GROUND SPEED: ITS INFLUENCE ON THE DIRECT SEEDING OF JACK PINE (*Pinus banksiana* Lamb.) WITH THE BRÄCKE SCARIFIER

by

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ABSTRACT

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Key Words: Bräcke scarifier, direct seeding, ground speed, site preparation, seed labelling, ^{46}Scandium, obstacles.

The effects that ground speed and obstacle height have upon microsite creation by the Bräcke scarifier and upon the seeding characteristics of the integral seeder were studied. The study was conducted in a former gravel pit with homologous soil conditions and uniform obstacle sizes to minimize sources of variation. Jack pine (*Pinus banksiana* Lamb.) seed was treated with ^{46}Scandium, a gamma-emitting labelling agent. The trial involved running the scarification unit at four speeds, over three obstacle sizes. Data were collected on microsite dimensions, seeder performance and seed placement. A field trial was also conducted to follow trends seen in the gravel pit portion.

Results indicated that the height of an obstacle had more effect on microsite attributes, seeder performance and seed placement than did the ground speed at which the scarifier was drawn. Microsite length and longitudinal seed placement decreased as obstacle height increased, while lateral seed placement increased with increasing obstacle height. It was recommended that the Bräcke scarifier/seeder be operated at 40 m/min in order to reduce the influence of obstacles. The seeder must be properly calibrated to account for the influence of obstacles: a modified technique was discussed. Trends observed in the gravel pit trial were not apparent in the smaller field trial.

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INTRODUCTION

The purpose of mechanical site preparation in the Boreal forest is to remove or displace material that may impede the progress of a tree planter, prevent seed from reaching a suitable microsite or seedbed, or inhibit growth once germination or tree establishment has occurred (Cameron, 1978). Site preparation creates biologically-effective microsites while providing a method to control stocking and spacing in the new forest (Brown, 1977).

In Ontario during the mid-1980's, 50-60,000 hectares (ha) per year were planted, funded primarily through Forest Management Agreements (Kuhnke, 1989). The high costs associated with tree planting have renewed the interest in improving direct seeding success as a way to reduce regeneration costs. Direct seeding reduces or eliminates the need for nurseries, storage facilities, transportation equipment and skilled labour. The cost of seeding jack pine (*Pinus banksiana* Lamb.) at the time of site preparation has been shown to be less than one-half that of planting jack pine container stock and about three-quarters the cost of aerial seeding with site preparation (Sidders, 1985). Clark (1984) reported similar cost advantages to direct seeding inclusive of the cost of site preparation.

Many factors influence seedbed production and seed distribution from a scarifier/seeder. Ryans (1984) stated that ground speed, the speed at which a scarification unit traverses terrain, should be regulated to achieve prescribed microsite conditions. More specifically, consideration should be given to the factors that contribute directly to the creation of microsites favourable to seed germination. The weather, terrain and soil conditions, various site factors (i.e. stump height, stump density and slash loading), the suitability of the prime mover/implement match, and the comfort and well-being of the equipment operator (Ryans, 1984) all have an influence upon microsite creation. While many of the variables affecting site preparation and seed distribution vary substantially between sites, ground speed can be controlled and varied to suit site conditions.

The predominant implement used in eastern Canada for direct seeding at the time of site preparation is the Swedish-made Bräcke scarifier. It is an adjustable patch scarifier capable of releasing a small number of seeds simultaneous with microsite formation.

While the microsites formed by the Bräcke are well suited to tree planting, the results of direct seeding attempts have been variable (Sidders, 1985). Earlier research into seeding techniques or seedbed requirements concentrated on the biological environment created within the microsite (Riley, 1980). More recently, efforts have been made to optimize microsite shape and seed placement by improving the scarifier/seeder (Pye, 1989). However, tracing the location of seeds once released by the scarifier/seeder is difficult as they blend in well with the ground. Therefore, it is unknown if the seeds actually reach the prepared seedbed.

The purpose of this study was to investigate the influence of ground speed and obstacle height upon Bräcke site preparation and jack pine seed placement by the Bräcke. The hypothesis was that a ground speed may be prescribed for direct seeding operations considering the quality of the microsites formed and the seed-dispersal patterns produced. The hypothesis was tested using various ground speeds and obstacle sizes to study the effect on microsite attributes and seed placement. A stationary, bench trial was done to determine the nature of the seed fall as released from the Bräcke. A controlled trial was done in a former gravel pit to test the effect of ground speed and obstacle height on the placement of seed and on microsite characteristics. A field trial was also done to determine the effect of speed on microsite and seed dispersal characteristics under operational conditions.

The determination of a ground speed specific to direct seeding with the Bräcke should assist equipment manufacturers in designing site preparation prime movers to work efficiently at a specific ground speed. Applying a specified ground speed, forest managers should find Bräcke seeding results to be more consistent between sites and contractors. The results of direct seeding operations should be more predictable, and thus encourage greater use of direct seeding as a forest regeneration technique.

LITERATURE REVIEW

MECHANIZED DIRECT SEEDING

Artificial regeneration of conifers by seeding has taken place in Ontario since the early 1900's, though much of the area treated to the mid-1950's was research-orientated (Waldron, 1973). Jack pine became the predominant species seeded in the 1960's, usually as treatment of large burn areas or cutovers with sandy soils (Waldron, 1973).

Jack pine is a major commercial species of the Boreal forest region and it regenerates best in disturbed soil conditions (Clarke, 1977). Jack pine seed requires a mineral-soil seedbed to achieve satisfactory germination and early survival (Riley, 1980; Smith, 1986). The two main agents for exposing mineral soil favouring jack pine germination and growth are fire and mechanical site preparation.

Early direct seeding was primarily done aerially using various broadcast seeding devices (Foreman and Riley, 1979). A device commonly used for jack pine seed distribution was the Brohm seeder, mounted either on airplanes (Worgan, 1973; Foreman and Riley, 1979; Edwards, 1984) or helicopters (Richardson, 1973). Aerial broadcast seeding was typically done in conjunction with continuous-row scarification, though as much as 80 percent of the seed released did not fall on a suitably-prepared seedbed (Foreman and Riley, 1979).

A variety of hand-operated as well as small motorized seeding devices have been used in ground-based seeding applications (McNutt and Warrington, 1989). Hand-held seeders permit greater prescription flexibility as they may be used with or without mechanical or manual site preparation. Many homemade, hand-held devices have been used, including tin-can shakers and squeezable mustard containers (McNutt and Warrington, 1989). A variety of shelter-cone seeding systems have been developed (Van Damme and Bax, 1991). Small, readily-available Cyclone broadcast seeders have been mounted on snowmobiles (Edwards, 1984) and permit efficient seeding when snow conditions allowed easy site access.

Two categories of ground-based mechanical seeding devices exist. Seeding devices that distribute seed directly onto a continuously-prepared microsite at the time of site preparation are termed row seeders (Mattice, 1975). Row seeders are superior to broadcast (aerial) seeders as seed is used more economically and a mechanical method is provided to control the inter-row spacing of the new forest stand (Mattice, 1975). Spot seeders differ from row seeders as they deposit seed at distinct intervals within the microsites created, thus controlling both inter-row and intra-row seed placement. Seed is usually targeted at a particular point within a microsite (Mattice, 1975).

The earliest, large-scale row seeder employed in northern Ontario was the seed barrel used in conjunction with heavy tractor drags (Smith, 1979; and Clark, 1984). Jack pine seed was contained in a modified scarification barrel and metered through several nozzles located at the rear of the barrel. Seed was released by the shaking action of the barrel during scarification. The seed bomb, smaller and lighter than the seed barrel, was used in the same manner as the seed barrel (Smith, 1979). Results obtained with these row seeders have been inconsistent. The brass/bronze nozzles that controlled the gravity-assisted seed metering often became plugged with mud during use in wet weather or on damp sites. Wet weather operation typically resulted in variable seed-release densities (Smith, 1979). The larger and heavier seed barrel did not bounce out of the prepared trench as much as the smaller, lighter seed bomb, however, seed was still deposited out of the trench (Smith, 1979). The use of the seed bomb and seed barrel in Ontario have been discontinued due to the inconsistent results (Clark, 1984).

Mechanical row-seeding devices have been developed to allow a one-pass treatment including site preparation and metered seed deposition. The McBorkan air seeder (Ardron, 1985) and the Bartt seeder (Pilkey, 1988; McNutt and Warrington, 1989; Dominy, 1991; and Van Damme and Bax, 1991) were developed to operate in conjunction with skidder-mounted, powered-disc trenchers. Dominy (1991) reported jack pine seed placement from the Bartt seeder on level ground and upslope sites was favourable. However, poor downhill performance of the seeder seemed to be related to an electrical deficiency within the prime mover. The results of the Dominy (1991) study served to highlight the importance of a proper match, or marriage, between the prime mover and implement in realizing the potential of the equipment. Dominy (1993) updated the testing of the Bartt seeder, and reported that the use of a more appropriate prime mover improved the performance of the seeder.

The Bräcke scarifier, designed in Sweden, was the first scarifier that integrated site preparation with mechanical spot seeding. Introduced to Canada in 1968, it was first available only in a two-row configuration: it consisted of two scarification frames to produce two rows of intermittent microsites (MacBrien, 1982). The operation of the rear-mounted seeding devices were coordinated with the operation of the scarifying mattocks, causing seed to be deposited within the prepared microsites (McNutt and Warrington, 1989). A typical, well-formed Bräcke microsite is shown in Figure 1.

The optimum location for seed placement has been found to be on the midslope portion of a properly-formed Bräcke microsite (Parker, 1972; Anderson, 1982; Clark, 1984; Sidders, 1985; and Van Damme, 1988). Soil moisture conditions are more likely to be favourable for germination within the target area, and the germinant has some degree of shade cover (Clark, 1984). Clark (1984) stated the dig portion is the next-favoured seeding position, though periodic microsite flooding is a hazard here. The overturn portion is the least-favoured location as moisture availability varies, coupled with a lack of protective shade for a seedling (Clark, 1984). Results of the Clark (1984) study showed the occurrence of naturally-seeded jack pine seedlings to be 32 percent in the dig portion, 43 percent on the midslope, 6 percent on the hinge, 11 percent on the overturn portion and 14 percent within the edges surrounding the microsite.

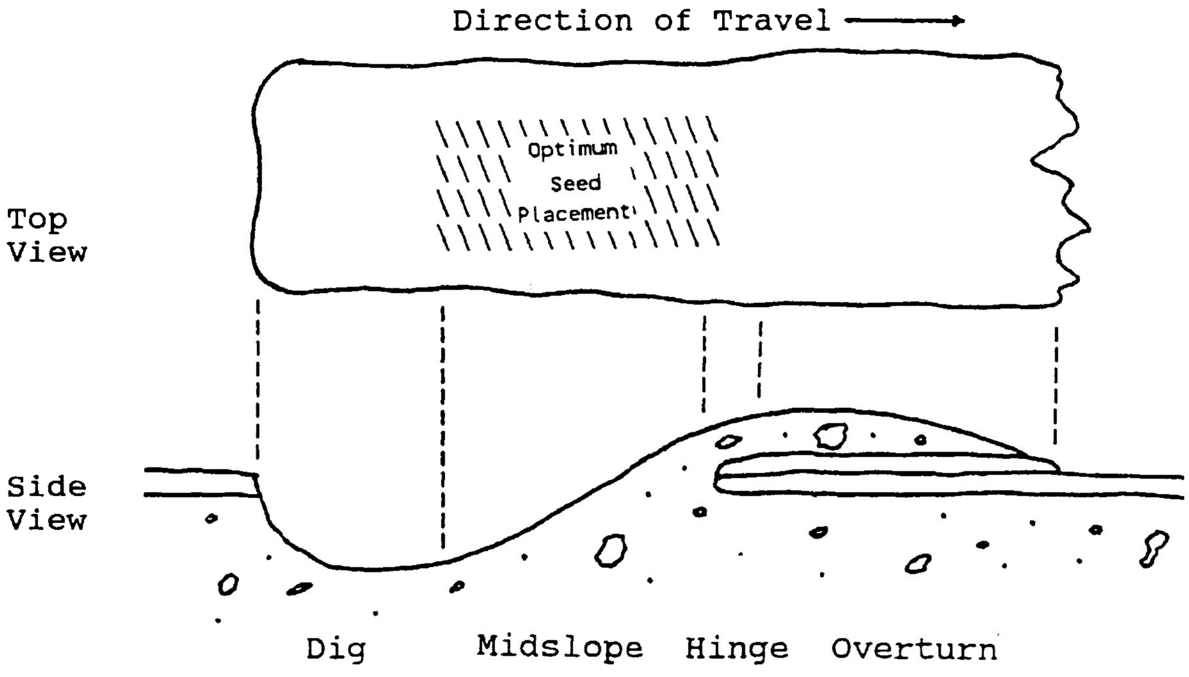


Figure 1. Cross-section of a typical, well-formed Bräcke microsite indicating the optimum seed placement location (after Clark, 1984).

Early seeding attempts with the Bräcke produced either variable results (Sidders, 1985) or failures (Clark, 1984). Difficulty in calibrating the seeder to drop a prescribed number of seeds was reported by Sidders (1985), and McNutt and Warrington (1989). Sidders (1985) speculated that seeder calibration may not be receiving the close attention it should. The seeding device is a small component of the scarifier relative to the bulk and sophistication of the Bräcke and prime mover. Anderson (1982) published instructions detailing the proper maintenance and repair of the Bräcke, including instructions on the calibration of the seeding device.

Moisture has proved to be a problem associated with seeding with the Bräcke scarifier. Once metered by the seeder, the seed is released from a small delivery tube mounted at the rear-most part of each Bräcke machine frame. The tube is easily plugged by debris and/or water-logged seeds in wet or humid weather, or during the treatment of wet sites (MacBrien, 1982; Bamsay, 1985; and Kolk, 1988). The seeders must be checked often in wet and/or humid weather to ensure their proper operation (Parker, 1972; and Anderson, 1982). Recommendations are given by Sidders (1985) to minimize problems associated with moisture. The seed hoppers should be removed at night to prevent moisture from condensing on the seeds, while sponges should be placed in the seed hoppers to absorb excess moisture. The seed hoppers should only be filled to one-half capacity to minimize the amount of seed exposed to excess moisture at one time.

A new seeder was developed for the Bräcke in 1988. The design used air pressure to propel seed from the seed-delivery tube of the scarifier (Kolk, 1988). The primary advantage of the pneumatically-assisted seed delivery was that air pressure prevented debris and wet seeds from collecting in the delivery tube when the seeder was used in wet and/or humid conditions (Kolk, 1988). Contractors were then allowed to seed in weather conditions that previously caused unacceptable seeder operation.

A study completed by McNutt and Warrington (1989) determined that a prototype model of a pneumatically-assisted Bräcke seeding device (of a different metering design) caused significantly less damage to jack pine seed than did the original, mechanical seeder. The incidence of seed shearing, and seed-coat cracking and crushing were reduced in the development of the new seeder. Germination tests and x-ray analyses of seeds passed through the seeding devices revealed seed viability was reduced by the metering and dispersal action of the majority of the 13 seeders tested (McNutt and Warrington, 1989).

The undulating shape of the Bräcke microsite profile, shown in Figure 1, is adjustable. A gear train, housed within each machine frame, connects the weight-carrying rubber tire to the scarifying mattock using sprockets and roller chains (Seabrook and Bax, 1981). Three gear selections are possible by changing sprocket sizes between 15, 17 and 19 teeth on an intermediate shaft. The gear train allows the production of short, steeply-sloped microsites with the 19-tooth intermediate gear setting, graduating to long, gently-sloped microsites with the 15-tooth gear setting (Seabrook and Bax, 1981).

Direct seeding with the Bräcke has been done with the aim of producing a maximum number of seeded microsites per hectare to increase stocking percentage (Pye, 1989). Typically, the above prescription has been accomplished by operating the Bräcke on the 17-tooth intermediate-gear setting (Clark, 1984). Van Damme and Bax (1989) reported that many jack pine seeds were washed to the bottom of the steeply-sloped microsites and buried, thus hampering germination. Pye (1988) suggested using the 15-tooth intermediate-gear setting when seeding. Fewer microsites would be produced per hectare, though they would be of higher quality for seeding. The gently-sloped microsite produced by the 15-tooth gear setting was also longer. Thus, the probability of seed landing on mineral soil was increased, while at the same time, the chance of seed being displaced by erosion was decreased (Pye, 1988).

Published jack pine seeding rates for the old, mechanical seeder tended to be between 10 and 20 seeds per microsite. Parker (1972) reported that calibration for fewer than 7 to 10 seeds per microsite caused the seed-metering mechanism to plug. Clark (1984) suggested that a rate of 15 seeds per microsite be used when spring sowing jack pine, while fall sowing should be done at 20 seeds per microsite to account for over-winter seed losses and prolonged seed dormancy.

Seeding rates related to the physical arrangement of the Bräcke scarifier were recommended by Sidders (1985). He suggested sowing 15 to 20 seeds per microsite if the Bräcke is to be used at a 2 metre (m) inter-row spacing, while only five seeds per microsite should be sown at a 1 m inter-row spacing. Sidders (1985) estimated the area seeded at a 1 m spacing (1 m by 2 m microsite spacing) would be stocked to approximately 90 percent, as opposed to 55 percent at a 2 m row spacing (2 m by 2 m microsite spacing). The stocking estimates are higher at the 1 m row spacing than the 2 m row spacing, even though less seed is deposited. His estimates were determined with a regeneration assessment method based upon 4 m^2 plots. The differences in the stocking estimates were made as stocked microsites within rows spaced at 1 m would be more likely to be contained within a 4 m^2 plot than microsites made at a 2 m inter-row spacing.

Seed dispersion from the pneumatically-assisted Bräcke seeder differs substantially from the mechanical seeder. Rather than releasing 15 seeds in one concentrated drop, the seeder releases three to four groups of one or two seeds per microsite (Van Damme and Bax, 1991). The longer distribution of seed over the microsite increases the probability that seed will be deposited where suitable conditions for germination occur. The ability of the seeder to release seed over specific areas of the microsite compensates for differences in microsite formation caused by site and operational variables (Van Damme and Bax, 1991).

GROUND SPEED

Ryans (1985) stated the ground speed applied in site preparation operations should be determined by the quality of the microsite being produced. Microsite quality is governed by site factors, compatibility of the prime mover/implement match and the well-being of the equipment operator.

Site Preparation with Respect to Ground Speed

The effect of speed on seed distribution from the Bräcke has received little more than casual mention in the literature. Parker (1972) stated that once the Bräcke is adjusted to seed at a specific speed, it should always be run at that speed. More specifically, Anderson (1982) recognized the possibility that excess speed could cause the seed to be sown outside the prepared microsites. He suggested reducing speed if seed is not deposited within the microsite though there was no elaboration on seed placement or speed recommendations.

