Switchgrass Ukraine

Overview of switchgrass research and guidelines

Project Pellets for Power: Sustainable Biomass import from Ukraine

Sustainable Biomass Import Program – NL Agency – Netherlands

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Date of publication:	October 2013
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Content

Abstract

Between 2008 and 2013 switchgrass experiments have been conducted in Ukraine which have showed what varieties are locally adapted, how switchgrass can be established, what yields may be expected, what row space should be used, what seeding rate is optimal, etc.
At the moment (2013) the following data on switchgrass are available (see Figure A).

- 5-year experiments at Veselyi Podil Research Station experiment station
- 4-year experiments at Yaltushka Research Station
- 2-year experiments (on degraded lands) in Poltava.
- 1-year large scale commercial experiment (Lviv region).

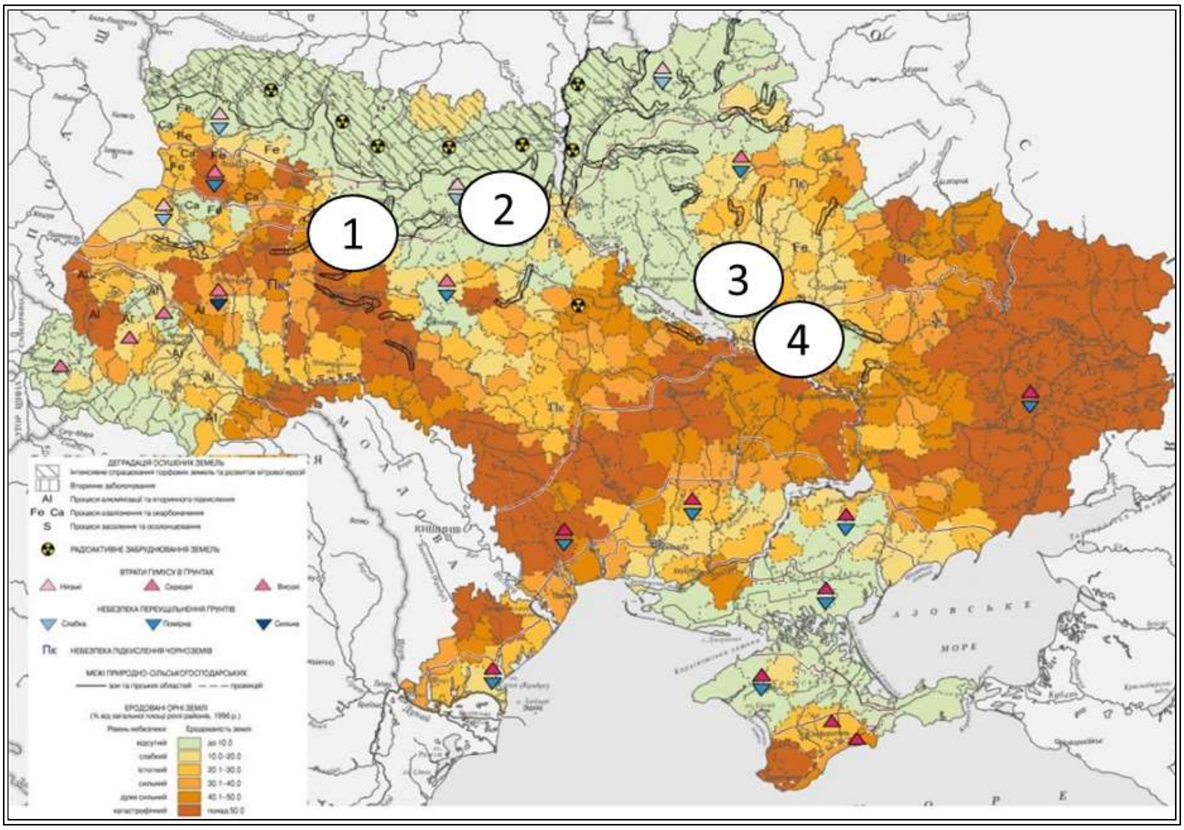

Figure A*. Map of Ukraine showing the locations of the 4 sites where switchgrass experiments have been conducted since 2008. 1)Lviv Branch, 2) Yaltushka Research Station (Vinnitsa oblast), 3) Veselyi Podil Research Station, 4) degraded soils experiments near Poltava.*

Switchgrass establishment is inexpensive because it is propagated by seed. Establishment is also difficult due to slow growth in spring, when weeds will outcompete switchgrass and risk of drought later in the season. Optimizing seedbed preparation, exact placement of the seed and using the right weed management will generally lead to a good switchgrass stand that should last for 15 years or more under good management practices.
Switchgrass takes 2 to 4 years to attain maximum yields. Small plot DM yields of up to 20 tons were measured. Long term data from large fields are still lacking. We made relatively conservative estimates for the expected average switchgrass yield based on extrapolations. Based on this we assumed an average yield of 7 tons DM on a low quality, marginal land that should be less or not suitable for arable cropping and which could be used without causing iLUC (indirect land use change). For good quality land we assumed an average yield of 12 tons DM when harvesting after a killing frost. Based on these preliminary yield estimates and the best available information on inputs, the cost of switchgrass delivery to a pellet plant was estimated at €52 per ton pellet under high productive conditions and €42 per ton

pellet under low productive conditions. We concluded that growing switchgrass iLUC free for this case would increase local delivery cost by 22%.
Assuming a cost of €33 per ton for pelletization and a cost for transport to a coal co-firing power plant in The Netherlands of €48 per ton this would give a (very preliminary) cost estimate of between €122 and €132 for switchgrass pellets delivered from Ukraine to The Netherlands. Based on the same data we estimate a GHG emission of between 9.0 and 12.0 g CO2-eq per MJ pellet delivered to The Netherlands (depending on the transportation mode; train, river, sea). For electricity production this would be equivalent to between 22.6 and 29.9 g CO2-eq per MJ electricity generated, assuming a conversion efficiency for pellets to electricity of 40%. Compared to the fossil fuel reference (coal) of 198 g CO2-eq per MJ electricity, the GHG savings of the entire chain would be 85 to 89%, which is above the 70% minimum GHG saving as required under the NTA 8080 certification system.
In the experiments over the past 5 years the Ukrainian experts have gained much experience in establishing switchgrass and in management of switchgrass. This has made it possible to make a description of switchgrass management in Ukraine and to establish with success large fields. Further information is still needed, especially with respect to efficient harvesting on a larger scale and storage and conversion into pellets and conversion to energy. Feedback from switchgrass users should help to optimize switchgrass management and harvest.
The option to produce switchgrass biomass on marginal lands (outside of competition with food) should require investigation into zoning options and related policies for Ukraine.

