# A review of the impacts of Short Rotation Coppice cultivation on water issues

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## Abstract

Cultivation of Short Rotation Coppice (SRC) with poplars (*Populus sp.*) and willows (*Salix sp.*) for production of biomass for heat and/or electricity is energy effective and coincides with several environmental objectives. Since an increase of cultivation of poplar and willow SRC has been projected in Europe, the consequent implications on water issues arises. For instance, water use of SRC can be higher compared to annual agricultural crops or previous set-aside land, but water quality can be improved. The paper examines such implications based on a review of the existing scientific literature. Rates of evapotranspiration ($V_{ET}$) of SRC are reported to be fairly higher than arable crops, but reported values vary markedly and are related to site-specific factors such as the local precipitation and conditions (e.g. soil type, temperature, groundwater level), the species/sorts and the age of the crop, and their interactions. Despite the predicted local effects on water balances, effects on water balances/hydrology on catchment level have not been reported or justified. This, combined with the reported positive effects of SRC on groundwater quality in terms of nutrient leaching, imply average positive effects of SRC on water issues, if the identified potentially negative impacts would be considered and minimized. For this, comparisons of $V_{ET}$ between SRC and arable crops, and the relation of $V_{ET}$ with local precipitation and other local factors (root development, groundwater availability) should be better examined and combined with positive effects of SRC on groundwater leaching compared to other crops. Upscaling of water issues for SRC is needed to promote future decision-making processes with respect to the envisaged broadening of SRC on productive but also on marginal soils.


*Keywords: Short Rotation Coppice, poplar, willow, water quality, nutrient leaching, water balance, biomass, bio to energy*


## Zusammenfassung

**Zum Einfluss von Kurzumtriebsplantagen auf den Wasserhaushalt – eine Übersicht**

Kurzumtriebsplantagen (KUP) mit Pappel und Weide sind eine energieeffiziente und umweltfreundliche Möglichkeit zur Erzeugung von Biomasse für die Energiegewinnung. Die prognostizierte Ausdehnung von KUP-Flächen in Europa wirft die Frage nach deren Wasserverbrauch auf. Dieser kann bei KUP höher sein als bei einjährigen, landwirtschaftlichen Kulturen oder bei Stilllegungsflächen, wobei sich gleichzeitig die Qualität des Sickerwassers verbessern kann. Basierend auf einer Literaturauswertung beschäftigt sich die vorliegende Arbeit mit Fragen zum Wasserhaushalt von KUP. Dabei liegt die Evapotranspiration ($V_{ET}$) von KUP deutlich über der des herkömmlichen Ackerbaus, schwankt aber stark in Abhängigkeit von der lokalen Niederschlagshöhe sowie anderen Standorts- und Bestandesbedingungen (z. B. Bodentyp, Temperatur, Grundwasserstand, Art/Sorte, Alter der Kultur) und ihren Wechselbeziehungen. Auswirkungen auf den Wasserhaushalt auf Einzugsgebietsebene sind bisher kaum untersucht worden. In Verbindung mit möglichen positiven Auswirkungen von KUP auf die Wasserqualität durch eine Minimierung der Nährstoffauswaschung ergibt sich bei Vermeidung eines erhöhten Wasserverbrauchs ein insgesamt positives ökologisches Potential für KUP. In diesem Zusammenhang sollten Vergleiche zur $V_{ET}$ zwischen KUP und landwirtschaftlicher Nutzung sowie die Bezüge von $V_{ET}$ zur Niederschlagsmenge und anderen Standortsparametern (Wurzelentwicklung, Grundwasserverfügbarkeit) besser herausgearbeitet werden, um die positiven Einflüsse von KUP auf den Grundwasserabfluss darzustellen. Weiterhin muss die Übertragbarkeit von Ergebnissen auf Wassereinzugsgebietsebene gefördert werden, um politische Entscheidungen bezüglich der Ausbreitung von KUP auch auf Marginalstandorten besser absichern zu können.


