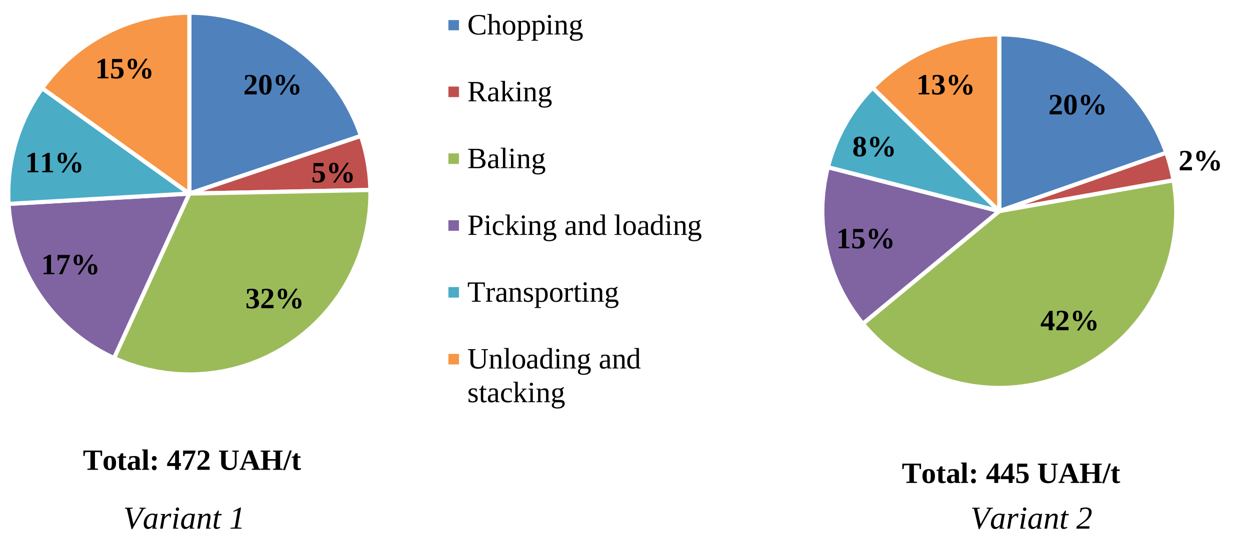


Fig. 32. Cost structure of BPGC harvesting and logistic on storage facility by the technological operation

Price of nutrients in biomass, using ordinary fertilizers with returning ash in the field, by the variants 1 and 2, respectively, is ***132 UAH/ton*** and ***128 UAH/ton***. Thus, with the addition costs for harvesting and transportation of BPGC, the **cost price** of biofuel in stock is ***604 UAH/ton*** with the calorific value of 12 MJ/kg (variant 1) and ***573 UAH/ton*** at 11.7 MJ/kg (variant 2). In the 1st variant energy cost of biofuel per unit is ***50.3 UAH/GJ***; in the 2nd variant – ***49.0 UAH/GJ***.

Recommendations for by-products of grain corn harvesting in Ukraine

Can be identified the following ***barriers*** to wide introduction of BPGC harvesting practice in the conditions of Ukraine:

1. the lower corn yield compared with the leading agricultural countries;
2. method of determining allowable share of corn residues alienation, which can be taken from the fields with ensuring the sustainable agricultural production, is not widely used;

3. the widespread use of traditional tillage;

4. climate change causes changes in agricultural technologies and the necessity of irrigation for providing sustainable high yields, that is connected with additional costs;

5. rainy weather during the harvesting period prevents BPGC harvesting;

6. there are no sustainable BPGC market. It is difficult for buyers and sellers to make an agreement on prices;

7. logistics infrastructure is not developed;

8. the low proposal of specialized machines for BPGC harvesting in Ukraine. Single imported machines are very expensive and do not have proper maintenance and spare parts;

9. row width in Ukraine is 70 cm, while in the USA – 76 cm (30 inches), which requires adaptation of American agricultural technology and agricultural machinery.

To ***address*** these barriers is considered necessary the implementation of the following measures:

1. study and adaptation the USA experience for Ukraine conditions;
2. distribution of information about modern technologies, equipment for harvesting and logistics of BPGC. Cooperation with agricultural machinery producing plants;
3. the creation of biomass fuel market;
4. the creation of specialized harvesting and logistics enterprises with mobile units.