Relationships have been identified linking ground speed to the quality of the microsite formed. A study completed by Summerby (1987) showed that as forward operating speed decreased, the proportion of high-quality Bräcke microsites increased; i.e. fewer unacceptable microsites were created and average microsite size increased. On-site factors, including stump height, diameter and density, slash loading and terrain, were found to reduce the productivity of powered-disc trenchers (Hedin, 1990) and the Bräcke (Flemming *et al.*, 1987). Generally, reduction in productivity has been due to variation in ground speed as the operator negotiates obstacles. MacBrien (1982) recommended that the ground speed not exceed 60 metres per minute (m/min) for Bräcke scarification/seeding. Further increases in speed caused excessive wear on the scarifier and reduced the ability of the scarifier to penetrate slash. Edlund (n.d.) reported that scarification experience in Sweden showed a direct relationship between ground speed and repair time to the prime mover. The findings showed that at an average, season-long ground speed of 53 m/min, approximately 17 percent of scheduled operating time was needed to repair the prime mover. Conversely, at a seasonal-average ground speed of 31 m/min, only 6 percent of the scheduled operating time was lost to prime mover repairs.

Prime Mover/Implement Match

The wheeled skidder is used as a prime mover for many site preparation applications. Skidders are designed for a duty-cycle typical of a harvesting operation. A skidder used in harvesting pulls a full load of trees from the cut site to roadside, and then operates for a relatively easy period of time as the machine is returned empty for another load. The empty travel time, as well as time spent at low idle while the operator performs other duties, allows the skidder to dissipate some of the heat generated when it worked at or near full capacity (Ryans, 1984). However, the duty-cycle of a skidder used in site preparation involves almost continuous operation at or near its rated capacity. The entire cutover is traversed as well: the operator has little choice in the path of travel (Ryans, 1984). Deficiencies in skidder design when used for site preparation were noted as early as 1973 when excessive mechanical failures caused delays on site preparation projects (von Fraassen, 1975). Manufacturers have been reluctant to change the design of their skidders to suit site-preparation duty, primarily due to the limited market of site preparation prime movers (Ryans, 1984).

Several authors have reported problems associated with prime movers operated outside of the designed duty-cycle. Hedin (1986) reported premature final drive failures on FMC 220 tracked skidders used for slash-raking operations. Puttock and Smith (1986) reported an implement/prime mover mating problem where a powered-disc trencher was mounted on an unmodified cable skidder designed for harvesting. The hydraulics of the skidder were tapped to power the implement, however in this case, the skidder was not able to provide the trencher with sufficient hydraulic power at the ground speed required for site preparation. The slow ground speed required during site preparation did not permit the skidder to be run at a sufficiently-high engine speed (rpm) to provide the hydraulic flow required by the trencher. Mechanical problems and poor-quality site preparation resulted.

The most popular prime mover for powered site preparation implements has been the John Deere (JD) 740A (Olson, 1989). It has eight forward speeds (Hedin, 1990), allowing the engine to be operated closer to the optimum rpm on a wider variety of sites, while providing sufficient hydraulic power for the implement. Standardized hardware for mating the JD 740A with Donaren and TTS disc trenchers has been manufactured (Hedin, 1986 and 1990). However, the JD 740A model was discontinued in 1987. John Deere has since introduced the JD 748E grapple skidder. Engine power, hydraulic capacity and cooling ability were improved compared to the JD 740A. Several contractors have mounted powered-disc trenchers on these machines and have provided favourable comments on performance, operator comfort, reliability and productivity (Anon., 1991).

Several studies have reported modifications to increase the suitability of prime movers for use in site preparation. Common modifications were to increase fuel capacity to allow longer work times at full load (Orynik, 1985), and to increase cooling efficiency to dissipate heat generated under continuous, heavily-loaded operation (Orynik, 1985; Puttock and Smith, 1986; and Leblanc and Sutherland, 1987). Reducing the gearing of a prime mover with either a mechanical or hydrodynamic (power shift) transmission has been accomplished to allow the engine of the prime mover to operate at an efficient rpm, while providing an acceptable ground speed (Orynik, 1985; Leblanc and Sutherland, 1987; and Cormier and Ryans, 1990a). Increased engine rpm also provides a more consistent hydraulic flow (Puttock and Smith, 1986) or sustained electrical amperage from the prime mover's alternator (Dominy, 1991), as required by many implements. Auxiliary engines have been added to provide the hydraulic require-ments of the implement. Providing the implement with its own hydraulic system allows a skidder, with a hydraulic system designed for the harvesting duty-cycle, to be used as a prime mover for powered implements (Ryans, 1982; and Cormier and Ryans, 1990b). Auxiliary engines are typically mounted in place of the skidder's winch or above the winch, allowing the winch to be retained.

Canadian Pacific Forest Products has converted several Koehring shortwood harvesters into silvicultural prime movers. The machines were originally converted for drag scarification, however, they were later equipped with powered, cone-head scarifiers (Smith, 1984). These machines are driven hydrostatically: a hydraulic motor powers each of the four wheels individually (Leblanc and Smith, 1989). The advantages of hydrostatic drive includes: a better matching of ground speed to the required travel speed as the hydraulic flow to the drive motors is controlled by the operator, and a better ride for the operator since the wheels turn at a constant speed, independent of the influence of obstacles (Ryans, 1984). The constant engine rpm used to power the hydrostatic vehicle also provides consistent hydraulic flow to the implement. The mating of the four hydraulic cone scarifiers to the converted Koehring harvester confirms this principle (Leblanc and Smith, 1989).

Several prime movers have been developed specifically for use in site preparation. The Franklin 595 'Site Prep' skidder was built with high engine power and hydraulic capacity, as well as extra fluid-cooling ability. The skidder was powered by a 187 kW engine and equipped with a 10-speed, direct-drive transmission. Operating speeds between 23 and 232 m/min were possible (St-Amour, 1989). Long term use of the skidder in site preparation yielded acceptable availability and performance (St-Amour, 1993). The Supertrak SK-250 Forester had high engine power and over-size axles and final drives to withstand the site preparation duty cycle

(Anon., n.d.).

The unique Timberjack 480BT is basically a wheeled skidder to which crawler undercarriages have being installed in place of tires (Moshenko, 1991). Though produced for harvesting in steep-terrain conditions, the gear reduction created by the addition of the crawler running gear produces an operating-speed range between 40 and 187 m/min, with typical gradability to approximately 60 percent (Moshenko, 1991). These operating specifications are desirable in a silvicultural prime mover.

Ergonomics

The comfort and well-being of the operator affects site preparation production and quality. An operator uncomfortable in his work environment does not produce at the potential of the equipment he is operating (Ryans, 1985). The immediate effects of an uncomfortable operator are lower production through lower travel speed and increased operator fatigue. Eventually, long-term health problems will arise (Ryans, 1985).

Ergonomics is defined as the scientific study of the efficiency of workers in their working environment (Nugent, 1985). Ergonomics can be used to show what is important within the working environment to the health of the site preparation operator (Golsse, 1989). The duty-cycle, harsh conditions and long work days normally associated with site preparation have exposed equipment operators to temperature extremes, excessive noise levels and an increased danger of being struck by debris entering the cab (Ryans, 1984). Similarly, site preparation operators are subjected to whole-body vibrations (WBV) as the equipment traverses rough terrain. Whole-body vibrations are low-frequency oscillations that cause the entire body to shudder (Thompson, 1977). Various studies have shown that skidder operators working on site preparation projects exceed International Organization for Standards (ISO) limits for WBV after one hour (Garner, n.d., cited in Nugent, 1985) to two and one-half hours exposure (Golsse, 1989). Golsse (1989) stated that levels of WBV can be expected to be higher in site preparation than on the same prime mover used for harvesting. The intense duty-cycle combined with a prescription of 100 percent area coverage expose the operator to increased WBV levels .

A study completed by Webb and Hope (1983) on exposure of cable-skidder operators to WBV, found operator fatigue to be a problem resulting from entering and exiting the skidder many times per day. Another major finding was that the cab dimensions are frequently less than those recommended by ISO, causing the operators to enter, exit or occupy the cab in an awkward and/or unsafe manner.

Improvements have been made to the environment in which the machine operator works. Screened cabs are now standard on most prime movers, and fully enclosed, climate-controlled cabs are available.

A study to improve the ability of a skidder seat to isolate the operator from WBV showed that a suspension seat, isolated from the prime mover's frame, reduced the operator's exposure to WBV. However, while exposure to WBV was reduced, exposure time was still not acceptable in the context of typical working shift under ISO guidelines (Golsse, 1991a).

Golsse (1991b) reported that a study is in progress to determine the capability of skidder-cab suspension systems to reduce WBV. Early results indicate that metal-spring suspension systems, equipped with shock absorbers, show the most promise. Air and air/liquid suspensions systems dampen WBV less effectively.

Acknowledgement of the importance of the operator's comfort to the quality and productivity of site preparation is increasing, making the goal of achieving site-, species- and implement-specific prescriptions more realistic.

SEED LABELLING

The use of radioactive elements to trace the location of objects of interest has been done for many years. An isotope of Cobalt (^{60}Co) was used to trace the movements of several species of moles (Godfrey, 1954 and 1955), as well as aiding in the recovery of amphibians (Karlstrom, 1957).

Cobalt releases high-energy radiation and possesses a half-life of 5.3 years (Godfrey, 1954). One drawback of Cobalt as an element for use in animal-movement or seed-fate studies is that high dosages are required to achieve satisfactory soil penetrability by the alpha radiation (Karlstrom, 1957). A dosage level of 20 microcurries (μCi) was needed to penetrate 30-38 centimetres (cm) of soil (Karlstrom, 1957). The successful use of a Scandium isotope (^{46}Sc) for tracing the fate of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seed was reported by Lawrence and Rediske (1959). The isotope is a strong gamma emitter, producing greater soil penetrating power than either alpha- or beta-emitting isotopes. It has a half life of 85 days and decays to stable ^{46}Titanium, thus making it more suitable for use in short-term studies (Lawrence and Rediske, 1959).

Several studies have used ^{46}Sc as a tracer element. Lawrence and Rediske (1959; and 1962) used the element at a concentration level of 3 μCi per seed and were able to recover 95.5 percent of the seeds sown. A hand-held, sodium-iodide crystal scintillator was used to determine the location of the seeds. Radvanyi (1966) used ^{46}Sc on white spruce (*Picea glauca* (Moench.) Voss.) seed at a concentration of 3 μCi per seed. Ninety-one percent of the seed used in the study was recovered after 17 weeks in the field. Radvanyi (1970) conducted a similar study on white spruce, using ^{46}Sc at 3 μCi per seed to study seed destruction by mammals. In the study, seeds were recovered from burrows without difficulty. Similarly, Quink *et al.* (1970) reported they were able to recover ^{46}Sc-treated seed from hidden seed caches when only one treated seed was present.

SUMMARY

Advances in direct-seeding technology combined with more suitable prime movers, as well as increased concern for the well being of the site preparation operator, have necessitated that the parameters associated with site preparation work be quantified to a better degree. The necessity of knowing the speeds at which satisfactory seed placement is achieved is important to all parties concerned, including equipment manufacturers who must design equipment capable of operating efficiently at such speeds. Vibration-damping systems must be engineered around a defined set of operating conditions. Similarly for the forester, having a site-, species-, prime mover- and implement-specific ground speed would allow more consistent and reliable results to be obtained. Therefore, a study to determine a suitable ground speed for the common prescription of direct seeding jack pine with the widely-used Bräcke scarifier/seeder is justified.

METHODS

A stationary trial was first made to determine the pattern of the Bräcke seed fall without the effect of wind and jarring movements. A controlled trial was then done in an old gravel pit, permitting the application of uniform obstacle and speed treatments. A field trial was also done to provide a comparison between the results obtained by controlled study with those obtained in operational use of the Bräcke.

STATIONARY TRIAL

A stationary, bench trial was conducted to determine the nature of the seed fall as released from the Bräcke. A single Bräcke scarifier frame was positioned on blocks, allowing the rubber tire and mattock to turn freely above the ground. A plywood platform, one square metre in size, was positioned below the hole from which the seed was released. The platform was adjustable to three heights, separated by 17.9 cm, relative to the seed release hole: 40.7 cm, 58.6 cm and 76.5 cm. The seed release hole is approximately 40-45 cm from the soil when seeding.

The seed release pattern was studied over four simulated ground speeds: 40, 60, 80 and 100 m/min, applied by manually spinning the tire. Three replications of speed were made.

A high-speed, Super Eight 8 millimetre camera was positioned approximately two metres from the Bräcke seeding device, perpendicular to the machine frame. It was focused on the seed release hole to capture the trajectory path of the seeds as they fell. The camera was adjusted to run at 72 frames per second. A film camera was used since the still-frames can be counted to determine the time that was required for the seed to drop from the Bräcke, and the trajectory path of the seed could be followed frame by frame.

The seed fall from the Bräcke may be explained by simple physics developed by Galileo (1564-1642). Seed, released from the moving scarifier, travels at the same forward speed as the scarifier, but is also accelerated downward by gravity. The trajectory that the seed will take is known to be a parabola (Tilley and Thumm, 1976). The position where a seed, with initial vertical velocity of zero, will land relative to the point of seed release can be determined by applying Equations (1) and (2) below (from Galileo):

$$\Delta x = v * t \qquad (1)$$

$$\Delta y = 1/2*g*t^2 \quad \text{(with zero initial velocity)} \qquad (2)$$

where:
Δy = vertical displacement
Δx = horizontal displacement
g = acceleration due to gravity = 9.8 m/sec^2
v = velocity of scarifier
t = seed-drop time

Equations (1) and (2) assume that air resistance to a seed's fall would be negligible (Tilley and Thumm, 1976). The trajectory of a released seed is shown in Figure 2.

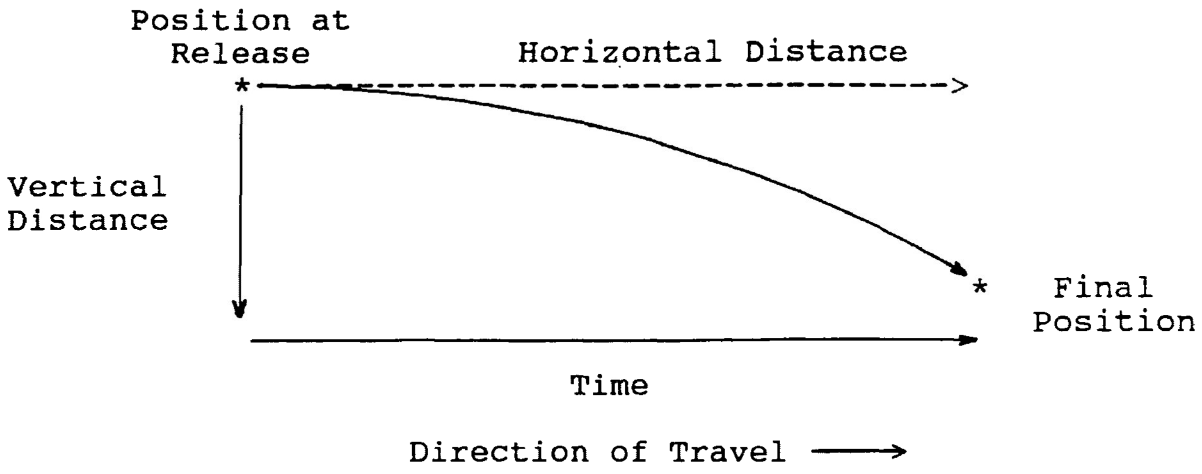


Figure 2. The parabolic trajectory of a jack pine seed as released from a moving Bräcke scarifier/seeder (after Tilley and Thumm, 1976).

Air pressure created by the air-assisted Bräcke seeder would provide the jack pine seed with an initial downward velocity. The initial velocity is additive to the velocity created by gravity, thus any initial downward velocity would serve to shorten the trajectory shown in Figure 2. Vertical displacement with an initial vertical velocity may be predicted by equation (3), below:

$$\Delta y = v_o * t + 1/2 * g * t^2 \quad (3)$$

where:
Δy = vertical displacement
v_o = initial vertical velocity
g = acceleration due to gravity = 9.8 m/sec^2
t = seed-drop time.

Thus, by quantifying the time taken by a seed to reach the ground upon release, the effect of release height and ground speed may be predicted.

STUDY AREAS

The study was conducted in two areas. An abandoned gravel pit close to Thunder Bay was selected for the controlled trial, while the operational field trial was implemented in a one-year-old, jack pine cutover.

The abandoned gravel pit was located approximately 20 kilometres (km) east of Thunder Bay, near MacKenzie, at 48° 32' north latitude by 89° 04' west longitude. The site was a major glacio-fluvial deposit of sand and gravel. The removal of the gravel left a flat, homologous area approximately one hectare in size. The pit floor consisted of sand and fine gravel with few stones larger than five centimetres in diameter.

The operational trial was conducted approximately 250 km northwest of Thunder Bay, near Graham, at 49° 30' north latitude by 90° 45' west longitude. The property belongs to Abitibi Price Inc. and is known as API Freehold Block 6. The site was mechanically harvested in the summer of 1988. The forest stand consisted of approximately 90 percent jack pine and 10 percent black spruce (*Picea mariana* (Mill.) B.S.P.), with scattered aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.). A full tree logging system was used, with the slash from the delimbing operation being piled at roadside. Tables 1 and 2 provide the slash loading and stump information, respectively. Slash loading information was measured based upon the line intersect method presented by Van Wagner (1968). Stump data were obtained using 50 m^2 circular plots. Stump diameter was measured at the point where the trees were cut. Stump height was measured from the mean ground level within each plot to the point where the trees were cut.

Table 1. Average slash-loading results from three line-intersect transects on the field trial site.

Number pieces /line <5 cm	Std. dev.	Number pieces /line >5 cm	Std. dev.	Slash depth /line (cm)	Std. dev. (cm)	Volume (m^3/ha)	Std. dev. (m^3/ha)
19	2.4	7	1.1	12	3	42.6	5.1

Table 2. Stump-survey results from three 50 m^2 circular plots on the field trial site.

Avg. Number/ plot	Std. dev.	Avg. height (cm)	Std. dev. (cm)	Avg. dia. (cm)	Std. dev. (cm)	Density (No./ha)	Std. dev. (No./ha)
7.6	0.4	18.6	3.4	21.7	4.3	1440	220

The area is within the Upper English River Forest Region (region B.11) of the Boreal forest (Rowe, 1972). The terrain was essentially flat to gently rolling and the soils were well drained. The deep soil consisted of a medium-course sand, covered with a 5 to 15 cm duff layer. The Canadian

Pulp and Paper Association's Terrain Classification for Canadian Forestry code for the site was 2.1.1 (Mellgren, 1980). The site was within Vegetation Class V29 and Soil Class S3 of the Forest Ecosystem Classification for Northwestern Ontario.

