The impact of Short Rotation Coppice plantations on phytodiversity

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Abstract

There is currently an increasing demand for wood as a renewable energy source. Plantations with fast growing trees, such as poplars and willows, have been established, grown in a short rotation coppice (SRC) system. A further increase of SRC plantations is expected in the future, but their effects on biodiversity are little known. We give an overview of the current state of knowledge on the phytodiversity in SRC plantations.

Many factors influence the vegetation in a SRC plantation. E.g. light climate and the tree age play important roles for species composition, species number and vegetation cover. The older the planted crop, the shadier the conditions for the ground vegetation, which is associated with a shift from annual to perennial and from light demanding to shade tolerant species. Furthermore, the land use history and the vegetation in the surrounding landscape have considerable influence on species composition in SRC plantations. The more diverse the surrounding landscape, the more species are able to establish in the plantation. Smaller plantations with longer edge habitats (ecotones) facilitate species immigration from the surroundings better than larger plantations. Smallscale structured plantations increase biodiversity.

When comparing SRC plantations with other land uses, diversity is often higher than in arable fields and coniferous forests, but lower than in oldgrowth mixed deciduous forests. If established in areas dominated by agriculture or coniferous forests, these plantations may increase regional diversity. Habitats of threatened species as well as areas adjacent to lakes or rivers should be avoided, whereas former arable lands and grassland fallows are generally well suited.

Keywords: biodiversity, energy crop, land use, landscape scale, poplar (Populus), sewage sludge, site preparation, species richness, SRC, willow (Salix)

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Zusammenfassung

Der Einfluss von Kurzumtriebsbeständen auf die Phytodiversität

In den letzten Jahren ist die Nachfrage nach Holz als nachwachsender Rohstoff zur energetischen Nutzung gestiegen. Dazu werden Plantagen mit schnell wachsenden Baumarten, sog. Kurzumtriebsplantagen (KUP), angepflanzt. Mit einem weiteren Anstieg kann gerechnet werden, wobei der Kenntnistand über die Auswirkungen der KUP auf die Biodiversität bislang gering ist. Der Artikel gibt einen Überblick über den gegenwärtigen Wissensstand zur Phytodiversität in KUP.

Die Begleitvegetation in KUP wird durch viele Faktoren beeinflusst. Licht und damit verbunden das Alter der Plantage spielen eine wichtige Rolle für die Artenzusammensetzung, Artenzahl sowie die Bodenbedeckung der Vegetation. Umso älter die Plantagen sind, desto weniger Licht steht für die Begleitvegetation zur Verfügung. Dies bewirkt eine Verschiebung von einjährigen zu mehrjährigen und von lichtliebenden zu schattentoleranten Arten.

Die vorherige Vegetation sowie die umgebenden Landnutzungstypen haben einen großen Einfluss auf die Artenzusammensetzung der KUP. Umso vielfältiger die Umgebung ist, desto mehr Arten können sich in einer KUP etablieren. Kleinere Plantagen mit längeren Randzonen sind besser für eine Besiedlung aus der Umgebung geeignet als größere Plantagen. Kleinstrukturierte KUP erhöhen die Biodiversität.

Verglichen mit anderen Landnutzungen sind KUP häufig artenreicher als Ackerflächen und Nadelwälder, aber artenärmer als alte, gemischte Laubwälder. In einer von agrarischer Nutzung oder von Nadelwäldern dominierten Umgebung erhöhen KUP oft die regionale Diversität. Es wird davon abgeraten, KUP in Gegenden mit seltenen Arten sowie an Seen und Flüssen anzulegen, während ehemalige Ackerflächen und Grünlandbrachen häufig gut geeignet sind.

