Optimizing Miscanthus Biomass Production - OPTIMISC

Reporting

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RESULTS PACK
A biomass boost to Europe’s bioeconomy

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Final Report Summary - OPTIMISC (Optimizing Miscanthus Biomass Production - OPTIMISC)

Executive Summary:
This paper describes the complete findings of the EU-funded research project OPTIMISC, which investigated methods to optimize the production and use of miscanthus biomass. Miscanthus bioenergy and bioproduct chains were investigated by trialling fifteen diverse germplasm types in a range of climatic and soil environments across central Europe, Ukraine, Russia and China. The tolerance of a wider panel of germplasm types to the abiotic stresses of drought, salinity and low temperatures was measured in the laboratory and a field trial in Belgium. Performance of a small selection of germplasm types was evaluated on marginal lands in Germany and the UK. Variation in growth traits determining the potential of biomass quality and quantity was analysed. Several potential high-value bioproducts were identified. The combined results were used to parameterize models providing recommendations to policymakers, growers and industry. The major technical advances in miscanthus production achieved by OPTIMISC include: 1) demonstration that novel hybrids can out-yield the standard commercially grown genotype Miscanthus x giganteus; 2) characterisation of the interactions of physiological growth responses with environmental variation within and between sites; 3) quantification of biomass-quality-relevant traits; 4) abiotic stress tolerances of miscanthus genotypes; 5) selections suitable for production on marginal land; 6) field establishment methods for seeds using plugs; 7) evaluation of harvesting methods; and 8) quantification of energy used in densification (pellet) technologies with a range of hybrids with differences in stem wall properties. End-user needs were addressed by demonstrating the potential of optimizing miscanthus biomass composition for the production of ethanol and biogas as well as for combustion. The costs and life-cycle assessment of seven miscanthus-based value chains, including small- and large-scale heat and power, ethanol, biogas and insulation material production, revealed GHG-emission- and fossil-energy-saving potentials of up to 30.6 t CO2eq C/ha*y and 429 GJ/ha*y, respectively. Transport distance was identified as an important cost factor. Negative carbon mitigation costs of -78 €/t CO2eq C were recorded for local biomass use. The OPTIMISC results demonstrate the potential of miscanthus as a crop for marginal sites and provide information and technologies for the commercial implementation of miscanthus-based value chains.

Project Context and Objectives:

1. Introduction

Miscanthus is a C4 perennial rhizomatous grass native to East Asia. The genus Miscanthus has its origins in the tropics and subtropics, but its various species are found over a wide climatic range throughout East Asia (Greef and Deuter, 1993). The remarkable ability of miscanthus to adapt to different environments (Numata, 1974) makes this novel crop suitable for production over a range of European and North American climatic conditions. Miscanthus was first cultivated in Europe in the 1930s, when it was introduced from Japan. Today it has become a leading candidate crop for production of lignocellulosic feedstocks for both bio-energy and material uses, thanks to its rapid biomass accumulation in temperate climates (Clifton-Brown et al., 2016).

Field experiments with the only genotype currently commercially available, Miscanthus x giganteus, a clone-based interspecies hybrid, have revealed its great photosynthetic efficiency, high biomass yield capacity, low input demands and good tolerance of temperate climates, and many of the characteristics that make miscanthus an ideal biomass crop (Lewandowski et al., 2000; Dohleman and Long, 2009; Heaton et al., 2010; van der Weijde et al., 2013; Davey et al., 2016). Analyses of the environmental
impacts of miscanthus cultivation on a range of factors, including greenhouse gas mitigation, show that the benefits outweigh the costs in most cases (McCalmont et al., 2015). At present, only about 20,000 ha of miscanthus are commercially grown in the EU, mostly in the UK (10,000 ha), France (4000 ha), Germany (4000 ha), Switzerland (500 ha) and Poland (500 ha). There are several reasons for the low implementation and even decreasing cultivation area of miscanthus in Europe (Lewandowski, 2016) including:

- Biomass production costs are still too high
Biomass production costs for miscanthus are presently are too high to compete commercially with fossil fuels on an energy basis. The high biomass production costs for miscanthus result from insufficient development of agricultural production technology, accompanied by additional costs for agricultural inputs, land and labour for a relatively low-value biomass. Although they are amortized over a production period of 10-25 years, initial establishment costs for miscanthus are still comparatively high. This is because the only commercially available genotype Miscanthus x giganteus is a triploid hybrid that does not produce viable seeds. Consequently, costly establishment via rhizome or in vitro propagation has to be performed. Miscanthus is also new to farmers and they have neither the knowledge nor the technical equipment to cultivate it. Thus inefficient production technology is currently limiting its widespread uptake as a biomass crop.

- There are no stable markets for miscanthus biomass and relevant applications are low-value
Farmers are hesitant to cultivate miscanthus because it involves dedicating their fields to long-term biomass production. They will only be willing to do this once biomass markets are stable or if long-term contracts are available (Wilson et al., 2014). The main use of lignocellulosic biomass from perennial crops is as a solid fuel for heat and power generation - a comparatively low-value use, its profitability being ultimately determined by the price of fossil fuels. In Europe, subsidies are generally necessary for bioenergy products to be able to compete in retail energy markets - with the notable exception of forest wood and forestry by-products that cannot be used for wood material products. Therefore, higher-value applications for miscanthus biomass are required in order to provide attractive market options.

- There are no miscanthus varieties adapted to different site characteristics and biomass use options
In Europe, Miscanthus x giganteus is the only genotype commercially available. Major barriers to the breeding of miscanthus varieties are the high costs involved and the long breeding periods, necessary because most yield- and quality-relevant parameters are not quantifiable until after the establishment phase of 2-3 years.

The EU project OPTIMISC (Optimizing Miscanthus Biomass Production) was initiated in 2012 with the objective of providing solutions to remove some of these barriers to miscanthus production. More specifically, the following research goals were the starting point for the OPTIMISC R&D activities (see also Table 7; Annex I)

- Identification of novel miscanthus genotypes adapted to different climatic conditions and to adverse and marginal site conditions, such as cold, drought and salinity;
- Improvement of productivity and yield stability of miscanthus;
- Improving marketing opportunities for miscanthus biomass by assessing genetic determinants of
biomass quality, identifying novel value chains and developing logistic technology;
- Reduction of biomass production and supply costs by demonstrating large-scale field production based on seeded hybrids;
- Optimization of miscanthus-based product supply chains in terms of costs and environmental performance.

To address these objectives, miscanthus bioenergy and bioproduct chains were optimized by trialling diverse germplasm types over a range of sites across central Europe, Ukraine, Russia and China. The key traits that currently limit the potential of miscanthus were analysed, high-value bioproducts identified and the combined results modelled to provide recommendations to policy makers, growers and industry. Here we provide a summary of the OPTIMISC project's achievements and discuss their relevance for the advancement of miscanthus development and its implementation.

Project Results:

2. Materials and Methods

An overview of the OPTIMISC consortium partners and abbreviations used for their institutions is provided in Annex III. Figure 1 (Annex II) gives an overview of the research and development activities of the OPTIMISC project. Diverse miscanthus germplasm (provided by IBER from Aberystwyth University, the Department of Plant Breeding from Wageningen University (WU), ILVO, Schwarz and the Dongying Agricultural Institute) was propagated (Work package 2; WP2) and experiments were conducted on different scales in laboratories, glasshouses, field plots and in pre-commercial scale field trials. About 100 genotypes were studied under controlled conditions to obtain insights into the available genetic variation in the miscanthus genepool for traits such as growth under low water input, saline conditions and low temperatures (WP3). Fifteen genotypes were screened on field sites in the UK, Germany, the Netherlands, Turkey, Ukraine, Russia and China (WP4). Harvest systems designed to optimise biomass quality and costs were applied on large-scale farm demonstration trials with one to three genotypes (WP5). The composition of the biomass was investigated with regard to its quality for various energy supply chains and material uses (WP6). Yields and miscanthus-based value chains were modelled with the objective of identifying the best options for different climatic settings and biomass uses (WP7). The following chapters give a more detailed description of the methods of the experimental work packages.

2.1 Work package 2: provision of germplasm and plant material

Miscanthus germplasm was provided by several partners from the UK, the Netherlands, Germany, Belgium and China. Table 1 (Annex I) summarises the germplasm used by species and provider.

By 2013, about 100 miscanthus genotypes had been successfully transferred to in vitro culture. Clones were supplied as in vitro cultures partner Schwarz to WP3 participating partners who then propagated them further to use in the trait screens in controlled environments. A subset of 15 germplasm types (11 genotypes by clones, and 4 seed populations - a total of 22,200 plants) were produced for the WP4 multi-location trials.

2.2 Work package 3: Trait screen in controlled environments

Quantifying variation in low temperature tolerance of (i) the overwintering rhizome (ii) spring growth
A large number of the miscanthus genotypes propagated in vitro in WP2 were tested in WP3 for tolerance to key abiotic stresses identified previously as limiting miscanthus production. Chilling and winter frost tolerance were tested in the field (Table 2, Annex I). Rhizome frost tolerance was tested as follows. Rhizomes were dug out and cleaned, cut into 10-cm lengths with at least one viable bud, and stored at different freezing temperatures in a temperature controlled bath. The rhizomes were left to thaw and then allowed to grow in optimal conditions. Frost tolerance was quantified by determining the temperature at which 50% of the rhizomes of each genotype was killed (LT50). Shoot frost tolerance and winter survival were evaluated in field trials. Chilling tolerance was investigated by studying early vigour at the beginning of the growing season in field trials and by measuring growth under chilling stress in growth chambers. From these experiments, a number of growth traits were calculated (including longest shoot, no. of leaves and shoots, growth rate, leaf formation rate) and these traits were analysed to determine which can best be used to describe early vigour and chilling tolerance, and which are most reproducible and useful to breeders.

Tolerance to drought and salinity was screened under controlled conditions in both 12.7-cm pots and 1-m long tubes (drought) or hydroponics (salinity) (Table 2, Annex I).

