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O4: Good practice examples in optimization of forest operations

Mechanized Direct Seeding

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1. What is direct seeding? A short description

Direct seeding is reforestation through the active placement of tree seeds (Figure 1). This active placement distinguishes direct seeding (also termed sowing) from natural regeneration, where you passively let nature take care of the actual placement of the seeds.

In Sweden, direct seeding almost exclusively means the sowing of conifers, mainly pine (either ordinary Scot's pine, *Pinus sylvestris*, or lodgepole pine, *Pinus contorta*); the same applies in Finland (Helenius 2015). Stand seeds are most often used because orchard seeds are more expensive and the supply is limited (Bergsten & Sahlén 2013). An advantage of sowing orchard seeds is that you probably sow genetically improved seed. Additional advantages of orchard seeds are that they generally have higher germination rates (Simak & Gustafsson 1954), and that the subsequent germinants have higher growth and vitality (Wennström 2001). In general, orchard seeds are larger and heavier than stand seeds, which further increases the germination rate of orchard seeds (Wennström et al. 2002).

An advantage of direct seeding compared to natural regeneration is that you do not become dependent on good seed years or the nearby presence of enough seed trees. This advantage becomes increasingly important the further north and the higher above sea level you are, because years of good seed maturity and cone occurrence become rarer the colder the climate is (Hagner 1958).

Figure 1. Germinants of pine on site-prepared forest soil (left), and a seedling one year after seeding (right). Photo: Pekka Helenius and NordGen.

2. Why direct seeding?

Why?

… direct seeding generally results in dense and cost-efficient regenerations (of pine).

In general, we can regenerate forests either through natural regeneration, direct seeding, or tree planting. Compared to natural regeneration, direct seeding has the following advantages (Bergsten et al. 2003; Bergsten & Sahlén 2013):

- direct seeding enables the use of genetically enhanced seed from seed orchards;
- the time of seeding can be chosen so that the germinating conditions are favourable;

- the placement of the seeds can be controlled;
- the forest owner is neither dependent on good seed years nor the presence of seed trees (which makes direct seeding more reliable than natural regeneration).

Compared to tree planting, direct seeding has the following advantages (Bergsten et al. 2003; Bergsten & Sahlén 2013):

- direct seeding enables cheaper regeneration, which can lead to higher returns on investments when clear-cutting on less fertile sites in e.g. northern Sweden (Magnusson 2010).
- direct seeding enables denser regeneration (Figure 2), which in turn:
  - ✓ provides more freedom of choice in forest management practices for a long part of the stand's rotation period;
  - ✓ leads to higher biomass growth that can be harvested during first thinning;
  - ✓ can provide high quality timber;
  - ✓ can reduce the negative effects of heavy grazing pressure.
- sown seedlings have well-developed root systems without deformation and/or stability problems (historically, these have been significant problems during tree planting);
- direct seeding is easier to mechanize, whereby it is relatively easy to create diverse forests and/or mechanize subsequent silviculture. When direct seeding is mechanized, the forest industry becomes less vulnerable to a lack of competent and motivated tree planters.

Figure 2. Plenty of seedlings in disc trenched furrows 4 years after direct seeding in the interior of Västerbotten, northern Sweden. Photo: Tomas Nordfjell.

3. Where is direct seeding suitable?

Where?

…direct seeding is most successful on dry to mesic sites of medium fertility (with sandy-silty soils).

According to the Swedish Forest Agency, the sites to be seeded should be of "blueberry or poorer" fertility class and of "dry to mesic" soil moisture class (Skogsstyrelsen 2020). According to Bergsten & Sahlén (2013), "ordinary" soils (with the common soil type sandy-silty moraine/till) are suitable for direct seeding.

On coarse-grained soils, mixing humus with the mineral soil can increase the soil's water holding capacity. And on fine-grained soils, mixing humus with the mineral soil can increase porosity, which leads to increased soil aeration (Bergsten et al. 2003). In both these cases, direct seeding (seed germination and the survival and growth of the germinants) can thus be improved by mixing the humus layer with the underlying mineral soil horizon (eluviated horizon).