Schlüsselworte: Biodiversität, Energiepflanze, Landnutzung, Landschaftsebene, Pappel (Populus), Klärschlamm, Bodenbearbeitung, Artenvielfalt, KUP, Weide (Salix)

1 Introduction

Since the early 1970s, many countries around the world have been developing new crops in order to increase the biomass resource base for production of bioenergy (Wright, 2006). Fast growing trees have been cultivated for many years in various European countries, with test-trials on willows grown in short rotation for the purpose of biomass production initiated in the 1980s (Kuzovkina et al., 2008). Commercial willow plantations are grown in a short rotation system on 15,000 ha in Sweden (Nordh, 2007), while in Poland the planted area is about 6,800 ha and in Germany less than 1,000 ha (Thrän and Seiffert, 2008). In general, short rotation coppice (SRC) plantations consist of fast growing trees or shrubs and are characterized by higher wood productivity in time and space than conventional cultivated forests, due to high juvenile growth rates of the trees. SRC plantations are mainly grown for producing wood fuel for heat and power production. The most important tree species grown in European SRCs are willow, poplar, aspen (including hybrids) and robinia, which all are characterized by fast juvenile growth, often with the capacity for asexual reproduction and an ability to regrow from rootstocks or stools. The plantations are established at high densities on arable land in spring and harvested in winter during vegetation dormancy when the ground is frozen. Prior to the plantation establishment, chemical or mechanical weed control is needed to minimize competition for resources and thereby allow for vigorous growth of the planted crop (Larsson et al., 2007). In many sites, especially in Central Europe, fertilization is not needed if the plantation is established on former arable land. When plantations are fertilized with sewage sludge, which is common in Sweden, the plantations act also as vegetation filters.

The demand for wood as a renewable resource for energetic use is currently increasing due to increasing energy use, the decline of fossil fuels and increasing energy prices. Further arguments for increased biomass demands include global environmental problems related to climate change in connection with CO_2-emissions and political requirements. As a result, demand is expected to continue to increase in the future. The cultivation of fast growing trees on agricultural land is a viable alternative for the production of renewable resources, particularly because these trees can achieve high biomass yields with relatively low input of nitrogen fertilizer and are regarded as efficient nitrogen users (Karp and Shield, 2008). However, knowledge is scarce about the effects of SRC plantations on the environment. The objective of this paper is to give an overview of the current state of knowledge about phytodiversity in SRC plantations and to derive recommendations for phytodiversity management in SRC stands. The overview is based on a survey of the literature mostly from Europe.

2 Establishment and management of SRC plantations

Rotation times and planting densities

In central Europe, there are currently three recognised kinds of rotations. In mini-rotation, which is the main cultivation method for willow, the trees are harvested after two or three years. The tree density is 16,000 to 20,000 per hectare. Midi-rotation takes four to six, at most ten years with a tree density of 6,000 to 9,000 per hectare and is often used for poplar. The third rotation type is maxi-rotation, suitable for trees like aspen, sycamore, basswood, mountain ash as well as alder and takes 10 to 20 years with densities between 1,500 and 3,000 trees per hectare (NABU, 2008). These data are only approximations because of the strong dependence of growth rate and adequate planting densities on site conditions.

Site preparation

Because of the enormous quantity of other seeds in the soil of agricultural fields and the weak competitiveness of young willow and poplar plants, action has to be taken to facilitate a successful establishment of SRC crops (Larsson et al., 2007; Stoll and Dohrenbusch, 2008). There are chemical and mechanical measures for preparing a field. For economic reasons chemical treatment is recommended in most cases before establishing a SRC plantation (Boelcke, 2006; Stjernquist, 1994), although sometimes only mechanical methods are used (Sage, 1998). However, the options of mechanical treatments have not yet been fully explored (NABU, 2008). For creating optimal conditions it is common practice to plough or grub up to 30 cm depth and harrow afterwards like in conventional agriculture. Treatment is recommended in autumn for cohesive soils whereas spring is the best time for more loose soil, so that already germinating seeds can be ploughed in (Larsson et al., 2007; Röhle et al., 2008). It is common to apply a broad-spectrum herbicide after ploughing the field in autumn (Boelcke, 2006; Burger et al., 2005; Fry and Slater, 2009; Schildbach et al., 2009). In spring, before planting, the field is grubbed (Schildbach et al., 2009), ploughed (Burger et al., 2005) or harrowed (Boelcke, 2006; Burger et al., 2005). Application of a pre-emergence herbicide is often recommended (Boelcke, 2006; Burger et al., 2005; Fry and Slater, 2009).

