Response of Transplanted Aspen to Irrigation and Weeding on a Colorado Reclaimed Surface Coal Mine

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Abstract

Successful re-establishment of aspen (*Populus tremuloides* Michx.) on surface-mined lands in the western United States is problematic because the species generally regenerates vegetatively by sprouting from parent roots in the soil; however, topsoil is removed in the mining process. Previous attempts to plant aspen on reclaimed mine sites have failed because transplanted root sprouts or seedlings do not have an extensive root system to access water and nutrients. This study identified factors that limit the survival and growth of aspen on reclaimed surface-mined lands by examining planted aspen saplings with supplemental irrigation and removal of competing vegetation in a fenced plot. The aspen saplings were grown on reclaimed roto-tilled, fresh-hauled soil or on dozer-cleared stored soils. Separate observations were made on survival and growth of nearby plots of natural aspen sprouts (fenced or unfenced) and on potted aspen seedlings. The best combination of conditions for aspen survival used transplanted saplings from local sources on fresh-hauled soil directly removed and placed from local aspen stands. Growth was better when competing vegetation was controlled by hand-hoeing around individual trees. The plants responded less to irrigation, but irrigation with non-saline water may enhance survival and growth in years with drought conditions. Aspen trees in an unfenced plot were heavily damaged by browsing ungulates.

Keywords: *Populus tremuloides*, aspen, reforestation, irrigation, mine reclamation, fencing, weeding

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Introduction

Quaking aspen (*Populus tremuloides* Michx.) is the most widespread tree species in North America (Baker 1925; Preston 1976; Lieffers and others 2001). Aspen is found in most of eastern Canada and the United States (except the Southeast), throughout the upper Midwest and Lake States, across sub-boreal Canada and Alaska, in the Rocky Mountains from Canada through the United States and into northern Mexico, and in mountain ranges paralleling the west coast from Alaska through British Columbia south through Washington, Oregon, California, and Mexico's northern Baja California (Preston 1976). The species is most abundant in Canada's central provinces and the U.S. states of Colorado and Utah (Jones 1985; Lieffers and others 2001). Aspen is a mid-elevation, shade-intolerant species and is a relatively minor component of more widespread conifer forests in much of the western United States.

Aspen has several physiological characteristics that permit it to attain great geographic distribution. Lieffers and others (2001) outlined several important adaptive traits for aspen. It seems to have a very high stress tolerance among the wide ranging genus *Populus* spp. (cottonwoods, poplars, and aspen). Usually, high stress tolerance is associated with slow growing species and those with a limited reproduction strategy. Aspen appears to rely on vegetative reproduction via root suckering more than other *Populus* spp., and the passing of extensive root systems between generations enhances tolerance to climate stress (DesRochers and Lieffers 2001). Aspen has the ability to adapt leaf size to xeric and mesic conditions (that is, smaller leaves for drier sites). The species' smaller leaf size could keep the leaf surface slightly cooler, allowing earlier shut down of stomata and thus tempering water stress during drought. Aspen seems to tolerate cold temperature and short growing seasons better than most hardwoods (Pearson and Lawrence 1958), and its leaf fluttering may be an adaptive advantage in leaf cooling. Aspen appears to have higher rates of photosynthesis than other *Populus* spp. and is comparable to that of high yield poplar hybrids.

Although aspen does produce abundant crops of viable seed (McDonough 1979), it primarily reproduces vegetatively by root suckering throughout most of its western range. Occasional seedlings do establish but require bare mineral soil and constant moisture to survive (McDonough 1979). Aspen typically grows in genetically identical groups referred to as clones. All stems in a clone sprouted from the roots of parent trees and share a common genotype. However, they do not share a common root system as connections break down from generation to generation as new trees grow new roots.

The aggressive nature of weed invasions at some sites suggests that vegetative competition may limit survival and growth of aspen trees. The inability to easily control competing vegetation with herbicides around broad-leaved species such as aspen presents additional constraints. Having access to a well developed parental root system gives aspen sprouts a great advantage over other plants. The parent roots supply carbohydrates and access water deeper in the soil profile, allowing sprouts to grow rapidly and out-compete other vegetation and to withstand frequent droughty conditions in the West.

Re-establishing aspen on surface-mined lands is therefore problematic, since the parent root systems are destroyed when topsoil is removed. Planting containerized aspen seedlings in a non-irrigated location in a study near Tabernash, Colorado, was not successful (Shepperd and Mata 2005). Transplanting greenhouse or nursery-grown aspen seedlings into the field has similar problems to those of natural seedlings; the small root mass of transplanted seedlings is insufficient to absorb enough moisture to maintain the seedlings during periods of summer drought in the wild.

In contrast, transplanting sapling-sized aspen in irrigated urban landscapes has not been a problem because the abundant supplies of water in lawns and landscape beds enable the transplants to thrive. Although aspen are somewhat tolerant of drought conditions (Lieffers and others 2001), we expect that irrigation could benefit survival and growth of planted aspen stock because moisture stress negatively affects aspen response to nutrient uptake (van den Driessche and others 2003). Water deficit stress also reduces stomatal conductance, root hydraulic conductivity, and shoot leaf water potential in aspen (Siemens and Zwiazek 2003). Irrigation has been shown to increase growth of hybrid poplar, a closely related species (Hansen 1988; Strong and Hansen 1991).

Therefore, it seems reasonable to hypothesize that supplemental irrigation of aspen planted on reclaimed surface-mined lands could increase initial survival and allow trees to grow sufficient root systems to ultimately survive without additional water and to establish new self-regenerating clones on mined lands. Testing this hypothesis, gaining additional knowledge about different planting methods, and documenting factors that potentially limit the re-establishment of aspen is crucial to re-establishing aspen on surface-mined lands in the arid West.

Experimental Design

This study was conducted on the Peabody Energy's Seneca Coal Company II-W Mine near Hayden, Colorado (Figure 1). The site is typical of the Colorado Plateau of western Colorado and eastern Utah. Habitat before mining consisted of vegetation dominated by Gambel oak (*Quercus gambelii* Nutt.), serviceberry (*Amelanchier alnifolia* [*Nutt.*] *Nutt. ex M. Roem.*), sage (*Artimesia* spp.), and mountain grassland with scattered stands of aspen and Douglas-fir (*Pseudotsuga menziesii* [*Mirb.*] *Franco var. gluaca* [*Beissn.*] *Franco*). Original soils in the mined area derived from sedimentary sandstone and shale and were rocky and shallow. The study site was located at an elevation of 2300 m. The project was designed as a case study of the feasibility and effectiveness of using irrigation to establish native aspen sprouts transplanted from a nearby un-mined site to a fenced area on a reclaimed surface coal mine. We examined the survival, growth, and water status of aspen transplants planted on a reclaimed site. Top soils are normally removed prior to mining and stored for a number of months before replacing over resurfaced, overburden materials. Half of our study plot has topsoil that had been dozer-cleared and stored before placement at the site. The other half of the plot had topsoil that had been roto-cleared and fresh-hauled directly to the plot site.

Prior to planting, mine overburden material had been used to re-contour the original topography of the study site, and the two types of topsoil had been placed in separate locations on the overburden at the site. Roto-cleared topsoil consisted of the original vegetation, including aspen trees on the site, chopped and mixed into the topsoil with a large roto-tilling machine prior to removal. This mixture was directly fresh-hauled from its original site to the experimental plantation site. All above-ground vegetation in dozer-cleared soils was bladed aside for disposal prior to topsoil removal and storage before final placement. The dozer-cleared soil used in this study had been stored for several months before placement at the experimental site, evidenced by the indication of decay of vegetation present in the soil and the few herbaceous plants that initially grew from this soil. Both soil

