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Influence of Soil Types on Establishment and Early Growth of *Populus trichocarpa*

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Abstract

When planning poplar plantations there are many factors to consider that can influence young plant development. In addition to soil preparation, vegetation management, protection against browsers, and plant-type, it is important to have information on how soil properties influence young plant development. Comparisons of establishment and growth in different soils are complicated as experimental sites often are geographically distant where temperature, precipitation and vegetation can vary, thus complicate the analysis. In this case study, a new approach of studying growth of different soil at one experimental site are undertaken by translocating agricultural soils, a silty clay loam and a sandy soil, and common forest soil types, forest moraine soil and forest peat to a single experimental site, thus guaranteeing identical climatic conditions. In all soils, transplanted *P. trichocarpa* cuttings initially developed in to plants. After 4 weeks though, plants grown in forest peat stopped their growth while plants in the other soils gradually continued their growth with no evidence that soil types influenced above ground plant development. Unlike above-ground growth, root growth and morphology were influenced by soil texture with more root growth occurring if soils have sandy texture. These findings give advice to some of the limitations when planning for establishment of poplar plantations either at agricultural or at forest land.

Keywords

Poplar Establishment, Soil Texture, Cutting Growth, Nutrient, Agricultural Soil, Forest Soil

1. Introduction

Soil texture and drainage are two of the most important factors for successful poplar plantation establishment and growth (Baker & Broadfoot, 1979). Poplars have the ability to initiate adventitious roots from the stem and therefore hardwood cuttings can be planted in order to establish plantations (DeBell & Harrington, 1997; Hartmann, 1975; Hofmann-Schielle et al., 1999). Poplars are generally considered to prefer well drained alluvial soils with sufficient moisture and nutrients and an intermediate soil texture (sand/loam) (Baker & Broadfoot, 1979). In northern climates, sandy soils can favor the growth of *Populus x wettsteinii* (hybrid aspen) as these soils warm earlier in spring, but this advantage may be offset by the risk of drought conditions later in the growing season (Bergante et al., 2010; Scotti et al., 2010; Tullus et al., 2011). Heavy soils with clay, clay loam, and silty clay loam textures are considered less favorable for poplar growth (Stanturf et al., 2001). However, once established, high growth of poplars can occur on heavier soils (Johansson & Karačić, 2011). Pinno and Belanger (2009) found that poplar growth is best in soils with more silt and clay. However, Pinno et al. (2009) found that maximum poplar tree growth occurred at a sand content between 55 and 70% with pH near 6. In other tree species, for example *Citrus volkameriana*, soil texture only slightly affects growth (Bouma & Bryla, 2000). For *Salix nigra*, biomass production was found to be clearly affected by soil characteristics, with higher production in coarse-grained (sand) than in finer-grained sediments (silt/clay): fine textured soil negatively affected leaf size, leaf mass and leaf area (Schaff et al., 2003). Different soil types can influence plant development through differences in available nitrogen (N) resources leading to a shift in carbon allocation from root to shoot (Albaugh et al., 1998; Beets & Whitehead, 1996; Coleman et al., 2004), resulting in differences in fine root production (Burton et al., 2000; Gower et al., 1992; Kern et al., 2004; Keyes & Grier, 1981) and changes in leaf size and total leaf area (Knops, 2000). To date, plantations of poplars are mainly located on marginal abandoned agricultural land (Christersson, 2008; Christersson, 2010; Tullus et al., 2011). On forest land however, our knowledge of establishment and growth of poplars are limited but there is a large potential in available area if establishment would be possible.

How young poplar growth is influenced by a specific soil type is hard to predict and comparisons are also difficult because sites with different soils are generally geographically distant, so that factors such as precipitation and temperature vary, thus complicating the analysis. In order to undertake accurate comparisons of establishment and growth in different soil types, distances between experimental sites needs to be minimized. In this paper, we created tree cases with different soils and investigated how poplar cutting development is influenced by texture (sand and clay) and origin (agricultural and forest). We used soils with different characteristics and from different sites to grow poplar cuttings under similar conditions to study the effects of soil characteristics.