Undersown crops to repress ground vegetation are not recommended, because these would be strong competitors to the planted sprouts (Boelcke, 2006). Thus, experiments with undersown clover resulted in increased sprout mortality, sites with no treatment had a reduced crop growth rate, whereas herbicide application directly before or after sprout insertion stimulated crop growth (Wolf and Böhnisch, 2004).

If there is good nutrient supply from former land use, nutrient fertilization is not needed in the establishment year (Boelcke, 2006; DEFRA, 2004; Fry and Slater, 2009; Larsson et al., 2007). Annual nutrient extractions are low (Boelcke, 2006) and the crop is harvested in winter, when the trees are defoliated. The main part of nutrients is allocated to the leaves and therefore remains in the field after leaf abscission (Schildbach et al., 2009).

In comparison with conventional farming practices, SRC plantations require substantially less pesticide and herbicide treatment (Ledin, 1998; Perttu, 1998). Species composition is particularly strongly affected by herbicides applied during the establishment phase due to its impact on competition. This can cause long-term changes in the local species diversity. Herbicide application in mature stands has the potential to remove nearly all ground flora (Gustafsson, 1987), but in most cases herbicide applications are not necessary after establishment of commercial SRC plantations (Larsson et al., 2007).

Mechanical treatment like ploughing, harrowing or grubbing influences species composition as well, with the time of treatment playing an important role. The seeds from the surroundings influence the field strongly when cultivated in autumn, whereas this seed spread is insignificant in spring. Due to the fact that plant species are either spring or autumn-germinating, species of one of these germination types will be supported depending on whether soil cultivation is arranged early or late in the season (Gustafsson, 1987).

Many hardwood species (such as willows and poplars) are poor competitors in the juvenile plant stage when grown in a non-native environment. The poor competitiveness of the hybrid species grown in most commercial plantations makes weed control an extremely important management action, but implies also that the planted hybrids are unlikely to invade the surrounding areas and affect biodiversity (Weih, 2008a).

Sewage sludge

In Sweden it is common to use sewage sludge as fertilizer in willow SRC plantations. The practice may solve a waste problem, but is debated, because of environmental concerns (Dimitriou et al., 2006; Hasselgren, 1999). The sludge is normally dewatered and applied in spring after winter harvest every 3 to 5 years. Nutrient losses and leakage to the groundwater zone are reduced by applying sludge to an actively growing crop instead of bare soil (Hasselgren, 1998; Hasselgren, 1999). Hasselgren (1998) recommends application of 5 tonnes dry substance of sewage sludge per hectare per year. This amount should produce no adverse effects on soil, groundwater or vegetation. Sludge is also mixed with wood-ash from district heating plants (Dimitriou et al., 2006). Via irrigation of nutrient-bearing water such as wastewater from households, collected run-off water from farmlands and leachate of landfills, plantations can be used as vegetation filters for treatment. It is possible to locate plantations as buffer strips for capturing the nutrients in passing run-off water (Berndes et al., 2008).

Sludge application as a fertilizer may influence the ground vegetation and has been reported to affect ground vegetation cover (Hasselgren, 1999), but very little knowledge of sludge application on phytodiversity is currently available.