1 Introduction

1.1 Introduction

Switchgrass (*Panicum Virgatum* L.) is a warm season perennial herbaceous grass C_4 grass indigenous to North America and is found from Mexico into Canada but it does not occur naturally above the 55º N latitude. The plant has been developed as a model energy crop in North America and has also been introduced and studied in Europe for more than 15 years. The crop is propagated by seed and can therefore be established at low cost. It develops rhizomes and is also deep rooting, often more than 2 m deep. It grows 50 to 250 cm tall depending on variety and climatic conditions. It has the C4 photosynthetic pathway which leads to efficient use of nutrients (nitrogen, phosphate) and water. This makes it potentially a very productive and efficient biomass crop. Productivity will vary between 6 tonnes dry matter at low fertile up to more than 15 tons on fertile sites. In USA up to 25 tons DM have been measured. The grass has a high resistance to drought. If properly managed it has long-term productivity potential of more than 15 years.

As far as we know this report describes the first switchgrass experiments conducted in Ukraine with this crop. As demand for biomass increases in importance in Ukraine it is expected that switchgrass can play an important role in supplying sustainable lignocellulosic biomass. One of the main attractive features of switchgrass is its wide adaptation to different soils and its ability to be grown on "marginal" land which includes abandoned and/or eroded and/or polluted lands. The total area in Ukraine of this type of land has been estimated at over 15 million Ha.

***Figure 1**. Switchgrass varieties have been found that are adapted to Ukrainian conditions reaching more than 2 m in height at the end of the season.*

There are two main switchgrass types: lowland types that are found on wetter sites such as flood plains. They have tall, thick, coarse stems and bunch growth habit. The upland type is adapted to drier habitats. It has thinner stems than the lowland type and stem number is greater. Some have a turf -like growth habit.

Switchgrass is best compared to *Miscanthus*, another C_4 biomass grass that is widely used in Europe and also more recently in the USA) for biomass production (see Figure 2). Compared to *Miscanthus* (x *gigantheus*), switchgrass is smaller, thinner and generally leafier and should have a lower yield compared to *Miscanthus x gigantheus* when harvested in winter or early spring. As it is established from seed, establishment is less expensive and involves less risk than for *Miscanthus* (which is propagated by rhizomes). There are indications that switchgrass is more drought tolerant and should be more attractive under low fertility (low input) conditions. Note that in Ukraine there is little experience with growing Miscanthus and (long term) winter survival of *Miscanthus x gigantheus* is unproven.

***Figure 2.** Miscanthus (left) and switchgrass right. Miscanthus has not extensively been tested in Ukraine.*

1.2 Applications

In the USA switchgrass is used for erosion control and to provide forage under hot and dry conditions i summer. It is also used as an ornamental crop. In recent years switchgrass has been intensively studied in North America and more recently in Europe as a potential biomass crop for power production through direct combustion and possibly for lignocellulosic ethanol production. Other uses of switchgrass include fibre production, and wildlife habitat improvement.

This report focuses on switchgrass as a perennial crop for the production of biomass for thermal conversion. This means that the crop is harvested after a killing frost usually in winter or early spring in order to increase biomass quality (for thermal conversion) and reduce nutrient content. This type of management should also maximize stand persistence. If the crop would be used for forage or other purposes different management measures would be needed. The delayed harvest system for energy purposes, will reduce the content of Potassium (K) and Chloride (Cl) by up to 95%. These compounds greatly reduce the quality of biomass for thermal conversion as K lowers the ash melting point (resulting in slagging) and Cl will lead to corrosion problems in boilers.

This report presents an overview of the switchgrass experiments executed in Ukraine at different locations between 2008 and 2013 (Chapter 2) and it describes guidelines for growing switchgrass based on the experiments and on other (literature) sources and experiences (Chapter 3).

2 Switchgrass tests in Ukraine

Since 2008 switchgrass experiments have been established in Ukraine. First at the Veselyi Podil Research Station, and since 2009 – at the Yaltushka Research Station. In 2010 trials were established in Poltava on degraded soils in an abandoned quarry. In 2011 a large scale commercial switchgrass plot was established at Lviv at the Institute of Agricultural Techniques. The experiments have tested what varieties are best suited for Ukraine, yield potential of these varieties, optimal row spacing, optimal time of seeding, optimal weed control, optimal time of harvesting, etc.

At the moment (2013) the following data on switchgrass are available (see Figure 3 for the location of the sites):
- 5-year experiments at Veselyi Podil Research Station experiment station
- 4-year experiments at Yaltushka Research Station
- 2-year experiments (on degraded lands) in Poltava.
- 1-year large scale commercial experiment (Lviv region).