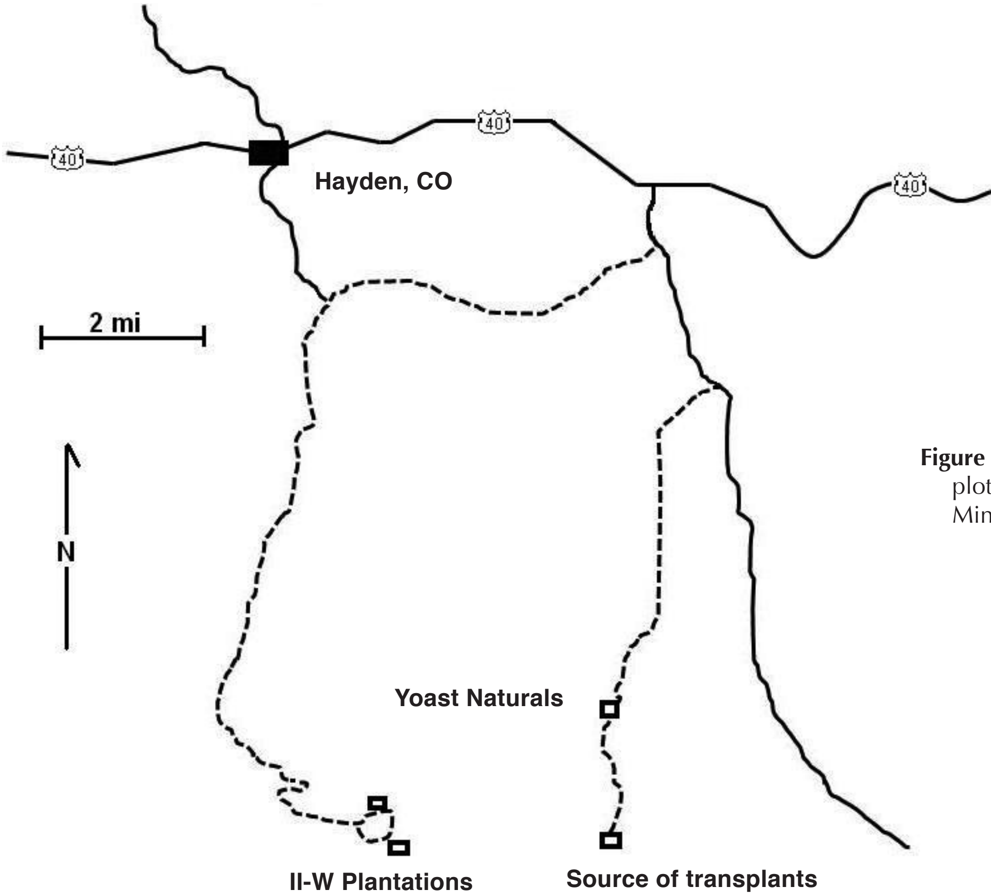

Figure 1. Map of experimental plot location, Seneca Coal Mine, Hayden, Colorado.

types were from aspen stands containing aspen roots and were placed to a depth of approximately 1 m on top of the overburden at the plantation site. The soils were spread by scraper in late summer of 2003 and were final graded in May/June of 2004 prior to aspen planting in October 2004.

Aspen trees were planted on the reclaimed soils during the fall of 2004 and examined for survival, growth, and water status for the 2005-2007 growing seasons. The aspen transplant trees were drip irrigated at three watering levels and a non-watered control, and all plots received natural precipitation. In addition to the irrigation treatments, beginning at the second growing season, competing vegetation was removed from half the experimental plots on each soil type by hand hoeing.

This study was designed to measure the effect of supplemental irrigation on bare root aspen saplings that had been transplanted from a naturally regenerating un-mined site on the nearby (<3 km) Yoast Mine where the original forest had been dozer-cleared in preparation for mining. Aspen saplings between 1 and 2 m in height and about 1.5 to 3 cm basal diameter were selected from this site at the end of the growing season in 2004 and pruned to leave only the uppermost branches intact. In October, 2004, these saplings were dug using a small backhoe, and their roots were immediately immersed in a truck-mounted water tank. The dug saplings were transported to the experimental site and transplanted the same day into 0.3 m diameter by 0.75 m deep power augered holes that had been prepared inside a fenced planting site at the II-W Mine. All saplings were presumed to be from the same genetic clone since they were collected from the same area and had similar morphological characteristics. Trees were planted in 8 blocks consisting of 5 rows of 10 trees, (50 trees total) spaced on a 1.5 m x 1.5 m grid (Figure 2). Four blocks were placed in each of the two types of topsoil.

Water was delivered to the transplanted aspen saplings during the 2005-2007 growing seasons by drip irrigation via a data-logger-controlled system that timed the daily application of water through calibrated emitters. The four water treatments (high, medium, low, and non-irrigated control) were randomly assigned to one of the four blocks in each of the two soil types, with all 50 trees in each block receiving the same amount of water (Figure 2). The gravity-fed drip system, supplied by a 7500 l tank located 63 vertical m upslope from the test site provided an adequate head to maintain water pressure greater than 4100 mb in all lines. The tank was filled by Seneca Coal Company workers as needed, generally once or twice a week. Drippers delivered water at 4.4 l/minute, and were programmed in 2005 to deliver water daily at 0, 1.4, 2.7, and 5.6 l/day/tree for the control, low, medium, and high irrigation levels, respectively, equivalent to 0.0, 9.1, 18.3, and 36.6 cm of supplemental precipitation per month. Irrigation treatments were applied at half the 2005 rate during the 2006 and 2007 growing seasons—0.0, 0.7, 1.4, or 2.8 l each day of treatment. The non-irrigated control received no supplemental water. Irrigation treatments were applied daily during the early morning. Drippers required 276 mb pressure for activation; the valve box and distribution lines were configured so that head pressure downstream of the valves did not exceed this value to avoid leakage between irrigation treatments. Standard meteorological conditions were monitored at an automated weather station located at the center of the plot, and we recorded hourly wind speed, wind direction, relative humidity, and precipitation. All data were recorded on a Campbell 23x data logger, which also was programmed to activate the irrigation solenoids. Power was supplied from 12 V batteries charged by a solar panel.

Source of irrigation water used to fill the bulk tank in 2005 and 2006 was a sedimentation pond lower in the reclaimed watershed. White salt deposits were observed around some of the irrigated treatments in 2005 and 2006, particularly those trees receiving the high irrigation treatment, suggesting contaminated irrigation water. Only clean, potable water from a Hayden, Colorado, municipal hydrant was used to irrigate the trees during 2007. Root zone soil samples were analyzed by a soils testing laboratory for determination of saturated paste extract conductivity.

Circumstances allowed us to expand our observations beyond the original irrigation study to collect survival and growth data from additional aspen reproduction at the mine site. These included natural sprouts growing inside the fenced site where our irrigation plot was located, potted seedlings in another near-by fenced area, and unfenced sprouts. Un-watered aspen sprouts grew in the fenced area outside our irrigated plot, originating from aspen root segments that had been transported to the site in the two topsoil types. Natural aspen sprouts grew from root segments buried in un-irrigated areas of the roto-cleared and dozer-cleared soil adjacent to the irrigated blocks. Half of a selected number of these sprouts of uniform size were hand-hoed (hand weeded) and half were not, and the trees were measured for survival and growth. The natural sprouts grew at random spacing, and trees selected for measurement were thinned where necessary to no closer than 1.5 m spacing—the spacing of the irrigated plot trees. The potted and natural trees in all locations were from unknown genotypes, likely different from the irrigated study transplants. The natural sprouts growing on the roto-tilled soil were all probably from the same genotype since they came from the same area. Similarly, the natural sprouts on the dozer-cleared soil were likely from the same area and genotype. But since the two soil types were from different areas on the mine, the genotype from the dozer cleared and roto-cleared were likely different.