*Schlüsselworte: Kurzumtrieb, Wasserverbrauch, Wasserqualität, Pappel, Weide, Biomasse, Bioenergie, Eutrophierung Grundwasserschutz*

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## Introduction

Cultivation of Short Rotation Coppice (SRC) with poplars (*Populus sp.*) and willows (*Salix sp.*) for production of biomass for heat and/or electricity has been identified as the most energy efficient carbon conversion technology for reducing greenhouse gas emissions and thus meeting the ambitious European commitments to increase the amount of renewable energy sources (Heller et al., 2004; Cocco, 2007; Styles and Jones, 2007). Moreover, SRC cultivation seems to coincide with other social, economic and environmental EU policies and objectives, such as the EU Rural Development, the CAP reform and the Water Framework Directive (EEA, 2006). Therefore, this combination of agricultural and energy drivers has stimulated interest in growing SRC as a source of renewable energy, and different incentives have been introduced in different European countries. Already in the short to term, a rapid increase of SRC in several European countries has been projected. For example, in Sweden the Swedish Board of Agriculture predicts a short to term increase of SRC to 30 000 ha (Jordbruksverket, 2006) and the UK Biomass Strategy predicts that perennial energy crops will occupy some 350 000 ha by 2020 (DEFRA, 2007). In Germany the present area under SRC cultivation is less than 1 500 ha (BMELV, 2008) but may also increase markedly during next years due to a changing subsidise policy and the identification of high cultivation potential for certain areas, e.g. 200 000 ha for the federal state Brandenburg according to Murach et al. (2008).

If the projected increase of agricultural land with SRC would be realised and a shift to SRC instead of other usual agricultural land use systems takes place, a range of positive and negative environmental implications will arise. For water to related issues, such implications are connected to questions concerning plant water use and water use efficiency, groundwater recharge, soil erosion as well as water quality. SRC as a perennial and woody crop differs from arable crops in a number of physical traits and thus its management is less comparable to other usual crops. In particular, SRC plantations are expected to remain in place for a number of years (10 to 25, depending on EU and national regulations, but also on management practices) taking the land out of arable rotations which implies no annual soil cultivation. Furthermore willow and poplar plants are thought to be deep to rooting and to have high water consumption, their height is ca. 5 to 8 m at harvest, and agrochemical inputs in the form of fertilizers and pesticides are minimal after SRC is once established. The anticipated increase of SRC will probably be concentrated in agricultural areas neighbouring power stations using biomass as fuel, since an approximate radius to a maximum of 50 to 100 km from customers should be considered as appropriate with respect to economically and energy efficient operation strategies (Rosenqvist and Dawson, 2005). This, depending on the size and the type of the power station, will be decisive for the "market" needs for SRC and therefore for the surface to be cultivated in a certain region.

The above indicate that a qualified estimation about the impact on water to related issues is rather complex when SRC is introduced instead of other crops in a certain area. The impacts of SRC will depend on a range of factors such as the specific site (climatic and soil conditions), the species used (willows or poplars), the management and the amounts of biomass produced, the age of the crop, the previous land use, and their interactions. SRC is a rather new cropping system and although considerable research in several countries has been conducted on water to related issues, there is still the need to combine the so far acquired knowledge to better understand the anticipated impact of SRC in small (field) and in large to scale (catchment).

This paper will give an overview of the available literature to estimate the expected impact of SRC on water to related issues. Although some direct impact on flooding prevention using SRC in buffer strips might exist (Kuzovkina et al., 2004; Volk et al., 2006) this paper will not deal with such issues but will mainly focus on the impact on water use and water quality. Implications for water balances and water quality issues when SRC is introduced in areas previously cultivated with arable crops and/or other crops will be discussed and analysed based on the related literature. Further, gaps in current knowledge will be identified, and therefore some future research aspects on water to related issues will be proposed.

## SRC effects due to water use patterns

### *General about water balance for SRC*

The decision behind using willow and poplar cultivated as SRC for production of biomass for energy was mainly based on the characteristic of these species to be fast to growing producing higher biomass compared to other tree species, especially in central and northern Europe where the development of such biomass systems was initiated and adapted commercially (Christersson and Sennerby to Forsse, 1994). Increased biomass accumulation has been linked with high water use, especially in warmer climates. Willows in particular are known to grow in places with high water availability such as river banks. Coupled with the fast to growing feature of SRC, fears for high water use and consequent concerns about the effects on local hydrological balances and flow to neighbouring streams/ rivers have been expressed in several reports predicting future biomass supply from agriculture (EEA, 2006; Eppler et al., 2007; EEA, 2008).

In general, water balance of plant crops can be described by the water balance equation

$$N_n = N - V_I = W + V_{ET} + A_{Vs},$$

*where*

| | | |
|---|---|---|
| $N_n$ | = | crop precipitation, |
| $N$ | = | field precipitation, |
| $V_I$ | = | interception, |
| $W$ | = | change of water storage in ecological systems (soil, dead and living plants), |
| $V_{ET}$ | = | evapotranspiration |
| $A_{Vs}$ | = | runoff, including infiltration (Schaefer, 2003). |

Evapotranspiration ($V_{ET}$) can be distinguished in transpiration (evaporation over stomata in the leaves of the plants) and evaporation (evaporation from bare soil or water surface). Precipitation remaining in the vegetation layer is termed as interception.

