Terravesta Ltd

Sustainable land use change

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OVERVIEW **3**
Goals of this report 4
Miscanthus 4
Biodiversity 4
LAND USE CHANGE SUMMARY **6**
Primary forest use 7
Arable land use 7
Efficient farm management 8
Miscanthus plant physiology 8
Nutrient requirements 8
Improved soil and water health 9
Carbon net zero 9
High-yielding biomass with minimal water 10
Low on fertiliser and herbicide 10
Wide field margins 10
Monoculture vs intercropping 11
Biodiversity compared to other arable crops 11
Restoring soil health 12
Soil erosion 12
Agrochemical treatments 13
Flooding 13
Invertebrates 13
Pollinating insects 14
Birds 14
Mammals 15
RECOMMENDATIONS **16**
CONCLUSIONS **18**
ABOUT **20**
Terravesta 21
Terravesta ATHENA TM 21
Projects 21
REFERENCE LIST **22**

OVERVIEW

Goals of this report

1. Gather evidence to support the thesis that Miscanthus can be used to produce products without a detrimental impact on biodiversity, the environment and food production.
2. Define strategic methods for specifying, locating and cultivating land that is suitable to sustainable cultivation and relay these as a guideline to suppliers of Miscanthus biomass.

Miscanthus

Miscanthus x Giganteus, a perennial rhizomatous grass, is a promising lignocellulosic feedstock originating from Asia. After establishment from the third season onwards, this sterile, thus noninvasive hybrid of M. sinensis and M. Sacchariflorus, grows to heights of up to 4 metres per season. Miscanthus receives little or no cultivation in its 20+ year life span. Its root structure stabilises and helps improve soil quality, as well as slowing flooding, thereby preventing soil runoff and subsequent sedimentation into waterways.

Harvest in late winter or early spring and increased soil carbon and organic matter and ample leaf litter are considered favourable to biodiversity. Due to its suitability to a wide range of climatic and soil conditions the average fresh mass yield is a generous 8 - 14 metric tons per hectare per year [54].

Miscanthus' fertiliser and herbicide demand is very low and limited to the period right after establishment. This and its low maintenance characteristic allows farmers to grow the crop sustainably mostly on unproductive agricultural land or on the field margins thus not affecting the global food supply.

Miscanthus comes from a rare group of C4 plants which feature a more efficient carbon absorption pathway in their photosynthesis process. The repeated annual CO_2 absorption in the above-ground biomass and the significant carbon sequestration in its roots makes Miscanthus one of the most sought after zero carbon second generation biomass crops for fighting climate change.

Biodiversity

Biodiversity measures the variety of plant and animal life in a particular habitat, a high level of which is usually considered to be desirable. Biodiversity refers to the ability of an ecosystem to better maintain its natural balance and its higher robustness against external shocks. The case for high levels of biodiversity is based on the fact that all species are to some extent unique, each important for or performing a different set of functions. The sum of all these functions maintains the balance of an ecosystem and keeps it healthy and prospering. If one function is removed due

to species loss, this loss can potentially have knock-on effects on other species and eventually imperill the ecosystem as a whole.

The level of biodiversity is not easily captured as it consists of a combination of several aspects among which the most important and commonly observed are *richness* which measures the number of different types of species in an ecosystem, *abundance* which refers to the number of individuals of a species that are present in a given area and *evenness* which evaluates how common or rare a species is compared to other species.

Most of the approaches for the quantification of biodiversity rely purely on the mentioned aspects, which are then most commonly aggregated into a single index, while other important aspects such as rarity and endangerment are rarely considered. Other factors which may substantially influence biodiversity, but which are independent of the established crop itself and are seldomly measured by studies are seasonality, field size, applied agricultural practices, plant age, landscape context and planting density.

Research on biodiversity is domain and habitat specific. The data gathering methods vary in many studies due to the different nature of their study objectives. Therefore, conclusions of these studies may not accurately reflect the reality when applied on a different geographical location and must be assessed on a case by case basis.