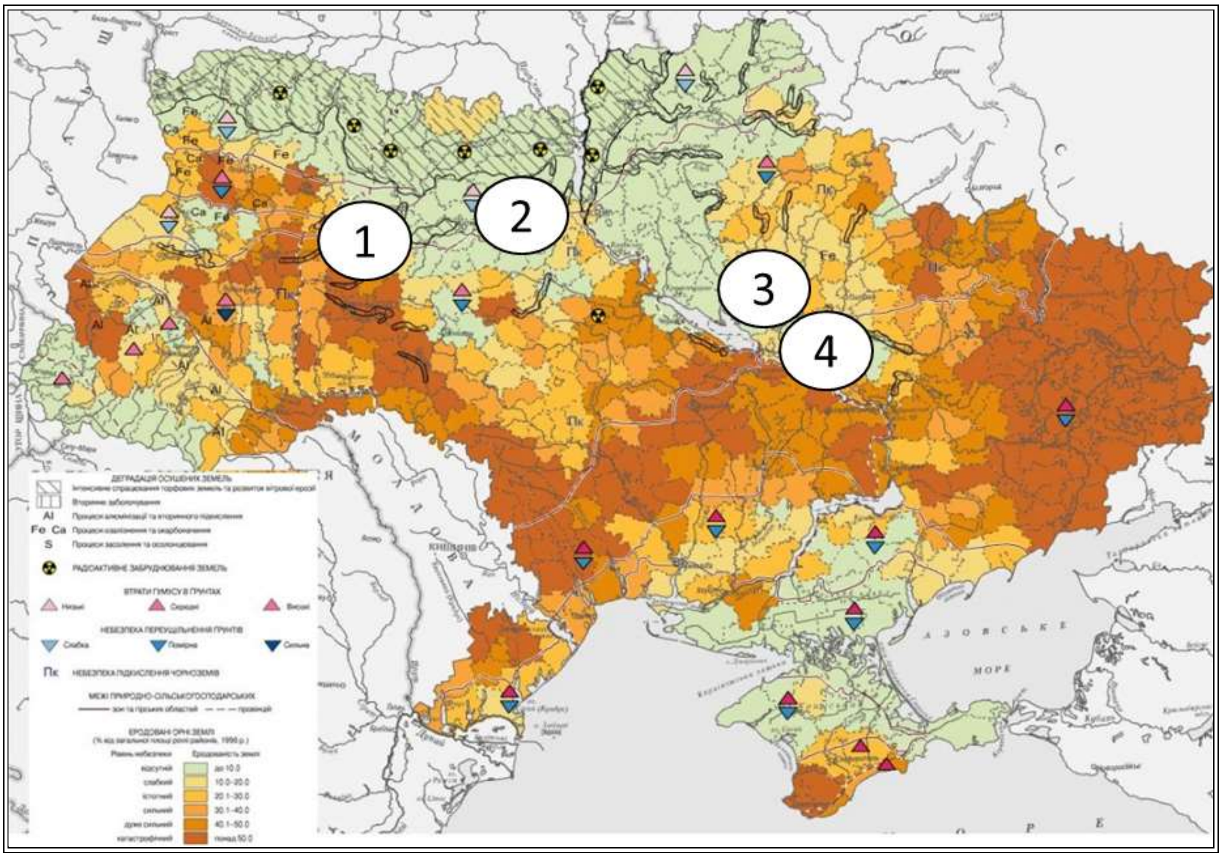

Figure 3*. Map of Ukraine showing the locations of the 4 sites where switchgrass experiments have been conducted since 2008. 1)Lviv Branch, 2) Yaltushka Research Station (Vinnitsa oblast), 3) Veselyi Podil Research Station, 4) degraded soils experiments near Poltava.*

The data and experience gained from the experience have been used to make a description of switchgrass crop production in Ukraine (See Chapter 3).

2.1 Veselyi Podil Research Station

The Veselyi Podil Research station is located in the black soil region and has an average precipitation of 584 mm evenly distributed over the year. Since 2008 a number of experiments were executed including:

1. The effect of seeding depth on switchgrass establishment and productivity (variety Cave-in-Rock).
2. The effect of seeding rate on establishment and productivity (varieties Cave-in-Rock and Shelter).
3. The effect of row spacing on biomass production (varieties Cave-in-Rock and Shelter).
4. Stand survival and yields of different varieties, 3 growing seasons (varieties Kanlow, Dacotah, Nebraska, Sunburst, Forestburg, Cave-in-Rock, Carthage).
5. Stand survival and yields of different varieties, 4 growing seasons (varieties Cave-in-Rock, Alamo, Shelter, Carthage, Forestburg, Kanlow, Sunburst, Nebraska, Dacotah).
6. The effect of seeding rate and row spacing on productivity of switchgrass, 3 growing seasons (varieties Cave-in-Rock and Shelter).
7. The effect of seedbed preparation on establishment and yield of switchgrass.

Dry matter yields and moisture content
Average yield of best varieties was 14.3 tons in fall and 10 tons in spring. This means that over winter 29% of yield was lost mainly due to loss of tops and leaves. Note that spring harvesting should also increase long time stand survival, increase biomass quality for thermal conversion and decrease nutrient losses. Highest yielding varieties were Cave-in-Rock, Carthage and Kanlow. Moisture content decreased from 22% in fall to 11% in early spring. Note that Kanlow shows reduced survival leading to stand loss (see Figure 4).

Row spacing
Row spacing of 15, 30 and 45 cm was tested. General a wider row spacing yielded more or the same as the narrower row spacing. Overall it seems that a row spacing of at least 30 cm is to be recommended. A wider row spacing should also reduce the cost of seed and may make weed management by tilling between the rows easier.

Winter Survival
In at least one occasion Kanlow and Alamo did not survive winter in the first year. It was also observed that long term stand survival is sometimes reduced for these varieties. This is explained by the later maturity of these varieties making them vulnerable to over wintering losses.

Figure 4*. Some varieties did not survive a harsh winter as shown here for Kanlow, a variety with a long growing season and high yield potential but also a large risk of overwintering losses as illustrated here (right picture).*

2.2 Yaltushka Research Station

The Yaltushka Research Station lies in the grey forest soil region. The average long term annual precipitation is 472 mm. A range of switchgrass test have been executed here to test:

1. Yield and winter survival of different switchgrass varieties
2. The effect of row spacing on biomass production
3. The effect of seedbed preparation on establishment and yield of switchgrass.
4. The use of a marker crop (mustard) to be able to better harrow between the rows in order to remove weeds.
5. The effect of seeding date on establishment and yields.

At Yaltushka similar results are obtained as in Veselyi Podil. The results indicate that wider row spacing should be favourable (see Figure 5).

