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Article

Effects of Direct Application of Fertilizers and Hydrogel on the Establishment of Poplar Cuttings

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Abstract: The aim of poplar plantations is to achieve high biomass production over a short rotation period. This requires low mortality and fast development of the transplants. The experiment described in this paper examines methods aimed at enhancing survival and development of *Populus trichocarpa* plants by application of fertilizers, a hydrogel or a combination of both to dormant cuttings just before planting. The experiment was carried out at two agricultural sites with different soil characteristics, a loamy sand and a silty loam. It was demonstrated that none of the treatments influenced survival or early growth at the silty loam soil site, and plant development was delayed by the solid fertilizer. At the site with loamy sand, the solid fertilizer negatively affected both survival and early growth. Hydrogel and the combination of hydrogel and the solid fertilizer also hampered early growth. Overall, treatments of poplar cuttings with hydrogel or fertilizers alone, or in combination, may not be a method to reduce poplar cutting mortality or to enhance early plant development on agricultural land. However, our results demonstrate that establishing poplar with cuttings as transplants can be used on both loamy sand and silty loam soils.

Keywords: *Populus trichocarpa*; regeneration; cuttings; coating; fertilizer; hydrogel; plant development; establishment

1. Introduction

There is an increasing demand for forest biomass as a replacement for oil and coal products. Plantations of fast growing broadleaved species, such as poplars have an important role in this transition. Currently, poplar plantations in the Nordic hemisphere, for example in Sweden, are mainly established on agricultural land [1]. The Swedish MINT investigation showed that there are about 400,000 ha of agricultural land available for planting without interfering with agricultural production [2]. These sites possess properties, such as high fertility and good water availability. However, another investigation revealed that there is a large potential for planting poplars on forestland, with about 2,500,000 ha being suitable for fast growing broadleaf species [3]. Planting poplars on a part of this area, as opposed to agricultural land, will pose further challenges in terms of nutrient and water availability, since these sites do not have a long history of fertilizer amendment and soil cultivation. Today, most poplar plantations in Sweden are established by planting of bare-rooted seedlings. However, poplar cuttings have the possibility to initiate adventitious roots and poplar plants are therefore often propagated from cuttings [4]. This property has made it possible to use cuttings as transplants in establishing poplar in other countries [5,6], but it has remained unknown whether this propagation method would work under Swedish climate- and soil-conditions. Survival and early growth are two important factors when establishing new forests. Low survival might result in additional costs due to the need of supplementary planting, which often results in gaps and stands of uneven height [7]. A rapid initial growth will minimize the time the plants are vulnerable to top browsing, a problem that might cause considerable damage to young stands [8].

Poplars are a demanding tree species in terms of water, nutrients and light and there are several studies demonstrating that vegetation control during the initial phase has a positive impact on both survival and initial growth [9–11]. Given that vegetation control enhances water and nutrient availability, application of fertilizers and hydrogel may have a positive effect on plant establishment. Van den Driessche (1999) demonstrated that the application of fertilizers about 20 cm from the poplar cuttings enhanced growth compared to untreated cuttings and was about twice as effective as banding of fertilizers [12]. Similarly, Bilodeau-Gauthier (2011) found that the application of fertilizers applied to the base of a planted tree positively influenced its growth [13]. Since poplars are sensitive to competing vegetation [9,14,15] and fertilizing whole areas increases the growth of competing vegetation [16], the application of fertilizers directly to the transplant could be an alternative strategy for addition of extra nutrients at the time of planting.

One major cause of unacceptable rates of mortality by using poplar cuttings as transplants is their inability to maintain water uptake from the bulk soil water during dry conditions. For bud break and development of leafs and shoot, access to soil water is essential [17]. An alternative treatment could therefore be to use hydrogel closely associated to the cutting at the time of planting. Hydrogels have the capacity to absorb large volumes of water and water-soluble nutrients that can be released when needed, and in the same time water and nutrients are kept close to the transplant and not lost to the surrounding soil and ground water. The use of hydrogel alone or in combination with fertilizers during poplar establishment could thereby enhance establishment, root development and early growth even further. Hydrogel applied to the root plug decreased eucalyptus seedling mortality [18] and poplar plants treated with hydrogel exhibited longer root length and increased root surface area [19].

