University of Alberta

A Greenhouse Study of Selected Native Plant Species for Dewatering CT

by

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To
my husband, Yan, my lovely daughter, Yehua, and all my families for their support, love and understanding along the way

Abstract

This greenhouse experiment was conducted to determine the suitability of native plant species for dewatering CT; to assess the application of direct seeding techniques on vast CT deposits; and to evaluate the evapotranspiration effect on CT by native plants. Selected native plant species were directly seeded via broadcast seeding; hydro-seeding with mulch; and fresh discharged CT slurry seeding techniques. The results indicated that native plant species: Slender wheatgrass and Northern wheatgrass seeded via using broadcasting and slurry seeding techniques are applicable for dewatering of CT deposits in the field. The evapotranspiration during 15 weeks experiment was highest for Slender wheatgrass and Northern wheatgrass, which indicated that these species have the ability to uptake water from CT. The solids content of the CT mixture increased from 65% to a range of 87.6% to 90.5% by evapotranspiration via plants.

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LIST OF SYMBOLS AND ABBREVIATIONS

The units used in variables or symbols are defined the first time they occur in each chapter.

CT	Composite Tailings or Consolidated Tailings
MFT	Mature Fine Tailings
C'	effective cohesion of a saturated soil
φ'	effective angle of internal friction of a saturated soil
LAI	Leaf Area Index, defined as
A	dimensionless parameter, defined as plant dewatering capacity over limited soil water storage in percentage
$CaSO_4{\cdot}2H_2O$	gypsum, which is made of two molecules of water and one molecule calcium sulphate
EC	electrical conductivity
Na	sodium
Ca	calcium
SO_4	sulfate
Cl	chloride
SAR	sodium absorption ratio
ppm	part per million
N	nitrogen
P	phosphorus
K	potassium
E	evapotranspiration
E_s	soil Evaporation
E_p	plant transpiration
K_{evap}	an evaporation limiting factor
P'	precipitation
M_{w0}	initial soil water storage
ΔS	the change in the amount of water stored in a certain volume of soil

1 INTRODUCTION

1.1 Introduction

The world's largest petroleum resource - Canada's Athabasca Oil Sands have been commercial mined by Suncor Energy (Oil Sands) Inc. and Syncrude Canada Limited since 1967 and 1978, respectively. The industries have grown substantially over the last five years, producing output in excess of one million barrels per day. In 2005, the crude oil output accounted for 50% of Canadian crude oil production and 10% of North America's output (Alberta Department of Energy, 2005), making Canada the seventh-largest oil producer in the world. This production has the potential to double within the next five to seven years, and triple by 2020 (Government of Alberta, 2005). Alberta's oil sands have become essential to the security of energy supply for North America.

However, oil sands development results in significant disturbance to land, both during operations and reclamation phase. Existing policy, legislation and planning initiatives (e.g. Mineable Oil Sands Strategy, 2005) require oil sands operators to reclaim disturbed land to an equivalent land capability that will support the intended end land uses on the reclaimed area. The long-term reclamation goal of these operations is the reestablishment of vegetative communities that eventually are self-sustaining and compatible with the surrounding undisturbed terrain (HBT AGRA Ltd. 1992).

Suncor's reclamation efforts began in the late 1960s, soon after mining began. In 2005, Suncor has reclaimed about 858 cumulative hectares land (about 9% of disturbed land) (Suncor Energy, 2005). Suncor also plans to spend 25 million dollars on reclamation and reclaims approximately 5,000 cumulative hectares by 2020 (about 37% of disturbed land) (Suncor Energy, 2003).

It was also reported in the Syncrude Canada Ltd. 2004 Sustainability Report that

18,653 hectares of landscape were disturbed by oil sands mining and 4,055 hectares were reclaimed which is about 21% of disturbed land.

The oil sands industry's hot water-based bitumen separation process results in an extensive volume of high moisture content clay-rich tailings (MFT). The disposal of these vast quantities of tailings is an enormous waste management problem. The existing two extraction and upgrading plants produce 180 million tones tailing stream per year and requires approximately 29 square kilometers of tailings ponds for its containment. This results in a rate of one-quarter to one-third of a ton of fine tailings per barrel of oil production. This large volumes of fine tailings results in geotechnical and environmental challenges to meet their reclamation goal, such as, how to safely store it, how to reclaim the disturbed soil landscape, and how to develop economical and feasible revegetation techniques on the tailings.

The traditional method for reclamation of the tailings is capping with one or two layers of organic topsoil to meet the requirements for revegetation and to improve plant growth (Naeth and Wilkinson, 2004). However, with a large disturbed area during oil sand operation, the available capping soil is limited. Using soil cover is considered impractical and costly (Ludeke, 1972). At present, the major geoenvironmental engineering issues associated with the reclamation of these tailings to a dry landscape are their soft character and inability to support reclamation personnel and equipment. Since reclamation will not be possible before the surface of the deposits is stabilized and capable of supporting human traffic, it is a crucial issue facing operations to develop innovative, environmentally acceptable and economic methods to dewater these high water content tailings and to enhance their surface stability.

Previous research performed at the University of Alberta and Syncrude (Scott et al. 1993; Matthews, et al. 2000) for both Syncrude and Suncor has revealed that addition of a chemical coagulant (gypsum; lime; acid) to a mixture of cyclone underflow (tailings sand) and mature fine tailing (MFT) produces a non-segregating tailings stream known as CT (Composite Tailings at Syncrude, Consolidated Tailings at Suncor and Non Segregating Tailings at Albian Sands Energy Inc). This process alters the fine tailings to hold the sand as a non-segregating mixture that reduces the inventory of fluid-fine tailings, accelerates the consolidation of fine tailings once deposited, and enables a wider range of reclamation alternatives to be used. The solids content of the CT mixture presently being deposited can reach 65% solids content when discharged. This mixture induces a rapid release of water and causes the combined tailings to dewater faster than mature fine tailings (MFT) would achieve on its own.

Although the process of making non-segregating tailings at 60-65% solids content exists, consolidated undrained compression triaxial tests carried out by Qiu and Sego (2001) indicate that the cohesion of the CT mixture was about 3 kPa, the friction angle is approximately 30^0 (c'=3 kPa, $\phi'=30^0$). The bearing capacity of CT deposits is still very low and it cannot support the weight of the operating machine and even human activities. To able to support the weight of human activities and the weight of light seeding, the bearing capacity should be higher than 85 kPa (Silva, 1999).

To further increase the bearing capacity of CT deposits, in general, natural dewatering processes which include freeze-thaw, evaporation and evapotranspiration are considered as economically practical techniques (Johnson, 1993). The principle of dewatering is to rearrange the soil particles by changing the drainage condition. After monitoring the dewatering performance at the Coal Valley mine site located in Alberta, Stahl (1996) highlighted the key natural processes, such as, evaporation, freeze-thaw consolidation, evapotranspiration and plant root reinforcement methods, for actively enhancing the strength and surface stability of coal wash tailings.

However evaporation results in formation of a salt crust on the surface, which interferes with further evaporation and reduces the evaporation rate to 12% of potential evaporation (Qiu and Sego, 2001). The effective dewatering layer is thus limited to a thin layer of less than 20 cm (Burns et al., 1993).

In the freeze-thaw process, the geotechnical behavior of fine tailing is significantly altered. There is a separation of solids and water as the ice crystals grow during freezing. Upon subsequent thawing during the following spring and summer time, the consolidated solids sink under gravity to the bottom while water is released to the surface. Immediate dewatering can be observed after thaw in the laboratory and field tests. The hydraulic conductivity can be increased significantly (Sego et al., 1994; Proskin et al., 1996). Freeze-thaw not only causes immediate volume and water content changes but it can also cause changes to the soil structure and its engineering properties.

Using plants to dewater the high water content, low bearing capacity deposits by evapotranspiration is regarded as an economical technique. Plants growing in fine tailings remove water via evaporation and transpiration, to decrease the water content and pore water pressure, and eventually, to increase the effective stress which results in increasing shear strength and bearing capacity of fine tailings (Johnson 1993; Stahl, 1996; Silva, 1999). More over, the plant root system also provides reinforcement within the root zone. The mechanical effect of the root system is to enhance the confining stress and increase the strength of the soil-root mass through the binding action of roots in the fibre-soil composite (Gray, 1982; Coppin and Richards, 1990), which will increase the cohesion of the CT.

In the past, non-native plant species were considered as suitable plant species for reclamation and dewatering CT deposits because of the high germination and water uptake ability (Johnson et al., 1993; Naeth et al., 1999; and Silva, 1999). On the other hand, their faster germination and growing ability could result in the competitive exclusion of native plant species and even changes to the native landscape and the local ecosystem. However, native plant species have advantages of growing well in local soils and of adaptation to annual fluctuation in rainfall and temperature. Moreover, native plant species often have minimal insect problems and perform satisfactorily without the need for supplementary irrigation and maintenance.

The priority in studies of biological dewatering CT deposits is to select suitable native plant species that grow directly under these adverse conditions. The selection of plant species from available native plant lists should consider the particular chemical and physical conditions of the growth medium. Since CT deposits have low bearing capacity, the identification of innovative seeding techniques is also critical for dewatering vast surface area of the planned CT deposits.

1.2 Research objectives

The primary objectives of the present study are to select suitable native plant species capable of growing directly in CT, to estimate the potential emergence rate via using different seeding techniques and to evaluate the effect of plant dewatering or increases to solids content via evaporation and evapotranspiration.

1. In a greenhouse experiment, Bluejoin, Creeping red fescue, Hairy wild rye, Northern wheatgrass and Slender wheatgrass were selected. Those may have an ability of dewater during the initial stage of stabilizing CT deposits. Specific objectives are to determine and compare species emergence and growth performance when seeded directly in CT deposits.

2. Selected plant species seeds were planted using different seeding treatments (broadcast seeding, hydro-seeding with mulch, fresh discharged CT containing seeds) to determine the effect of seeding techniques on plant emergence and early plant growth. Based on the emergence rates, number of shooting, identify the selected native plant species that would be appropriate for use to test individual seeding techniques.

3. Conduct a greenhouse experiment under simulated climatic conditions (Fort McMurry, Alberta) to evaluate the growth of plants in CT deposits during one complete growing season. The specific interests are a focus on Leaf Area Index (LAI), total biomass and the height of plant above ground.

4. Monitor the dewatering via evaporation, transpiration with time and compare it with unplanted controls to enhance understanding of the processes which influence the native plant dewatering characteristics within these high water content CT materials.

1.3 Organization of thesis

This thesis is organized into a series of four chapters. Appendices provide detailed experiment results. The chapter 2 and 3 manuscrips are waiting submission for publication in conference proceedings and/or journal.

Chapter 1 gives the general introduction to this study and outlines the structure of the work undertaken.

An initial literature review of plants species for vegetation application and tailings reclamation are presented in **Chapter 2**. Of those native plant species listed for reclamation use on Alberta's disturbed lands, five native grass species were selected which can adapt to the particular chemical and physical conditions present in CT deposits. The emergence tests using six different seeding treatments are described. The seeding treatments include broadcast seeding on self-weight consolidated CT mixture, mulch-based hydro-seeding with or without fertilizer, a 0~4 mm thickness and 4~6 mm thickness of fresh CT containing seeds being discharged on the surface of a CT deposit. The test results represented in this chapter include a comparison of emergence rate, number of shoots and growth rate in the vigor stage. The optimum seeding treatments were evaluated for these selected species and two of the six seeding treatments were selected for additional study of dewatering. Two of the five native plant species were recommended for field studies to evaluate the practical seeding techniques capable of distributing seeds widely on fresh CT deposits.

Applying plant dewatering mechanisms, greenhouse experiments are designed and discussed in **Chapter 3** to evaluate the plant performance evaluated using the leaf area, the height of plant, plant density and total dry biomass measurements. A dimensionless parameter α defined as plant dewatering capacity over initial soil water storage was introduced to indicate evapotranspiration capacity by native plant species. Chapter 3 also presents the solids content profile at the end of these experiments to evaluate the effect of dewatering by evaporation alone and via plant evapotranspiration.

Chapter 4 provides a summary and conclusion of the main contributions of this study and recommendation for the future field studies.

Appendix A summarized the screening program to select suitable native plant species, which could grow directly in CT mixture. The measurements of plant height in individual seeding treatments are presented in **Appendix B**. The evapotranspiration and evaporation from the surface of the CT mixture while using different seeding techniques are summarized in **Appendix C**. **Appendix D** summarized the dimensionless parameter α for each selected native plant species in this greenhouse experiment.

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2 NATIVE PLANT SELECTION AND DIRECT SEEDING OF COMPOSITE TAILINGS (CT)

2.1 Introduction

The oil sands operations in Northern Alberta generate large quantities of synthetic crude oil annually. The Clark Hot Water Extraction (CHWE) of bitumen produces significant amount of waste consisting of water, sand, fines and residual bitumen. Since 1995, addition of gypsum to mature fine tailings (MFT), which is then mixed with a stream of cyclone underflow (tailings sand), produces non-segregating Composite/Consolidated Tailings(CT). The non-segregating mixture has improved dewatering characteristics over MFT alone. Consequently, within a relatively short time, these non-segregating tailings consolidate to form a 65% solids content deposit (Liu et al., 1996; Matthews et al., 2002). Freshly deposited, CT still has slurry characteristics and low surface bearing capacity (Qiu and Sego, 1998). The time required for these deposits to dewater via consolidation and natural processes to support traffic loads is uncertain since they are deposited at such high rates that the deposit grows in thickness faster than the underlying material can undergo self-weight consolidation. This results in ongoing upward flow of water to the surface following final layer placement which delays formation of a trafficable surface.

Dewatering of the CT deposits to support reclamation equipment or human activities, using natural processes such as evapotranspiration by plants is an economical and practical technique to stabilize the surfacial deposit.

The use of plants to dewater various tailings has been identified as a viable mechanism (Johnson, 1993; Stahl, 1996; Silva, 1999). Suitable plant species have the ability to germinate and survive within freshly placed CT, to economically enhance the surface stability of these weak deposits, and in turn, to stabilize the surface materials to support reclamation activities. In the plant-water-atmosphere system, water is released from CT through evaporation and plant transpiration. Plants are able to uptake water from below the surface and provide a continuous pathway via the roots, stems, and leaves to the atmosphere. In addition, plant roots provide fiber reinforcement that binds the soil to increase the equivalent cohesion of CT material.

One of the greatest challenges in using plants to dewater CT deposits is the poor germination and the ability of the plants to establish in the harsh environment. Chemical analysis of the CT mixture indicates that this material has a relatively high pH (>7.6) and high concentrations of ions including Na^+, SO_4^{2-}, and Cl^- (MacKinnon et al., 2001). High salinity surface crusts formed after consolidation and rapid evaporation from the surface contribute to seed mortality, inhibit germination and reduce seedling emergence. Deficient nutrients may result in stunted growth and a burning or drying of plants and the tissue at the leaf edges. Selection of the proper species and variety is an important step in successfully establishing and growing plants directly in CT. Plant species and varieties differ in their growth habit, productivity, tolerance to salinity, winter hardiness, seedling vigor and other characteristics.

Introduced grass species were considered as suitable plants for dewatering CT after greenhouse studies (Johnson et al., 1993; and Silva, 1999). Since introduced plant species are germinated faster and grew faster than local native species and may invade and displace undisturbed landscape plant species. The regional biological system may change, thus, it is desirable that native plant species be tested for use in stabilizing for reclamation of CT deposits (Naeth et al., 1999; and Renault et al., 2004). Transplanting seedlings to CT was used to assist with early plant establishment in these reported studies. This is complicated since low surface bearing capacity renders it inaccessible to traditional seeding equipments or transplanting by humans. Developing an innovative yet practical direct seeding technique on CT is therefore desirable.

The objective of this study is to evaluate the selected plants through evaluation of their emergence, survival, and early growth. An additional objective is to determine the applicability of direct seeding techniques to evaluate the survival of plants to assist with dewatering of CT deposits and their effectiveness at improving bearing capacity prior to reclamation. Achievement of both objectives depends on proper emergence and early survival of the seeds and plants within the CT deposit.

2.2 Background

Dewatering of oil sands mine wastes is a major technological, economical, and environmental challenge for the oil sands industry of Northern Alberta. Natural processes, including evaporation, freeze-thaw and evapotranspiration, are considered the most practical methods for dewatering the surfacial deposits of these high water content materials on a large scale and to enhance surface stability (Johnson et al., 1993; Sego et al., 1994; Stahl, 1996; Silva, 1999).

Presently, the use of plant species that grow directly in these wastes to assist with dewatering the soft deposits is partially understood. Suitable plant species can grow in CT materials and increase the solids content to approximately 90% to 95% in one growing season (Johnson et al., 1993; Silva, 1999). If a self-perpetuating vegetative cover can be established, wind and water erosion can be minimized, and the surface of the impoundment can be returned to some semblance of its original appearance and land use (Vick, 1983; Ludeke, 1973).

However, at present, few studies have been conducted using native grass species to dewater CT, rather than via introduced non native species. In addition, little evaluation work has been carried out on seeding techniques that directly distribute seeds over the surface of these vast CT deposits.

In the past, exotic non-native species were preferentially selected because of the higher dewatering ability. Since 1993, many native and non-native plant species have been tested in the laboratory and on site for oil sand tailings dewatering and reclamation purposes. The experimental results indicated that the germination and survival of introduced species is high compared to native species (Johnson et al., 1993; Silva et al., 1998; Naeth et al., 1999; Renault et al., 2004). Also, Barley, which is native to western Asia, was tested as a potential species for initial reclamation of saline CT materials (Renault et al., 2003). But these germinate earlier and grow faster characteristics that make those exotic species successful also result in their dominances and competitive exclusion of the slower growing native species. Threats to the remaining native landscape include further fragmentation into increasingly smaller areas and the introduction and expansion of weeds and invasive agronomic species. In these cases, the past use of non-native plants on revegetated sites has resulted in the exclusion of native species (Alberta Environment, 2003). They also have the potential to alter natural communities when they invade non-disturbed areas. The loss of native plant species may negatively impact the way an ecosystem functions (Lyster et al. 2001). Over time, Alberta's native landscape has been changed by agricultural, commercial, industrial, recreational and residential/urban development.

The benefits of using native plant species to reclaim oil sand tailings ponds is that native plant species have evolved over time under local soil and climate conditions. They are, once established, well adapted to annual fluctuations in the local climate. Native plants often have minimal insect problems and perform satisfactorily without supplementary irrigation or maintenance. Therefore, their use in reclamation projects is preferred.

Johnson and Putwain (1981) provided several case histories of the use of native species on iron, bauxite, manganese, nickel, copper, and other types of tailings, and demonstrated that native species can be successful in establishing a self-perpetuating cover on mine waste sites even though they have low seed production and slower establishment rates.

Today's increased desire to use native species follows the increasing emphasis on multiple uses for disturbed land, as well as, on enhancing ecosystem diversity and functionality and conserving biological resources. The use of native plants in urban landscapes and along highway rights-of-way is gaining acceptance as a benefit of using native plants becomes better understood (Smreciu et al., 2003).

Field trial experiments were conducted at Mildred Lake, Alberta in 1981 to evaluate the growth performance of nine native grass species on tailing sands (Russell Ecological Consultants, 1982). The results showed that most species performed reasonably well, suggesting the trial site (tailings sand) offered no particular revegetation problems. Wheatgrass species were recommended as the most successful native grass for use in reclamation work in Alberta. Since they are tolerant to salt and alkali, native grass species: Slender wheatgrass (*Agropyron trachycaulum*), Northern wheatgrass (*Agropyron dasystachyum*) and Creeping red fescue (*Festuca rubra*) were recommended for reclamation of the tailings sand after growth room, green house and field tests (Dames and Moore, 1970; Naeth et al., 1999; Renault et al., 2004).

In general, there are five principal methods of applying seeds on a given site: drilling, broadcasting, hand seeding, hydro-seeding, and transplanting. All these seeding methods have been successfully used for land revegetation and for reclamation during different developmental stages. The use of transplants has been successful used for dewatering CT deposits (Johnson et al. 1993, Silva, 1999). But in the field, the rule of thumb requirement for applying transplants is that the planted materials should have enough bearing capacity to support the weight of operating machines or human activities. The freshly discharged CT at 65% solid content will not support either human or mechanical seeding equipment. Drilling, transplanting, and hand seeding are therefore not applicable for seeding CT deposits.

Hydro-seeding techniques were applied for revegetation on sand tipped in large uncompacted heaps in England to examine the effect of hydraulic seeding techniques (Roberts and Bradshaw, 1985). When the hydraulic slurries containing seeds were sprayed, establishment was quite successful, provided sufficient microsites exist to permit good contact between the seed and sand. Using water-base hydroseeding techniques, the seed lies on the surface in poor contact with available moisture and it is subject to surface drying, temperature extremes and erosion by rain or flowing water.

As currently practiced seeding techniques used in reclamation of tailing slopes (Berry, 1970) and stabilization of sand slopes in England, hydro-seeding involves the application of fertilizer or/and seed to steep slopes. Mulch was typically added as the seeds were sprayed to aid in covering the seed as well as to retain moisture as the seeds germinate. In field plots, conventional water-based hydro-seeding techniques produced limited germination and establishment of grasses (Roberts and Bradshaw, 1985).

A field investigation into the effect of slurry seeding on the persistence of Italian ryegrass was carried out by Jones and Roberts (1989). Four seeding treatments, including seeding without slurry, slurry only, broadcasting followed by slurry, and slurry seeding with a pre-mix of slurry and seeds, were tested. The results showed that the application of seed and slurry, either mixed or applied separately, gave a significant increase in dry-matter production since the slurry provides adequate soil moisture essential for germination. Seed mixed within the slurry germinated satisfactorily.

To determine the effect of slurry seeding on plant germination and early survival, 3 seed mixes and 18 individual native and agronomic species were seeded by slurry seeding techniques (Naeth and Wilkinson, 2003). The growth chamber study results identified slurry compositions that can support plant growth by using slurry seeding techniques for early reclamation of oil sands tailings.

The review indicated that broadcast seeding, hydro-seeding and slurry seeding techniques are more likely to succeed with plant germination and early plant survival over the vast surface area that will exist in a typical oil sands CT deposits.

2.3 Materials and methods

Composite Tailing (CT) was prepared by mixing sand, MFT, tailing pond water and gypsum ($CaSO_4 \cdot 2H_2O$). The amount of gypsum added was approximately 1.2 kg/m^3, which increases the viscosity of the fine particles to form CT and also functions as an excellent source of Ca and S for the plants.

On 20 August, 2006, fine tailings, pond effluent water, tailings sand, and synthetic gypsum (calcium sulfate) were shipped to University of Alberta from Suncor Energy Inc.

All solids contents presented in Table 2-1 were determined using standard gravimetric analysis and represent the average of three samples. All samples, except for gypsum, were placed in a dish and dried in an oven at 110 ^{0}C overnight and/or until a constant mass was reached. Solid contents were calculated according to the standard definitions used in geotechnical engineering. The solids content of the gypsum was measured and calculated after drying the sample to a constant weight at 80 ^{0}C (Boratynec, 2003).

Two trials of tailing sand samples were first weighted to obtain their mass, then it is washed through a #325 sieve to determine the mass of fines. The material retained on the #325 sieve (sand) was oven dried at 110 ^{0}C overnight to determine the mass retained on the #325 sieve (44 μm).

In the laboratory, a proportion of sand, MFT and pond water were mixed with gypsum to produce a CT mixture with an initial solids content of 65% with a 20% fines. These CT mixtures were prepared in several batches. The size of the batch had sufficient volume to fill one container at a time and to produce a homogenous CT mix for each test series.

Two representative samples of pond water, MFT and CT mixture were used to determine the nutrient status, pH and electrical conductivity (EC). Chemical analysis and major ions of CT are summarized in Table 2-2. This CT mixture was slightly saline with a range of pH 7.3 to 7.6 (Herrera, 2005), with $Na^{+}, Ca^{+}, SO_4^{2-}, \text{and} Cl^{-}$ being the dominant ions. Nitrogen, phosphate, and potassium levels were deficient and magnesium was at the optimum level for plant. Calcium was a little higher than the optimum level. The electrical conductivity is 1.51 to 1.59 ds/m which is slightly higher than 1.5 ds/m level indicating soluble salt level high enough to impact sensitive plant species (Hanlon et al. 2002). The calculated values of Sodium Adsorption Ratio (SAR) were 10.3 and 10.4 for the two samples, respectively, which are less than 13. Therefore, base on SAR, EC and pH value, the CT can be classified as a slightly saline, non-sodic material (Davis et al. 2006).

When the prepared CT mixture is transferred from the mixer to the storage pail, some of water trapped within the pore spaces is under a small excess pressure, which results in self-weight consolidation of the CT. To relieve the excess pressure, water seeps from the deposits. The greatest excess pressure occurs at the bottom of the container and it takes some time for the water to travel from the bottom to the surface. To reduce this time, a 25 mm thickness coarse sand layer covered with geo-textile was placed at the bottom to act as a filter and accelerate the self-weight consolidation process. One end of 5/7 mm (I/O) diameter plastic tube wrapped with geo-textile was inserted into the filter and another end was located over the top of the pail to rapidly dissipate the excess pressures.

Ninety four-liter plastic pails having a diameter of 218 mm and a height of 145 mm were used during the experimental program. The container was filled with CT to the depth of 130 mm. Self-weight consolidation was allowed to occur and the expressed water was siphoned from the surface. The plastic tube was knotted after a few days to prevent additional water loss from the base. Three duplicates were prepared for each plant species and for each different seeding treatment. In addition, three samples were left unplanted as controls.

According to the seed availability and plant growth characteristics, the native plant species selected for use in this greenhouse experiment were Bluejoint (*Calamagrostis canadensis)*, Creeping red fescue (*Festuca rubra*), Hairy wild rye (*Elymus innovatus Beal*), Northern wheatgrass (*Agropyron dasystachyum*), and Slender wheatgrass (*Agropyron trachycaulum*), which have medium to high tolerance to salt and alkali. Seeds were obtained from a commercial seed supplier Pickseed Canada Inc. in Edmonton, Alberta and delivered to University of Alberta with seed certificates. For each species, fifty seeds were counted by hand and selected based on their appearance such as plumpness, absence of spots and cleanliness.

2.4 Direct seeding treatments

The studies consisted of six different seeding techniques using the five native grass species.

Broadcast seeding (Treatment-1): the surface of each pail was roughened with a fork. Fifty seeds of each species were spread evenly on the surface and lightly covered with CT.

Hydro-seeding with Fibramulch^{TM} (Treatment-2): Hydro-seeding slurry was a mixture of fresh CT, fifty (50) seeds and Fibramulch^{TM} that was placed on the CT. The nutrients free natural paper fiber hydro-seeding mulch—Fibramulch^{TM} was purchased from Can-cell Industries Inc. The application rate used was 0.14 kg/m^2 (1250 lbs/acre).

Fresh CT containing the 50 seeds was discharged as a 0-4 mm thick layer (treatment-3) and as a 4-6 mm thick layer (treatment-4). These were allowed to flow over the surface of the CT.

After discussion with greenhouse staff, Fertilizer 20-8-20 (N-P-K) was added to the hydro-seeding slurry with Fibramulch™ (Treatment-5) and to a 0-4 mm thick layer of fresh CT slurry (Treatment-6). Because of their lower emergence rate in treatment–1, Hairy wild rye and Bluejoint grass species were not used to evaluate influence of fertilizer on emergence and early survival. In each of these seeding treatments (Treatment-5 and Treatment-6), Creeping red fescue, Northern wheatgrass, and Slender wheatgrass species were used to assess the impact of fertilizer on native plant seeds emergence.

A geo-grid system was used during the hydro-seeding to prevent seeds being concentrated as standing water following the operation may cause the seeds float to the edge of the pail (Figure 2-1).

2.5 Greenhouse experiment design

The pails were placed in a controlled environment greenhouse held at 22 ^{0}C with 15 hours of light and 9 hours darkness, simulating the typical growing climatic condition in Fort McMurray during June. Mercury and sodium vapor lights (400 W) acted as supplemental light to complement the low light intensity in the greenhouse during late fall and winter when this test program was conducted. This supplemental light was not turned on for the first 14 days following seeding to reduce surface desiccation and allow for maximum emergence. To minimize the effect of any environmental differences, the plants were placed randomly in the greenhouse.