EQUIPMENT

The equipment studied was the latest production model of the Bräcke hydraulic 3-row patch scarifier, equipped with pneumatically-assisted seeders. The prime mover used was a Franklin 595 wheeled skidder, equipped with a 187 kilowatt diesel engine, a 10-speed, direct-drive transmission and a 16,330 kilogram capacity winch. Specifications for the skidder are given in Appendix I while the Bräcke used is detailed in Appendix II.

The Bräcke 3-row is the most technologically advanced patch scarifier produced by Robur Maskin AB, of Sweden. The length of and distance between the microsites produced, as well as the distance between adjacent strips are adjustable. The length of and distance between microsites within one strip are adjusted by scarifier gear selection, while inter-strip spacing is hydraulically adjustable between 1.025 and 2.080 m.

The Bräcke was adjusted to run on the 15-tooth intermediate gear to produce long, gently-sloping microsites. The 15-tooth position maximized the amount of exposed mineral soil and minimized the microsite slope (Pye, 1989).

The scarifier was equipped with seeding devices, mounted on the rear-most part of each of the three machine frames. Seed release from the seeder was synchronized with the position of the mattock teeth through an internal camshaft. A piston-style plunger generated compressed air used to aid the expulsion of seed onto the ground.

SEED TREATMENT

The jack pine seed was labelled with a radioactive isotope of Scandium (^{46}Sc). The strong gamma-emitter ^{46}Sc was obtained in solution as scandium chloride ($ScCl_3$) at a concentration of 10 μCi per vial. The $ScCl_3$ was diluted to 40 millilitres (ml) in water. Twenty millilitres of solution was used to label the seed for the gravel pit trial, while the balance was used to label the field trial seed. The seedlots were labelled separately, one day prior to their use. Approximately 8500 seeds were labelled with each 20 ml of solution. The seeds were soaked until all the solution had been absorbed by the seeds. Rhodamine Red, a highly-visible red dye, was added to the labelling solution to make the seeds more visible on the soil. Once removed from the labelling solution, the seeds were air dried for 24 hours in a fume hood to prevent them from sticking together in the seeding device.

A M^{c}Phar TV-I scintillometer was used to determine the location of the seeds on the ground. The device emitted an audible tone that became more intense as a radiation source was approached.

GRAVEL PIT TRIAL

Study Design

A split-plot, factorial experimental design (Anderson and McLean, 1974) was chosen for the controlled, gravel pit portion of the study (refer to Figure 5). The split-plot design maximized the number of experimental units that could be obtained considering the size of the gravel pit, the number of seed to be labelled and the time available for data collection.

The objective of the gravel pit experiment was to test the effect of speed and obstacle height on the placement of seed and microsite characteristics produced by the Bräcke scarifier. Four ground speeds were applied to separate 60 m strips in the gravel pit. Twelve strips were needed as each speed was replicated three times. The three replications of the four speeds were randomly assigned to each of the twelve 60 m strips. Within each 60 m strip, the three obstacle heights were randomly assigned to three 20 m plots. Each obstacle height covered a 20 m section of the strip. Each of the thirty-six 20 m sections was an experimental unit, while the microsites created within each plot were the sampling units. The model and expected mean square (EMS) table (Table

3) are presented below (similar to Anderson and McLean, 1974).

$$Y_{ijk} = \mu + S_i + R_{(i)j} + \delta_{(ij)} + O_k + SO_{ik} + RO_{(i)jk} + \epsilon_{ijk} \qquad (4)$$

where: Y_{ijk} = response obtained from the jth occurrence of the ith speed with the kth obstacle height.
μ = overall mean
S_i = effect of the ith speed, i = 1,2,3,4
$R_{(i)j}$ = effect of the jth occurrence of the ith speed, j = 1,2,3
$\delta_{(ij)}$ = restriction error caused by the three obstacle heights being run in the jth occurrence of the ith speed. It has zero degrees of freedom and no sum of squares.
O_k = effect of the kth obstacle height, k = 1,2,3
SO_{ik} and $RO_{(i)jk}$ = interaction effects
ϵ_{ijk} = error

Table 3. Table of expected mean square equations for the gravel pit trial.

Source of Variation	Degrees of Freedom	Expected Mean Square
S_i	3	$\sigma^2 + 3\sigma^2_\delta + 3\sigma^2_R + 9\Phi(s)$
$R_{(i)j}$	8	$\sigma^2 + 3\sigma^2_\delta + 3\sigma^2_R$
$\delta_{(ij)}$	0	$\sigma^2 + 3\sigma^2_\delta$
O_k	2	$\sigma^2 + \sigma^2_{RO} + 12\Phi(O)$
SO_{ik}	6	$\sigma^2 + \sigma^2_{RO} + 3\Phi(SO)$
$RO_{(i)jk}$	16	$\sigma^2 + \sigma^2_{RO}$
ϵ_{ijk}	0	σ^2
Total	35	

Implementation

Four ground speeds were selected that covered the range of speed at which the Bräcke is most often operated. The speeds were 40, 60, 80 and 100 m/min. The prime mover was equipped with an engine tachometer, allowing the operator to repeatedly produce the same ground speed through transmission gear selection and careful monitoring of engine rpm.

Six obstacles were placed within each plot, randomly located between 2.0 m and 18.0 m from the beginning of each plot. Obstacles were not placed in the first nor the last 2.0 m of each plot. It was determined that the presence of an obstacle immediately adjacent to another plot would not allow enough distance for the influence of the obstacle to be expressed within the proper plot. The obstacles were placed perpendicular to the direction of travel. Figure 3 illustrates the manner by which the obstacles were randomly placed within each plot.

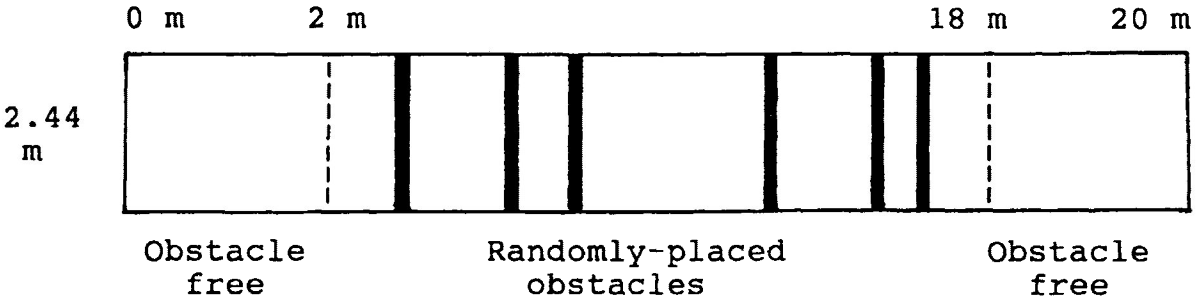


Figure 3. Random obstacle placement between 2.0 m and 18.0 m of each plot in the gravel pit trial (Note: not to scale).

The three obstacle treatments were: 1) no obstacles, 2) single railway ties 20 cm high (2.44 m long) and 3) three railway ties arranged in pyramidal form (40 cm total height). Railway ties were selected as they were consistent in size, shape and weight, available in quantity and could be stacked pyramidally to form the highest obstacle. Two 2.5 cm holes were drilled in each tie, 30 cm from each end to allow the ties to be anchored to the ground. Reinforcement bar (re-bar) 45 cm long for the 20 cm high obstacles and 75 cm long for the 40 cm high obstacles, were driven through the drilled holes and into the ground until the re-bar was flush with the top surface of the tie. An electrically-powered jackhammer was used to drive the re-bars into the ground. Although the obstacles were anchored to the ground, it was expected the Bräcke would dislodge them. Figure 4 illustrates the obstacles used and the way in which they were anchored to the ground. Figure 5 illustrates the experiment layout, detailing the speed and obstacle assignments.

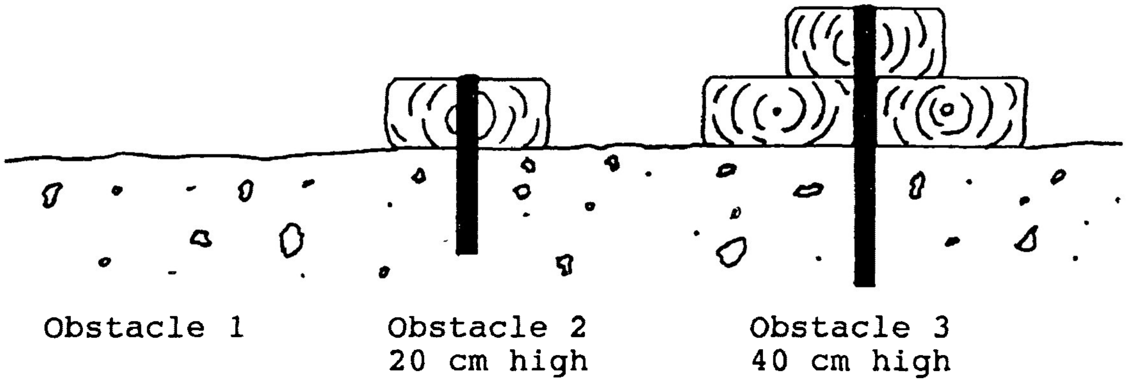


Figure 4. Obstacles used, showing reinforcement bar used to anchor the railway ties to the ground (side view).

The procedure used to complete each strip was to position the machine about 20 m from the beginning of a strip and install the seed hopper. The 20 m distance allowed the operator to accelerate the prime mover to the required speed prior to entering each strip. The seed hopper was removed at the end of each strip to conserve the labelled seed and allow the operator to position the machine for the next strip.

Two VHS video cameras were used to record the treatments. A fixed-location camera was positioned behind the starting point of each strip. The camera operator was able to tape the progress of the machine, aided by a telephoto lens. The second camera was handheld by a passenger on a 4-wheel, all-terrain vehicle (ATV) driven beside the Bräcke. The use of the ATV allowed taping perpendicular to the Bräcke as it advanced along each strip. Thus, each run in the trial was taped from the rear and the side of the machine.

The machine was timed over each 20 m plot to determine the actual speed produced within each strip. The axle of the Bräcke frame containing the treated seed was the reference point used for the timing.

Strip number	Obstacle height within each 20 m plot (cm)			Speed (m/min)
12	40	0	20	100
11	20	40	0	40
10	20	40	0	60
9	40	0	20	60
8	40	0	20	100
7	20	0	40	100
6	0	20	40	80
5	20	40	0	80
4	40	20	0	40
3	40	0	20	80
2	40	0	20	40
1	0	20	40	60

Figure 5. Layout of gravel pit trial illustrating the split-plot design, and the obstacle-height and speed randomization within each 60 m strip.

<u>Assessment</u>

The response variables measured in the gravel-pit trial are listed in Table 4. The variables were assigned symbols for identification in the analysis and use in the text as well.

The variable LENGTH was the length of the complete microsite. The lack of a root mat in the gravel pit prevented the formation of a proper hinge and overturn section, thus preventing distinct dig and overturn portions from being produced. LENGTH was measured from the point where the mattock teeth entered the soil to the end of the overturned mineral soil. All LENGTH measurements were taken parallel to the direction of travel and represented the mean length of each microsite.

Table 4. Symbol assignment by response variable for the gravel pit trial..

	Symbol	Response variable
1	LENGTH	Average length of the microsite
2	WDIG	Average width of the dig-portion
3	WOVER	Average width of the overturn
4	DISTY	Longitudinal distance to the point of mean seed release as measured from the start of the microsite
5	DISTX	Lateral distance to the point of mean seed release as measured from the microsite centerline
6	SPREADY	Maximum distance between dropped seed measured parallel to the direction of travel (longitudinal axis).
7	SPREADX	Maximum distance between dropped seed measured perpendicular to the direction of travel
8	NSEEDS	Number of seeds found in each microsite
9	INTER	Inter-microsite distance between microsites entirely in each plot.

The width of the dig portion, WDIG, was defined as the maximum microsite width as measured between the point where the mattock teeth entered the ground to the point of inflection on the midslope joining the dig and overturn portions. The width of the overturn, WOVER, was measured at the point of maximum width between the point of inflection on the midslope to the end of the overturned mineral soil. All width measurements were taken perpendicular to the direction of travel.

The position of the obstacles were measured after treatment. The distance to each obstacle from the start of each 20 m plot was recorded, measured at the point where the obstacles crossed the centre-line of each strip. Detailed drawings of each microsite were made, indicating the obstacle number and final position.

To locate the seed, a 1.0 m by 1.0 m grid, containing one-hundred 10.0 cm by 10.0 cm squares, was first positioned over each microsite. The reference point for all microsite measurements was the point of entry of the Bräcke teeth into the soil. The surface of the microsite was then scanned with the scintillometer. A seed within detectable range of the scintillometer caused an audible tone to be produced: the louder and faster the pulses of the tone, the nearer the scintillometer to a seed. The scintillometer was lowered through the centre of each grid square in the area of the most intense readings. Numerical meter readings from the scintillometer were recorded from each square in the vicinity of the seed. Once the area above and surrounding a seed was scanned, visible seed were then removed and the procedure repeated to determine if multiple seeds were dropped within a grid square. The position of the grid with respect to the microsite was marked on the ground, and the procedure was repeated on the next portion of the microsite. Efforts were made to find all seeds, so that the number of seeds dropped per microsite could be determined. The exact position of each seed located was mapped with respect to the grid overlay. The response variables DISTY, DISTX, SPREADY, SPREADX and NSEEDS were measured from the microsite maps drawn during the assessment process. Figure 6 illustrates the measures that DISTY, DISTX, SPREADY and SPREADX represent.

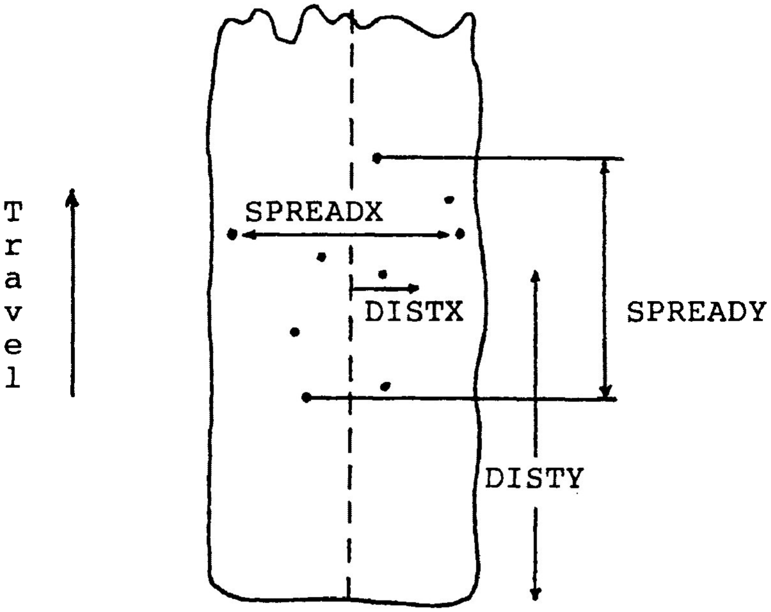


Figure 6. Illustration of the measurements represented by the symbols DISTY, DISTX, SPREADY and SPREADX.

Analysis

Prior to analyzing the effect of the speed and obstacle treatments, the response variables were separated into sets of related variables. Correlation and factor analyses of the variables were used to determine how the variables were to be grouped for univariate and multivariate analyses (ANOVA and MANOVA). A Pearson correlation was applied to determine the strength of the relationship between response variables and direct grouping of variables for ANOVA or MANOVA. A factor analysis, using the maximum likelihood approach (Chatfield and Collins, 1986), was also done to confirm the grouping of response variables from the correlation analysis. All of the analyses were performed using Statistical Package for the Social Sciences (SPSS) software (Anon., 1988) installed on a Microvax mainframe computer.

Each set of response variables was analyzed separately, using either ANOVA or MANOVA. ANOVA was used to determine the treatment effects on single variables that were unrelated to other variables. MANOVA was used to detect significant speed and obstacle effects on sets of two or more related variables.

The means of significant response variables were analyzed with Tukey's Multiple Range Test (MRT) to determine which treatments produced significantly different results.

FIELD TRIAL

Study Design

The objective of the field trial was to determine if the results of the controlled, gravel pit trial would parallel those seen under operational conditions. A completely randomized design was used, with speed being the only treatment applied. The obstacle height was not controlled: obstacles were represented by the slash and stumps found in the cutover (refer to Tables 1 and 2). The analytical model is shown as equation (5) below while Table 5 presents the EMS table (after Anderson and McLean, 1974).

$$Y_{ij} = \mu + S_i + \varepsilon_{(i)j} \tag{5}$$

where: Y_{ij} = response obtained from the jth occurrence of the ith speed
μ = overall mean
S_i = effect of the ith speed, i = 1,2,3,4
$\varepsilon_{(i)j}$ = within error, the effect of the jth occurrence of the ith speed, j = 1,2,3.

Table 5. Table of expected mean square equations for the field trial.

Source of Variation	Degrees of Freedom	Expected Mean Square
S_i	3	$\sigma^2 + 3\Phi(S)$
$\epsilon_{(i)j}$	8	σ^2
Total	11	

Implementation

The trial was applied using twelve 20 m strips representing the four ground speeds with three replications of speed (Figure 7). The speeds used were the same as in the stationary and gravel pit trials, and obstacles were represented by those found in the cutover. Thus, the field trial was one-third the size of the gravel pit trial.

The field trial was video taped from the side and the rear of the Bräcke, similar to the gravel pit trial. However, the camera taping from the side was still-mounted as the cutover was too rough to allow the ATV to be used.

The seed hopper was removed at the end of each strip to conserve seed. The Bräcke was timed in the same manner as at the gravel pit.

Strip Number	20 m Plot	Speed (m/min)
12		100
11		40
10		60
9		60
8		100
7		100
6		80
5		80
4		40
3		80
2		40
1		60

Figure 7. Layout of the field trial illustrating the randomization of the ground speeds applied.

Assessment

The response variables measured in the gravel pit trial were also used in the field trial (refer to Table 4), with the exception of LENGTH. Microsite length was divided into two distinct portions as the root mat present in the field allowed fully-formed microsites to be produced. The length of the dig portion, LDIG, was measured from the point where the mattock teeth entered the soil to the point of inflection on the midslope separating the dig and overturn portions (approximately the position of the hinge). Similarly, the length of the overturn portion, LOVER, was measured from the point of inflection on the midslope to the end of the overturned mineral soil. All length measurements were taken parallel to the direction of travel.

The assessment of seed placement in the field trial was conducted in the same manner as in the gravel pit trial. The grid was placed over each microsite, beginning at the point of entry of the mattock teeth into the soil, and it was moved along the microsite until the entire patch had been scanned and mapped. The area surrounding the microsite was also scanned for seed deposited outside of the microsite.