2. Materials and Methods

2.1. The Experimental Site and Collection of Soils

The experiment was performed in the experimental garden at the Swedish University of

Agricultural Sciences in Alnarp, Sweden (Lat N 55˚39'33" Lon E 13˚4'46"). In 2006, holes measuring 2 × 2 m and 1 m deep were dug at the experimental site. The soils (Table 1) were collected in 10 cm layers to a depth of 1 m and placed in the holes in their original order. To separate the experimental soils from the surrounding soil, a polyethylene plastic woven carpet (Mypex,) was placed along the walls of the pits. The only treatments applied during the period from soil collection to the beginning of the experiment were non-chemical vegetation control and irrigation, no fertilizers were added.

2.2. Soil Characteristics

Three different soils were chosen for the experiment: two agricultural soils with different textures and one moraine soil, typical of Swedish forest land and a forest peat also commonly found in Swedish forest land (Table 1). The soil texture was determined by sieve analysis, the humus content by Loss on Ignition (LOI) (Table 1), soil Nitrogen (N), Potassium (K) and Phospurus (P) (Table 2) at the analytical laboratory Eurofins, Kristianstad, Sweden. It should be noted that the forest moraine soil (For-mor) contained larger stones (2 - 5 cm in diameter) than the agricultural soils. The soil pH was measured at a soil-to-water ratio of 1/2 (v/v).

Table 1. pH and soil Characteristics, including pH, humus, clay and sand content and the origin of the soil.

	Soil Characteristics					
	Ph	Humus (%)	Clay (%)	Silt (%)	Sand (%)	Soil origin
For-peat	3.7	34	3	5	58	Forest
For-mor	4.9	1.8	6	4	81	Forest
Agri-clay	7.0	6.1	48	33	19	Agricultural
Agri-sand	6.9	3.2	5	13	82	Agricultural

Note: the soils are; agricultural soils, a silty clay (Agri-clay) and a sandy soil (Agri-sand, and forest moraine soil (For-more and forest peat (For-peat).

Table 2. Soil conten of Nitrogen (N), Potasium (K) and Phosporus (P) Data shown are mg per kg soil.

	Soil content		
	Nitrogen (N)	Potasium (K)	Phosporus (P)
For-peat	18	34	73
For-mor	14	18	16
Agri-clay	160	320	260
Agri-sand	24	41	94

Note: the soils are; agricultural soils, a silty clay (Agri-clay) and a sandy soil (Agri-sand, and forest moraine soil (For-more and forest peat (For-peat).

2.3. Plant Material and Experimental Treatments

Populus trichocarpa clone SRF 93 (STT 7/3.26) was used as the plant material. This clone originates from British Colombia, Canada and was selected because it is robust and has a high rooting capacity. Dormant cuttings measuring 20 cm long and with a diameter of 12 - 15 mm were used in the experiment. Before planting, cuttings were soaked in water for 24 h. To avoid severe drought stress during the experiment, the lowest acceptable level of precipitation was set to 10 mm per week. If the natural precipitation was less than 10 mm per week the young plants were irrigated with water equivalent to 10 mm precipitation. Such irrigation was necessary three times during drought periods (Figure 1(a)). During the experimental period, the temperature varied between 13.4˚C and 22.9˚C (Figure 1(b)). Precipitation and air temperature were determined at a local weather station less than 1 km from the experimental site.