According to Lundström's (2015) study of the forest company Holmen's land throughout Sweden, direct seeding is best on mid-fertile sites (lingonberry vegetation type) with medium-coarse soil texture (sand). Despite the fact that direct seeding works all over Sweden, the possibility of successful sowing increases the further north the site is located (Lundström 2015). Direct seeding on soils with thick humus layers has also been shown to work well (Svensson 2021).

4. When to direct seed?

When?

…after snowmelt in April, May, and June (for *Pinus sylvestris*).

Direct seeding of Scot's pine (*Pinus sylvestris*) should take place on bare ground during spring/early summer (Bergsten & Sahlén 2013; Lundström 2015). The most suitable months are thus April, May and June. In general, late summer sowing (in July-August) shows poorer seeding results than early summer sowing and is not recommended in e.g. Finland (de Chantal et al. 2003). Autumn sowing of Scot's pine is not recommended as the seeds "have very limited ability to survive in the soil over the winter" (Bergsten & Sahlén 2013), although occasional studies (e.g. in Finnish Lapland; Hyppönen & Hallikainen 2011) have shown successful seeding results in late autumn sowing. In practice, late autumn sowing means that the seeds are stored at the germination site during the winter.

However, direct seeding of *Pinus contorta* is suitable on bare ground during autumn (Bergsten & Sahlén 2013). *Pinus contorta* seeds, unlike Scot's pine seeds, are naturally adapted to overwintering at the germination site. If for some reason one would like to sow *Pinus contorta* seeds in the spring, the seeds must be stratified (ie. cold-wet treated) before seeding if they are to have enough time to germinate during the same vegetation period (Bergsten & Sahlén 2013).

5. Mechanized direct seeding –how?

How?

…directly following site preparation, preferably on microsite-prepared mineral soil.

Direct seeding of forest seeds is done manually or mechanically. However, the seeding (sowing) should take place as near in time to the soil preparation as possible. Direct seeding is therefore suitably combined with soil preparation, whereby mechanized sowing saves time and labour compared to manual sowing (Bergsten et al. 2003). Also, mechanized direct seeding has been shown to lead to better regeneration results than manual sowing in Finland (Kankaahuhta et al. 2009). Nevertheless, a lack of

available machinery (e.g. no available seeder-equipped scarifiers in springtime) is one reason why direct seeding may have to be done manually.

Planning

Direct seeding should be planned before final felling. By prescribing mechanized seeding, site preparation will hopefully be routed to the springtime/early summer (autumn if *Pinus contorta* is to be seeded). But before commissioning direct seeding, there are a number of questions to answer:

- **Stand seed or orchard seed?** Stand seed is cheaper, while orchard seed generally has higher germination and growth rates, and enables genetically enhanced material to be used (Wennström 2001). However, the availability of orchard seed may be limited, and predation has sometimes been shown to be more severe on orchard seed than on stand seed (Wennström et al. 2007). In general, of course, orchard seeds are more expensive.. Today, when direct seeding mechanically, a potential compromise is to mix in the seeder orchard seed together with stand seed, e.g. 25% orchard seed (Wennström et al. 2001).

- **How dense do I want the stocking rate to be?** This question affects how many seeds per linear meter should be sown (called the seed rate). This, in turn, is a central issue when seeding because, during direct seeding, you really have an opportunity to vary the seedling density (which in practice means the density of pine since this is practically the only seeded tree species in Swedish forestry). The seed rate also influences heavily the cost per hectare of direct seeding, because the seeds themselves are the most expensive cost component of direct seeding (Bergsten & Sahlén 2013). Holmen Skog, a major player in mechanized direct seeding in Sweden, generally aims for about 10 seeds/m (Svensson 2021), while Bergsten et al. (2003) stated 16 seeds/m as the minimum rate. Bracke Forest (the manufacturer of seeders) states 5-6 seeds/m as a relatively common seed rate for mechanized direct seeding in Sweden. Many factors affect the seed rate, see Bergsten & Sahlén (2013, p. 51) or Bergsten et al. (2003, p. 29) for a formula that can be used to calculate the seed consumption/seed rate when direct seeding.