Distilled water was added twice a week to the CT surface to simulate the average precipitation from May through September and to keep the surface moist. Long-term values of precipitation for Fort McMurray are 40.7 mm for May, 74.8 mm for June, 81.3 mm for July, 72.7 mm for August, and 46.8 mm for September (source Environment Canada). Since standing water would float the seeds out of the soil reducing emergence rates, 9.8 mm distilled water added weekly to the samples, which represents approximately 89% of the average summer precipitation.

100 ppm 20-8-20 (N-P-K) fertilizer was used biweekly after 8 weeks. Fertilizer was added cautiously to prevent the total solute load from exceeding the salinity tolerance of the plants. For some fresh or weak plants shoots, total amount of fertilizer was added using two or three separate watering events.

2.6 Plant measurements

Weekly monitoring began 7 days after seeding and continued for 8 weeks to record the emergence rates and then an additional 2 weeks to monitor early plant survival. Initially, it involved counting the number of plant shoots per pails that had emerged at 4, 6, and 8 weeks. Following the plant emergence study, seedling height was measured and the degree of survival was observed at 6, 8 and continued to 10 weeks. Degree of early survival included whether the seedling was rooted or floated. The leaf number range and the maximum seedling height were recorded weekly for 6 weeks after seeding. At the end of the experiments, the color of the seedlings was also observed as an indicator of early performance. The plants were recorded as green, yellowish, pale green, whitish and notes were recorded to describe them as healthy, vigorous, lush or wilted (Naeth et al., 1999).

The plant height of these five native species planted using broadcast seeding technique (Treatment-1) was recorded during 15 weeks (105 days) to assess the effect of fertilizer application on the plant growth.

2.7 Results and discussions

2.7.1 Plant Emergence

During 8 weeks of monitoring, plant emergence rates varied from 0 % to 55.4 % (Table 2-3) depending on plant species and seeding techniques. The reduction in emergence rate may be attributed, at least in part, to the high amount of Na^{+} and Cl^{-} in CT (Table 2-2). The presence of salts in the CT solution decreases the osmotic potential of the soil, creating potential for water stress and makes it more difficult for plants to absorb water. Another reason for the low emergence rate is the seeding techniques. During slurry seeding and hydro-seeding, seeds floated on the surface water giving a poor seed mineral soil contact. Some failed to root even after they germinated.

The seeding techniques had effects on all five selected native grass species. In terms of emergence, the best results were achieved via broadcast seeding (treatment-1). Six days after seeding, seeds of all five grass species started to emerge (Figure 2-2). Seedlings survived throughout the 10 weeks experiment.

Compared with treatment-1, seeds of some species emergence were delayed about 4 days in treatment-3, treatment-4, and treatment-6 (Figure 2-2). Bluejoint did not emerge in the other treatments but did in treatment-1. Fertilizer added to the slurries during seeding did not contribute to higher emergence because fertilizer added during seeding introduced a risk of soluble salt injury and is somewhat inefficient since plants do not really use the nutrients until after they germinate and begin rooting (Comer, 2003).

2.7.2 Survival and visible injury

The results of this study showed that CT did not affect the survival of Slender wheatgrass, Northern wheatgrass and Creeping red fescue significantly, at least during the first eight weeks (Table 2-4). The early survival rate for selected native grass species were above 90%. In 8 weeks, Bluejoint shoots were too weak to withstand fertilizer addition, which burned and dried the seedlings and cause a low establishment rate. This indicates that Bluejoint is not tolerant to CT as expected.

2.7.3 Plant performance

Plant growth in the CT deposits varied. Bluejoint only emerged in treatment-1, grew poorly and died before the end of the experiment. Hairy wild rye was stunted and produced little new growth over the 10 weeks experiment. The measurements of plant growth in treatment-1 are given in Table 2-4 and Figure 2-3. Of the species tested, Slender wheatgrass and Northern wheatgrass had the greatest emergence, plant height, biomass and developed the largest leaf areas. These two plant species also produced the longest root system. At the end of this experiment, roots of Slender wheatgrass and Northern wheatgrass reached and crawled at the bottom of the containers and may have developed deeper if not limited by the container. Creeping red fescue grew well with little stunted growth and short rootstalks. Hairy wild rye wilted at the end of experiment. Figure 2-3 showed the average plant height curve monitored every week after seeding in treatment-1, After 8 weeks, Fertilizer (20-8-20) added biweekly, the average plant average height increased dramatically after 10 weeks for Slender wheatgrass, Northern wheatgrass and Creeping red fescue. However, Bluejoint had wilted and dry leaves and died at 9 weeks after fertilization since its seedlings were small and too weak to survive fertilizer.

2.8 Conclusions

Selected five native grass species emerged in the CT when different seeding techniques were used. The most successful native plant species were Northern wheatgrass, Slender wheatgrass and Creeping red fescue. Northern wheatgrass and Slender wheatgrass were tolerant of the CT mixture and grew well during 15 weeks (105 days), at least in these greenhouse experiments. Selected native grass species have the potential to dewater CT. The CT substrate resulted in the reduction of emergence rates, leaf injury and a reduction in growth due to the high concentration of soluble salt and deficiency in nutrient during the first 8 weeks of this study. Additional research is required to determine long-term plant management strategies and appropriate fertilizer addition rates for these five native grass species.

Broadcast seeding, hydro-seeding with mulch and discharge of CT slurry containing seeds were successful for seeding grasses onto CT deposits. Some seeds floated during all seeding techniques. Broadcast seeding covered with subsoil and slurry seeding provided good soil seeds contact which increased plant emergence rate. However, the thickness of slurry mixed with seeds is important, especially when compared to the seeds size. Hydro-seeding with mulch worked so well that the seed is suspended in the mulch, which seals in the moisture to help seeds germination and rooting in CT, and the seed is at an ideal depth for good germination and further growth.

Fertilizer 20-8-20 (N-P-K) added at 100 ppm during seeding did not increase plant germination and emergence but did help plant grow for Slender wheatgrass, Northern wheatgrass and Creeping red fescue. Over fertilization occurred in Bluejoint burned its leaves and cause it die before the end of experiment.

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Table 2-1 Geotechnical parameters of tailings samples

Tailings sample		Water content (%)	Solids content (%)	Fines content (%)
MFT	Barrel 1	121.6	45.1	64.6
	Barrel 2	243.3	29.1	93.0
Sand		3.8	96.3	3.0
Gypsum		7.5	93.0	N/A
CT mixture		63.6	65.1	20.0

Table 2-2 Chemical analysis and major ions of pond water, MFT and CT mixture

	Pond water		MFT+		CT+		Optimum of grow media*
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	
pH	7.69	7.69	6.95	6.95	7.47	7.49	6-8
E.C (dS/m)	3.19	3.19	1.42	1.43	1.59	1.51	<1
Nitogen (ppm)	39	41.9	63.5	65.1	61.1	62.5	100-199
Phosphate (ppm)	BDL	BDL	BDL	BDL	BDL	BDL	6-10
Potassium (ppm)	20.9	24.0	26.8	27.1	29.0	29.6	150-240
Magnesium (ppm)	5.0	5.5	11.6	12.9	64.7	62.2	30-70
Calcium (ppm)	5.8	4.8	15.0	17.3	241.7	234.6	80-200
Sodium (ppm)	1696.3	1718.9	1863.1	1727.3	707.7	689.2	0-80
SAR	124.95	127.39	87.90	76.60	10.44	10.32	<13#
Sulfate (ppm)	339.2	341.2	1.4	1.5	1514.9	1520.2	N/A
Chloride (ppm)	292.0	289.6	135.5	141.6	192.9	193.0	N/A
Fluoride (ppm)	2.9	2.6	1.4	1.0	1.4	1.3	N/A

* Warncke (1998)

Davis et al. (2006)

+ Concentrations of ions are for the paste saturate water for each sample

BDL: Below detection level

Table 2-3 Average percent emergence and average percent survivial for individual seeding treatments

Native plant species	Seeding treatments *	Average number of emerged			Average number of seedling suvivial		Average emergece rate (%)		Average survival rate (%)	
		4 weeks	6 weeks	8 weeks	6 weeks	8 weeks	4 weeks	6 weeks	6 weeks	8 weeks
Hairy wild rye	Treatment-1	10.7	11.0	11.3	11.0	10.7	21.4	22.0	100.0	94.7
	Treatment-2	9	10.7	10.7	10.7	9.7	18.0	21.3	100.0	90.6
	Treatment-3	--	--	--	--	--	--	--	--	--
	Treatment-4	0.7	1.3	1.7	1.3	1.7	1.3	2.7	100.0	100.0
	Treatment-5	--	--	--	--	--	--	--	--	--
	Treatment-6	--	--	--	--	--	--	--	--	--
Northern wheatgrass	Treatment-1	24.3	25.0	27.7	25.0	27.7	48.6	50.0	100.0	100.0
	Treatment-2	21.3	26.7	27.3	26.7	27.0	42.7	53.3	100.0	98.8
	Treatment-3	11.0	16.0	15.7	15.7	14.7	22.0	32.0	97.9	93.6
	Treatment-4	7.3	15.0	22.7	15.0	22.7	14.7	30.0	100.0	100.0
	Treatment-5	20.7	25.0	26.3	25.0	25.3	41.3	50.0	100.0	96.2
	Treatment-6	13.0	19.0	22.0	17.7	20.3	26.0	38.0	93.0	92.4
Creeping red fescue	Treatment-1	11.0	11.7	14	11.7	14	22.0	23.4	100.0	100.0
	Treatment-2	18.0	20.0	21.7	19.3	20.7	36.0	40.0	96.7	95.4
	Treatment-3	10.3	15.0	18.0	13.7	16.3	20.6	30.0	91.1	90.7
	Treatment-4	0.7	2.3	9.3	2.3	9.3	1.4	4.6	100.0	100.0
	Treatment-5	4.7	11.0	14.3	11.0	13.7	9.3	22.0	100.0	95.4
	Treatment-6	7.7	15.0	18.0	14.3	17.0	15.4	30.0	95.5	94.4

Table 2-3 (Cont.)

Slender wheatgrass	Treatment-1	21.7	21.7	25.3	21.7	25.3	43.4	43.4	100.0	100.0
	Treatment-2	8.0	9.3	11.0	9.3	10.3	16.0	18.7	100.0	93.9
	Treatment-3	15.0	21.0	24.7	20.7	24.3	30.0	42.0	98.4	98.6
	Treatment-4	5.3	9.7	12.3	9.7	12.3	10.6	19.4	100.0	100.0
	Treatment-5	10.0	13.7	14.0	13.7	13.7	20.0	27.3	100.0	97.6
	Treatment-6	14.0	21.0	22.0	20.3	21.7	28.0	42.0	96.8	98.5
Bluejoint	Treatment-1	6.7	6.7	6.7	1.3	0.6	13.3	13.3	19.9	9.0
	Treatment-2	0.0	0.7	0.7	0.7	0.3	0.0	1.3	100.0	50.0
	Treatment-3	--	--	--	--	--	--	--	--	--
	Treatment-4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Treatment-5	--	--	--	--	--	--	--	--	--
	Treatment-6	--	--	--	--	--	--	--	--	--

* Note: Treatment-1: Broadcast seeding
Treatment-2: Hydroseeding with mulch
Treatment-3: 0-4 mm Fresh discharged CT slurry seeding
Treatment-4: 4-6 mm Fresh discharged CT slurry seeding
Treatment-5: Hydroseeding with mulch and fertilizer
Treatment-6: 0-4 mm fresh discharged CT slurry seeding with fertilizer

Table 2-4 Number of living seedling, survival rate, leaf number ranges, seedling colour, average maximum height in treatments after 6 and 8 weeks

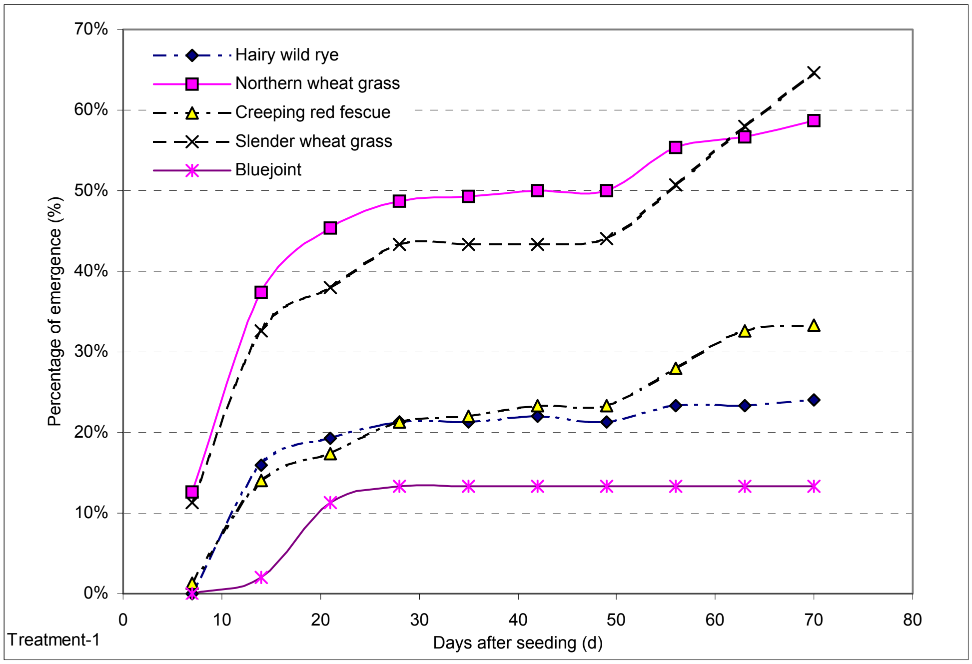
Treatments	Native plant species	Emergence rate (%)		Number of living seedling		Survival rate (%)		Leaf Number range		Seedling colour *	Maximum Seedling Height (mm)		
		6 weeks	8 weeks	6 weeks	8 weeks	6 weeks	8 weeks	6 weeks	8 weeks		6 weeks	8 weeks	10 weeks
Treatment-1	Hairy wild rye	22.0	22.6	11.0	10.7	100.0	94.7	1-3	1-5	1,5 (D/W)	126.0	126.0	126.0
	Northern wheatgrass	50.0	55.4	25.0	27.7	100.0	100.0	1-3	1-6	1,5 (D/W)	123.0	131.0	152.0
	Creeping red fescue	22.0	22.0	11.7	14.0	100.0	100.0	1-3	1-5	1,2,5 (D/W)	109.0	109.0	123.0
	Slender wheatgrass	43.4	50.6	21.7	25.3	100.0	100.0	1-3	1-5	1,4 (D)	175.0	178.0	201.0
	Bluejoint	13.3	13.3	1.3	0.6	19.9	9.0	1-2	1	--	45.0	16.0	17.0
Treatment-2	Hairy wild rye	21.3	21.3	10.7	9.7	100.0	90.6	1-3	1-3	1,5 (D/W)	74.3	76.3	73.7
	Northern wheatgrass	53.3	54.7	26.7	27.0	100.0	98.8	1-3	1-4	1,5 (D/W)	129.3	128.7	141.0
	Creeping red fescue	38.7	43.3	19.3	20.7	96.7	95.4	1-3	1-3	1,2,5 (D/W)	81.0	95.0	105.3
	Slender wheatgrass	18.7	22.0	9.3	10.3	100.0	94.0	1-3	1-4	1,4 (D)	136.6	159.0	161.0
	Bluejoint	1.3	1.3	0.7	0.3	100.0	50.0	1-2	1	--	20.0	15.0	0.0
Treatment-3	Northern wheatgrass	32.0	32.0	15.7	14.7	97.9	91.7	1-3	1-3	1,5 (D/W)	117.0	142.3	140.7
	Creeping red fescue	30.0	36.0	13.7	16.3	91.1	90.7	1-2	1-3	1,2,5 (D/W)	78.0	87.3	102.0
	Slender wheatgrass	42.0	49.3	20.7	24.3	98.4	98.7	1-3	1-3	1,4 (D)	157.3	157.7	162.3

Table 2-4 (Cont.)

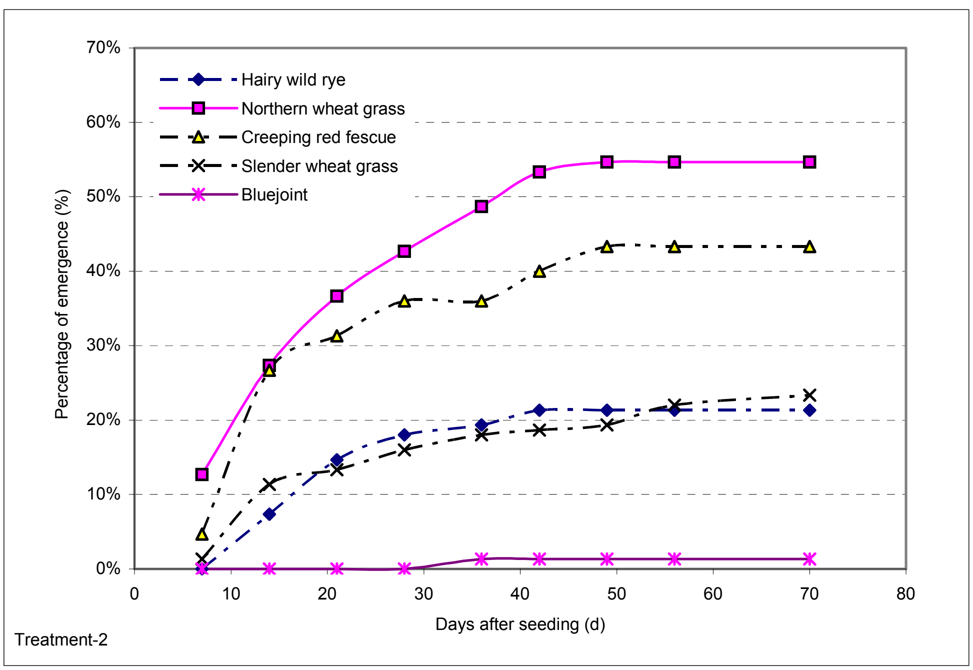
Treatment-4	Hairy wild rye	2.7	3.3	1.3	1.7	100.0	100.0	1-2	1-3	1,5 (D/W)	45.5	46.0	50.7
	Northern wheatgrass	30.0	45.3	15.0	22.7	100.0	100.0	1-3	1-3	1,5 (D/W)	107.3	141.7	152.3
	Creeping red fescue	4.6	18.7	2.3	9.3	100.0	100.0	1-3	1-3	1,2,5 (D/W)	60.6	79.3	79.7
	Slender wheatgrass	19.4	24.7	9.7	12.3	100.0	100.0	1-4	1-4	1,4 (D)	130.0	130.0	148.3
	Bluejoint	0.0	0.0	0.0	0.0	--	--	--	--	--	0.0	0.0	0.0
Treatment-5													
	Northern wheatgrass	50.0	52.7	25.0	25.3	100.0	96.2	1-3	1-4	1,5 (D/W)	109.0	116.7	137.3
	Creeping red fescue	22.0	28.7	11.0	13.7	100.0	95.4	1-2	1-2	1,2,5 (D/W)	48.7	71.7	77.3
	Slender wheatgrass	27.3	28.0	13.7	13.7	100.0	97.6	1-3	2-4	1,4 (D)	141.7	143.3	176.0
Treatment-6													
	Northern wheatgrass	38.0	44.0	17.7	20.3	93.0	92.4	1-3	1-3	1,5 (D/W)	111.3	112.3	122.0
	Creeping red fescue	30.0	36.0	14.3	17.0	95.5	94.4	1-4	1-4	1,2,5 (D/W)	78.0	101.3	93.0
	Slender wheatgrass	42.0	44.0	20.3	21.7	96.8	98.4	1-4	1-4	1,4 (D)	160.7	174.3	170.0

Note: * green=1, yellowish green=2, pinkish or purple=3, reddish=4, yellow=5, black or brown=6, white=7, brownish green=8,
D: indicates drying tips, W: indicates wilting.

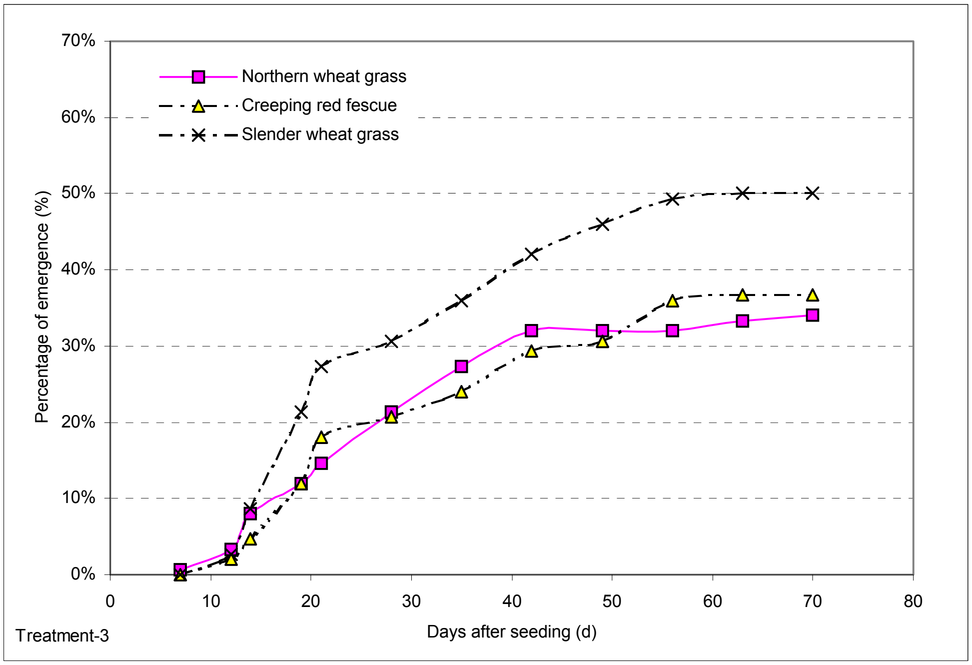
Figure 2-1 illustration of Geo-grid system used in hydro-seeding treatments


Hairy wild rye
Northern wheat grass
Creeping red fescue
Slender wheat grass
Bluejoint
Percentage of emergence (%)
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
80
Days after seeding (d)
Treatment-1

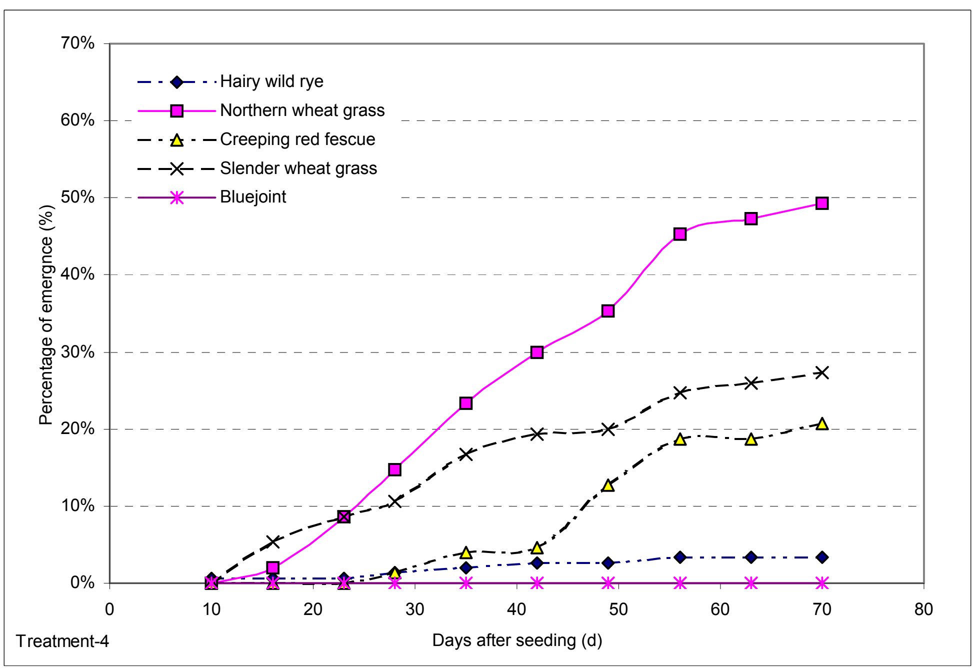
(a)


Hairy wild rye
Northern wheat grass
Creeping red fescue
Slender wheat grass
Bluejoint
Percentage of emergence (%)
70%
60%
50%
40%
30%
20%
10%
0%
0
10
20
30
40
50
60
70
80
Days after seeding (d)
Treatment-2

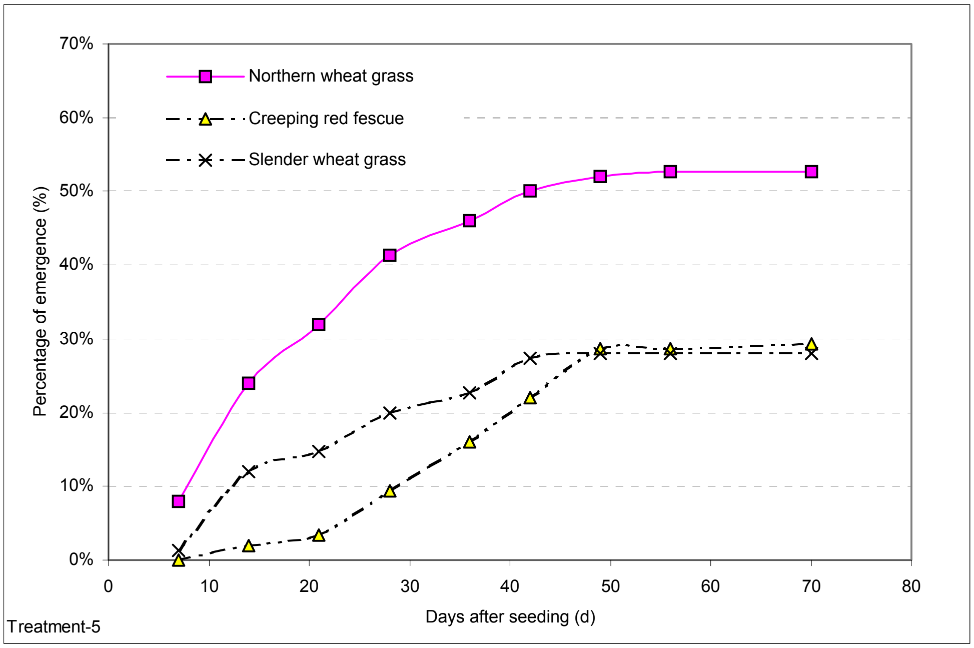
(b)


70%
60%
50%
40%
30%
20%
10%
0%
Percentage of emergence (%)
Northern wheat grass
Creeping red fescue
Slender wheat grass
0
10
20
30
40
50
60
70
80
Days after seeding (d)
Treatment-3

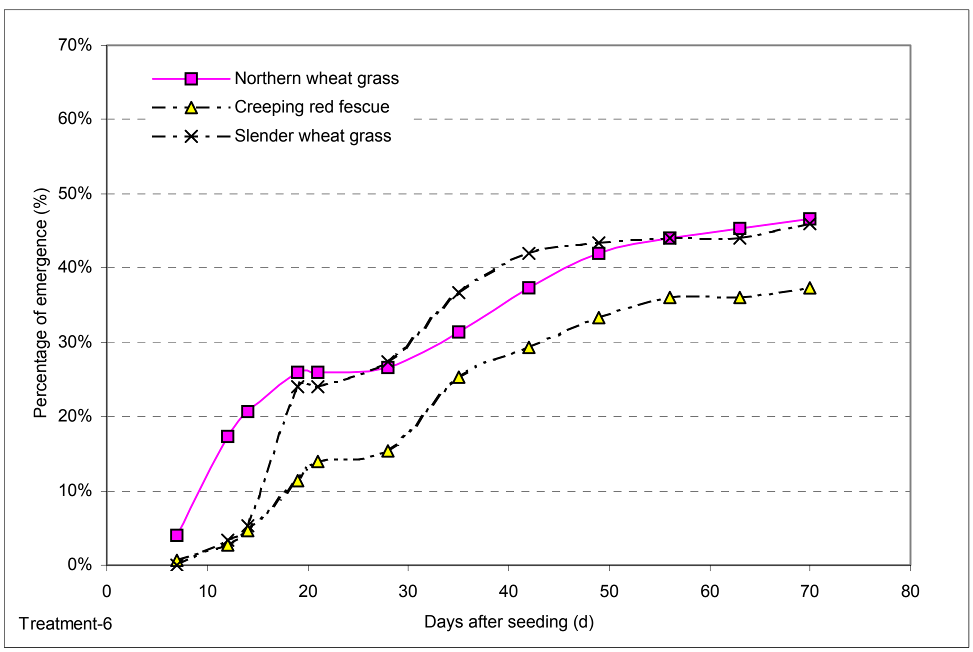
(c)