The special features of both willow and poplar that differentiate their water use patterns compared to other crops are the fast canopy development and the high leaf area index (LAI) during vegetation period. These affect significantly rates of transpiration from leaves and interception evaporation from the canopy. Furthermore potential deeper rooting of SRC species compared to annual crops might favour higher rates of water consumption. There are several difficulties to accurately determine the $V_{ET}$ from any agricultural field, since a matter of factors such as air temperature, air humidity and wind force interfere. Nevertheless, a series of studies has been performed so far to estimate in precision the $V_{ET}$ in SRC fields with the aim to speculate about changes in water balances in relation to other land uses. For willows, most of them were primarily conducted in Sweden, since it was there that cultivation of SRC for biomass was initiated and then commercially practiced, and later in the UK for the same reasons. Similar research on poplars has been conducted in a range of countries with more temperate climate than Sweden such as in Germany and the UK, where poplar has been considered as more appropriate species than willow grown as SRC, gaining large interest during the last years.

*Transpiration and evapotranspiration rates of SRC*

From the several estimates for $V_{ET}$ for poplar and willow, there seem to be variations in the figures reported. For irrigated and fertilized willow SRC grown in clay in south Sweden for four years, Persson and Lindroth (1994) simulated seasonal (May to November) $V_{ET}$ between 360 to 404 mm. Persson (1995) estimated that the average seasonal $V_{ET}$ (May to October) from six fields in different locations in south Sweden areas was 435 mm, confirming in a way the previous findings. For SRC poplar fields,

Table 1:

Indicative reported evapotranspiration (Eta / $V_{ET}$) rates from poplar (P) and willow (W) SRC stands in different countries

| Stand/ shoot age | Site | Soil | Species | Precipitation (mm) | $V_{ET}$ (vegetation period) | $V_{ET}$ (year) | Source | Country | Annotation. |
|---|---|---|---|---|---|---|---|---|---|
| 9/9 | Methau | loamy loess | P | 690 (lta) | 480 | | 1 | GER | |
| 3/3 | Neuruppin | loamy sand | P | 585 | | 356 | 2 | GER | |
| 9/9 | Neuruppin | loamy sand | P | 585 | | 393 | 2 | GER | |
| Diverse | div | clay soil | W | 700 (lta) | | 500 | 3 | GB | |
| 8/8 | Welzow | clayy sand | P | 749 | | 404 | 4 | GER | |
| 8/8 | Welzow | clayy sand | P | 749 | | 388 | 4 | GER | |
| 2/2 to 5/2 | Uppsala | loamy clay | W | 352 prec. +222 irrigation during vegetation period | 435 | | 5 | SE | Irr, Fert, Mean |
| 3/3 | Börringe | sandy loam | | 586 (lta) | 360 | | 6 | SE | |
| 6/3 | Alyckan | sandy loam | W | 641 (lta) | 440 | | 6 | SE | |
| 7/2 | Brinkendal | sandy loam | W | 641 (lta) | 374 | 481 | 6 | SE | |
| X/2 | Silsoe | sandy clay loam | W | 574 (lta) | | 441 | 7 | GB | |
| X/2 | Selby | sandy clay loam | W | 643 (lta) | | 462 | 7 | GB | |
| X/2 | Cirencester | sandy clay loam | W | 776 (lta) | | 594 | 7 | GB | |

Sources: [1]Petzold et al., 2008; [2] Knur et al., 2007; [3] Hall, 2003; [4] Bungart et al., 2004; [5] Persson and Lindroth, 1994; , [6] Persson, 1995; [7] Stephens et al., 2001

lta – long to term average
Irr – irrigated
Fert – fertilized
Mean – mean value calculated from different sites
P – poplar
W – willow

Bungart and Hüttl (2004) estimated mean annual transpiration rates between 1996 to 2002 at the Lusatian mining region in Germany equal to 266 and 241 mm, for two different poplar clones, respectively (Beaupré, *Populus trichocarpa* x *P. deltoides* and Androscoggin, *P. maximowiczii*). $V_{ET}$ was 404 and 373 mm, respectively. Annual $V_{ET}$ of 351 mm and 360 mm for a 3- and a 9-year old SRC poplar plantation, respectively, located in Neuruppin, Germany, has been calculated by Knur et al. (2007). Another 9-year old poplar plantation estimated to transpire 480 mm water during the vegetation period (April to November) in middle Saxony, Germany (Petzold et al., 2008). In the UK, Hall (2003) estimated that ca. 600 mm will be used by SRC willow in a clay soil which receives precipitation of 700 mm. According to Hall (2003) this corresponds to an annual $V_{ET}$ of about 500 mm. Allen et al. (1999) estimated that the average daily transpiration rates of about 5 mm in poplar plantations in South England throughout the vegetation period, which is much higher than the previous reported values in Sweden and Germany. An indicative compilation of reported evapotranspiration values for willow and poplar SRC can be found in Table 1, showing the rather vast differences and factors that these might be depended on.