LAND USE CHANGE SUMMARY

Primary forest use

Forests are both one of the most important carbon sinks for mitigating climate change and their loss is one of the leading causes of carbon dioxide emissions. Old-growth, primary and natural forests are more effective carbon sinks than plantations or industrially managed productive forests. Forests are home to most of Earth's land-based biodiversity. Losing primary and old-growth forests, to managed new-growth forests, means losing habitats and thus decreasing biodiversity. Therefore, from a biodiversity perspective where possible, using biomass crops from marginal lands are always preferable to converting primary forests to industrial uses.

Arable land use

Miscanthus grows on unproductive arable land not used or suitable for food production offering economically viable yields of biomass [40]. Unproductive lands mean different things in different locations and contexts, such that it is difficult to estimate the available amount of unproductive lands. Unproductive land may be characterised as *idle, under-utilised, barren, inaccessible, degraded, excess or abandoned lands, lands occupied by politically and economically marginalised populations, or land with characteristics that make a particular use unsustainable or inappropriate*. [1]

Examples of unproductive land:

- land that would yield poor return for food crops due to soils with naturally poor conditions
- partially or occasionally flooded land
- land that was once used for agricultural purposes and has since been abandoned
- land too distant from the farm rendering transportation of machinery uneconomical
- land marked by erosion, salinization, low organic carbon contents
- land which suffers from pollution from previous industrial activities

Miscanthus has a high potential for cultivation over a wide range of climates [41]. The EU project MAGIC estimates that there is 45 million hectares (449.901 km^2) of marginal land suitable for Miscanthus x Giganteus plantations in the European Union [31].

The 2007 UK biomass strategy (DEFRA, 2007) set a target of 0.35 Mha of UK agricultural land growing perennial biomass crops by 2020. Its updated version the 2012 UK Bioenergy Strategy (DECC, 2012) suggests that the potential land available specifically for Miscanthus that would not impinge on food production is in the range of 0.72–2.8 Mha. In Germany in 2022, around 11.66 Mha of land in Germany were used as arable land, 25% of which is considered to be of either of very poor or poor quality and thus qualifies as marginal land [55, 56].

Efficient farm management

Contrary to the food versus biomass discussion, Miscanthus helps farmers increase their arable output by reducing time spent on difficult land to farm. With Miscanthus this land can be planted once in 20 years and does not require any input or management for the rest of its useful life. Concentrating agronomic effort and resources away from these less productive lands to more productive land while cultivating low-input, low labour Miscanthus on these poorer areas could offer a mechanism for both intensification and diversification within farms. In addition, the phytoremediation property of Miscanthus actually increases the availability of arable land for food production in the long term by converting low quality and possibly contaminated marginal land unsuitable for food production back into food quality land [25].

After the third year from establishment, harvesting consists in cutting and eventually baling the yearly grown biomass. These steps can be outsourced to contractors for harvest therefore costing the farmer very little time or effort. In fact many farmers in a later stage of their life prefer to switch to farming Miscanthus as it requires no physical effort to speak of and no machinery use at all.

Miscanthus plant physiology

Miscanthus produces bamboo-like canes during late spring and summer which are harvested in late winter or early spring. Miscanthus spreads naturally by means of underground storage organs known as rhizomes. However, their spread is slow and there is little risk of uncontrolled invasion. Rhizomes can be split and the pieces re-planted to produce new plants. All propagation, maintenance and harvest operations can be done with conventional farm machinery.

Leaves shedding is part of Miscanthus senescence process. The leaves fall off in the winter, contributing to the development of soil humus and nutrient cycling [12]. Since Miscanthus leaves have low-nitrogen, high-carbon content, they thus degrade slower than many other plant species such as hay or other typical farm residues. Therefore, despite the fact that Miscanthus as a crop is annually harvested, this particular characteristic provides a potentially significant advantage for biodiversity in Miscanthus cultivations as its ample and slowly degrading floor litter offers protection against predation and reduces soil surface moisture loss [19, 38, 39].

Nutrient requirements

Miscanthus is deep rooted and can abstract nutrients from a large area of soil which it then uses with efficiency compared to arable crops such as wheat or barley. As the plant senesces excess nutrients are exported from the above ground parts back to the rhizome during the autumn as the leaves first dry and then die. These are then stored in the rhizome during the winter and are

used to support early growth of shoots during the following spring. Nutrient off-takes are confined to the amount of nutrients in the stems at harvest as nutrients in the leaves fall to the ground and are thus returned to soil. This explains why the application of fertiliser on for-profit-managed fields is practically unheard of and studies have shown that Miscanthus is generally unresponsive to its application during the growing season. [23, 24, 25, 50]

Improved soil and water health

Miscanthus has been reported growing, and producing high or reasonable yields on a wide range of soils, from sands to high organic matter soils. It is also tolerant of a wide range of pH, but the optimum is between pH 5.5 and 7.5. Miscanthus not only grows on soils not suitable for food crops but improves poor soils through increased organic matter and no cultivation for 20 years [19, 21].