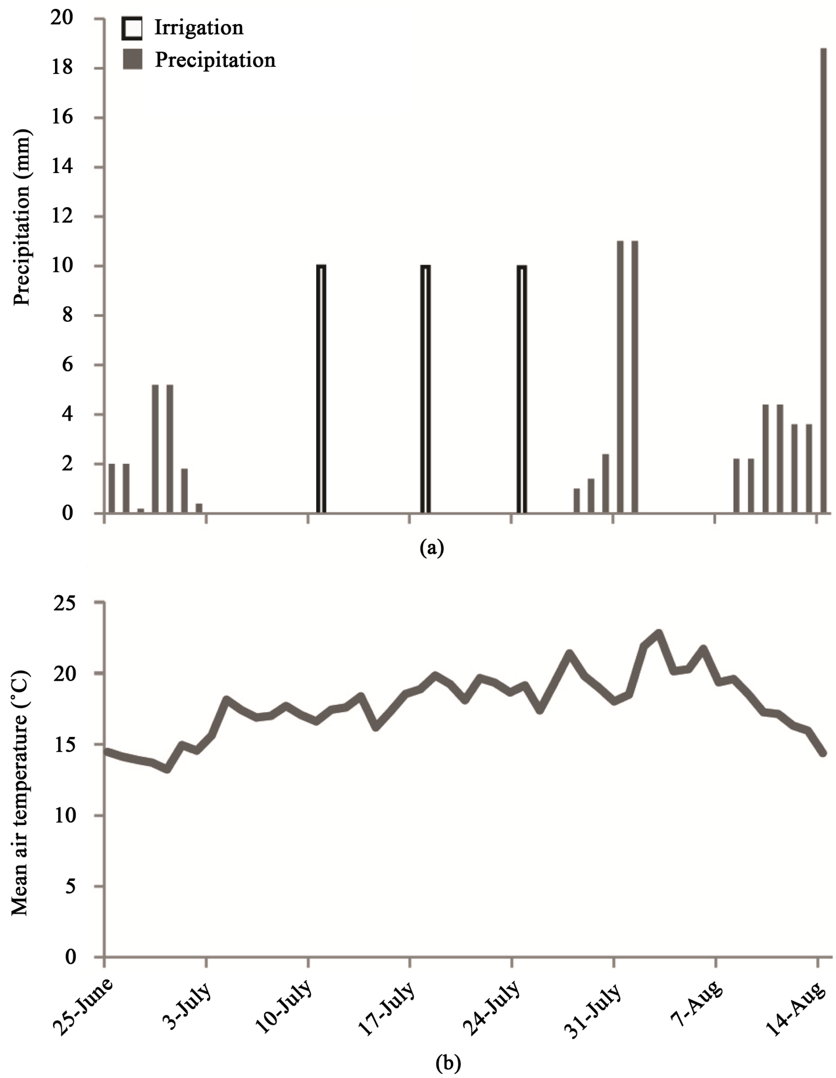

Figure 1. Temperature and precipitation at the experimental site. (a) precipitation and (b) air temperature at a local weather station.

2.4. Experimental Design and Plant Analysis

In each soil, eight rows each of seven cuttings were planted. Each week, seven plants from each soil were sampled according to a pattern were each of the planting positions were represented. The parameters analyzed were height, total root number, development of fine roots and mean root length of each cutting. Fine root development was recorded as follows: 0 = no fine roots, 1 = few fine roots, 2 = fine roots found on all roots, 3 = fine roots abundant on all roots. Mean and total leaf area were determined eight weeks after planting. Individual leaf area was determined from one fully expanded leaf of each plant eight weeks after planting. The total leaf area was calculated by multiplying the total number of leaves on each individual plant by the individual leaf area of the same plant. To determine the biomass eight weeks after planting, roots were washed and together with the leaves, the stems dried at 80˚C for 48 hours. The nutrient analysis was performed on leaves and stem samples eight weeks after planting using material from four cuttings in each soil type, following Leco AN 203821-394, ISO 16634 (Nitrogen) and NMKL 161, 198, mod (minerals) at the analytical laboratory Eurofins, Kristianstad, Sweden.

3. Results

3.1. Plant Survival, Height Growth and Root Development

All the cuttings survived and developed into plants in all soil types during the experiment (Figure 2). A gradual increase in height was observed throughout the experiment for plants growing in all soil types except For-peat, reaching heights of 47 cm in For-mor, 57 cm in Agri-clay and 69 cm in Agri-sand (Figure 2) For plants grown in For-peat, plants grow up to 10 cm at week 4 but after this no further height growth occurred.