To add to the uncertainty about which species is a higher "consumer" of water, Linderson et al. (2007) found that the estimated transpiration rate of a willow stand with different clones in south Sweden from April to October was between 100 to 325 mm (therefore markedly lower than the previous findings for poplar), whereas the Penman to Monteith transpiration in that area for willow reached 400 to 450 mm for that period. This was attributed to the relative high temperatures in the summer when the measurements took place. Busch (2009 – see this issue) reveals that there is a trend between total annual evaporation (evapotranspiration plus interception) and mean annual precipitation (see also Table 1). With respect to all limits due to sparse data, methodological uncertainty and varying modelling approaches, the given data show a trend of increasing total annual evaporation with higher annual precipitation. Currently this trend could be only derived for a "window" of annual rainfall between 580 mm and 800 mm. This window, however, covers a range of annual precipitation which is typical for large regions in Middle to Europe.

The above $V_{ET}$ estimations indicate that safe predictions for $V_{ET}$ level from an SRC stand cannot be granted. Even stem sap flow measurements for calculating the daily transpiration rates gave varying results. Hall and Allen (1997) reported that transpiration of individual poplar plants grown in UK reached 9 ± 2 mm/day in June, and suggested based on these results that an effect on reduced stream flow and aquifer recharge and in reduced peak flows is to be expected. Others using similar methods, however, such as Hinckley et al. (1994), Allen et al. (1997) and Hall (1998) found that poplar transpiration rates in June/July were 4.8 mm/day, 5 ± 1.8 mm/day and 6 ± 0.5 mm/day, respectively, therefore significantly lower than the value of Hall and Allen (1997). Although willows seem to reach higher LAI earlier in the vegetation period (peak at 6.9 LAI) compared to poplars (peak at 4 LAI) (Stephens et al., 2001), there are only few reports to our knowledge suggesting that $V_{ET}$ from willow is higher than poplars after direct comparison, e.g. a lysimeter test from Guidi et al. (2008). Hall et al. (1998) conducted sap flow measurements of willow and poplar plants planted in the same area and their conclusion was that transpiration rates for willow were, within measurement uncertainties, similar to those from poplar.

*Aspects to be considered affecting SRC evapotranspiration*

The reported vast variations in the transpiration rates from willow and poplar indicate that a number of aspects is probably affecting water use processes and water balances in SRC plantations in time and space. Based on the available literature, a short evaluation of most important aspects that should be accounted for, when considering water balances of SRC is presented in the following.

Fast canopy development and high LAI in SRC during the vegetation period have been reported (Persson, 1995; Hall, 1998). For poplars grown in the UK for instance, it has been reported that LAI reaches 2 in mid to May and maximum around 4 after mid June. Willows in the same area developed leaves faster reaching LAI 3 in mid to April and maximum of 6.9 in mid to June, reducing to 2 by mid to October (Stephens et al., 2001). Consequently, the crop coefficient for the Penman equation is rather high throughout the year and so is the interception, which indicates that "water losses" will be high (high $V_{ET}$).

Interception of rainfall by foliage has been reported to be rather high in SRC, and therefore "water losses" due to interception are feared to be high with consequent effects on soil infiltration. Interception as a percentage of rainfall during the examined period was reported to be from as high as 31 % in willow SRC grown in Finland (Ettala, 1998), to 21 % in poplar SRC grown in the UK (Hall and Allen, 1997), to 18 % in poplar SRC in Germany (Bungart and Hüttl, 2004), down to 11 % in willow SRC in Sweden (Persson and Lindroth, 1994). Knur et al. (2007) calculated based on simulations an age to depended increase of interception losses from 20 % for three year poplar plantations to 29 % in nine year old plots under identical site conditions, referring to annual precipitation values. Thus variations depended mainly on stand ages, local conditions (higher leaf humidity results in higher interception) and the species examined, but are rather representative. Indicatively, the maximum rates for interception in food crop fields are ca. 15 % (Hall, 2003), therefore in most cases significantly lower than for SRC.