70%
60%
50%
40%
30%
20%
10%
0%
Percentage of emergnce (%)
Hairy wild rye
Northern wheat grass
Creeping red fescue
Slender wheat grass
Bluejoint
0
10
20
30
40
50
60
70
80
Days after seeding (d)
Treatment-4

(d)



(e)



(f)

Figure 2-2 Seedling emergence of plants in CT substrate seeding by different seeding treatments

(a) broadcast seeding; (b) hydro-seeding with mulch; (c) 0-4 mm slurry seeding; (d) 4-6 mm slurry seeding; (e) hydro-seeding with mulch and fertilizer; (f) 0-4 mm slurry seeding with fertilizer

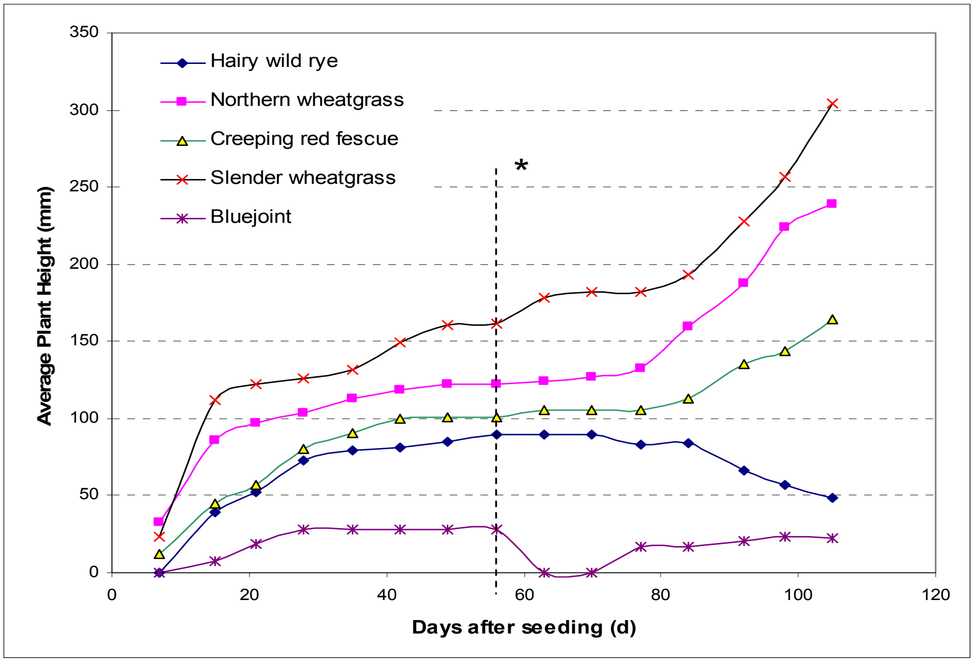


Figure 2-3 Average Plant Height in Treatment-1
Note *: Fertilizer added every two weeks

3 NATIVE PLANT EVAPOTRANSPIRATION EFFECT ON DEWATERING CT

3.1 Introduction

The Clark Hot Water Extraction (CHWE) of bitumen from Oil Sands located at Fort McMurray produces significant amounts of waste consisting of water, sand, fines and residual bitumen annually. These wastes are deposited hydraulically in safe impoundment areas. Currently, approximately 700 million cubic meters of mature fine tailings (MFT) at a solids content of 30% (gravimetric water content of 233%) is stored and if current discharge methods continue, one billion cubic meters of storages will be required by 2020 (Liu et al. 1994). Upon deposition in tailings facilities, sand segregates from the tailings slurry, leaving fine tailings (silt and clay) with 5% solids content, which flows into the pond. These gradually settle and undergo self-weight consolidation to form MFT after about two or three years. MFT is an unstable liquid with extremely low strength and will take centuries to dewater via self weight consolidations.

The major challenges emanating from this disposal method are the difficulty of dewatering the waste because of its low hydraulic conductivity, high compressibility, the potential risk to release water and contaminate the groundwater, and the stability of containment dykes. The ultimate reclamation of MFT deposits is a substantial long-term environmental challenge. Conventional reclamation will not be possible until the surface of the tailings is able to support light machines and human activities.

Since about 1995, CT prepared by mixing MFT with a stream of cyclone underflow (tailings sand) and the appropriate amount of gypsum to produce non-segregating Composite/Consolidated Tailings (CT) has been used. At this 65% solids content, CT is semi-plastic, but still a weak slurry (Qiu and Sego, 2001). CT needs to be dewatered to 85% solids content for its shear strength to be sufficient to support traffic that allows reclamation activities to proceed (Silva, 1999).

Natural evaporation has been used in land reclamation (Volker, 1982) and in dewatering tailings (McFarlin et al. 1989; Johnson et al. 1993; Li and Feng, 1995). The studies on dewatering Mature Fine Tailings (MFT) have indicated that the evaporation of water from fine tailings depends on the potential atmospheric evaporation and the physiochemical characteristics of the fine tailings. While the saturated tailing surface de-saturated by evaporation, the evaporation rate drops dramatically due to salt crust formation on CT test samples (Qiu and Sego, 2001). This crust interferes with the evaporation process and causes the evaporation rate to dramatically decrease limiting further evaporation.

Plants utilize biological processes to dewater these oil sands waste. The mechanisms of dewatering by plant species have been identified by many researchers. Laboratory and field experiment results (Johnson et al. 1993; Stahl, 1996; and Silva, 1999) have indicated that suitable plant species are able to transpire water through their leaves depleting soil moisture and enhancing soil shear strength. Furthermore, the plant root system provides fiber reinforcement, which also contributes to increasing bearing capacity by increase cohesion within the rooted tailings zone (Gray, 1982; Coppin and Richards, 1990; Stahl, 1996; Silva 1999).

During the past decade, non-native introduced plant species have been considered as preferred plant species for dewatering high water content CT materials since they are tolerant to the high salinity CT materials and have substantial survival characteristics (Johnson et al., 1993; Silva et al., 1998; Naeth et al., 1999; Renault et al., 2003; 2004). These aggressive characteristics that make these exotic species successful also result in their dominance and competitive exclusion of slower growing native plant species. Past use of non-native plants on revegetated sites in Alberta has resulted in the exclusion of native species (Alberta Environment, 2003). These non-native plants also have the potential to alter natural communities when they invade nearby non-disturbed areas. Presently, Alberta’s native landscape has been changed by industrial and commercial development. The loss of these important native plant species may negatively impact ecosystem development and how it functions (Lyster et al. 2001).

Nowadays, the use of native plant species in reclamation projects is preferred because native plant species have established over long period of time under local soil conditions and are well adapted to survive in the annual climate fluctuations. Also, native plants often have minimal insect attack and perform satisfactorily without supplementary irrigation or maintenance (Alberta Environment, 2003).

For the purposes of dewatering CT, cool season grasses have been considered, allowing effective dewatering to be achieved in the first season, because grasses usually establish quickly and develop an extensive root system. Grass species have many advantages for enhancing the surface stability of CT soils: first, their root systems are fibrous, which makes them excellent soil binders. Some grasses also have underground stems, which produce new shoots at each node (Alberta Agriculture, 1981); second, grass leaves have parallel veins and are flat or folded. Leaf growth is therefore necessary for good growth of the plant and evapotranspiration; third, grasses offer adaptability and flexibility. Various grass species have superior adaptation to extreme climate and soil conditions. This includes a high tolerance to flooding, water-saturated soil, drought, heat, cold, salinity, acidity, and alkalinity. Many grasses are long-lived and establish vigorous stands.

Other reasons for utilizing grasses include the short growth period required, higher germination rate, easier and more economical seeding techniques and development of continuous ground cover. When the grasses are established, other local plant species may also then invade these grass covered surfaces. This is expected to result in natural processes of dewatering the high moisture content tailings and even vegetative succession at these sites.

Plants have been widely used in civil engineering to enhance slope stability, erosion prevention and landscape reclamation (Schiechtl, 1980; Bache and MacAskill, 1984; and

Coppin and Richards, 1990). Plants have the ability to modify the water content of the soil by evapotranspiration and interception in the foliage to limit buildup of soil moisture. Mechanically, plants increase the strength and competence of the soil in which it is growing and therefore contributes to its surface stability (Gray and Leiser, 1982). Results of a model study by Brenner (1973) indicated that the matric suction of soil with trees increased 64% in 160 hours after a storm. Forest cover therefore accelerates soil moisture depletion in a shallow soil mantle beneath the forest.

The capacities to uptake water and chemical elements from soil through evapotraspiration have been well studied in agriculture and water resource management. Linear and nonlinear simulation models exist (Feddes et al., 1974; 1978; Gardner, 1960, 1983; Molz and Remson, 1970; Prasad, 1988; Raats, 1976; Wu et al. 1999). Plants can significantly affect soil moisture through evapotranspiration resulting in soil moisture depletion and soil weight reduction (Bache and MacAskill, 1984; Coppin and Richards, 1990).

Vegetation has been noted as one practical and economical approach to reclaim high water content materials (Krizek, 2004). For some materials conductive to vegetation growth near surface dewatering can be accomplished by transpiration through the leaves fed by upward movement via the root systems of appropriate plants. They transpire large quantities of water during the growing seasons. The rate of water loss generally exceeds free water evaporation rate from the saturated surface and continue long after the surface becomes dry.

In addition, after comparing the cost of different methods, using physical, chemical, vegetative, and combined stabilization procedure were developed, these were used in protecting fine grain tailings from wind blowing in United States mining waste disposal, Dean and Havens (1972) indicated that the vegetative method was the most economical reclamation method, and recommended vegetative stabilizing procedure should be preferred.

The pioneering and practical application of plants to dewater lacustrine and marine sediment was carried out in polder reclamation (Public Relations and Information Department of the Netherlands, 1959; Volker, 1982). Ocean bottom sediments have an extremely high water content, low hydraulic conductivity and low bearing capacity, which is similar to oil sands tailings in these physical and engineering properties. Plants applied in polder reclamation accelerated the drying process via evapotranspiration.

The influence of plants in dewatering high water content materials has been observed in the reclamation of tailings. Based essentially on the research and reclamation work carried out on tailings disposal areas in northeastern Canada, Leroy (1972) highlighted that a fully vegetated acre will transpire from 4.5 to 9.0 mm of water daily, and summarized the basic guidelines of soil amenity, fertilizer application, seeding and mulching for successful and acceptable reclamation of mine tailings.

The dewatering of fine grain mine tailing and Composite/Consolidated Tailings (CT) by natural processes has been also recognized by Stahl (1996), Johnson et al. (1993), and Silva (1999). The laboratory and field experimental results concluded that suitable plant species are capable of increasing surface stability by increasing the cohesion and friction angle of the reinforced soil mass. Plants growing in tailings can remove the water via evapotranspitation increasing the solids content causing negative water pressure (suction) and increasing the effective stresses, which result in increasing the shear strength and bearing capacity of soils.

Greenhouse experiments carried out by Silva (1999) evaluated the response of introduced plant species: Altai wildrye (*Elymus angustus*); Creeping foxtail (*Alopecurus arundinaceus*); Red top (*Agrostis stolonifera*); Reed canarygrass (*Phalaris arundinacea*); and Streambank wheatgrass (*Agropyron riparian*) to dewater CT. He identified that CT was not phytotoxic to those species. After one growing season, the solids content of the upper layer increased from 68% to 95% by evapotranspiration.

In this research greenhouse experiments were carried out to follow the studies of native plant selection for dewatering CT deposits. The objective of this study is to evaluate the dewatering response of these native grass species on Composite/Consolidated Tailings (CT). Seeds of these grass species were directly seeded using broadcast seeding, hydro-seeding with Fibramulch^{TM}, and fresh discharged slurry seeding techniques. An additional objective is to evaluate the water loss from the CT materials via native plant evaportranspiration during 15 weeks testing period. These studies were carried out in a climate controlled greenhouse previously described.

3.2 Theoretical model for estimating plant evapotranspiration

Evapotranspiration is a crucial component of the water balance. The rate of water uptake from soil through plant root-stem-leaves system in a crop with a uniform but incomplete canopy may be limited by soil, plant and atmosphere factors. Evaporation from a wet soil surface is primarily influenced by the energy available. When the plants are in an early growth stage with little vegetative cover, the evapotranspiration rate from the entire field surface is dominated by the soil evaporation. As the surface dries, evapotranspiration becomes more important and it depends on the hydraulic properties of the near surface soil. As the plant canopy increases, transpiration via plant becomes more dependent on the leaf area and the ability of the root system to supply water to the plants (Penman et al. 1967).

An empirical relationship presented by Ritchie (1972) is widely used to predict the plant transpiration in which the evaporation from soil surface and transpiration from plant surface are considered separately. The evapotranspiration (E) is then distributed into soil evaporation (E_s) and plant transpiration (E_p).

$$E = E_s + E_p \qquad (1)$$

Based on the local data including rainfall, temperature, wind speed, and the net radiation data in the central Texas, U.S.A., the plant transpiration under incomplete cover condition can be expressed as:

$$
\begin{aligned}
E_p &= 0 && LAI < 0.1 \\
E_p &= E_0\,(-0.21 + 0.7LAI^{1/2}) && 0.1 \le LAI \le 2.7 \\
E_p &= E_0 && LAI > 2.7
\end{aligned}
\tag{2}
$$

The potential evaporation (E_0) is calculated from the measured actual evaporation (E_s) as:

$$E_0 = E_s/K_{evap} \tag{3}$$

Where, K_{evap} is an evaporation limiting factor (Silva, 1999). For CT deposits, accounting for hydraulic properties and salt crust formation, the surface evaporation rate drops to about 0.6 of potential evaporation after approximately 10 days (Qiu and Sego, 2001). LAI is leaf area index, which is defined as the area of one side of leaves per unit of soil surface (Jensen et al., 1990).

A dimensionless parameter α representing the ratio of dewatering by plant defined as plant dewatering capacity over initial soil water storage ((E-P')/M_{w0} in percentage) was introduced in this green house study to estimate the transpiration by plant. According to the Ritchie (1972) model that plant transpiration is a function of LAI.

$$\alpha = \frac{(E - P')}{M_{w0}} = f(LAI) \tag{4}$$

Where, E is evapotranspiration, P' is precipitation, M_{w0} is initial water mass in the soil.

3.3 Materials and Laboratory Experiment Design

3.3.1 Tailings (CT)

Composite Tailing (CT) was prepared by mixing sand, MFT, pond water and gypsum ($CaSO_4{\cdot}2H_2O$), provided by Suncor Energy Inc. The amount of gypsum added was approximately 1.2 kg/m^3. The CT mixture has an initial solids content of 65% and contains 20% fines (< 44 μm, # 325 sieves). In the laboratory, the CT mixture was prepared in several batches to produce a homogenous material.

The value of nutrient status, pH and electrical conductivity (EC) for the CT mixture used in this study had a pH of 7.48 and Sodium Adsorption Ratio (SAR) of 10.4. Based on the combined value of SAR and pH, CT can be classified as a slightly salinity soil as outlined in Chapter 2.

3.3.2 Plant species

The prerequisite of using plants to dewater tailing slurry is the screening of available plant species. Vegetation is a complex mosaic of types influenced by aspect, elevation, micro-site climate, and soils. The selection of plants, which are capable of growing directly in CT deposits and remove water from soft deposits, requires that the selected species should be tolerant of the adverse soil conditions and local climate condition of the specific site (Ripley et al. 1978).

Salinity is a common problem in CT deposits which contains high concentrations of Na^+, Cl^-, and SO_4^{2-}. In the initial stage, plant species need high salinity tolerance since seeds and shoots will be exposed to relatively high levels of salt resulting from contact with CT. In addition, the seeds should be viable and germinate quickly at low surface temperatures. Once established, the plants should grow quickly, producing high Leaf Area Index (LAI) and a deep root system to enhance dewatering of the CT deposits. However, selected plants should not mature early since plants, which flower or set seed usually stop root production. This would significantly shorten the duration of rapid transpiration and thus reduce dewatering.

Through screening of native plant species listed in Alberta Agriculture (1981); Hardy BBT Ltd (1989); Johnson et al. (1993); Naeth et al. (1999); Native Plant Working Group (2001), five native grass species: Bluejoint (*Calamagrostis canadensis*), Creeping red fescue (*Festuca rubra*), Hairy wild rye (*Elymus innovatus Beal*), Northern wheatgrass (*Agropyron dasystachyum*), and Slender wheatgrass (*Agropyron trachycaulum*) were selected for this greenhouse experiment. Seeds were planted using different seeding techniques as outlined in Chapter 2.

3.3.3 Greenhouse experiments

Ninety four-liter plastic pails having a diameter of 218 mm and a height of 145 mm were used as containers during the experimental program. The container was filled with CT to the depth of 130 mm. Self-weight consolidation was allowed to occur and expressed water was siphoned from the surface. Three replicates were prepared for each plant species and each different seeding treatment. In addition, three samples were left unplanted as a control.

The pails were placed in a controlled environment greenhouse at 22 ^{0}C average air temperature with 15 hours of light and 9 hours darkness, simulating the typical growing climate condition in Fort McMurray in June. Mercury and sodium vapor lights (400 W) acted as supplemental light to complement the low light intensity in the greenhouse during late fall and winter when the tests were carried out. Plants were placed randomly rather than placing all the plants with a particular seeding method together to minimize the effect of any environmental differences.

Distilled water was added twice a week to the surface of CT soil to simulate the average precipitation (9.8 mm per week) from May through September. Since the standing water would float the seeds out of the soil causing germination decrease, the amount of distilled water added was approximately 89% of the average precipitation.

Fertilizer 20-8-20 (N-P-K) was added biweekly after the initial germination study (week 1 to 8). The application rate was 100 ppm.

In treatment-1, broadcast seeding was applied on September 21, 2006 and plants were harvested on January 5, 2007. In treatment-4, seeds were seeded using 4-6 mm fresh discharged CT slurry seeding techniques on October. 23, 2006 and plants were harvested on February 4, 2007.

3.4 Measurements

3.4.1 Plants

Plant density could affect the plant growth height and canopy light interception (van der Werf, 1997). The population of the plant was determined by counting the plant tillers, the plant density then was calculated in plants per m^2. Weekly plant height measurements began 7 days after seeding and continued for 15 weeks to monitor the plant growth in treatment-1 and treatment-4 during 15 weeks (105 days). At the end of the experiment, the leaf area index was determined using the following procedure. The leaves of a subsample from each container were carefully put on a scanner (HP C5195). The leaf areas were then measured using UCPE-leaf area measurement program (The University of Sheffield, UK). The total leaf area was determined by multiplying the area of the subsample by the total number of leaves. These leaf areas were then used to calculate the Leaf Area Index (LAI, dimensionless), which is defined as the area of one side of leaves per unit of soil surface (Jensen et al. 1990).

After fifteen weeks, plants in treatment-1 and treatment-4 were harvested by using a scissor cutting the plant from the CT surface; gently cleaned with soft paper towel and weighted to measure the wet plant weights. Then, the plants were washed three times with distilled water, the samples were air dried for three days and weighted, then they were oven dried for 12 hours or until the constant weight at 65 ^{0}C to determine the dry plant weight.

One random whole soil sample for each plant species was used to determine the root weights of selected grass species. Samples were submerged in a pail of water, then loose soil and the roots were removed carefully. Roots were washed using distilled water and paper towel dried. The samples were air dried for three days and weighted to determine the wet weight of roots, then oven dried 12 hours or until the constant weight at 65 ^{0}C and the dry weights were determined. Plant dry biomass (mg dry wt.) above and below ground was calculated.

3.4.2 Solids content profile

After fifteen weeks of plant growth, solids contents were measured by taking soil samples using a 37.7 mm diameter thin walled tube sampler at depths of 0-15 mm, 15-30 mm, 30-45 mm, 45-60 mm, 60-75 mm to obtain a profile of solids content resulting from evapotranspiration in the planted samples and evaporation in the unplanted control samples.

3.4.3 Evapotranspiration and evaporation

Water lost by plant evapotranspiration and evaporation was measured weekly by weighting the planted samples and unplanted sample containers, respectively (Ritchie and Burnett, 1968). The dimensionless parameter α was calculated for estimating native plant dewatering capacity.

3.5 Results and discussions

Native grass species germinated reasonable in CT when using different seeding techniques. In treatment-1, Slender wheatgrass and Northern wheatgrass produced the highest plant density, 1167 plants/m^2 and 1008 plants/m^2, respectively, followed by Creeping red fescue, 583 plants/m^2. Hairy wild rye and Bluejoint had the lowest plant density (Table 3-1) because of the poor emergence (Chapter 2).

Average plant growth height versus time curve shown in Figure 3-1 indicated that the average plant height reached the maximum height after approximately fifteen weeks. Slender wheatgrass and Northern wheatgrass demonstrated a high degree of tolerance to the growing conditions in CT deposits, the heights of Slender wheatgrass and Northern wheatgrass reached 30.4 cm and 23.9 cm, respectively, at fifteen weeks in treatment-1 (Figure 3-1 (a)). Fertilizer added biweekly after 8 weeks did help with the plant growth. Slender wheatgrass and Northern wheatgrass would have grown higher if the experiment continued. However, it appears that the growth of Hairy wild rye and Bluejoint was dramatically delayed. Creeping red fescue presented a stunted growth. Similar observations can be made when the seeds were spread using the fresh CT discharge slurry to assist with seeding (Figure 3-1 (b)). The initial waterlogged conditions, slightly salinity soil, and the climate conditions likely contributed to lower growth in treatment-4.

Leaf area index (LAI) of each plant species for each treatment was calculated from the measured leaf area (Table 3-2). The ability of a plant to intercept energy and to transpire water from soil increases with leaf area index (LAI) (Ritchie, 1972). LAI was greatest for Slender wheatgrass in all treatments followed by Northern wheatgrass. Hairy wild rye and Bluejoint produced the lowest LAI because of low emergence rates, plant density and stunted plant growth in the treatments.

Slender wheatgrass and Northern wheatgrass species produced the highest shoots and roots dry weights (Table 3-3) compared to Creeping red fescue, Hairy wild rye and Bluejoint. Moreover, Slender wheatgrass and Northern wheatgrass produced the higher root to shoot ratio (1.05 and 1.49, respectively), followed by Creeping red fescue (0.79) and Hairy wild rye (0.67).

Selected native grass seeds were seeded by using the broadcast seeding technique (treatment-1), after fifteen weeks of growth, the dry biomass (Figure 3-2 (a)) ranged from 1.05 mg to 2306.4 mg below ground, from 1.8 mg to 2421.7 mg above ground, and from 2.85 mg to 4728.1 mg for total biomass. Slender wheatgrass produce the highest total dry biomass (4728.1 mg) followed by Northern wheatgrass (2087.2 mg). The data shown in Figure 3-2 (b) also indicated the dominance dry biomass for Slender wheatgrass and Northern wheatgrass.

The total amount of water lost from CT through evapotranspiration or by evaporation alone in the case of unplanted samples after 15 weeks of plant growth is schematically illustrated in Figure 3-3. The plant species with the highest dewatering capability were Northern wheatgrass (164.2 mm in treatment-1 and 191.3 mm in treatment-4) and Slender wheatgrass (164.3 mm in treatment-1 and 190.1 mm in treatment-4). The evaporation from the CT mixture surface in the unplanted samples was 156.4 mm and 184.7 mm, in treatment-1 and treatment-4, respectively. Plant evapotranspiration is greater than soil evaporation. Bluejoint transpired less water than other plant species because of its poor plant emergence and physiological state.

In Figure 3-3, at the end of the experiment, the water lose in all planted samples are higher than unplanted samples. It indicates that the water lose via plant evapotranspiration is greater than via soil surface evaporation and selected native plants have capacity of uptaking water from CT. But very little difference in dewatering was observed between individual plant species and the unplanted samples. The following evidence can explain this results: first, plant evapotranspiration test followed emergence tests, plant density is low to uptake a significant amount of water from CT materials; second, when simulated precipitation water was added to test experiments, free water stood on the surface in the unplanted samples which resulted from salt crust formation and prevented water from soaking into the CT. In this condition, the tests are similar to pan evaporation tests. However, planted samples having plant root channels guided water into the CT (Figure 3-4). The free pan evaporation rate is much greater than CT surface evaporation (Johnson, 1993).

Using the dimensionless parameter α to present plant evapotranspiration is shown in Figure 3-5, Most of α values are greater than zero. It can be seen that all selected native plant species that grew in CT materials did uptake more water by plant transpiration than CT surface evaporation. Northern wheatgrass and Slender wheatgrass had higher plant dewatering capacity ratios α.

Figure 3-6 showed the trend lines between parameter α and LAI for Northern wheatgrass and Slender wheatgrass. The dewatering capacity parameter, α, generally increases while the LAI increases.

Based on the limited data obtained, it is difficult to find an accurate formula to represent the relationship between parameter α and LAI. In this study, the test data were attempted trending with linear curves. R-square values of those curves were obtained as 0.72 and 0.016 for Northern wheatgrass and Slender wheatgrass, respectively, indicating the inaccuracy of those two trend lines. Further research is required to obtain an accurate relationship between dewatering capacity parameter α and LAI to simulate the prediction of plant dewatering capacity.

As water evapotranspired or evaporated from the surface, a moisture gradient was established that directly reflected the solids content profile at the end of the experiment (Figure 3-7). The average solids contents in all planted samples increased to the range of 87.6% to 90.5%. Slender wheatgrass species increased the solids content of the CT mixture from 80% to 90.5% at the end of the experiment. For all plant species, solids content generally decreased with depth, averaging about 84.6% to 87.3% at the bottom of the profile and about 92.4% to 94.5% at the top of the profile. Evaporation alone (in unplanted sample), increased solids content from 80% to 87% at the end of the experiment. The salt accumulations and the presence of the crust on the unplanted samples reduced dewatering via surface evaporation.

The fitting curve shown in Figure 3-8 indicated that the native grass species transpiration from CT mixture increased slightly as the LAI increased. Native plant transpiration was dependent on LAI. Compared to the prediction presented by Ritchie (1972), the actual transpiration of these five selected native plant species that grew in CT were over predicted, at least in this study. The source of the inaccuracy in using this model was the low plant population and the fact that water supply to plant roots was limited during this test period. The accuracy of the leaf area measurement program also affects the results. In addition, the model used the standard local rainfall and solar radiation to calculate the potential evaporation (E_0) and E_s was calculated as if the surface was freely evaporating. However, in this experiment, to avoid standing water that could float the seeds out of the slurry, the water added to the CT mixture was only 89% of the average local precipitation.

3.6 Conclusions

A greenhouse experimental program was conducted to identify suitable native plant species for dewatering Composite/Consolidated Tailings (CT), based on the measurement of plant height, dry biomass, and leaf area. Selected native plant species can germinate and grow in a CT mixture. Slender wheatgrass and Northern wheatgrass produced the highest dry biomass and Leaf Area Index which indicated that these two native plant species had a capacity of dewatering CT deposits and increasing the surface bearing capacity. Slender wheatgrass and Northern wheatgrass also had the highest evapotranspiration in 15 weeks greenhouse experiment.

A new dimensionless parameter α can be used to indicate the plant dewatering capacity when soil water storage quantity is limited. Slender wheatgrass and Northern wheatgrass also have higher plant dewatering ratio α. which indicated that native plant species were indeed able to uptake water from high water content material and increase the solids content and therefore its bearing capacity. Plant dewatering capacity increases while its leaf area increases. More greenhouse experiments and field tests should be carried out to determine the relationship between dewatering capacity parameter α and LAI to increase the accuracy of the dewatering capacity prediction for each selected native plant species.