For the preferred protocol for screening for drought tolerance, in vitro-grown plants were transferred and established in soil conditions. After one year of establishment in soil, the senesced year-1 biomass was harvested in the spring. Like sized, newly emerged tillers were subsequently selected per genotype (n=20) once emerged, and grown in 5-inch pots (37 genotypes) and 1-metre long pipes (50 genotypes), where water was withheld for 12 and 28 days respectively. Half the plants were harvested at the end of the drought treatment, and the other half water was reinstated for a period of recovery. During the experiment, plants were observed for leaf rolling, wilting, leaf marginal burn and leaf tip senescence, earliness of flag leaf and flowering, relative chlorophyll content (SPAD index), leaf surface temperature and (leaf) relative water content. Growth measurements included leaf elongation of the newest emerging leaf, number of tillers, and fresh and dry weight of leaves, stems and roots at the time of harvest. A subsequent similar evaluation of six selected genotypes exhibiting a variety of responses to drought stress included additional physiological traits: Stomatal conductance, stomata count, and maximum efficiency of photosystem II (Fv/Fm).

For evaluation of salt tolerance, 70 in vitro-grown genotypes were transferred to a hydroponics system in the greenhouse and grown under normal conditions as well as saline conditions (150 mM NaCl added to the growth medium). The salt treatment was continued for three weeks. During the stress period, tiller number, leaf elongation and leaf elongation rate, plant height and chlorophyll content were measured, and senescence was visually assessed. At the end of the stress period, the plants were harvested and shoot and root fresh and dry weight determined. The dried samples were used for determination of ion contents (Na, K, Ca, Cl, Mg, SO4, PO4). A selected set of genotypes was further evaluated in pots. These included in vitro- and hydroponics-propagated plants, as well as plants started from rhizomes (collected in the field). Rhizomes were divided to similar sizes. The plants were subjected to normal conditions (no added salt), 150 mM and 250 mM NaCl salinity after 3 weeks of acclimation. The salt treatment was continued for 6 weeks, after which the plants were harvested. Measured traits included plant height, chlorophyll content, tiller number, and senescence. Leaves, stems and root fresh and dry weights were determined at harvest, and the dry material was used for determination of ion contents (Na, K, Ca, Cl, Mg, SO4, PO4).
2.3 Work package 4: Agronomic plot trials
In 2012, plot-based trials with 15 miscanthus types (see Table 6 of Annex I for description) were established in four replications at six locations in Europe, Russia and Turkey (see Table 3, Annex I). Biomass yields were assessed in winter-spring 2013, 2014 and 2015. In 2014, the growth measurement protocols standardised for all the locations were used to measure the development of the plants in the multi-location trial. Biomass yields of the preceding growing season were measured in spring 2013, 2014 and 2015.
Thirty-six novel natural miscanthus germplasm types, selected under saline conditions in China, were planted at Dongying in China in 2013 and were measured for growth response to salinity throughout 2014. The effects of different planting and mowing regimes on miscanthus establishment in grassland and yields in the mixed grassland/miscanthus production systems were assessed in the trials established on marginal land in Germany.

2.4 Work package 5: Commercial-scale trial and pelleting
Large-scale field trials (5 ha, 20 plots of 0.25 hectares) were established in the UK in 2012 and in Ukraine (2 ha) and Germany (0.6 ha) in 2013 by planting seed-derived plugs. The chlorophyll and protein production potential from the stay-green OPM-111 hybrid planted at all three large-scale trial locations was quantified for in-season and end-season harvests. The efficiency of several harvesting methods with different hybrid types was compared using the 5-ha trial in the UK. The impacts of these methods on the environment and economics was extrapolated from the data.

2.5 Work package 6: Composition and high-value products
The main goal of WP6 was to identify high-yielding miscanthus genotypes with excellent biomass quality for different biobased products. Applications assessed included bioethanol, biogas, combustion and fibreboards. The plant cell wall composition of all 162 genotypes used in OPTIMISC was analysed in various experiments and correlations with the quality for different biobased applications were evaluated. Three new field trials were established to study the interplay between cell wall composition and saccharification yield as a measure of bioethanol production (van der Weijde et al. 2016a, van der Weijde et al. 2016b), combustion quality (van der Weijde et al. 2016b), biogas yield (Kiesel and Lewandowski, 2016; van der Weijde et al. 2016b) and cutting tolerance of the different miscanthus genotypes (Kiesel and Lewandowski, 2016). Additionally the effects of abiotic stresses and geographic location on biomass quality were studied using the material harvested in the multi-location trials (WP4) and the abiotic stress tests (WP3).

2.6 Work package 7: Modelling (yield, quality, LCA, costs)
A cost and life cycle assessment (LCA) was performed for seven selected miscanthus-based product chains. For this purpose, data from field trials was used wherever possible (see Wagner et al., submitted). The overall biomass transport distance was assumed to be 400 km when bales were transported to the bioethanol plant or to the plant producing insulation material as well as in the value chain “Combined heat and power (CHP) bales”. For the value chains “CHP pellets” and “Heat pellets” the bales were transported 100 km to a pelleting plant and from there the pellets were transported 400 km to the power plants. The average farm-to-field distance was assumed to be 2 km. This transport distance is also assumed for the value chain “heat chips” in which a utilization of the chips as a biomass fuel on the
producing farm was assumed. Because of the higher biomass requirements of the biogas plant an average transport distance of 15 km from field to plant was assumed. Data from sequential harvests in the multiple-locations trials in Germany, Russia and Turkey were used to model the quality and yield development of different genotypes at different harvest times.

3. Results and discussion
The results of the various research activities are summarized in Table 7 (Annex I). These are then discussed, focusing on their relevance for the advancement of miscanthus and implementation of miscanthus-based value chains.

3.1 Options for producing miscanthus in different climates and on marginal land
This chapter presents the results of testing novel miscanthus germplasm in comparison to Miscanthus x giganteus over a wide range of European climates and also recommendations for miscanthus production on marginal land.

3.1.1 Yield performance of novel miscanthus genotypes over a wide range of climatic conditions in Europe, Ukraine, Russia and Turkey
Some of the trial locations represented marginal (limiting) growth conditions for miscanthus. In particular, the field trial in Adana (Turkey) exhibited the highest air temperature and driest soil conditions among the OPTIMISC experiments, and the trial in Moscow (Russia) represented the coldest location with cold winter temperatures, late spring frosts and longer summer photoperiod than at the other sites. The Moscow site also suffered a summer drought in 2014.

As part of the OPTIMISC multi-location trial, 15 genotypes were planted on a marginal land site at Aberystwyth (UK). This field site was formally grassland, with low nutrient levels and shallow soils. Additionally, the growing season temperatures and radiation levels in cool wet summers here delay establishment rates. The shallow soils lead to rapid changes in soil moisture levels, with flooding conditions after rainfall and drought stress in summer. The high stone content of the soil made miscanthus establishment difficult.

The more challenging growth conditions at these sites resulted in lower miscanthus yields at Aberystwyth and Moscow (Figure 2, Annex II) than at the other four locations. The drought at the Mediterranean site Adana caused the miscanthus to start senescing in July and therefore only dry matter (DM) yields of up to 15 t/ha*a could be harvested here (Figure 2, Annex II). The highest DM yields (up to 20 t /ha*a harvestable biomass in early spring) were achieved at Potash/Ukraine, where good clay-rich soils and good water supply prevailed. The south German site Stuttgart is characterized by low soil depth (on average 60 cm soil horizon) and encountered a drought in summer 2015. It was only possible to harvest up to 18 t DM/ha*a here.

Apart from the Ukrainian site Potash, miscanthus genotypes with yields exceeding that of M. x giganteus (OPM-09, green box in Figure 2, Annex II) were identified at all sites. These were either other M. sinensis x M. sacchariflorus hybrids (Moscow, Aberythwyth, Wageningen, Stuttgart), M. sacchariflorus (OPM-02, Stuttgart) or M. sinensis (Adana).

We therefore conclude that new genotypes are available that can out-perform M. x giganteus, especially on marginal lands.

Table 8 (Annex I) gives a ranking of genotypes according to yield and yield stability. Both absolute yield (top section) and yield stability (lower section) are important factors in selection.
Table 9 (Annex I) gives recommendations for the use of different genotypes, with reasons, based on field observation. M. sacchariflorus types are characterized by spreading rhizomes, which can lead to escape of the crop. Overall, M. sacchariflorus types tested here are only recommended for southern European sites with irrigation or no susceptibility to drought. M. sinensis x M. sacchariflorus hybrids, including M. x giganteus, are recommended for most areas of Europe (OPM-09, OPM-10) or northern Europe (OPM-08), mainly on account of their high yields.

The M. sinensis type OPM-11 is recommended here for Mediterranean areas, where it can make best use of the spring period before the onset of summer droughts (Table 9, Annex I).

The potential miscanthus growing area for Europe was modelled based on measurements of field performance of the genotypes OPM-01 to OPM-15. Compared to a scenario where only the genotype M. x giganteus is available (Figure 3a, Annex II), a large potential expansion of the miscanthus growing area to the east, south and north of Europe is predicted for a scenario where the genotypes screened in OPTIMISC can be grown commercially (Figure 3b, Annex II).

3.1.2 Identification of stress-tolerant miscanthus genotypes

One important result from the OPTIMISC project is the expansion of the potential miscanthus production area in Europe (as shown in Figure 3, Annex II). This is achieved mainly by the successful identification of stress-tolerant genotypes for biophysically marginal cultivation conditions (see Chapter 3.1.1). Biophysical marginality is often caused by the abiotic stresses of water shortage, unfavourable temperature or poor soil conditions, including salinity.

The evaluation of stress tolerance in plants is not straightforward, as it is strongly affected by environmental conditions. Therefore, we focused on finding relevant traits and mechanisms for four abiotic stressors that are relevant to miscanthus cultivation (drought, salinity, chilling and frost), assessing genetic diversity in a range of cultivars and breeding material, and identifying traits that can be used for selection and improvement of miscanthus cultivation on marginal lands. At the same time, genotypes were selected that are expected to have a relatively high production under marginal conditions where they experience drought, salt, chilling and/or frost stress.