The degree of how much of the interception is a "water loss" or how well it substitutes transpiration (therefore not being a "loss") depends on the canopy height and structure. This is expressed in the radiation and aerodynamic terms of the Penman to Monteith equation. The decoupling factor (Ω) is the mathematical expression of this effect and has values from 0 up to 1, where 0 represents a vegetation fully coupled (higher plants having "evaporative demands" as a tall forest) and 1 a vegetation fully decoupled (short grasses and agricultural crops), respectively. There are indications that although willows and poplars grow high, their decoupling factor (Ω) is close to 1 when leaf area index is above 2 (Persson and Lindroth, 1994). As referred previously and in Persson and Lindroth (1994), LAI for willow and poplar for most of the vegetation period is above 2, and therefore interception should not entirely be considered as a "hydrological loss" since it seems to substitute transpiration to some extent.

The size and the formation in space of the field seem to be important for the expected $V_{ET}$ of an SRC field. Allen et al. (1998) dealt with the relation between the width and height of SRC plantations and the crop coefficient in the Penman equation. The results show that the narrower the fields the higher the crop coefficient of plants of a certain height. It was also shown that this effect was accelerated when plants were higher. Therefore, if an SRC field is planted in narrow strips, which in reality results in edge effects with taller plants, the crop coefficient and consequently $V_{ET}$ will be high. This is confirmed by Zhang et al. (1999) who reported low decoupling factor (Ω) for small to size poplar stands. When size increased, the decoupling increased indicating that evaporation would be lower (Hinckley et al., 1994). Therefore, small and narrow fields should be avoided for SRC in terms of water consumption. However, if SRC plantations are thought to be used as buffer zones for prevention of flooding in areas of high danger for such phenomena, then narrow strips parallel to the water course would have better results

Root system development between willow and poplar seem to differ, since in general willow roots are more concentrated at the top compared to poplars; Rytter and Hansson (1996) suggested that most willow roots in a Swedish field were concentrated in the top 50 cm and Hall (2003) described that poplar roots were found down to 3 m depth. For Germany, Raissi et al. (2001) reported that for eight year old poplar stands the effective rooting depth ranged between 70 to 110 cm on sandy and loamy sites, thus nearer to the surface than Hall (2003) found. This does not necessarily mean that willows are not able to extract water from deeper soil depths in case of drought, but that probably poplars have another strategy for root development. However, when comparing willow SRC with other agricultural crops in the UK, Finch (2009) reported in a preliminary study that the "dense" willow root system does not go deeper than 30 to 40 cm and that "sparse" roots go to 1.5 m deep. In the same study, maize roots where at the same depth as willows, and winter wheat roots were only slightly less deep than these of willows indicating minor differences in the patterns for extracting groundwater between these species. It seems therefore rather unsure how differently the rooting development of SRC species would affect local water balances, since this will be depended on the groundwater level as well.

*Water balances in SRC in relation to other crops*

The impact of SRC on the water use and balances in a certain area must be judged in comparison with the crops that will be replaced in a potential shift to SRC. For most of the European countries future scenarios suggest that SRC will be established at productive agricultural land, therefore comparisons with arable crops would be relevant. In older literature, willow and poplar as tree species were usually compared to common forest species as well. The $V_{ET}$ from SRC fields with willow and poplar is reported in most cases as significantly higher than arable crops and lower than other forest (Persson, 1995; Stephens, 2001; Hall, 2003; Knur et al., 2007). However, the estimated total evaporation from SRC in clay soils when adequately supplied with water was reported to be higher than this from mature coniferous forests (Persson and Lindroth, 1994). Hall (2003) reported that on a clay site with 700 mm rainfall SRC is expected to use 600 mm compared to 400 mm for barley and 450 mm for pine forest. In contrast to this, Hall et al. (1998) indicated that in case of dry summers when there is significant water deficit, the water use of poplar SRC will probably be considerably less than that of coniferous forest and closer to that of grassland. Sensitivity of willow SRC to dry summers have been also reported by Linderson et al. (2007), where transpiration rates varied between willow clones and were equal to 100 to 325 mm. Therefore, the levels of water consumption of SRC in relation to other crops grown in the same area seem to depend on site to specific factors as soil type, precipitation and others, and might vary from case to case, although SRC seem to have higher $V_{ET}$ than arable crops in most cases.