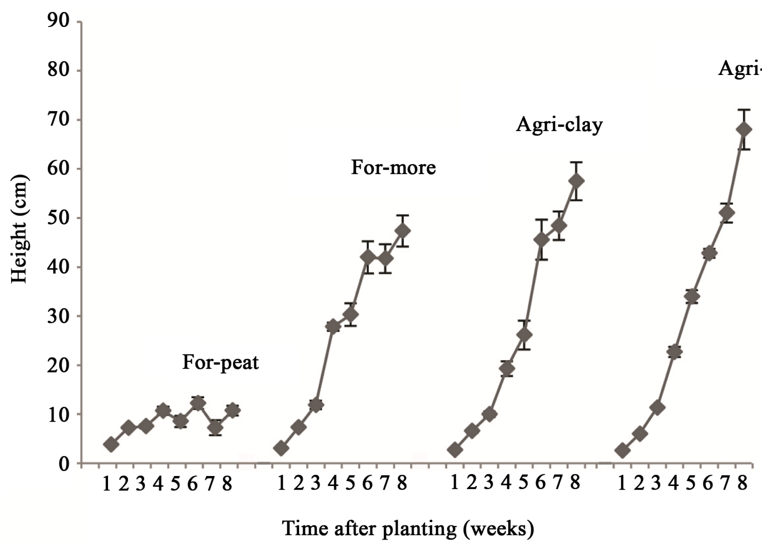

Figure 2. Height growth. *P. trichocarpa* cuttings were planted in forest peat (For-peat), forest moraine soil (For-mor), agricultural silty clay soil (Agri-clay) and agricultural sandy soil (Agri-sand). Data shown are mean values (n = 7). Error bars represent ± SE.

After this week plants turned yellow and were dying. For this reasons plants grown in For-peat are not included in further analysis. The number of roots gradual increase for plants grown in For-mor and Agri-sand while those in Agri-clay remained quite constant throughout the experiment (**Figure 3(a)**). Mean root length were gradually increased during the experimental period in all soil types, reaching 8.2 cm and 10 cm for plants grown in For-mor and Agri-sand soils and 4.4 cm for plants grow in the Agri-clay soil (**Figure 3(b)**). On plants grown in For-mor and Agri-sand, fine roots were developed after three week while no fine roots were found in the Agri-clay soil (**Figure 3(c)**).

3.2. Biomass Allocation, Production and Leaf Area

Root biomass of plants grown in Agri-clay, Agri-sand and For-more were 0.4, 0.3 and 0.3 g (**Figure 4(b)**). Stem biomass production varied form 1.9 g for seedling in For-mor to 6.1g for plants in Agri-clay and 4.3 g in Agri-sand. Leaf biomass of plants grown in For-more reached 2.3 g while plants grown in Agri-clay and Agri-sand reached 7.3 and 5.0 g. Root fraction varied for plants with 3.6% For-more, 3.6% Agri-clay and 6.5% in Agri-sand **Figure 4(a)**. Stem biomass allocation changed from 42% in seedlings growing in For-more to 40% - 38% in plants growing in Agri-clay and Agri-sand. For plants grown in For-more leaf biomass were 52%, Agri-clay 55% and Agri-sand 58%. Mean leaf area reached 17 cm^2 and total leaf area 335 cm^2 for plant grown in For-more (**Figure 4(c)**). In the agricultural soils, Agri-clay and Agri-sand, individual leaf area reached 30 to 28 cm^2 and the total leaf area was determined to 645 cm and 628 cm (**Figure 4(d)**).

