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Growth and carbon capture of grey alder (*Alnus incana* (L.) Moench.) under north European conditions – Estimates based on reported research

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ABSTRACT

Biomass from woody crops is regarded as a future major source of renewable energy. Wood production therefore has to be enhanced to meet the energy needs of an increasing population. This can be reached by using fast-growing tree species. Grey alder (*Alnus incana* (L.) Moench.) is an indigenous and fast-growing species, which is well adapted to the harsh climate of northern Europe, and could complement other biomass-oriented species used today. This study aimed to assess the potential for wood production and carbon (C) sequestration in biomass and soil of grey alder plantations under north European conditions. The estimates were based on literature data on above- and below ground biomass production, including fine roots, biomass allocation patterns and litter decomposition. By applying logistic functions on production figures and adding an estimated breeding response, grey alder would be able to produce on average 6–7 Mg ha^{-1} yr^{-1} of above ground woody biomass during a rotation up to 25 years. This would significantly contribute to increased biomass availability in the Nordic and Baltic countries when applied on agricultural land. By assuming that grey alder will mostly be used on areas suitable for the species, e.g. sites with harsh climate or moist conditions, an estimate of 560,000 ha of newly abandoned agricultural land will be available. Thus, afforestation of those areas with grey alder would result in a total annual increase of aboveground woody biomass of 3.7 Tg, corresponding to 69,000 TJ yr^{-1}. Grey alder would also be an efficient C sink when used on newly abandoned agricultural land. Using the same areas as for biomass the annual C sequestration in biomass and soil would reach 2.6 Tg C. These figures show that grey alder has a potential to be a significant contributor for increasing biomass supply and capture C in northern Europe.

1. Introduction

Biomass from agriculture and forestry is a major resource of renewable energy that can substitute for fossil energy sources in northern Europe. It is also an important way of carbon sequestration which may counteract the ongoing global temperature rise. Today a large part of the biomass comes from harvest residues where other assortments than energy wood are the main goals, but cultivations aiming directly at energy wood from tree-formed species are increasing. The ambitions are high and the Nordic countries have adopted a vision of carbon neutrality by 2050 (IEA, 2013). Biomass from woody crops will, in this context, be a major source of renewable energy. It follows that wood production has to be enhanced and this can, for example, be reached by using fast-growing tree species.

Grey alder (*Alnus incana* (L.) Moench.) may offer a complement to the biomass-oriented species used today, where at present, major investments are made in *Salix* and *Populus* species. Grey alder has a number of favourable characteristics giving it a great potential to contribute to our energy supply. A key feature is the growth capacity. Studies in the Nordic and Baltic countries have shown that the growth is high on various types of sites. On peatlands mean annual increments of 4–5 ton DM ha^{-1} yr^{-1} of above ground woody biomass have been reported for 7–13 year-old stands (Rytter et al., 1989; Rytter, 1995, 2004; Hytönen and Saarsalmi, 2009) and on forest land on mineral soil the same production level has been found in different countries (Børset and Langhammer, 1966; Utkin et al., 1987; Rytter et al., 2000; Johansson, 2005). On agricultural land figures around 8 tonnes DM of above ground biomass ha^{-1} yr^{-1} have been recorded (Granhall and Verwijst, 1994; Telenius, 1999; Lõhmus et al.,

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1996; Uri et al., 2009). Even on sandy soils, grey alder grows relatively well (Saarsalmi et al., 1985, 1992; Elowson and Rytter, 1993). Moreover, the natural regrowth with root suckers and stump sprouts after harvest is also high (Saarsalmi et al., 1991; Paukkonen et al., 1993; Rytter et al., 2000; Daugavietis et al., 2009), which is favourable for the future naturally regenerated tree generations. It should be noticed that the production levels presented above have been obtained with local, unimproved plant material, giving further possibilities for increased growth of grey alder with future breeding efforts (Rytter and Stener, 2015).

Commercial plant material of grey alder is scarce, but is currently available for hybrid aspen and poplar for mild climate zones in the southern part of the region, i.e. southern Sweden, southern Finland, Denmark and the Baltic countries. *Salix* material is also available for more northern latitudes, but since *Salix* is not cultivated on forest land its occurrence is restricted to agricultural land. All *Salix* and *Populus* species and clones used for biomass production are recommended for fertile soils which are not subjected to frost. In general, these species, especially aspen, are attractive for browsing ungulates and fencing is recommended for hybrid aspen and poplar since plants are expensive and planted with relatively sparse initial density. Expensive plants and fences impose a burden on the economic outcome. Under these prevailing conditions the genus *Alnus* may offer a complement to the efforts made on *Salix* and *Populus*, thus contributing to a larger and more stable energy-oriented market for woody crops. Primarily grey alder is considered to have great potential in this field as it does not attract browsing animals (Sennerby-Forsse, 1982; Schrötter, 1983; Hjältén and Palo, 1992).