The aim of this study was to evaluate the impact of fertilizers, a hydrogel and the combination of these, directly applied to poplar cuttings at the time of planting. The experiments were conducted at two experimental sites with different soil characteristics, a loamy sand and a silty loam soil.

2. Material and Methods

2.1. Plant Material, Study Sites and Experimental Design

The genetic poplar material selected to this study was the *Populus trichocarpa* clone SRF 21, also referred to as STT7/3.8. *Populus trichocarpa* is one of the most used poplar species in Sweden and is the dominant species used in the commercial clone mixture used in southern Sweden. The chosen clone is a robust clone with a high rooting capacity. Dormant cuttings were harvested in February and stored in a cold room (+2 °C) until time of planting. We selected to use cuttings with a similar length (20 cm) and root-collar-diameter (12–15 mm), since these properties could have an implication on plant development. The cuttings were randomly distributed with in each treatment.

The experiment was carried out at two former agricultural sites with differences in soil characteristics. Experimental site 1 is located in Våxtorp, (56°25′ N, 13°05′ E, 40 m above sea level), situated 12 km from the west coast in southern Sweden. The soil is a loamy sand. Experimental site 2 is located in Alnarp (55°39′ N, 13°4′ E, 6 m above sea level), situated 2 km from the west coast in the south of Sweden. The soil type is a silty loam. Both areas are fenced to exclude browsing. The annual precipitation is about 1000 mm in Våxtorp and about 800 mm in Alnarp and the mean annual temperature is about 8 °C at both sites. In Våxtorp experimental site, the soil pH is 5.8, NO_3^- 0.74 mg kg^{-1}, NH_4^+ 0.38 mg kg^{-1}, while at Alnarp experimental site the soil pH is 7.4, NO_3^- 24 $mg \cdot kg^{-1}$ NH_4^+ 2.3 $mg \cdot kg^{-1}$. At each site three blocks were defined with each block containing 10 treatments with 5 cuttings in each treatment. The treated cuttings were planted randomly within each block at a spacing of 1 m. Average values of the five cuttings per treatment and block were used for the statistical analyses.

2.2. Selection of Fertilizers, Hydrogel and Perlite and Preparation of Substrates

Perlite is able to absorb large volumes of liquids that can be released over a long time. Therefore, this substrate was used for the slow release of fertilizers alone or in combination with a water-holding gel. The hydrogel used in these experiments was purchased at Svensk skogsgödsling AB, Jularp, Sweden. The hydrogel used is a bio-degradable, starch-based polymer of dry grains of irregular shape ranging from 1–3 mm. In contact with water, the hydrogel absorbs (up to 500 times of its own weight) and swells in to a gel. Approximately 95% of the water absorbed by the hydrogel is available for the plants. The hydrogel used in this experiment was recommended by the manufacturer to be used at silty loam soils to retain water or at heavy soils making better soil structures by improving air-water relations. The fertilizers used were selected on the basis that it should be commercially available and contain most of the important nutrients required for plant growth. The solid fertilizer (N-P-K 16-6-12), the liquid fertilizer (N-P-K 10-4-6) and Perlite were purchased at Plantagen plant nursery Malmö, Sweden.

The ten treatments consisted of:

- C—Control, no treatment
- SG—Starch gel
- SGLF—Starch gel containing liquid fertilizer
- SF—Solid fertilizer
- HG—Hydrogel
- HGSF—Hydrogel containing solid fertilizer
- P—Perlite
- PLF—Perlite containing liquid fertilizer
- PLFP—Perlite containing liquid fertilizer diluted with fertilizer-free Perlite
- PLFHG—Perlite containing liquid fertilizer and hydrogel