3.3. Leaf and Stem Nutrient Content

In the stem and leaf, the N concentrations reached 0.75% and 1.5% when plants were grown in For-mor (**Figure 5(a)**). Plants grown in Agri-sand and Agri-clay, N concentration in stem reached 0.95% to 0.85% and in leave 2.3% to 2.0%. P concentration reached 0.11% in stem and 0.12% in leaves of plants grown in For-more. For plants grown in agricultural soils, Agri-clay and Agri-sand, P concentration in stem were 0.11 and 0.13 respectively and in leafs 0.15 and 2.0. K concentration was 0.96% in leaf and 0.8% in stem of plants grown in For-more. In Agri-clay and Agri-sand, K concentration reached 0.6% and 0.71% (leaf) and 0.45% and 0.71% (stem) (**Figure 5(c)**). Total N content for plants grown in For-mor reached 0.005g in leaves and 0.0025g in stem (**Figure 5(d)**) and for plants grown in Agri-clay or Agri-sand total N content varied between 0.2 and 0.14 (leaves) and 0.075 to 0.05 g (stem).

In the analyzed from all the soils, P:N ratios were below 0.1 for leaf and stem of plants grown in For-mor and total for Agri-clay. The other samples were all close or above 0.1 (**Figure 5**).

Except leaf samples from plants grown in the Agri-clay all other samples (leaves, stem and combination of Leaf and stem) K:N ratio that exceeded 0.35.

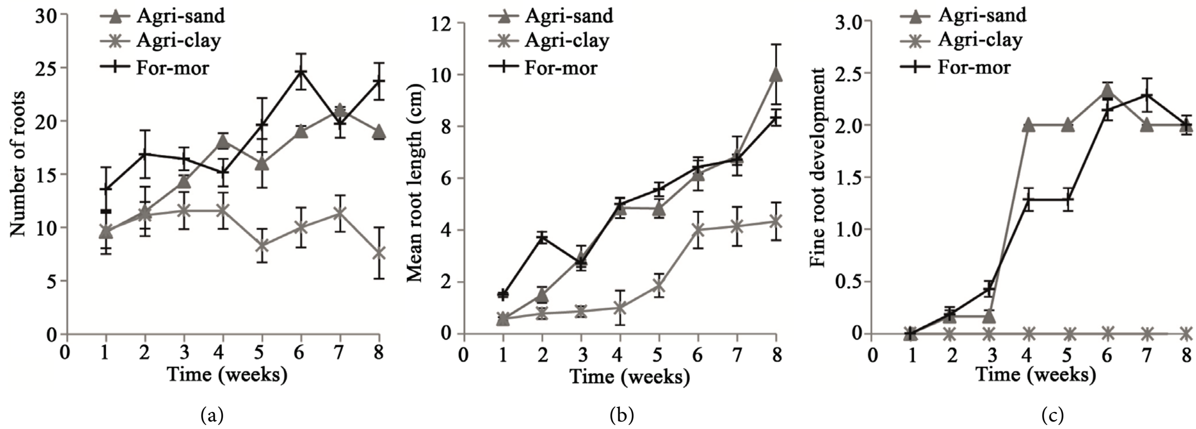

Figure 3. Root development. *P. trichocarpa* cuttings were planted in forest moraine soil (For-mor), agricultural silty clay soil (Agri-clay) and agricultural sandy soil (Agri-sand): the total number of roots per cutting (a); mean root length (b) and development of fine roots (c) were analyzed. Fine root values shown are means of the four root development categories 0 = no fine roots, 1 = few fine roots, 2 = fine roots on all roots and 3 = fine roots abundant on all roots. Data shown are mean values (n = 7), error bars represent ±SE.