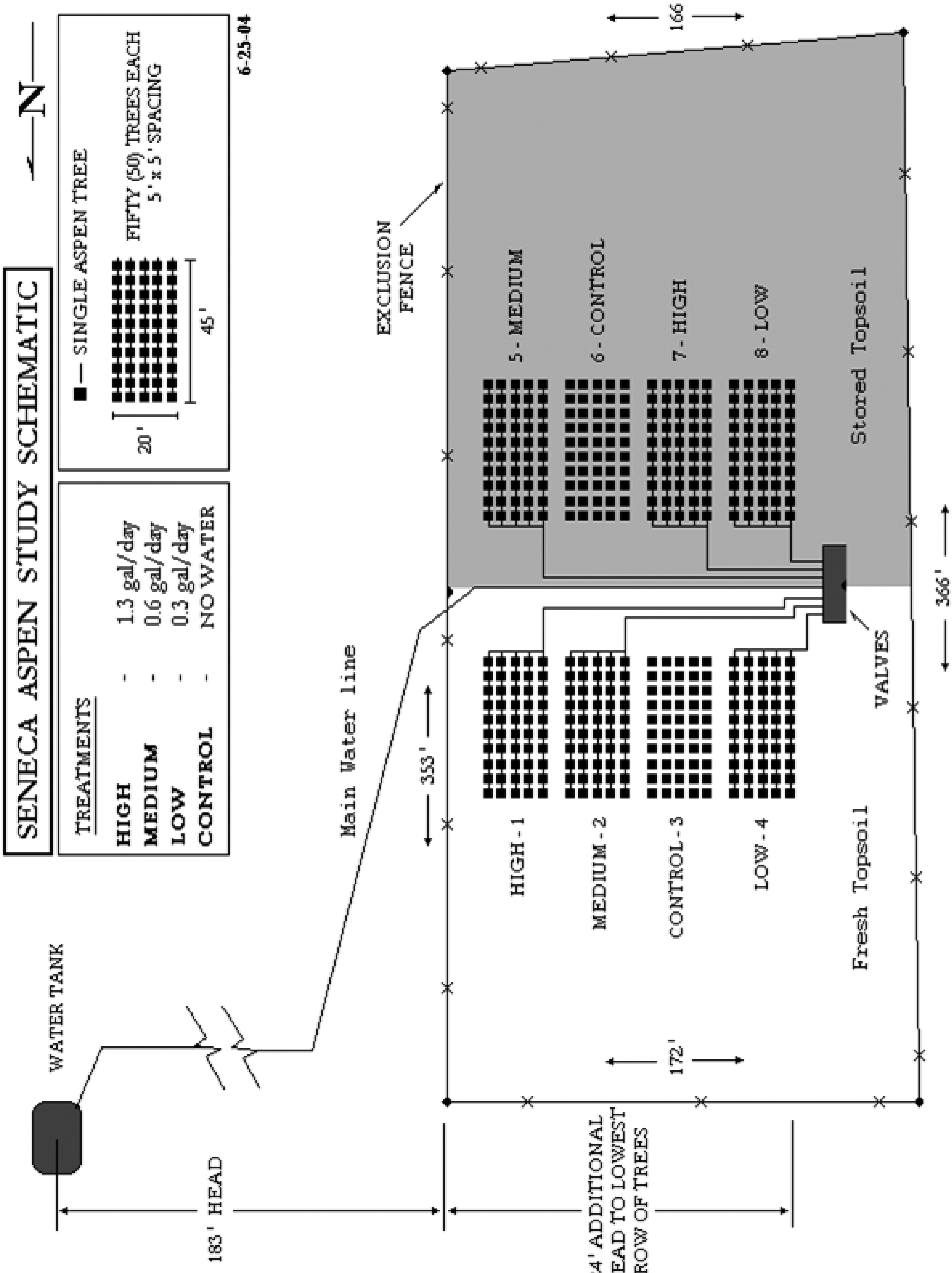

Figure 2. Experimental design for aspen reclamation project, Seneca Coal Mine, Hayden, Colorado. The inside 5 trees closest to the center of each row of 10 trees were weeded; the outer 5 trees of each row were left unweeded.

Commercially grown potted aspen seedlings that were planted in a nearby un-irrigated fenced area were also measured for survival and growth. Although the commercially grown potted aspen trees were planted on dozer-cleared soil, it was not determined if the seedling roots grew out of their potting mix or their augered hole into the dozer-cleared soil during the study. An un-mined and un-fenced area on the nearby Yoast Mine and the source area for the aspen samplings used in the irrigation study were dozer-cleared of mature aspen. The sprouts growing on this site were monitored for ungulate impact on young aspen.

None of the experimental treatments were replicated, so this experiment is considered a case study for the survival, growth, and water status of trees in this specific study. Extrapolation of findings beyond the study site must be made with caution. Nevertheless, the findings of this study can provide valuable information useful for revegetation of reclaimed surface coal mines with aspen in similar settings.

Data collected

Survival and growth were recorded for each tree prior to budbreak and at the end of each growing season. Water status and tree growth were measured periodically throughout the experiment. Physical measures of growth were height (cm), basal caliper (mm), number of basal sprouts (count), length of the terminal leader (cm), and length of each of the next three branches on the upper portion of each tree (cm). Any disease and insect infestation on each tree was recorded at the end of each growing season.

During the 2007 growing season, water status (leaf water potential) of the plants was measured twice during the summer season as near to dawn as possible (0.5 hr predawn to 0.5 hr after sunup) to capture the minimum stress before rapid morning transpiration depleted leaf moisture. Treatment, ambient temperature, time of sampling, and exuding pressure level were recorded. Leaves were randomly collected from the different treatments to minimize time of sampling biases.

Leaf water potential increases as plant water stress increases when water is withheld from the plant. Water status measurements required removing one fully matured leaf from randomly selected trees in each treatment and measuring for water holding capacity using a Plant Water Status Console. The leaf was removed from the plant and immediately placed in a sealed chamber with the petiole extending through a sealing hole in the chamber. A fresh, slightly angled cut was made and nitrogen gas was delivered to the leaf under slowly increasing pressure until water exuded from the petiole surface. The pressure necessary for this to occur is an indication of the water potential or water holding capacity of the leaf, which is an indication of the water stress and thus physiological stress of the plant. Different plants from each treatment were selected at each testing to minimize leaf loss from sampling. Two to three total measurements were made from each treatment each day of measurement. Number of measurements depended on the time necessary for each measurement so that all measurements fell within the dawn-time window. Each day of measurements included leaves collected from all irrigation treatments.

Competing vegetation

Invasive weeds, including tumbleweeds (*Salsola* spp.) and thistles (*Cirsium* spp.), were common in the plantations from 2005-2007 as well as numerous native herbaceous species. Landscape fabric (about 1 m diameter) placed around potted trees during planting prevented weeds from growing next to those trees. We controlled competing vegetation in the irrigation and root-sprout treatments by repeatedly hand-hoeing and cutting all vegetation growing around half of the trees in each irrigation and soil treatment. The irrigation plots on each soil type were divided into two sections—one to be hand-hoed and one not to be hoed—with hoeing treatments superimposed on the existing study design. Growth, physiological parameters, and survival were compared as in other treatments. Soil samples were collected from each treatment for moisture content analysis.

Differences in soils

Soil samples from the two soils types (roto-tilled/fresh-hauled and placed, and dozer-cleared/stored before placement) were collected and analyzed for organic matter and nutrient content, water holding capacity, and chemical and physical properties. Since the soils were mixed and soil horizons present in normal soils were missing, integrated samples were collected through the entire surface soil profile, approximately 0.75 to 1 m depth. Soils were analyzed for texture and fertility (organic matter, pH, nitrogen, phosphorus, potassium, and cation exchange capacity). Bulk soil samples were periodically collected and oven-dried for soil moisture determination.

It was important to quantify how the replaced soil differed from natural soils on the Seneca II-W Mine. Samples of undisturbed soil were collected under aspen stands in undisturbed areas of the mine and subjected to the same analysis previously described. In addition, differences in soil conditions between reclaimed soils in the study area and those under nearby undisturbed aspen clones were quantified by comparing physical and nutrient characteristics of soil samples from both the normal and augmented reclaimed soils to those of the natural soils. Sampling of the soils under nearby native, undisturbed aspen stands were extended to the same depth investigated in the reclaimed soils on the study plot.

Root growth

Aspen is a relatively short-lived tree that is susceptible to injury and disease and relies on periodic re-sprouting from lateral roots to maintain its presence on a site (Shepperd and others 2006). Therefore, the development and lateral extension of new roots is critical for the ultimate survival and re-establishment of any aspen planted on mined lands. We quantified new root development since planting by excavating randomly selected surviving trees at the end of the 2007 growing season and washing soil from the roots to quantify total root biomass and new root growth. Trees were chosen from each of the different irrigation, soil, and transplant treatments studied. Soil was carefully loosened and roots were exposed by washing soil away with a high pressure water jet. We then measured the spread of any lateral roots away from the tree base as distance of root spread down to 4 mm diameter size. Total below-ground biomass dry weight of roots was measured. It was particularly crucial to see if roots had extended beyond the planting hole for transplants or beyond the potting mix for potted aspen. Roots must reach a large enough size and be close enough to the surface for suckering to occur.

Results and Discussion

This study verified that aspen can be successfully established on reclaimed surface coal mine lands when certain conditions are met. The study was initially conducted to demonstrate the effectiveness of supplemental irrigation (four levels of watering) on survival and growth of transplanted saplings. We were also able to examine control of competing vegetation (hand-hoed or not hoed) in this experiment. Experimental conditions at this site allowed us to study soil type, roto-cleared/fresh-hauled and dozer-cleared/stored. Other aspen plantings available at the mine site allowed examination of additional factors: plant source and stock type (transplanted rooted saplings, natural sprouts, and potted plants) and fencing (fenced or not fenced).

Since not all treatment combinations existed, and none of the treatments were replicated, statistical analyses and inferences are limited. For example, differences in survival and growth between aspen at Yoast and II-W Mine soil sprouts, between dozer-cleared and roto-cleared, and among dozer-cleared seedlings, sprouts, and saplings may be due to differences in soil disturbance, genetic stock of aspen, transplant type, fencing, or microclimatic differences between sites. Although this was a case study, several observations were evident that are helpful for future aspen management and to identify areas for additional research. We present our data as box-plots, useful to compare different datasets for range, skewedness, and the presence of outliers.