Analysis

Analysis of the field trial data were conducted using the same procedures as for the gravel pit trial.

RESULTS

STATIONARY TRIAL

The filming of the stationary trial with the high-speed camera did not produce an estimate of the time necessary for a seed to fall from the Bräcke. Dust and other contaminants on the film were indistinguishable from the jack pine seed, making counting impossible. However, theoretical estimates were calculated, using Equation (2), of the displacement that was expected as speed and release-height increased. Table 6 presents the estimates, with zero initial downward velocity.

Table 6. Predicted forward displacement of seed from the point of release from the Bräcke scarifier as ground speed and release height vary.

Ground speed (m/min)	Predicted forward displacement (m) from drop height				
	0.20m	0.40m	0.60m	0.80m	1.00m
40	0.135	0.190	0.233	0.269	0.301
60	0.202	0.282	0.350	0.404	0.452
80	0.270	0.381	0.467	0.539	0.602
100	0.337	0.476	0.583	0.673	0.753

GRAVEL PIT TRIAL

The use of the Rhodamine Red dye and seed labelling allowed the recovery of approximately 93.5 percent of the seed sown in the gravel pit trial. Some seed was not recovered as extensive excavating would have changed the physical aspects of the microsite and possibly disturbed adjacent microsites.

The factor analysis of the response variables in the gravel pit trial produced four groups of related response variables (Table 7). The factor analysis was performed since correlations between variables were anticipated: response variables that were correlated to one another were analyzed with multivariate techniques.

Table 7. Grouping of related response variables from the gravel pit trial for analysis of variance, based upon factor analysis.

Factor 1	Factor 2	Factor 3	Factor 4
LENGTH	NSEEDS	DISTY	DISTX
WDIG	SPREADY		
WOVER	SPREADX		
INTER			

A Pearson's correlation matrix of the nine response variables is shown in Table 8. Variables were shown in a manner that allowed the factor grouping to be seen. Each bivariate correlation coefficient in Table 8 was calculated using approximately 200 observations (n = 200), therefore, nearly all the coefficients were significant. In consideration of the factor analysis and the Pearson's correlation, a decision was made that a correlation coefficient, r, of 0.50 or greater was large enough to have practical importance in the context of the study. The variables LENGTH, WDIG, WOVER and INTER were correlated to each other ($r > 0.54$). The variables NSEEDS and SPREADY were correlated as well ($r = 0.59$). The remaining variables, DISTX, DISTY and SPREADX, were not strongly correlated to any other variables.

Table 8. Results of a Pearson correlation analysis of the variables measured in the gravel pit trial (the critical value of the correlation coefficient, r, was 0.12 at $\alpha = 0.05$, based upon approximately 200 observations).

					Variable number					
Variable		1	2	3	4	5	6	7	8	9
1	LENGTH	1								
2	WDIG	.69	1							
3	WOVER	.54	.74	1						
4	DISTX	-.33	-.28	-.16	1					
5	DISTY	.38	.35	.25	.00	1				
6	NSEEDS	.36	.19	.13	-.22	.32	1			
7	SPREADX	-.13	-.11	-.08	.37	.03	.31	1		
8	SPREADY	.17	.13	.05	-.06	.04	.59	.37	1	
9	INTER	-.88	-.70	-.59	.34	-.14	-.27	.20	-.15	1

The correlated response variables of LENGTH, WDIG, WOVER and INTER were analyzed using multivariate methods according to the EMS table (Table 3). The variables NSEEDS and SPREADY were analyzed in a separate multivariate analysis. Univariate analyses were performed on the variables DISTX, DISTY and SPREADX. Table 9 summarizes the results of these various analyses. The full ANOVA tables are available in

Appendix III. The treatment effects were significant if the observed F-ratio was greater than the 0.05 tabular value.

Table 9. Summary of analysis of variance on data from the gravel pit trial.

Response variable	Source of variation	Probability of F > F-ratio
Multivariate of LENGTH, WDIG, WOVER and INTER	Speed	0.212
	Obstacle	0.016*
	Speed by Obstacle	0.128
Univariate of DISTX	Speed	0.422
	Obstacle	0.000**
	Speed by Obstacle	0.166
Univariate of DISTY	Speed	0.001**
	Obstacle	0.000**
	Speed by Obstacle	0.822
Univariate of SPREADX	Speed	0.168
	Obstacle	0.045*
	Speed by Obstacle	0.279
Multivariate of NSEEDS and SPREADY	Speed	0.070
	Obstacle	0.000**
	Speed by Obstacle	0.509

Note: significance of the F statistic is indicated by one asterisk (*) at the 95 percent confidence interval and by two astericies (**) at the 99 percent confidence interval.

The multivariate analysis of the microsite response variables (LENGTH, WDIG, WOVER and INTER) showed that obstacle height influenced the size and shape of the Bräcke microsite, as shown in Figure 8. The microsites became shorter in length, narrower in width and spaced further apart as the height of the obstacle increased. Figure 9 illustrates the multivariate effect of obstacle height on

LENGTH and INTER, the two most responsive variables shown in Figure 8.

In further analysis, the change in the variable LENGTH was used to represent the effect of obstacles on microsite dimensions. LENGTH was highly correlated (r = -0.88) to INTER as obstacle height increased: an increase in microsite length corresponded to a decrease in inter-microsite distance. Obstacle height had only a small influence on microsite width (Figure 8). Tukey's MRT was used to indicate which obstacle treatment produced a significant effect on microsite dimensions. Table 10 presents the results of the Tukey's MRT for the significant effects in the ANOVAs.

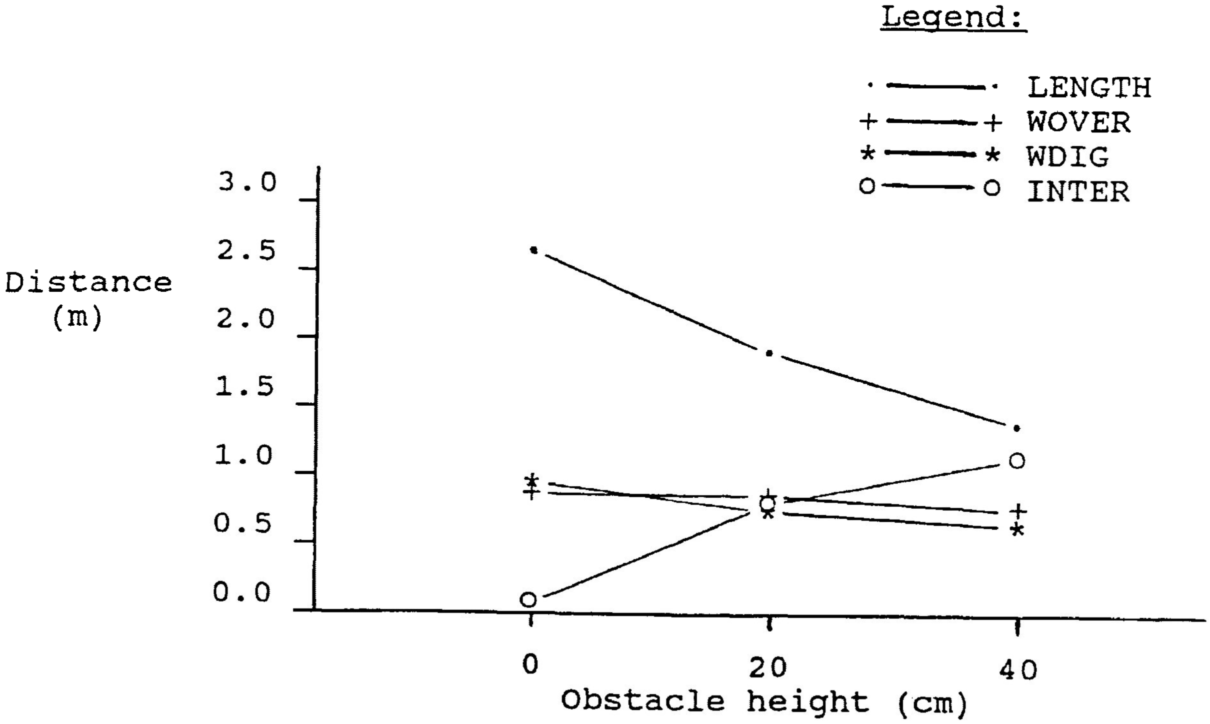


Figure 8. Dimensional changes in microsite features as obstacle height increased: gravel pit trial.

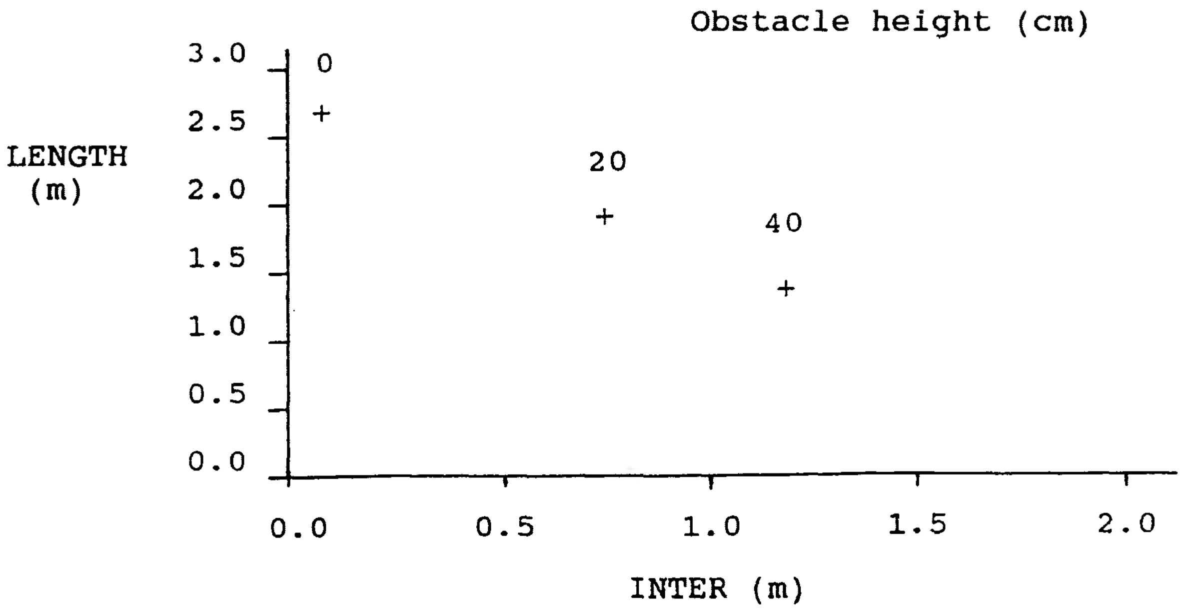


Figure 9. Changes to microsite length and inter-microsite distance as obstacle height increased.

Table 10. Results of Tukey's multiple range test for the significant effects of obstacle height and ground speed for the gravel pit trial ($\alpha = 0.05$).

Response variable	Obstacle height (cm) 0	20	40
LENGTH (m)	2.650	1.900	1.392
DISTX (m)	0.071	0.081	0.131
DISTY (m)	2.225	2.082	1.919
SPREADX (m)	0.149	0.146	0.184

Response variable	Ground speed class (m/min) 40	60	80	100
DISTY (m)	1.943	2.003	2.114	2.239

Note: Response variable values underscored by the same bold line are not significantly different, while values not underscored by the same bold line are significantly different.

The variable DISTX, the distance the seed dropped to either side of the microsite centerline was affected by obstacle height. Tukey's MRT of the DISTX means for the three obstacle heights showed that increasing obstacle height increased the distance the seeds dropped from the centerline (Table 10). The 40 cm obstacle effect produced seed spread significantly wider than that produced by the lower obstacle heights (Figure 10). The two lower obstacle heights were not significantly different from each other.

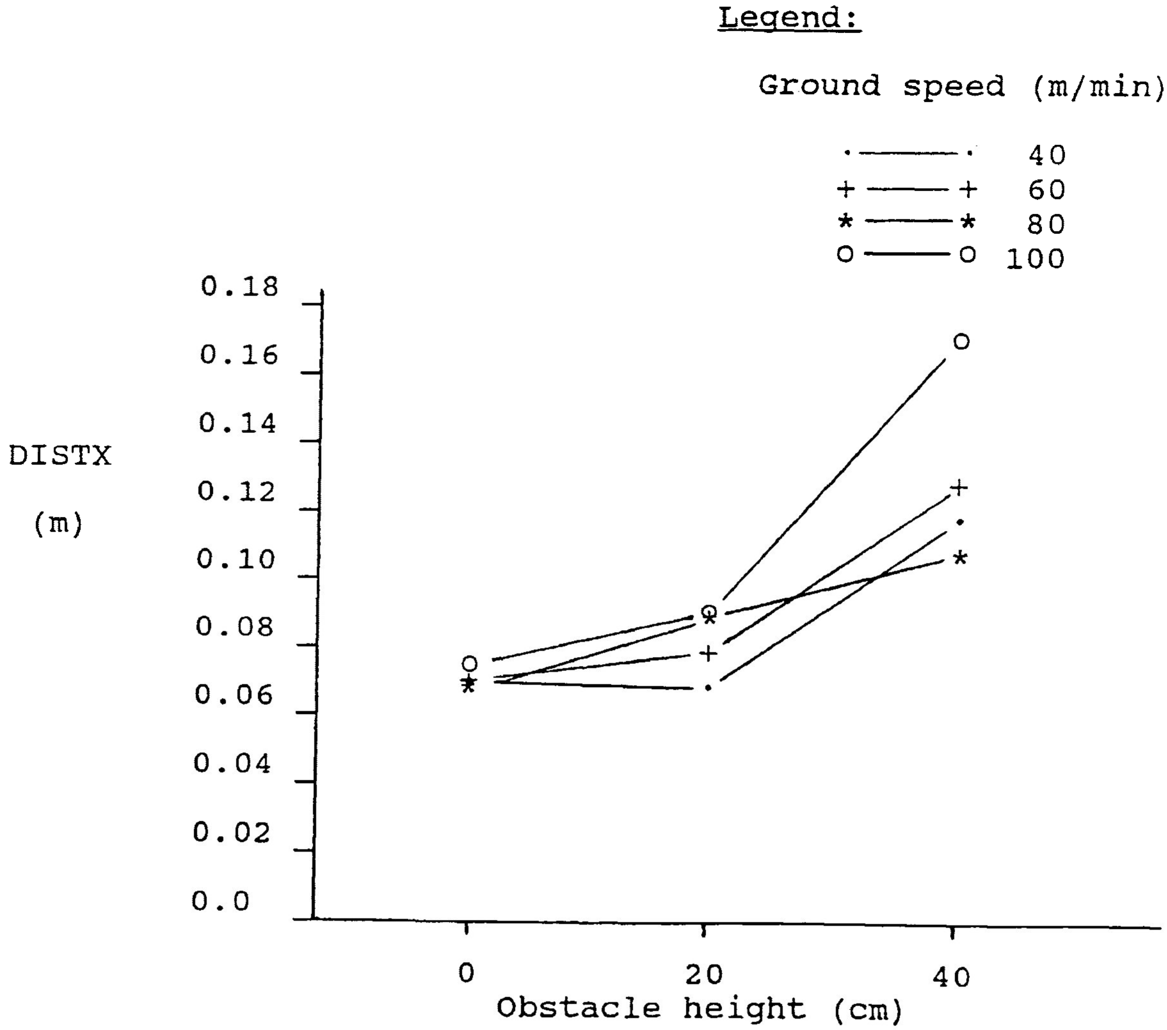


Figure 10. Increase in distance from the microsite centerline to the point of mean seed release as obstacle height increased.

The variable DISTY, the distance that the mean number of seeds were dropped from the beginning of the microsite, was affected by obstacle height. The introduction of obstacles resulted in a decrease in the distance to the point of mean seed drop (Figure 11). A Tukey's MRT showed that seed was dropped significantly further from the beginning of the microsite with no obstacle present than when the highest obstacle was present (Table 10).

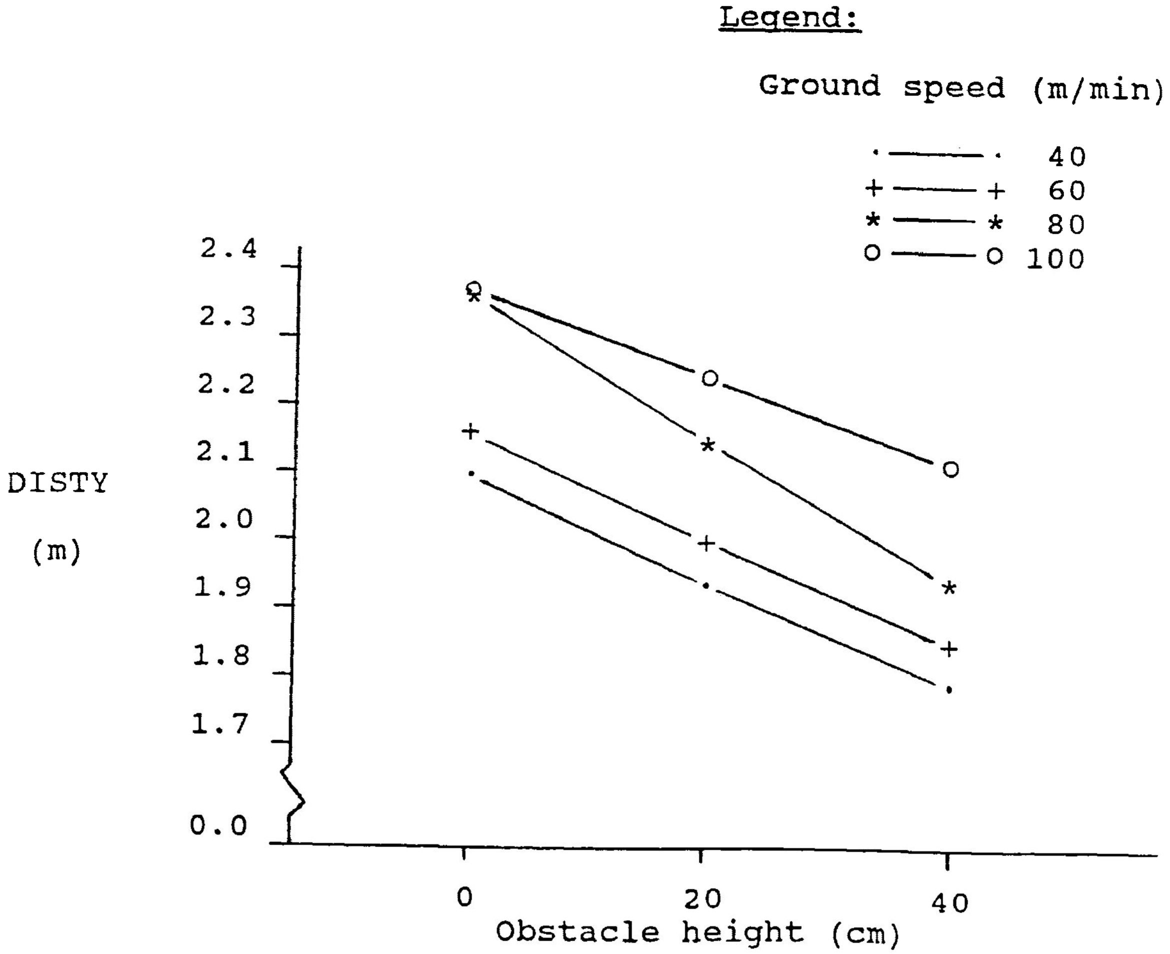


Figure 11. Decrease in distance from the start of the microsite to the point of mean seed release as obstacle height increased.