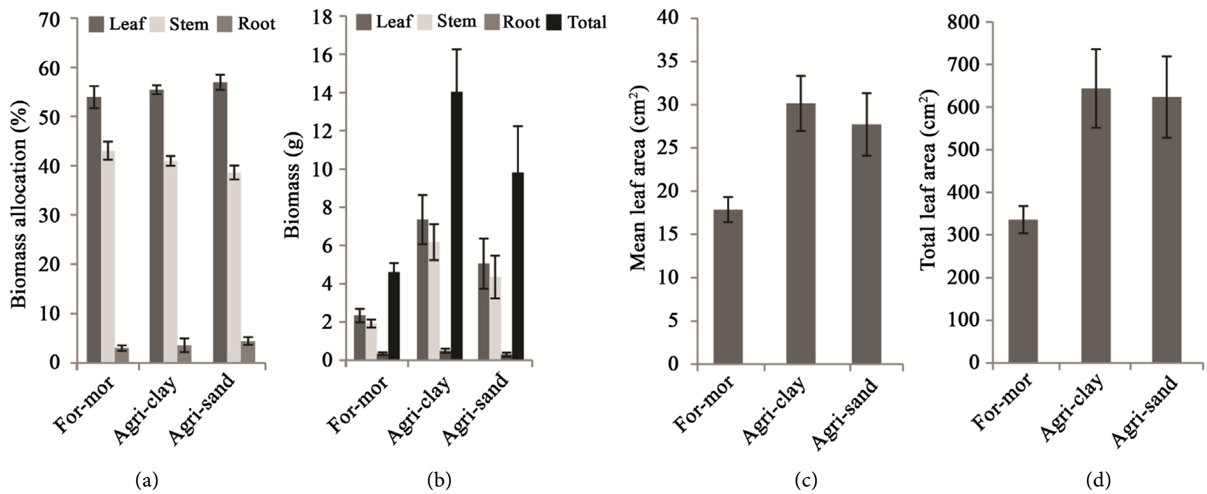

Figure 4. Biomass growth, allocation, individual and total leaf area. Biomass allocation (a) and leaf, stem, root and total biomass production (b); individual leaf area (c); total leaf area (d) of *P. trichocrapa* plants eight weeks after planting in forest moraine (For-mor), agricultural silty clay (Agri-clay) and agricultural sandy soil (Agri-sand). Data shown are mean values (n = 7). Error bars represent ±SE.

4. Discussion

We investigated how soils with different textures and origins influenced establishment with dormant *P. trichocarpa* cuttings and how development of plants proceeded during the first 8 weeks. Our results revealed that survival were not influenced by soil texture or origin. Cutting planted in the agricultural soils, Agri-sand and Agri-clay or in forest moraine (For-mor) all developed in to plants with no obvious differences. In contrast to height, soil texture influenced root development with more and longer roots with fine roots present in the soils with sandy texture. Our intention were not to identify the optimal soil for establishing poplars but to describe how transplanted poplar cuttings