- **Is micro-preparation possible?** During micro-preparation, small pyramid-shaped depressions are temporarily created in the ground (Figure 3), and are made to: i) increase the contact area between the seeds and the germination substrate; ii) provide the seeds with a secure water supply; and iii) reduce seed predation (Bergsten 1988). In the case of mechanized direct seeding, micro-preparation is usually done by means of a waffle-patterned wheel (Figure 4), but it can also be made as small grooves in the ground using sharp points on various soil preparation tools (e.g. Figure 6, bottom right). In the case of manual sowing, micro-preparation can be done with e.g. special micro-preparation shoes (Figure 4), or with studded football shoes, rakes, etc.

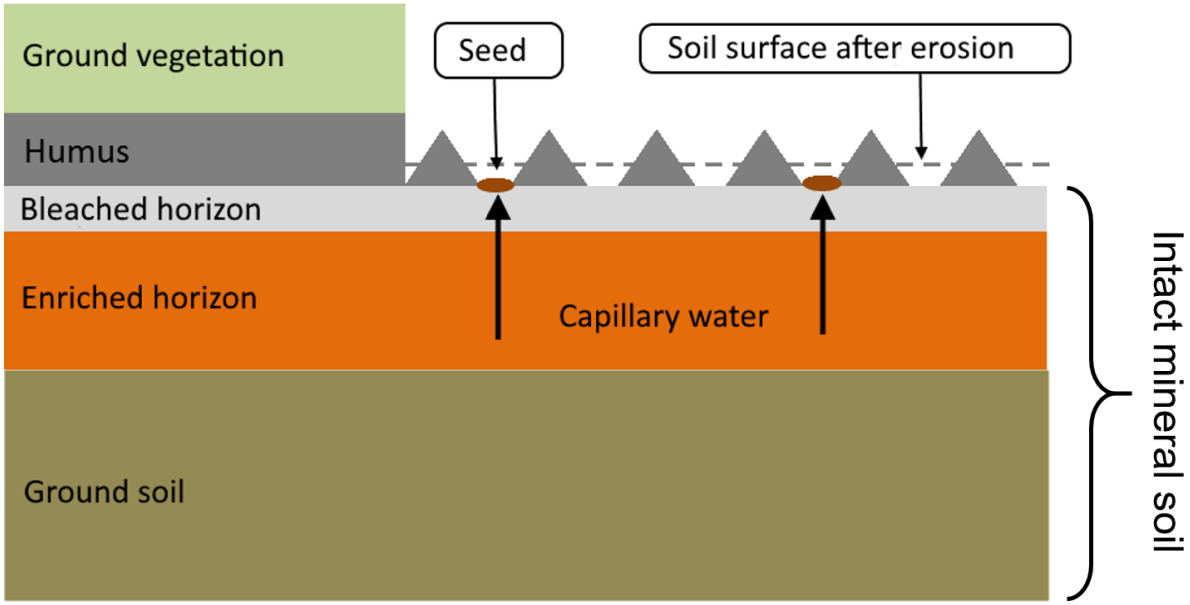

Figure 3. An ideal seedbed for direct seeding in boreal forestry. The soil is disturbed only down to the beginning of the eluviated (bleached) soil layer, i.e. the top mineral soil horizon of a podzol (Nordic soils suitable for sowing forest seeds are almost exclusively podzols), which enables the seed to germinate on mineral soil of suitable particle size. Micro-preparation is performed in the humus layer just before seeding. Then rain (for example) erodes the tops of the small pyramids and covers the seeds just enough, thereby reducing desiccation and seed predation. Drawing from Helenius (2016).