The univariate test for SPREADX showed that obstacle height significantly affected the distance the seeds were spread along the x-axis of the microsite. The conservative Tukey's MRT indicated that there were no significant differences between any of the treatment means. However, by looking at the means, it appears that the highest obstacle caused the seed to be spread wider than the other two obstacle heights (Figure 12).

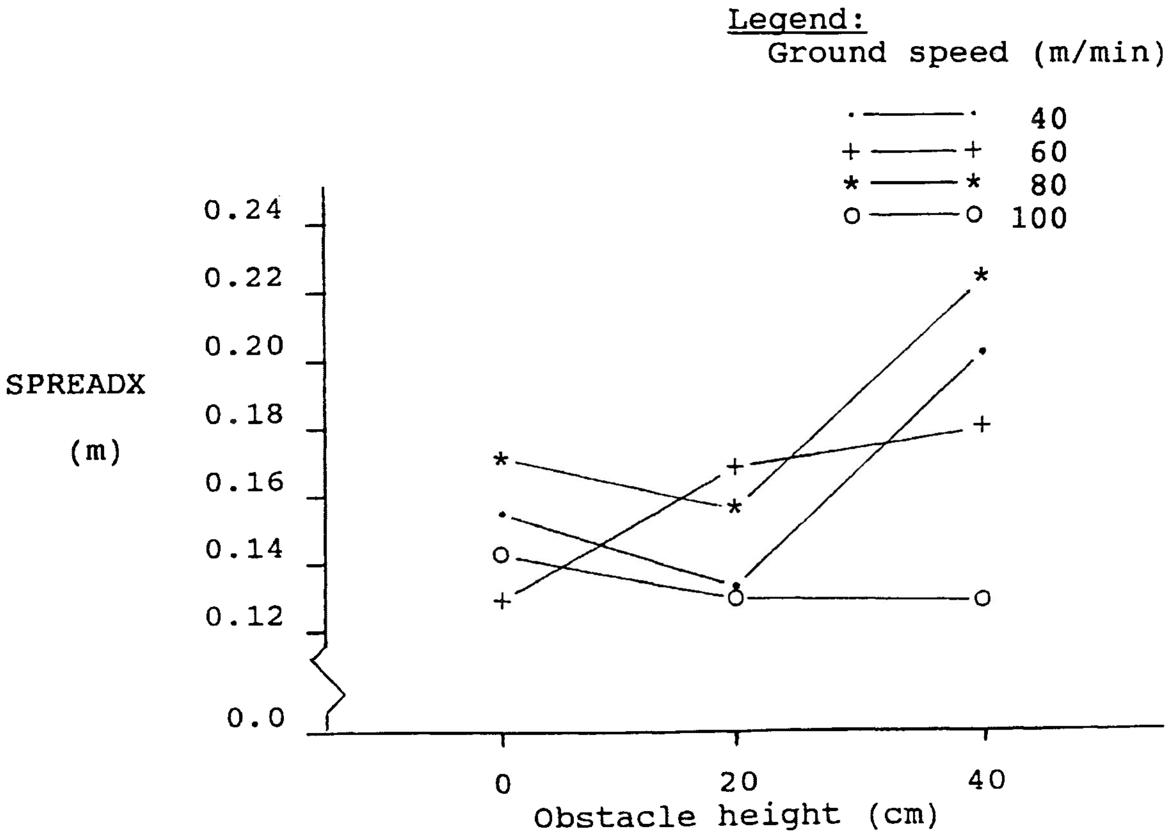


Figure 12. Increase in seed dispersal along the microsite x-axis as obstacle height increased.

A Tukey's MRT for the effect of speed showed no significant difference to DISTY between any of the speed treatments, even though the ANOVA indicated a speed effect. Tukey's MRT is a conservative test, therefore, it did not distinguish between the small differences deemed significant by the ANOVA. A graph of DISTY for the four speeds showed that as speed increased, the seed dropped further from the start of the microsite (Figure 13).

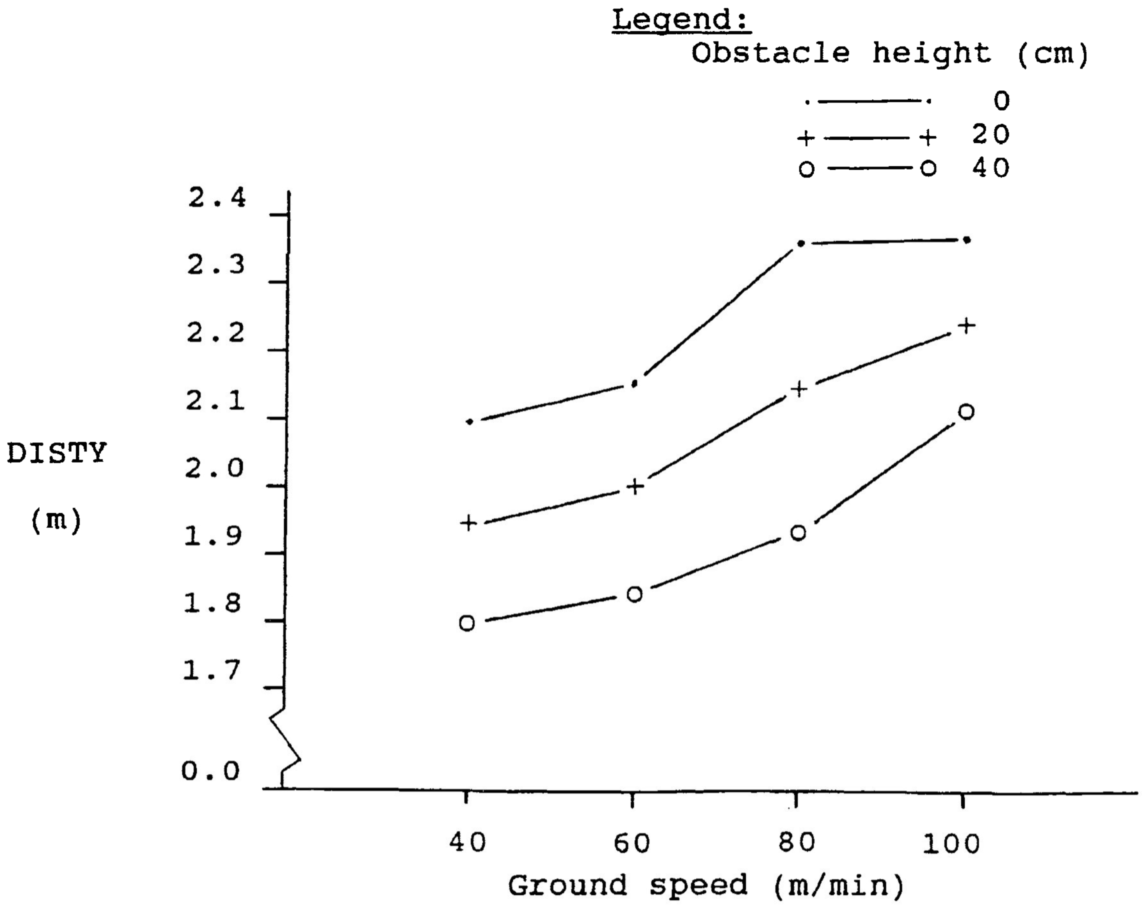


Figure 13. Increase in distance from the start of the microsite to the point of mean seed release as ground speed increased.

The multivariate analysis for the NSEEDS and SPREADY variables showed that obstacle height affected the number of seeds dropped per microsite, as well as how the seeds were spread on the longitudinal axis (y-axis) of the microsites. The number of seeds released over each microsite decreased as the obstacle height increased, as shown in Figure 14. The Bräcke seeder was calibrated to drop approximately 5 seeds per cycle, as indicated by the horizontal line in Figure 14. Similarly, the rate of decrease in the number of seeds released was substantially less for the 100 m/min ground speed.

The SPREADY values decreased as the obstacle height increased to 20 cm. As the obstacle height increased from 20 to 40 cm, the SPREADY values continued to decrease at speeds of 60 and 80 m/min, though they increased at speeds of 40 and 100 m/min (Figure 15). Figure 16 illustrates the effect of obstacle height on SPREADY and NSEEDS.

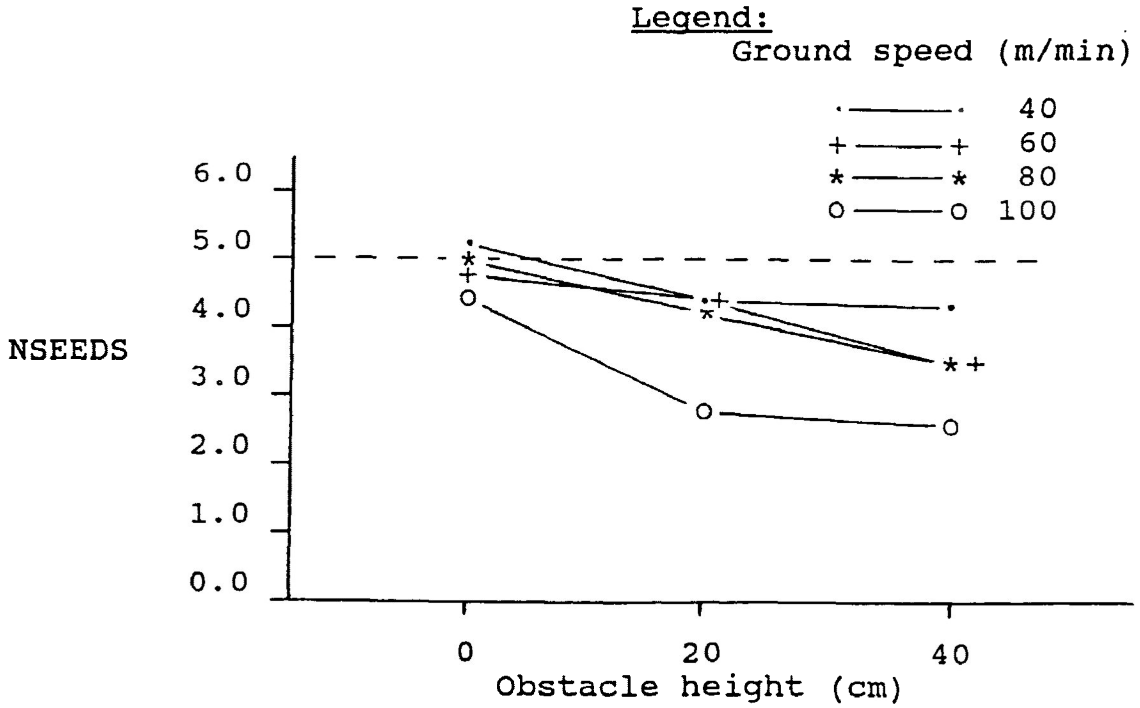


Figure 14. Decrease in the number of seeds released per microsite as obstacle height increased (horizontal line indicates calibration setting).

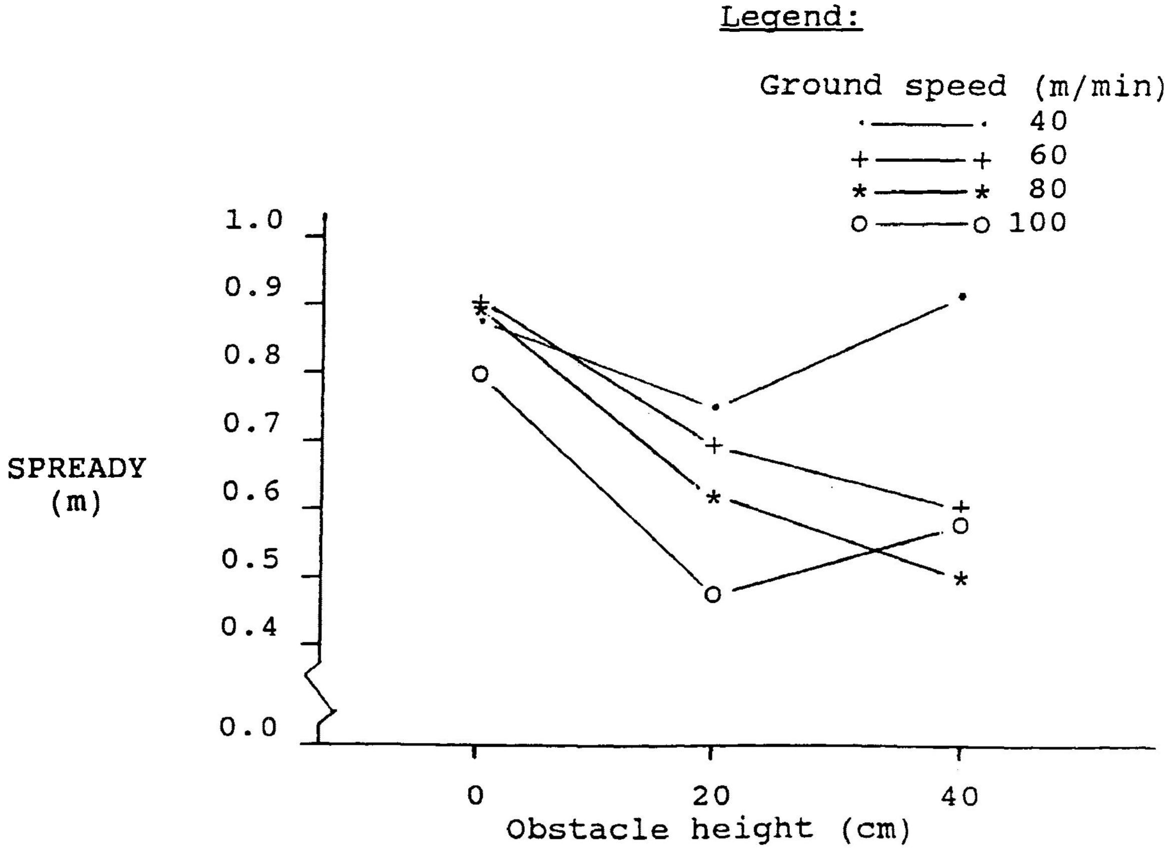


Figure 15. Length of seed release pattern along microsite y-axis as obstacle height increased.

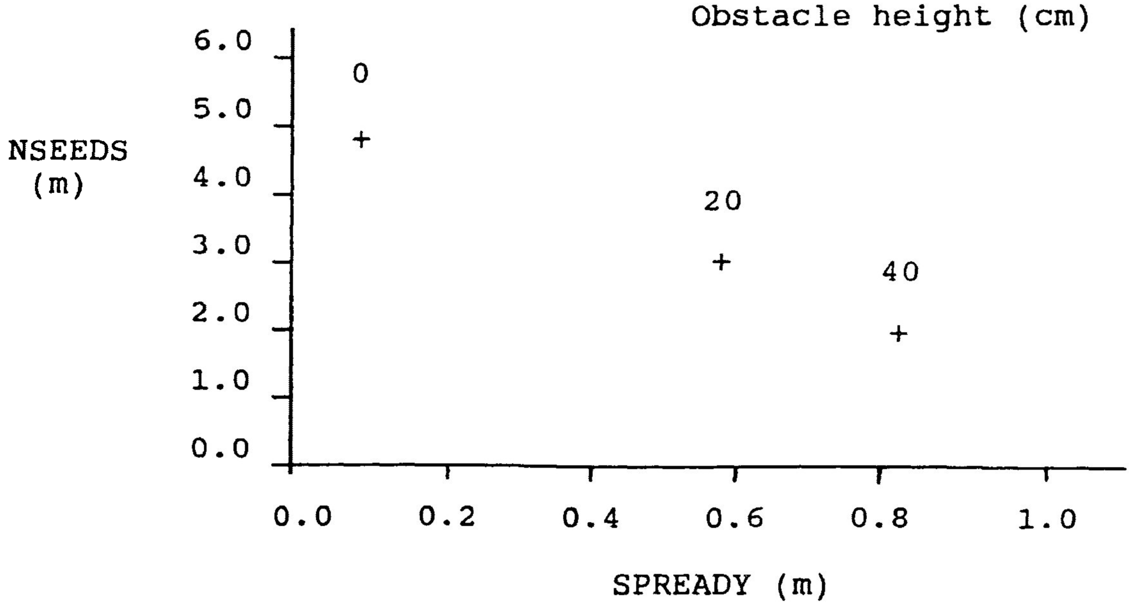


Figure 16. Changes to NSEEDS and SPREADY as obstacle height increased in the gravel pit trial.

The approximate percentage of the seed that landed on the optimum seeding location, as illustrated in Figure 1, are presented below. Results were obtained as the seeder was calibrated for use in the field trial.

Table 11. Approximate percentage of sown seed to be placed within the optimum area for seed placement as ground speed and obstacle height varied.

Ground speed (m/min)	Percent of seed sown in optimum area on the microsite Obstacle height (m) 0	20	40	Mean
40	36	29	17	27
60	32	25	14	24
80	31	23	10	21
100	27	19	9	18
Mean	32	24	13	23

The following figures were constructed from the significant data in the gravel pit trial. Figure 17 summarizes the changes that occurred to microsite shape and seed deposition as obstacle height increased. The hatched areas indicate the area of mean seed placement, as defined by DISTY, SPREADY and DISTX values for each treatment studied. Similarily, Figure 18 illustrates the effect of ground speed on microsite and seed-deposition attributes.