3 SRC effects on vegetation

Species composition

Species composition in SRC stands depends very much on light intensity which is highest in young plantations due to the lack of canopy closure. Light intensity is also dependent on the planted tree species and greatly influences the development and composition of the ground vegetation. For example, species that demand large amounts of light and nutrients, along with mild temperatures, typically colonize the plantations in the early stage (Delarze and Ciardo, 2002), in which the ground vegetation is dominated by annuals (Delarze and Ciardo, 2002; DTI, 2004; DTI, 2006). As a consequence of increasing canopy closure, radiation and temperature decrease, ground vegetation shifts from the initially ruderal and pioneer species towards woodland species (Britt et al., 2007; Delarze and Ciardo, 2002; Kroiher et al., 2008), and from annuals and biennials towards perennials (DTI, 2004; DTI, 2006). These changes are in accordance with the typical succession of dominant vegetation, i.e., short-lived species are usually more common early in succession whilst long-lived species usually dominate at later stages (Townsend, 2003). The shift from light demanding to shade tolerant species is likely to occur at some degree even after harvest, but has not yet been thoroughly investigated due to a lack of long-term surveys (NABU, 2008). Thus, DTI (2004) found that recently established SRC plantations are dominated by low vegetation cover dominated by annual species characteristic for disturbed ground, whereas plantations cutback after one year growth showed a higher vegetation cover, although still including a high portion of annuals. In contrast, Fry and Slater (2009) recorded almost equal proportions of annuals (34 %), short-lived perennials (39 %), and long-lived perennials (35 %) in the establishment year of willow SRC plantations grown on former grassland sites, where most of the species were typical of arable habitats or areas of recently disturbed ground. In year one and two they found a decrease of annuals, whereas short-lived perennials increased in the first year and remained constant in the second year. The proportion of the long-lived perennials increased slightly, but not significantly, and did not return to dominance like it had been the case before the establishment of the SRC plantation.

In many cases, only few species with regional conservation status are found in SRC plantations (Britt et al., 2007; DTI, 2006; Gustafsson, 1987; Vonk, 2008; Weih et al., 2003). Some rare species can occasionally be found in older stands (Gustafsson, 1987). Half of the willow plantations Gustafsson (1987) surveyed in southern Sweden were dominated by ruderal species like *Cirsium arvense, Galeopsis tetrahit* and *Urtica dioica*. *Urtica dioica* and grasses dominated the ground vegetation of 21 poplar plantations in southern and central England surveyed by Britt et al. (2007). On a plantation with poplars, hybrid aspen and willows in Bavaria (Germany), Heilmann et al. (1995) recorded five years after establishment mainly species typical of agricultural weed communities: 54 % of the species were perennial, among these mainly grasses, plus 6 % woody species as well as 40 % ephemeral species. This composition suggests the relatively undisturbed development of the vegetation (Heilmann et al., 1995).

The few rare or endangered species occasionally found in SRC plantations are predominantly light demanding pioneer species recorded in the first years of a plantation and disappearing with increasing plantation age. For example, Weih et al. (2003) found not a single rare species in 21 young poplar stands grown in Sweden, but Vonk (2008) found in a Dutch survey the orchid *Epipactis helleborine*, which has conservation status. Kroiher et al. (2008) recorded a higher number of rare species in SRC plantations in northern Germany: six out of 77 identified vascular plants are on the Red List of threatened species. These species have their main distribution in nutrient-poor habitats (Kroiher et al., 2008). Also a poplar plantation in Switzerland hosted many rare species: 18 out of more than 220 recorded species were on the Red List, for example *Ranunculus sceleratus*, *Carduus crispus* and *Carex riparia* (Delarze and Ciardo, 2002). The relatively high occurrence of rare species is probably related to the great tree distances at this Switzer site and the resulting favourable light and temperature conditions. The number of Red List species declined with increasing canopy closure of the poplars after two years, implying that the shortening of rotation time probably supports the establishment and/or survival of endangered species (Delarze and Ciardo, 2002).

The plant colonization of a plantation occurs from the surrounding area, the soil seed bank and through living vegetative tissues like rhizomes, tillers or living roots in the soil (Gustafsson, 1987; Stjernquist, 1994; Weih, 2008a). Therefore, the former vegetation and land use plays an important role for the composition of the ground flora in these plantations. The influence of former vegetation generally decreases with increasing age, but the magnitude and temporal development of the changes differs between land uses. A willow plantation in Sweden showed similar species composition compared with the meadow that used to be on this site, and a stabilization of the vegetation occurred four years after plantation establishment (Gustafsson, 1987). In contrast, changes were much more apparent on a former peatland site, in which no stabilization was recorded four years after establishment: half of the original species had then disappeared and those species still remaining had a very low cover (Gustafsson, 1987). Apart from former vegetation, also management regime greatly influences the floral composition in poplar and willow stands, as the results by Fry and Slater (2009) demonstrated.