3.1.2.1 Drought

The response to drought and recovery after drought differs between and within species. Recovery potential is likely to be of critical importance for yield under conditions with regular drought spells. As this is a likely climate-change scenario, it should be part of any drought tolerance evaluation for miscanthus. The highest-yielding genotype in our drought condition test set was OPM-19 (M. sacchariflorus). In drought conditions, this genotype did not invest in roots, but ceased growing and reduced photosynthesis and water content. It is possible that this genotype has an efficient mechanism to protect itself from drought damage, enabling it to recover fast. Its rapid biomass accumulation makes it a promising genotype under well-watered or periodic drought conditions. Damage control during drought spells may therefore be an important drought tolerance mechanism. Genes that may underlie this mechanism have been identified and include coding for dehydrins and reactive oxygen species (ROS) scavengers. Another genotype (OPM-18, M. sacchariflorus) showed increased investment into both root and rhizome growth after drought stress compared to controls. Continued investment in rhizomes may be another important mechanism, but is a challenging trait to monitor for selection in breeding programmes.

It should be noted that different traits may be of more or less importance depending on the timing and severity of the drought stress, and that it is a combination of traits that provided tolerance under the
conditions applied in this experiment. While growth cessation and damage protection may be good strategies to withstand the adverse effects of a relatively short but severe drought, long-term mild droughts were not tested in this study. It remains to be seen whether the same genotypes are productive under such conditions, or whether traits enabling the maintenance of growth may be more favourable. Among the genotypes tested, some produce high biomass yield under both well-watered and drought conditions. Other genotypes may not be the highest producing under well-watered conditions, but show only a small reduction in yield under limited water availability. While it is tempting to speculate that these would be potential sources of drought tolerance traits to be utilized in breeding programmes, it is important to exclude genotypes that require less water simply due to their small size and slow growth. Several of the genotypes screened demonstrated a harvestable biomass yield greater than that of the standard M. x giganteus (OPM-09). Four of the genotypes that produced more biomass than M. x giganteus under control conditions were also among the most drought-tolerant genotypes (maintaining a high percentage biomass under drought): OPM-06, OPM-25, OPM-77 and OPM-27. A further 10 genotypes showed medium tolerance (OPM-05, OPM-86, OPM-38, OPM-69, OPM-02, OPM-19, OPM-20, OPM-23, OPM-07 and OPM-39) and also exceeded M. x giganteus yield under control conditions. These 14 genotypes had higher yields than M. x giganteus in both drought and well-watered conditions. A single drought-susceptible genotype (OPM-50) yielded more than M. x giganteus when well-watered but not under drought. This again emphasizes the importance of biomass yield per se as opposed to maintaining biomass yield in a smaller plant. Of the 10 highly tolerant genotypes (in terms of maintained biomass yield), 5 also demonstrated relatively high maintained soil moisture. This indicates that these plants are water-use efficient and are able to maintain biomass production without depleting soil moisture. Of the 14 genotypes that outperformed M. x giganteus under both control and drought conditions, five were M. sacchariflorus, five were M. sinensis and four were hybrids (Figure 4, Annex II). Six high-yielding genotypes with differing responses to drought stress were selected for additional experimentation and RNAseq analysis: two M. sacchariflorus, two M. sinensis, and two interspecific hybrids. All genotypes were diploid except OPM-09 (M. x giganteus) which is triploid.

• OPM-06 (M. sacchariflorus x sinensis), OPM-98 (M. sinensis), OPM-18 (M. sacchariflorus) were selected for maintained high yield under drought and designated TOLERANT.

• OPM-19 (M. sacchariflorus) was high yielding under drought and control conditions, although the yield was reduced as a result of water stress. OPM-09 (M. x giganteus, control) demonstrated moderate yield production under drought compared to OPM-06, OPM-19, OPM-98 and OPM-18 and was adversely affected by drought. OPM-103 (M. sinensis) was high yielding under watered conditions, but the biomass was adversely affected by drought. These were designated SUSCEPTIBLE.

Both M. sacchariflorus and hybrids responded more to drought in terms of gene expression than M. sinensis, in line with physiological observations. However, most genes were not equally up- or downregulated in the two representative genotypes per species. Overall, approximately twice as many transcripts were downregulated than upregulated. For M. sacchariflorus, over twice as many transcripts were downregulated and for hybrids approximately twice as many were downregulated. OPMs 09 and 19 showed the highest differential expression; the two M. sinensis genotypes OPMs 98 and 103 showed the lowest number of differentially expressed transcripts. By contrast, in M. sinensis, not only were far fewer transcripts regulated but they were up and down in similar proportions. With the exception of 13 genes in M. sinensis, expression patterns (up vs down regulated within a tissue) are similar within species.

Suppression of gene expression was more common than upregulation of gene expression, and most of this occurred in the roots as opposed to the leaves. There were slightly more downregulated than
upregulated transcripts in the leaf, however there were nearly three times as many downregulated than upregulated transcripts in the root. A gene identified as a dehydrin-encoding was differentially expressed in all genotypes. Nineteen genes were differentially expressed in all three tolerant genotypes. These included genes identified as coding for heat-shock proteins, a gene associated with flowering time and several genes involved in sugar metabolism and regulation. Thirty genes were differentially expressed in two of the three tolerant genotypes but not in the susceptible genotypes (excluding OPM-103). There was diversity among all genotypes. All of the differentially expressed transcripts common to the three drought tolerant genotypes were differentially expressed in at least one of the sensitive genotypes. It is likely that the tolerant genotypes combine traits found in the sensitive genotypes rather than implementing unique strategies. These data indicate that miscanthus employs similar strategies to those identified in other plants, but it is yet to be seen whether there are additional, miscanthus-specific drought responses.

3.1.2.2 Salinity
Saline soils affect crops in two ways: it induces water shortage due to osmotic stress and accumulation of salt in the plant can have toxic effects.
In our screen, we found indications that miscanthus uses both mechanisms to mitigate the effects of salinity. The best performing genotype (OPM-56, M. sinensis) utilizes a mechanism that actively keeps the ions from accumulating in the leaves, thus minimizing damage to essential physiological processes like photosynthesis. This mechanism is known as salt exclusion, and is known to be able to confer salt tolerance to rice and wheat (Munns et al., 2012). The causal gene in these two cereal crops is HKT1;5, an ion transporter that takes Na+ out of the xylem and into the parenchyma cells in the roots, avoiding Na+ accumulation in the leaves. This is a strategy that can be effectively selected for by measuring ion contents in the leaves of plants. In addition, it would be interesting to target the HKT1;5 gene in miscanthus as the causal gene for this mechanism. Further exploration in miscanthus germplasm to identify the most effective alleles of this gene and for the Na+ exclusion mechanism is therefore recommended. In view of the quality of harvestable yield, the salt exclusion mechanism may also be preferred. High concentrations of ions are known to interfere with combustion quality, and may be a problem for saline cultivation of miscanthus. Improving salinity tolerance by improving salt exclusion properties enhances yield under saline conditions, and at the same time improves product quality.
Field trials were performed with the genotypes M. x giganteus (OPM-09), OPM-01, -03, -06, -08 and several M. sacchariflorus genotypes, selected from marginal and saline land in North-East China. The trials revealed that M. x giganteus is not suitable for saline land. Different M. sacchariflorus genotypes proved salinity-tolerant. The yield declined with increasing soil salt electrical conductivity (EC) values. A soil EC value under 2.5 had little effect on yield, but at a soil EC above 3 yields decline dramatically. Compared to slightly saline land (average EC of 1.10) the yields of the most salinity-tolerant genotypes on the heavily saline site (average EC of 3.85) declined by 30–55% in the second stand year.
In conclusion, the highest-yielding genotypes under controlled conditions (especially M. sinensis OPM-56) have potential to grow in saline soils, and should be tested under field conditions. In addition, several of the M. sacchariflorus genotypes tested in the field can be recommended for growth under saline soil. Land areas with a soil EC value up to 2.5 are suitable for miscanthus production.

3.1.2.3 Low temperature
A small number of genotypes were analysed for photosynthetic and biochemical traits, which are likely to
be linked to chilling tolerance. These revealed large variations for both trait types (Fonteyne et al., 2015; Mortaignie, 2014). This indicates that a combination of these traits may in fact enhance chilling tolerance and can be targeted for combined selection (Fonteyne et al., 2016). Outdoor evaluation of chilling tolerance indicated a wide variation in the germplasm and that emergence of first shoots, time to reach 50 cm shoot length and early growth rate are good parameters for large-scale chilling tolerance evaluation. Frost tolerance evaluation of a set of miscanthus genotypes was performed using potential marker traits such as moisture content, ion leakage and phenological characteristics. None of these markers was strongly correlated to frost tolerance. The best marker trait to determine frost tolerance turned out to be the LT50 in artificial rhizome freezing tests. The LT50 can be directly related to winter survival (Clifton-Brown and Lewandowski, 2000). Mechanisms underlying freezing tolerance in miscanthus are still elusive, but may be linked to production of specific metabolites and molecules that stabilize cell structures, most notably membranes, under freezing conditions (Thomashow, 1999).

In general, the hybrid genotypes were more frost-tolerant and the M. sacchariflorus and M. x giganteus genotypes were less frost-tolerant. On average, the M. sacchariflorus genotypes had a significantly higher LT50 than the hybrids, while the M. sinensis genotypes were not different from either group, but genotypes with higher frost tolerance than M. x giganteus were found in all species groups.

Based on our observations, the miscanthus genotypes tested under various conditions display a wide range of variation in response to abiotic stresses, but this may not be the full range of tolerance to stresses that can be exploited in miscanthus germplasm. For instance, the salinity field trial in Dongying showed that several of the newly collected Chinese M. sacchariflorus genotypes were relatively tolerant to saline conditions (with CN32 being most tolerant), although its tolerance was not much higher than some of the genotypes tested under controlled conditions. Further collection of miscanthus material growing on marginal soils is required, and this should be tested using the screening procedures developed within this project as well as in the field, alongside the best performers selected in this project.