Also it is important to provide the following ***practical*** approaches:

- BPGC harvesting should be done during dry weather – in autumn; during dry and freezing weather – in winter;
- to minimize the earth falling into the bales;
- equipment for the consecutive technology process are selected by the related capacity;
- forced working bodies of machines, that use corn stalk;
- the moisture of BPGC, that are going to be harvested should be up to 30%, and preferably – up to 20%;
- during the long storage in the local warehouse on the field stacked bales should be covered with a lamina or a special coating material;
- availability of roads access to the local warehouse for machinery;
- indoor central warehouse.

Implementation of BPGC harvesting after combine harvester can be based on the *available* agricultural machinery: shredder, rake and baler. When purchase *specialized* equipment, such as reaper with windrowing, shredder with windrowing, the need for additional equipment passes across the field decreases and the quality of biomass due to lower ash content improves.

To determine amounts of BPGC agricultural producers can use given in **Table 16** ***algorithm***. In general, BPGC are recommended to be harvested by agricultural producers, which are located in the Forest-Steppe or Polissya zone; use minimum tillage or No-till without organic fertilizers or any tillage technology with entering organic fertilizers; apply repeated growing corn on the same fields; have available shelterbelt forest; have high yields of corn – more than 80 m.c./ha. Other agricultural producers can alienate BPGC if: provided the balance of humus and nutrients; and prevent erosion and adversely effect on the characteristics of the soil.

Table 16. Procedure for determining of corn residues rate for alienation

Condition	Limitation	
	Min	**Max**
Agro-climatic zone	Forest-steppe, Polissya	Steppe
Crop rotation	continuous corn	After sunflower and sugar beet
Corn yield	more than 80 m.c./ha	less than 80 m.c./ha
Moisture	level of moisture in the root layer of soil more than 60%	less than 30 mm rainfall in a month
Erosion	slope of field surface less than 4^0, availability of forest belts	slope of field surface more than 4^0
Tillage technology	No-till, conservation	moldboard plow
Fertilizers	organic and mineral	only mineral
Humus balance	positive	negative
Weather condition during corn harvesting	dry weather	Strong rainfall

Conclusions

The production of corn in the world, by gross harvest (***1008.8 mln. tons in 2014/2015 MY***), occupies a leading position among other crops. Yield of corn is steadily growing due to the use of the latest achievements in agricultural science (e.g., in the USA in 2000 – ***on 2% annually***) and is currently 107.3 m.c./ha in 2014. In Ukraine the average yield is 61.6 m.c./ha in 2014 but it has significant increasing potential. It should be noted, that some Ukrainian householders through the use of modern hybrids and high developed agricultural technologies have already reached harvests on the leading countries' level.

Besides the main product – grain, corn generates significant amounts of by-products, which is a valuable raw material for the various types of products, including biofuels. ***Mass ratio of BPGC to grain is 1.3***. In 2014 in Ukraine the weight of BPGC was ***37 mln. tons***. Considering, that to provide a sustainable humus balance should be left and used as organic fertilizer ***6.1 ton/ha*** of the BPGC, that was formed with ***47 m.c./ha*** corn yields, in 2014 the ***24%*** of the BPGC could be alienated for energetic use. This is ***8.9 mln. tons of biomass***, that could replace **3.45 billion m^3** of natural gas. So, the ***47 m.c./ha*** corn yield ***is the minimum*** for evaluation the alienation of BPGC. With corn yields increasing, the amounts of BP, that can be alienated for energetic use grow as well.

There is the world experience of industrial BPGC harvesting. In the USA DuPont cellulosic ethanol plant (Nevada, Iowa) is capable to process ***375 kt of corn stover*** annually. The alienation is organized, according to the sustainable development principles, under the conditions and recommendations of the Natural Resources Protection Service of USDA.

When determining the amounts of BPGC harvesting, under the Ukrainian conditions, must be: taken into account the balance of humus and nutrients; avoided consequences such as erosion and soil deterioration.

In recent years, due to significant increase in prices for energy resources, farmers began providing the BPGC harvesting technologies based on the use of modern equipment, including high-performance balers. It is expected that the use volumes of BPGC in energetic sector will grow, considering that it has better fuel performance than cereal straw. In particular, ***by the indexes of the ash fusibility, corn straw is approaching to the wood biomass.***

BPGC for energetic use should be harvested in the period when biomass moisture is decreasing to 20%. It is necessary to coordinate the harvesting company plans with the weather forecast. Important factors for ensuring biomass quality are properly selected technology and equipment.

In accordance to recommendations provided in this position paper, the allowable share of BPGC alienation can be determined and the technology and equipment can be chosen.