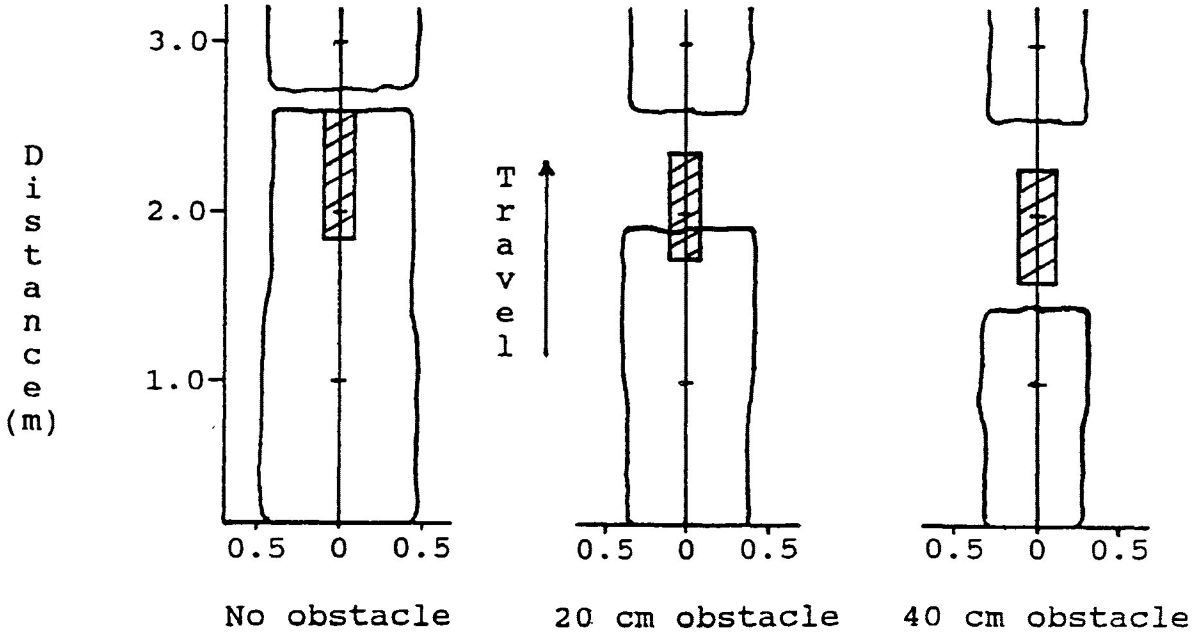


Figure 17. Summary of the effect of obstacle height on microsite shape and seed placement for the gravel pit trial (the hatched areas indicate seed placement).

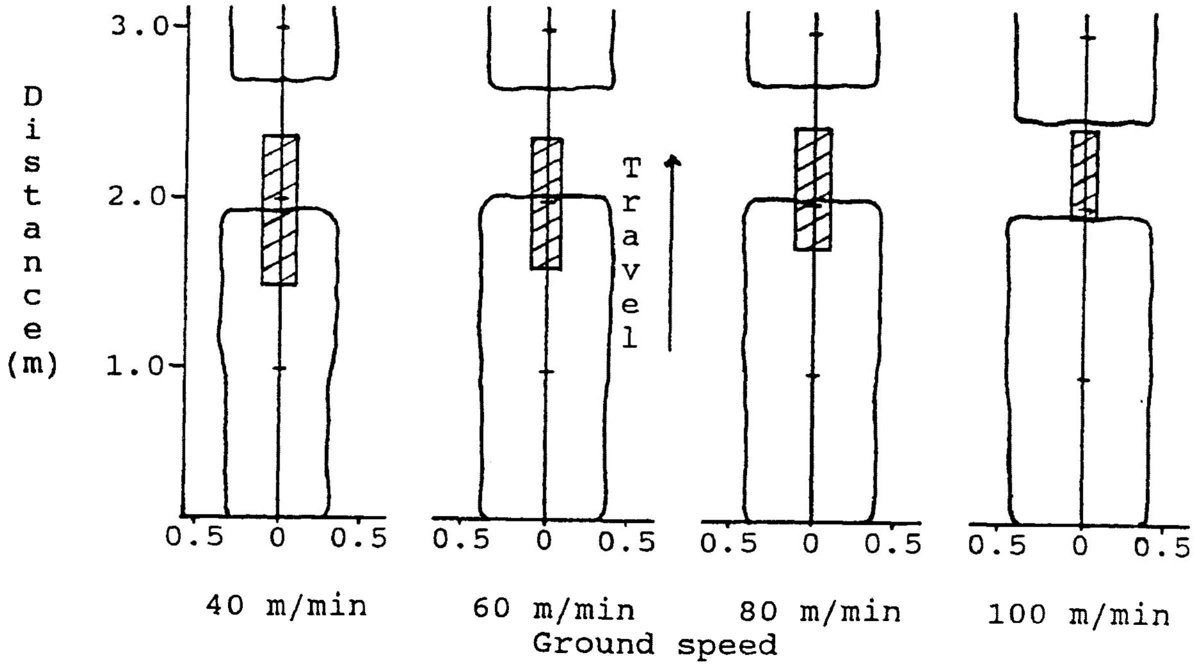


Figure 18. Summary of the effect of ground speed on microsite shape and seed placement for the gravel pit trial over the complete obstacle range (the hatched areas indicate seed placement).

FIELD TRIAL

The field trial was done to see if the trends seen in the gravel pit trial were paralleled under operational conditions. The obstacles present on the field-trial site (Tables 1 and 2) were not visibly clumped on any portion of the trial area and appeared to be equally represented in each of the plots. Obstacles thought to be more severe than the 40 cm obstacle height used in the gravel pit trial were few in number. The prime mover performed the trial at the speeds prescribed.

The factor analysis (using the maximum likelihood approach) of the response variables in the field trial produced the variable groups shown in Table 12. Factor analysis was investigated as a method to group the related variables for ANOVA and MANOVA. A total of six factors were identified, including the response variables WOVER and DISTY that were not grouped with other variables.

Table 12. Grouping of related response variables from the field trial, based upon factor analysis.

Factor 1	Factor 2	Factor 3	Factor 4
LOVER	NSEEDS	LDIG	WDIG
INTER	SPREADY	DISTX	
	SPREADX	INTER	

The Pearson's correlation analysis of the ten response variables is shown in Table 13. Each correlation coefficient in Table 13 was calculated using a large number of observations ($n = 72$). Therefore, most of the coefficients were statistically significant. However, examination of the correlation matrix and factor analysis lead to the decision that a coefficient greater than $r = 0.50$ was large enough to have practical importance (Chatfield and Collins, 1986). The variables NSEEDS and SPREADY were correlated ($r = 0.60$). The variable INTER was correlated ($r \geq 0.53$) to four other variables (LDIG, LOVER, DISTX and DISTY) though these four variables were not correlated to each other. The variables WDIG, WOVER and SPREADX were not correlated to any other variable.

Table 13. Pearson correlation results from the field trial (the critical value of r was 0.27 at $\alpha = 0.05$, based upon 72 observations).

Response variable	Variable number 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. NSEEDS	1									
2. SPREADY	.60	1								
3. SPREADX	.42	.42	1							
4. LOVER	.08	.03	.07	1						
5. INTER	-.30	-.25	-.16	-.59	1					
6. LDIG	.28	.21	-.01	-.17	-.53	1				
7. DISTX	-.10	-.14	.11	.06	.54	-.06	1			
8. DISTY	.29	.32	.36	.29	-.61	.35	-.14	1		
9. WDIG	.21	.16	-.05	-.10	-.02	.20	-.02	.21	1	
10. WOVER	.11	.08	.08	.29	-.21	.06	.16	.20	.39	1

The results of the correlation analysis suggested that two MANOVA and three ANOVA analyses be done. The variables correlated to INTER were analyzed in one MANOVA, however, insignificant results encouraged individual analyses between INTER and each of the other variables. Therefore, a total of five MANOVA and three ANOVA analyses were done. Appendix III presents the complete ANOVA and MANOVA tables. Table 14 summarizes the results of these analyses. The treatment effects were significant if the observed F-ratio was greater than the 0.05 tabular value.

Table 14. Summary of ANOVA on data from the field trial.

Variable	Source of variation	Probability of F > F-ratio
Multivariate of NSEEDS and SPREADY	Speed	0.163
Multivariate of INTER and LDIG	Speed	0.072
Multivariate of INTER and LOVER	Speed	0.206
Multivariate of INTER and DISTX	Speed	0.005**
Multivariate of INTER and DISTY	Speed	0.310
Univariate of WDIG	Speed	0.195
Univariate of WOVER	Speed	0.101
Univariate of SPREADX	Speed	0.958

Note: significance of the F statistic is indicated by one asterisk (*) at the 95 percent confidence interval and by two astericies (**) at the 99 percent confidence interval.

Only one of the analyses in Table 13 showed a significant effect. Speed affected the combination of inter-microsite distance (INTER) and the distance the seed dropped from the microsite y-axis (DISTX). As ground speed increased, INTER decreased as speed increased to 80 m/min; beyond 80 m/min INTER increased. A similar trend is seen in the DISTX values. Figure 19 illustrates the treatment means for INTER and DISTX, as influenced by speed. Figure 20 illustrates the multivariate response of INTER and DISTX to increasing ground speed.

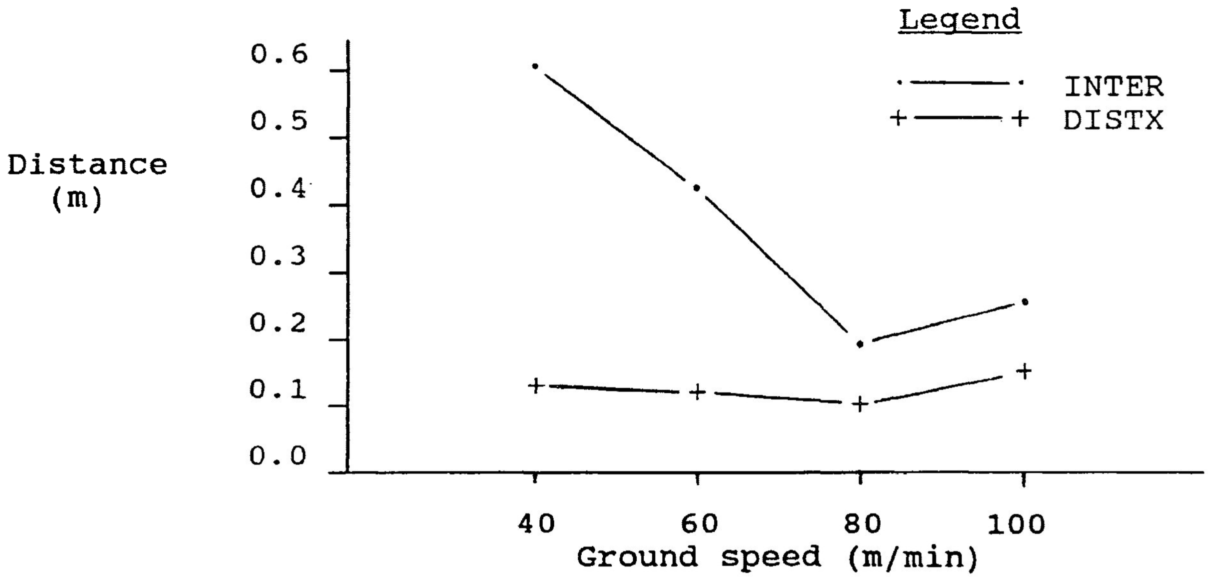


Figure 19. Treatment means for INTER and DISTX from the field trial.

The multivariate analysis of LDIG and INTER by ground speed produced an F-ratio of 0.072, slightly above the 0.05 level of significance. Inspection of the data revealed that several poorly formed microsites, created at the highest ground speed, exaggerated the INTER values while reducing the LDIG values. Figure 21 illustrates the effect over and summarizes the results over the ground speeds applied.

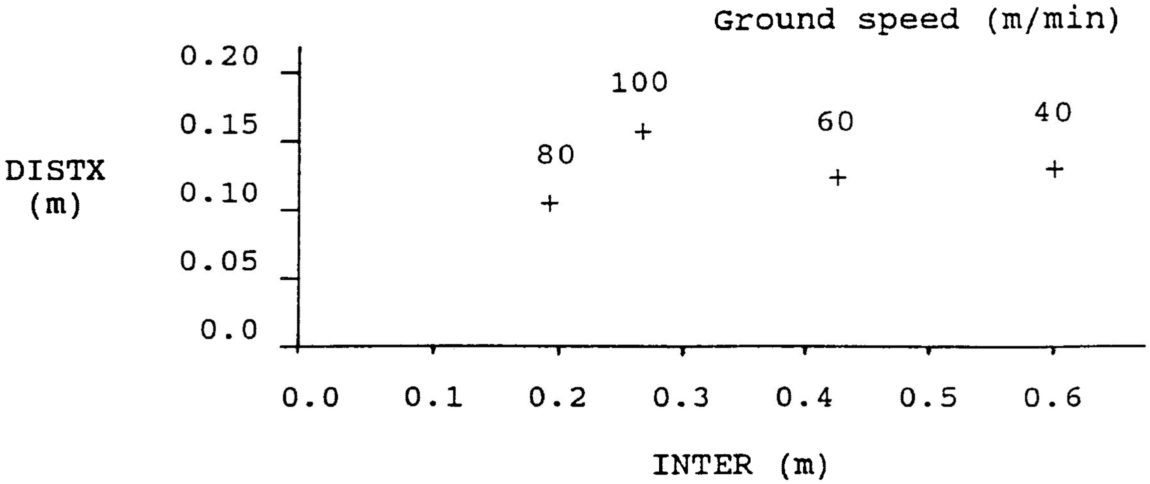


Figure 20. Changes to DISTX and INTER as the ground speed increased in the field trial.

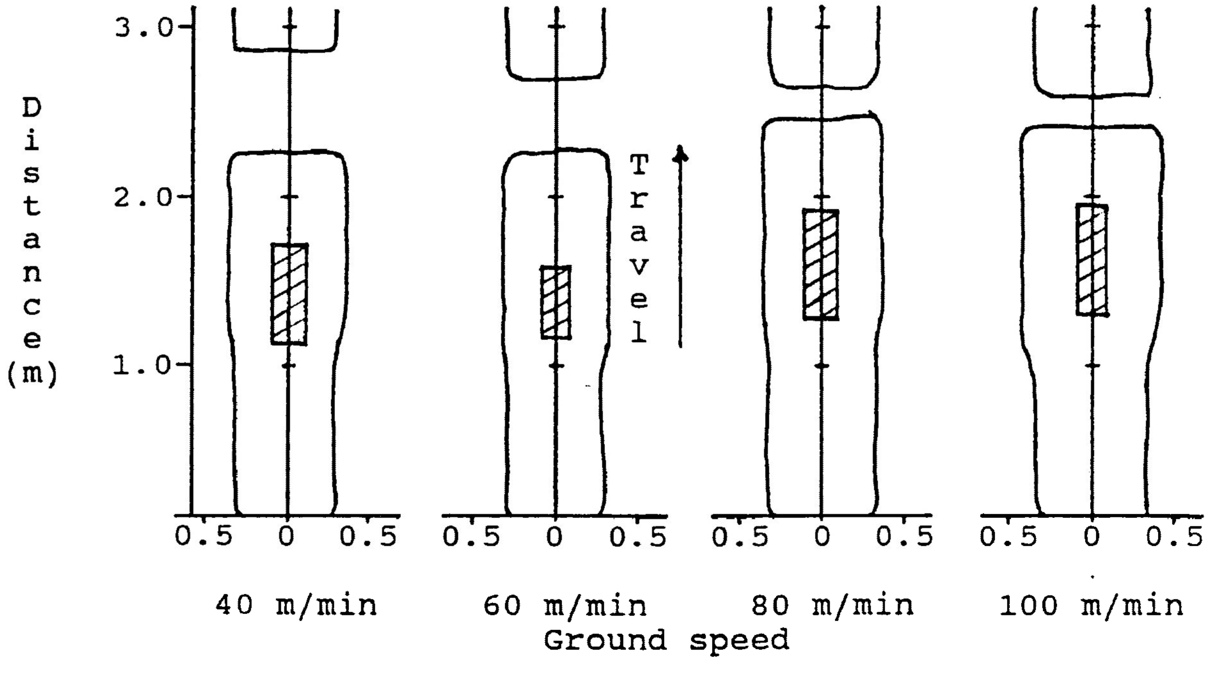


Figure 21. The effect of ground speed on the inter-microsite distance, length of the dig portion and lateral distance to mean seed placement from the field trial.

DISCUSSION

STATIONARY TRIAL

The use of the high-speed camera did not produce a satisfactory image of the actual seed fall from the Bräcke during the stationary trial. Dust and other contaminants either on the film or in the lens created many images that appeared to be seeds. However, Table 6 presented estimates, calculated using Equations (1) and (2), of the effect of speed and release height on seed displacement.

The actual seed-fall trajectories should resemble those predicted by physics. The seed displacement estimates (Table 6) serve to emphasize the importance that an initial horizontal speed (physicists refer to speed as velocity) has on the ideal trajectory path of a seed. Table 6 indicated that the linear distance a seed will (ideally) travel once released is directly proportional to increases in travel speed. However, Table 6 showed that the height at which the seed is released (as affected by obstacle height) has a lesser effect on seed displacement than does speed. Obstacle height increases the forward displacement by a factor equal to the square root of the relative change in release height. The above ideal relationship points to the importance of calibrating the Bräcke to release seed on a particular point in the microsite at a ground speed that is realistic for the site conditions.

The addition of an initial vertical velocity to the seed serves to reduce the displacement distance. The Bräcke air seeder uses a gush of air to assist seed from the delivery tube, thus providing the seed with an initial downward push. The initial downward velocity would, from Equation (3), result in a shorter horizontal trajectory since the seed would be in the air for a shorter period of time. The manufacturer of the Bräcke was contacted to quantify the velocity added to the seed fall by the air assistance. However, that information remains unknown.

The design of the air-assist mechanism may have a compensatory action to seed displacement as ground speed increases. The seeder and mattocks of the scarifier are linked mechanically to the rubber tire: the faster the scarifier travels, the faster the seeder cycles. With each seeder cycle, a piston evacuates a fixed-volume cylinder to produce the air stream that assists seed delivery. The faster the seeder cycles, the greater would be the velocity of the air stream, since the cylinder is evacuated more quickly. Therefore, the variable evacuation rate, linked to ground speed, may to some degree compensate for increased ground speed with a shorter time required for the seed to reach the ground.

GRAVEL PIT TRIAL

Microsite Attributes

The results of the gravel pit trial indicated obstacle height to be more influential on the physical attributes of the microsite than was the speed of the scarifier.

The correlation between the physical attributes LENGTH, WDIG, WOVER and INTER, as shown in Figure 8, was expected. The dimensions of the various portions of a Bräcke microsite are related to one another. The size of the overturn portion of the microsite is dependant upon the volume of material removed from the dig portion (from mattock penetration), therefore, the lengths and widths of the dig and overturn portions were expected to be related. Similarly, microsite length and inter-microsite distance are influenced directly by the gearing of the intermediate axle within the scarifier, the number of teeth on the mattock, and indirectly by the slippage of the rubber tire and the resistance encountered by the mattocks. Resistance to the mattocks includes the effects of soil texture and obstacles. The soil in the gravel pit was uniform in texture, density and compaction, while the obstacles were uniform in size and shape.