Ground vegetation cover

As a consequence of the necessary field preparations prior to plantation establishment (Larsson et al., 2007; Stoll and Dohrenbusch, 2008), ground vegetation is very sparse when the crop is planted. Ground vegetation cover increased in the four years studied after establishment of willow plantations in England. Vegetation cover varied between individual plots, with some plots still dominated by bare ground even years after establishment (DTI, 2004). The vegetation cover of recently planted and cutback plots of year one was 10 % on average. In the last year of this four year study the average was 45 % (DTI, 2004). In recently established willow plantations, DTI (2004) detected higher vegetation cover in plots near the plantation edge compared to the plots situated closer to the center of the plantation, while the increase in vegetation cover over time tended to be more pronounced at the edges of the plots than in the interior.

According to calculated Evenness, older willow plantations show a higher heterogeneity than younger ones (Fry and Slater, 2009). The total number of species covering > 10 % increased throughout the three-year growth cycle, whereas the number of grasses covering > 10 % stagnated in the second year and decreased thereafter as fewer more competitive species like *Holcus lanatus* and *Dactylis glomerata* became increasingly abundant (DTI, 2004).

After harvesting a plantation, the cover of the ground flora increases (Heilmann et al., 1995), as it is expected from succession theory (Townsend, 2003). Still, vegetation cover is lower in willow plantations cutback after one year of growth than in recently planted stands (DTI, 2004). Although radiation would be expected to be one of the most important drivers for vegetation cover, Gustafsson

(1987) found no correlation between willow cover, ground vegetation cover and species number in southern Sweden. These plantations were not older than three years. It is expected that a longer rotation time would reduce the vegetation cover (Gustafsson, 1987) and species number, as was found by Heilmann et al. (1995).

Ground vegetation cover is also dependent on the planted crop. Different species and genotypes have different growth habits and are differently affected by habitat conditions. There is an increasing gradient in ground vegetation cover from poplar to hybrid aspen and willow due to differences in radiation climate resulting from different leaf phenology, growth habit and biomass of the trees (Heilmann et al., 1995).

Stoll and Dohrenbusch (2008) showed the influence of the former land use on biomass production and found the productivity of the ground vegetation to be higher on former grassland than on former arable land.

Species richness

Species numbers ranging from around 10 to more than 220 were recorded in willow or poplar plantations in Sweden, the Netherlands, the UK, Germany and Switzerland, with a trend to increasing species richness with decreasing latitude (Burger et al., 2005; Delarze and Ciardo, 2002; DTI, 2004; Gustafsson, 1987; Heilmann et al., 1995; Vonk, 2008; Weih et al., 2003). The number of species usually increases in the first two years after establishment and decreases thereafter with increasing age of the plantation (Delarze and Ciardo, 2002; DTI, 2004; Gustafsson, 1987; Wolf and Böhnisch, 2004). This pattern probably can be attributed to deteriorating light conditions on the ground over time, so that the conditions become increasingly similar to traditional forests. Especially the number of endangered species decreases over time (Delarze and Ciardo, 2002). DTI (2004) found more than six times more species in plantations cut back after one year of growth compared to recently planted ones.

A positive edge effect was recorded for species number in a similar way as was seen for ground vegetation cover (DTI, 2004). For example in willow and poplar plantations grown in southern and central Sweden, species numbers decreased with distance from the edges (Augustson et al., 2006; Gustafsson, 1987; Weih et al., 2003). A generally positive edge effect on species numbers was also found during the first two years after plantation establishment in UK investigations of willow stands grown on former arable land or grassland pasture (DTI, 2004; DTI, 2006). However, in the third and fourth year there was no relationship found between species number and distance from the edge, and a great proportion of total species numbers were only detected at the edges of the plots (DTI, 2004; DTI, 2006).

The above mentioned studies suggest that colonization occurs predominantly from the surrounding landscape, so that the location of a SRC plantation in the landscape context is critical for species numbers. The more diverse the surrounding landscape, the more species can colonize the plantations and thereby increase biodiversity (Weih, 2008a). Furthermore, the former vegetation normally influences the composition of the ground flora, especially in early stages (Gustafsson, 1987).