REFERENCES

1. *D. Shpaara*. Corn. Growing, harvesting, conservation and use // К: LTD «Alpha-stevia», 2009 – 396 p.
2. *Tsykov V.S.* Corn: technology, hybrids, seeds // Dnepropetrovsk: Publisher «Zorya», 2003 – 296 p.
3. *Tsykov V.S., Matiukha L.A.* The intensive corn cultivation technology // М.: Agropromizdat, 1989 – 247 p.
4. *Cherenkov A.V., Tsykov V.S., Dziubetskyi B.V., Shevchenko M.S. and other.* The intensification of corn technologies – a guarantee for yield stabilization at 90-100 m.c./ha level (practical recommendations) // Dnepropetrovsk: NU Institute of Steppe zone agriculture NAASU, 2012 – 31 p.
5. *V.D. Hrechkosii, M.D. Dmytryshak, R.V. Shatrov and other*. Complex mechanization of grain production: Textbook // К: Ltd. "Nilan-Ltd", 2012 – 288 p.
6. *O.A. Demydov, A.T. Rudiuk, A.S. Zaryshiak and other.* The use of straw and crop residues as organic fertilizer for improving soil humus state (recommendations) // Kharkiv: "Miska drukarnia", 2012 – 38 p.
7. *V.M. Kabanets, M.H. Sobko, I.I. Dubovyk and other.* Technology of grain corn harvesting // Institute of north-east Agriculture, 2012 – 20 p.
8. *M.H. Tsekhmeistruk, N.M. Muzafarov, K.M. Manko.* Aspects of corn growing // Ahrobiznes sohodni, 2014 – vol. 8 (279) – 28-33 p.
9. *M.P. Kosolap, O.P. Krotinov.* The No-till tillage system. Teach. manual // К: "Logos", 2011 – 352 p.
10. *S.A. Baliuk, V.V. Medvediev and other*. National report on the state of soil fertility in Ukraine // К: 2010. – 112 p.
11. The method of generalized estimation of technically achievable energy potential of biomass. Agreed by chairman of the State Agency of Energy Efficiency and Energy Saving of Ukraine, 2013. http://www.journal.esco.co.ua/industry/2013_11/art225.pdf
12. *L. Kocsis, Z. Hudoba and T. Vojtela.* Investigation of the corn stalk gathering for energetic use www.tankonyvtar.hu/.../publikacio_67.pdf
13. *Brittany Schon, Matt Darr.* Corn Stover Ash. https://store.extension.iastate.edu/Product/Corn-Stover-Ash
14. *Tormosov R.Iu.* Bioenergy projects: from idea to implementation. Practical Manual // К.: LLC "Polygraph Plus", 2015 – 208 p.
15. *Vyll Varesa*. Handbook for biofuel consumer // Tallinn: Tallinn Technology University, 2005 – 183 p.
16. *Geletukha G.G., Zheliezna T.A.* Prospects for the use of agricultural residues for energy production in Ukraine. UABio’s Position Paper N 7, 2014 http://www.uabio.org/img/files/docs/Position-paper-UABIO-7-EN.pdf