Competing vegetation

Trees on weeded plots grew considerably better (Figure 3) and had higher rates of survival. Weeding was particularly important for survival of natural sprouts occurring from residual aspen roots in the replaced topsoil. Of 34 natural sprouted trees initially marked for study on the roto-tilled/fresh-hauled soil in year 1, half were weeded and half un-weeded in years 2 and 3. All of the weeded trees survived into year 3 while only four of the un-weeded trees survived the first three years of the experiment. Of the 21 natural sprouts selected for study on the dozer-cleared stored soil, 8 of the 11 weeded trees but only 2 of the 10 un-weeded trees

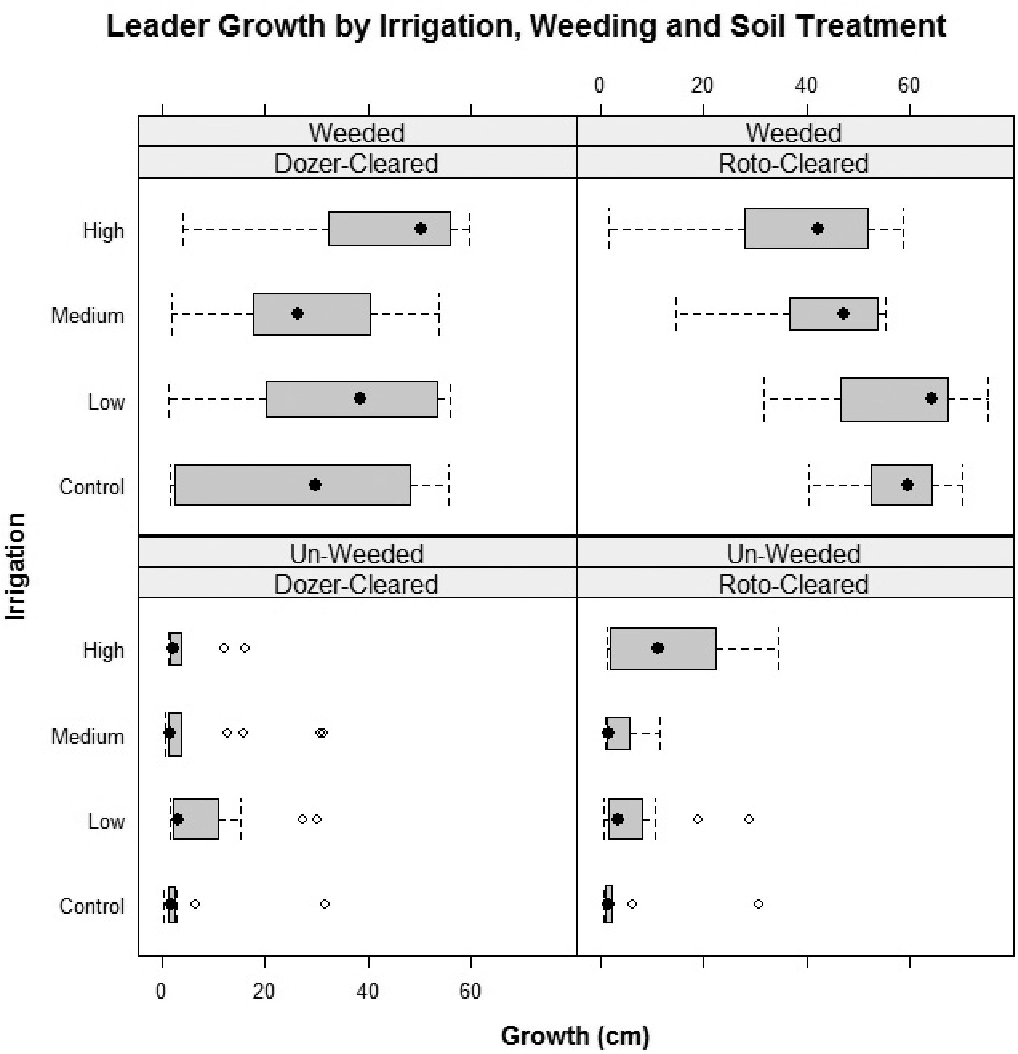

Figure 3. Box-plots of average growth by irrigation, weeding, and soil type. Box-plots describe the distribution of the data, with the grey box showing the 25th to 75th percentiles (the middle 50% of the data), dashed horizontal and vertical lines (H-line) indicate the maximum and minimum values (unless outliers are present where it extends to 1.5 times the inner quartile range), solid circle is the median, and open circles values beyond the H-line are considered outliers.

survived after 3 years. Most of the vegetative competition consisted of annual herbs, perennial grasses, and weed species. Weeds were primarily thistle species and tumbleweeds. Shading was not a factor since the trees were larger and growing above the competing vegetation canopy. Data from this study suggest that surface vegetation and trees may be competing for a limited amount of available water and nutrients.

Although soil moisture did not appear to be much higher in the weeded plots (Figures 4-6), weedy vegetation may have been a competitor for moisture and nutrients in the planted aspen plots. Soil moisture was lower near the surface than deeper (Figures 7-8).

Irrigation treatment

Rainfall was plentiful for the first two years during the study, and soil moisture was relatively high even in non-irrigated plots, as indicated by soil moisture matrix potential values and low leaf water potential data for all treatments. This prevented a good examination of the irrigation treatment effects in this experiment. Aspen survival and growth did not appear to be dependent on or, in some cases, consistent with irrigation treatment (Figure 9), suggesting that soil moisture from the frequent rain events was sufficient even in the non-irrigated plots. The supposition of adequate moisture available to all trees was further evident in that there appeared to be no relationship among irrigation treatment and average leaf area, total leader growth, terminal leader growth, stem diameter growth or caliper, or survival. Growth of second, third, and fourth lateral branches appeared to be

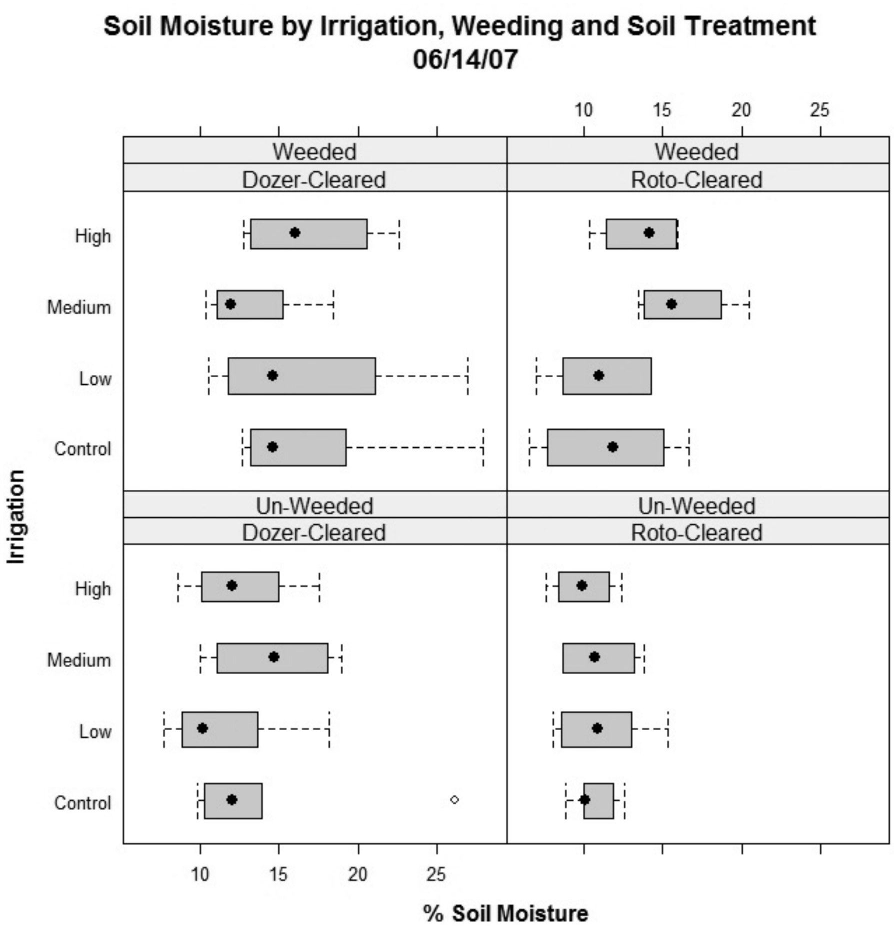

Figure 4. Average soil moisture by soil type and weeding treatment, June 14, 2007.