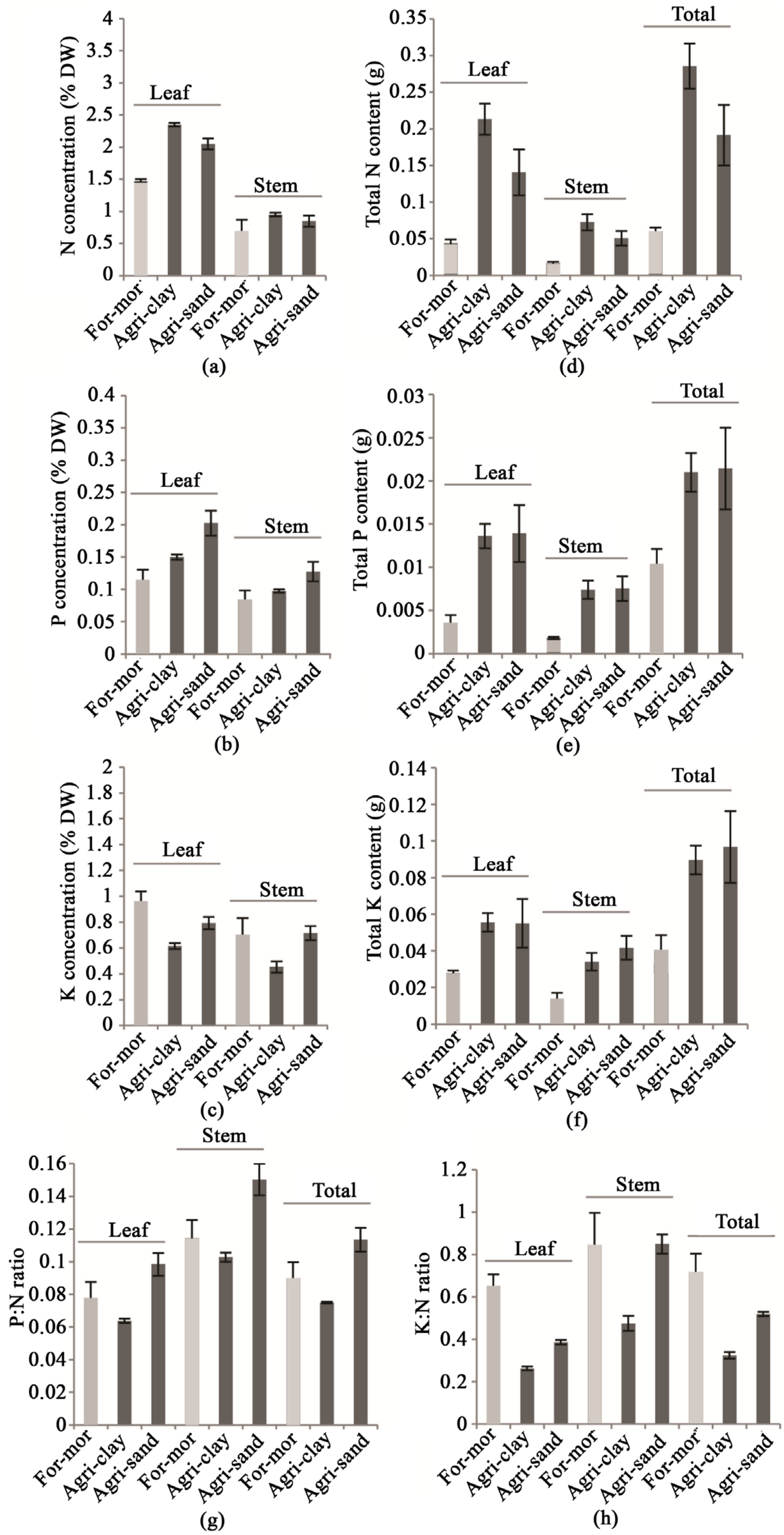

Figure 5. Concentration of macronutrients and total content. Concentrations of (a) Nitrogen; (b) Phosphorus and (c) Potassium; total content of (d) Nitrogen; (e) P:N ratio and (f) K:N ratio The analyzed soils were forest moraine (For-mor), agricultural silty clay soil (Agri-clay) and agricultural sandy soil (Agri-sand). Data shown are mean values (n = 4). Error bars represent ±SE.