In recent measurements however, preliminary published by Finch (2009), the cumulative transpiration difference between winter wheat and SRC willow for a 3 to year period in the UK was only 50 mm (ca. 800 for winter wheat and 850 mm for SRC). Interception was on the other hand lower for SRC than winter wheat during 3 seasons (ca.

190 mm for SRC vs 220 mm for winter wheat), and therefore, the total difference in water use (or evaporation as the writer describes it) was very little between the two crops. This contradicts with results obtained in Germany stating that infiltration from poplar SRC fields was almost 3 times less than neighbouring arable fields (Knur et al., 2007). These results indicate that the water use by SRC in comparison to other crops largely depend on site to specific factors and probably on the methods chosen for calculation, and that probably the general perception that SRC "consume" significantly more water than other crops should not be generalised for all cases.

*Implications for SRC effect on local hydrology*

A range of studies indicated that the expected $V_{ET}$ from SRC was elevated in comparison to this for other crops. Consequent implications for reduction of the water that reaches the soil and percolates in deeper layers resulted in negative assumptions concerning the effect of willow and poplar SRC on streams by Hall et al. (1998). The authors suggested that extensive establishment of SRC should be restricted to wetter parts of the UK, but they add that in case of warm summers, the water use of SRC will be similar to that of grassland. Perry et al. (2001) also predicted that poplar SRC in Northwest Minnesota may influence average peak flows in streams, after comparisons with much older hardwood stands and the conclusion that the same behaviour is to be expected. In this case however, the potential effect of SRC was claimed as positive reducing annual floods in the area. Allen et al. (1999) also assumed that introduction of poplar SRC in the UK will have adverse effects on water resources in the UK, and added that this impact will vary depending on rainfall and the alternative use as well.

Modelling exercises conducted by Stephens et al. (2001) indicated reductions of 10 to 15 % of the hydrologically effective rainfall in SRC fields compared to arable crops in the UK. Despite this, the authors claimed that the effect on hydrology to the catchment level would be minimal, after extrapolations based on the model results obtained and the assumption that 2 500 ha SRC will be planted in an area of 40 km radius from a biomass to driven power plant. This was due to the fact that the mean reduction in hydrologically effective rainfall for the catchment area would be ca. 0.5 % of the mean annual amount, which would be only a very minor portion, compared to the respective effect of cereals. Hall (2003) also suggested that even if SRC "consumes" more water than other arable crops, catchment scale effects of SRC on hydrology will be negligible, and that even when used as riparian buffers SRC will have little effect on river or streams due to low abstraction rates. He suggested however that in places where the potential biomass production from SRC exceeds 12 t DM/ha/yr, and precipitation happens to be lower than 550 mm, then these areas should be avoided for SRC planting since the consequences of reductions the hydrologically effective rainfall are much more serious in such areas.

As a conclusion, despite the predicted higher water "consumption" by willow and poplar SRC in the local (field) level, it seems that SRC poses no threats to the hydrology of a larger area e.g. having a distance from a biomass power plant up to 50 km, if the area is planted with 2 500 to 3 000 ha with SRC. Indicatively, and if we approximate, the referred area corresponds to ca. 30 % of the annual energy produced in a power plant in Sweden with capacity of 35 MW.

**SRC effects on water quality**

SRC is generally considered as a crop that improves the water quality in a certain area due to the management practices of this crop (EEA, 2008). Pest and weed control are conducted only during the establishment phase, and despite using chemical preparations, the total application rates considering the life to span of the crop (10 to 20 years) are minimal, especially comparing with the respective for arable crops. The appearance of fungus as leaf rust (*Melampsora sp.*) is rather common, especially in countries where the climate is humid for long periods, e.g. Northern Ireland, but even there application of fungicides is considered uneconomical and therefore not recommended (Dawson, 2007). Moreover, tillage is practiced only once before the establishment phase of the crop, and therefore soil disturbances that could enhance potential leaching to the groundwater of already existing hazardous chemical compounds (mainly N) are decreased. Due to all these facts, hardly any research on groundwater quality in SRC fields has been conducted aiming at determination of chemical compounds as pesticides and heavy metals in the groundwater.