Miscanthus can help to improve water health, and is suitable to be planted as buffer strips to reduce soil, chemical and nutrient runoff from intensively farmed arable land [15, 20].

Minimal care is needed for established Miscanthus crop:

- reduced use of tractors (and thus fuels) on the field
- reduced fuel/chemical use
- reduced environmental impact from spraying (once in its lifetime, before establishment)

Carbon net zero

Plants sequester carbon through photosynthesis, a sunlight-driven process where CO_2 and water are absorbed and then combined to form carbohydrates. When the harvested biomass is combusted, the absorbed carbon is released back to the atmosphere as CO_2 but the belowground parts of the plant (roots and rhizomes) remain in the soil and can potentially add substantial amounts of carbon to the soil over the years.

Perennial crops sequester more carbon than annual crops due to three factors:

- the root buildup is allowed to continue undisturbed over the life of the plant and
- yearly tillage procedures associated with growing annual crops are not necessary
- over the years high amounts of harvest residues and foliage are absorbed into the soil

Over its life cycle, Miscanthus crops store carbon in the soil as organic carbon and the above ground biomass captures carbon as it regrows every year [16, 17, 19]. As Miscanthus grows, its above ground biomass will absorb the equivalent of 26 t/ha/year of CO_2. The underground rhizome locks away the equivalent of 3.5 t/ha/year of CO_2 as it grows, building healthier soils.

Emissions of all on-farm and delivery activity, a total of 2.35 t/ha/year of CO_2 is offset by the underground biomass [33].

Depending on use of biomass, the biomass carbon is either stored in addition to the below ground storage above, or released in which case the use process is carbon neutral, with the released CO_2e being reabsorbed by the above ground biomass for the next harvest [10, 11, 32].

High-yielding biomass with minimal water

Miscanthus is unusually efficient at turning solar radiation into biomass [23], and its water use efficiency is among the highest of any crop. It has twice the water use efficiency of its fellow C4 plant maize, twice the efficiency as the C3 energy crop willow, and four times the efficiency as the C3 plant wheat [25].

The typical UK winter harvest ranges from 8 to 14 tonnes dry mass per hectare. This compares to forest plantation yields which range from 0.4 to 12.2 tonnes per hectare of dry mass per year. [26]

Low on fertiliser and herbicide

Miscanthus' fertiliser and herbicide demand is very low and limited to the period right after establishment once in its 20 year lifetime due to the plant's efficient nutrient recycling and the absence of major pests [42, 46]. For example in the UK and Poland, based on Terravesta’s experience, no fertiliser is applied at all and herbicide application is limited to clearing the field before establishment of the new crop. After the second year the dense canopy and the mulch formed by dead leaves effectively reduces weed growth [43].

The use of synthetic fertiliser and pesticide has not only negative consequences for the environment but also for crop production itself. Nitrogen pollution (from both agricultural runoff and aerial deposition) in terrestrial ecosystems causes species loss throughout the food chain [28]. Pesticides can be found at far distances from their site of use accumulating in soils and food chains, with toxic effects also on non-target species threatening ecosystems and human health [29].

Wide field margins

Miscanthus planting and harvesting requires large machinery. In order to guarantee accessibility to the crop in the first place, to allow turning at the field’s head sections and for stacking of bales after harvest, Miscanthus plantations feature regular and wide field margins. This is beneficial to pollinating insects as there is a consistently higher species richness and abundance of insects in the field margins, which act practically as pollinator strips, compared with the field centres of arable crops [9]. This suggests that these features of Miscanthus fields should be conserved to

maintain pollinator communities despite understandable tendencies by growers to move towards ever greater field surface efficiencies.