17. *C. Igathinathane, Alvin R.Womac, Shahab Sokhansanj, Lester O.Pordesimo*. Vertical Mass and Moisture Distribution in in Standing Corn Stalks // 2004 ASAE/CSAE Annual International Meeting (Ottawa, Ontario, Canada, 1-4 August, 2004). – 20 p.
18. *R.Morissette, P. Savoie, J. Villeneuve.* Corn Stover and Wheat Straw Combustion in a 176-kW Boiler Adapted for Round Bales // Energies, 2013, 6. –5760-5774 p.
19. *Susan S. Andrews*. White paper. Crop Residue Removal for Biomass Energy Production: Effects on Soils and Recommendations // USDA-Natural Resource Conservation Service – February 22, 2006
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053255.pdf
20. *Mark Jeschke and Andy Heggenstaller.* Sustainable Corn Stover Harvest for Biofuel Production
http://www.dupont.com/content/dam/assets/products-and-services/industrial-biotechnology/documents/IB-PDF-01_Pioneer_Crop_Insights.pdf
21. http://energy.gov/eere/bioenergy/articles/largest-cellulosic-ethanol-plant-world-opens-october-30
22. *Ryan Milhollin, John Hoehne, Joe Horner and other*. Feasibility of Corn Stover in Missouri http://crops.missouri.edu/corn/CornStoverReport.pdf
23. *S. Sokhansanj, Anthony Turhollow, Erin Wilkerson.* Development of the integrated biomass supply analysis and logistics model (IBSAL) // Oak ridge National laboratory – ORML/TM – 2006/57, March 2008 – 49 p.
24. *Milan Martinov, Djordje Djatkov, Marko Golub, Miodrag Viskovic*. Harvestable biomass of corn, wheat, soybean and sunflower, experiences in Vojvodina (agricultural region of Serbia)
http://iet.jrc.ec.europa.eu/bf-ca/sites/bf-ca/files/files/documents/events/martinov.pdf
25. DuPont Nevada Site Cellulosic Ethanol Facility Feedstock Collection Program http://www.dupont.com/content/dam/dupont/products-and-services/industrial-biotechnology/documents/IB-PDF-04-Feedstock_Collection_Program_2015.pdf
26. *David Ertl*. Sustainable corn stover harvester
http://www.iowacorn.org/documents/filelibrary/research/research_reports/IowaCornResearchBrochureExtended_EBC92457EA83D.pdf
27. Fertilizers and their use: Handbook // K: Aristey, 2010 – 254 p.
28. Estimating a Value for Corn Stover
https://store.extension.iastate.edu/Product/Estimating-a-Value-for-Corn-Stover
29. *H.A. Holub, S.M. Kukharets*. Two models of soil environment humus state in agroecosystems // Science. Visn. NUBiP Ukraine. Avg. Technology and Energy AP – Vol. 212, part. 2, 2015 – 302-307 p.
30. *Hrekov V.O., Datsko L.V., Zhylkin V.A., Maistrenko M.I. and other*. Methodological guidance for soil protection // K: 2011 – 108 p.
31. *Geletukha G.G.* REA's Manual "Preparation and Implementation of projects on natural gas substitution with biomass in heat energy production in Ukraine" // K: «Polihraf plius», 2015 – 72 p. http://rea.org.ua/ru/usaid-mer/81-booklet-heat-production

Abbreviations

BP – by-products;

BPGC – by-products of grain corn;

CB – cob;

CCM – corn-cob mix;

CH – cornhusk;

CR – cob core;

d.m. – dry matter;

GR – grain;

hp – horsepower;

kt – thousand tonnes;

LV – leaves;

m.c. – metric centner (c =100 kg);

MOG – material other than grain;

MY – marketing year;

ST – stalk.

Previous publications by UABio

http://www.uabio.org/activity/uabio-analytics

1. *Position Paper N 1* (2012) “Position of bioenergy in the draft updated energy strategy of Ukraine till 2030”.
2. *Position Paper N 2* (2013) “Analysis of the Law of Ukraine “On amending the Law of Ukraine «On Electricity” No5485-VI of 20.11.2012”.
3. *Position Paper N 3* (2013) “Barriers to the development of bioenergy in Ukraine”.
4. *Position Paper N 4* (2013) “Prospects of biogas production and use in Ukraine”.
5. *Position Paper N 5* (2013) “Prospects for the electricity generation from biomass in Ukraine”
6. *Position Paper N 6* (2013) “Prospects for heat production from biomass in Ukraine”
7. *Position Paper N 7* (2014) “Prospects for the use of agricultural residues for energy production in Ukraine”.
8. *Position Paper N 8* (2014) “Energy and environmental analysis of bioenergy technologies”
9. *Position paper N 9* (2014) “State of the art and prospects for bioenergy development in Ukraine”
10. *Position paper N 10* (2014) “Prospects for the growing and use of energy crops in Ukraine”
11. *Position paper N 11* (2014) “Prospects of biomethane production and use in Ukraine”
12. *Position paper N 12* (2015) “Prospects for the development of bioenergy as an instrument for natural gas replacement in Ukraine”
13. *Position paper N 13* (2015) “Analysis of energy strategies of the EU and world countries and the role of renewables in their energy systems”.
14. *Position paper N 14* (2016) “Analysis of tariff setting in the district heating sector of EU countries”.
15. *Position paper N 15* (2016) “Analysis of additional sources of wood fuel in Ukraine”.

Civic union "Bioenergy Association of Ukraine" (UABio) was established to create a common platform for cooperation on bioenergy market in Ukraine, as well as to provide the most favorable business environment, accelerated and sustainable development of bioenergy. General constituent assembly of UABio was held on September, 25, 2012 in Kyiv. The Association was officially registered on 8 April 2013. Among UABio members there are over 10 leading companies and over 20 recognized experts working in the field of bioenergy.

http://uabio.org

UABIO
Bioenergy Association of Ukraine