To achieve high biomass production, recommendations for inorganic fertilization to SRC fields have been developed in different countries (for Sweden Ledin et al., 1994; for the UK DEFRA, 2002; for Mecklenburg to Vorpommern Germany Boelcke 2006; for Northern Ireland Dawson, 2007). Fertilization during the year of establishment is not recommended to avoid competition with weeds and potential leaching to the groundwater when the roots are not well to developed. For the next years, there are significant variations in the different recommendations for fertilization applications rates; for example, in the UK, ca. 70 kg N on average per hectare and year are proposed to be applied depending on the year of the cutting cycle. In Northern Ireland the respective amount is 120 to 150 kg N per hectare and year, and in Sweden the recommendations is ca. 100 kg N per hectare and year, but not after the second year of growth when no fertilization occurs. In general, SRC fertilization recommendations can be considered rather moderate compared to respective ones for arable crops (Hofmann, 2007). However, the fact that fertilization to SRC fields cannot be applied every year but usually only every year after harvest due to the nature of the crop (high stems that do not allow the available equipment to apply fertilizer every year) makes the applied amounts of nutrients relatively high. Therefore, to estimate any danger from N leaching in the groundwater, relevant information from intensively irrigated field with N should be collected, taking also into consideration potential critical management factors such as the time of N to application and methods selected (e.g. use of nitrification inhibitor).

Bergström and Johansson (1992) measured very low N concentrations (less than 1 mg/l N) in the groundwater of an intensively fertilized willow SRC field in south Sweden. Measurements of N in the surface groundwater at the same field for a period of eight years with average annual application rates of 112 kg N/ha showed that N concentrations remained below 1 mg/N for the whole period except during the year of establishment (Aronsson et al., 2000). These results came in agreement with Mortensen et al. (1998) that measured close to zero N concentrations in drainage water from Danish SRC fields, except for the establishment year. The maximum N concentrations in the drainage water that year was up to ca. 100 mg/l N for fertilized plots with 75 kg N, but were high even for control plots that did not receive any N (maximum ca. 60 mg/l N). This indicates that extensive mineralization probably occurs during the establishment phase. Goodlass et al. (2007) also reported high N concentrations in drainage water during the establishment phase, with reduction to low levels after the crop is established despite application of 200 kg N/ha in 3 years. In the same study, the authors studied the N concentrations in the drainage water after removing a poplar SRC field and found them equally high as for the establishment phase, and therefore concluded that SRC stands should be maintained for as long as possible. This conclusion was partly made after comparisons with the maximum N concentrations in the drainage water from arable crops in the area, which consistently exceeded 60 mg/l every year. Big differences in the amounts of N leached in the groundwater between SRC and a series of arable crops were reported in Denmark by Jørgensen and Hansen (1998). In a sandy soil, ca. 15 kg N/ha were leached on average from fertilized willow SRC, whereas the respective value for different cereals was between 70 to 120 kg N/ha.

Although differences in N leaching to groundwater from SRC compared to the reported "usual" N leaching figures from arable crops are rather striking, they could be attributed in some cases to the lower input of fertilizer applied to SRC compared to "normal" fertilization rates for arable crops. Moreover, in some cases some arable crops might be also irrigated in case of water shortage in summer, making comparisons difficult. To examine if SRC is equally good in N to leaching performance under circumstances with higher N amounts fertilized and when irrigation occurs, it is worth comparing results from related work of wastewater irrigation to SRC. This is a method used for treating and utilising nutrient to rich wastewaters (usually in N but also P) by irrigation to SRC fields, which has gained interest during the recent years in countries where SRC cultivation is rather common (Aronsson, 2000; Sugiura et al., 2008; Werner and McCracken, 2008). According to Aronsson (2000) after testing different irrigation regimes with wastewater under different soil conditions, wastewater application at least 150 kg N/ha yr should not pose any threat to extensive $NO_3$ to N leaching in Sweden. Concentrations of N in the drainage water below 5 mg/l were recorded in an experimental willow SRC field in N. Ireland where ca. 200 kg N/ha/yr were applied (Werner and McCracken, 2008). Moreover, Sugiura et al. (2008) applied much higher amounts (ca. 300 kg N/ha/yr) and N concentrations in the drainage water at different depths was between 5 to 10 mg/l. This figure is rather low considering the high application rate and comparing with findings for other arable crops. The above findings suggest that in general leaching of N from SRC in comparison to arable crops is significantly lower and a shift from arable crops to SRC will probably imply an improvement of the groundwater quality and consequently of the surface water quality in a certain area, even when N fertilization exceeds the recommendations for good practice.