The no-obstacle treatment in the gravel pit provided a bench mark for the performance of the Bräcke. Microsite attributes as well as seed dispersal characteristics were well defined by the treatment combination of 40 m/min ground speed and no obstacles.

Microsite LENGTH and INTER were the two most closely related quality parameters to deteriorate as obstacle height increased. Figure 17 summarized the changes in microsite characteristics as related to obstacle height. The addition of a single 20 cm obstacle, had the significant effect of reducing a 2.65 m mean microsite length to 1.90 m, a reduction of 0.75 m. The 40 cm high obstacle reduced the mean length by 1.26 m relative to no obstacles. The decrease in microsite length coincided with an increase in the inter-microsite distance at almost a -1:1 ratio; microsite length decreased by 1.26 m while inter-microsite distance (unscarified ground between the microsites) increased by 1.09 m.

The deterioration of microsite attributes with increasing obstacle height is expected. The mattocks are driven by the rubber tire, and the effectiveness of the Bräcke at forming properly-shaped microsites depends upon the rubber tire maintaining contact with the ground (Seabrook and Bax, 1981). When the tire is in firm contact with the ground, the tire drives the mattock, producing long, well-formed microsites. Conversely, when the mattock teeth encounter immovable objects or the rubber tire is bounced from the ground, the mattocks will accelerate (spin) the rubber tire in the direction of travel in order to overcome the obstacle. The ability of the mattocks to unload excessive resistance via the gear train to the tire acts as a shock absorbing feature for the scarifier. This feature helps to prevent damage to the scarifier and prime mover. When the mattocks spin the tire, microsite length decreases as the mattock teeth pivot over the obstacle creating the resistance. The spinning of the rubber tire, combined with reduced ground contact by the tire as bouncing occurs, cause the microsite to be shorter than it would otherwise be. Similarly, as proportionately less time is spent digging a microsite, the unscarified inter-microsite distance increases.

The significance of a reduction in microsite length is that the gross and acceptably prepared area of the microsite is reduced: an important consideration for tree planting. A larger area of exposed soil absorbs more of the heat from the sun, allowing a seedling to establish itself more quickly prior to competition invading the microsite (McMinn, 1984). Similarly, a large microsite is also important to direct seeding efforts. A small seedbed also reduces the probability of a seed landing on prepared mineral soil. A reduction in microsite length due to the effect of obstacles may also mean that more microsites are created per hectare than prescribed. Spacing changes would affect seedling density, implying increased future cost to space or thin the regeneration appropriately.

Seabrook and Bax (1981) suggested several methods of achieving higher mineral soil exposure levels with the Bräcke scarifier. Suggestions centre around improving the contact the rubber tire has with the soil; minimizing tire spin and slip. Adding calcium-loading to the tires as well as changing the tires to a type with a more aggressive tread are two modifications that are easily done. J. A. Pera (pers. comm., 05 05 91) agreed, though he mentioned that his experience has shown the addition of the above modifications can have a negative effect on the life expectancy of the drive chains and intermediate axles of the Bräcke when scarifying difficult sites. The extra weight and reduced tire slippage increases the shock-loading on the drive components of the Bräcke, leading to early fatigue and/or failure.

The results indicated that, on average, a 1.90 m long microsite was produced when the obstacle was 20 cm high. The speed effect was insignificant. A microsite approximately 2 m long is acceptable for direct seeding with the Bräcke: the profile is gently sloped to minimize seed washing (Pye, 1989) and the potential amount of exposed mineral soil is acceptable. As obstacle height rose to 40 cm, the microsite length dropped approximately 27 percent, reducing the quality of the microsite with respect to seeding. The angle of the midslope section of the microsite would increase while the amount of mineral soil exposed would decrease.

The action of microsite formation makes an interaction between obstacle height and ground speed seem possible. Though the results of the gravel pit trial showed the deterioration of microsite attributes were not significantly related to ground speed nor to an interaction in the gravel pit trial, an argument may be made that speed and obstacles together do result in lower microsite quality. If, for example, a site with 40 cm obstacles was scarified at a ground speed of 40 m/min, approximately 15-16 microsites would be produced by each machine frame per minute, or approximately four seconds per microsite. Traversing the same site at 80 m/min, approximately twice the number of microsites were produced in one minute, and the time taken to create a microsite decreases to two seconds each. At twice the speed, the probability of producing a properly-formed microsite should decrease. The machine would bounce more violently as the force of impact with obstacles would be greater. As well, at high speed, more distance would be covered while the scarifier was under the influence of an obstacle. Summerby (1987) found that as ground speed decreased, the proportion of high quality microsites increased over the range of obstacles present. If the above interaction does occur, and its existence does seem plausible, the practical way to minimize the problem would be to decrease ground speed.

Microsite width, including width of the dig and overturn portions, was reduced as obstacle height increased. The effect of bouncing reduced the contact time of the mattocks with the soil, preventing the full influence of the mattocks to be expressed in microsite width. A reduction in width directly reduces the prepared area available for seeding.

Seed Deposition Rate

Almost all of the seed deposited in the gravel pit was accounted for. The area surrounding each microsite was scanned to ensure that seed was not deposited out of the microsite. The 93.5 percent retrieval rate for the labelled seed used at the gravel pit was consistent with other studies. The seed was recovered within five rain-less days of being placed. Much of the non-recovered seed (still included in the results) was seed that fell into cracks in the wooden railway ties. The scintillometer indicated seed was contained in the ties, and the seed was often visible in the cracks. The position and intensity readings of those seeds were recorded.

The ground speed and obstacle height affected the number of seeds released from the Bräcke. The seeder was calibrated to drop 5 seeds per cycle at 40 m/min. Speed, though not a significant effect at the 5 percent confidence level, was significant at a slightly lower level of confidence, 7 percent. Fewer seeds were dropped as speed increased (refer to Figure 14). Obstacle height significantly affected the number of seeds released from the seeder. Approximate net reductions due to the treatment effects amounted to 1.5 seeds per patch at the highest obstacle level relative to the base levels.

An average reduction of 1.5 seeds per microsite, projected over one hectare typically containing 2500 microsites, is an important consideration. The Bräcke normally seeds 6-8 seeds per microsite. The reduction in seed release resulted from fewer seeds entering the metering device at each cycle of the seeder. Two hypotheses may be put forward. The actuation time of the seeding device is controlled directly by the speed of rotation of the rubber tire, or ground speed. Therefore, the time that the metering device has to reload at each seeding cycle is dependant upon ground speed. The seeding cycle at the manufacturer-recommended ground speed of 60 m/min is approximately two seconds. The metering device is therefore reloading within the seed hopper for no more than one second at this ground speed (e.g. approximately one second to reload plus one second to release the metered seed). An increase in ground speed decreases the time available for seeds to settle within the metering device, possibly resulting in the cycle being completed without returning a full load of metered seed. Conversely, slowing the scarifier allows more time for the seeder to properly reload, contributing to a more consistent seed drop.

The introduction of obstacles had the effect of violently shaking the seeding device as it worked. Jack pine seed was held loosely within the seed hopper, and was therefore tossed about as the scarifier bounced. The bouncing of the scarifier, occurring at the same time that the seed metering device was being filled, may have prevented available seed from staying within the metering device. Speeds of up to and including the fastest rate tested in the trial, 100 m/min, permit the seeding rate to be maintained if no obstacles are present: a very rare situation. Encountering an obstacle height of 20 cm, a ground speed of 80 m/min may be used without incurring severe reductions in seedfall. Obstacle heights of 40 cm, typically seen in Boreal forest cutovers, demand that a ground speed of no more than 40 m/min be used at the calibration level used in this study (refer to Figure 14). Otherwise, substantially less seed may be released due to the violent shaking of the seeding device. The reduction in ground speed to 40 m/min, necessary to maintain the prescribed seeding rate, is consistent with the creation of higher-quality microsites.

The quantity of seed released at each cycle is adjustable by enlarging the detents on the metering shaft. Though planned variations in seeding rates were not a part of this study, it can be noted that corrective adjustments to the seeding rate could be made. Knowing the effect of speed and obstacles on seed metering, an increase in the seeding rate from 5 seeds per cycle to 8-10 seeds per cycle, as calibrated under obstacle-free conditions, may perhaps provide 6-8 seeds per microsite under rougher conditions. Consistency of delivery would be questionable. However, this adjustment may permit the Bräcke to seed a prescribed rate while travelling at the higher manufacturer recommended ground speed of 60 m/min.

Seed Placement

The Bräcke seeder is typically calibrated at very slow speeds while on obstacle-free ground: a potential hazard exists to the person calibrating the seeder from flying debris. The seeder used in this study was calibrated to drop the seed on the midpoint of the microsite at a ground speed of approximately 40 m/min, however, Figure 17 illustrates that this was not the case. Care was taken to calibrate the seeder, yet the mean seed placement occurred upon the overturn portion for the no-obstacle treatment. The results showed that, including the effect of a calibration error, approximately 23 percent of the seeds were deposited within the desired target zone of the treatments applied. The gradient visible in Table 11 illustrated the effect of the treatments on the ammount of seed to reach the optimal placement position. The majority of those seed that were considered to be placed properly occurred within the no-obstacle and 20 cm high obstacle treatments. Few seeds sown at the 40 cm high obstacle were considered to be sown properly: most seeds were beyond the microsite. Ground speed produced similar placements. Few were found to be misplaced to either side of the microsites.

The calibration error shown in Figure 17 serves to highlight the importance of ensuring that the seed is being deposited where it is intended. Seed placement on poorly-formed microsites (i.e. formed under the high obstacle treatment) was beyond the prepared ground. The setting of the seeder cam remained the same for the duration of the trial, illustrating the result of improper calibration.

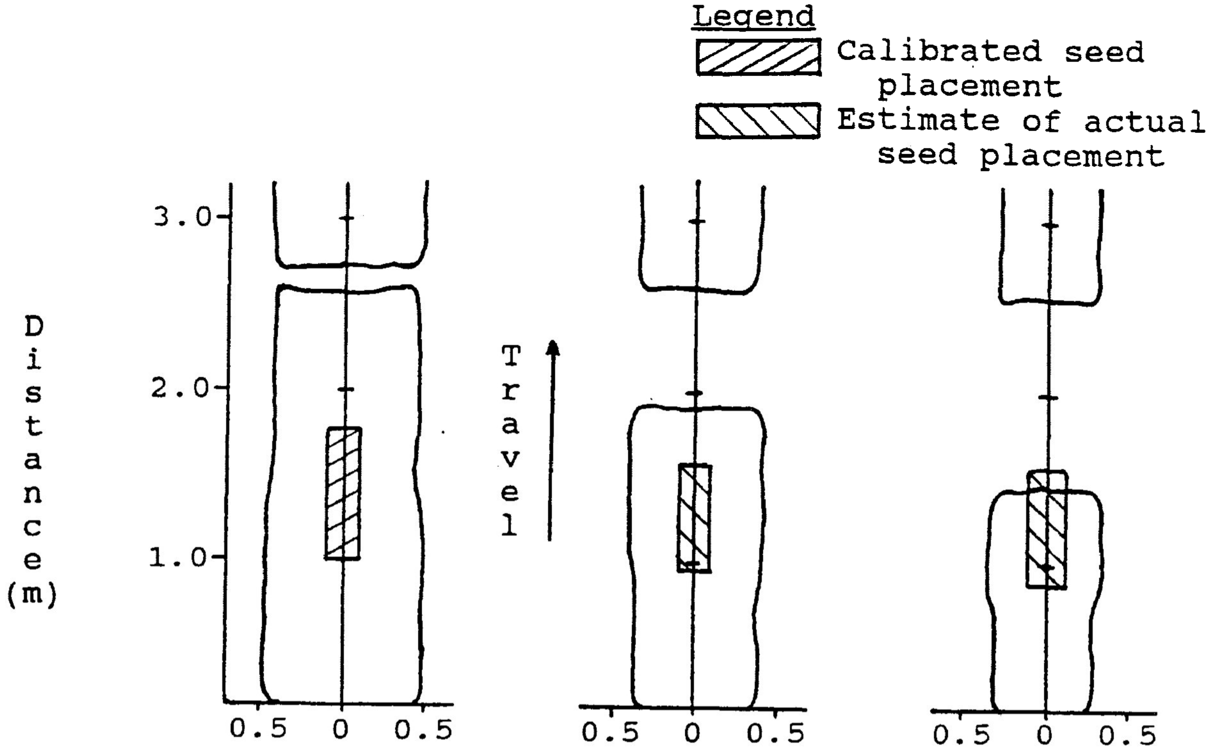
A desirable target area may be identified on the microsite. An area 30 cm wide by 60 cm long, cantered on the midpoint of the midslope of a microsite. The area is particularly desirable for seed placement as it offers a variety of moisture conditions that should enhance germination. If the soil is too dry on the overturn portion of the target zone, moisture may be available in the portion of the zone extending into the dig portion (Van Damme and Bax, 1991). The midslope area of the microsite also affords the germinant some shade (Clark, 1984) while providing sufficient room for the seedling to grow before competition invades the microsite (McMinn, 1984).

The mean value of DISTX increased significantly with increasing obstacle height. An increase in the lateral distance to the mean point of the seed placement was expected. The seeder was shaken violently as the Bräcke travelled over or dislodged obstacles, skewing the seed-drop trajectory. The 40 cm obstacle produced the greatest displacement, resulting in the point of mean seed placement being 13.1 cm to either side of the microsite centerline. This value is within the 15 cm target zone extending to either side of the microsite centerline. At the same obstacle height, WDIG and WOVER values showed 33.5 cm and 37.7 cm of mineral soil, respectively, was available to either side of the microsite centerline: a substantial area yet available for seed placement (refer to Figure 17).

The variable DISTY, the location of mean seed release along the longitudinal axis of the microsite, decreased significantly as obstacle height increased. The point of seed release from the Bräcke was dependant upon the position of the mattock wheels at the time of microsite formation. The resulting seed placement was also dependent upon the release height above the soil (due to obstacles) and the forward speed at which the seed was moving when released (ground speed). The increase in obstacle height (severity) contributed to more slipping of the rubber tire, meaning the mattocks arrived at the position of seed release sooner: seed release occurred closer to the beginning of the microsite.

The above relationship between increasing obstacle height and decreasing DISTY values is expected, yet, the rate of decrease in DISTY values was less than the rate of decrease in microsite length. The results from the no-obstacle treatment showed seed was, on average, deposited in the prepared microsite 43 cm back from the end of the overturn. The highest obstacle affected DISTY, with seed deposited 53 cm beyond the microsite overturn on average.

A mathematical correction to the DISTY values can be made for the improper calibration in the timing of the seed release seen in Figure 17. The DISTY values may be adjusted to the optimal zone on the midslope of the microsite, under no-obstacle conditions (as the scarifier is calibrated in practice) (Figure 22). The adjustments were done using the proportional relationships between LENGTH and DISTY values shown in Figure 17. The appearance of the seed release pattern under no obstacle conditions appears correct. However, it is seen that the 20 and 40 cm high obstacles still caused the DISTY values to lie within the undesirable overturn portion of the microsite or partially out of the microsite. The importance of this estimate is that the Bräcke may have been historically maladjusted, underestimating the effect of obstacles. This theory may provide a partial explanation for the varying results seen in operational Bräcke seedings.

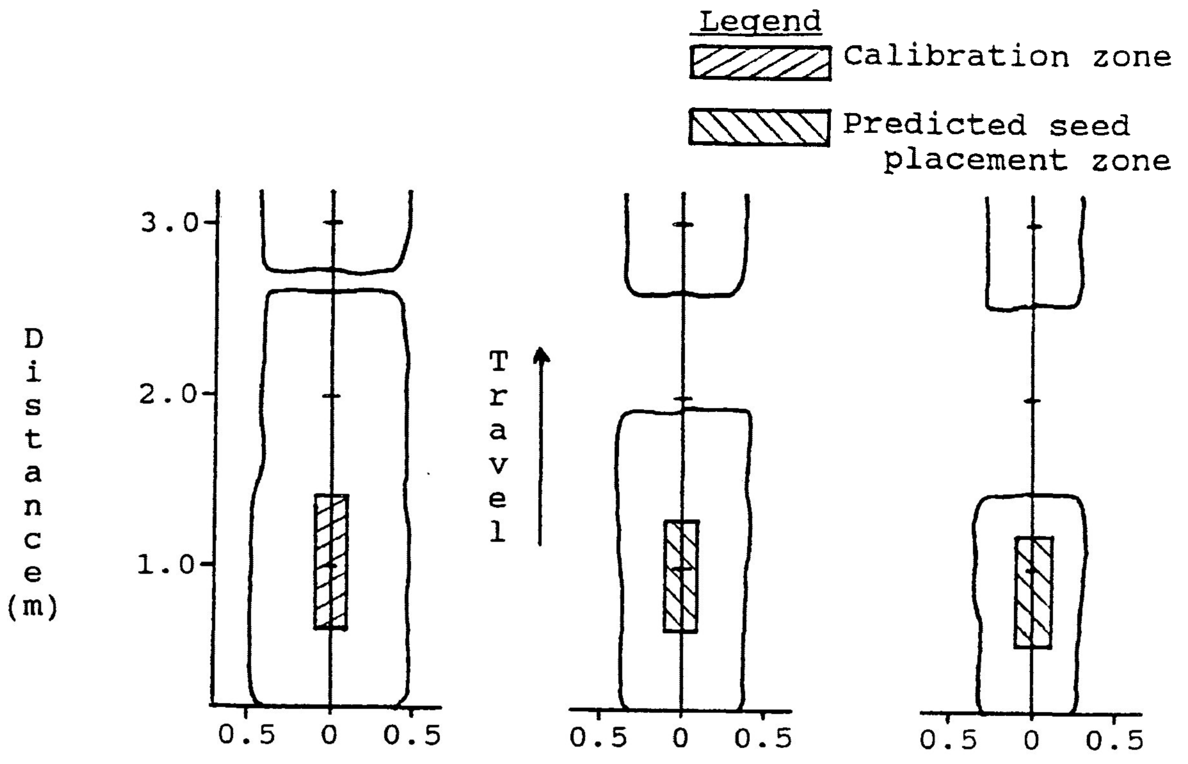


No obstacle 20 cm obstacle 40 cm obstacle

Figure 22. Estimate of the effect of obstacle height on seed placement when the seed-release timing is calibrated under obstacle-free conditions.

The Bräcke is often calibrated while seeding long microsites on obstacle-free ground in order to ensure the safety of the person gathering the seed at the point of release from the seeder. Once the scarifier is placed in the cutover, the effect of obstacles shortened the acceptable area of the microsites, causing the seed to be placed on the overturn or beyond the microsite, as was the case here. The requirement of jack pine to have a mineral soil seedbed is therefore not met if seed is deposited beyond the microsite. The chances of successful germination of jack pine on the overturn portion are reduced (Clark, 1984).