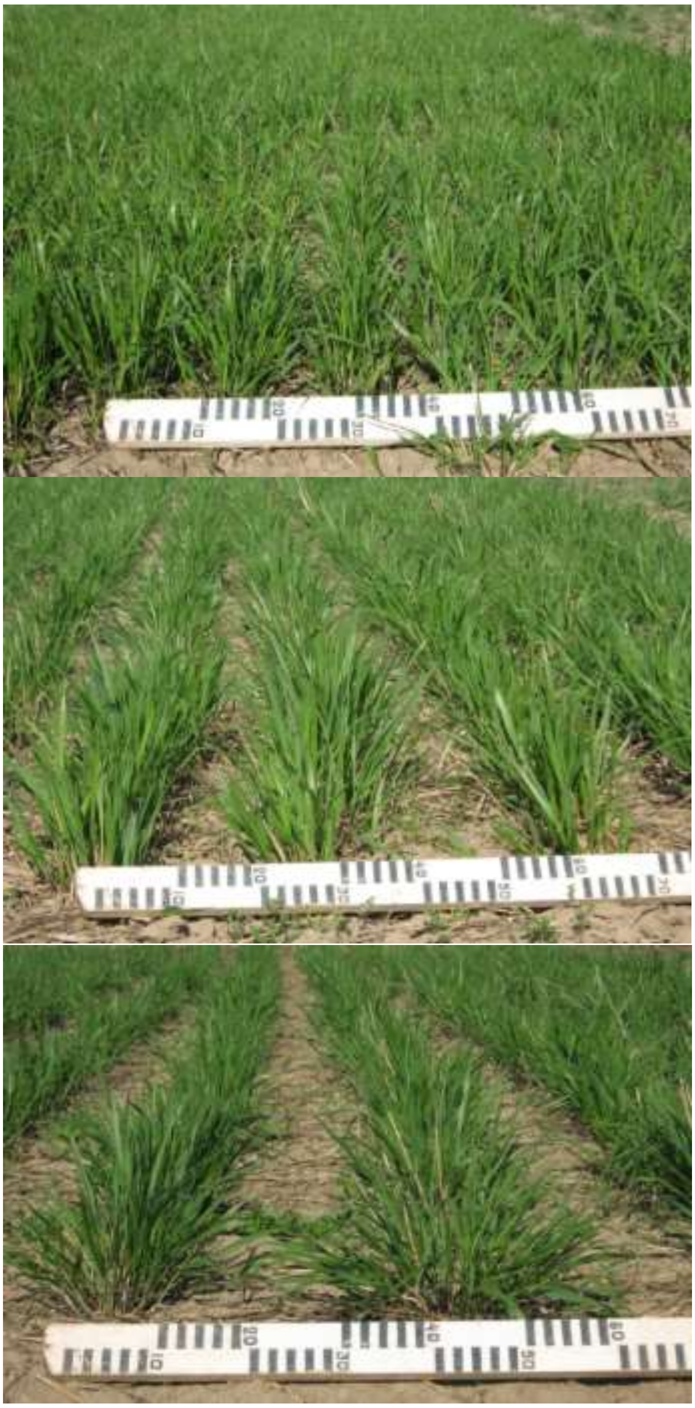

***Figure 5**. Switchgrass in spring at 15, 30 and 45cm spacing in Yaltushka.*

2.3 Poltava, degraded soils in an abandoned quarry.

The experiment was set up in 2011, it includes switchgrass varieties: Cave-in-Rock, Carthage, Forestburg. The varieties Alamo and Kanlow died during winter.
The 3 varieties were tested at 30 and 45 cm row spacing on degraded soils. Results are presented in Figure 6. Here too wider row spacing showed higher DM yields.

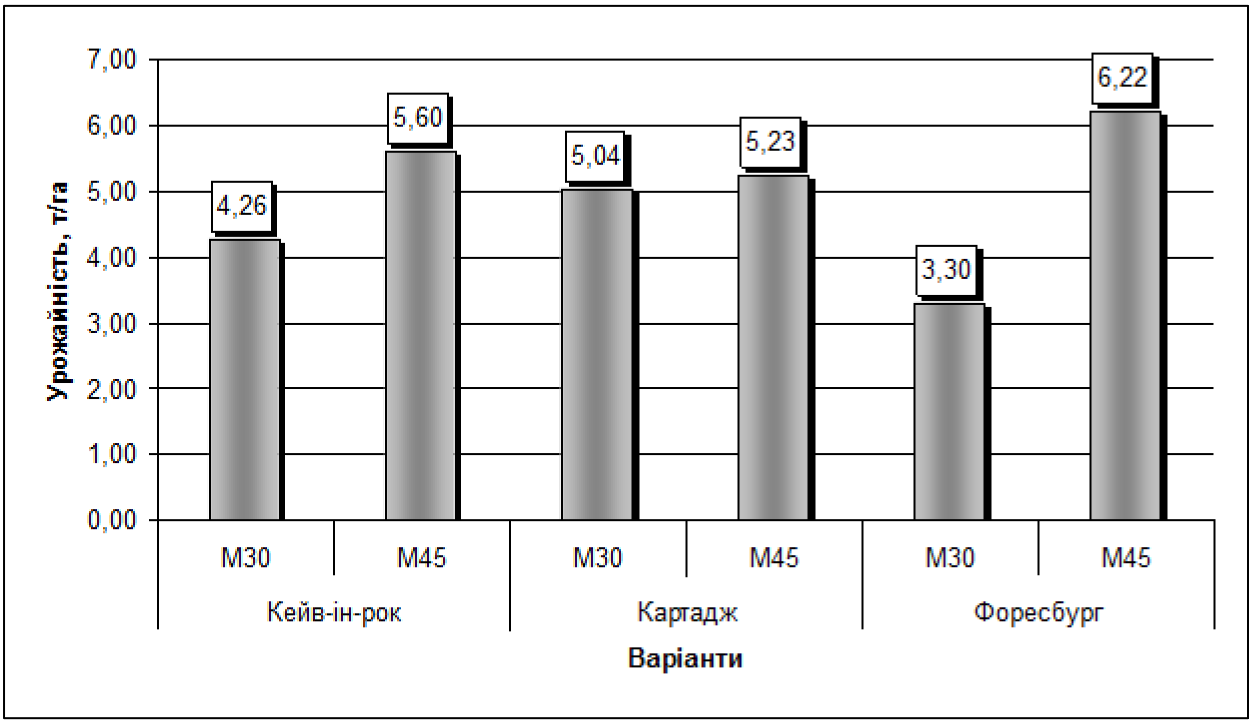

Figure 6. *Dry matter yield after one year of varieties Cave-in-Rock, Carthage and Forestburg grown at 30 and 45 cm row spacing.*

2.4 Lviv region, large scale commercial experiment

In 2012 3 ha of variety Cave-in-Rock and 2 ha of variety Carthage was established in the Lviv region. The lessons learned in the experiments were used to establish the fields successfully (Figure 7 and 8). Regrowth in 2013 will show if winter re-growth is also successful.