Predicting how tolerant to stresses the selected genotypes will be in terms of water requirements and temperature is not straightforward. The field trials indicate that some genotypes perform better in relatively hot climates, while others thrive even after cold winters. However, the set of genotypes tested in the multi-location trials was too small and not enough of the best-performing genotypes were tested under controlled conditions. Thus, the logical next step would be to test the top performers from the controlled condition evaluations in different climatic regions to establish whether these selections are also relatively tolerant under varying field conditions.

For salinity at least, it can be deduced that the best-performing miscanthus genotypes’ tolerance of saline soils is higher than in cereals, even barley (considered to be a salt-tolerant cereal). This offers opportunities for miscanthus cultivation in marginal, saline areas.

We would recommend that genotypes with extreme traits are crossed into highly productive parental lines, and the progeny are evaluated for resilience in further laboratory screens and field trials. Identification of the trait variation is an important step, but only one of many steps necessary for genetic improvement. This is part of a longer-term programme of breeding and evaluation, which needs ongoing public support to deliver the resilient hybrids required to drive the feedstock supply for the bioeconomy.

3.1.3 Methods for the establishment of miscanthus on marginal land

Challenging establishment conditions, including drought, stoniness and low temperature, present a major barrier to miscanthus production on marginal land are (Xue et al., 2015). The OPTIMISC project developed technical approaches for the establishment of miscanthus under marginal soil conditions and
The planting of seed-derived plugs proved to be most successful method for miscanthus establishment on marginal soils. Covering the plants with a plastic film accelerates their growth. The film keeps the humidity in the topsoil and increases the temperature. This is beneficial for the plants, especially on light soils with a higher risk for drought stress and in cool temperatures.

In Europe, there are large areas of marginal land covered by grassland. The OPTIMISC project performed field trials for the establishment of miscanthus into grassland. The hypothesis was that the inclusion of miscanthus (high-yielding C4 grass species) into C3 grasslands could be beneficial for biomass yield, given that suitable miscanthus genotypes are to be carefully selected for this purpose. Examples of yield increase in C3/C4 mixed grasslands compared to pure C3 grasslands can be found in the scientific literature (Adler and Sanderson, 2009). Growth patterns of C3 and C4 grasses are often complementary and lead to higher total annual harvestable yield (Thumm et al., 2012). Addition of miscanthus into C3 grasslands in temperate climates could also improve biomass quality for certain purposes, such as combustion.

The establishment of miscanthus on grassland proved successful with two propagation techniques: 1) direct planting of rhizomes in the soil and 2) transplanting of pre-grown, rhizome-derived plantlets. The second technique appeared to lead to better establishment success, although this depended on the genotype.

Pre-treatment of the existing vegetation is important to ensure good establishment of the introduced miscanthus plants. Cutting the existing vegetation and spraying herbicide in narrow strips (defined as intermediate in severity) appears to be the most advantageous pre-treatment of the grassland. This improves miscanthus establishment without negatively impacting on the productivity and existing vegetation of the C3 grassland itself.

Strong, competitive miscanthus genotypes with tall, thick shoots seem to be a better choice for establishment on grassland than genotypes with short, thin shoots, regardless of the species. The C3/C4 grasslands can and should be managed by multiple in-season mowing of green biomass, as is usually performed on European grasslands. Our results demonstrated that a mowing regime with two harvests per year (spring and autumn) is most suitable to achieve good biomass yields from these mixed grasslands. Harvesting once per season in autumn leads to a higher proportion of miscanthus biomass but to a lower biomass gain from the C3 grassland due to its natural senescence early in summer.

### 3.1.4 Meeting biodiversity concerns

Biodiversity issues need to be considered when planting miscanthus into C3 grasslands. In our trials, vegetation analyses performed before and three years after the establishment of miscanthus revealed that the species richness and abundance did not change significantly with this addition. However, the miscanthus was planted at a relatively low density and remained only a small contributor to the plant canopy and biomass (3-6%) due to high competition. Planting at higher densities or development of the miscanthus over time could potentially bring about changes in the existing plant communities.

As miscanthus is a not native to Europe, there are also concerns about uncontrolled spreading of this crop. There are two potentially relevant pathways for such spreading: 1) via creeping rhizomes and 2) via seed. Creeping rhizomes were observed in several M. sacchariflorus genotypes, one of which was strongly creeping. We therefore recommend excluding genotypes with this feature from commercialization (see Table 9, Annex I).

Germination tests carried out under controlled conditions showed that 10 of the 15 miscanthus genotypes...
tested in the OPTIMISC multi-location trials produced viable seeds. All these genotypes belonged either to M. sinensis species or M. sinensis x M. sacchariflorus hybrids. The highest seed germination rates were observed in Germany and the Netherlands and the lowest in the most southerly trial location of Turkey and two more northerly (colder) sites in Russia and Ukraine. The germination rate was especially low (on average $0.2 \pm 0.13$ seeds per panicle in 2014) in Russia (Moscow area), where long-day conditions retarded the transition to flowering and the vegetation period is short, preventing complete seed ripening (plant senescence occurs earlier). Strong genotypic differences were observed for seed germination. Two M. sinensis genotypes/accessions (OPM-12 and OPM-13) showed particularly high numbers of viable seeds per panicle (on average $150 \pm 38$ and $123 \pm 34$ seeds per panicle, respectively, in 2014). The M. sacchariflorus genotypes produced no viable seeds at all six trial locations. The M. sinensis x sacchariflorus hybrids (OPM-05-OPM-10) showed an average (six locations pooled, 2014) of 38% lower seed germination per panicle than the M. sinensis accessions. This ratio varied however between locations and genotypes. In the UK for example, the number of germinating seeds per panicle was approximately 50% higher in the hybrids than in the M. sinensis accessions. By contrast, in Germany, Ukraine and Turkey, this number was much lower in the hybrids than in M. sinensis. The highest number of germinating seeds per panicle was observed for the genotypes OPM-05 and OPM-10 (all locations pooled, in 2014).

Spreading via seeds was carefully monitored in the OPTIMISC trials. Volunteer miscanthus seedlings were found at two of the six locations of multi-location trials, the Netherlands and Germany. These seedlings were found outside the planted plots but within the plantation borders. No accidental spreading via seeds was observed at any of the more southerly or more northerly locations. In the south, seed germination in the field was possibly prevented by drought conditions, in the north by low temperatures and a shorter vegetation period. No volunteer miscanthus seedlings were found outside the plantation borders.

From these observations, we conclude that spreading via seeds in miscanthus - relevant for M. sinensis and M. sinensis x M. sacchariflorus hybrids - can be prevented by careful choice of genotype. Therefore genotypes should be recommended that either do not form fertile seeds or that are unable to establish via seed due to the climatic conditions of a specific site.

Another biodiversity concern is that miscanthus, as a perennial crop with tall and dense stands, may give rise to a monoculture, which supports only low species diversity. Our results show that young miscanthus stands sustain high plant species diversity before the canopy closure. Species richness was found to correlate negatively with the density of the stands and to be lower in mature plantations. However, even the 16-year-old, dense miscanthus plantations supported up to 16 different weed species per 25-m² plot, accounting for up to 12% of the plantation. The literature data support this finding: miscanthus stands are usually reported to support farm biodiversity, providing habitat for birds, insects and small mammals (Bellamy et al., 2009; Semere and Slater, 2007a). Studies by Semere and Slater (2007b) have shown biodiversity in miscanthus to be higher than in other crop stands, but still lower than in open field margins.

### 3.1 Scaling up miscanthus production and connecting to markets

The results of the OPTIMISC project can contribute to the fulfilment of requirements for scaling up miscanthus production by:
- Providing seed-based, low-cost and safe establishment methods;
- Providing germplasm for the development of stress-tolerant miscanthus varieties, adapted to a wide
range of climatic conditions in Europe (Chapter 3.1.1);
- Providing higher and more stable-yielding miscanthus genotypes that can also be produced economically on marginal lands (Chapter 3.1.2);
- Developing genotypes that are optimally suited to harvesting, processing and biomass user requirements;
- Developing harvesting and densification technologies;
- Improving the marketability of miscanthus biomass by assessing new miscanthus-based value chains and demonstrating how the biomass can be suited to user requirements.

3.1.1 Seed-based establishment methods
Cloning is expensive and the process of upscaling to the large areas necessary to deliver sufficient biomass for a future European bioeconomy would be too slow. For this reason, four seeded hybrids were included in the WP4 and WP5 trials. Although these were not as productive as the interspecific hybrids (including M. x giganteus (OPM-9)) and therefore not commercially ‘recommended’, we have pioneered the upscaling of the planting of seed-based hybrids using plugs. These plugs are also called “modules” and were originally developed for the vegetable industry. Seeds are sown by machine and raised in the greenhouse (Figure 5A, Annex II) before being planted out in the field (Figure 5B, Annex II). It is anticipated that seed-based establishment methods will prove most effective for the scaling up of miscanthus production because they have the following advantages:
- With increasing market demand, large quantities can easily be provided, once seed production has been well developed
- Short growing period for plantlets: only 8-10 weeks from seed to final product (plugs)
- Plug production is energy efficient (no need for refrigerators)
- Low establishment costs

When establishing miscanthus via seed in temperate climates, it is recommended that newly planted stands are protected with plastic film (Figure 5C, Annex II) as this increases establishment success and it is anticipated that it can reduce the length of the establishment period so that an economic biomass yield is produced earlier.

However, if seeds cross out or are not genetically uniform, inhomogeneous field stands are possible. During the term of the OPTIMISC project, major advances in breeding interspecific hybrids have been made in the UK (Clifton-Brown et al., 2016). The next steps in this development include determining how to: 1) increase the seed production potential of elite interspecific crosses; 2) optimize planting density ; 3) maintain effective weed control during establishment – especially where the crop is to be established on marginal land.

If investment in breeding and trialling is sustained, we expect to be able to apply the knowledge gained from these parallel roads of development to achieve commercial upscaling by about 2020.