Slender wheatgrass and Northern wheatgrass proved to be the best candidate for further field research using different seeding techniques and in high plant density to dewater the CT mixture. Field tests, to evaluate practical seeding techniques capable of distributing seeds widely on fresh CT deposits, should be carried out.

3.7 References

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Table 3-1 Average plant density in treatment-1

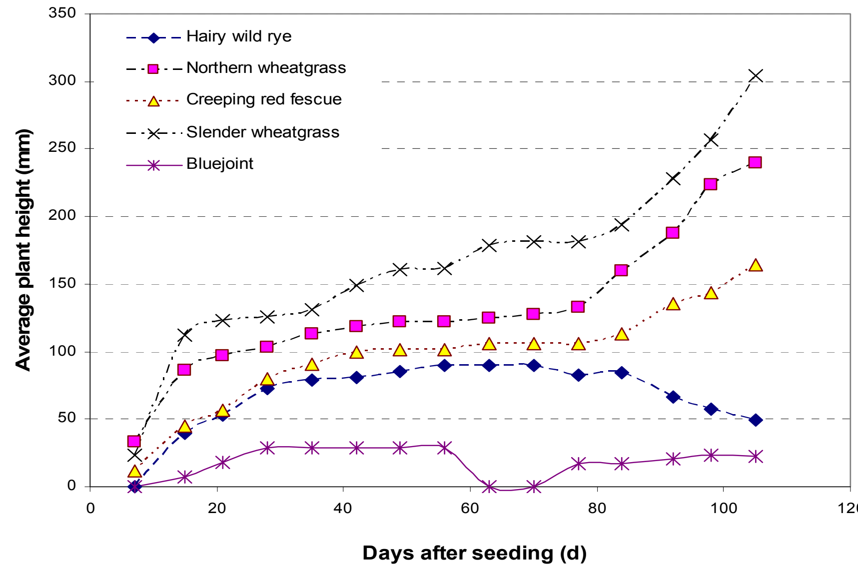
Plant species	Plant density (Plants/m^2)	Total Plant leaves	Plant Leaf Area (mm^2)
Hairy wild rye	201.7	97	2,737.5
Northern wheatgrass	1,008.5	501	12,660.2
Creeping red fescue	583.9	219	5,137.1
Slender wheatgrass	1,167.7	556	26,841.3
Bluejoint	21.2	3	--

Table 3-2 Plant shoots and roots dry weight and wet weight in treatment-1

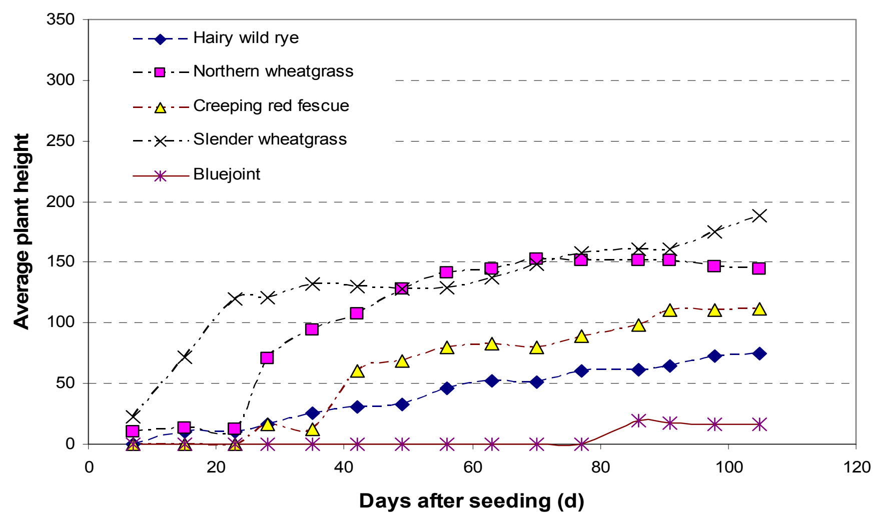
Plant Species	Shoots wet weight (mg)	Shoots dry weight (mg)	Roots wet weight (mg)	Roots dry weight (mg)	Root: Shoot ratio
Hairy wild rye	490	157.4	333.45	236.1	0.67
Northern wheatgrass	2600	1249	1870.14	835.8	1.49
Creeping red fescue	740	265.5	594.5	336.1	0.79
Slender wheatgrass	5760	2421.7	1997.87	2306.4	1.05
Bluejoint	2.1	1.8	--	--	--

Table 3-3 Leaf Area Index (%) in treatment-1, 3, 4, 6

Plant species	Treatment-1 (15 weeks)	Treatment-3 (10 weeks)	Treatment-4 (15 weeks)	Treatment-6 (10 weeks)
Hairy wild rye	2.91	--	0.65	--
Northern wheatgrass	13.44	1.51	9.31	2.59
Creeping red fescue	5.45	0.76	3.76	2.14
Slender wheatgrass	28.30	12.49	19.44	13.15
Bluejoint	--	--	--	--

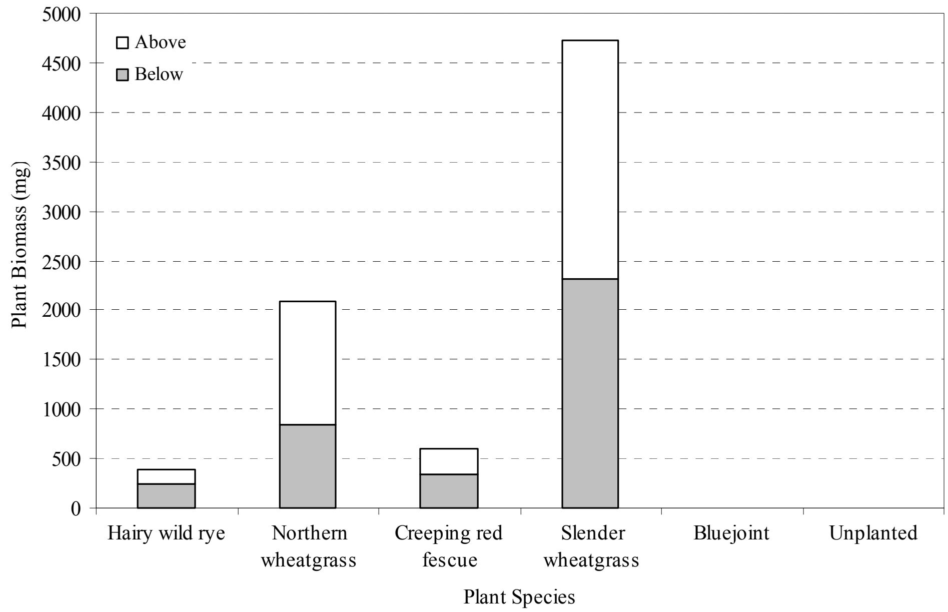


(a)



(b)

Figure 3-1 Average plant growth height versus time in different seeding treatments
(a) Treatment-1: broadcast seeding;
(b) Treatment-4: 4-6 mm fresh discharge CT slurry seeding.



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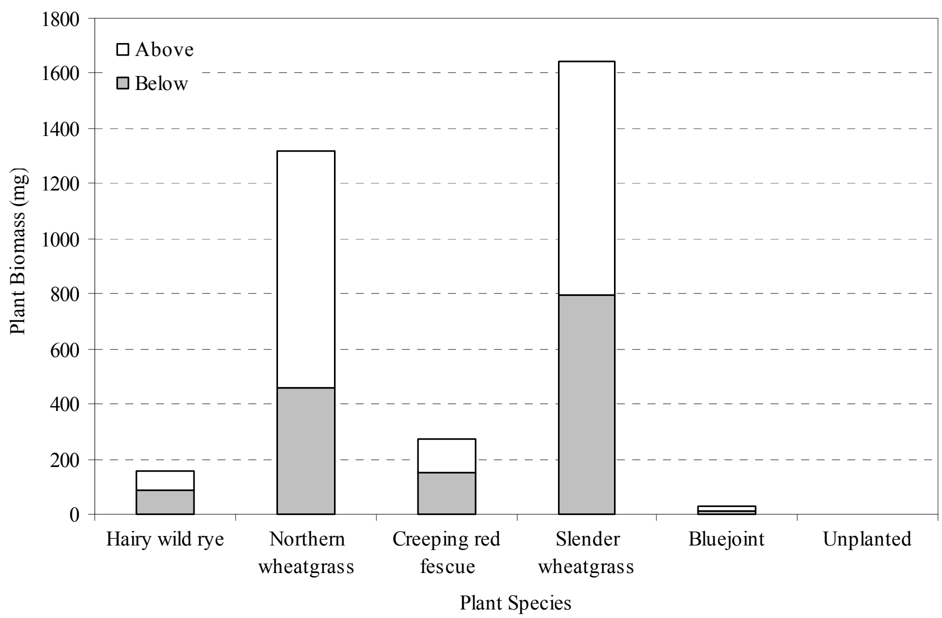
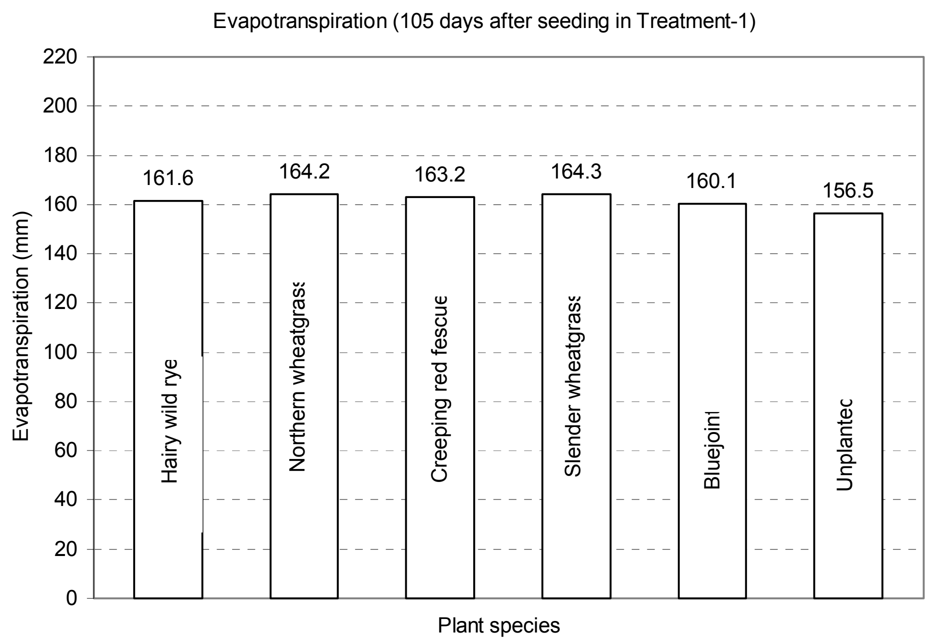


(b)

Figure 3-2 Plant biomass above and below ground
(a) Treatment-1: broadcast seeding;
(b) Treatment-4: 4-6 mm fresh discharge CT slurry seeding



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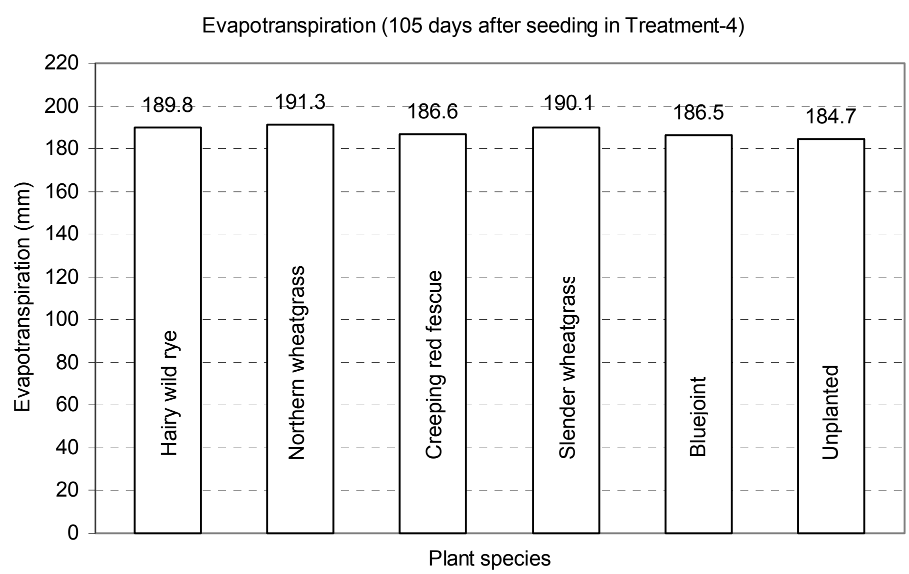


(b)

Figure 3-3 Evapotranspiration of CT after 15 weeks plant growth
(a) Treatment-1: broadcast seeding;
(b) Treatment-4: 4-6 mm fresh discharged CT slurry seeding

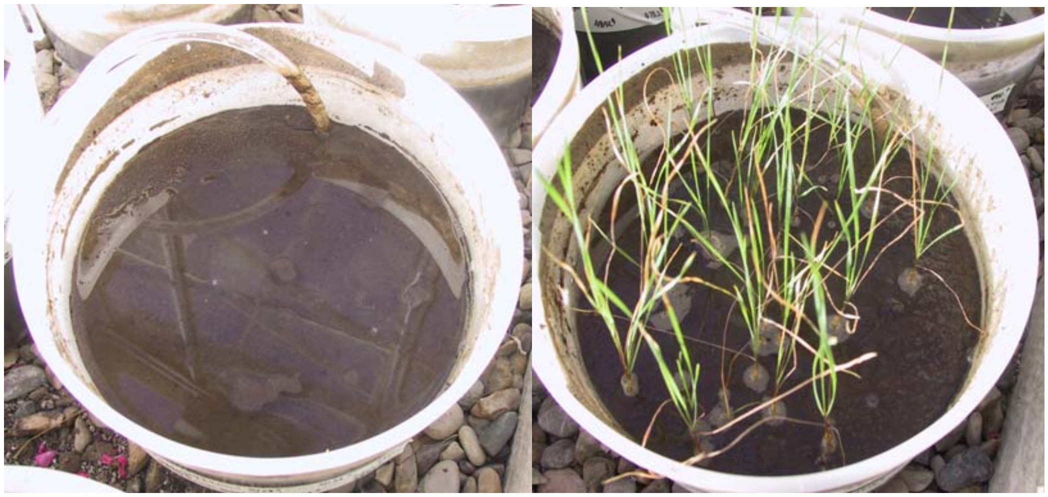
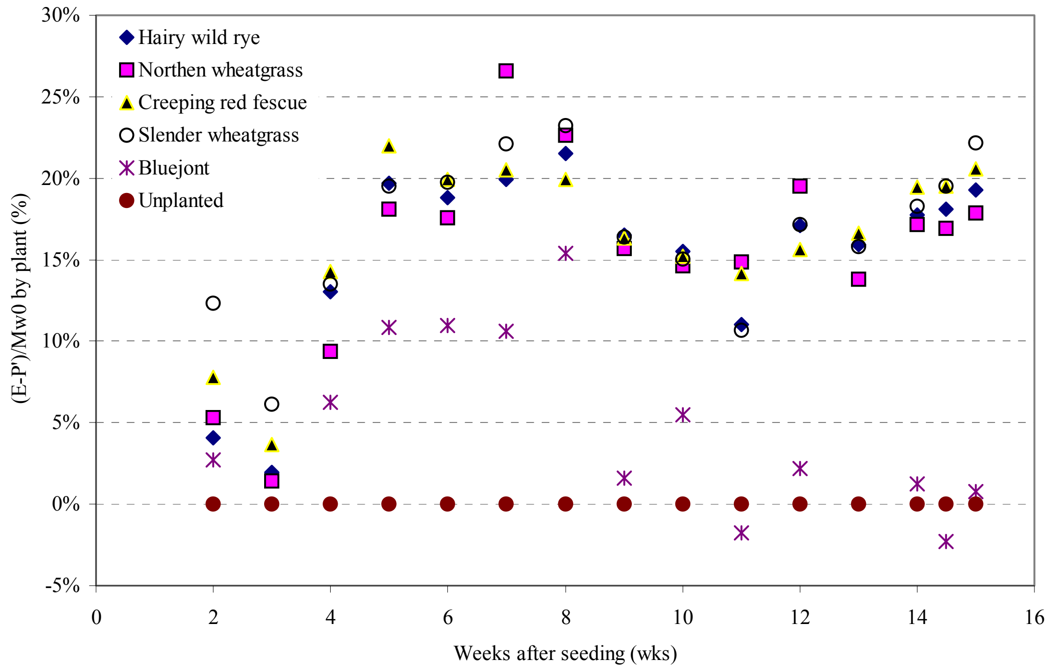
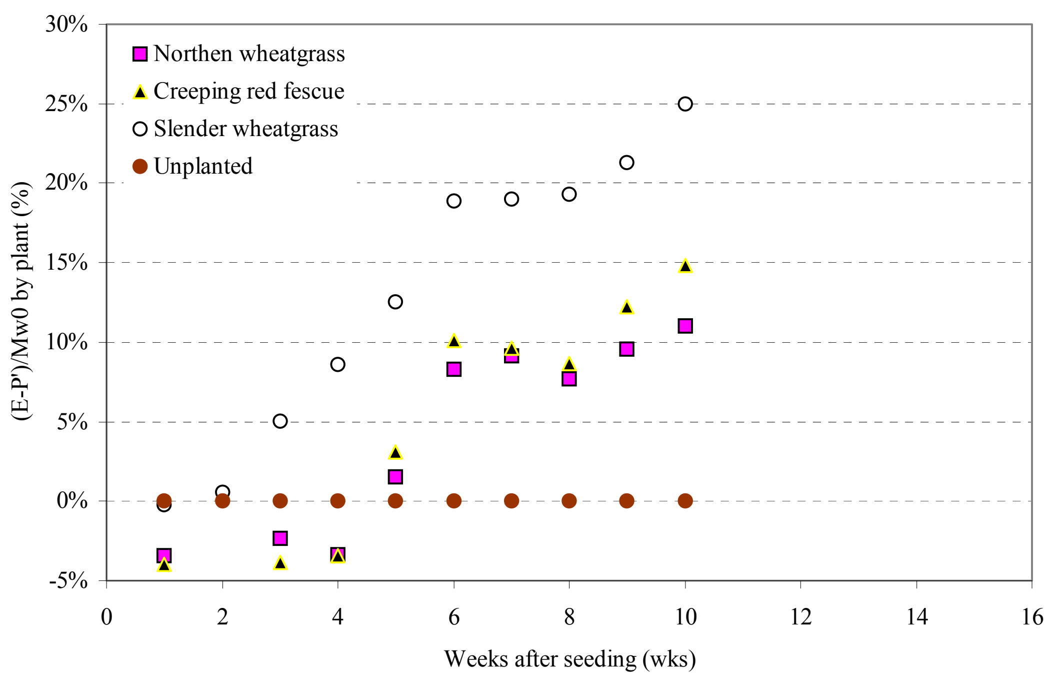


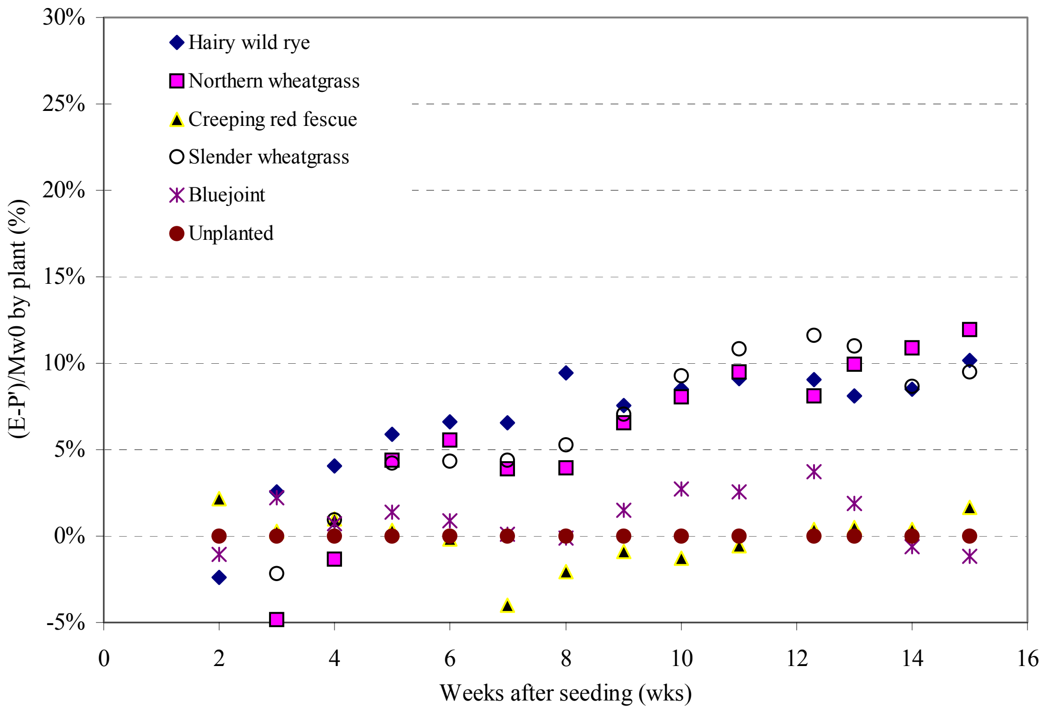
Figure 3-4 Free water in unplanted sample and plant channels in planted samples


Hairy wild rye
Northen wheatgrass
Creeping red fescue
Slender wheatgrass
Bluejont
Unplanted
(E-P')/Mw0 by plant (%)
30%
25%
20%
15%
10%
5%
0%
-5%
0
2
4
6
8
10
12
14
16
Weeks after seeding (wks)

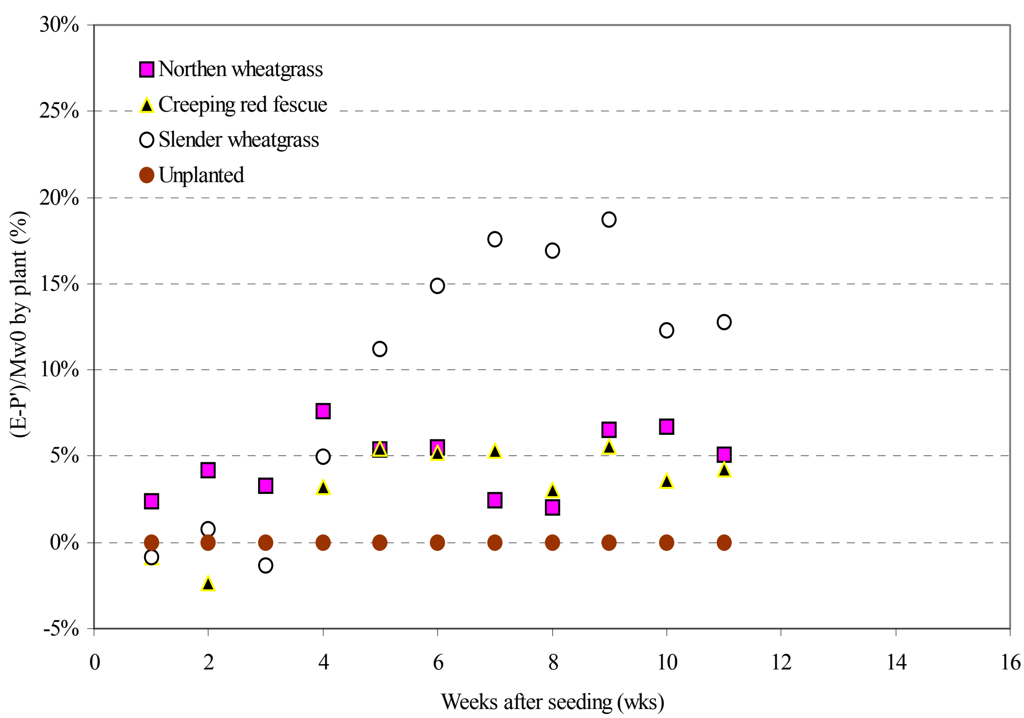
(a)


Northen wheatgrass
Creeping red fescue
Slender wheatgrass
Unplanted
(E-P')/Mw0 by plant (%)
30%
25%
20%
15%
10%
5%
0%
-5%
0
2
4
6
8
10
12
14
16
Weeks after seeding (wks)

(b)



(c)



(d)

Figure 3-5 Parameter α by native plant species in treatments

(a) in treatment-1, (b) in treatment-3, (c) in treatment-4, (d) in treatment-6

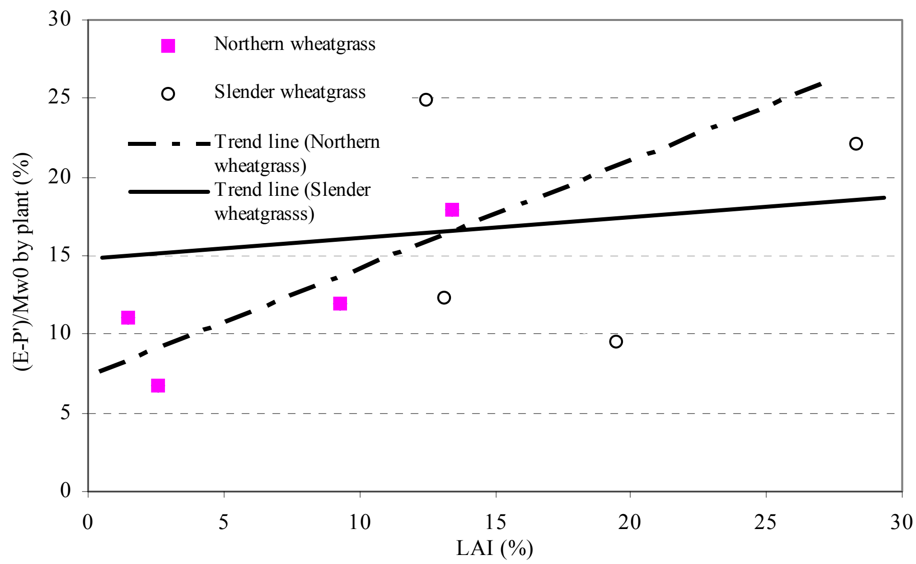


Figure 3-6 α versus. LAI and trend lines for estimating plant dewatering capacity of Northern wheatgrass and Slender wheatgrass

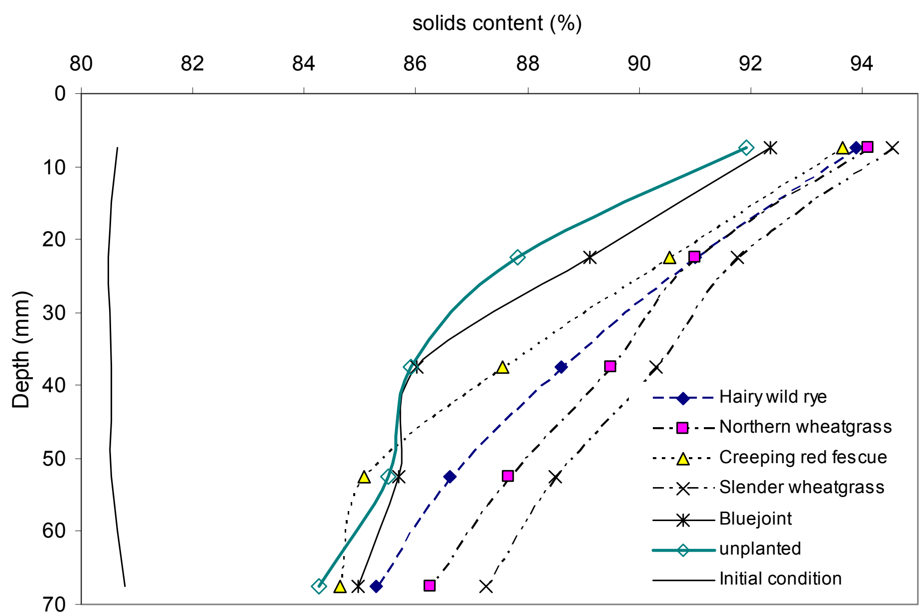


Figure 3-7 Solids Content Profile in Treatment-1

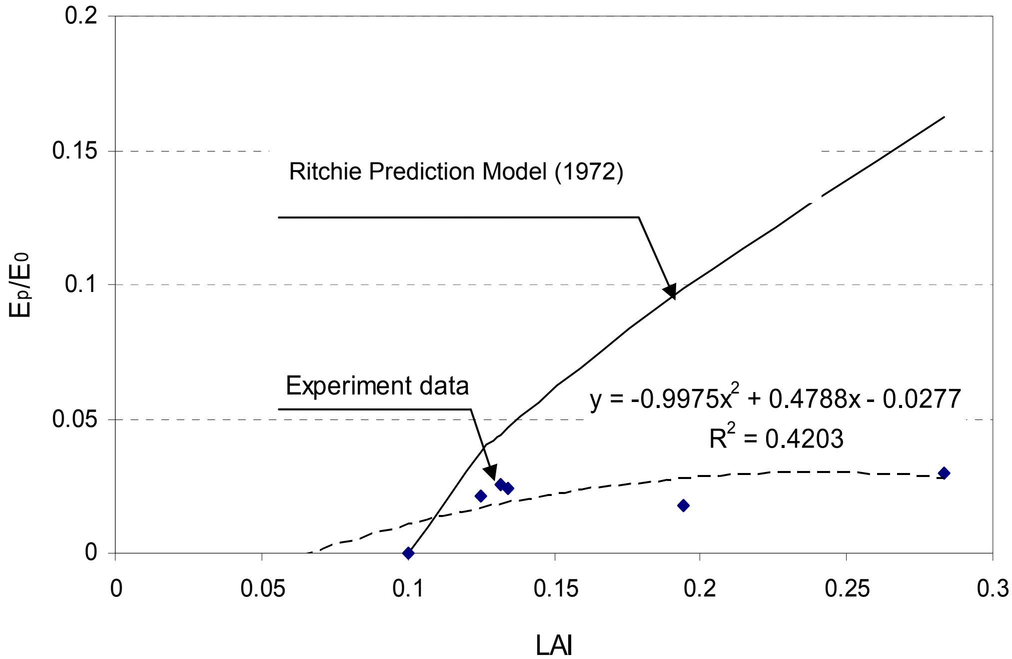


Figure 3-8 Native plant transpiration E_p influenced by LAI

4 SUMMARY AND CONCLUSIONS

4.1 Summary of research objectives

The oil sands operations developed the CT (Composite/Consolidated Tailings) process to improve the dewatering characteristics of their tailings. Using plants to increase the bearing capacity via evaporation, transpiration from plant leaves, and root fiber reinforcement has been identified as being beneficial. Introduced grass species are considered as suitable plants for dewatering CT after greenhouse studies. However, these recommended introduced plant species grow faster than local native species and may invade undisturbed landscape, thus replace native plant species and even change the local ecosystem. Moreover, when freshly deposited, the CT is too soft to support the weight of light reclamation equipments and even human activities. Direct seeding on soft CT deposits remains a challenge for tailing reclamation.