Monoculture vs intercropping

Intercropping is an agricultural practice that involves growing two different crops at the same time, very close together, to benefit from how they interact. The first and most immediate benefit of intercropping over monoculture is biodiversity. Crop biodiversity has positive effects not only on farmers' revenues but also on soil fertility.

Smaller farms tend to have higher yields, harbour greater crop diversity and higher levels of non-crop biodiversity than comparably larger farms. Plant biodiversity promotes and stabilises the provisioning of ecosystem functions and services, such as biomass production, nutrient cycling supporting processes, soil carbon storage, pollination, or the reduction of pests and pathogens [34].

While intercropping through diversifying planting profolio is a good mitigation against monoculture, further considerations can add to the benefits. Scaled crop production often will benefit by having the field "squared off". As such it will leave space for inserting buffer strips to plant Miscanthus that would result in reduced operational burden and biodiversity gain; minising soil erosion; and improves water health [15]. By leaving the lighter land that is better for food production while cultivating Miscanthus on less productive and heavier land, it can increase arable productivity by allowing resources to be redirected to food production. Also taking advantage of intercropping margins by breaking bigger plots to include prairie mixes can further encourage birds/pollinators to nest [6, 9, 13]. In addition, if Miscanthus is planted strategically, it can be an effective wind breaker for higher pasture yield [4].

Last but not least, Terravesta has developed seed-based Miscanthus hybrids that are not clonal and therefore not monocultural, offering better pest resistance and genetic diversity.

Biodiversity compared to other arable crops

Miscanthus provides cover for most of the year because, although the crop is harvested annually, it is harvested shortly before the following year's growth begins. This cover can act as a wildlife corridor linking existing habitats.

Miscanthus can also act as a nesting habitat, for both ground nesting birds in the early spring and reed nesting birds, later in the summer. Miscanthus is a useful game cover crop and nursery for young pheasants and partridges.

Field sizes tend to be small or medium sized which is beneficial to biodiversity in general as biodiversity has been observed to be inversely correlated to field size [22].

Restoring soil health

Industrial, mining, urban, and agricultural activities have resulted in soil and water contamination by heavy metals. Some can be transferred into the food chain from crops to animals and humans resulting in environmental and health hazards [44]. Miscanthus can endure soil pollution and survive in adverse environmental conditions and as a non-consumable crop reduces their transfer into the food chain. Therefore, it also has applications in ecological remediation of contaminated soil, and reclamation of polluted soil and water resources allowing farmers to diversify and provide biomass without compromising food security [7, 8, 18, 45, 46].

Owing to its ability to stabilise trace elements in its roots and degrade some organic pollutants, Miscanthus limits pollutant transfer by reducing groundwater contamination, pollutant run-off, surface water contamination, pollutant emissions into the atmosphere that potentially can transfer into food chains [43]. Overall, reduced toxicity in the biota allows for a healthier environment for wildlife.

Soil erosion

Soil erosion goes beyond losing fertile land. It has increased pollution and sedimentation in streams and rivers, clogging waterways and reducing fish and other species. And degraded land is often less able to retain water. This can make flooding worse. For many organisms that can no longer live there, a barren landscape ultimately leads to a reduction in the biodiversity of the ecosystem [58].

Water erosion is listed first among the factors degrading soils worldwide [20]. Water soil erosion, in particular, is one of the biggest environmental threats in the Mediterranean area as it causes pollution of water bodies, critical losses of water, and deteriorates the physical and chemical properties of soils. It leads to reduced soil fertility, thus to decreased crop yields and increases flood risk and destruction of infrastructure [51].

Even in the first two years of vegetation, when Miscanthus has not yet reached the stage of full development, its significant mass of underground roots rapidly strengthens the topsoil and its dense canopy protects against splash erosion. Later on as it grows to full height its deep roots penetrate the soil to up to 2 metres further strengthening the soil's resistance to erosion [20]. Large amounts of plant residue accumulate over the years on the soil surface and associated with its no-till characteristics influences the total amount of soil cover on the field mitigating further soil erosion [1, 15].

In order to protect soil from wind erosion, Miscanthus shelter belts may be established increasing downwind fruit, arable and horticultural crops yields and accelerating ripening. Its benefits extend

also to pastures, in fact pasture height increased when exposed to a shelter belt of Miscanthus [4].