The different treatments were prepared by the following procedures. Starch gel (SG) was prepared by dissolving 60 mL of starch powder (Kockens AB, Fjälkinge, Sweden), in 1000 mL H_2O and heated until the starch started to solidify. Starch gel containing liquid fertilizer (SGLF): after the starch gel (SG) had cooled down, liquid fertilizer N-P-K 10-4-6 was added to a final concentration of $N = 3.3\ g{\cdot}L^{-1}$, $P = 1.3\ g{\cdot}L^{-1}$ and $K = 2.0\ g{\cdot}L^{-1}$. Solid fertilizer (SF): solid fertilizer Plantagen (N-P-K 16-6-12) was diluted to a final concentration of $N = 5.3\ g{\cdot}L^{-1}$, $P = 2.0\ g{\cdot}L^{-1}$ and $K = 4.0\ g{\cdot}L^{-1}$ in Perlite and homogenized. Hydrogel (HG): the purchased hydrogel was left untreated. Hydrogel containing solid fertilizer (HGSF): solid fertilizer was diluted to a final concentration of $N = 5.3\ g{\cdot}L^{-1}$, $P = 2.0\ g{\cdot}L^{-1}$ and $K = 4.0\ g{\cdot}L^{-1}$ in Hydrogel and homogenized. Perlite (P): the purchased perlite was left untreated. Perlite containing liquid fertilizer (PLF): was prepared by first soaking Perlite in 1 time Plantagen liquid fertilizer for 24 h followed by air drying of Perlite at room temperature for 48 h. Perlite containing fertilizer diluted with fertilizer-free Perlite (PLFP): Perlite containing liquid fertilizer (PLF) was diluted 2 times in untreated Perlite and homogenized. Perlite containing fertilizer and Hydrogel (PLFHG): Perlite containing liquid fertilizer (PLF) was diluted 1:2 (v/v) ratio in Hydrogel and homogenized.

2.3. Application of Substrates

Before the application of the different substrates, the cuttings were soaked in water for 24 h. Thereafter, with the exception of the control treatment, the cuttings were dipped in starch gel, followed by directly applying in the different substrates, covering 15 cm of the lower part of the cuttings. After application of each treatment, the cuttings were left to air-dry for 30 min before planting. This method added 0.033 g nitrogen (N), 0.013 g phosphorus (P) and 0.02 g potassium (K) to the SGLF cutting, 0.28 g N, 0.1 g P and 0.2 g K to the SF cutting, 0.14 g N, 0.05 g P and 0.1 g K to the HGSF cutting, 0.5 g N, 0.2 g P and 0.3 g K to the PLF cutting, 0.25 g N, 0.1 g P and 0.15 g K to the PLFP cutting and 0.25 g N, 0.1 g P and 0.15 g K to the PLFHG cutting.

2.4. Planting and Measurements

The cuttings were planted on May 21 (silty loam site) and May 23 (loamy sand site) in 2012. The first height measurement was made 4 and 6 weeks after planting on the silty loam site and the loamy sand site, respectively. The final height measurements and survival inventory were carried out after bud set at the end of the growth period. Bud break was assessed at the silty loam site 7, 14 and 21 days after planting according to two different development criteria: closed bud and actively growing shoot.

2.5. Calculations and Statistical Analyses

Apart from examining the effect on survival of the different substrates, these were also divided into two groups: one with substrates containing liquid fertilizer (SGLF, PLF, PLFP and PLFHG) and another with substrates containing solid fertilizer (SF and HGSF). The cutting survival rate of each group was compared together with the control treatment for each site.

To test the effects of the treatments on the measured variables at the different sites, the generalized linear model (GLM) and mixed model procedures as implemented in SAS (SAS Institute Inc. Cary, NC, USA) were used. Treatment was set as fixed factor and block as random factor. Tukey's test at the 5% level was used to determine significant differences [20]. All variables tested were examined for distribution, residuals and homoscedasticity using the UNIVARIATE procedure and transformed when necessary to achieve an even variable distribution. The response factor y was transformed by using either y^2, $\sqrt{y}$, $\log y$ or $1/y$. When none of these transformed factors produced a satisfactory variable distribution, the Wilcoxon rank method was used [21]. In this way the transformation $1/y$ was used for autumn height growth for both sites. The Wilcoxon rank y was used for survival for the different treatments for both sites, for substrate groups containing fertilizers for both sites and for active growth proportion after two and three weeks.