The main objectives of this thesis were to study and evaluate how well selected native plant species directly grow in the CT, the application of direct seeding techniques on vast CT deposits, and the effects of dewatering of CT via evapotranspiration by native species.

The research objectives were achieved in a progressive manner. In Chapter 2, a greenhouse study was designed to determine the feasibility of five native grass species (Bluejoint, Creeping red fescue, Hairy wild rye, Northern wheatgrass, and Slender wheatgrass) growing directly in CT. This study assessed emergence, early plant growth and survival of selected native grass species directly seeded via applying broadcast seeding; hydro-seeding with mulch; slurry seeding with the mixture of seeds and 1-4mm and 4-6mm freshly discharged CT. The initial plant screening program described in Appendix A provided a summary of suitable plant species for dewatering of CT from Alberta Oil Sands operated by Suncor Energy Inc. Chapter 3 described the greenhouse experiment conducted to evaluate the dewatering of CT by native plant evapotranspiration.

4.2 Conclusions

The dewatering capacity of five native plant species under low plant density has been evaluated. The specific conclusions of this research program are as follows:

Composite/Consolidated Tailings (CT) from Alberta Oil Sands operated by Suncor Energy Inc. is not toxic for these native plant species. In this greenhouse experiment, native plants (Bluejoint, Northern wheatgrass, Creeping red fescue, Slender wheatgrass, and Hairy wild rye) germinated, emerged and grew in these high water content materials.

These selected native grass species germinated in the CT when seeded using different techniques. The most successful tested native species were Northern wheatgrass, Slender wheatgrass and Creeping red fescue. Northern wheatgrass and Slender wheatgrass were tolerant of the CT and grew well, Creeping red fescue was stunted, at least during the 15 weeks (105 days) tests in the greenhouse. Native grass species: Northern wheatgrass and Slender wheatgrass can be used for dewatering CT since they had highest emergence rate and grew well.

It is possible to grow the plants directly from seeds in CT, which reduces the need and challenges of transplanting. Broadcast seeding covered with slight substrate, hydro-seeding with mulch, and discharge of CT slurry containing seeds are practical and applicable for seeding grasses on vast CT deposits. These seeding techniques provide good seed-soil contact which increases the seeds germination and plant emergence.

Fertilizer 20-8-20 (N-P-K) added at 100 ppm concentration during seeding did not increase the germination. However, fertilizer added biweekly after 8 weeks increased the growth rate and biomass for Northern wheatgrass and Slender wheatgrass.

Based on the dimensionless dewatering capacity parameter α and water loses during experiment, all selected native plant species uptake more water via plant evapotranspiration than via evaporation from CT surface. Native plants growing in high water content tailings indeed have the ability to dewater CT through evapotranspiration thus increasing the solids content. Plants growing in CT results in an increase to the bearing capacity of the CT deposit by increasing the cohesion.

4.3 Recommendation for further research

Although the main objectives of this thesis were achieved, several exciting issues were encountered during the course of this research that deserve further investigation. Some of these issues are as follows:

Slender wheatgrass and Northern wheatgrass proved to be the best candidate for field studies on planting using difference seeding techniques to dewater CT. Field tests, to evaluate practical seeding techniques to distribute native seeds widely on fresh CT deposits should be carried out.

The seeds size should be the other consideration during native plant selection for seeding in these studies. In this laboratory study, Bluejoint only emerged in treatment-1, and had the lowest germination and emergence, probably because the seeds were so tiny that they did not develop shoot even when covered with a thin layer of the CT or mulch.

The studies of the CT properties used in seeding slurries should be conducted in future research program. The thickness and the viscosity of seeding mixture, which mixed CT materials with seeds, are important, especially when compared to the seeds size. Some seeds floated on the surface for all seeding techniques, which reduced their establishment.

Additional research is required to determine long-term plant management strategies and appropriate fertilizer and its application rates for the native grass species to compensate for deficiency of nutrients in the CT deposits. Fertilizer should be added cautiously to avoid over fertilization that burns the young plants.

APPENDIX A

INITIAL SCREENING PROGRAM OF PLANT SPECIES SELECTION FOR DEWATERING CT DEPOSITS

A.1 Introduction

The prerequisite of using plants to dewater tailing slurry is the screening of available plant species. Vegetation is a complex mosaic of types influenced by aspect, elevation, micro-site climate, and soils. The selection of plants, which are capable of growing directly in CT deposits and removing water from soft deposits, requires that the ultimately selected species should be tolerant to these adverse soil conditions and local climate condition of this specific site (Ripley et al. 1978). Plant species must adapt to the particular chemical and physical conditions of the growth medium, the macro- and micro-climates and waterlogged condition.

For dewatering of oil sands tailings purposes, cool season grass species are recommended as effective dewatering is achieved in the first season since the grasses usually establish quickly and develop extensive root system. Other reasons for utilizing grasses include short growth period required, higher germination rate, easer and more economical seeding techniques and the capability of continuous ground cover. When the grasses and legume are established, other local plant species may invade. This is expected to result eventually in natural processes of plant dewatering, even vegetative succession.

Salinity is a common problem in CT deposits which contains a high water content and high concentration of Na^{+}, Cl^{-}, and SO_4^{2-}. In the initial stage, plant species should have high salinity tolerance since seeds and shoots will be exposed to relative high levels of salt resulting from contact with the CT materials.

However, selected plants should not mature early since plants, which flower or set seed usually stop root production. This would significantly shorten the duration of rapid transpiration and then reduce the dewatering.

A.2 Climate consideration

Climate is the driving force for selection of plant species in a certain region. Temperature and moisture may be considered as the most important climate factors in term of plant germination and growth. A study of their seasonal distribution yields information pertinent to limiting condition of growing season, precipitation, and evapotranspiration.

The oil sands industry sites in Fort McMurray, Alberta are located within the North-western Forest Climate Region of Canada and Plant Hardiness Zone 1a on agriculture (National Resources Canada, 2006) characterized by short growing season, cool temperature and moderate to high precipitation.

A.3 Site Temperature

The oil sands disposal ponds located north of Fort McMurray, Alberta, near the Athabasca River, at approximately 57^0 N, 111^0 W. This means it is a large distance from the equator so they do not receive as much sun's heat because the sun's rays are at a large angle from vertical. There is also a very high albedo, resulted from the sun's rays reflection off snow and are bounced back into the atmosphere as light rather than heat, causing winter temperature to be cold. The average temperature for Fort McMurray is -18.8 ^{0}C in January and 16.8 ^{0}C in July and the mean annual temperature is 0.7 ^{0}C (data based on Canadian Climate Normals 1971-2000) (Environment Canada, 2004).

A.4 Precipitation

Located so far north means that Fort McMurray receives precipitation in term of snow for 5 or 6 months of the year. There is very little precipitation in winter and summer rainfall accounts for the larger precipitation in summer. Based on Canadian Climate Normals, 1971-2000 climate data (Environment Canada, 2004), annual precipitation amounts is 455.5 mm with snowfall making up 155.8 mm.

Figure A-1 and Figure A-2 represented the average temperature and precipitation for Fort McMurray, Alberta, over last 25 years (Environment Canada).

A.5 Selected native plant species for dewatering CT deposits

According to the predominant components presented in CT mixture, particular interests of plant species selection will be a tolerance to high pH, high salinity level, water logging, residual bitumen, a short growing season and longer longevity. For a species to be considered suitable for dewatering, several criteria must be achieved, including the ability of seeds to germinate and young seedling to survive.

Through screening of native plant species listed in references (Alberta Agriculture, 1981; Seip et al., 1985; Hardy BBT Ltd, 1989; Johnson et al. 1993; Naeth et al. 1999; Block et al., 2000; Landmark Seed Company, 2000; Native Plant Working Group, 2001; and Alberta Government, 2005), five native grass species: Bluejoint (*Calamagrostis canadensis*), Creeping red fescue (*Festuca rubra*), Hairy wild rye (*Elymus innovatus Beal*), Northern wheatgrass (*Agropyron dasystachyum*), and Slender wheatgrass (*Agropyron trachycaulum*), were selected for greenhouse germination tests. The reclamation suitability criteria used in this selection are summarized in Table A-1 (I) and Table A-1 (II).

A.5 References

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Alberta Government. 2005. *Alberta Centennial-Sustainable Development, Native plant revegetation guidelines, Appendix I*, http://www3.gov.ab.ca/srd/land/m_li_nativeplant_contacts.html

Block, N., Bonneau, A., Champion, M., Cory, J., Harrison, S.,Horvath, J., Pollock, T., Silzer, T., and Sykes, C.. 2000. *Fact Sheets For Some Common Plants On Rangelands In Western Canada.*

http://www.usask.ca/agriculture/plantsci/classes/range/elymusinnov.html

Johnson, R. L., Bork, P., Allen, E. A. D., James, W. H., and Koverny, L.. 1993. *Oil Sands Sludge Dewatering by Freeze-thaw and Evapotranspiration*, Alberta Conservation and Reclamation Council Report No. RRTAC 93-8. Queen's Printers. Edmonton, Alberta, 246 p.

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Seip, D.R. and F.L. Bunnell. 1985. *Species composition and herbage production of mountain rangelands in northern British Columbia*. Canadian Journal of Botnay, Vol. 63, pp. 2077-2080.

Table A-1 (I) Summary of the reclamation suitability criteria for selected native plant species # (I)

Reclamation suitability criteria	Plants species		
	Northern wheatgrass (Agropyron dasystachyum)	Bluejoint (Calamagrostis canadensis)	Slender wheatgrass (Agropyron trachycaulum)
Origin and Range	Native	Native	Native
Longevity	Hardy long-lived perennial grass, high seed yield, and strongly rhizomatous	Hardly winter long-lived perennial species	Short-lived cool season perennial grass
Ecological setting	* Moist to dry, withstands moderate flooding	* Moist to dry, good tolerance of flooding * Occurs in lowland wet sites	* Tolerant of flooding * used for reclamation of oil sands and saline areas
Nutrient requirements	Low nitrogen required	Low nitrogen required Fertilizer addition increases plant vigor.	Moderate nitrogen required
Seeding or planting method	* drilling or broadcast on dry land * high seedling vigour and easy	*the seed has many callus hairs * moderate seedling vigour * establish slowly	* Dense and fibrous roots * Good seedling development
Drought tolerance	Very high to high	High	N/A
Salt/Alkali tolerance	Medium	Medium	Very High

Table A-1 (I) (Cont.)

pH tolerance	Acid	Medium	Medium	High
	Base	High (9.5)	Medium	Medium
Winter hardiness		Medium	Very high	Medium
Erosion control		High	Medium	High
Persistence		Very high	Very high to high	Very high
Moisture preference		Moist to dry, withstands moderate flooding	Moist to dry, withstands moderate flooding	Moist to dry, withstands 49-63 days flooding.
Soil preference		Medium to coarse textured.	Wide range, moderately well to imperfectly drained	Well-drained soils of medium texture and moderate salinity
Recommended Area		Lethbridge and Medicine Hat	Fort McMurray	

Note: # source from:

(1) Alberta Government. *2005. Alberta Centennial-Sustainable Development*, *Native plant revegetation guidelines, Appendix I,* http://www3.gov.ab.ca/srd/land/m_li_nativeplant_contacts.html

(2) Block, N., Bonneau, A., Champion, M., Cory, J., Harrison, S.,Horvath, J., Pollock, T., Silzer, T., and Sykes, C.. 2000. *Fact Sheets For Some Common Plants On Rangelands In Western Canada.* http://www.usask.ca/agriculture/plantsci/classes/range/elymusinnov.html

(3) Landmark Seed Company. 2000. *Grasses for the future*. http://www.landmarkseed.com/showseeds.asp

(4) Seip, D.R. and F.L. Bunnell. 1985. *Species composition and herbage production of mountain rangelands in northern British Columbia*. Can. J. Bot. 63: 2077-2080.

Table A-1 (II) Summary of the reclamation suitability criteria for selected native plant species # (II)

Reclamation suitability criteria	Plants species		
	Hairy Wild Rye (Elymus innovatus Beal)	Creeping red fescue (Festuca rubra)	
Origin and Range	Native	Native	
Longevity	* High cold season hardiness, * perennial grass, high seed production, and deep and spreading root system	* Cool season perennial grass. * Disease reduces its longevity. * It is unaffected by frost.	
Ecological setting	* Moist to dry, found growing on well drained sand dune and also on glacial outwash. * Has apparent tolerance to bitumen materials. Potential suitability for oil sands revegetation. * Deep and spreading root system can form a sod-like mat.	* Found in lake meadows in Alberta. * Best in cooler, moister region.	
Nutrient requirements	Low nitrogen required	Best with moderate fertilizer application	
Seeding or planting method	*seeding resulted in about 50% germination and survival. * The hairy seeds could cause problems in a seed drill or broadcasting	* Good seedling vigor, aggressive seedling growth and fast sod development.	.

Table A-1 (II) (Cont.)

Drought tolerance		Low, does best where the probability of drought is low.	High to Medium	
Salt/Alkali tolerance		Low, presumed to be tolerant of mildly saline soils	High to Medium	
pH tolerance	Acid	Low (pH: 7.2—8.0)	High	
	Base	Low	Medium	
Winter hardiness		Medium to High	Very high to High	
Erosion control		Medium to High	High	
Persistence		Medium	High	
Moisture preference		Moist to dry	Moist	
Soil preference		Coarse to fine textured, well drained	Wide textural range	
Recommended Area		Northern area of Alberta	Fort McMurray, E, L and MH etc.	

Note: # source from:

(1) Alberta Government. 2005. Alberta Centennial-Sustainable Development, *Native plant revegetation guidelines*, Appendix I, http://www3.gov.ab.ca/srd/land/m_li_nativeplant_contacts.html

(2) Block, N., Bonneau, A., Champion, M., Cory, J., Harrison, S., Horvath, J., Pollock, T., Silzer, T., and Sykes, C.. 2000. *Fact Sheets For Some Common Plants On Rangelands In Western Canada,* http://www.usask.ca/agriculture/plantsci/classes/range/elymusinnov.html

(3) Landmark Seed Company. 2000. *Grasses for the future*. http://www.landmarkseed.com/showseeds.asp

(4) Seip, D.R. and F.L. Bunnell. 1985. *Species composition and herbage production of mountain rangelands in northern British Columbia*. Can. J. Bot. 63: 2077-2080.

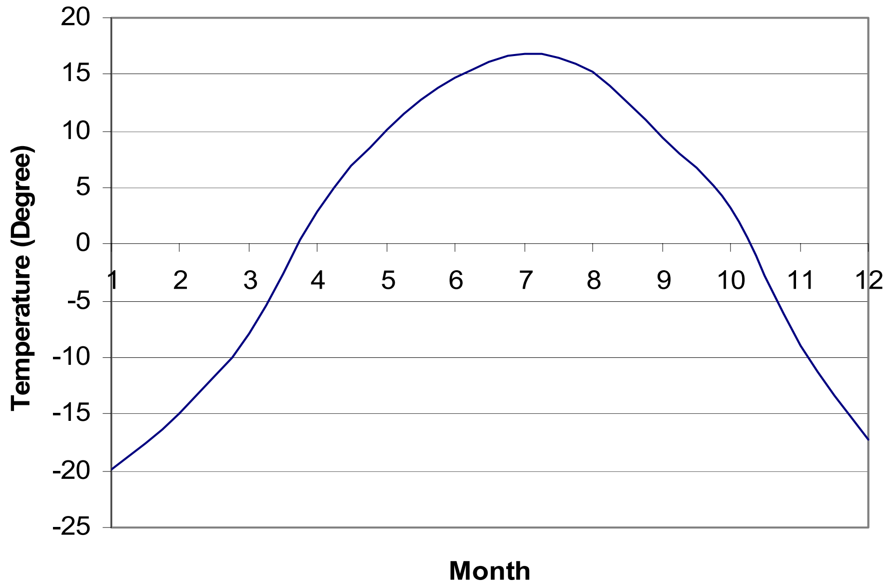


Figure A-1 Average temperature (degree) in Fort McMurray, Alberta

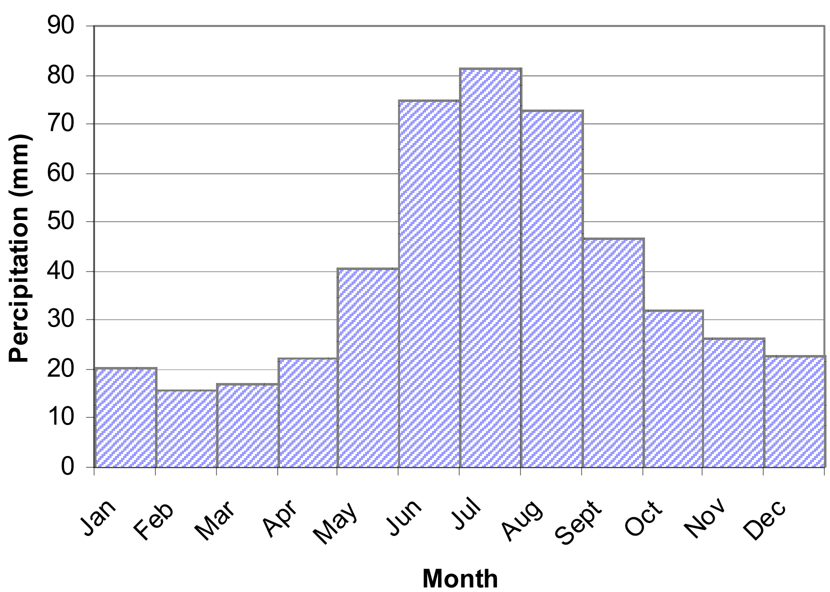


Figure A-2 Average precipitation (mm) in Fort McMurray, Alberta

APPENDIX B

SUMMARY OF AVERAGE PLANT HEIGHT IN DIFFERENT SEEDING TREATMENTS

Weekly plant height measurement began 7 days after seeding to monitor the plant early growth performance for the different seed treatments. 20-8-20 (N-P-K) fertilizer was added biweekly after 8 weeks of planting. Distilled water was added twice a week to simulate the average precipitation at Fort McMurray, Alberta.

In treatment-1, seeds were planted by using broadcast seeding covered with a very thin layer of CT on September 21, 2006 and plants were harvested on January 05, 2007. The average plant heights in mm are shown in Figure B-1.

In treatment-2, hydro-seeding using mulch on top of seeds was placed on the CT. Hydro-seeding using a slurry made up of fresh CT, seeds along with a nutrient free mulch (Fibramulth^{TM}) was sprayed on the surface of the CT mixture. Mulch application rate was approximately 1250 lbs/acre (recommended by Fibramulth^{TM}). Seeds were planted on December 18, 2006 and the experiment ended on February 25, 2007. The average plant height in mm was illustrated in Figure B-2.

In treatment-3, seeds were planted by flowing fresh CT slurry containing seeds over the CT mixture. The thickness of the slurry in this treatment was 1~4 mm. The experiment started on November 8, 2006 and ended on January 17, 2007. Figure B-3 showed the average plant height versus time.

In treatment-4, seeds were planed by discharging fresh CT slurry. The thickness of slurry in treatment-4 was 4~6 mm. The experiment started on October 22, 2006 and ended on February 4, 2007. The average plant height over time was schemed in Figure B-4.

In treatment-5, started on December 18, 2006, seeds were planted by a hydro-seeding slurry mixed with 100 ppm 20-8-20 (N-P-K) fertilizer. The experiment ended on February 25, 2007. The average plant height was shown in Figure B-5.

In treatment-6, seeds were planted by discharging CT slurry that had seeds added. The seeded slurry was a mixture of a 1~4 mm thick of fresh CT, seeds and 100 ppm 20-8-20 (N-P-K) fertilizer. The experiment began on November 08, 2006 and ended on January 17, 2007. Figure B-6 showed the average plant height versus time in this seeding treatment.