3.1.2 Genotypes suitable for processing and use – biomass quality
The properties of miscanthus biomass determine its harvestability, transportability, marketability and usability. Moisture content must be appropriate for harvest technology and storage. If the moisture content exceeds 20%, there is a danger of self-ignition of the biomass during storage. For ensiling, the water content should ideally be in the range of 65–72%. The combustion quality of biomass is determined by both water content and the concentration of elements that cause corrosion and reduce the ash melting
point, mainly chloride (Cl), potassium (K) and nitrogen (N) (Lewandowski and Kauter, 2003). Densification of biomass, for example in the form of bales or pellets, is often necessary for storage or long-distance transport. (The economic relevance of this is discussed in Chapter 3.3). The organic composition of the cell walls affects the digestibility of the biomass and therefore determines its usability in ethanol or methane (biogas) production.

The OPTIMISTIC project found that the different miscanthus genotypes exhibit extensive variation in both biomass composition and characteristics relevant for energy use and that these are affected by their growing environment and crop management (mainly harvest).

3.1.2.1 Genotypic differences in biomass composition and properties

The moisture content of miscanthus biomass is mainly determined by harvest date (see Figure 6; Annex II), but is also affected by genotypic variation resulting from morphological differences and senescence patterns. Data from the Blankney Estate large-scale (5-ha) trial in WP5 show that shorter-growing hybrids with thinner stems had lower moisture content (below 13% in the standing crop in 2015), significantly higher bale weight (650 kg versus 500 kg for M. x giganteus, with less string breakages) and require about 20% less power for pelleting. However, short-statured types were lower-yielding than M. x giganteus and the pellets were approx. 5% less dense.

A trade-off between biomass yield and quality was also observed for the production of biomass for combustion. The concentration of combustion-critical elements declines over winter, as does the biomass yield (Figure 6, Annex II). Therefore, for combustion purposes, we recommend genotypes with the best combination of good combustion qualities and relatively low biomass losses (and high biomass potential) such as OPM-11 for Adana/Turkey, OPM-03, OPM-06 and OPM-09 for Stuttgart/Germany and OPM-06 and OPM-09 for Moscow/Russia.

Of the eight compositionally diverse M. sinensis genotypes evaluated in a field trial in Wageningen, biogas yield ranged from 441 to 520 ml/g dry matter and glucose yield for fermentation ranged from 146 to 208 g/kg dry matter (in very mild processing conditions). Furthermore, variation in genotype performance for these value chains was found to correlate strongly with cell wall compositional characteristics, such as contents of lignin, hemicellulosic polysaccharides, arabinose, trans-ferulic acid, para-coumaric acid and ratios of these cell wall components. Biogas yield and saccharification efficiency were not highly correlated to each other, although they were both influenced by some of the above compositional characteristics. Nonetheless, some genotypes performed relatively well in both value chains. Unfortunately, these genotypes were not the best-performing genotypes in terms of yield. Thus one of the challenges for the future is the crossbreeding of biomass-quality and biomass-yield-related traits.

The large variations observed in genotype performance indicate that, by developing and utilizing higher-quality feedstocks, vast improvements could be made in processing efficiency for these value chains.

3.1.2.2 Effect of environmental factors, especially abiotic stress, on cell wall composition

Variation in biomass composition was also shown to be highly influenced by environmental factors. Location accounted for a large part of the variation in cell wall composition in 15 genotypes that were evaluated across six locations in Europe and Russia. Some of this environmental influence can be explained by differences in relative stand maturity during the establishment phase of the trials, but it was still significant after the third growing season. Stand maturity was also found to affect cell wall composition. The cell wall composition in the first growing season had a low predictive value of that in the third growing season. However, cell wall composition in the second year was predictive of that in the third year with
reasonable accuracy across all locations. Significant genotype-by-location interaction was seen for cell wall, cellulose, hemicellulose and lignin contents, indicating that the ranking of genotypes terms of cell wall components varied across locations. Some genotypes showed considerably more sensitivity to environmental factors than other more stable genotypes. The environmental influence on biomass quality is substantial and should be taken into account when matching genotype, location and end-use of miscanthus.

As lignocellulosic feedstocks are considered low-value, high-volume commodities, most scenarios consider their cultivation on low-quality/marginal land where the occurrence of various abiotic stresses is highly probable. The fact that agricultural inputs need to be minimized on such land may lead to additional stresses. As miscanthus is seen as a robust perennial crop with high potential for low-quality/marginal soils (Quinn et al., 2015), it is very likely to experience abiotic stresses during its cultivation. Apart from the adverse effects of abiotic stresses on plant growth, another challenge is the fact that abiotic stresses result in changes in cell wall architecture and that in some cases these can lead to a reduction in the industrial quality of the biomass. It has been shown that subjecting plants to abiotic stress treatments often results in cell wall biosynthesis genes being differentially expressed (Frei, 2013; Le Gall et al., 2015; Moura et al., 2010; Tenhaken, 2015). However, there have not been may investigations into the specific effects of the various abiotic stresses on cell wall composition and biomass quality (Tenhaken, 2015).

The OPTIMISC project assessed the effects of the abiotic stresses drought, salinity and cold on miscanthus biomass quality. The abiotic stress treatments were found to lead to substantial changes in biomass composition. Drought stress caused significant reductions in cell wall and cellulose content and a significant increase in hemicellulosic polysaccharides. However, it had only a small effect on lignin content. It was hypothesized that the reduction in cellulose is the result of an increase in osmolyte production at the expense of cellulose as a strategy for maintaining turgor at a lower water potential. Cold stress caused a significant decrease in cell wall, cellulose and lignin content, again with a significant increase in hemicellulosic polysaccharides. The same trends were observed in response to salt stress, but the effects were smaller.

Overall, the main response observed to all of these abiotic stresses was a decrease in cellulose content and a concomitant increase in hemicellulosic polysaccharides. The reduction in cellulose content has a negative impact on the industrial quality of the biomass for biofuel production, as it implicates a reduction in the main source of fermentable sugars. However, as also seen in the drought-treated samples, the increase in hemicellulosic polysaccharides led to a substantial increase in saccharification efficiency of the biomass. There is often a positive correlation between hemicellulosic polysaccharides and increased cell wall degradability, as an increase in these highly branched polysaccharides is associated with a reduction in crystallinity (Xu et al., 2012). Thus, although the stressed samples contain a lower amount of fermentable sugars, they are more easily extracted. This could potentially reduce processing costs for many potential value chains, including biofuel production. The higher degradability of plants experiencing abiotic stresses makes miscanthus an interesting crop for exploitation of marginal soils for the production of second-generation biofuel.

3.1.2.3 Harvest regime
Several of the OPTIMISC trials included evaluations of the effects of different harvest regimes on miscanthus biomass yields. As Figure 6 (Annex II) shows, the yield reaches a peak in autumn and then decreases, mainly due to leaf loss. The assessments concentrated on the effect of harvest time on biomass yield and quality and investigated whether multiple cutting systems could improve yield
performance.
For M. sinensis, a double-cut harvest (summer cut in July, winter cut in February) was shown to yield significantly less biomass than a single-cut harvest in February. Averaged over eight genotypes, the double-cut regime yielded an annual biomass of ~2.4 t DM/ha while the single-cut regime yielded ~6.3 t DM/ha for the first complete growing season after establishment. The weather conditions in summer 2015 favoured a higher biomass quality for ethanol and biogas value chains, but the yield penalty of an early cut was too substantial to recommend a summer cut for any of the miscanthus value chains considered. Similar results were observed in a cutting tolerance trial using M. x giganteus (Kiesel and Lewandowski, 2016). In this trial, a double-cut harvest regime (first green cut in July, second green cut in October) and two single-cut harvest regimes (early harvest in August and late harvest in October) were compared with a conventional spring harvest. The double-cut and the early single-cut harvest regime showed serious yield decline the following year, indicating that both regimes were not tolerated by the crop and are not sustainable in terms of yield formation. The harvest in late October delivered very high and stable yields of 25-28 t DM/ha, suggesting that M. x giganteus can tolerate a green harvest at this time. Relocation of carbohydrates was identified as an important factor influencing the cutting tolerance. It appears that the crop had enough time to relocate sufficient carbohydrate reserves to the rhizome before the harvest in late October (Kiesel and Lewandowski, 2016).

The biomass quality of green-harvested miscanthus for biogas production and consequently substrate-specific biogas yield declined with later harvest dates. However, the early green harvest led to a biomass yield decline the following year due to insufficient cutting tolerance. This lower biomass yield was not compensated by the higher substrate-specific biogas yield. Therefore cutting tolerance was identified as a crucial factor for the long-term productivity of green-harvested miscanthus. October was identified as the most promising and cutting-tolerant harvest date for biogas production. On average it delivered a 45% higher methane yield than the conventional winter harvest, due to higher biomass yield and improved biomass quality. Cutting tolerance is also relevant for the use of miscanthus biomass for protein and chlorophyll production. These can be extracted from the biomass prior to its processing for bioenergy or other applications. Chlorophyll is used as a food additive, whereas protein is used as a feed additive. As such, both are important added-value bioproducts and can contribute to the value of miscanthus biomass in the biorefinery chain. In the large-scale field trials at Blankney and Stuttgart, it was found that harvesting OPM-111 later than early July resulted in a significant decrease in both chlorophyll and protein content. At harvest earlier than July, the protein content of leaves and stems were about 12 and 11% of DM, respectively. At Blankney, the chlorophyll content reached up to 3.5% of DM in leaves and 2.8% of DM in stems. At Stuttgart however, leaf and stem chlorophyll contents only reached about 2.5 and 1.8% of DM, respectively.

3.1.3 Technologies for harvesting and logistics
Harvesting miscanthus is a fuel- and labour-intensive process (depending on harvest procedures), and has the largest cost and environmental impact (in terms of fuel usage) for a producer. For this reason, it is important to gather data that can help growers make use of methods best suited to their existing equipment and facilities. In addition, data is required that take the variation in harvest efficiencies of the different genotypes into account to allow farmers to cultivate the genotype best suited to their harvesting needs, thus maximizing profitability in the biomass value chain. Harvesting techniques, climatic conditions and plant morphology all interact to affect biomass quantity and
quality and the resultant options for downstream biomass utilisation (see Chapter 3.2.2). Self-propelled forage harvesters (normally used for maize) have been successfully used to produce chips from M. x giganteus in the UK, France and Germany following cold winters, which force the crop to ripen with a moisture content below 25%. This direct chipping approach results in biomass losses of only 5% (Meehan et al., 2013). The chips dry well in covered storage. However, miscanthus chips have a number of drawbacks. Firstly, they have a low bulk density (150 kg/m3), which leads to high storage costs and limits the location of markets to within the proximity of the available crop. Secondly, the low bulk density reduces the fuel mass in the combustion chamber, which lowers the thermal output of most boilers. Thirdly, unless the chips have been produced using a high-precision chop forage harvester, bridging and clogging can be a problem with automated feed systems.