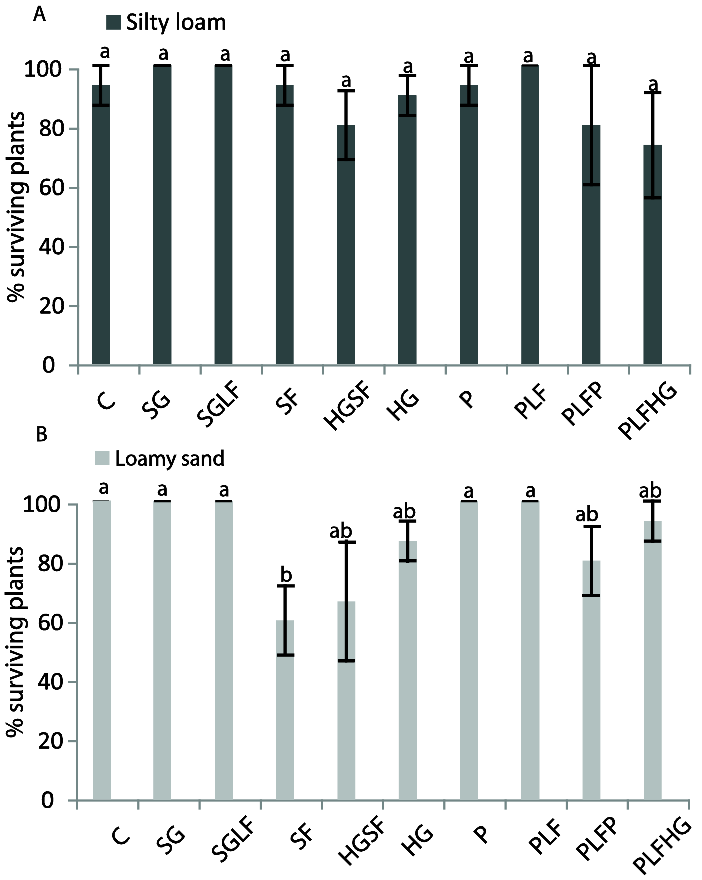
3. Results

3.1. Plant Survival

No differences in survival were found for the silty loam soil site for any of the treatments (Figure 1a). At the loamy sand site, however, cuttings treated with solid fertilizer (SF) displayed a lower survival rate compared to the control cuttings (C), starch gel with and without liquid fertilizer (SG and SGLF) and Perlite with and without liquid fertilizer (P and PLF) (p = 0.046) (Figure 1b). Hydrogel containing solid fertilizer (HGSF) also had low survival, but it was not significantly separated from any of the other treatment.

No difference in survival between the substrate groups containing liquid or solid fertilizer was found for cuttings at the silty loam site. At the loamy sand site, however, the analyses showed lower survival for cuttings treated with substrates containing solid fertilizer (SF and HGSF) compared to cuttings treated with substrates containing liquid fertilizer (SGLF, PLF, PLFP and PLFHG) (p = 0.0209) and to the untreated cuttings (C) (p = 0.0153).