Figure 23, below, illustrates a methodology to aid in the calibration of the Bräcke seeder. The methodology should compensate for the influence of obstacles. Calibration of the scarifier/seeder would take place on obstacle-free ground for personnel-safety reasons. The seeder is calibrated to drop seed earlier than desired, approximately 1.0 m along a typical 2.6 m microsite. The results indicated average microsite length to be 2.65 m on obstacle-free ground. Results of the gravel pit trial indicated that as the obstacle height increased, the microsite became shorter, however, the point of mean seed release did not shorten at the same rate. Projecting the rate of decrease in microsite length against the decrease in DISTY values with 40 cm tall obstacles, the seed would be deposited approximately 0.9 m from the beginning of a 1.4 m long microsite. The end result, as estimated in Figure 23, is that the seed will land within the target area on the midslope portion of the microsite with obstacles present.



No obstacle 20 cm obstacle 40 cm obstacle

The seeder/scarifier is calibrated to place seed in the area indicated under no-obstacle conditions, resulting in seed placement as indicated as obstacle height increases.

Figure 23. A technique of seed-placement calibration to compensate for the effect of obstacles to the placement of seed.

The seed metering device is manufactured specifically for jack pine seed, so perhaps a standard timing-cam calibration could be developed to minimize the need to calibrate under field conditions. In the event field calibration is needed, several alternatives to the technique described above are available. Calibration could be performed with highly-visible seed in the cutover at 40 m/min. The seed could be more easily recovered without endangering anyone and the exact location of the seed would be known without any guesswork. If many scarifiers needed to be calibrated (e.g. government-owned or contracted units), the use of labelled seed could be justified to fine-tune the seed drop upon the microsite. Seeder calibration with consideration to the effect of obstacle height may improve the success rate of Bräcke seeding projects. Accurate seed placement on gently-sloped microsites (created by the 15-tooth intermediate axle gearing) should increase the probability of seed germination and survival.

As site conditions deteriorate, seed placement results may be expected to become more variable. All of the obstacles used in the trial were placed perpendicular to the direction of travel. The intention was to influence the Bräcke in the vertical and horizontal directions while minimizing the side to side pitch of the machine. Seed placement would be expected to become more widespread as sideways accelerations become more pronounced. Random distribution of obstacles would increase the side to side pitch as the machine slips and rolls over obstacles. It is not uncommon to see a machine frame slide sideways as, for example, it is pulled over a wet log. DISTX and SPREADX values in particular could be expected to increase. The easiest way to minimize the lateral accelerations and the possible affect on seed placement is to reduce the ground speed.

FIELD TRIAL

Results from the field trial were, as expected, more variable than the gravel pit results. The field trial was done as close to operational conditions as possible. The purpose of the field trial, at one-third the size of the gravel pit trial, was to follow trends observed in the gravel pit.

The only significant speed effect was to the correlated variables INTER and DISTX. Looking at the changes to INTER and DISTX as speed increased (see Figure 19), the increase in these values at 100 m/min was due to an observed deterioration in microsite shape. Increased bouncing of the scarifier caused both the inter-microsite distances to increase and the lateral seed spread to increase.

The decrease in INTER and DISTX values seen from 40 to 80 m/min may be due to the braking effect of the mattock wheel on the rubber tire at the instant when microsite formation begins. As speed increases in cutover operation, the scarifier would tend to bounce more as obstacles are encountered. When bouncing occurs to the rubber tire, the result is that the mattock will accelerate the tire as the mattock seeks the path of least resistance. As the mattock causes the rubber tire to spin, the mattock pivots on the teeth engaged with the soil. The result would be a shorter microsite length and inter-microsite distance as the next set of mattock teeth begin to dig another microsite sooner.

Similarly, DISTX (and DISTY, though DISTY values were not significantly affected) values would be expected to decrease as the seed release is concentrated due to the pivoting action of the mattock teeth in the soil: seed release would be advanced.

The field conditions present on the study location could be classed as very easy for Bräcke scarification: low stumps, little slash and no rock. These conditions, usually found on jack pine sand flats, challenged neither the prime mover nor the Bräcke when compared to sites more typical of current harvest areas in the Boreal forest. There was no significant speed effect on microsite length over the speeds studied. However, notes were made on the tally sheets to comment on the appearance of the microsites produced. Generally, those produced at the two slower speeds were of better and more consistent form that those produced at the higher speeds. The slash, stumps and ground irregularities presented a variety of obstacles in the field trial, though the obstacles appeared to be uniformly distributed in the trial area. Time constraints prior to running the trial did not allow the distribution of obstacles to be surveyed in detail.

Another field study may be of interest in order to confirm several of the relationships seen in the gravel pit portion of this study. The effect of obstacles on microsite length, the number of seed dropped and upon the seed distribution pattern would be of interest. The trial should be conducted on a variety of sites with distinct differences in obstacle severity. While the field trial was of limited size in this study, any future study should expand on the experiment to produce more accurate estimates of the significant effects in various cutovers. Similarly, as obstacle variation increases, the sample size should increase. The field trial analysis was based upon 18 microsites per speed class, possibly not a sufficient number for trends to be expressed.

SUMMARY

Considering all of the variables that were significantly affected by the treatments, a recommended ground speed for Bräcke seeding should be 40 m/min. Of the speeds studied here, microsite quality, seeding-device performance and seed-release patterns decreased as obstacle height increased. The only practical way to minimize the effect of obstacles and ensure that the basic prerequisite to seeding, a quality microsite, is created is to reduce the ground speed of the scarifier.

A ground speed of 40 m/min is slow by operational standards, particularly if a contractor is being paid on an area basis. The contractor always places emphasis on production in terms of area treated per hour. Perhaps to encourage the contractor to maintain a consistent 40 m/min speed, the method of payment for seeding/scarification should change. Payment on a machine-hour basis would have the desired effect of slowing the operation, encouraging more complete coverage of an area, ensuring proper microsite formation and more accurate seed placement.

A comparison of the cost of direct seeding at 40 m/min compared to the current practice of 60 m/min produces some interesting results. A 3-row Bräcke scarifier/seeder and prime mover, rented for $140 per hour, and operated at a 40 m/min ground speed (1.83 m inter-row spacing, operating at 85 percent efficiency) would treat approximately 1.12 ha per hour. That equals approximately $125 per hectare, excluding of the cost of seed. At 40 m/min, a 1.83 m inter-row spacing may be used, as the slower speed should minimize the effect of obstacles, allowing the seed to reach the desired target zone. The 1.83 m spacing is more consistent with the spacing used in planting pulpwood stands of jack pine.

The current practice of seeding at 1 m inter-row spacing at a ground speed of 60 m/min (85 percent efficiency) yields a production rate of approximately 0.92 ha per hour. A rental rate of $140 per hour produces a treatment cost of $152 per hectare. Much of the production difference is due to the pass width used to ensure that sufficient quantities of seed are placed in the microsites at 60 m/min. At a 40 m/min ground speed, the wider inter-row spacing would require approximately one-half of the seed used (and placed less accurately) at 60 m/min.

Other benefits to operating at 40 m/min include less shock to the operator of the prime mover as WBV levels would be reduced (Golsse, 1989). The proportion of time needed to repair the prime mover should decrease (Edlund, n.d.). Prime mover manufacturers, knowing a desired ground speed, could engineer their products to operate efficiently at that speed.

CONCLUSIONS

The results of the gravel pit trial indicated that obstacle height had the greater influence on the quality of the microsite produced than the ground speed of the scarification unit. The primary attribute affected was microsite length: length decreased significantly with increasing obstacle height. The practical way to obtain proper microsite formation is to slow the scarifier to minimize the influence of obstacles.

The number of seed released from the scarifier was also significantly reduced with increasing obstacle height and ground speed. Obstacles had the effect of reducing the mean number of seeds released per cycle, as the scarifier shook violently. Approximately 1.5 fewer seeds were released per microsite when seeding over 40 cm high, when compared to no obstacles. Similarly, speed reduced the number of seeds released per cycle. Slowing the Bräcke allows the metering device more time to fully reload. Therefore, the Bräcke seeder may be overcalibrated by 1 to 2 seeds per microsite if the seeder is calibrated without the influence of obstacles (e.g. in a workshop or on a roadway).

Lateral and longitudinal seed placement within a microsite was significantly affected by obstacle height. In concert with the decrease in microsite length as obstacle height increased, the distance to the point of mean seed placement along the microsite also decreased. However, the rate of decrease of microsite length was greater than that of the point of mean seed placement. The implication was that seed was being deposited either on the undesirable microsite overturn, or completely beyond the microsite when influenced by obstacles.

A technique for calibrating the Bräcke was described that considered the reduction in length and seed placement figures. It involved calibrating the seeder to release seed prematurely when calibrated on obstacle-free ground. As obstacles are encountered in the cutover, seed placement should occur within the preferred target area in concert with a reduction of microsite length. The preferred target area is cantered on the midslope of the microsite.

The operational field trial indicated a speed effect that increased lateral seed spread as speed increased. Correlated to lateral seed spread, the inter-microsite distance increased with increasing speed, possibly due to the scarifier having poor contact with the ground as obstacles influenced the scarifier at the higher speeds used in the trial.

It is recommended that the Bräcke scarifier be operated at a ground speed of 40 m/min when seeding jack pine. Microsite quality, seeding-device performance and seed-release patterns deteriorate with increasing obstacle height. Site preparation done at 40 m/min will minimize the effect of obstacles. Microsites formed at a slow speed should be of higher quality than those formed at higher ground speeds.

A comparison of seeding at 40 m/min with predictable seed placement versus the present practice of seeding at 60 m/min indicated cost savings could result. Improved microsite quality and seed placement at 40 m/min allows wider inter-row spacing, reducing the cost and the amount of seed required under a 60 m/min prescription done at 1 m inter-row spacing.

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APPENDICES

APPENDIX I

SPECIFICATIONS OF THE FRANKLIN 595 'SITE PREP' SKIDDER
(from St-Amour, 1989)

ENGINE:	
Manufacturer	Cummins Engine Co.
Model	LT-10-C/6
Cylinders	6
Maximum power (kW)	187 @ 2100 rpm
Net flywheel power (kW)	159 @ 2100 rpm
Maximum torque (N.m)	1022 @ 1300 rpm
DRIVE TRAIN:	
Transmission	Spicer SST-10
Forward speeds	5 x 2
Reverse	Single-lever, air shift
Transfer case	Franklin T-108
Axles	Franklin T-301
Differentials	No-Spin brand
Service brake	Enclosed, wet, multiple disc
Parking brake	33 cm diameter caliper
Clutch	36 cm diameter, double-disc
HYDRAULIC SYSTEM:	
Two fixed-displacement pumps, engine driven	
132 L/min. @ 2100 rpm	powers steering cylinders
132 L/min. @ 2100 rpm	powers winch and blade
Reservoir capacity	160 l
Filter system	Canister, 10-micron element
ELECTRICAL SYSTEM:	
Rating	65 amps @ 24 volts
WINCH:	
Manufacturer	Franklin
Model	H-42
Maximum linepull (kg)	16 330
Maximum linespeed (m/min)	34 (bare drum)
Drum capacity	50 m of 22 mm diameter wire rope
FRAME:	
Articulation angle	45°
Rear oscillation angle	15°

OPERATING SPEEDS:

The speeds were determined at governed rpm with transfer case in low range.

30.5 x 32 tires (as tested)			35.5 x 32 tires		
gear	km/h	m/min	gear	km/h	m/min
1st	1.38	23.0	1st	1.47	24.5
2nd	1.79	29.8	2nd	1.91	31.8
3rd	2.29	38.2	3rd	2.42	40.3
4th	2.94	49.0	4th	3.12	52.0
5th	3.83	63.8	5th	4.06	67.7
6th	4.94	82.3	6th	5.23	87.2
7th	6.39	106.5	7th	6.77	112.8
8th	8.25	137.5	8th	8.74	145.7
9th	10.81	180.2	9th	11.46	191.0
10th	13.93	232.2	10th	14.79	246.5

APPENDIX II

SPECIFICATIONS OF THE BRÄCKE 3-ROW HYDRAULIC SCARIFIER

(Source: Promotional brochure)

PRIME MOVER:	
Power requirement	104 - 134 kW wheeled skidder
Drawbar pull requirement	2.5 t
HYDRAULIC SYSTEM:	
Power source	Pressure/return hose from the prime mover
Pressure requirements	85 BAR
Cylinders	6 - lift cylinders 2 - spacing cylinders
GENERAL DATA:	
Weight	4 900 kg
Height	1.500 m
Length	6.075 m
Min. 3-row spacing width	1.025 m
Max. 3-row spacing width	2.080 m
Seeding device	Pneumatically assisted, cam activated and rear mounted.

APPENDIX III

ANALYSIS OF VARIANCE TABLES FOR UNIVARIATE AND MULTIVARIATE ANAYSES

Significance of the F statistic is indicated by one asterisk (*) at the 95 percent confidence interval and by two astericies (**) at the 99 percent confidence interval.

GRAVEL PIT TRIAL

Table A3.1. MANOVA results for the variables LENGTH, WDIG, WOVER and INTER (Gravel pit trial).

Source of variation	Test name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Speed	Wilk's	0.10	1.56	12	13.52	0.22
Obstacle	Wilk's	0.01	28.33	8	26.0	0.00^{**}
Spd x Obst	Wilk's	0.17	1.29	24	46.56	0.22

Table A3.2. The MANOVA results for the variables NSEEDS and SPREADY (Gravel pit trial).

Source of variation	Test name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Speed	Wilk's	0.23	2.55	6	14.0	0.07
Obstacle	Wilk's	0.27	6.96	4	30.0	0.00^{**}
Spd x Obst	Wilk's	0.52	0.96	12	30.0	0.51

Table A3.3. ANOVA table for the variable DISTX (Gravel pit trial).

Source of variation	Sum of Squares	DF	Mean Squares	F	Sig. of F
Speed	0.02	3	0.01	1.05	0.42
Replicate	0.06	8	0.007		
Obstacle	0.14	2	0.07	25.51	0.00^{**}
Spd x Obst	0.03	6	0.00	1.78	0.17
Rep x Obst	0.04	16	0.003		
Total	0.29	35			

Table A3.4. ANOVA table for the variable DISTY (Gravel pit trial).

Source of variation	Sum of Squares	DF	Mean Squares	F	Sig. of F
Speed	2.92	3	0.97	18.66	0.001^{**}
Replicate	0.42	8	0.052		
Obstacle	3.87	2	1.93	35.48	0.00^{**}
Spd x Obst	0.15	6	0.03	0.47	0.82
Rep x Obst	0.87	16	0.054		
Total	8.23	35			

Table A3.5. ANOVA table for the variable SPREADX (Gravel pit trial).

Source of variation	Sum of Squares	DF	Mean Squares	F	Sig. of F
Speed	0.06	3	0.02	2.18	0.17
Replicate	0.07	8	0.009		
Obstacle	0.04	2	0.02	3.78	0.045*
Spd x Obst	0.05	6	0.01	1.39	0.28
Rep x Obst	0.09	16	0.006		
Total	0.31	35			

FIELD TRIAL

Table A3.6. MANOVA results for the variables LDIG and INTER (field trial).

Source of variation	Test name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Speed	Wilk's	0.23	2.53	6	14.0	0.07

Table A3.7. MANOVA results for the variables LOVER and INTER (field trial).

Source of variation	Test name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Speed	Wilk's	0.34	1.65	6	14.0	0.21

Table A3.8. MANOVA results for the variables DISTX and INTER (field trial).

Source of variation	Test name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Speed	Wilk's	0.09	5.37	6	14.0	0.005**

Table A3.9. MANOVA results for the variables DISTY and INTER (field trial).

Source of variation	Test name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Speed	Wilk's	0.41	1.32	6	14.0	0.31

Table A3.10. MANOVA results for the variables NSEEDS and SPREADY (field trial).

Source of variation	Test name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Speed	Wilk's	0.31	1.84	6	14.0	0.16

Table A3.11. The ANOVA table for the variable WDIG (field trial).

Source of variation	Sum of Squares	DF	Mean Squares	F	Sig. of F
Speed	0.10	3	0.03	1.98	0.195
Replicate	0.14	8	0.017		
Total	0.24	11			

Table A3.12. The ANOVA table for the variable WOVER (field trial).

Source of variation	Sum of Squares	DF	Mean Squares	F	Sig. of F
Speed	0.46	3	0.15	2.92	0.101
Replicate	0.42	8	0.053		
Total	0.88	11			

Table A3.13. The ANOVA table for the variable SPREADX (field trial).

Source of variation	Sum of Squares	DF	Mean Squares	F	Sig. of F
Speed	0.01	3	0.00	0.10	0.958
Replicate	0.18	8	0.022		
Total	0.19	11			

APPENDIX IV

RESULTS OF MULTIPLE RANGE TEST COMPARISONS ON THE GRAVEL PIT DATA

DISTX as influenced by obstacle height (Tukey MRT):

		Obstacle height (cm)		
		0	20	40
Obstacle height	Mean	0.071	0.081	0.131
40	0.131	0.06*	0.05	-
20	0.081	0.01	-	
0	0.071	-		

The critical value is w = 0.055, therefore an obstacle height = 0 cm produced significantly different DISTX results than the 40 cm obstacle.

DISTY as influenced by obstacle height (Tukey MRT):

		Obstacle height (cm)		
		40	20	0
Obstacle height	Mean	1.919	2.082	2.225
0	2.225	0.31*	0.14	-
20	2.082	0.16	-	
40	1.919	-		

The critical value is w = 0.246, therefore the obstacle height = 0 cm produced significantly different DISTX results than did the 40 cm tall obstacle.

LENGTH as influenced by obstacle height (Tukey MRT):

		Obstacle height (cm)		
		40	20	0
Obstacle height	Mean	1.392	1.900	2.650
0	2.650	1.26*	0.75*	-
20	1.900	0.51*	-	
40	1.392	-		

The critical value is w = 0.211, therefore Obstacle height produces a significantly different microsite length over the treatment range.

SPREADX as influenced by obstacle height (Tukey MRT):

		Obstacle height (cm)		
		20	0	40
Obstacle height	Mean	0.146	0.149	0.184
40	0.184	0.038	0.035	-
0	0.149	0.003	-	
20	0.146	-		

The critical value is w = 0.080: obstacle height produced no significantly different SPREADX results over the treatment range, though the ANOVA indicated that the results differed significantly.

DISTY as influenced by speed (Tukey MRT):

		Ground speed (m/min)			
		40	60	80	100
Ground speed	Mean	1.943	2.003	2.144	2.239
100	2.239	0.296	0.236	0.095	-
80	2.144	0.201	0.141	-	
60	0.149	0.060	-		
40	0.146	-			

The critical value is w = 0.345, therefore speed produced no significantly different DISTY results over the treatment range, though the ANOVA indicated that the results differed significantly.