Agrochemical treatments

Soil microbes constitute the biosphere that is the most important fraction of soil involved in nutrient cycling responsible for maintaining soil fertility. Agrochemicals are used to enhance the productivity of crops but when entering into the soil they affect soil microbes with an overall detrimental impact on soil health. [30].

Miscanthus fields show reduced N leaching when compared with arable crops [1, 51]. N_2O (Soil nitrous oxide) has a global warming potential of almost 300 times greater over 100 years than CO_2 [52], and agriculture is the largest producer of this gas [53]. N_2O emissions can be 5 times lower under unfertilized Miscanthus than annual crops and up to 100 times lower than intensive pasture. Nitrogen fertiliser is generally unnecessary except in low fertility soils.

Weed control with the application of herbicides is essential in the establishing year but becomes redundant as the crop matures and the effectiveness of the Miscanthus canopy structure and litter layer kicks in as natural weed suppression. Pesticides are unnecessary [25].

Flooding

Flooding has no detriment to Miscanthus, research shows that it not only thrives on waterlogged land. It survives without any impact to its yield even in winter-flooded environments [2]. But not only, Miscanthus improves soil hydraulic properties and ground water storage capabilities compared to annual row crops due to its more fibrous, and extensive rooting systems [25]. Its root structure stabilises and feeds soils, as well as slowing flooding, thereby preventing soil runoff and subsequent sedimentation into our critical waterways. Miscanthus helps to drain wet soils by its transpiration characteristic, with which the plant on warmer days releases humidity through its leaves to the air (canopy evaporation). Current Miscanthus cultivation practice is to harvest the plant in late winter or early spring allowing the above ground material to remain standing in the flooded area. This prevents soil losses, mitigates flood depths, and reduces velocity of overland flow [2]. Its capability of draining wet soils, preventing run-off of water as well as its dense canopy and thick leaf litterage keeping the soil humidity are all beneficial to creating a more stable habitat to ground dwelling organisms.

Invertebrates

Since the perennial grass Miscanthus requires a single initial planting and related tillage, and also no major chemical inputs over its life time and because the crops are harvested in the spring and the land is not disturbed by cultivation every year, Miscanthus fields are used by invertebrates as over-wintering sites with immediate benefits to biodiversity [6]. The diverse ground flora which

can inhabit the soil beneath a mature miscanthus canopy will provide food for butterflies, other insects and their predators [49].

Land-use intensity is inversely correlated to earthworm abundance and in general to the total number of species [35]. But because of the typically extensive leaf litter on the ground, Miscanthus helps the soil to stay moist, and also protect from predators. Miscanthus, even in intensive agricultural landscapes, has an overall positive effect on earthworm communities, spider abundance and spider richness and thus offers food for birds and other mammals [4, 6, 50]. The positive effect on earthworms is of particular relevance as earthworms are regularly used as general bioindicators, by reason of their key role in modifying the soil environment and by this they crucially affect further soil organisms, soil microflora and related enzyme activities [36].

Pollinating insects

Pollinating insects require flowering plants to forage from, but also need nesting, mating, ovipositing, larval and overwintering sites. Agricultural intensification and land-use change and many other human activities are drivers for pollinator decline. Miscanthus compares well with conventional grass fields and there are detectable patterns towards higher abundances of butterflies in Miscanthus versus grasslands. In general, Miscanthus compared to conventional first generation biomass crops, has been suggested as beneficial for insects as it features longer rotation periods, low inputs of agrochemicals, fewer disturbances during the growing season, is harvested in winter, generally is planted with ample field margins and provides a greater richness of spatial structures [37]. Miscanthus provides better nesting opportunities due to its low-disturbance, perennial nature and potential nest sites offered by dead stems and leaf litter left in the field after harvesting [9, 14].

Birds

Birds are the largest group of terrestrial vertebrates. Ongoing global change, in particular agricultural intensification, forest cover change, urbanisation and temperature change, has widespread impacts on avifauna. Of these, agricultural intensification has the greatest impact on birds due to the use of pesticides and fertilisers. Insects are an important part of the diet of many birds. The cultivation of Miscanthus, which does not require any spraying after establishment, would make a massive difference to birds, at least during some stages of their development, such as the breeding season. This would ensure better food availability for invertebrate feeders. It would also reduce contamination for birds with a more granivorous diet [59].