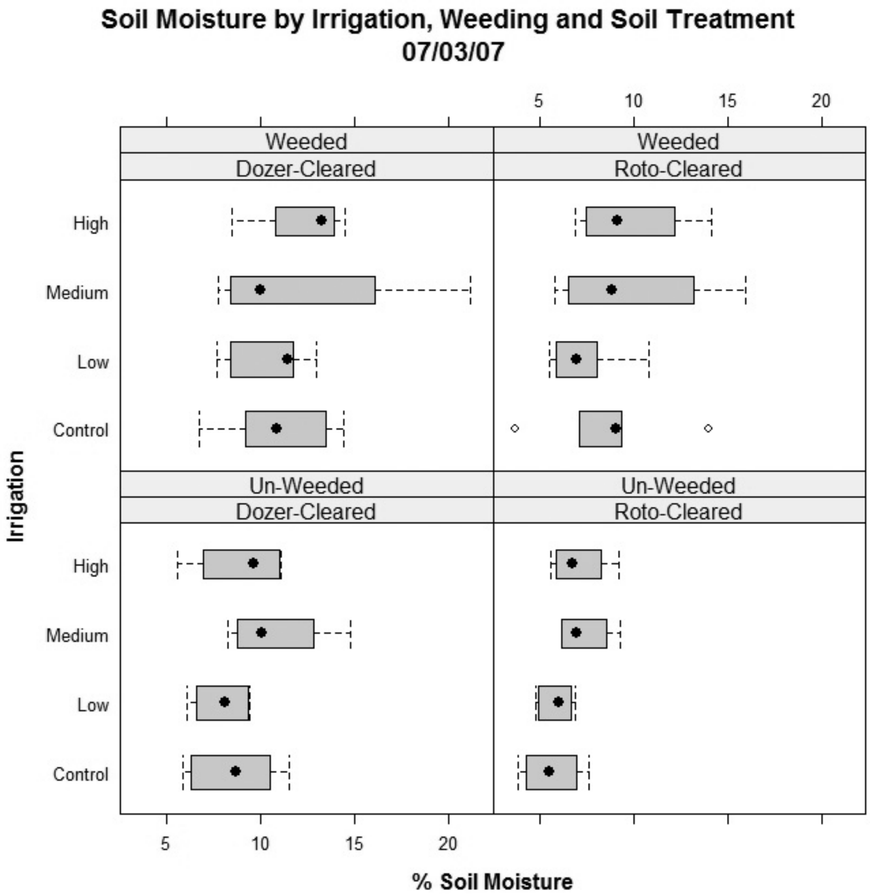

Figure 5. Average soil moisture by soil type and weeding treatment, July 3, 2007.

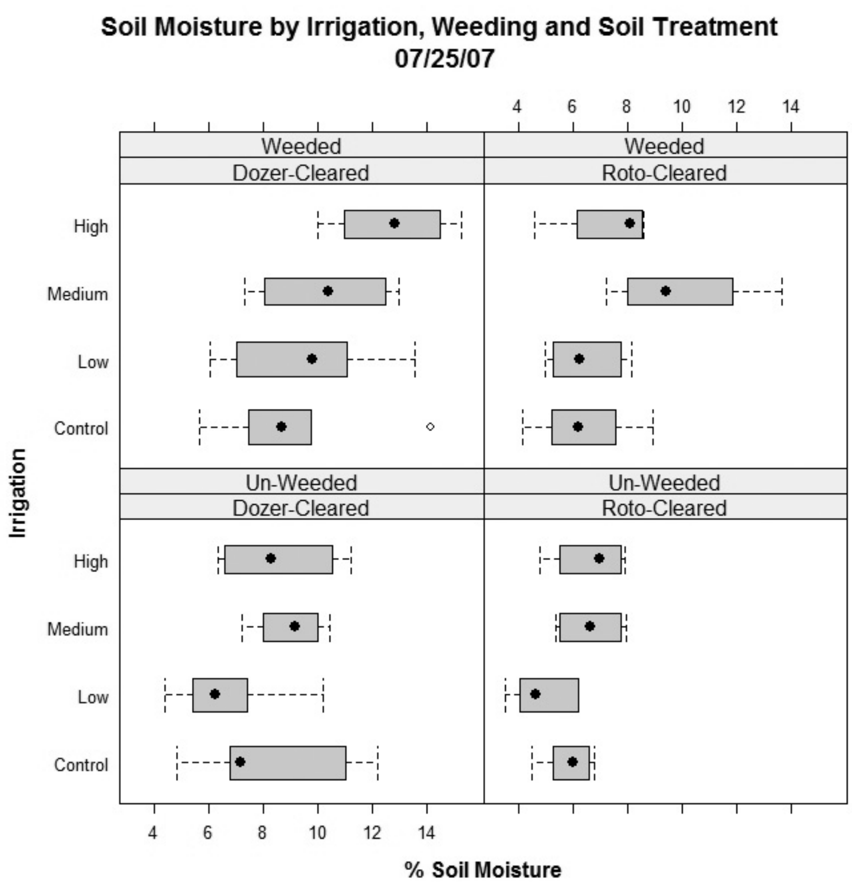

Figure 6. Average soil moisture by soil type and weeding treatment, July 25, 2007.

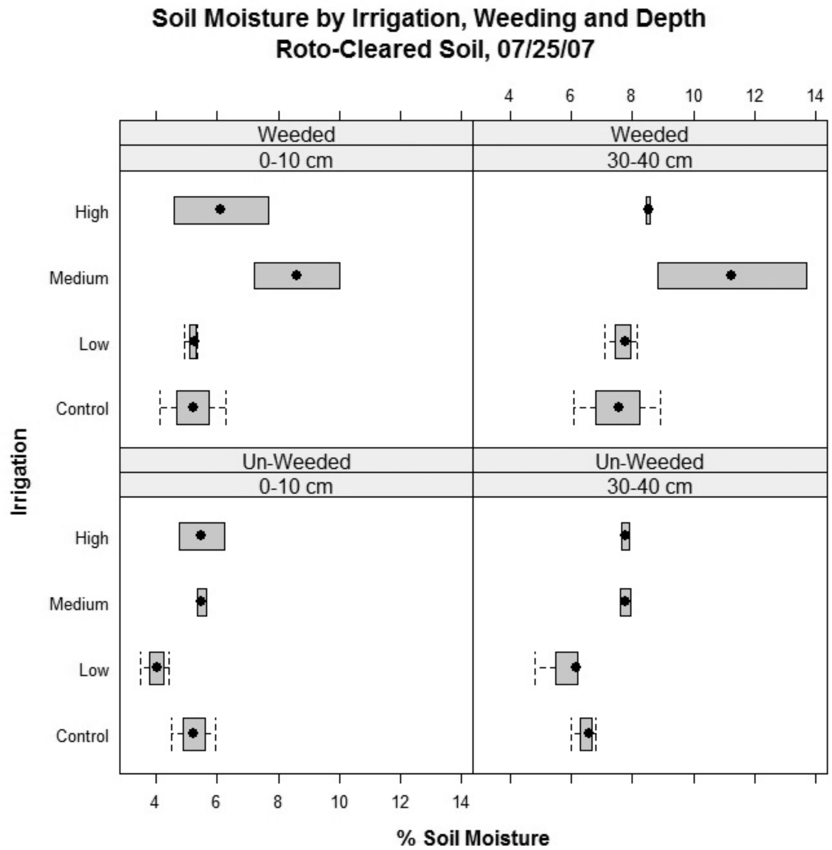

Figure 7. Average % soil moisture by depth for roto-cleared soil.