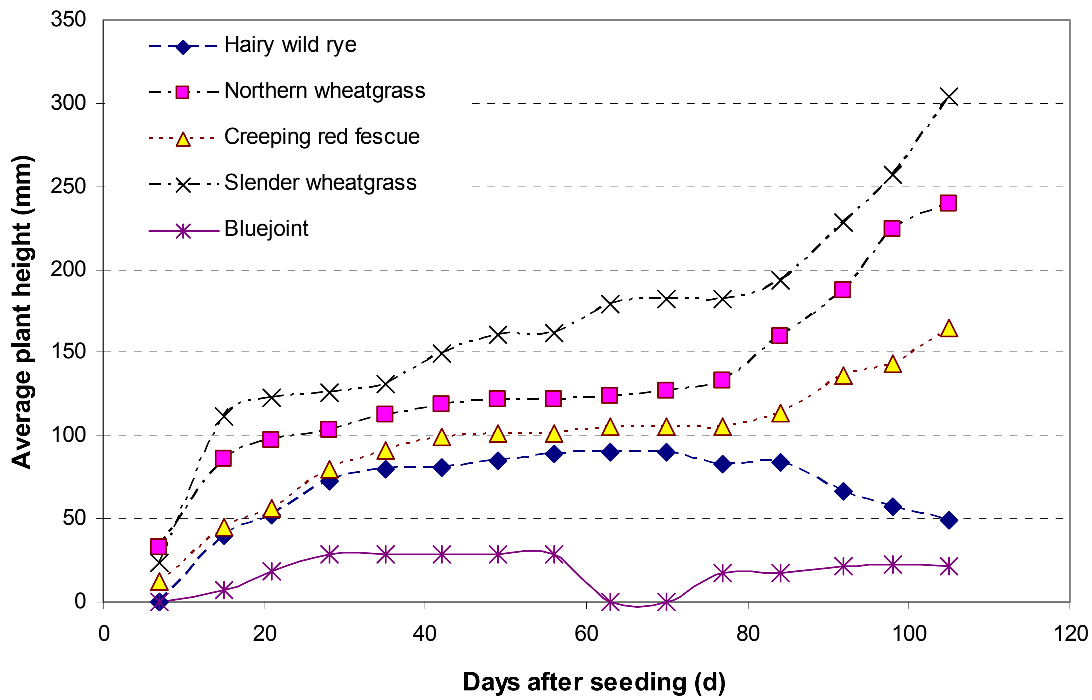


Figure B-1 Average plant height over time in treatment-1

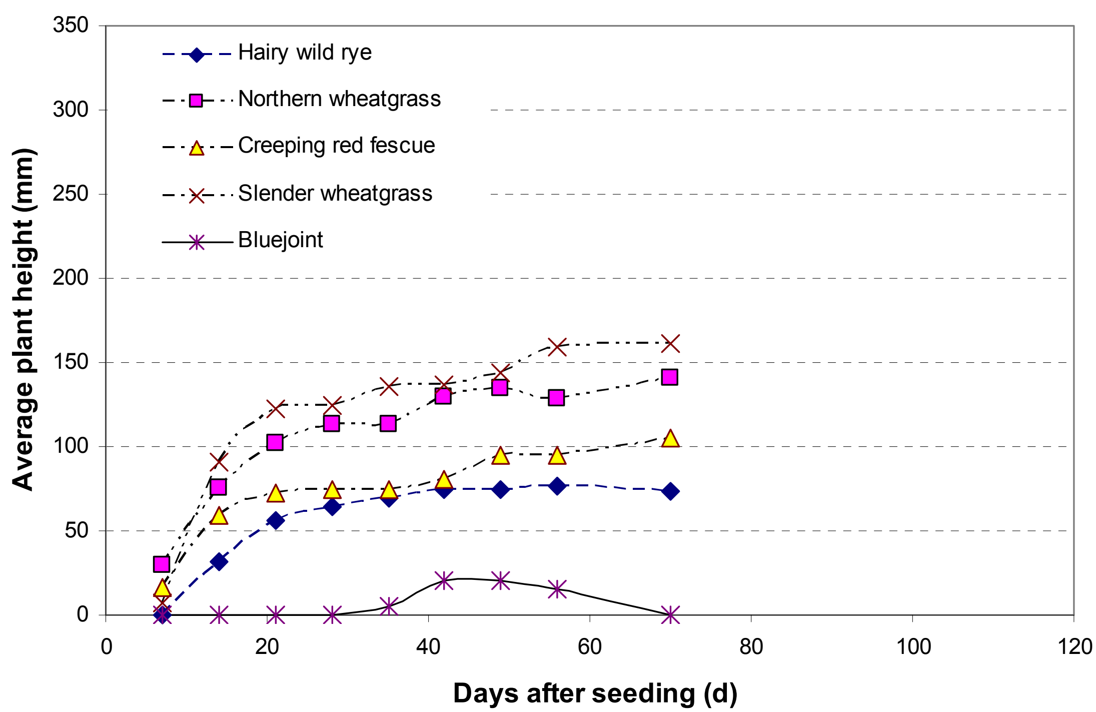


Figure B-2 Average plant height over time in treatment-2

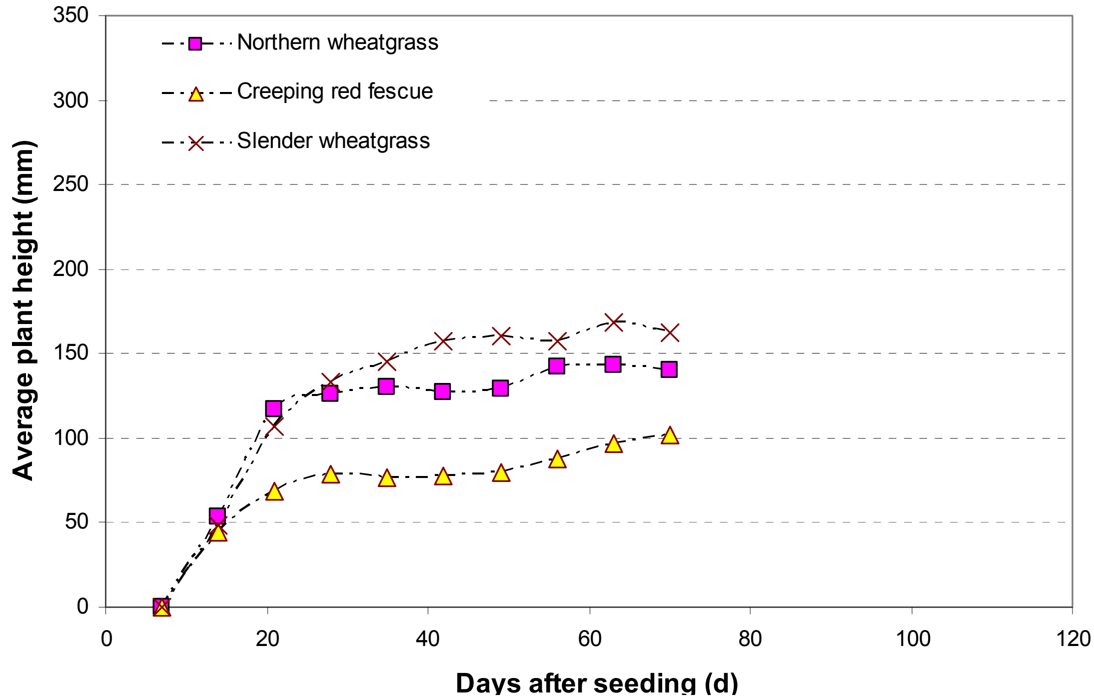


Figure B-3 Average plant height in treatment-3

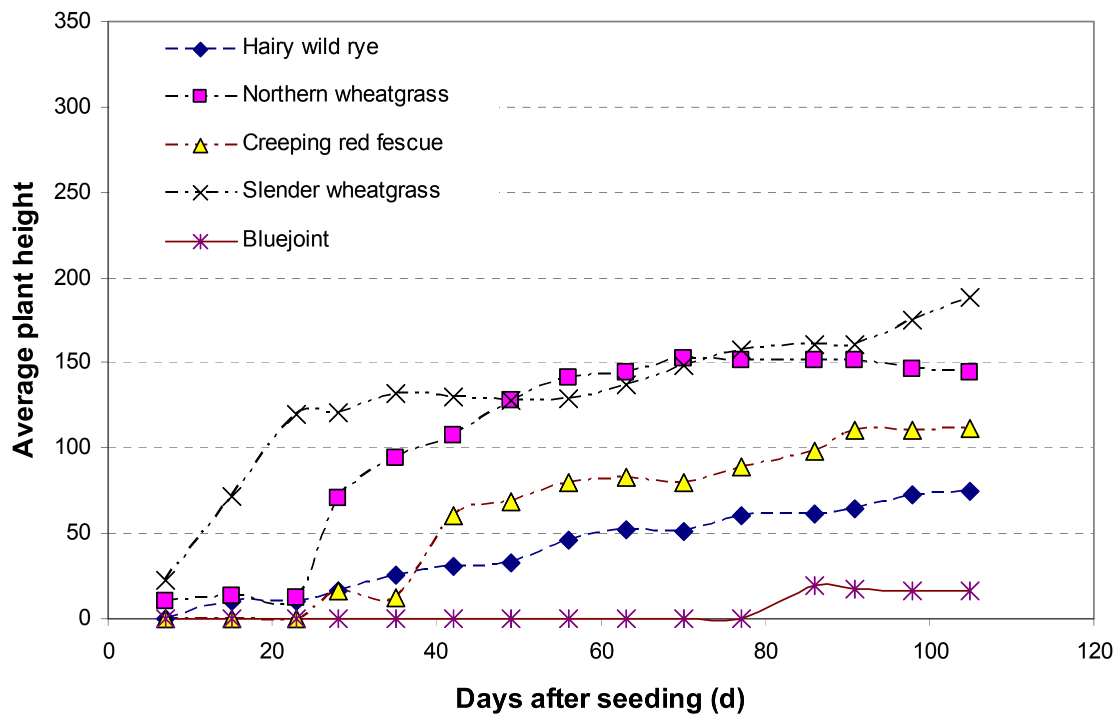
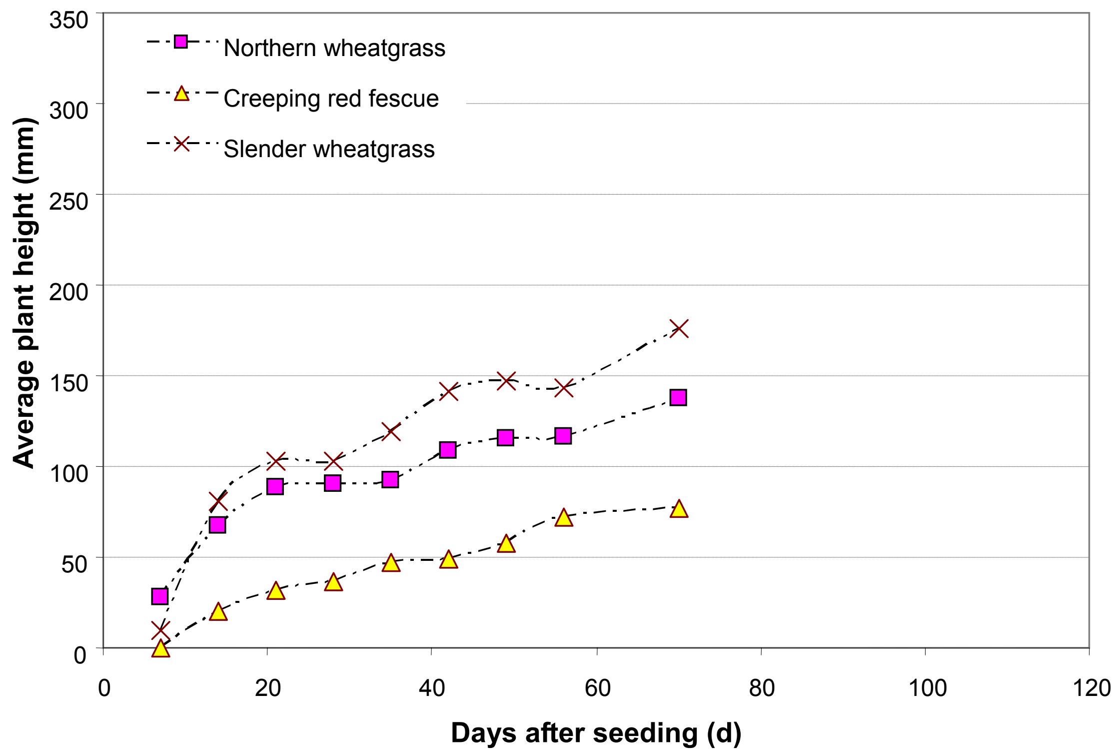


Figure B-4 Average plant height in treatment-4



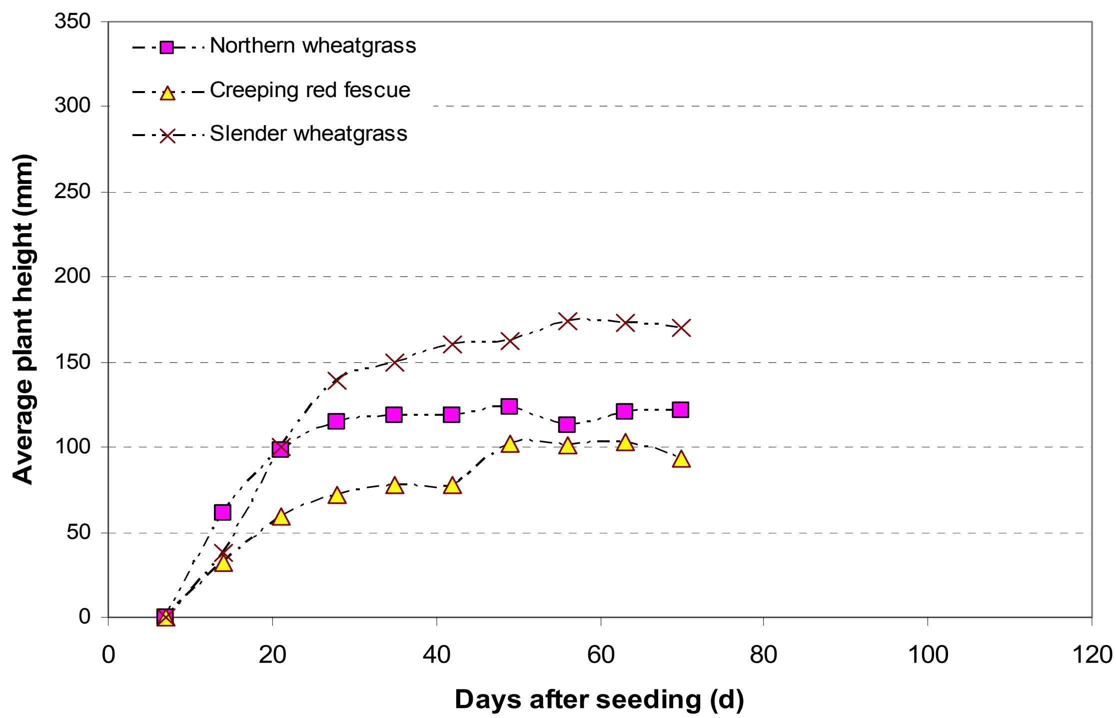


Figure B-6 Average plant height in treatment-6

APPENDIX C

EVAPOTRANSPIRATION BY PLANTS AND EVAPORATION IN UNPLANTED CONTROL

C.1 Introduction

Evapotranspiration (E) was evaluated by creating a water balance equation which balances the change in the amount of water stored in a certain volume of soil (ΔS) with inputs and outputs during a defined time period. In these greenhouse experiments, precipitation (P') represented the inputs and the evapotranspiration or evaporation the outputs. The water balance in soil can be expressed as:

$$P' - E - \Delta S = 0 \qquad \text{(C-1)}$$

So, the evapotranspiration from the planted samples and evaporation from the unplanted samples can be calculated. Weekly evapotranspiration (E) and evaporation (E_s) were recorded by weighting the planted and unplanted samples containers, respectively (Ritchie and Burnett, 1968). Figure C-1 to C-64 provided the evapotranspiration and evaporation data for the individual treatments.

C.2 References

Ritchie, J.T. and Burnett, E.. 1968. *A precision weighting lysimeter for row crop water use studies*. Agronomy Journal, Vol. 60, pp. 545-549.

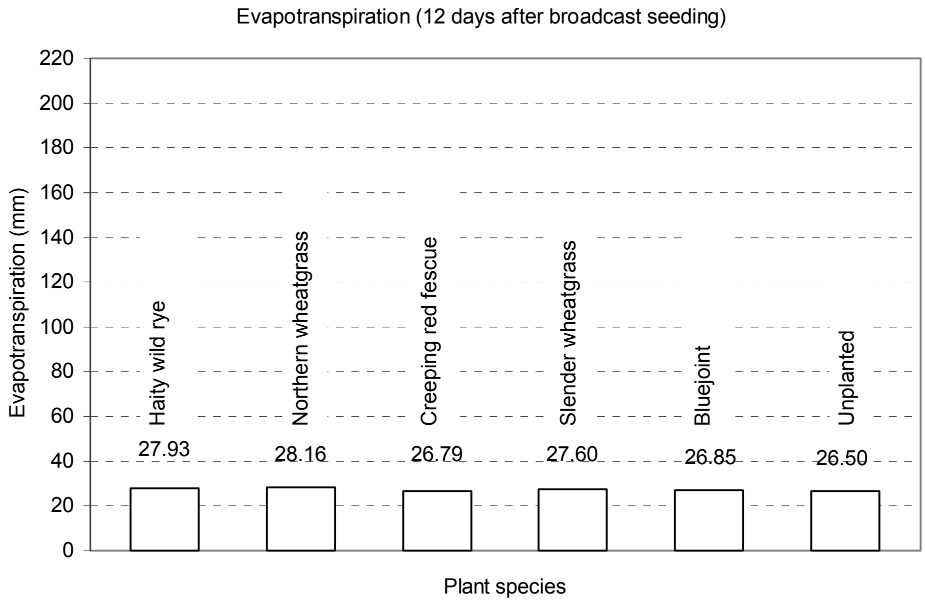


Figure C-1 Evapotranspiration and Evaporation 12 days after seeding in treatment-1

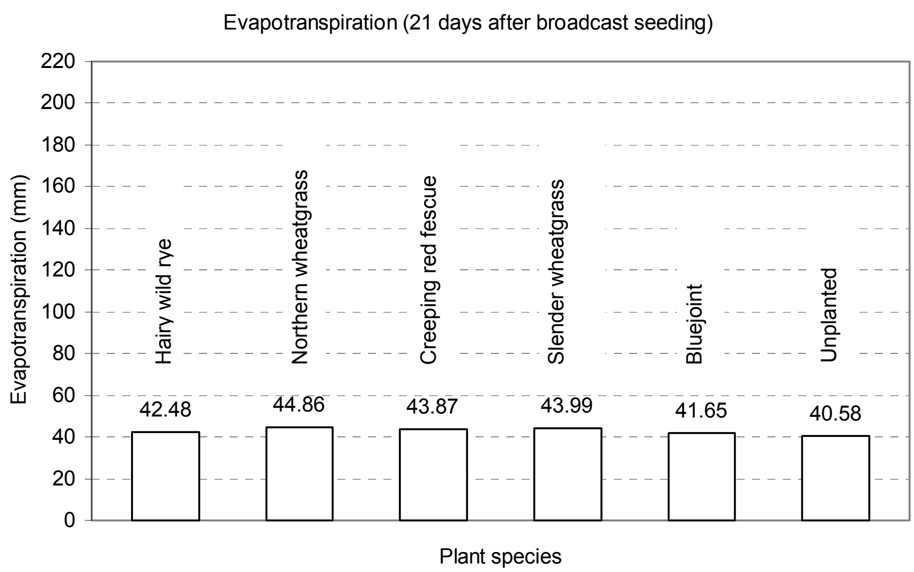


Figure C-2 Evapotranspiration and Evaporation 21 days after seeding in treatment-1

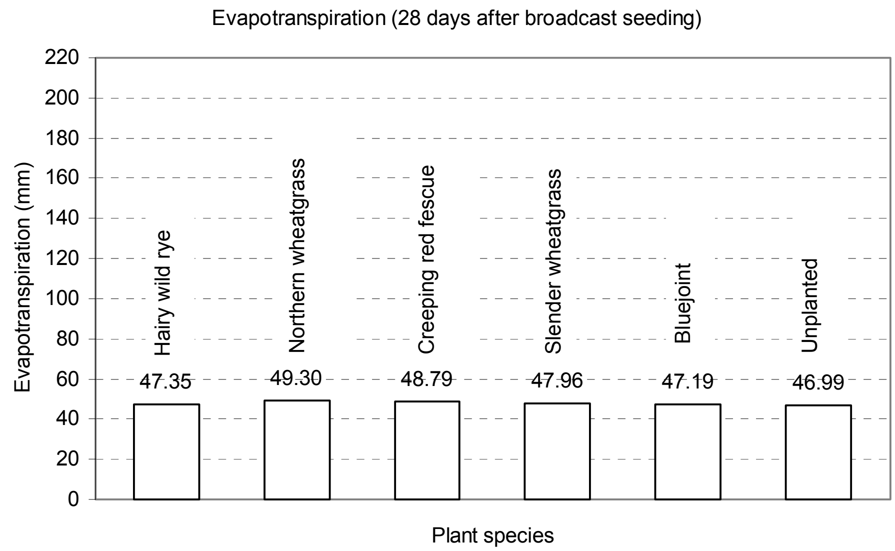


Figure C-3 Evapotranspiration and Evaporation 28 days after seeding in treatment-1

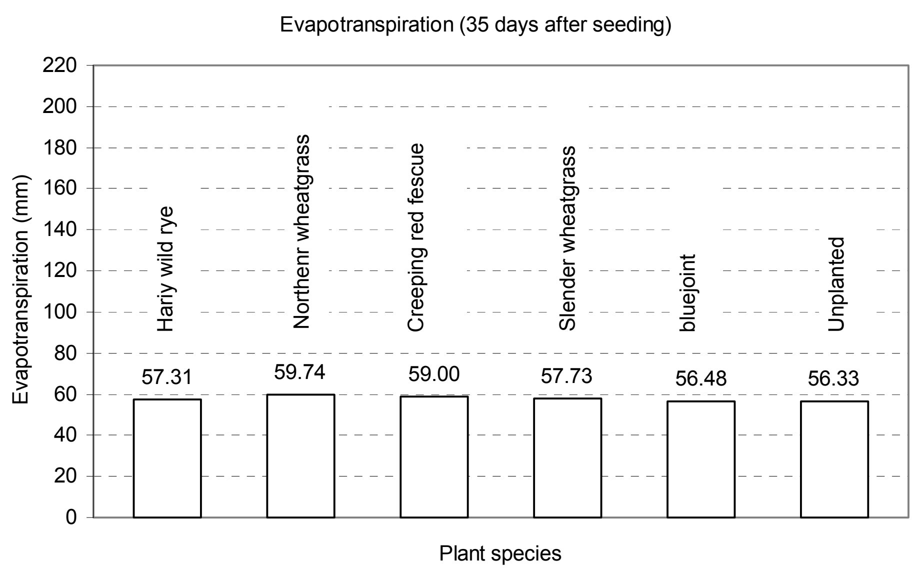


Figure C-4 Evapotranspiration and Evaporation 35 days after seeding in treatment-1

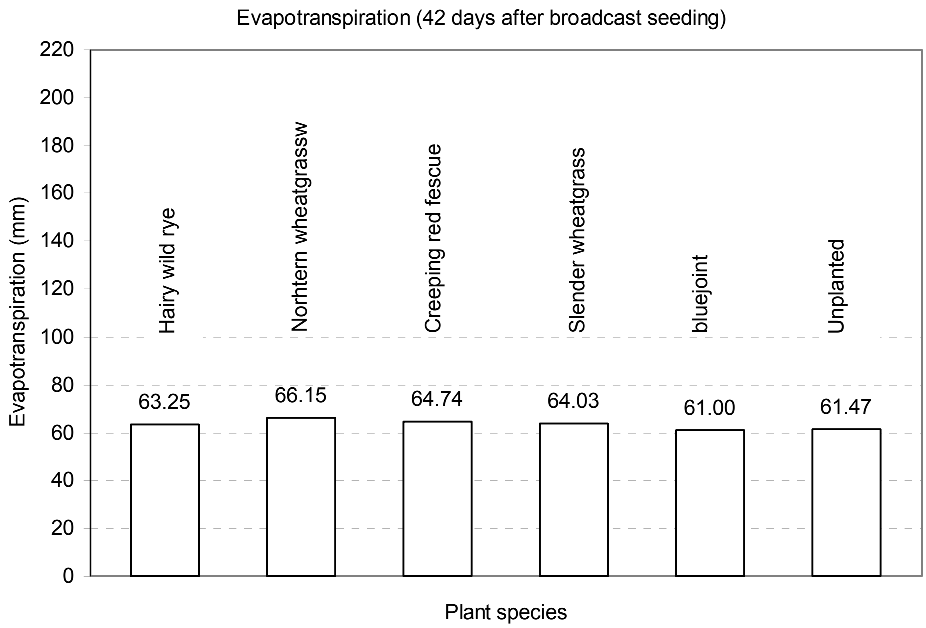


Figure C-5 Evapotranspiration and Evaporation 42 days after seeding in treatment-1

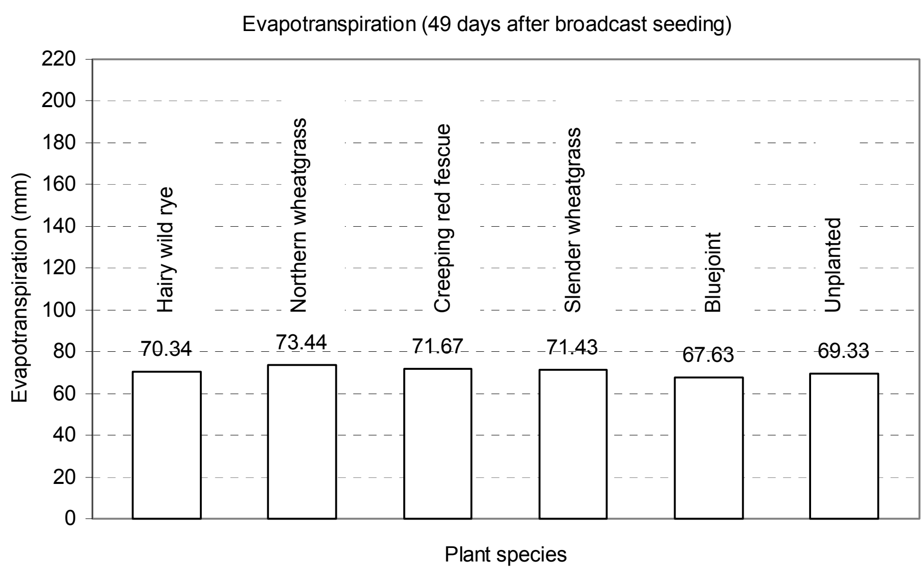


Figure C-6 Evapotranspiration and Evaporation 49 days after seeding in treatment-1

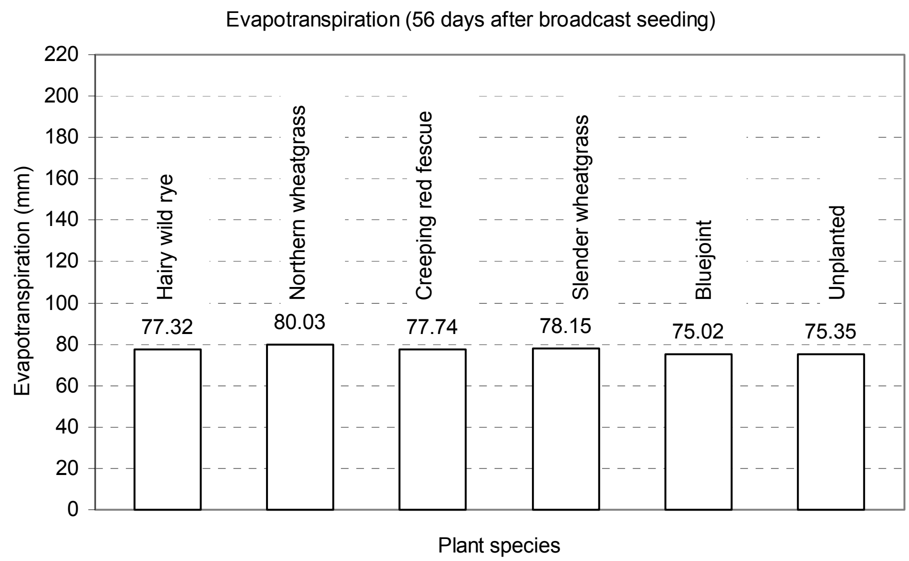


Figure C-7 Evapotranspiration and Evaporation 56 days after seeding in treatment-1

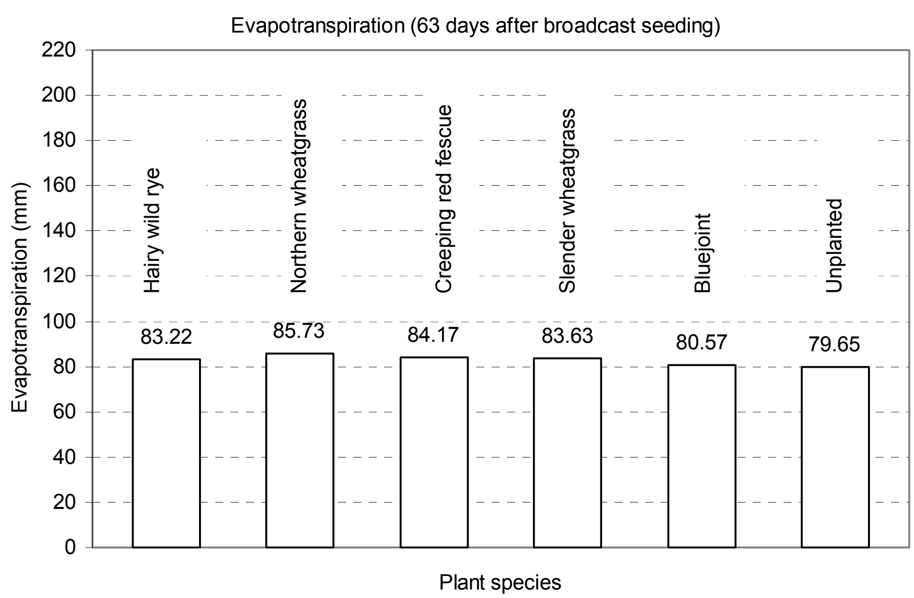


Figure C-8 Evapotranspiration and Evaporation 63 days after seeding in treatment-1

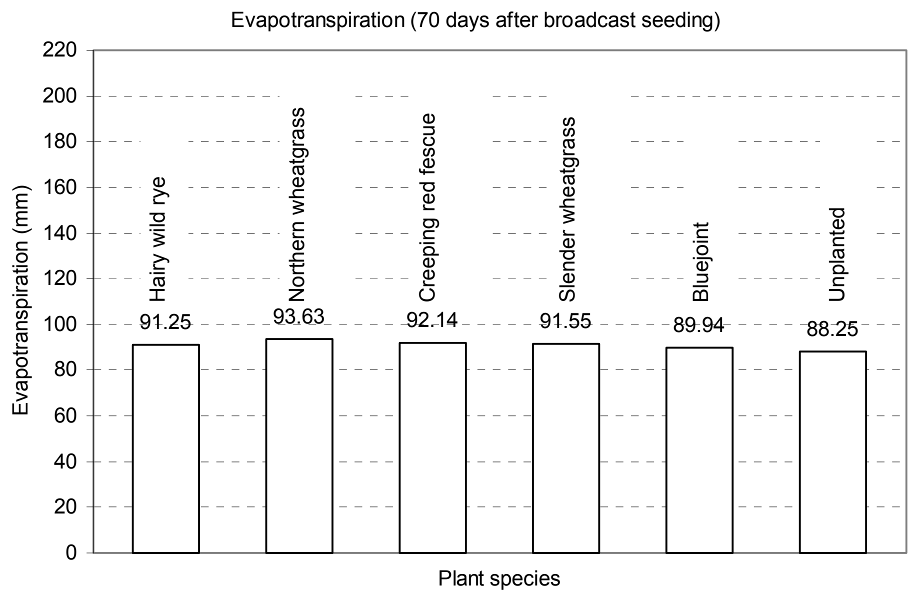


Figure C-9 Evapotranspiration and Evaporation 70 days after seeding in treatment-1