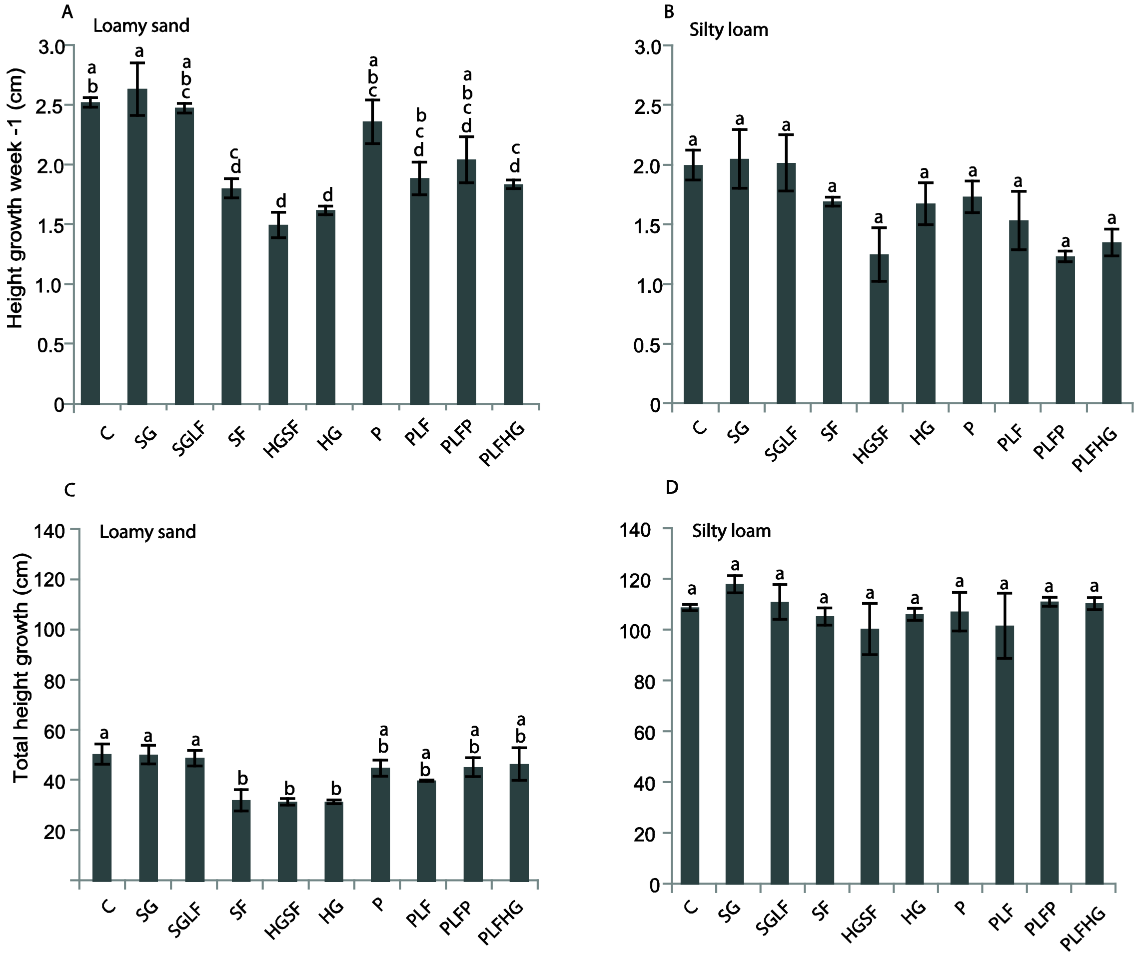
Figure 1. Effect on seedling survival after direct application of fertilizers, hydrogel or the combination of substrates. (**A**) Seedling survival at the silty loam site; (**B**) seedling survival at the loamy sand site. The treatments consisted of no treatment (C), starch gel (SG), starch gel containing liquid fertilizer (SGLF), solid fertilizer (SF), hydrogel (HG), hydrogel containing solid fertilizer (HGSF), Perlite (P), Perlite containing liquid fertilizer (PLF), Perlite containing liquid fertilizer diluted with fertilizer-free Perlite (PLFP) and Perlite containing liquid fertilizer and hydrogel (PLFHG). Cutting mortality was recorded at the end of the first growth season. Data shown are the percentage of survived cuttings as a mean value of *n* = 3 and standard error. Means with the same letter are not significantly separated at the *p* = 0.05 level.



3.2. Height Growth

Height growth was not influenced by any of the treatments at the silty loam site four weeks after planting or at the end of the growing season (Figure 2b,d). On the loamy sand site, however, height growth was hampered by some of the treatments compared to the control (Figure 2a,c). This was most obvious in the beginning of the growing season for the treatments containing Hydrogel (HG, HGSF and PLFHG) ($p = 0.003$, $p = 0.001$ and $p = 0.030$, respectively) and solid fertilizer (SF and HGSF) ($p = 0.021$ and $p = 0.001$, respectively). At the end of the growing season, only cuttings treated with SF, HG and HGSF displayed lower height growth compared to the control cuttings ($p = 0.022$, $p = 0.020$ and $p = 0.017$, respectively).

Figure 2. Height growth of *P. trichocarpa* cuttings after application of fertilizers, hydrogel or the combination of substrates. (**A**,**B**) height growth week^{-1}and (**C**,**D**) height growth after five months. The treatments consisted of no treatment (C), starch gel (SG), starch gel containing liquid fertilizer (SGLF), solid fertilizer (SF), Hydrogel (HG), Hydrogel containing solid fertilizer (HGSF), Perlite (P), Perlite containing liquid fertilizer (PLF), Perlite containing liquid fertilizer diluted with fertilizer-free Perlite (PLFP) and Perlite containing liquid fertilizer and Hydrogel (PLFHG).Data shown are mean values of $n = 3$ and standard error. Means with the same letter are not significantly separated at the $p = 0.05$ level. Note the different scales on the *Y*-axes.