develops in to plants in different soils. Therefore results from this study can give additional information how poplar establishment is influenced by different soils. If proper growth comparisons between different soils should be possible, soils need to be translocated to one experimental site. It could very well be that this translocation will influence the soil as much as an intensive site preparation would but in our experiment the soils was left to settle for eight years. This time period would probably remove some of the issues concerning altered growth conditions due to soil translocation. An alternative to our approach would be to grow the plant sin pots. Using this method would probably have additional effects. For example, the possibilities that the soil structure is altered during transportation and that growth volume will be restricted are likely to be increased. The connection between the soil layer were cutting are planted and the lower soil layers are also lost. These problems might create soil conditions that are altered to a higher extent than if a whole soil structure to a depth of 1m are translocated and left to settle for eight years, as in our experiment. One limitation to our case study is that only one soil of each type was tested. Therefore, extra care should be taken before general conclusion is made on where poplars should be planted. Pinno and Bélanger, 2009 found that soil texture was the best predictor of poplar growth: soils with more silt and clay produced better growth. Another report (Pinno et al. (2009) found that maximum poplar tree growth occurred at a sand content between 55% and 70%. For willow, Bouma and Bryla (2000) found that leaf and stem biomasses increased with increasing proportions of silty clay loam, while Schaff (2003) reported that willow growth was higher in sandy sediments than in silt clay sediments. Bouma and Bryla (2000), reported that growth of *Citrus volkameriana* was only slightly affected by soil texture. Our results suggest that poplar establishment is not dependent on a specific soil texture. We found that plants could develop and reach a height of 64 cm for Agri-clay and 68 cm for Agri-sand with stem biomass production of 7.3 g and 5 g form transplanted cutting (**Figure 2** and **Figure 4**), soils which differed specifically with respect to texture (**Table 1**). Our results also indicate that establishment of poplar in For-more is possible but that plants only reached a height of 47 cm with a stem biomass of 1.9 g (**Figure 5** and **Figure 4**), 17 cm shorter and 3.1 g lighter stems than plants grown in Agri-sand. This could indicate that the origin of the soils (agricultural or forest) are important for early growth and plant development. However, at other sites (similar soils as our case study), planting of other *Populus* genotype could result in growth differences. If differences in available nutrients between forest soils and agricultural soils are the reason for growth differences, plant macronutrient concentrations and total content could give an indication. Indeed, we found that total N was 0.06g in plants grown in For-mor and exceeded 0.2 g for plants grown in Agri-clay and Agri-sand (**Figure 5**). We did observe, however, that if K concentration was reduced, N concentration is increased; this is consistent with other research reporting that soil K concentration and content is decreased as nitrogen levels increase (Ring et al., 2011). Although N, P and K were low (1.5% (N), 0.125 (P) and K 0.96%) in plants grown in For-mor, total nutrient ratios were close to optimal (K:N 0.35 and P:N 0.1) (Aronsson & Elowson, 1980; Ingestad, 1979; Linder, 1995), suggesting that the plants where not suffering from nutrient imbalance. We observed that in plants grown in Agri-clay, N concentrations were high and P and K concentrations relatively low and, as a consequence, total K:N ratios were below their optimal levels, suggesting a nutrient imbalance despite the high growth. Differences in nutrient concentrations and contents in plants grown the agricultural soils and forest soil could be the result of a combination of differences in the soil water holding capacity (Zhou et al., 2014) and/or nutrient availability that together facilitate nutrient uptake. In addition, we found longer mean root length and more fine root development on cuttings grown in Agri-sand and For-mor. This root development indicates that plants grown in these soils need more roots to increase water uptake and/or nutrient uptake. In contrast, the plants grown in Agri-clay produced less root growth, but their nutrient content was high, suggesting that cuttings were grown in a soil environment where water and nutrients were abundant and high root growth was not required to allow the plant to access sufficient nutrients and water. These results agree with others research, reporting reduced root growth with increased N availability (Burton et al., 2000; Gower et al., 1992; Kern et al., 2004; Keyes & Grier, 1981). It should be noted that the results presented herein were obtained after a growth period of eight weeks. Height growth and biomass production influenced by soil texture may be more visible after a longer time period, as reported by others (Bouma & Bryla, 2000; Pinno et al., 2009; Schaff et al., 2003). In a real poplar plantation a slow start could be problematic as early plant development is important for stand development and perhaps one of the reasons why heavy soils such as Agri-clay are considered less suitable for poplars (Stanturf et al. 2001). Our results suggest that, under similar climatic conditions, survival and early plant growth are not dependent on the soil texture and that any difference in growth between soils (Bouma & Bryla, 2000; Pinno et al., 2009; Schaff et al., 2003) probably occurs in older plants.

5. Conclusion

This study sheds some light on our understanding on early poplar plant establishment in different soil types. The results obtained indicate that establishment of poplar cuttings in agricultural soils is independent of soil texture. Also, on forest land, where moraine is the most common soil type, poplars can be established but soil nutrient concentration and/or availability and differences in uptake capacity are presumably some of the factors limiting growth. For the practical work in establishing poplar plantations on forest sites, increased growth during the first few weeks after planting could be important for successful establishment. To further elucidate how poplar plantations can best be established on forest sites, we need to increase our knowledge concerning plant-forest soil interaction as well as our understanding of the type of mechanical soil preparation required for regeneration of poplars on such sites.

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