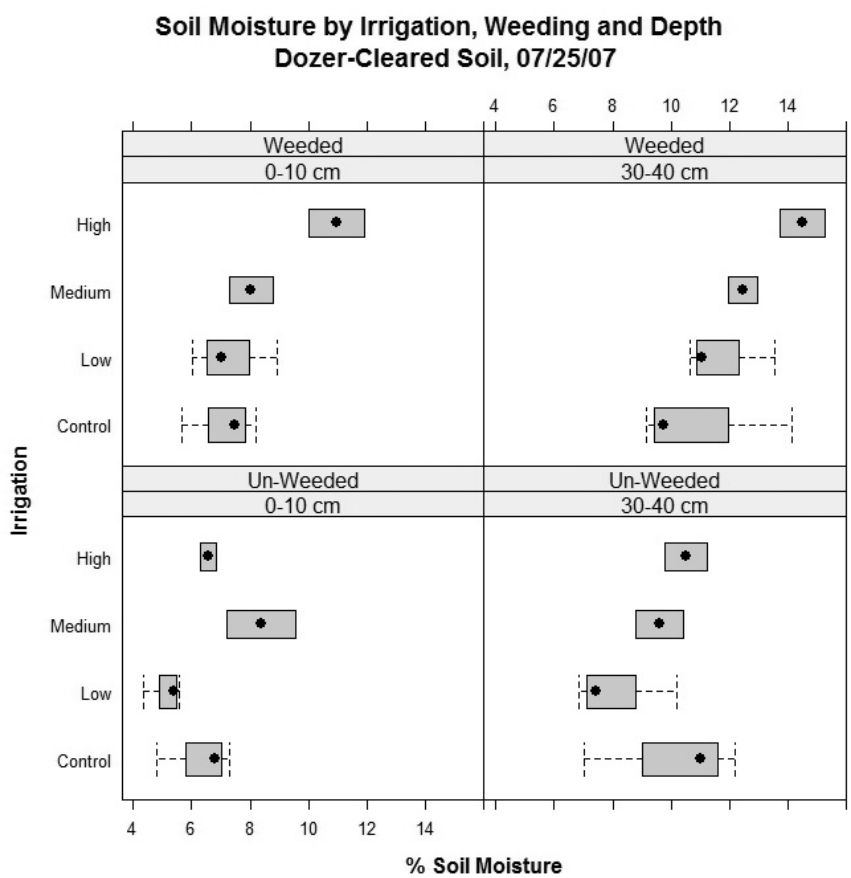

Figure 8. Average % soil moisture by depth for dozer-cleared soil.

similar for all treatments but are reflected in total growth. Pre-dawn leaf water potential levels also indicate moisture stress was generally less than 5 bars (0.5 mPa) pressure and did not appear to be related to irrigation treatments during the years when these measurements were taken.

Salt deposits were observed around the base of trees with high irrigation in 2005 and 2006, suggesting that salts were leached from the re-deposited topsoil or were present in the irrigation water. A soil chemistry salinity analysis confirmed that the soils with the highest rate of irrigation were indeed saline, likely the result of irrigation with saline water. An analysis of the water from the local pond used as a source for irrigation confirmed that the water was saline. Non-saline, potable water was used to irrigate the trees in 2007.

Saline water inhibited the growth of aspen on high and medium irrigation treatment plots the first and second year of the study. Remarkably, although these trees were still smaller in the third year, the annual growth of many of the trees had recovered to that of low and control irrigation treatments after discontinued use of local saline irrigation water (Figure 3). Growth of some of the low irrigation and no irrigation treatment trees was still higher than that for the high and medium irrigation treatments, suggesting that the reduced growth from the saline water used for irrigation in the first and second years of the experiment was still evident for those trees in the third year of treatment.

None of the trees that died in previous years re-sprouted from residual roots. Since growth of transplanted aspen saplings was good with the low and no irrigation treatments, there was sufficient natural rainfall during the three years of the study

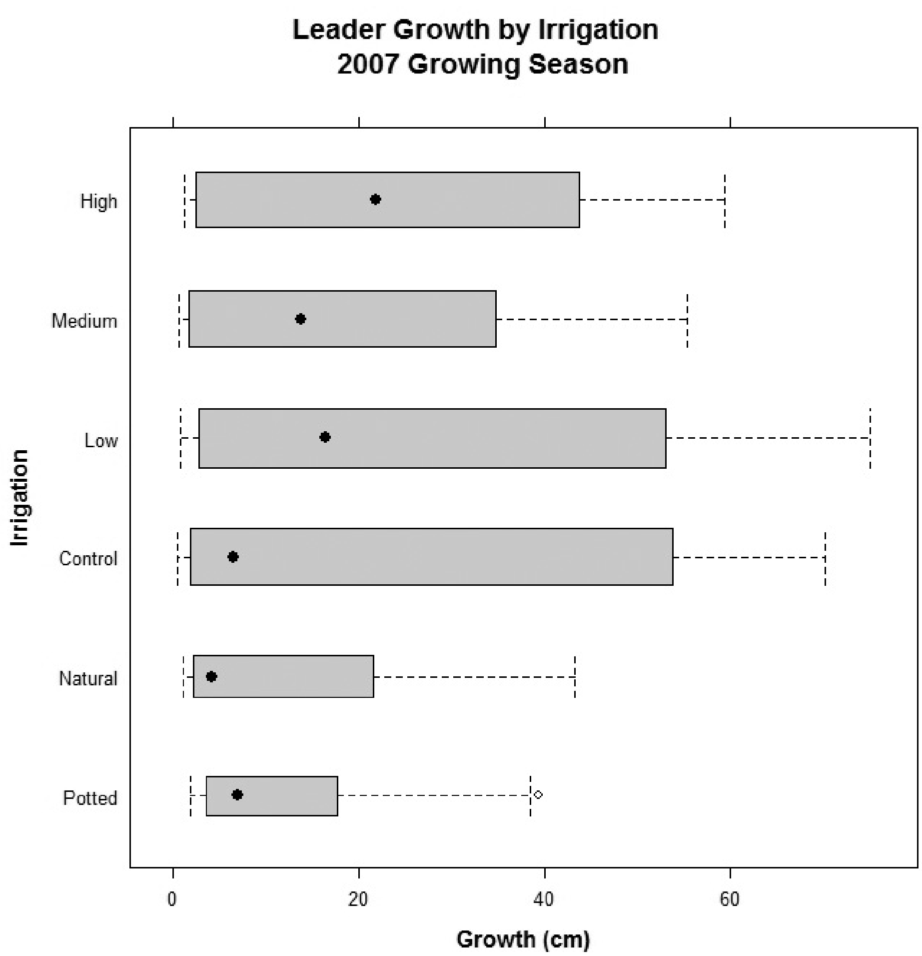

Figure 9. Average growth by irrigation treatment. Controls, naturals, and potted trees were not irrigated.

for the trees to survive and become established without irrigation. Nevertheless, it is expected that growth under the high and medium irrigation treatments might have been higher than the lower irrigation treatments had non-saline water been used. Determining the benefit of irrigation of newly planted trees was limited in this experiment by the saline irrigation water and lack of low rainfall or drought conditions during the study.

Transplant type

The aspen saplings used in the irrigation study that were transplanted from the nearby Yoast Mine site exhibited considerably more injury and more disease infections than natural sprouts arising from buried root segments or potted plants (data not shown). Transplant shock was evident only the first year when leaf area growth; leader, stem, and diameter growth; and survival were considerably less with these plants than with natural sprouts or potted plants. However, the transplanted trees that survived the first year grew well the second and third year of the study and generally surpassed that of the natural sprouts and potted trees in year 3 (Figure 9). After three years, survival was similar for all transplants and natural sprouted trees (50-57%) but was considerably higher for potted plants (80%). Survival and growth of the potted trees was excellent and appeared better than transplanted cuttings the first year of the study, but growth of the potted trees remained relatively stagnant after three years and these trees were considerably smaller than the transplanted trees. The transplanted trees were well established and growth was generally good by the third year of treatment. Growth of natural sprouts was less than that of transplants after three years.

Natural root sprouts had no lateral branches their first year. Leaves also appeared to be larger on these trees (data not shown). Nevertheless, these trees experienced somewhat greater pre-dawn water stress in July and September than trees in the irrigated treatments, including the irrigated controls with no water added. The data suggest that pre-dawn water stress levels as high as 14 bars and afternoon water stress levels as high as 20-25 bars were not of sufficiently high levels to cause enough stress to reduce survival or growth.

Soil type

Roto-cleared/fresh-hauled soil provided sufficient natural sprouting from residual aspen roots in the topsoil to provide an adequate stand of aspen trees, and these trees appeared to grow better and survival appeared higher than adjacent transplanted trees growing in the same soil in the first two years of the study. Dozer-cleared soil that had been temporarily stored had considerably lower numbers of natural sprouts than roto-cleared soil, and stocking was sparse (data not shown). Only a small number of sprouts occurred from the stored dozer-cleared soils, suggesting the lack of live roots for sprouting. Natural sprouts appeared to have greater total leaf area and stem diameter growth on roto-cleared soil than dozer-cleared soil, but terminal leader growth appeared similar on both soil types. While there appeared to be no difference in survival on the roto-cleared (53%) and dozer-cleared (52.5%) soils, average growth on dozer-cleared soils (18.9 cm) was only about two-thirds of that on the roto-cleared soils (29.4 cm). These data suggest that fresh hauling of soil from aspen stands to reclaimed land could allow for sufficient sprouting of aspen from residual roots without planting.

There were differences between the two soil types for many of the attributes measured in the experiment, particularly growth in the weeded plots (Figure 3).