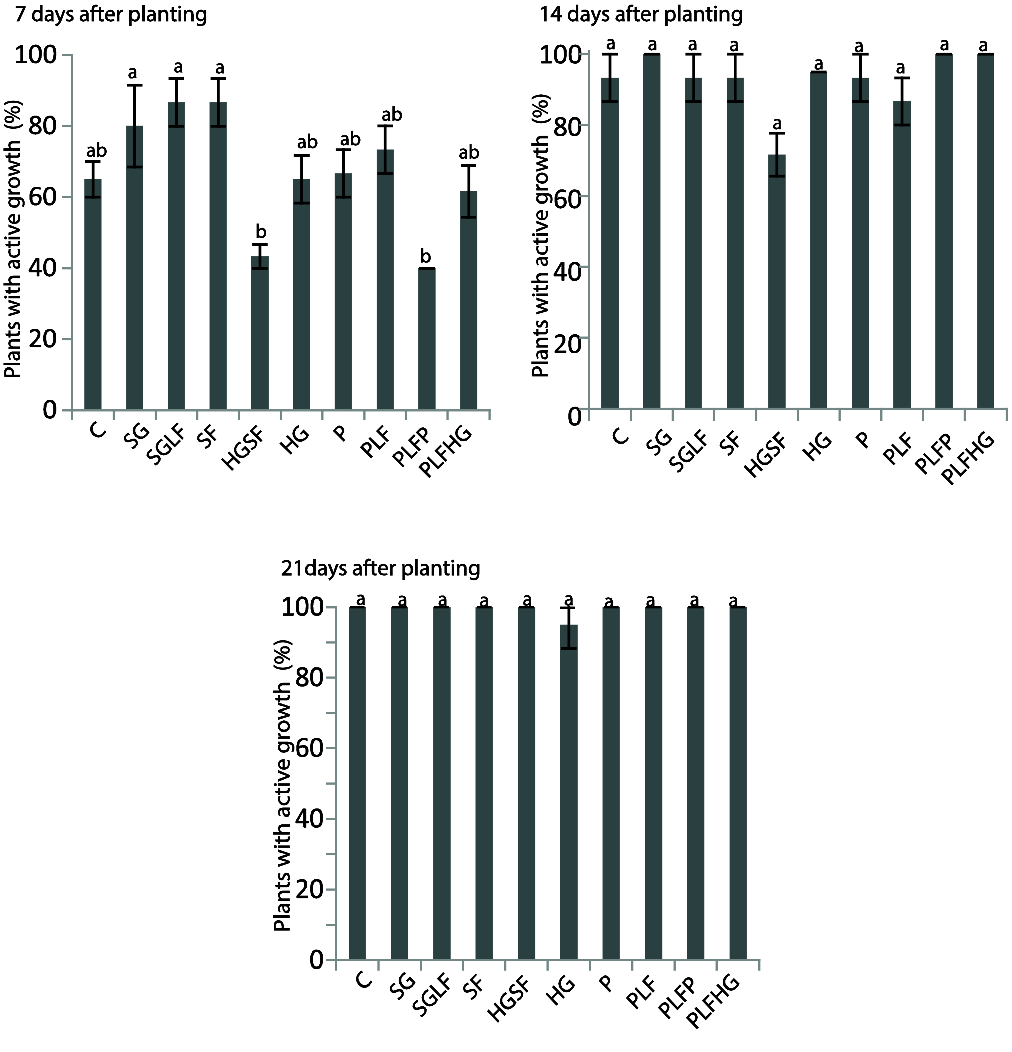


3.3. Early Plant Development

One week after planting, none of the treatments had a higher or lower proportion of plants in active growth compared to the control (Figure 3a). However, there were significant differences between the treatments HGSF and SG ($p = 0.027$), SGLF ($p = 0.065$) and SF ($p = 0.065$) and between PLFP and SG ($p = 0.013$), SGLF ($p = 0.031$) and SF ($p = 0.031$). Plants in the HGSF- and PLFP-treatments had a low proportion of plants in active growth, 43% and 40%, respectively. Cuttings coated with SG, SGLF and SF had the highest proportion: 80%, 86% and 86%, respectively. The other treatments, C, HG, P, PLF and PLFHG displayed no difference compared to the other treatments. Two and three weeks after planting, no differences in plant development could be found between the different treatments