- **Row seeding or spot (patch) seeding?** The terrain and/or the stand characteristics determine whether the seeds should be row or spot seeded. In the case of mechanized direct seeding, site preparation and sowing are carried out simultaneously.

  Row seeding is generally performed using continuously advancing machines (forwarders, tractors, skidders, etc.) and requires terrain that is rather trafficable. During row seeding, sowing takes place continuously at regular intervals, and the operator does not control exactly where the seeds end up. Row seeding is usually faster than spot seeding because continuously advancing machines generally have 2-5 times higher productivity during site preparation than intermittently advancing machines (Uusitalo 2010; Johansson 2016).

  Spot seeding is generally performed using intermittently advancing machines, often in long patches via directed site preparation with a crane. During directed site preparation, the operator actively chooses where the soil preparation takes place and where the seeds are sown. Directed site preparation (and thus spot seeding) is suitable on rocky, steep, or uneven terrain (Johansson 2016), and on sites/blocks that are irregular or small.

Figure 4. Micro-preparation, a trick to increase the germination rate during direct seeding, performed in theory (top, right) and in reality (left). Micro-preparation can be performed using a micro-preparation shoe for manual sowing (bottom, middle) or for mechanized sowing using a micro-preparation wheel. Photos: Sveaskog, Silvitec AB, and ForeCare AB. Illustration: Anna Marconi.

- **How do I know if the direct seeding has succeeded, and what to do if it has not succeeded?** Understandably, reforestation via seed (natural regeneration or direct seeding) is more uncertain than tree planting. Therefore, following-up the establishment results is more important when direct seeding than when planting. This follow-up is preferably done 3-4 growing seasons after sowing, when seedling mortality has stabilized to some extent (Bergsten & Sahlén 2013). Of course, direct seeding can be followed up earlier than 3-4 seasons after sowing, but the inventorying will then be more difficult and time-consuming, and the follow-up results more uncertain. The follow-up is suitably made via circular plot sampling (1.78 m radius, i.e. 10 m^2 plots; 10-30 plots per stand depending on the desired level of certainty).

  If the early establishment result is found to be unsatisfactory (i.e. the germination and early survival rate does not seem to meet the desired stocking rate), fill planting can be done, preferably in the prepared soil. Re-seeding a failed direct seeding attempt 3-4 seasons later rarely succeeds. See Bergsten & Sahlén (2013) for more information on following-up direct seeding.

- **What are the most suitable technical solutions for mechanized direct seeding?** In theory, there are several different tools to choose from during mechanized direct seeding. We'll take a closer look at them here below.

The Technology

In the case of ground-based mechanized direct seeding, the technology involved mainly consists of a base machine, a seeding apparatus (seeder), and a site preparation unit.

Base machine (prime mover): During mechanized direct seeding in Swedish forestry, it is mainly forwarders and occasionally tractors that have been used as continuously advancing base machines (which are used during row seeding). Similarly, it is mainly excavators but occasionally harvesters and backhoe loaders that have been used as intermittently advancing base machines (which are often used during spot seeding). With crane-equipped intermittently advancing base machines, the operator can chose the exact placement of the seeds.

Seeder: Historically (before the 2000s), seeders were not able to disperse seeds individually. Instead, the seeds came out more or less in clumps. This was a major disadvantage because seed consumption increased (thus making direct seeding more expensive) and trees were regenerated clump-wise with resulting higher pre-commercial thinning costs. This problem was solved in 2004 when Bracke's seeder S35 was invented (Figure 5). Today, seeds can be dispersed one-by-one, regardless of variation in advancing speed or interruption in soil preparation work. Seeders have long economic lifespans, which makes the world market for seeders relatively small. The Bracke S35 seeder is thus completely dominant on Swedish and international markets today. The disadvantage of seeders that feed seeds in clumps (e.g. SeedGun from Newforest Oy in Finland) is lessened during spot seeding. But dispersing seeds

individually is an advantage even during spot seeding. So today, when ordering mechanized direct seeding, the probability is high that your seeds will be sown using a Bracke S35 seeder.