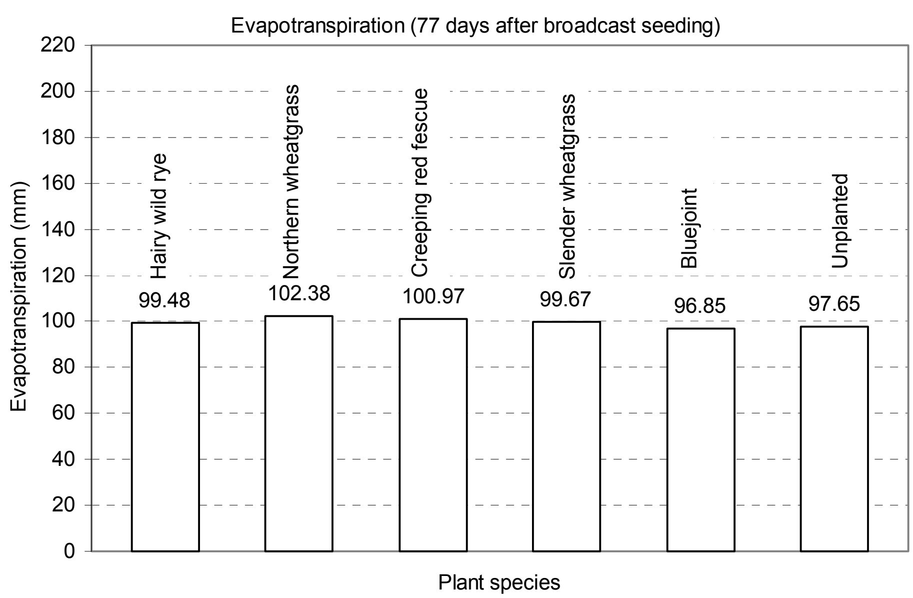


Figure C-10 Evapotranspiration and Evaporation 77 days after seeding in treatment-1

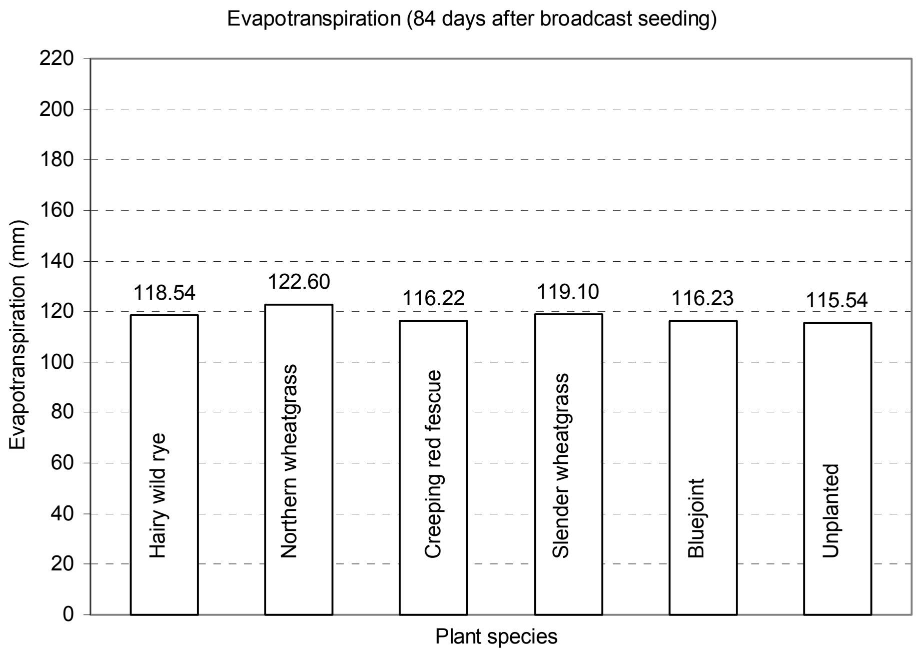


Figure C-11 Evapotranspiration and Evaporation 84 days after seeding in treatment-1

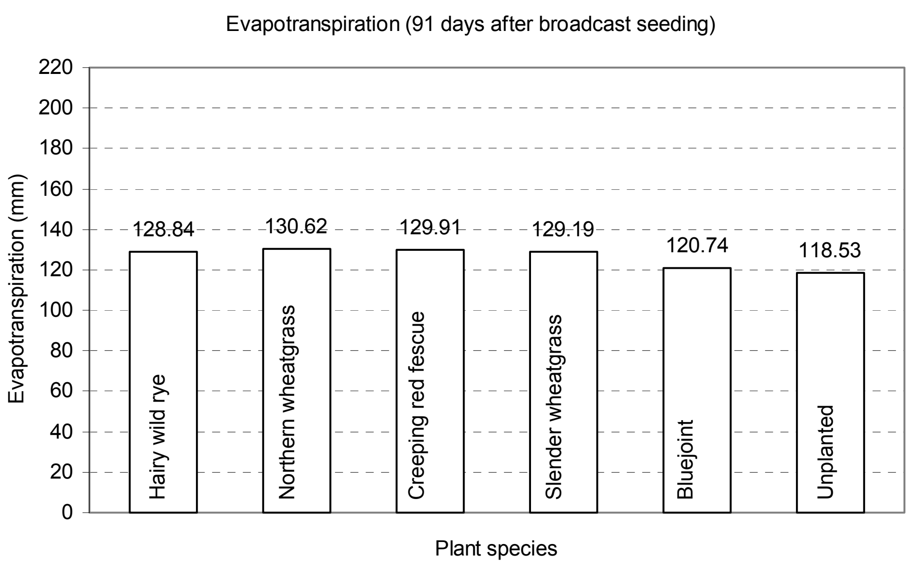


Figure C-12 Evapotranspiration and Evaporation 91 days after seeding in treatment-1

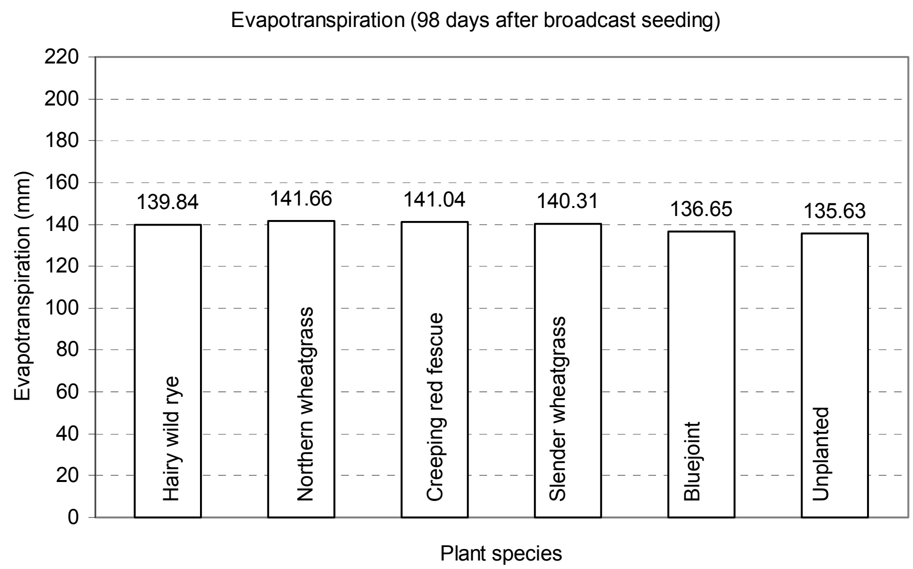


Figure C-13 Evapotranspiration and Evaporation 98 days after seeding in treatment-1

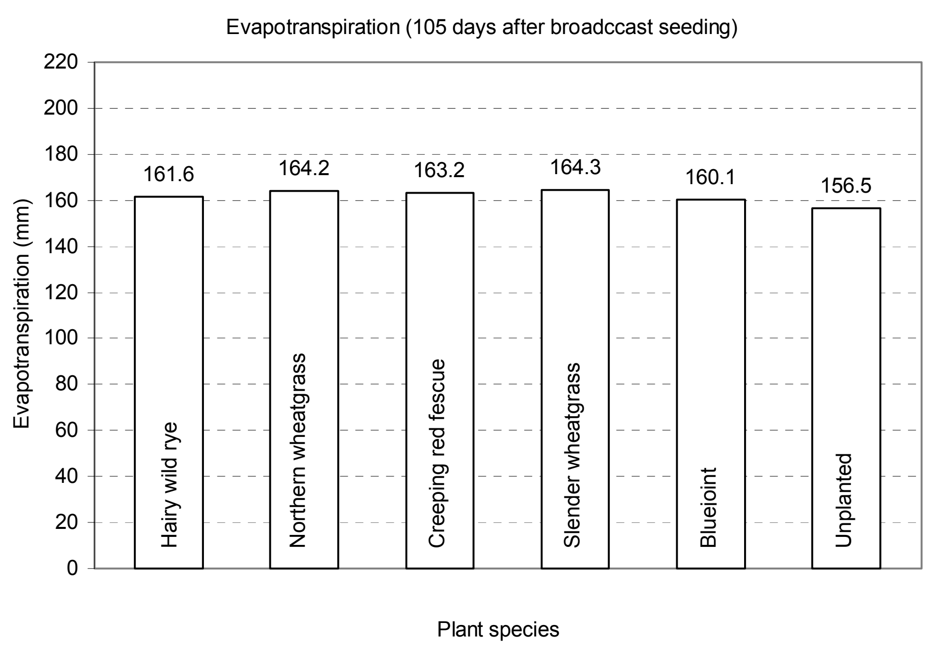


Figure C-14 Evapotranspiration and Evaporation 105 days after seeding in treatment-1

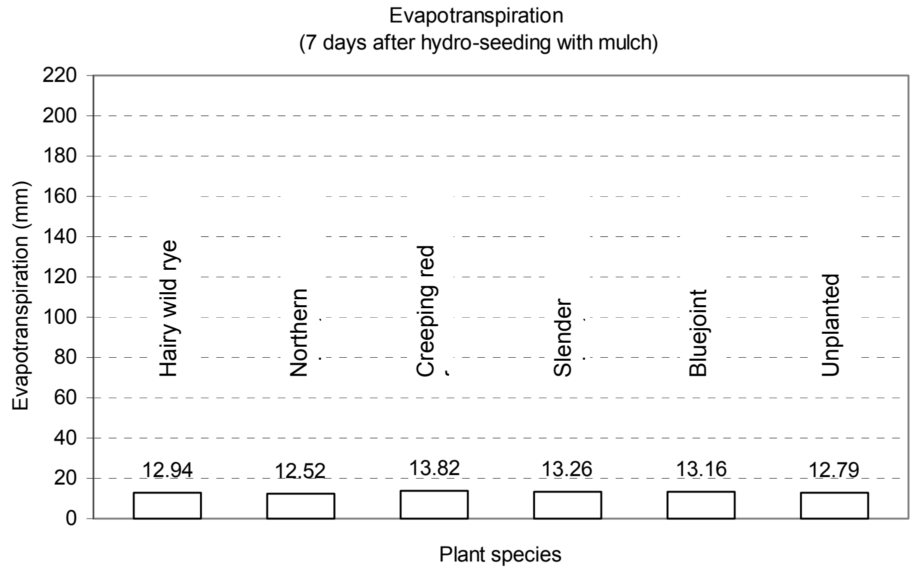


Figure C-15 Evapotranspiration and Evaporation 7 days after seeding in treatment-2

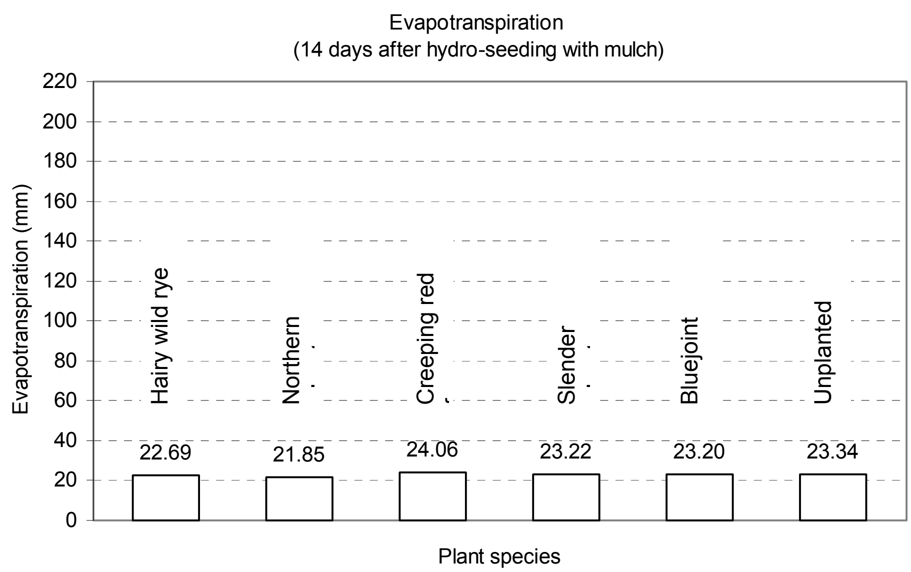


Figure C-16 Evapotranspiration and Evaporation 14 days after seeding in treatment-2

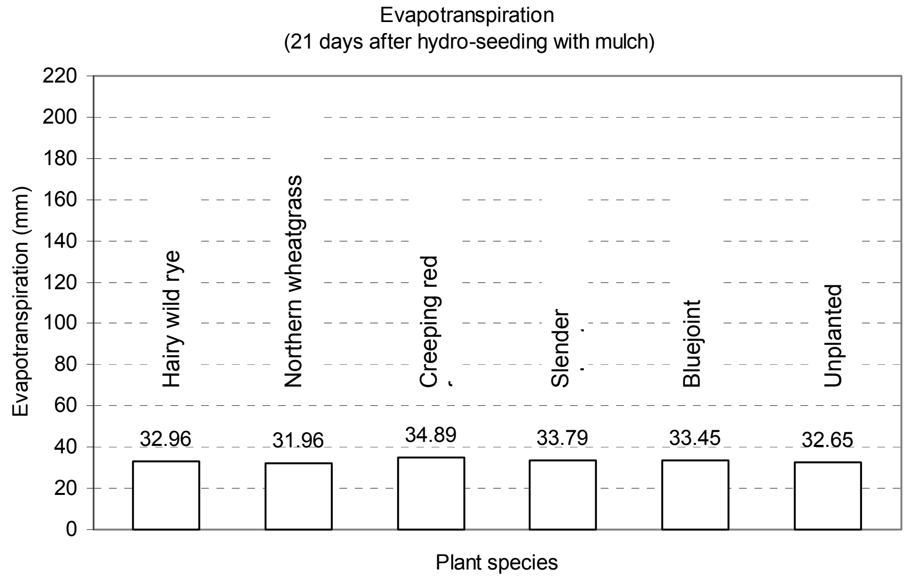


Figure C-17 Evapotranspiration and Evaporation 21 days after seeding in treatment-2

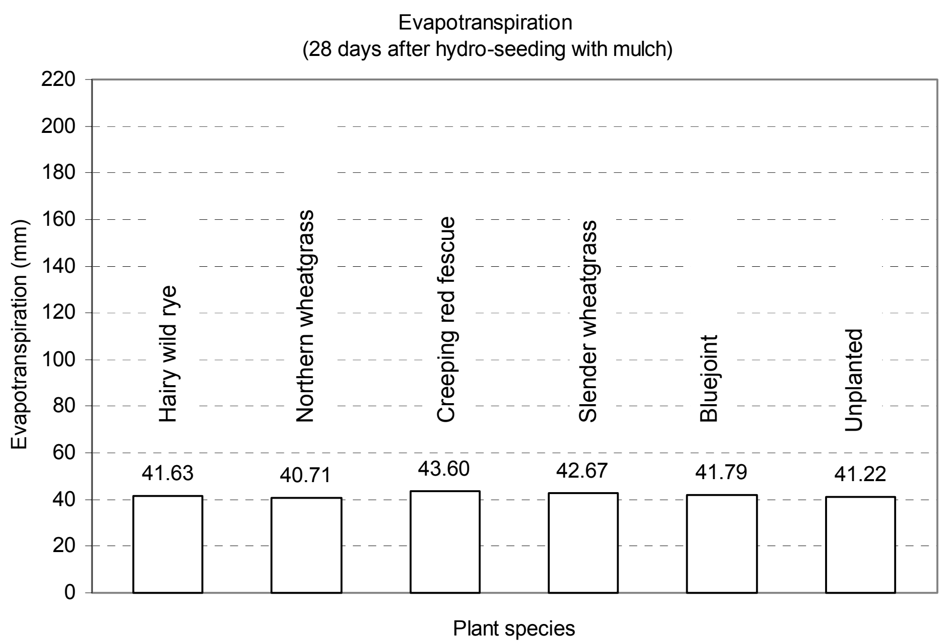


Figure C-18 Evapotranspiration and Evaporation 28 days after seeding in treatment-2

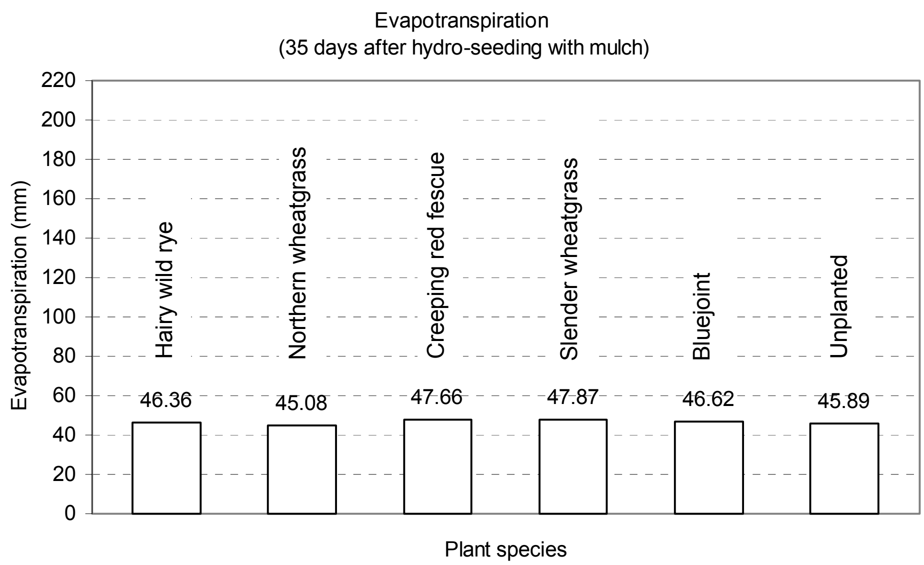


Figure C-19 Evapotranspiration and Evaporation 35 days after seeding in treatment-2

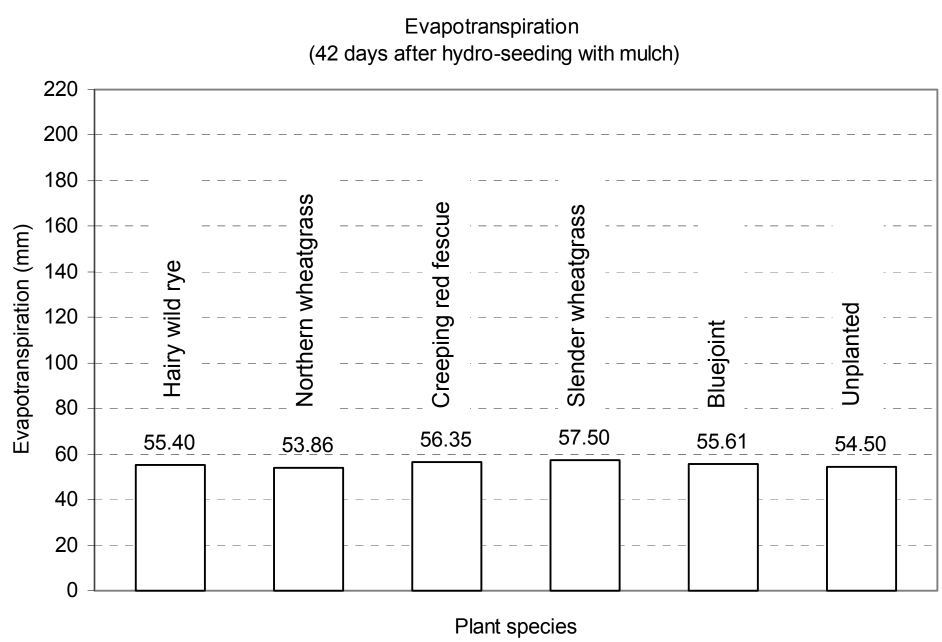


Figure C-20 Evapotranspiration and Evaporation 42 days after seeding in treatment-2

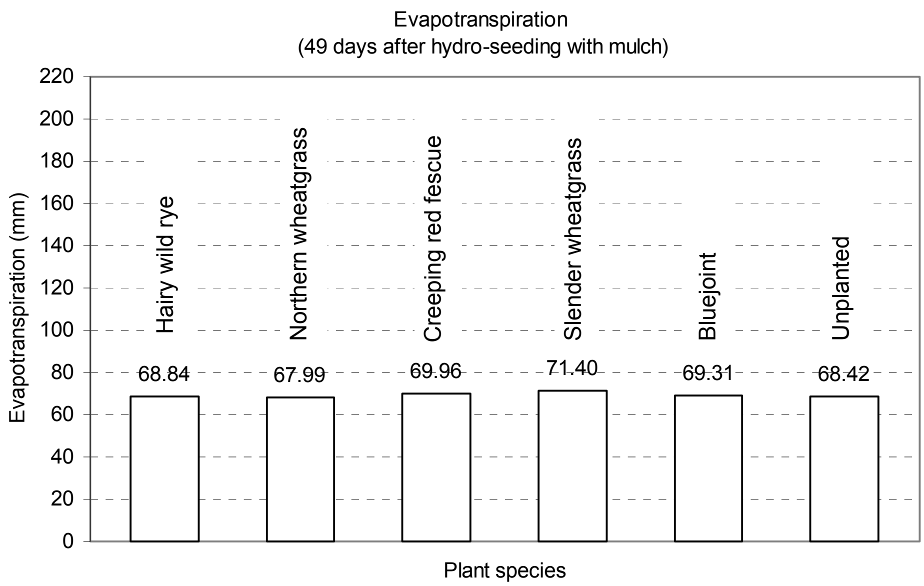


Figure C-21 Evapotranspiration and Evaporation 49 days after seeding in treatment-2

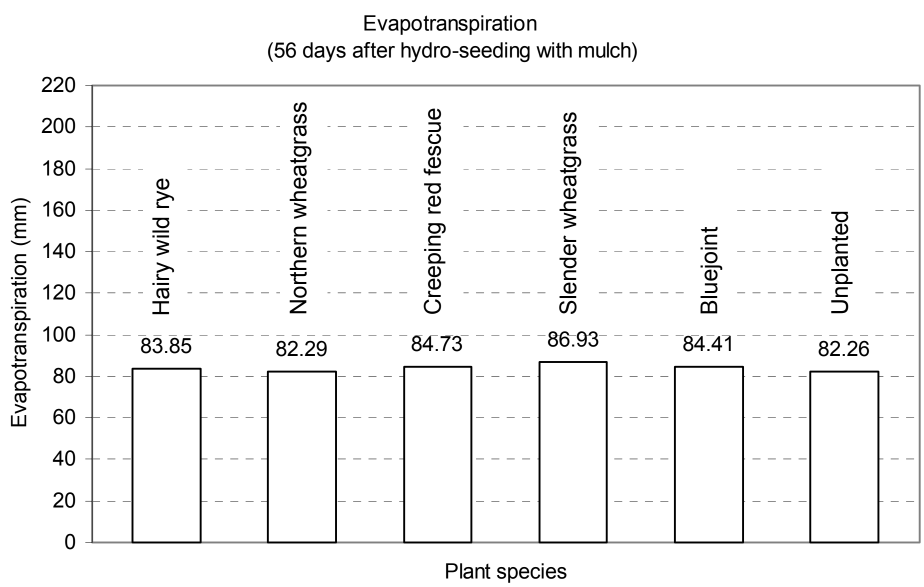


Figure C-22 Evapotranspiration and Evaporation 56 days after seeding in treatment-2

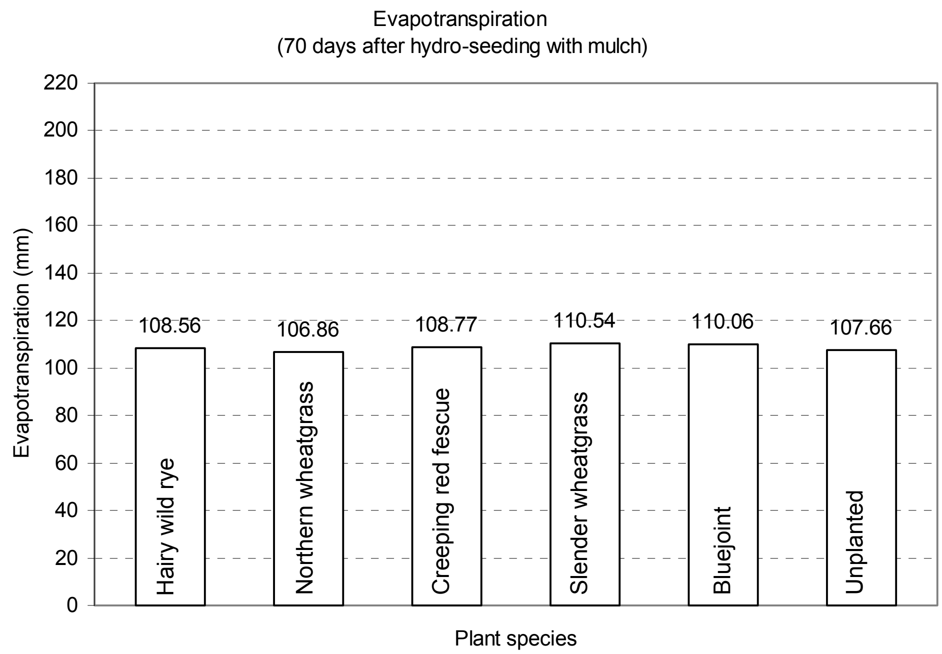


Figure C-23 Evapotranspiration and Evaporation 70 days after seeding in treatment-2

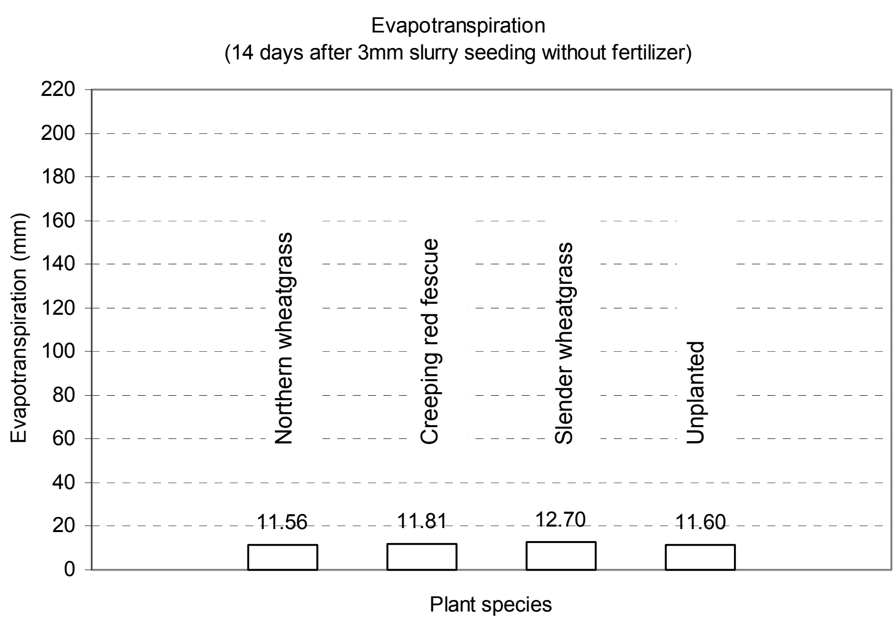


Figure C-24 Evapotranspiration and Evaporation 14 days after seeding in treatment-3

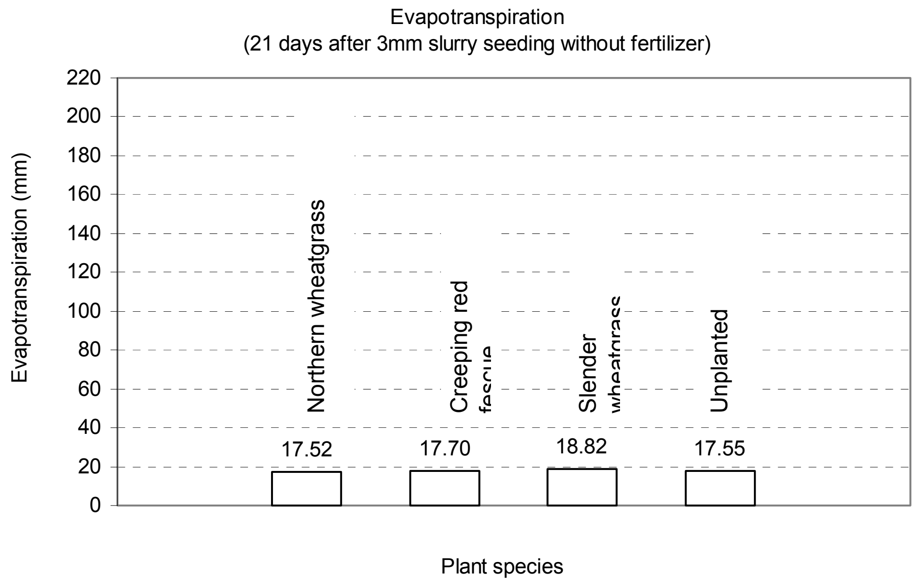


Figure C-25 Evapotranspiration and Evaporation 21 days after seeding in treatment-3