Soil samples from the two soil types and undisturbed soils were collected and analyzed for organic matter and nutrient content, water holding capacity, and chemical and physical properties. Samples were taken from the entire topsoil depth placed at the site, about 1 m deep, because the soils were mixed during digging, storage, and placement, and no soil profile existed. Soil chemical properties were similar for the different soil sources, including undisturbed soils. Data indicate that neither the roto-cleared nor dozer-cleared soil type was toxic, except for high electric conductivity in high irrigation treatments on both soil types for 2006. Nutrient content such as nitrogen did not seem to be related to soil type and was at high enough levels to not be the limiting factor in tree growth. The difference in response of aspen tree growth between the two soils types appeared to be primarily due to original soil source or to storage rather than to method of tree removal. Stored soils were observed to be anaerobic.

Soil moisture

Dozer-cleared and roto-cleared soils were similar in soil moisture content (Figures 4-8). Visual observations suggested that the dozer-cleared soil was more compact and poorly drained as evidenced by water ponding in a soil pit at the site. Higher organic matter content of the roto-cleared soil may have made it less susceptible to compaction (Shepperd 1993). Soil moisture seemed to have no relationship to amount of irrigation applied (Figures 4-6) but had a higher range of variability in the weeded plots. Soil moisture was higher at 30-40 cm depth in the soil compared to the surface 10 cm (Figures 7-8).

Although soil moisture content on the roto-cleared soil was similar to that on dozer-cleared soils the moisture should have been less tightly held on the roto-cleared soils since this soil was considerably less compact with better drainage. These conditions apparently favored growth of aspen trees and competing vegetation. The growth data suggest that roto-cleared soil could have provided other benefits such as improved aeration and soil structure or perhaps mycorhizae for tree growth.

Fencing

Fencing is necessary to obtain an adequate stand of aspen, regardless of the source of the trees. The unfenced Yoast Mine site had severe damage from ungulates, including stem breakage, browsing, and rubbing damage. Most trees at this site had some form of injury. Yet, survival and re-growth of these trees was good, suggesting that the presence of an extensive parent root system in undisturbed soil is ideal for aspen growth. Nevertheless, fencing of these trees is recommended in order to produce an adequate stand of mature aspen. Cattle were present in other areas of the mine, but aspen plantings were protected from browsing by fencing.

Physiological status

Initial analyses indicate that soil type and weed competition affected rate of physiological response, as reflected in plant growth. Highest rates of growth seemed to be in the weeded plots on roto-cleared soils, suggesting that these conditions are best for aspen survival and growth. Greater plant top and root growth of these plants seem to verify that finding. Plant water status measurements indicated that when these tests were conducted during the 2007 growing season (June 28 and August 1) the plants were not water stressed, with pre-dawn leaf water potential pressures not exceeding 20 bars in June or 10 bars in August (Figures 10-11). Most often, stress was less than 5 bars. Irrigation was particularly helpful during June when stress approached 20 bars on some low and un-irrigated plots.

Plant moisture stress was less with high and medium irrigation treatments than with low or no irrigation during June (Figure 10), but trees were more stressed on roto-cleared soils in August (Figure 11). Larger trees showed the most stress. Maximum leaf water potentials measured one warm mid-afternoon found stress levels of about 25 bars or less; the levels appeared to be unrelated to treatment or to survival and growth.

Rainfall was frequent during the relatively wet 2005 and 2006 growing seasons, and monitoring of leaf water potential indicated that varying irrigation treatment did not affect leaf water stress condition of the plants. However, additional physiological conditions such as stomatal conductance, photosynthesis, and respiration of the plant that affect survival and growth were unknown. These physiological conditions may have shown response to drought prior to indication by plant water status; or they could at least indicate which trees are stressed and not likely to survive.

Root growth

Root growth of transplants was best in weeded plots on roto-cleared soil where lateral roots extended far from the base of the original tree (Figures 12). Roots were of sufficient size (4 mm or more) where suckering could begin, but many were too deep (15 cm or deeper), a result of the deep planting of the transplanted

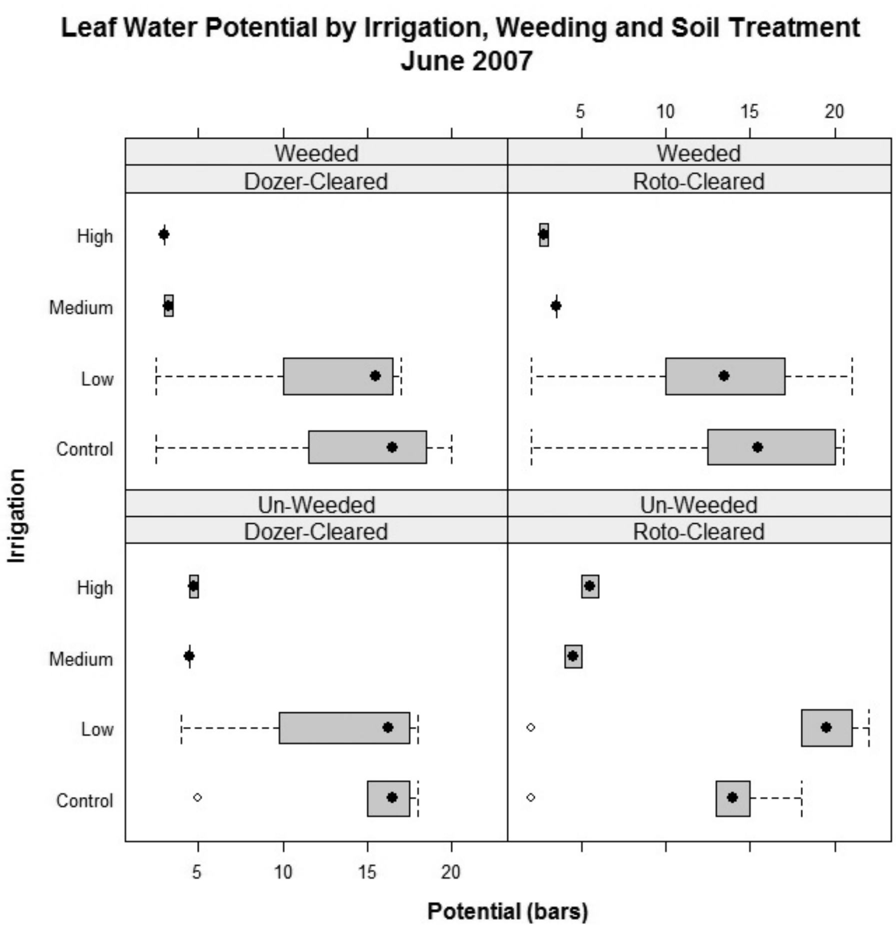

Figure 10. Average pre-dawn leaf water potential, June 28, 2007.

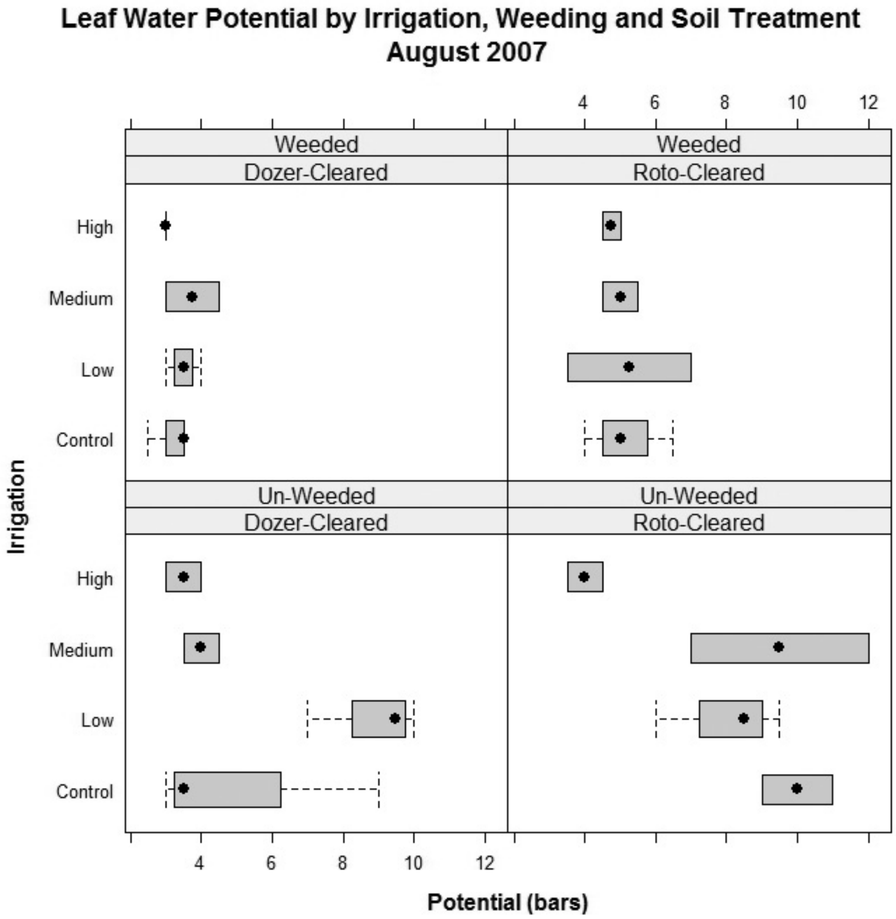

Figure 11. Average pre-dawn leaf water potential, August 2007.

trees. Effect of weeding on root growth of dozer-cleared soils was less evident, likely since weed competition was considerably less and growth was less on the dozer-cleared soils. Although root growth was best on roto-cleared soil plots, trees in other treatments are surviving and roots are extending outward. However, it will take additional years for most of these trees to obtain sufficient size at depths necessary for suckering. In any case, suckers are more likely to appear after injury or death of parent trees when apical dominance is inhibited.