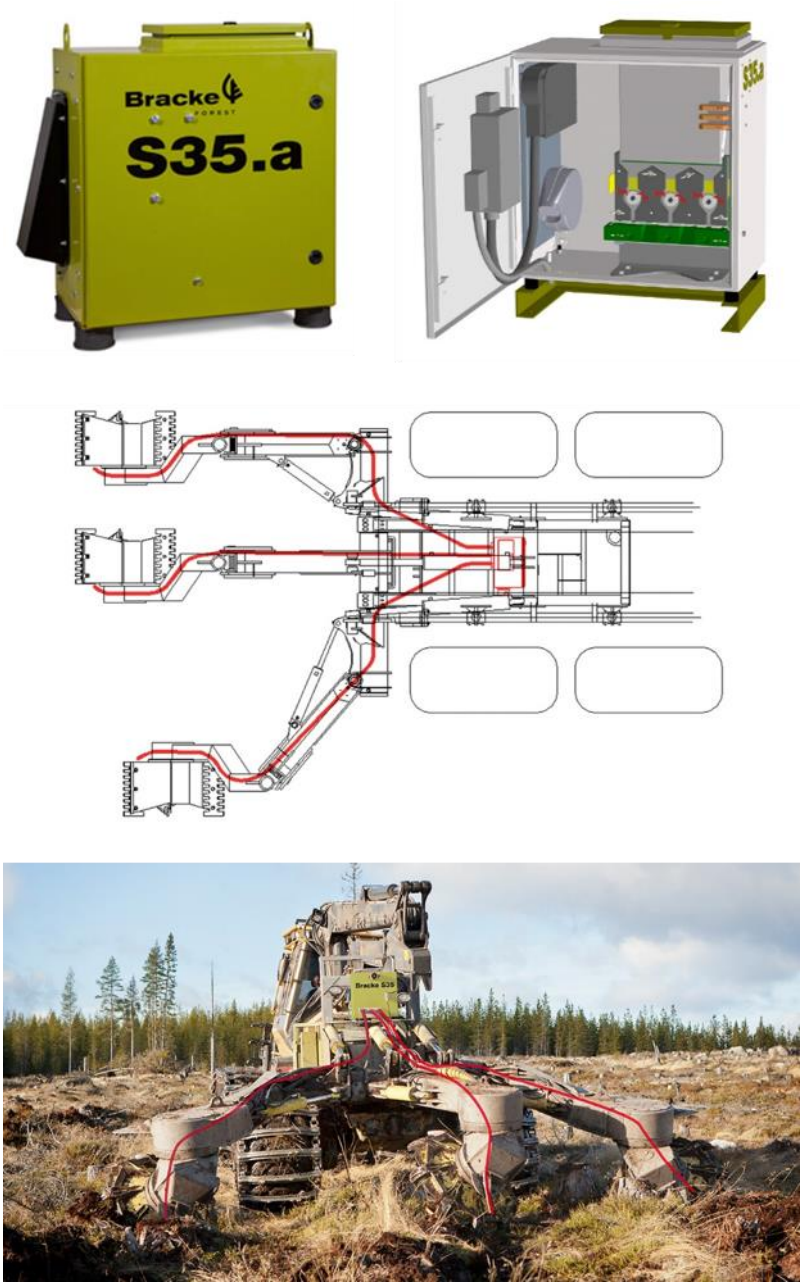

Figure 5. The Bracke Forest S35 seeder (top; right and left), and how it is mounted on a scarifier and how the seeds travel from the seeder to the ground (in this case on a three-row disc trencher, see the red lines; middle and bottom). The S35 seeder is currently the only commercially available seeder in Nordic forestry. Photos and drawings: Bracke Forest AB.