(Figure 3b,c). To summarize, initially, HGSF and PLFP coated cuttings developed slower compared to the SG, SGLF and SF treated cuttings but not to any of the other treatments. However three weeks after planting, none of the treatments resulted in a significantly faster or slower plant development.

Figure 3. Timing of bud break of *P. trichocarpa* cuttings planted at the silty loam soil site after treatments with fertilizers, hydrogel or a combination of substrates. Bud break was scored seven, 14 and 21 days after planting according to two different developmental criteria: closed bud and actively growing shoot. The treatments consisted of no treatment (C), starch gel (SG), starch gel containing liquid fertilizer (SGLF), solid fertilizer (SF), Hydrogel (HG), Hydrogel containing solid fertilizer (HGSF), Perlite (P), Perlite containing liquid fertilizer (PLF), Perlite containing liquid fertilizer diluted with fertilizer-free Perlite (PLFP) and Perlite containing liquid fertilizer and Hydrogel (PLFHG).Data shown are the mean percentage of plants at each developmental stage, $n = 3$. Means with the same letter are not significantly separated at the $p = 0.05$ level.



4. Discussion

Establishment of a microenvironment with high water and nutrients content close to the transplanted seedling could be beneficial for plant establishment and development. Planting of poplar cuttings instead of rooted seedling could further simplify the establishment of poplar plantation. We hypothesized that coating of poplar cuttings with hydrogel and/or fertilizers could create such an environment at two experimental sites with different characteristics, loamy sand and silty loam. Our result demonstrates that poplar cutting can be used as transplants to establish poplars at both soil types reaching 100% developing plants at the loamy sand site and 93% at the silty loam site. Unfortunately, our treatments with hydrogel and/or fertilizers failed to positively influence plant survival or growth.

However, within our results we could identify differences in survival between the treatments at the loamy sand site but not at the silty loam soil site. There was also a tendency that height growth was negatively affected by some treatments in the loamy sand but not in the silty loam soil. At the loamy sand site, height growth was lower for the SF, HGSF and HG treatments in the end of the investigation period. Our results do not correspond to other studies on hydrogel during plant establishment. It has earlier been demonstrated that the use of a water-holding gel during the establishment enhanced survival by promoting contact with the transplant roots and the soil or by retaining soil water near the newly planted seedling [22–24]. Moreover, application of a hydrogel to eucalyptus seedling root balls proved sufficient to prolong seedling health and survival [18] and during drought conditions, application of a hydrogel improved the growth performance of eucalyptus [25] and citrus [26]. Apostol (2009) found that hydrogel-treated seedlings of *Quercus rubra* had 80% greater root moisture than untreated roots following the transplant and desiccation period [27]. In our experiment, however, hydrogel was directly applied to the cutting as opposed to other reports where hydrogel was applied to the root plug [18] or to the pit at planting [25]. There could be several reasons for our decrease in growth at the loamy sand site. Firstly, dissolvent of the fertilizer could be reduced because the soil moisture was absorbed by the hydrogel. In the same way, the hydrogel also may have prevented soil moisture from reaching the planted cutting and thereby inhibit root initiation. Our purpose for using hydrogel was to give the cuttings better access to water but the result may have been the opposite. The water-holding capacity of the hydrogel may have been so high that, on the site with loamy sand not only was the soil water absorbed by the hydrogel but also the moisture inside the cuttings was presumably negatively affected, thereby causing dehydration.

It was also observed that the expanding hydrogel, in some cases, pushed the cuttings upwards thereby causing three types of problems; (1) the area from where new roots could appear shrank; (2) new brittle roots were broken or damaged by the movement of the cuttings and (3) movement of the cuttings made it difficult for new roots to establish in the soil. This is further supported by the fact that on the site with silty loam, where the soil moisture probably was more abundant, the HGSF treatment had a delayed plant development (Figure 3), probably dependent on movements of the cuttings until enough roots with sufficient length fixed the cuttings to the surrounding soil. Later in the experimental period the reduced height growth seen at the beginning was, to some degree, compensated for the effects of the hydrogel and the fertilizer (Figure 2b,c).