Some of the transplants on dozer-cleared soil had roots mostly confined to the potting hole, perhaps a result of the high density and compaction of this dozer-cleared and stored soil. Similarly, roots growing from the potted trees, also planted on dozer-cleared soils, were likely confined to the potting hole. Excessive reaming of the soil planting holes with the power auger could have also attributed to difficulty of roots penetrating beyond the augered hole.

Depth of the root systems for the transplanted aspen ranged from about 15 to 40 cm, with transplants in the roto-cleared soil planted somewhat deeper than those on the dozer cleared soil. These depths are too deep to allow effective suckering. Even though roto-cleared trees happened to have been planted somewhat deeper than dozer-cleared trees, growth was better on the roto-cleared trees. It is expected that trees planted deep will take longer to produce roots at a depth conducive to suckering, but those deep planted trees that survived are now producing shallower roots. Lateral root systems were already developing on most of the transplanted trees, and roots were observed near the surface several meters from the base of some trees, suggesting that these trees were becoming well established. Apical dominance of the rapidly growing transplanted trees likely prevented suckering

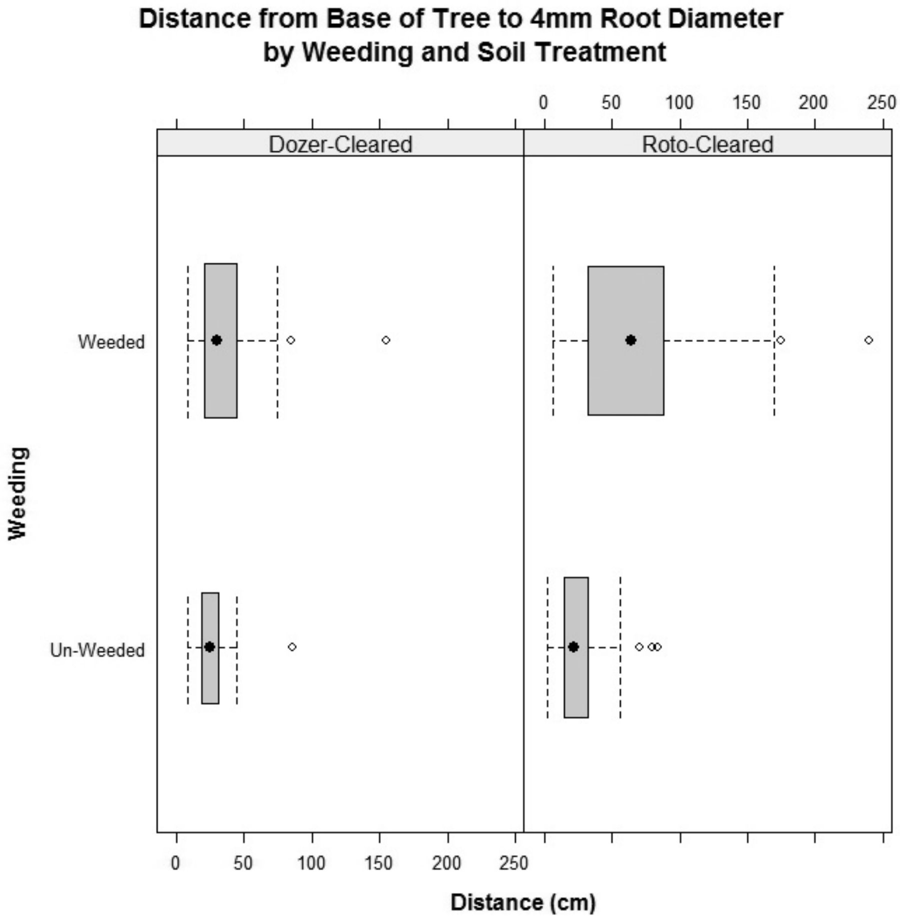

Figure 12. Average distance (cm) of root extension from base of tree to 4 mm root diameter.

of these lateral roots. It is expected that enough root system has developed that further irrigation of these trees is not necessary.

Conclusions

Although the results of this case study have limited application beyond the study area, several factors were important in survival and growth of the planted aspen. Insights gained have been used to design further studies to examine aspen survival under various weed control and irrigation conditions.

Fencing is necessary to protect small aspen trees from ungulate and cattle browsing. Aspen saplings in unfenced areas on the mines were badly damaged by browsing and by stem breakage from rubbing.

There was adequate natural rainfall during all three growing seasons, and survival and growth were not improved with supplemental irrigation treatment. Best survival and growth was with low or no irrigation, but salinity of irrigation water in the first two years of the experiment likely reduced growth of trees receiving high and medium amounts of irrigation. Reclaimed soils were not saline, but salinity levels were high enough in irrigation water from local ponds to reduce aspen growth. Care must be taken to provide low saline water when irrigating planted aspen trees on reclaimed lands. Survival and growth were similar with the low and no irrigation treatments, suggesting that enough rainfall and soil moisture occurred for the years of this experiment that irrigation was not necessary. It is expected that supplemental irrigation with clean water may have increased survival and growth above non-irrigated trees. All surviving trees now have developed enough root system after three years that further irrigation is not needed.

Best growth appeared to be the natural root segment sprouts on roto-tilled soils for the first year. But most of these natural suckers did not survive without weeding. Transplanted sprouts showed considerable transplant injury their first year, regardless of irrigation treatment. Survival and growth were lower and injury and diseases were higher in transplant cutting plots for the first year compared to natural sprouts and potted plants. The transplanted trees from local sources that survived the first year grew best in subsequent years. Potted aspen plants from nursery stock had a high rate of survival and grew well the first year, but after three years, growth was lower than for transplants and natural sprouts. Roots of potted aspens appeared to have stayed in the augured potting hole. This also occurred for a few of the transplanted trees in the more compact, stored dozer-cleared soil on the irrigation treatment plots, the same soil type where this occurred for the potted plants. This suggests that disking or other mechanical treatment to mitigate topsoil compaction may be beneficial after topsoil has been replaced. Care must be taken to avoid planting aspen saplings too deep. The upward growth of roots toward the soil surface that was observed indicates that care should be taken in future plantings to plant trees only to a depth of the original root collar.

Best survival and growth occurred on roto-cleared/fresh-hauled soil compared to dozer-cleared/stored soil. More natural sprouts from residual root segments were evident in roto-cleared soil. The higher number of natural sprouts and better growth was likely due to the shorter length of soil storage and the soil characteristics rather than the clearing method. The dozer-cleared soil appeared to be more compacted and was less well drained than the roto-cleared soil. It is expected that these physical characteristics and the storage effects contributed to the observed differences in response between soil types.

Weeded aspen trees showed the best growth. This was likely related to weeds competing with the trees for the limited water and nutrient supply and was particularly apparent on the roto-cleared soils where weed populations were high.

Overall recommendation

The best conditions for re-establishing aspen on reclaimed surface mined coal lands involved using transplanted saplings from local sources on freshly placed soil removed from aspen stands and controlling competing vegetation around individual trees (Figure 13). Care should be taken to avoid compaction of the replaced soil, and transplanted trees should be planted no deeper than the original root collar. Irrigation with non-saline water could enhance survival and growth in years with drought conditions. Follow-up observations through the 2010 growing season indicate that trees surviving the first three years of treatment are growing well, but treatment differences during 2005-2007 are still evident.

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Figure 13. Weeded (left) and un-weeded (right) plots on roto-tilled soil, August 2006.

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