Figure 7*. 5 ha Switchgrass field established in 2012 in the Lviv region of Ukraine.*

Figure 8*. Switchgrass field on November 16 2012 in the Lviv region of Ukraine.*

3 Switchgrass management in Ukraine

3.1 Site selection

Switchgrass is adapted to a wide range of soils though deep soils that have good water holding capacity and adequate drainage are best for switchgrass. Shallow soils, stony soils and occasionally waterlogged soils are also suitable. When grown under low soil fertility and pH (acidity) amendments may be used to increase pH though benefits may be limited as switchgrass is quite resistant to low pH conditions.

3.2 Previous crop and site conditions

Sites with severe weed problems should be avoided. If this is not possible weed management should be started well in advance of planting. Spring and summer germinating weeds, especially perennial weeds can be a serious threat to switchgrass establishment. It is important to plan well ahead. Start weed elimination strategy in the year before planting. Control of perennial weeds will be better because any re-growth can be dealt with before switchgrass is sown. Take into account any specific requirements resulting from the previous crop for example, avoid leaving surface residues because it can interfere with sowing and prevent good seed to soil contact.
Switchgrass is slow to establish and it is important to follow basic guidelines that have proven successful in North America and Europe in more recently in Ukraine. It is important to eliminate perennial weeds in particular, since these are most difficult to control after the crop has been planted. Prior to cultivation, compacted may be sub-soiled. After ploughing, use any secondary cultivation necessary to produce a firm fine seedbed. It has been shown both in the USA and in Westerm Europe that no-till drilling is also possible (this has not been tested in Ukraine yet).

3.3 Soil fertility

Neutral pH status of the soil is ideal. Still, switchgrass is well adapted to low fertility and acid soil conditions. It has a large and deep root system that is very efficient in scavenging nutrients. Therefore soil samples should be taken from 0 to 150 cm at the start and at 2 or 3 year intervals. Fertility, especially N, should not be applied before seeding, as fertilisation in the first year benefits weeds more than switchgrass. Phosphorus (P) and potassium (K) should only be applied if soil availability is low. Switchgrass has been shown to utilise mycorrhizae for efficiently taking up of phosphorus.

When soils have a good supply of nutrients no nutrient response has been shown over many years in western Europe (UK and The Netherlands). Therefore it is recommended to only apply fertilisation if nutrients are deficient in the first year. In the following years it is recommended to apply nutrients at a rate that is equal to amount of nutrients removed with the biomass at harvest. This is also a requirement is most biomass sustainability certification systems that require that soil quality has to be maintained or improved. In case of nitrogen natural deposition of nitrogen may also be subtracted. In Ukraine natural deposition of nitrogen should be around 10 kg N per ha per year. Typical N content of delayed harvested biomass should be 5 g N/kg DM (±50%). At 10 tons DM yield and a typical N deposition of 10 kg N per ha per year, fertilisation should therefore be approximately 40 kg N per ha per year. P content of biomass should be expected to vary between 0,5 ad 1 g/kg DM. K content is much reduced during overwintering reaching form less than 1 to 3 g/kg DM. N fertilisation is generally applied yearly while P and K is generally applied every 3 years.

Keep in mind that high N applications may contribute to lodging. Lodging has been observed at several experimental sites and can reduce yield and increase moisture content of the biomass at harvest.

3.4 Variety choice

A number of varieties are available from North America that have been found to be adapted to Ukrainian conditions (see Figure 3 for a map of testing sites). The most important factor determining area of adaptation of switchgrass varieties is latitude of origin.
Varieties originating at southern latitudes will generally not survive winter in northern Ukraine. Varieties originating from northern latitudes (in North America) will survive winter easily but will not produce much biomass.
See Table 1 for an overview of (9) switchgrass varieties tested in Ukraine, their latitude of origin and the yields that were found at different experimental sites in Ukraine. Varieties Forestburg, Sunburst, Nebraska, Dacotah have a shorter growing season and show relatively lower yields. Carthage, Kanlow, Alamo, Cave-in-Rock and Shelter have higher yields. The most yielding varieties were Kanlow, Carthage and Cave-in-Rock. Still, Kanlow and certainly Alamo have shown, as may be expected, winter partial or even complete winterkilling. Cave-in-Rock may be the variety of first choice based on current results.

Table 1. List of switchgrass varieties tested in Ukraine including characteristics and main result of tests in Ukraine. Switchgrass yields were measured at the end of season, mostly after a killing frost.

	Origin	Latitude	Tested in the Ukraine*	Winter hardiness	Yield in ton DM per year			
					Year 2	Year 3	Year 4	Year 5
Dacotah	North Dakota	46,30	V	+	-	7,8	7,0	7,4
Nebraska	northern Nebraska	42,60	V	+	-	12,8	10,4	11,6
Sunburst	South Dakota	43,80	V	+	-	14,3	12,8	13,6
Forestburg	South Dakota	44,20	V	+	-	12,5	11,4	12,0
"			P	+	6,2	-	-	
Cave-in-Rock	southern Illinois	38,30	V	+	-	16,8	14,9	15,9
"			Y	+	-	17,0	12,8	-
"			P	+	5,6	-	-	
"			L	+	-			
Carthage	North Carolina	36.00	V	+	-	14,2	15,6	14,9
"			P	+	5,2	-	-	
Kanlow	central Oklahoma	34,80	V	+ / -	-	13,6	16,6	15,1
"			P	+ / -	3,1	-	-	
Alamo	south Texas	27,00	V	-	0	-	14,5	-
"			P	-	0	-	-	
Shelter	West Virginia	41,70	V	+	-	-	19,1	-