The harvesting experiments at Blankney in WP5 led to the following conclusions:
- Large self-propelled direct chipping harvesters with 7.5-m cutting widths have high throughputs and are potentially more fuel (3%) and time (~10%) efficient than machines with a 4.5-m cutting width.
- Farmers (or machine rings) will most probably harvest with the locally available technology in order to minimise additional capital costs. Therefore, it is likely that smaller harvesting machines will be used. Harvesting speed and efficiencies do not represent a bottleneck to deployment. As the scale of planting increases, the machinery will develop to match demands.
- Moisture content of the different hybrid types ranged from 13 to 20% of DM. The hybrids with low moisture content are the most amenable to harvest by self-propelled direct chipping harvesters, since no degradation of the biomass occurs during storage at these low moisture levels.
- In mild winters, where senescence is incomplete in non-flowering genotypes such as M. x giganteus, mowing and then windrowing before baling will remain an important harvest method even though harvest losses are higher.

OPTIMISC also investigated the pelleting of miscanthus biomass. All the pellets produced are described as “good, hard and durable.” The highest bulk density (810g/l) was achieved using M. x giganteus biomass (OPM-09) and the lowest (664g/l) was observed for OPM-12. The highest percentage of fines (small particles of un-pelleted material) occurred in OPM-52 (24.98%) and the lowest in OPM-12 (16.19%). The pellet press performance was characterised by three parameters: roller temperature, load amps and feeder speed. The only significant difference in roller temperature was found with M. x giganteus, which also increased the average amps (i.e. more energy is used) from 18-20 to 20-22. The lowest temperature of the rollers after pellet production (95 degrees C) was found with OPM-12, compared to 127 degrees C for M. x giganteus. The feeding setting (rate) was 46% for all four new hybrids and 35% for M. x giganteus, indicating a decrease in capacity of 24% when pelleting M. x giganteus. The test showed the most easily pelletable genotype to be OPM-12 and the most difficult to pellet genotype to be M. x giganteus, which has significant morphological differences (much harder, larger stems) to OPM-12.

Large-scale commercial pelleting tests showed that all miscanthus hybrids could be successfully pelleted. Slight adjustments to the machinery normally used for wood pellets are needed with M. x giganteus to avoid overheating of the press. All the new (softer-stemmed) hybrids tested had lower pressing resistances and therefore lower die temperatures and power requirements.

The different miscanthus hybrids tested showed significant variation in pelletability. As was expected, M. x giganteus, with its hard, stiff stems, was the most difficult to pellet, but it gave the highest pellet bulk density. The softer-stemmed hybrids were easier to pellet but had lower pellet bulk density. Thus, M. x giganteus biomass has both an advantage and a disadvantage over the new hybrids.
The biomass of the softer-stemmed hybrids had both a lower moisture content at harvest and also lower levels of ash and chlorine after pelleting than that of M. x giganteus. This is important for industrial uses. The calorific values of the pellets from the different hybrids varied slightly, but there was wide variation in ash and chloride contents. The divergence in ash and chlorine content of the flowering, thinner-stemmed hybrids and the non-flowering, thicker-stemmed M. x giganteus is expected to widen in warmer winter conditions due to greater variation in senescence by harvest time.

The energy costs of large-scale pellet production can vary from 40 to 80 €/t pelleted biomass, at a capacity of approximately 3t/h. The final cost of production also depends on the wear and tear of pellet press parts (die and rollers), and there is a significant correlation between this wear and tear and biomass composition and structure.

3.2 Miscanthus value chains – options and implementation

In OPTIMISC, the economics as well as GHG- and fossil-fuel-saving potentials of seven miscanthus-based value chains were analysed in detail. The following tables give examples of the results: Table 10 (Annex I) for sites in north-eastern Europe (data from the Moscow/Russia site); Table 11 (Annex I) for Central Europe (data from the Stuttgart/Germany site); and Table 12 (Annex I) for southern Europe (data from the Adana/Turkey site).

3.3.1 Carbon mitigation and fossil energy substitution potentials

For all miscanthus energy and material applications, OPM-06 is most suitable in north-eastern and Central Europe, followed by OPM-10 and OPM-09 in north-eastern and OPM-03 and OPM-09 in Central Europe. In southern Europe, OPM-09 (M. x giganteus) proved most suitable for all the miscanthus-based value chains analysed, followed by OPM-11 and OPM-14 or OPM-06 for biogas. This means that M. x giganteus proved a feasible choice for all locations and applications. The suitability of the genotypes was determined according to yield and quality performance with regard to anticipated use.

The optimal harvest time differs for each value chain. For combustion, a late harvest leads to low moisture content and other favourable biomass quality criteria, but also to biomass yield losses. For ethanol and biogas production, a green harvest in autumn is optimal (Tables 10 – 12, Annex I). For biogas production, high DM yield and low lignin content are important determinants for high biogas yield and can best be achieved by a green cut. A green cut is also a prerequisite for biomass ensilage. However, so far the cutting tolerance of a green harvest has only been tested for M. x giganteus (Kiesel and Lewandowski, 2016). Further investigations are required to assess the cutting tolerance of a green harvest in the novel genotypes. The novel genotypes are not expected to be less cutting tolerant than M. x giganteus, because this is late senescing. It is assumed that relocation of carbohydrates and nutrients are linked to senescence, and that both influence cutting tolerance. Cutting tolerance could be very different in southern Europe where the winters are very mild winters and the yield peaks before the summer drought in June or July. In these climates the relocation processes may start much earlier (flowering also starts much earlier), so it is possible that a harvest in summer could be tolerated.

The highest biomass yields as well as the highest GHG- and fossil-energy savings potentials (up to 30.6 t CO2eq/ha*a and 429 GJ/ha*a, respectively) can be achieved on non-marginal sites in Central Europe (Table 11, Annex I). On marginal sites limited by cold (Moscow/Russia) or drought (Adana/Turkey) savings of up to 19.2 t CO2eq/ha*a and 273 GJ/ha*a (Moscow) and 24.0 t CO2eq/ha*a and 338 GJ/ha*a (Adana) can be achieved (Tables 10, 12, Annex I).

The GHG and fossil-energy savings are highest where miscanthus biomass is used as construction
material (our analysis uses the example of insulation material). A high GHG and fossil-energy saving potential was also found for domestic heating on account of the short transportation distance. Pelleting is only advantageous in terms of the minimization of GHG emissions and energy consumption where biomass is transported over a long distance, for example for heat and power production in CHP (Tables 10 – 12, Annex I). Pelleting requires additional energy, but at the same time reduces the energy required for transport due to its higher density.

The lowest GHG- and fossil-energy-saving potentials were found for power production via the biogas pathway, followed by bioethanol. However, this result is strongly influenced by the assumptions that a) only 50% of the available heat is used and b) transport distance from the field to the biogas plant are relatively long (15 km). A biogas chain with 100% heat utilisation and lower transportation distances would perform comparatively better. It is concluded that for miscanthus biomass power production via combustion should be preferred for base load power and the biogas pathway to cover peak loads.

The economics of biomass production for different value chains is shown in the example for the Stuttgart site (Germany) (Table 13, Annex I).

Biomass supply costs are assessed here as the costs for producing, densifying and transporting the biomass from the farm to the unit where the biomass is burned or processed into ethanol or insulation material. They range from 78 € per ton dry mass chips (for local, small-scale production) and 79 € per ton silage (50% water) for biogas production up to about 140 € per ton dry mass of bales for the production of insulation material, ethanol and pellets.

Compared to costs for producing energy from fossil fuels, small-scale combustion of chips proved to be highly profitable. Pelleting of biomass increases the cost by about 30%, but still costs per KWh thermal energy produced remain comparatively low. Both options lead to negative carbon mitigation costs (Table 13, Annex I).

Assuming a transport distance of 400 km leads to carbon mitigation costs of about 83 € per ton CO2equivalents avoided, either through biomass supply as bales or as pellets, when electricity is produced in a medium scale 5 MW CHP Power plant (Table 13, Annex I). The share of transportation cost has to be reduced to make CHP electricity a viable option for electricity production from miscanthus biomass. The same applies to biomass cost for bioethanol. If translated to costs per litre bioethanol about 24 € ct/l produced are caused by biomass. Reduction of transport distances is important to reduce the cost share of biomass. However, the advantage of producing a bio-chemical or liquid transport fuel should be considered.

Miscanthus biomass costs in biogas production are comparable to those caused by annual crops, providing a cost comparison builds on the same transport distances. However, with miscanthus biomass production is more sustainable than with annual crops.

Biomass supply cost per m³ of insulation is in the order of 28 €, if a transport distance of 400 km is assumed. This is competitive to the market prices of glass wool. The competitiveness of miscanthus insulation can be improved by producing miscanthus closer to the insulation material production site. There was a clear effect of yield level on the cost per unit of biomass. For the conditions given in Stuttgart relative cost of bale harvest was 28.9 €/t DM with 15 t/ha harvested. This decreased to 23.5 €/t DM when a yield increase to 18 t DM/ha was assumed. The example shows the limitations regarding the cultivation of miscanthus on marginal land because the costs per unit produced are rising and are not always compensated by lower cost for lease of land. However, it is expected that by the result of OPTIMISC the biomass yield of miscanthus on marginal land can be increased because on three of the five experimental OPTIMISC sites M. x giganteus was out yielded by novel genotypes. Near Stuttgart yield of OPM-6 was
20% higher. It can be expected that from the gene pools tested and characterized in OPTIMISC new hybrids will become commercially available in the near future.