Miscanthus plantations tend to have similar bird biodiversity as fields of grass. Compared to wheat, an intensively cultivated crop across Europe, Miscanthus shows a greater abundance and

diversity. For individual bird species, in general, the densities recorded in Miscanthus fields are similar to the highest values reported in studies from other crops.

Due to its exceptionally rapid growth and the impressive heights it reaches later in the year, Miscanthus offers a different ecological niche for each season [49]. The continually evolving structural heterogeneity, especially height and density, allows different bird species to find shelter at different times during its development, woodland birds in the winter and farmland birds in the summer [3].

In winter, the greater numbers of birds in Miscanthus fields are possibly attracted by the significantly better shelter provided by the crop and by the abundance of non-crop plants in the field itself and on field margins.

During the breeding season, the abundance of non-crop plants in Miscanthus fields, and greater numbers of insects associated with these plants, provides food resources and thus Miscanthus fields feature greater bird densities than in conventional arable crops. For some bird species It appears that the tall, dense crop provides a suitable nesting habitat. Eventually, based on geography, the harvesting of Miscanthus fields can be anticipated or postponed by a few weeks in order to allow the breeding season of native species to proceed unhindered.

Similarly, in summer, Miscanthus provides nesting habitat and therefore a greater abundance and diversity of invertebrate prey than cereal crops and thus attracts birds [3, 5]. Also minimal field work, basically just harvesting once a year, provides a safe and undisturbed habitat for ground nesting birds [3, 5].

Skylarks, meadow pipits and lapwings use Miscanthus, as well as 37 other species of birds including wren, linnet and goldfinch that feed on the grass seeds. Once the leaves are shed in winter, a suitable habitat is provided for yellowhammers. Open areas between stools provide ideal habitat for birds such as skylarks and meadow pipits.

Mammals

As a component of a mixed farming landscape, Miscanthus offers areas of low mechanical and chemical input of particular importance at times of the year when such areas are scarce in intensively farmed landscapes [49]. Miscanthus provide biodiversity benefits by increasing spatial heterogeneity and refuge areas for farmland species like brown hares, wood mice, field voles and common shrews [47, 48]. Other observed animals in Miscanthus fields include stoat, vole, shrew, fox and rabbit. Many of these are a useful source of food for larger carnivores such as the barn owl [51].

RECOMMENDATIONS

Independently from the current project, generally, the following best practice recommendations are accepted by literature for cultivating sustainable second generation biomass crops [57]:

- ensure that the scale and location minimises impact on landscape and the environment
- manage to benefit biodiversity
- reduce distance to market
- increase habitat and landscape diversity through time staggered planting
- use non invasive species resistant to pests & disease
- maximise the opportunities for buffering, extending and relinking habitats
- maximise carbon savings
- minimise the use of fertilisers, herbicides and pesticides
- involve the community and allow public access

CONCLUSIONS

Team Terravesta would like to thank you for consulting us.

ABOUT

Terravesta

Terravesta is a specialist in the energy crop and biomass supply chain, producing sustainable energy and biomass from marginal land with Miscanthus. Terravesta provides a sustainable solution for farmers and nature by improving soil, air and water health, biodiversity and reducing fertiliser use. Terravesta also provides high-yield IP protected, climate zone adapted varieties of Miscanthus, planting equipment, agronomic data and advice, and long term offtake contracts. Terravesta invests heavily in research and development. It works not only with growers and companies, but also with academia, NGOs and governments to meet the needs of nature, farmers and industry. The mission is to develop industrial crops that reduce atmospheric carbon while creating new sustainable markets, materials and products.