We could detect differences in mortality and height growth between the treatments in the loamy sand but not at the silty loam site (Figures 1 and 2). This might be explained by the lower water-holding capacity of loamy sands compared to silty loam soils [28]. This difference could result in a slower dissolution of the solid fertilizer in the loamy sands that in turn might have caused salt-induced damages to the cuttings. Poplars are in general intolerant to saline conditions and the North American species *P. trichocarpa* and *P. trichocarpa* hybrids are extremely intolerant of salt [29].

Moreover, poplars are prone to salt-induced growth reduction in saline areas of Northern China where periodic drought frequently occurs [30]. For example, *P. popularis* has been well documented to be salt sensitive [31–34]. In addition, the higher proportion of NH_4 in the solid fertilizer might explain why we observed a more pronounced negative effect than for the liquid fertilizer, as the poplar family (*Salicaceae*) is considered sensitive to damage form NH_4 [35]. In our experiments we could not identify any positive effect by combining solid fertilizer and hydrogel. This is surprising, since hydrogel in combination with fertilizers has been shown to have an inhibitory effect on salt stress and a positive growth effect in saline soils [19].

Overall plant growth and root proliferation are usually greater with a mixture of NO_3^- and NH_4^+ than either form alone [36–38]. Moreover, cottonwood (*P. deltoides*) root architecture is sensitive to changes in NO_3^- and NH_4^+ ratio [39]. The solid fertilizer used in this study contained 39% NH_4^+, 28% NO_3^- and 33% Urea and should thus contain a satisfactory NO_3^- and NH_4^+ ratio that would not negatively affect root development. In contrast to the solid fertilizer, the liquid fertilizer contained 10% NH_4^+ and 90% Urea $CO\text{-}(NH_2)_2$. However, we could only detect differences in plant growth when the solid fertilizer was used as a nutrient source at the site with loamy sand (Figure 2a,c). Moreover, the only decrease in height growth when liquid fertilizer was applied was after six weeks for the treatment combination Perlite—liquid fertilizer-hydrogel (PLFHG) (Figure 2a) and, in this case, the decrease was probably due to the combination of all three components.

5. Conclusions

The use of hydrogels and application of fertilizers in forest establishment by creating a microenvironment of high water and nutrient levels closely associated to the newly planted seedling could still be of interest for forest owners, although our investigation could not find evidence for positive effect on growth and survival. Alternative methods might be to mix the substrate (s), hydrogel and/or fertilizer, with the soil at the planting site or to include it to the seedling growth substrate. This would be most beneficial for plant establishment and at the same time only sparsely affect the competing ground vegetation composition or growth to the same extent as fertilization of the whole area. We have not been able to find other report demonstrating negative growth effects by using hydrogels in combination with fertilizes. Nevertheless, publishing plant growth defects caused by using hydrogel and solid fertilizer treatments are important to both the scientific and forest management community. For example, the use of these treatments on establishing bare-rooted seedling could result in similar negative results and it is desirable to avoid these types of errors in the future.

The treatments used here are complex mixtures of hydrogel and different fertilizers. This could have some practical limitations, as application of the different substrates might be too complicated for practical use. However, if any of the described treatments will be used in the future together with other soil types or other plant species, these problems could probably be solved by further research and development of the application techniques.

In Sweden today, poplar plantations are established by planting rooted cuttings. This makes establishment of new poplar plantations both time-consuming and expensive. Our results demonstrate that under Swedish climate conditions planting of un-rooted cuttings can be used as a regeneration method on loamy sand and heavier soils, such as silty loam. This finding could have an important role, both economically and by changing forest management regarding establishment of poplar plantations.

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Author Contribution

Henrik Böhlenius conceived and designed the experiments; Henrik Böhlenius performed the experiments; Rolf Övergaard analyzed the data; Henrik Böhlenius wrote the paper together with Rolf Övergaard.

Conflict of interest

The authors declare no conflict of interest.

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