Another option to alleviate the problem of marginal yield levels is the cultivation on larger field plots. Growing miscanthus for combustion on a 20 ha plot instead of a 2-ha plot can decrease biomass cost by 18% (KTBL, 2012). Growing miscanthus on marginal land has lower opportunity costs and therefore lower economic returns than on high yielding farmland are acceptable. If grown on fields were annual crops often fail the perennial crop always will give some return and can be more attractive, even with moderate yield levels. In Iowa USA, it is estimated that good opportunities for miscanthus exist on 10-20% of the marginal corn land where farmers lose money every year (Heaton, 2014).

A higher price for miscanthus with higher added value for industry is another option where OPTIMISC created new perspectives and opportunities. Research on quality aspects of different genotypes for specific end uses allowed the identification of novel genotypes with higher added value incorporated in the field level. For example, it could be demonstrated that there is scope for the development of new varieties with considerable potential to reduce pre-treatment costs in bioethanol production. Bioethanol yield after mild treatment of lignocellulosic biomass is a good indicator for possible savings in industrial bioethanol production. In Stuttgart/Germany hybrid OPM-6 had 37% higher ethanol yield after mild treatment than M. x giganteus (OPM-9). This should lead to higher payments for biomass due to cost savings in industrial processes.

3.3.2 Letting farmers benefit

It is unlikely that large areas of good agricultural land will be dedicated to miscanthus production. However, farms can benefit from the incorporation of miscanthus production in many ways. An integrated approach to miscanthus production can be seen in France where small miscanthus fields are established in a way that improves the landscape. In the UK, arable farmers working with the company Terravesta found that using the 10% poorer quality land for miscanthus bioenergy production resulted in practical examples of sustainable intensification with the better 90%, delivering increased yields and an overall better economic return at farm level. (Pretty et al. (2011) defined sustainable agricultural intensification as follows: “producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services”). Farms can benefit from the integration of miscanthus through the following aspects:

1. Making better use of the least suitable fields or areas of the farm to generate an income from biomass production.
2. Using miscanthus to improve the environmental performance of agriculture by integrating perennial crops in a way that fulfils ecological functions, such as carbon sequestration, prevention of erosion, flooding or nitrate leaching, and providing habitats for wildlife.
3. Improving soil quality and thus farm productivity by increasing the humus and nutrient content, improving soil structure, or remediation of contaminated soils.
4. Provision of biomass for on-farm use, e.g. heating purposes or animal bedding.
5. Making use of on-farm biorefinery concepts, where miscanthus biomass is processed and a higher-value product than biomass is brought onto the market (e.g. electricity from biogas).

3.3.3 Policy actions to support the implementation of miscanthus production and use in Europe

Breeding programs and development of agricultural equipment for miscanthus production are the most important technical elements to be developed. Another element is market access and for the development
of a robust supply chain from farmers to end user customers. Support is also needed to develop of high value biomass applications, such as bio-chemicals and bio-composites. A stronger engagement of farmers in the value chain through “on-farm biorefining” concepts would increase income opportunities for farmers because they can market high-value products instead of low-value biomass. It is also recommended to consider the ecological potential of miscanthus in the CAP, for example by giving further consideration to them in developing greening measures. These recommendations are elaborated in the following chapters:

- Ecological benefits of perennial biomass crops need to be recognised
  Remuneration for non-market ecosystem services should include funding matched to particularly high service provision, for example flood risk reduction, soil protection, nitrate mitigation etc. Include into Ecological Focus areas.

- Replacing less sustainable biomass with PBC
  About six million ha of agricultural land in the EU are used for so-called ‘first generation’ energy and industry crops. Rapeseed and maize are the most prominent examples. Linked to assessing the land resource, the replacement of these intensively managed annual crops with perennial biomass crops could be a priority to reduce nitrate leaching, erosion, the use of agrochemicals, and to increase soil carbon sequestration and biodiversity. Maize for biogas could be replaced by miscanthus, if the fermentation technique is adapted or biomass pre-treated.

- Support the development of miscanthus varieties that are adapted to marginal land
  Miscanthus shows good potential to make use of land, which is marginal or difficult to manage, or for land restoration. However, marginal production conditions can also result in low profit margins (van Dam et al., 2005) which are not compensated for lower land costs. Therefore, crop management systems which ensure safe establishment and optimal management in these conditions needs to be developed and stress-tolerant genotypes are required. Plant genetic improvement, even of the major agricultural crops such as wheat, is subject to significant market failure (Moran et al., 2007). This means private market actors under-invest in breeding because the market does not provide the incentive for the level of investment that is optimal for society. This failure is likely to be even greater for perennial biomass crops, particularly for adaptation to marginal land. Tolerance to abiotic stresses that characterize marginal land was shown in OPTIMISC for miscanthus. Informed by insights into the available land resource and thus the potential market for improve planting material, we suggest that a miscanthus strategy should lead to a plan for appropriate public investment in plant breeding, including through partnerships with private sector breeders stimulating and supporting demand for the ‘upstream’ research, which also required long-term support.

- Technical barriers to the implementation of PBC on marginal land need to be overcome
  Presently, the estimated area under miscanthus in the EU is about 20,000 ha and is decreasing in many regions. High production costs result from insufficient development of cultivars and agricultural production technology, along with high costs for agricultural inputs, land and labour for relatively low-value biomass. Although they are amortized over a production period of 4-25 years, establishment costs for miscanthus are high and need to be reduced. The development of agricultural machinery, such as planting or harvesting equipment, will remain
insufficient so long as there is no larger market for such machinery. Today, farmers often use self-made equipment, such as adapting potato harvesting machines for the harvest of miscanthus rhizomes. In addition, the development of service units, such as machinery cooperatives, will only develop once miscanthus production reaches a significant scale. The feasibility of public intervention to reduce the financial risks arising from high establishment costs should be investigated. It is noted though that there is less than encouraging experience from national schemes that have aided planting. The Defra Energy Crops Scheme that ran from 2000 to 2013 provided planting grants but uptake was low (Lindegaard, 2013). However, these schemes tended to be targeted at normal agricultural land. A framework for integrating the benefits, for example by targeting marginal land or to reduce the risk of flooding, was not used.

Grant-aid for planting is not the only mechanism. Integrated with local land-use strategies for multiple benefits, Pillar II funds (Rural Development) could be used to generate critical technical mass at local level. Options include supporting local processing, machinery development or cooperation. This will address low farmer acceptance and make the use of miscanthus to optimize agricultural land use a normal part of a more diverse farm sector. Farmers hesitate to produce miscanthus because it involves dedicating their land to long-term biomass production. They will only be willing to do this if biomass markets are reliable or if long-term contracts are available in recognised supply chains. Therefore, the development of biomass marketing structures should be supported. This could also be supported under Pillar II.

- Stabilizing markets and adding value on-farm

The main current application of miscanthus biomass is for bulk heat and power production - a comparatively low value market whose value depends on the price of fossil fuels used for large-scale heat and for electricity generation. Complementary to theses existing markets there is a need for programs for supporting smaller-scale but higher value applications of miscanthus biomass to develop attractive and new market options. This should also include options of “on-farm bio-refineries” that help to keep a higher proportion of the value generated from biomass and its processing and use remains on the farm. The development of on-farm biorefinery concepts, which allow decentralized biomass densification and valorisation, can help to involve farmers in the local bio-based value chains.

4. References


Lewandowski, I. (2016): The role of perennial biomass crops in a growing bioeconomy. In: Barth, S.,
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Potential Impact:
OPTIMISC resulted in significant advances in our understanding of the potential of Miscanthus genetic diversity and the impacts on production and end users systems in Europe. These findings are relevant for the (low cost) production of miscanthus especially under marginal growing conditions and for the improved supply of miscanthus biomass for energy and material applications to diverse markets. All relevant results and potential impacts of OPTIMISC are summarized in Table 7 of Annex I.

Several impacts of the OPTIMISC project are highlighted as follows:

+ Extension of the climatic range of miscanthus production area to northern, southern and eastern Europe. Compared to a scenario where only the genotype M. x giganteus is available (Figure 3a, Annex II), a large potential expansion of the miscanthus growing area to east, south and north of Europe is predicted for a scenario where the genotypes screened in OPTIMISC are developed as varieties to be grown commercially (Figure 3b, Annex II).

+ Miscanthus genotypes for biomass production on marginal land in Europe
A major output of OPTIMISC is the availability of miscanthus germplasm with tolerance to the key abiotic stresses such as drought, low temperatures and salinity. Often land classified as “marginal” with regard to bio-physical constraints to biomass production, is characterized by these stresses. According to the European Commission Joint Research Centre, Institute for Environment and Sustainability, salinization and sodification are among the major degradation processes endangering the potential use of European soils and there are an estimated 20.7 million ha of sodic and saline soils available in the EU, Ukraine and
Russia. Especially in Mediterranean and coastal areas, soils with increased salinity sometimes represent over 50% of an area.

In the OPTIMISC project, diverse germplasm (160 genotypes) was screened for abiotic stress tolerance traits for the future selection and genetic improvement of miscanthus cultivars for marginal lands. Concurrently, a set of fifteen diverse and promising germplasm types (11 clones, and 4 seed populations) were selected from wild accessions and a range of novel crosses for multi-location trials across a wide geographic range. These trials demonstrated tolerance to local conditions namely: differences water availability in the growing season (including drought at some locations in some years – in particular Adana and Moscow), salinity (in China), chilling and/or frost stress (at most sites, except Adana, Turkey).

OPTIMISC results show that there is a huge European potential for Miscanthus, especially on marginal land because its perennial features mean that it can 1) reduce erosion, 2) accumulate soil carbon 3) take up soil contaminants. Miscanthus biomass production from miscanthus has high potential to improve the bio-physical properties of soils in marginal sites for crop production and to simultaneously provide other ecosystem services.

+ Scaling up of miscanthus production becomes feasible

OPTIMISC results contribute to fulfilment of requirements for scaling up miscanthus production by:
- Providing technology for seed-based, low cost and safe propagation and establishment methods,
- Identifying germplasm for the breeding of stress tolerant miscanthus varieties, adapted to a wide range of climatic conditions in Europe,
- Providing higher and more stable yielding miscanthus genotypes that can also economically be produced on marginal lands,
- Providing new information linking genotype characteristics with the whole biomass value chain from in field harvesting to end use,
- Contributing to the development of efficient harvesting and densification technology,
- Diversifying markets for miscanthus biomass by assessing new miscanthus-based biomass value chains and showing how these could fit to a range of user requirements.