Plantation size and shape also seem to be important for biodiversity, with higher species numbers recorded at the edge of a plantation than within it (Augustson et al., 2006; DTI, 2004; DTI, 2006; Gustafsson, 1987; Weih et al., 2003). Stands of equal size have longer edges if they are long and narrow than if they are round or square. On one hand, longer edges support the immigration of seeds from the surrounding landscape, for example via wind and animals. On the other hand, round and squared stand shapes benefit the diffusion within the plantation (Gustafsson, 1987).

The more heterogeneous and species rich the surroundings are, the more species are likely to reach the plantation and establish there, suggesting a small-sized structure to favour species diversity (Gustafsson, 1987; Weih, 2008a). For example, on eight and nine year old poplar stands in Germany, 0.3 hectares contained almost all of the 38 species found in the whole plantation, and it was concluded that 1 ha of a homogeneous plantation hosts all the species found in larger plantations (Lamerstorf et al., 2008; NABU, 2008). Furthermore, large monocultures have been speculated to be more fragile to diseases than mixed stands. DEFRA (2004) therefore recommends a mix of species clones in a stand to minimize negative impacts of Melampsora rust damage, which is the most common fungal disease in willows and poplars.

Land-use effects on local and landscape scale

Species number in willow and poplar SRC plantations has frequently been reported to be higher than in conventional agricultural fields (Augustson et al., 2006; Britt et al., 2007; Burger et al., 2005; DTI, 2004; DTI, 2006; Fry and Slater, 2009; Heilmann et al., 1995; Perttu, 1998; Wolf and Böhnisch, 2004). Especially in the first year after establishment of a poplar plantation, its species number can be much higher than in comparison with an intensive cropland (Burger et al., 2005; Wolf and Böhnisch, 2004). On SRC fields in Bavaria, the recorded species numbers were up to ten times higher than in adjacent agricultural fields (Burger et al., 2005). Not only species number, but also vegetation cover (DTI, 2004) and floristic heterogeneity (Weih et al., 2003) have been reported to be higher in SRC fields than in arable land. In comparison to arable fields and grassland fallow, willow and poplar plantations have been shown to contain more species than arable land and higher or similar species richness to grasslands (DTI, 2004; Fry and Slater, 2009; Heilmann et al., 1995).

In comparison to old-growth mixed deciduous forests, species richness of young poplar plantations was similar or lower (Weih et al., 2003). In line with this observation, Schmidt and Gerold (2008) suggested that SRC plantations are closer to a natural state than conventional cropland, but cultivated forests are the vegetation types closest to nature in this comparison.

Considering habitat demands, one would expect differences in species composition of SRC plantations and arable fields. The differences in habitat demand are reflected by the Ellenberg values and the species in poplar plantations are characterised by low light, pH and nutrient demands, but high moisture demand (Britt et al., 2007).

The contribution of SRC species composition to gamma diversity at the landscape scale depends strongly on landscape structuring, land-use variability and habitat diversity (NABU, 2008). Positive effects of SRC plantations were found in agrarian regions with uniform landscape structures where SRC sites are reputed to be a source for plant species richness (Gustafsson, 1987; Weih et al., 2003). In an area of northern Germany with quite uniform land-use patterns, Kroiher et al. (2008) found that even small SRC stands (1,600 m² area) contained 8 % to 12 % of the species number of the surrounding landscape (25 km² area) which is a considerable share when considering their limited extent.

4 Recommendations to manage phytodiversity in SRC plantations

As shown in the previous sections, there are many factors influencing species cover, species richness and the type of species occurring in SRC plantations. In general, the location for establishing a SRC plantation should be chosen carefully and consider both economic and environmental aspects. Depending on the location, SRC plantations can have positive as well as negative effects on biodiversity (Weih, 2008a). If being established in an area dominated by agriculture (Fry and Slater, 2009; Gustafsson, 1987) or coniferous forests, SRC plantations form an additive habitat and can increase regional structural diversity, whereas it is not advised to establish energy forests in areas with rare species, rich fens, forested wetlands and edge-zones bordering to lakes and rivers as well as on undisturbed peat bogs (Gustafsson, 1987). Cook et al. (1991) point out that the current and world-wide trend in favour of increased biofuel plantations puts wetland habitats at a high risk to become prime candidates for conversion to plantations. Due to their wetness, these habitats could be particularly interesting for SRC plantations and the conversion would entail a loss of biodiversity. From a nature conservation point of view, arable land is suitable for establishing a SRC plantation, if plantation sites do not affect adjacent or nearby protected areas, and if the establishment has no negative influence on endangered species or disturbs wildlife corridors (Schmidt and Glaser, 2009).