Application of municipal sewage sludge to SRC fields is a common practice in Sweden and in the UK that compensates P losses in newly harvested fields (Sagoo, 2004; Dimitriou and Aronsson, 2005). The application rates of N with sludge can vary depending on each country's legislation, but in most cases it is P that is considered potentially more dangerous than N; although in most cases legislation regulates the P rates, ca. 150 kg N/ha can be applied to SRC fields with a sludge application (Dimitriou, 2005). Leaching of $NO_3$ to N to the drainage water has been reported during the application year of sewage sludge when applied to a willow SRC fields (Labrecque and Teodorescu, 2001; Sagoo, 2004). However, N to leaching was very low (below 10 mg/l) the subsequent years and results were similar for SRC fields treated with conventional inorganic fertilizers or wastewater, suggesting that N to leaching after sludge application should not be considered as a problem. Judging by the application rates of P when sewage sludge is applied to SRC (e.g. in Sweden 22 or 35 kg

P/ha/yr depending on the P content existing in the soil, for a 7 to year period), and from the fact that willows can accumulate in the stems ca. 8 kg P/ha/yr depending on the site, a surplus of P is usually applied with sewage sludge. Despite this, P is usually bound to soil particles and its leaching patterns differ that these of N which is in most cases related to water drainage. Therefore, P leaching when sewage sludge is applied to SRC should not be potentially considered a problem. Preliminary results by Dimitriou and Aronsson (submitted to Biomass and Bioenergy) from sewage sludge to amended lysimeters confirm the above speculation since P concentrations in the drainage water was close to zero throughout measurements during 2 vegetations periods. However, future P leaching cannot be excluded as a possible scenario when sewage sludge is applied for a number of years at high rates.

All the above about water quality and SRC indicate that when SRC replaces arable crops, an improvement of the groundwater quality is anticipated. In fact, several suggest the use of SRC in intensively to managed agricultural areas to improve the current water quality and meet EU obligations in terms of water quality expressed in the Water Framework Directive (Jørgensen and Mortensen, 2000; Eppler et al., 2007; EEA, 2008) and simultaneously use the land for agricultural production for biomass for energy that also fulfils other obligations concerning renewable energy.

## Conclusions and future research aspects

The special features of SRC as a crop have implications to water balance and water quality. The main aim with SRC plantations is to produce high biomass, but this can imply potential reductions of water availability, especially in places where precipitation is low or even when dry summers occur in areas with otherwise adequate precipitation. This will consequently have an effect on groundwater enrichment, but this effect needs to be balanced with the biomass produced and compared with effects of alternatives to SRC crops in the area. Potential benefits on water quality must be also taken into account when judging SRC compared to other crops.

Reported $V_{ET}$ of SRC vary markedly depending on the location (precipitation, soil type), selected species/clones, plant age and the climatic conditions during the estimation periods. Differentiations between the different estimation methods/models used and actual measurements occur as well. Willow and poplar $V_{ET}$ seem not to vary much between each other, but have been in most cases calculated to be higher than other arable crops. There are indications that in areas receiving precipitation less than 600 mm, poplar and willow SRC should be avoided since effects on both biomass and on groundwater recharge would be probably negative. However, although in the local (field) scale effects on water balances might be evident due to SRC, in the large (catchment) scale these effects seem not to be transferable and the total effect on water balances in a larger area around e.g. a combined power station using biomass has been judged as negligible or very marginal. This, combined with the considerable improvements of groundwater quality in terms of leached nutrients (and as a consequence surface water quality) when SRC replaces intensively managed arable crops (a projected scenario for many SRC in Europe), leads to promising conclusions in terms of SRC impact on water issues.

However, potential negative effects attributed to SRC should be minimized and uncertainties that could hinder future decision to making about SRC should be clarified. Therefore, better and more extended comparisons of $V_{ET}$ between SRC and arable crops, studying SRC fields grown for several years and are well to documented compared with respective arable crops in the same area, should be conducted. For this, certain measurements such as transpiration, rooting depth should be more precise and effects correlated to local conditions should be better examined (e.g. root function and depth in correlation to groundwater level). Also, an approach integrating effects of soil SRC issues on water (soil type or mycorrhizae abundance and their role) should be applied. Concerning water quality issues, and despite the very positive impact of SRC, the effects on groundwater quality of common management practices such as the application of sewage sludge and/or wood to ash to SRC fields should be studied in long to term perspective.

All these local effects on water issues must be extrapolated to the larger to scale estimating potential effects of a hypothetical introduction of SRC in high percentage of a certain agricultural area. These results should constitute the base for recommendations and future decision to making processes about SRC establishment in comparison to other arable crops. Water related investigations in SRC can be helpful also considering climate change issues and the fact that trees can survive and adapt better than arable crops when drought conditions occur – preconditioned that rooting systems reach deeper soil layers. With regard to future scenarios and changes in agricultural policies and priorities, studies related to the use of marginal soils for poplar or willow SRC production should be also included as a future research aspect, despite the current situation points at replacement of productive agricultural soils.

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