Figure 6. Mechanized direct seeding through hoses mounted on modern disc trenching units (top) and mounding units (bottom). Disc trenching units with standard discs (with worn-down excavator teeth, left) and newly developed discs (with durable plates instead of excavator teeth, right). Mounding units with side-mounted seeding hoses and standard three-pointed mattock wheels (with excavator teeth, left) and newly developed three-pointed mattock wheels (with "almost-micro-preparing" cutting teeth on one mattock wheel and durable plates on the other mattock wheel, right). The white arrows point to where the seeds come out. Photos: Bracke Forest AB.

Site preparation unit: Today, it is very common during direct seeding that the soil preparation unit is a traditional disc trencher or mounding unit (Figure 6). Disc trenchers are continuously working units and mounders are intermittently working units. When used for direct seeding, both types of unit are set to only scrape off the humus and expose the underlying eluviated soil layer. According to Bracke Forest, the manufacturer of both types of site preparation units, this is easier done with mounders than with disc trenchers. Usually, none of these units can perform any micro-preparation, although some mounders have been modified to scrape tracks in the soil that are somewhat micro-prepared (Figure 6, bottom right).

During the 1990s and 2000s, at least four specifically designed devices for mechanized direct seeding were invented in the Nordic countries. The first specifically designed unit was HuMinMix, a multi-functional rotovator for row seeding that mixes humus with mineral soil in shallow trenches, and then micro-prepares the soil (Åström 2006; Figure 7). Of all the site preparation units available in Sweden, HuMinMix has proven to produce the best seeding results with the least possible soil impact, a fact that has made the unit popular in reindeer husbandry areas. HuMinMix is mounted on a forwarder, is relatively productive and gentle, and there were up to three units in use in northern Sweden during the mid-2000s (Roturier 2010).

The second device was Humax 2-4, a boom/crane tip-mounted rotovating unit for harvesters (Figure 8). With Humax 2-4, operators actively chose where to sow (they worked in a directed manner) and it was gentle (low ground impact), but the unit required an expensive base machine and was inefficient on rocky and vegetation-rich sites (Nilsson 2009). Humax is not used today.

The third device was the KSM seeding bucket, a bucket for mounting on excavator cranes/booms (Figure 7). With KSM, the operator creates long patches where the humus is scraped off and seeds are sown simultaneously. The combination of KSM unit and excavator produces good seeding results even on rockier soils (Nilsson 2009). The seed dispenser is located on the bucket and the seeds are fed relatively evenly using a disc, 30-40 seeds per crane cycle. According to the manufacturer, about ten units have been sold, mainly for use in northern Sweden, with a number of units still in operation during the spring of 2021.

Figure 7. Examples of specifically designed devices for mechanized direct seeding: the KSM bucket (a crane/boom-mounted seeding bucket, left) on an excavator for direct seeding in patches; the HuMinMix (Humus Mineral soil Mix, right) mounted on a forwarder for continuously advancing row seeding in rototilled, micro-prepared, shallow trenches. Photo: Ida Nilsson and Tomas Nordfjell.

The fourth specifically designed device was the Havel rototiller. It was invented around 2010 (Figure 8). However, this crane-mounted rototiller did not produce better seedbeds than what scraping with ordinary excavator buckets did (Helenius & Saarinen 2013), so the device is no longer used today.

Summary

In practice, however, the private forest owner is often left to settle for the technology for direct seeding that is available in his/her vicinity. Despite this, it can be advantageous to know which techniques and tools for ground-based mechanized direct seeding exist or have existed in Swedish forestry. Then the forest owner knows what could be possible during direct seeding, and thus becomes a more competent client. Such awareness can help drive forwards the availability and/or development of better tools for mechanized direct seeding in Swedish/Nordic forestry.

Figure 8. Crane-mounted devices for direct seeding that are no longer used: Humax (left) from Humax Forest AB in Hammerdal, Sweden, and Havel-rototiller from Havel Oy in Ilomantsi, Finland. Poor soil preparation results were the main reason for discontinued use of both of these special devices (Nilsson 2009; Helenius & Saarinen 2013). Photo: Ida Nilsson and Pekka Helenius.

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