In summary, biodiversity in SRC plantations can be favoured by consideration of a few guidelines (after Weih (2008b)):

- Avoid areas with protection status for nature conservation and/or cultural heritage.
- Avoid very large plantation sizes – plant several smaller plantations instead.
- Locate the plantations close to existing native woodlands and/or incorporate ‘islands’ of native trees within large plantations.
- Leave buffer zones without any crop or with native vegetation at the edges of plantations.
- Plant several varieties (preferably of different gender) within the same plantation; different varieties may be planted in sections or parallel stripes in order to facilitate harvest actions.
- Apply chemical weed control only during plantation establishment.
- Do not apply more nutrient fertilizer than the biomass crops demand during a growing season.
- Try to plan harvest actions to be performed only when ground is frozen.
- Harvest parts of plantations in different years.
- Locate, design and manage the plantations in such a way that they maximize variation in habitat type and landscape.

5 Conclusions and future perspectives

Due to the expected increase of SRC plantations, more knowledge about how these plantations influence phytodiversity is urgently needed to enable sustainable management of SRC plantations and to gain extra benefits for the environment that might occur if the plantations are managed in a suitable way. Even though there has been research on the influence of SRC plantations on phytodiversity, there are still a lot of open questions which need to be clarified to enable the best management. Especially long-term studies are at this point of time still lacking.

As shown above, species composition and species number change over time in SRC plantations. Therefore, further research should focus on the question of what is an appropriate rotation duration to support species richness or endangered species. There cannot be a generalised answer to this question, because different plantation species as well as environmental factors play an important role in ground vegetation development.

Colonization of the SRC plantations happens not only from the surroundings, but also from the soil seed bank and through living vegetative tissues and is therefore dependent on the former usage. It should be clarified where the largest proportion of species in the SRC plantations comes from, in order to discover how strong the former use influences species composition of the plantations. Another interesting aspect is how long the influence of the former use lasts, which can be shown by long-term research.

Different tree species and clones are planted for energy crops, but little is known about how the different crops influence phytodiversity and about the variations concerning species composition and vegetation development on the ground over time.

Further research is also needed to clarify the contribution of SRC plantations to species diversity at the landscape scale, and correspondingly the influence of landscape factors on SRC plantations. Important variables include the crop species, the plantation age and the surrounding uses,. In this context it is very important to shift the experimental field design from the classical focal patch approach which focuses on the comparison of single patches or one patch and its surrounding to a mosaic-level approach - i.e. multiple sample patches have to be investigated in a given landscape mosaic. With this approach it is possible to address the question how on-site biodiversity is affected by the emergent properties of the surrounding landscape mosaic. These properties include the extent of habitat, composition of the landscape mosaic and spatial configuration of its elements. Thus, the quantification of the relative importance of determinants of species richness is an important task for biodiversity research. Further, this approach would allow the quantification of the specific contribution of SRC plantation patches to landscape species richness. Until now, this kind of approach does not exist for SRC biodiversity assessments. There is however experience from other investigations in agricultural environment to build on (Simmering et al., 2006; Wagner et al., 2000; Wagner and Edwards, 2001; Waldhard et al., 2003; Waldhard et al., 2004).

Using sewage sludge for fertilizing SRC plantations and at the same time solving a waste problem seems to be win-win situation as the planted crop acts like a vegetation filter. But in what manner sewage sludge application influences phytodiversity has not been analyzed until now.

SRC plantations can have clear benefits for biodiversity, but negative effects are also possible. As much knowledge as possible should be gathered about how the different factors influence phytodiversity for supporting sustainable management of energy wood plantations.

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