+ Sustainable production of biomass for new material and energetic applications

About six million ha of agricultural land in the EU are used for so-called 'first generation' energy and industry crops. Rape seed and maize are the most prominent examples. Linked to assessing the land resource, the replacement of these intensively managed annual crops with perennial biomass crops like miscanthus could lead to reduction of nitrate leaching, erosion, the use of agrochemicals, and to increase soil carbon sequestration and biodiversity. For example, maize, which is a crop considered of low ecological quality, could be replaced by miscanthus for biogas and /or biogas production from maize by thermal conversion of lignocellulosic biomass.

Most perennial crops produce lignocellulosic biomass with some less desirable properties that need to be overcome to maximise uptake for both energetic and material applications. In OPTIMISC the feasibility of different promising value chains were made: namely combustion, ethanol, biogas and insulation material production.

+ Benefits for farmers

Farmers can benefit from the incorporation of miscanthus production in many ways. An integrated approach to miscanthus production can be seen in France where small miscanthus fields are established
in a way that improves the landscape. In the UK, arable farmers working with the company Terravesta Ltd. found that using the 10% poorer quality land for miscanthus bioenergy production resulted in practical examples of sustainable intensification with the better 90%, delivering increased yields and an overall better economic return at farm level. Farmers can benefit from the integration of miscanthus through the following aspects:

1. Making better use of the less suitable fields or areas of the farm to generate an income from biomass production.
2. Using miscanthus to improve the environmental performance of agriculture by integrating perennial crops in a way that fulfills ecological functions, such as carbon sequestration, prevention of erosion, flooding or nitrate leaching, and providing habitats for wildlife.
3. Improving soil quality and thus farm productivity by increasing the humus and nutrient content, improving soil structure, controlling weeds, or remediation of contaminated soils.
4. Provision of biomass for on-farm use, e.g. heating purposes or animal bedding.
5. Making use of on-farm bio-refinery concepts where miscanthus biomass is processed and a higher value product than biomass is brought to the market (e.g. electricity from biogas).

+ Carbon mitigation and fossil energy substitution potentials
GHG and fossil energy savings potentials of up to 30.6 t CO2eq/ha*a and 429 GJ/ha*a were assessed for miscanthus on non-marginal sites in Central Europe. On marginal sites, limited by cold (Moscow/Russia) or drought (Adana/Turkey) savings up to 19.2 t CO2eq/ha*a and 273 GJ/ha*a and 24.0 t CO2eq/ha*a and 338 GJ/ha*a can be respectively achieved.

The implementation of miscanthus biomass production and use can therefore significantly contribute to achieve the GHG reduction aims of the EU.

Dissemination activities and exploitation of results
During the OPTMISC project results were disseminated frequently through conferences, farmer engagement events, peer reviewed publications and our project website.

Until March 2016 over 130 dissemination events have taken place and further dissemination of the project’s final results are occurring presently or will continue after the end of the project, for example at the 24th European Biomass Conference and Exhibition in Amsterdam (NL) in June 2016.

OPTIMISC team members attended more than 78 events in 12 countries (9 EU countries, Russia, USA and China). 47 oral presentations were given on national and international conferences and scientific symposia. On 14 occasions oral presentations were given at events of producers, manufacturers and other miscanthus stakeholders and for the wider public.

OPTIMISC scientists presented their work and results during 17 exhibitions and field days to professionals and interested visitors. Public relation activities informed on the possibilities of using miscanthus and ongoing research activities to cope with the needs of specific end users in different climatic zones of Europe. A web-based decision support tool (Link address: [http://www.anna-consult.de/transfer/DS_Tool_Final_12.xlsx](http://www.anna-consult.de/transfer/DS_Tool_Final_12.xlsx)) was developed for a quick and location-specific choice of adapted genotypes and biomass use options. On several occasions scientists, farmers, students and wider public were invited to field demonstrations organized by OPTIMISC team members.

At least 27 different posters were presented at conferences, during exhibitions and field days attended by OPTIMISC team members. Several public newsletters with a mix of information from the project activities and other interesting news from the world of miscanthus were sent out to 210 OPTIMISC newsletter
subscribers to keep in touch with dedicated European stakeholders along the miscanthus value chain. Following are some examples to illustrate OPTIMISC’s work of dissemination and knowledge transfer.

At conferences
• In September 2015 OPTIMISC took the lead in organising the conference on „Perennial Biomass Crops for a Resource Constrained World“ at the University of Hohenheim (Biomass2015). The meeting was organised jointly by the OPTIMA, OPTIMISC, GrassMargins, FIBRA and WATBIO research consortia and associated national projects. Several projects of the European Framework Program 7 were given the opportunity to consider their work together and present final project results. A conference summary was written and made available online at https://biomass2015.uni-hohenheim.de and also distributed as printed version to diverse stakeholders.
• A number of scientific articles from the Biomass2015 conference have been accepted to the special issue of Global Change Biology – Bioenergy Journal.
• Two scientific editors from OPTIMISC project have initiated a special issue (research topic) “Optimising Miscanthus for the sustainable bioeconomy: from genes to products” of “Frontiers in Plant Science”, where the major project results will be presented to a wider public and scientific community in a peer-reviewed open access scientific journal. In this Research Topic a set of 20-25 manuscripts will be compiled that report advances in fundamental and applied aspects of the C4 bioenergy crop Miscanthus and its role in mitigating climate change as part of the bioeconomy.

To farmers
• Major attention was also given to the bi-annual conferences of the International Society for Miscanthus and Perennial Energy Grasses (MEG), where mainly miscanthus farmers are members (http://www.miscanthus-society.com). At the bi-annual conferences of the Int. Miscanthus Society in Bonn (Germany) the project was introduced by the project coordinator and information and networking activities planned were presented by OPTIMISC dissemination officer. In Chartres (France) at the 8th Int. Conference of the Society five oral presentations were given and two posters were presented by OPTIMISC team members who also took the opportunity to debate current opportunities and implementation bottlenecks of miscanthus in Europe. Web content from OPTIMISC is linked to the webpage of the society and vice versa and it was agreed upon that the so far mainly German speaking society will create English language contents to continue the work of OPTIMISC (stakeholder platform and newsletter) to improve the information exchange between miscanthus stakeholders in Europe also in future. Contact data of more than 200 registered subscribers of the OPTIMISC newsletter will be handed over to facilitate this transition.

During several field days farmers and interested public were informed about the crop, miscanthus genetic variability, agronomy and farm technology available to produce and process the biomass. Five Open field days on miscanthus and other energy crops and an opportunity farming workshop held in Belgium explored added value applications of miscanthus. Open field demonstrations of current and novel genotypes were also held in Germany (2), in Russia (5) and in the Netherlands (2). In the UK new planting
technology with seed propagated plugs of novel hybrids was demonstrated at the CEREALS exhibition (1) and during the field visits (2).

Scientific publications

- Several papers from OPTIMISC scientists were accepted for inclusion in the a special issue of GCB-Bioenergy Journal on Perennial Crops (2016)
- A special issue of Frontiers in Plant Science on miscanthus in which many OPTIMISC final results will be presented is launched with the paper submission in November 2016
- 11 articles in scientific peer reviewed journals were published or accepted for publication until April 2016

Other publications

- On four occasions press releases were launched, a monograph on the development history of miscanthus in Europe and ten chapters in books were written to report OPTIMISC work. An article in popular press and a monograph on the main results and expected impacts from the international conference on perennial biomass crops were released.

Exploitation of results

The OPTIMISC results will be exploited at several levels:

- Provision of farmers with all information about options for improved and low cost miscanthus biomass production

As described above, farmers get fully informed about the results and findings of OPTIMISC. Information is provided in such a way (e.g. field demonstration, articles in farmer journals, homepage of the MEG) that it can directly implemented in their farming practice.

- Use of novel germplasm for breeding programmes

The novel genetic miscanthus material characterized in OPTMIMSC for cold, frost, water-stress and salinity tolerance, for higher biomass yields and better quality properties than the standard genotype M. x giganteus, will be used for miscanthus breeding programmes. Through these breeding programmes varieties to be applied by European farmers in different production environments and for the production of high quality biomass for different bioeconomic uses will be developed.

- Providing low cost planting material and safe establishment methods to the market

Methods for seed-based propagation and using mulch films are ready for the market. These technologies are actually used for scaling-up miscanthus production in Europe by a farm-based company and is a good example how farmers can benefit from the OPTIMISC results.

- Providing biomass users with information on the performance of quality optimised biomass

A reliable supply with biomass matched to the end use is a prerequisite for a growing bioeconomy. The results of OPTIMISC with regard to quality properties, along with biomass costs and carbon footprint, are all available to potential biomass users, who would be able to integrate these into the development of their business model.

- Providing methods for harvest and logistic optimisation
Based on the results of OPTIMISC procedures for pellet production were developed for a range of thick, medium and thin stemmed types. Pellets significantly contribute to the transportability and storability of biomass. Pellet production procedures are made available by OPTMISC dissemination. Also, recommendations for reduction of harvest losses are made and can be applied by miscanthus producers directly.

• Implementation of new miscanthus based value chains
Genotypes optimised for combustion, biogas, ethanol and simultaneous chlorophyll and protein production were identified. The optimal choice of miscanthus genotypes for these purposes under different production conditions is possible through the public decision support tool developed in OPTMISC http://www.anna-consult.de/transfer/DS_Tool_Final_12.xlsx.

• Policy recommendations were made on sustainable biomass production and GHG reduction options in a growing bioeconomy
Practical recommendations for the political support of a sustainable biomass production based on miscanthus in a growing bioeconomy were explored. These are complemented by recommendations for the production of perennial biomass crops in Europe through the summary of the Biomass2015 conference https://biomass2015.uni-hohenheim.de and include quantitative information on GHG mitigation options.

List of Websites:
http://www.optimisc-project.eu

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