* note:
V - Veselyi Podil Research Station Locations: 49.616883, 33.24185 and 49.607519, 33.225682
Y - Yaltushka Research Station. Location: 48.999901, 27.452044
P - Poltava (degraded soils). Locations: 49.595507, 34.447551 and 49.626885, 34.174637
L - Lviv Branch. Location: 50.116478, 23.710492

3.5 Seeding and timing of seeding

Switchgrass should be sown in late spring in Ukraine. Fall seeding is sometimes used in North America but seems to be more problematic. As with maize (*Zea mays*), switchgrass needs high temperatures (> 15 C) to germinate and to grow. Time of seeding for switchgrass is therefore a compromise: Too early will lead to risk of frost damage, slow germination and growth, leading to more competition from fast growing weeds.
Sowing too late will lead to risk of drought and stand loss and may result in delayed plant development and plants that are not mature enough to survive winter. Therefore it is recommended to seed when soil temperatures of 10C and above can be expected and when soil is sufficiently moist, though not too wet. Dry seedbeds will result in poor or no germination and establishment failures. In general switchgrass should be established at the same time as maize (*Zea mays*). In Ukrainian tests late May or early June seeding has been successful (2008 and 2009) but also unsuccessful (in 2010) due to a severe drought.
Seed can be sown in a conventional manner with a drill or broadcast (see Figure 9).

***Figure 9**. Example of switchgrass seeding in Ukraine.*

Whatever method is used, rolling before and after sowing is essential for good germination to take place. This will ensure good seed to soil contact. Sowing depth should be about 10mm. No-till establishment has also been tested though with a lower success rate compared to seeding in a well prepared seedbed. Further research to develop this option may be needed.

3.6 Seeding rate and drilling equipment

Switchgrass seeds often have a high degree of dormancy. Germination rates of the seed can vary widely, from less than 5% to more than 90%. Seed germination rate is low just after harvest and may increase as the seed is aged. Dormancy breaking methods have been used but

In general it is recommended to seed at least 100 to 200 germinating seeds per m^2. To be able to predict the germination rate of switchgrass it is recommended to do a "sand box test" . This means that seeds are seeded at 1 cm depth in a box containing sand which is kept most. The box is kept at room temperature and monitored for 2 weeks for seedling emergence. After 1 week emergence may start. The germination rate (%) is used to calculate how many seeds have to be seeded per meter to reach a field germination rate of 200 per m2. If the sand box test shows that the germination rate is 70%, the number of seeds that have to be seeded is: 100/70 x 200 = 286. In general this means that the seeding rate will need to be between 6 kg and 15 kg seed/ha.

Switchgrass seeds are small, and have a hard polished skin. There are about 500-1000 seeds/g depending on the variety. If a cereal drill is used, it may require a small seeds roll to be fitted. The seed drill must be capable of sowing the seed evenly along the row. Optimal row spacing is generally larger for switchgrass grown for biomass than for switchgrass grown for forage. Literature shows that wider row spacing are optimal for biomass production. This has also been shown in Ukrainian (See example in Figure 10). A row spacing of 45 has shown to be best in tests in Ukraine. This wider row spacing will also allow mechanical weed control, which has been practised with success in Ukraine.

Figure 10. *Experiments in Ukraine show that wider row spacing of 30 and preferably 45 cm is best (Yaltushka, Ukraine)*

3.7 Weed control and pests and diseases

switchgrass growth is slow in the first year and seedling competition with weeds is always problematic. The goal of switchgrass management in the first year is to have a stand that is strong enough to survive the winter and re-grow in spring. In the first year weeds will always be a problem which has to be managed. When this can be achieved, generally no further weed control should be necessary in following years as switchgrass will out-compete weeds when temperatures increase in spring. Good and timely seedbed preparation, possibly preceded by a false seedbed, is necessary. Glyphosate can be applied before seedbed preparation to reduce weeds. Few tests on herbicide use have been conducted in Ukraine.
Mechanical weed control measures have been proven effective in switchgrass. Generally mowing of weeds just above switchgrass height is practised. In Ukraine harrowing in-between rows of young switchgrass plants has been practised with success (see Figure 11). If this is done in a time before weeds are too large no herbicides may even be needed. The use of mustard seed as a market crop to

distinguish the rows when harrowing between the rows to remove weeds has also been tested with success in Ukraine.

***Figure 11**. Interrow tillage on switchgrass is effective in weed management in the first year in Ukraine.*

To increase the chances of adequate establishment and re-growth after the first winter, glyphosate can be used to check weeds before switchgrass emerges. To check broadleaf weeds ioxynil, bromoxynil, mecoprop, bentazone, and CMPP have been used on switchgrass.
Some of the herbicides can cause scorching and check growth especially in young at early growth stages of switchgrass. Therefore it is advised to first test the herbicides on a few switchgrass plants/seedlings before applying them on a larger scale. Diseases have not been reported as a problem in any of the switchgrass experiments in Ukraine so far.

3.8 Yield development

Large scale switchgrass production (in a delayed harvest system) has only been started in 2012 in Ukraine, so research experience is still limited. Based on current research results we expect that switchgrass yields will vary between 7.7 ton DM matter on lower quality soils and up to 12 tons dry matter on good soils in a delayed harvest system. Results in Ukraine have shown that delayed harvest will reduce DM yields by almost 30% (for the 5 best varieties in a test). So fall yields could be almost 50% higher compared to early spring harvest, albeit with lower quality for thermal conversion and higher cost for fertilisation.
Yields may increase as better varieties and production methods are developed during the next decades. Maximum yield potential may be expected to take a few years to develop and is faster on light soils than on heavy soils. Yield in the first year is low and may not be economic to harvest at low yielding sites. In the second year yields 50 to 75% of potential may be reached. Early frosts or droughty conditions may delay the development of full yield potential.