Grey alder is more climatically hardy and probably grows better than willow and poplar on acidic soils, i.e. typical forest soils. A pH level down to 4 works well (Ericsson and Lindsjö, 1981). Another positive feature is the fixation of atmospheric nitrogen in symbiosis with the *Frankia* bacteria. Measurements (Rytter et al., 1991; Uri et al., 2004) have shown that amounts in the order of 100 kg N ha^{-1} yr^{-1} can be fixed, suggesting that grey alder may be regarded as nitrogen self-sufficient in the long run. The N_2 fixing ability of alders will enhance the nitrogen availability in the soil (Tarrant and Trappe, 1971; DeBell and Radwan, 1979; Compton et al., 1997), which could be used to improve growth of other tree species by forthcoming planting or intercropping (DeBell and Radwan, 1979; Bormann and DeBell, 1981; Côté and Camiré, 1987; Binkley, 2003; Amoroso and Turnblom, 2006), and also implies that fertilization can be reduced. The growth dynamics of the species mix in intercropping is important for the effect as shaded alders will not contribute much to soil improvement (Dawson et al., 1983; Heilman and Stettler, 1983). It should also be noted that pH in soils of alder stands is generally lower than in adjacent stands of non-N_2-fixing species (Franklin et al., 1968; Bormann and DeBell, 1981; Van Miegroet and Cole, 1985) and that N_2 fixation has a metabolic cost (e.g. Huss-Danell, 1997) which may reduce growth to some extent.

Experiences from Estonia and Latvia indicate that alder is a suitable tree species for biomass production with a short rotation period of around 20 years (Tullus et al., 1996; Daugavietis et al., 2009; Uri et al., 2009). Mizaras et al. (2011) also noted that alder is an economically viable source of energy wood in Lithuania. Thus, there are a number of factors indicating that grey alder is a strong complement to *Salix* and *Populus*, with a potential to contribute to a significant increase in biomass availability in the region.

Today there is 1.6–2.0 million ha of surplus, and not yet afforested, arable land in the Nordic and Baltic countries that may be cultivated with fast-growing tree species and energy crops (Rytter et al., 2015a). Afforestation of former agricultural land has been considered as a meaningful contribution to the global energy supply (Campbell et al., 2008), but also as a major potential carbon (C) sink in Europe (Powlson et al., 1998) and in Sweden (Rytter, 2012). Conversion of natural ecosystems to agricultural land has caused a reduction of the soil organic C (SOC) stocks by 20–50% (e.g. Lal, 2005). Consequently, there is a potential to refill the depleted arable SOC stocks to their original levels. Nitrogen fixing tree species have shown higher SOC concentrations or stocks than non-N_2-fixing tree species (e.g. Johnson and Curtis, 2001). However, the outcome of grey alder plantations in this context is still unknown for northern latitudes.

Carbon is sequestered in woody biomass in stems, branches, stumps, twigs and coarse roots, but also accumulated in the forest floor and soil by litter from leaves, twigs and fine roots. Fine root turnover constitutes a main source of SOC that cannot be overlooked when calculating C budgets for plant and soil systems (e.g. Matamala et al., 2003; Rytter, 2012). About one third of net primary production (NPP) is allocated to fine roots in forests in general (Jackson et al., 1997), but figures up to 40–70% have been reported (Ågren et al., 1980; Rytter, 2001; Kalyn and Van Rees, 2006).

The supply of energy from woody biomass is expected to increase in the near future in order to substitute fossil fuel for generating heat, electricity, and transportation fuels. Different fast-growing tree species are relevant for this purpose and grey alder is found among them. Bioenergy plantations with grey alder, established on forest sites or on former agricultural land, may contribute to an environmentally sustainable energy supply. However, there is a need for realistic estimates of the possible outcome of stem wood production in grey alder plantations and also for C sequestered in non-harvested plant parts, i.e. stumps, coarse and fine roots and root nodules, and accumulation of SOC from decomposing litter. The main aim of the present study was to assess the general potential for biomass production and C sequestration in biomass above and below ground, and in the soil, of grey alder plantations growing on abandoned agricultural land during one rotation, i.e. up to 25 years under north European conditions. This was accomplished by using data on biomass production, biomass allocation patterns and litter decomposition obtained from the literature. The outcome of the calculations was discussed from a regional bioenergy perspective where available and suitable land areas were assessed.

2. Materials and methods

The assessments were based on dense experimental and commercial stands in the Nordic and Baltic countries presented in the literature and where biomass amounts have been recorded. We applied rotation periods of up to 25 years, thus covering the rotation cycle for short rotation forestry proposed by Tullus et al. (1996), Daugavietis et al. (2009) and Tullus et al. (2013).

2.1. Stem, branch and stump production data

We used data from studies reporting biomass of grey alder from Sweden, Finland, Estonia and Russia, which include both planted and natural regenerated grey alder stands. We checked the data but found no reason to separate planted and natural stands as their production levels were mixed within each other without any apparent pattern. We are aware of that more data exist on stem volume growth on grey alder. However, a translation from stem volume to above ground biomass from these data means rough estimates and therefore we have built our functions on the literature where biomass data are presented. We found a sufficient amount of data with this restriction.

In a first step all collected data on above ground woody biomass were used. A sigmoidal logistic 3 parameter function was fitted to