Terravesta ATHENA ™

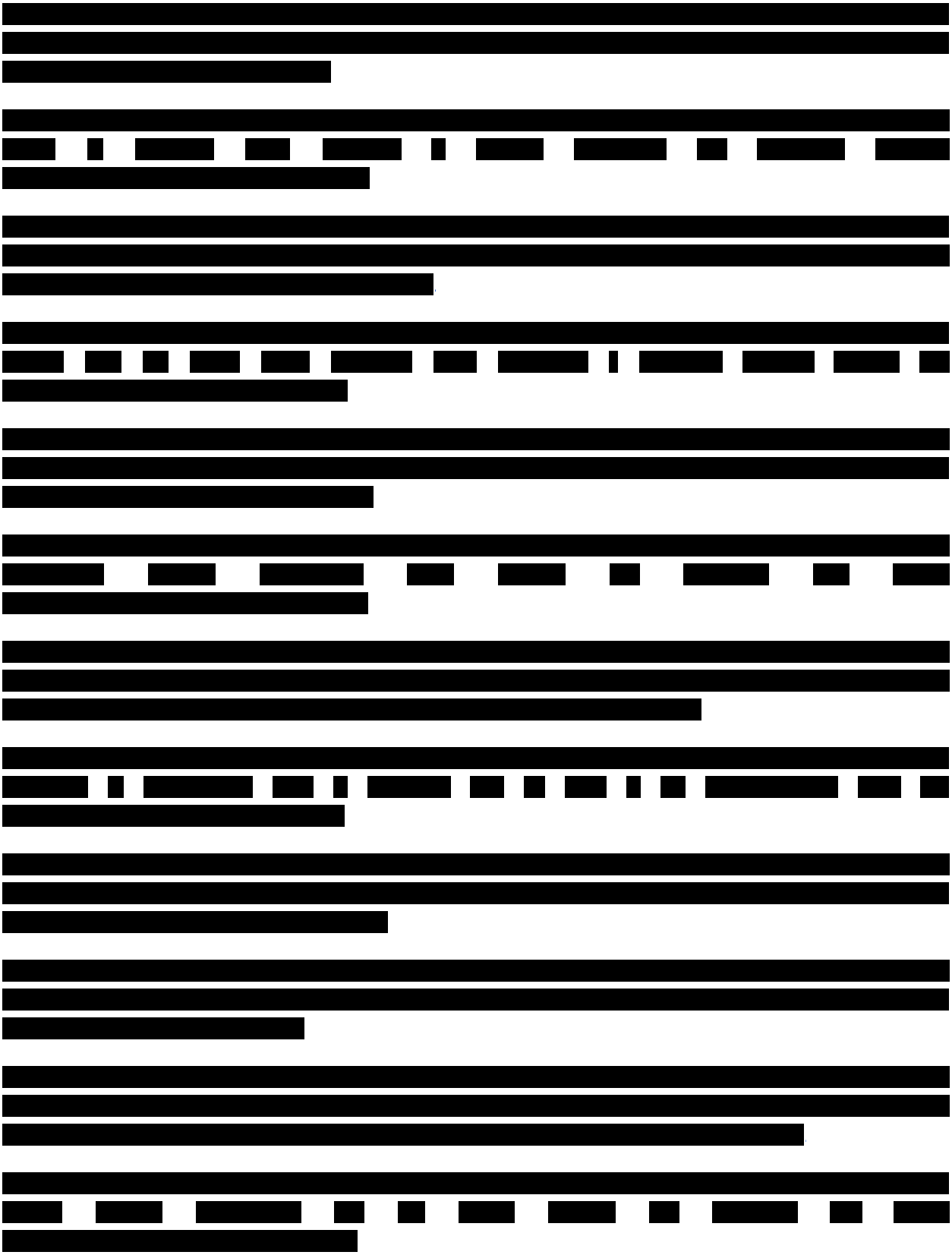
Terravesta Athena™ is the highest performing commercial variety of Miscanthus Giganteus. It has undergone rigorous selection and development to ensure more vigorous, stronger, hardier plants with stable yields, tolerance to more extreme conditions and increased yields. Compared to the original Miscanthus x Giganteus, biomass quality has improved with higher calorific values and lower ash content.

Projects

In the UK, Terravesta has signed long-term contracts with biomass power stations for a total capacity of 85 MW. Having established a network of hundreds of growers around the power station sites, Terravesta manages the agronomy, harvesting and logistics of the biomass, supplying tens of thousands of bales of dry Miscanthus each year from close by fields. This service is highly valued by farmers as it provides index-linked income from unproductive land over a 20-year period. For the industry Terravesta facilitates the procurement of a guaranteed supply of biomass. Terravesta is currently working on several projects that bring together biomass farmers, logistics companies and industrial users **for a better and greener future**.

REFERENCE LIST

Contact Terravesta for a version of this report with full access to sources.



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