3.9 Harvest

When switchgrass is produced for biomass (energy, fibre, etc.) delayed harvest in winter/early (March/April) spring is recommended. Harvesting the crop before senescence (in fall) will lead to lower winter survival and reduced spring re-growth, higher nutrient removal and possibly leading to stand loss over time. The harvest is executed using normal grass baling methods and equipment. If the crop is to be stored for a longer period the moisture content should not be above 15 to 20%. The rate of dry-down and the moment of re-growth determine the harvest window in winter/early spring. If the crop is not lodged, the crop has had time to senesce adequate moisture content reduction will be reached before spring. Test in Ukraine have shown that in fall moisture content of was reduced from 22% in fall harvesting to 11% when harvested in early spring. This would mean that fall harvested switchgrass would have to be dried before it could be stored.

3.10 Seed production

As explained above the best variety for a given latitude is a variety that will have a long vegetative growing period, to maximise biomass accumulation. At the same time the variety will have to mature early enough to winter harden (and translocate nutrients to belowground organs) to survive winter and be able to re-grow in winter. In a normal year a variety that provides the best compromise between yield and winter survival will not produce much viable seeds in Ukraine. If seeds production is required the varieties will have to be grown further south where the growing season is long enough for all the plants to produce ripe seeds.

3.11 Production cost

Large scale plantings have only been stared in 2012 and should yield much specific information of switchgrass production cost under practical conditions. In the Pellets for Power project the production cost for switchgrass (up to delivery to the pelleting plant) has been estimated for Ukraine for low productive conditions and under high productive conditions (see Table 2 for details on the location and Poppens et al. 2013 for details on the analysis). Land rents were assumed €20 and €40 per ha per year, for low and for high quality land respectively. Interest rates were not taken into account.

Table 2. Comparison of high and low productive switchgrass sites in Ukraine

Characteristic	High productive Veselyi Podil	Lower productive Yaltushkiv
Climate	Cool dry	Cool dry
Topography	Flat	Rolling
Land degradation	Few saline soils	Acid soils
Soil type	Chernozems	Phaeozems
SOC_{REF} stock (ton C/ha)	117 ton C/ha	86 ton C/ha
Unused / abandoned land	~2%	~25%
Switchgrass yield	12 ton DM/ha	7 ton DM/ha
Avg. distance to pelletizer	7.1 km	13.2 km

The results are shown in Figure 12. The cost of switchgrass delivery to the pellet plant was estimated at €52 per ton pellet under low productive conditions and €42 per ton pellet under high productive conditions. This implies that the economic cost of switchgrass biomass delivery from low productive land is 22% higher. The difference in cost was mainly due to higher cost of field operations per ton switchgrass of €6.81 for the low productive conditions versus €3.97 for the high productive conditions. Also the transport cost was 44% higher for the chain based on low productive (often previously unused) land. The cost for pelletisation for both chains is estimated at €33 per ton pellet.

The cost for transport to a co-firing power plant in The Netherlands was estimated at €48 per ton. The overall delivery cost is estimated at €133 per ton pellets for switchgrass pellets from low productive land, versus €123 per ton pellet for system based on growing switchgrass on good land. These cost are comparable to current wood pellet prices.

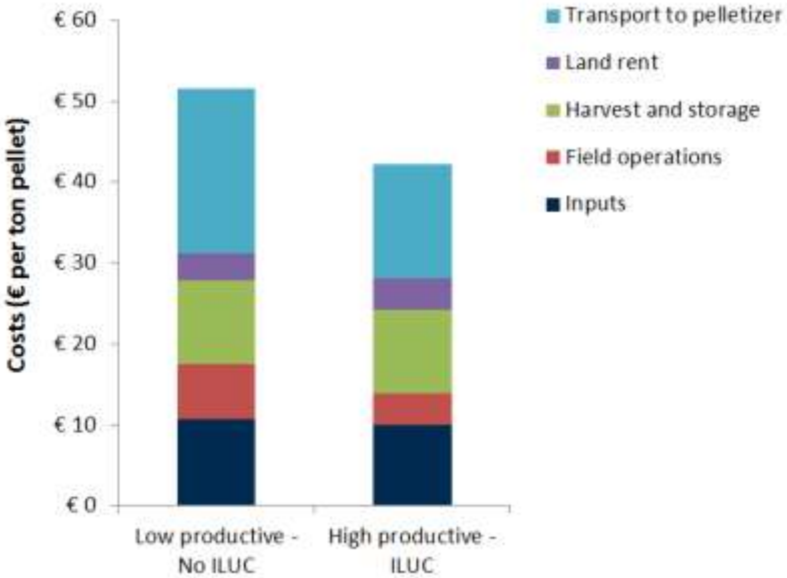

Figure 12. *Delivery cost of switchgrass under low productive conditions and under high productive conditions.*

3.12 Environmental and Green House Gas impact

Switchgrass environmental impacts and potential for certification under the bioenergy standard NTA8080 has been analysed in the Pellets for Power project (Poppens et al, 2013; Poppens and Hoekstra, 2013). Due to the low inputs switchgrass is very likely to have favourable environmental impact in water quality, erosion, emissions, etc. when compared to rotation crops.

As switchgrass is grown for bioenergy a positive GHG balance compared to the fossil fuel that it replaces is very important.
The GHG emissions were calculated for 4 scenario's:

1. Domestic use of the switchgrass pellets for heat generation with an average transport distance of 30 km by truck.
2. Transport via train and vessel to the Netherlands and co-firing in a coal plant
3. Transport via train and river barge to the Netherlands and co-firing in a coal plant
4. Transport via truck to the Netherlands and co-firing in a coal plant

The balance was calculated and a comparison was made between using coal to fire an electricity plant in the Netherlands and using switchgrass pellets grown in Ukraine or using switchgrass for heating in Ukraine (for details see Poppens et al., 2013).

The results are presented in Figure 13. The largest emissions are due to the processing, as the pelletizing process requires relatively large electricity inputs, in addition electricity use in Ukraine has a high CO_2 emission due to the large scale use of fossil coal. For the export scenario's (2,3,4) the emissions from transport are also large, which is not unexpected, considering the large distance.

Transport via train and sea vessel (scenario 2) is most GHG efficient, although the differences between the export scenarios are relatively small. It was assumed that return transport can be assigned to other products. Emissions from field operations are low due to the perennial nature of the crop. Relatively high emissions only occur in the first year due to field preparation, and is averaged out over the 15 years of the total crop life. GHG emissions from inputs are higher, mainly due to N_2O soil emissions and emissions from fertilizer production. However, compared to other agricultural energy crops the inputs are low, since switchgrass is a perennial crop with low nutrient requirements.

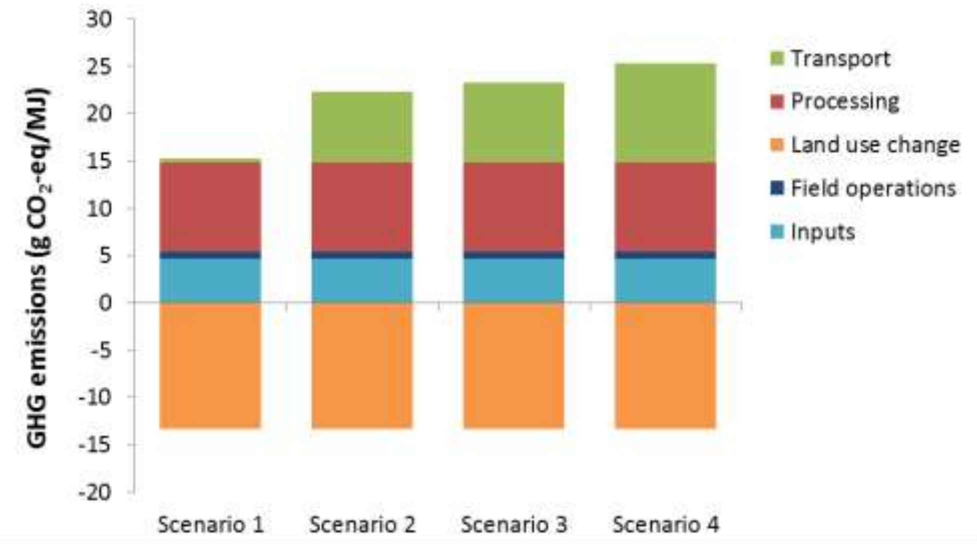

Figure 13. *GHG emission (per MJ pellet delivered) for the four switchgrass chain scenarios 1. Domestic use heat generation; 2. Transport via train and vessel to the Netherlands and co-firing in a coal plant; 3. Transport via train and river barge to the Netherlands and co-firing in a coal plant; 4. Transport via truck to the Netherlands and co-firing in a coal plant.*

Emissions from field operations are low, although these are relatively high in the first year due to field preparation, this is averaged out over the entire switchgrass rotation. GHG emissions from inputs are higher, mainly due to N_2O soil emissions and emissions from fertilizer production. However, compared to other agricultural energy crops the inputs are low, since switchgrass is a perennial crop with low nutrient requirements. The total GHG emission and saving of the switchgrass chain scenarios is shown in Table 3.

Table 3. GHG emission and savings for the four switchgrass chain scenarios. 1) Domestic use heat generation; 2) Transport via train and vessel to the Netherlands and co-firing in a coal plant; 3) Transport via train and river barge to the Netherlands and co-firing in a coal plant; 4) Transport via truck to the Netherlands and co-firing in a coal plant.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
GHG emission (g CO_2-eq/MJ pellet)	2.0	9.0	10.0	12.0
GHG emission (g CO_2-eq/MJ electricity/heat)	2.2	22.6	24.9	29.9
Fossil fuel reference (g CO_2-eq/MJ electricity/heat)	87.0	198.0	198.0	198.0
GHG savings (%)	97.5	88.6	87.4	84.9

For export to the Netherlands for electricity production the GHG emission is between 9.0 and 12.0 g CO_2-eq per MJ pellet, which is 22.6 – 29.9 g CO_2-eq per MJ electricity based on an efficiency of 40%. Compared to the fossil fuel reference of 198 g CO_2-eq per MJ electricity, the GHG savings of the entire chain is 85-89%, which is above the 70% minimum GHG saving as stated in the NTA 8080. For the domestic switchgrass chain for heat production (scenario 1) the total GHG emission is 2.0 g CO_2-eq per MJ pellet, which is 2.2 g CO_2-eq per MJ heat, based on an efficiency of 90%. Compared to the fossil fuel reference of 87 g CO_2-eq per MJ heat, the GHG savings of the entire chain are 97.5%, which is even higher than the other switchgrass chain scenarios.

4 Outlook

Between 2008 and 2013 switchgrass tests in Ukraine have made it possible to obtain enough experience and knowledge to establish large scale plots in Ukraine. This means that commercial initiatives are possible and expertise to set up large scale switchgrass plantations for biomass production is available.

Though the knowledge to start large scale cultivation is available, there is still a need for much development. One important issue is the need for long time data on switchgrass variety performance to see if stand productivity is maintained over longer times. Commercial viability should only be possible if a stand productivity is maintained for 10 to 15 years. Already later maturing varieties such as Kanlow have shown stand loss and are therefore not suitable even though initial performance seemed good.

Other issues such as optimisation of nutrient management, optimisation of harvest date and optimized delivery of biomass for energy production, management of switchgrass for optimal quality have to be addressed. Local testing of switchgrass in biomass conversion facilities is needed.

Another logical issue should be development of locally adapted switchgrass varieties for biomass production. Here selection for high yield, winter survival, less lodging, thicker stems, less lodging would be logical.

As discussed above switchgrass seems to be able to provide biomass at a low cost on lower productive soils and/or marginal areas. This potential only has a value if this type of land does indeed become available for biomass production. As we have shown in the project producing biomass on this type of land may be somewhat more expensive but also avoids competition for land used for food production. In addition switchgrass may be used to avoid further degradation due to erosion and even upgrade marginal lands. Further research into the methods of cultivation in these areas is needed. For example no-till establishment of switchgrass.

A very important issue is the identification of areas where perennial biomass crops such as switchgrass should be produced to not compete with food crops, and what policies are needed to make use of this potential. This may include new zoning systems and a recognition of iLUC free biomass by the national and international market.

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