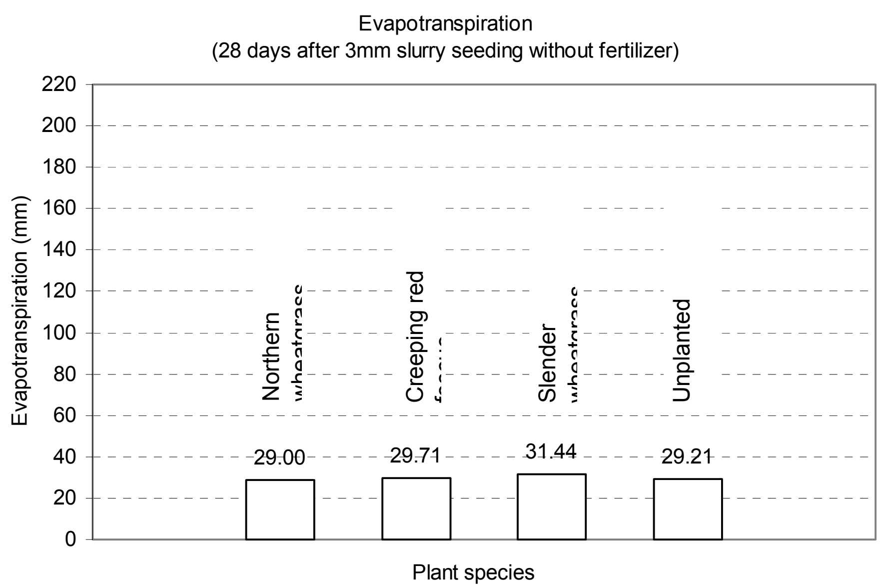


Figure C-26 Evapotranspiration and Evaporation 28 days after seeding in treatment-3

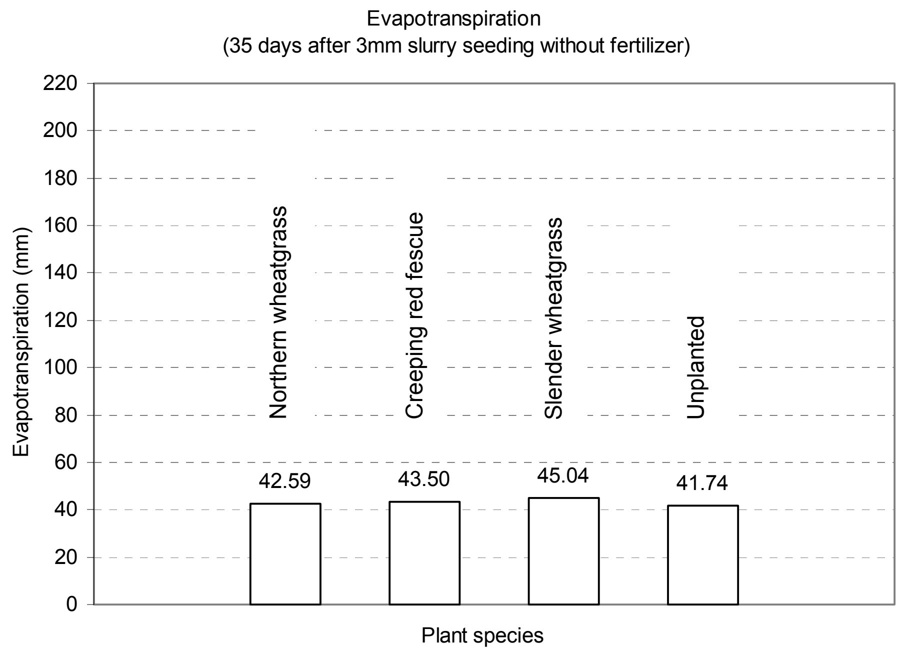


Figure C-27 Evapotranspiration and Evaporation 35 days after seeding in treatment-3

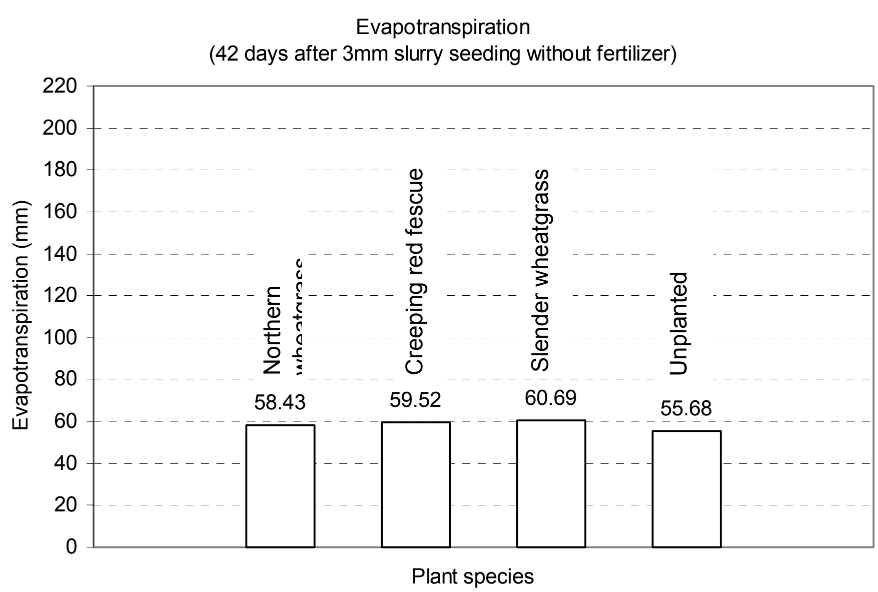


Figure C-28 Evapotranspiration and Evaporation 42 days after seeding in treatment-3

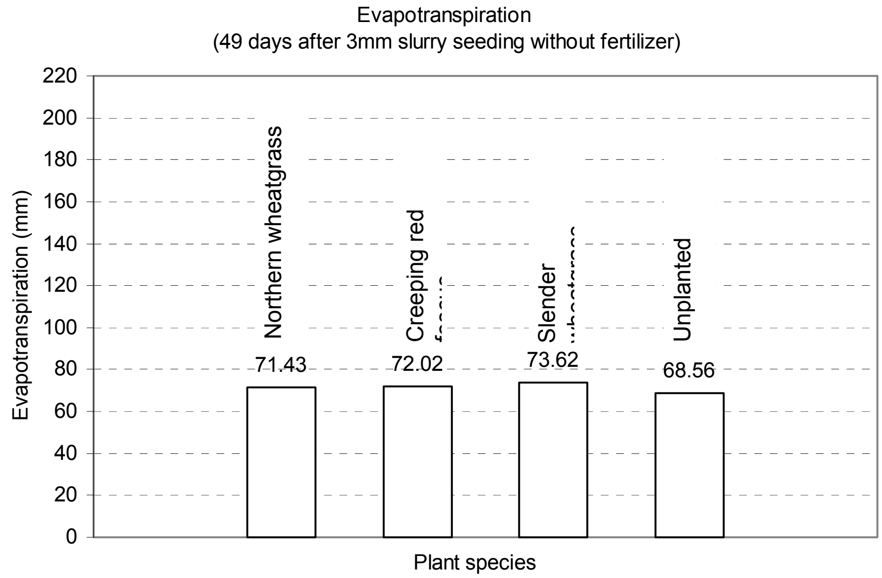


Figure C-29 Evapotranspiration and Evaporation 49 days after seeding in treatment-3

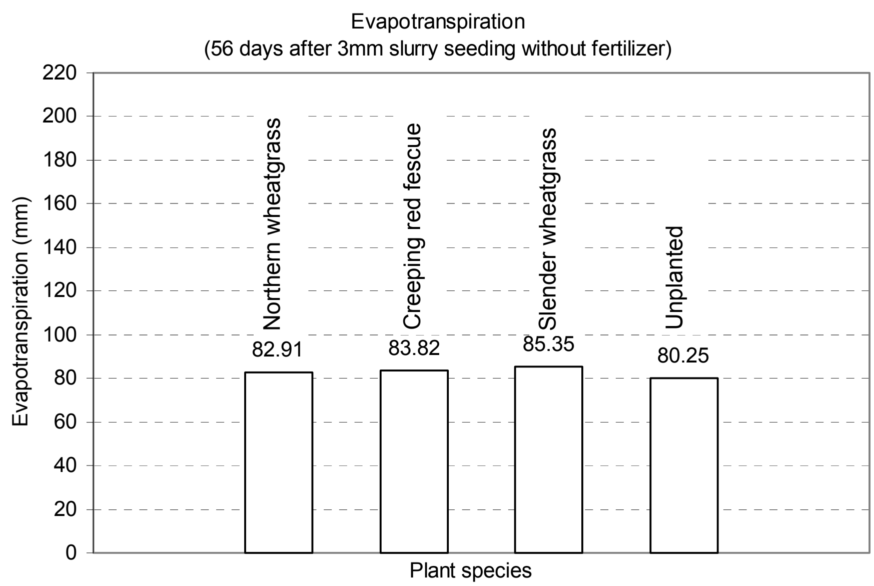


Figure C-30 Evapotranspiration and Evaporation 56 days after seeding in treatment-3

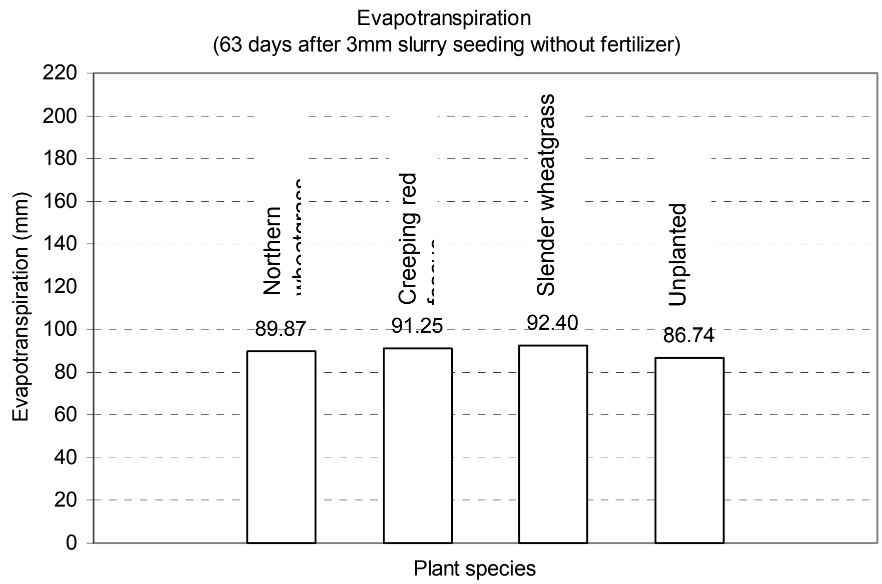


Figure C-31 Evapotranspiration and Evaporation 63 days after seeding in treatment-3

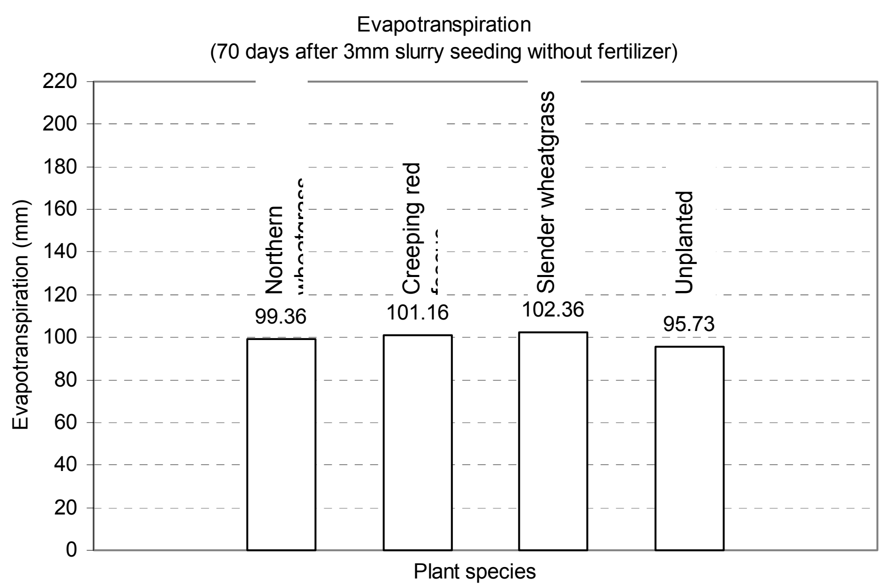


Figure C-32 Evapotranspiration and Evaporation 70 days after seeding in treatment-3

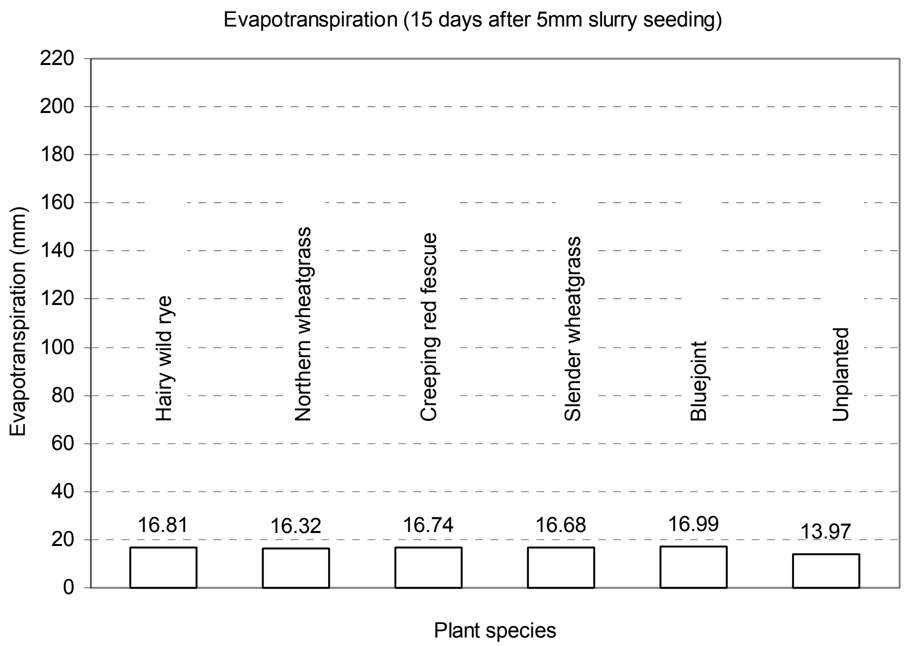


Figure C-33 Evapotranspiration and Evaporation 15 days after seeding in treatment-4

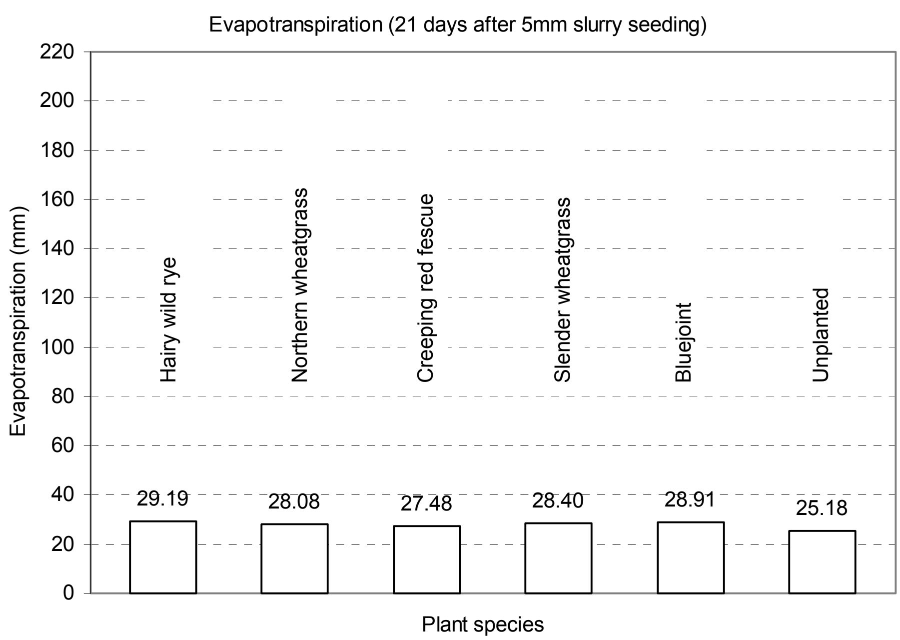


Figure C-34 Evapotranspiration and Evaporation 21 days after seeding in treatment-4

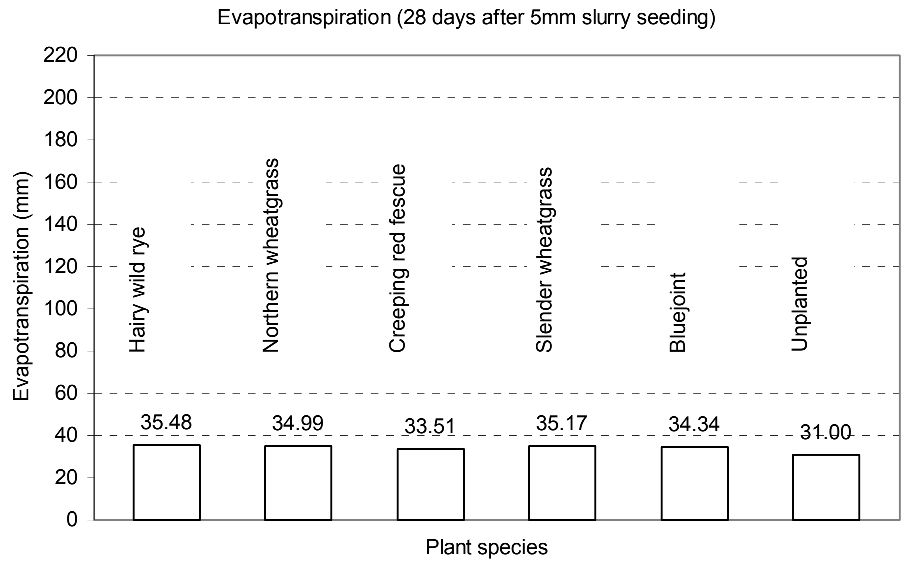


Figure C-35 Evapotranspiration and Evaporation 28 days after seeding in treatment-4

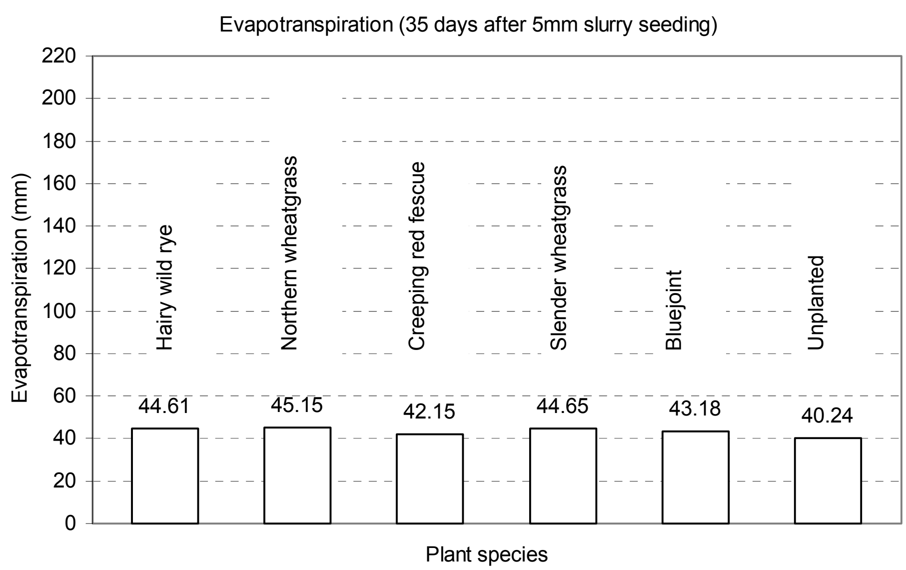


Figure C-36 Evapotranspiration and Evaporation 35 days after seeding in treatment-4

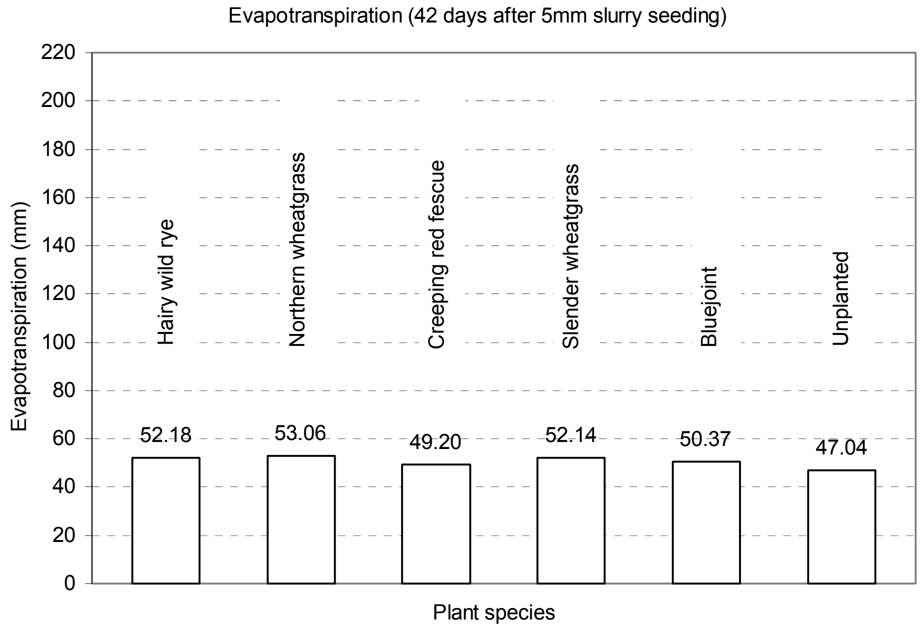


Figure C-37 Evapotranspiration and Evaporation 42 days after seeding in treatment-4

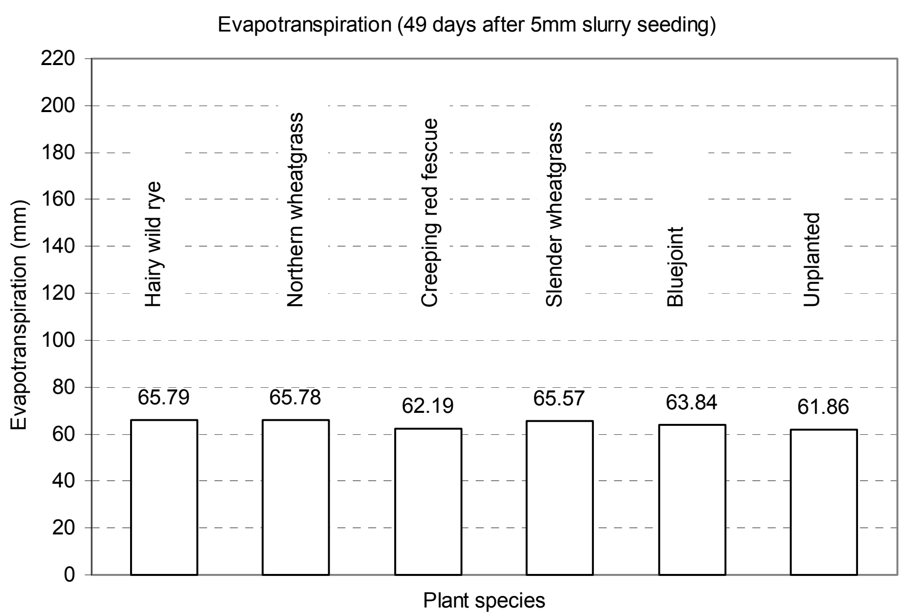


Figure C-38 Evapotranspiration and Evaporation 49 days after seeding in treatment-4

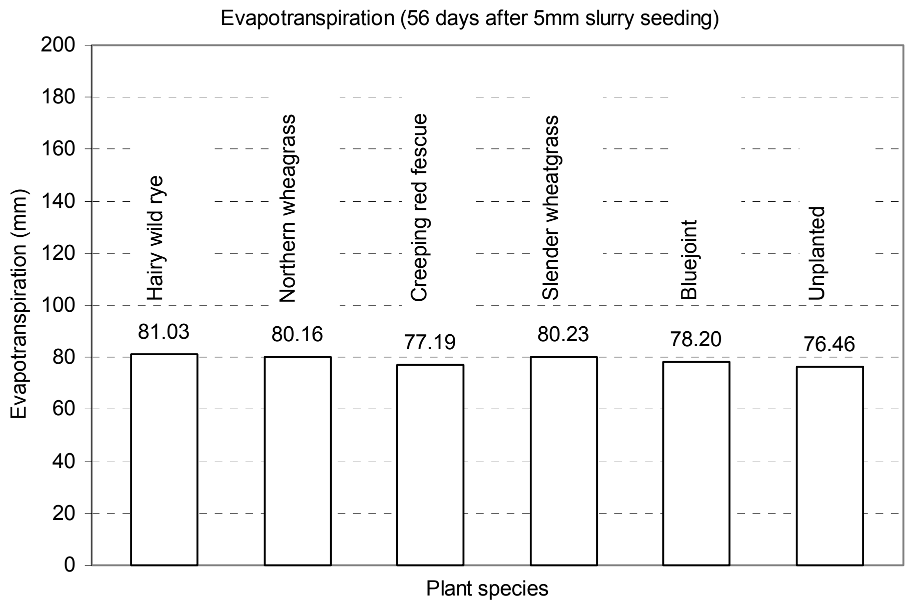


Figure C-39 Evapotranspiration and Evaporation 56 days after seeding in treatment-4

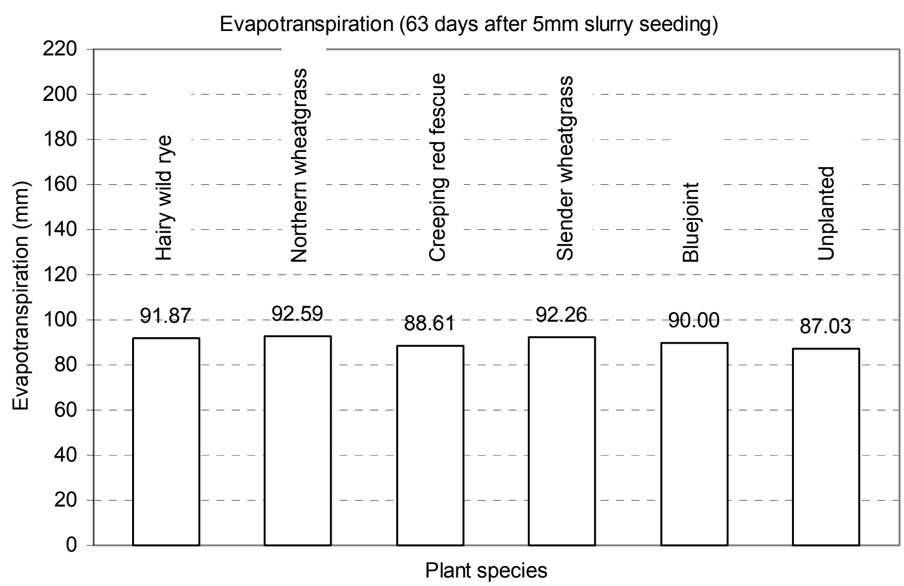


Figure C-40 Evapotranspiration and Evaporation 63 days after seeding in treatment-4

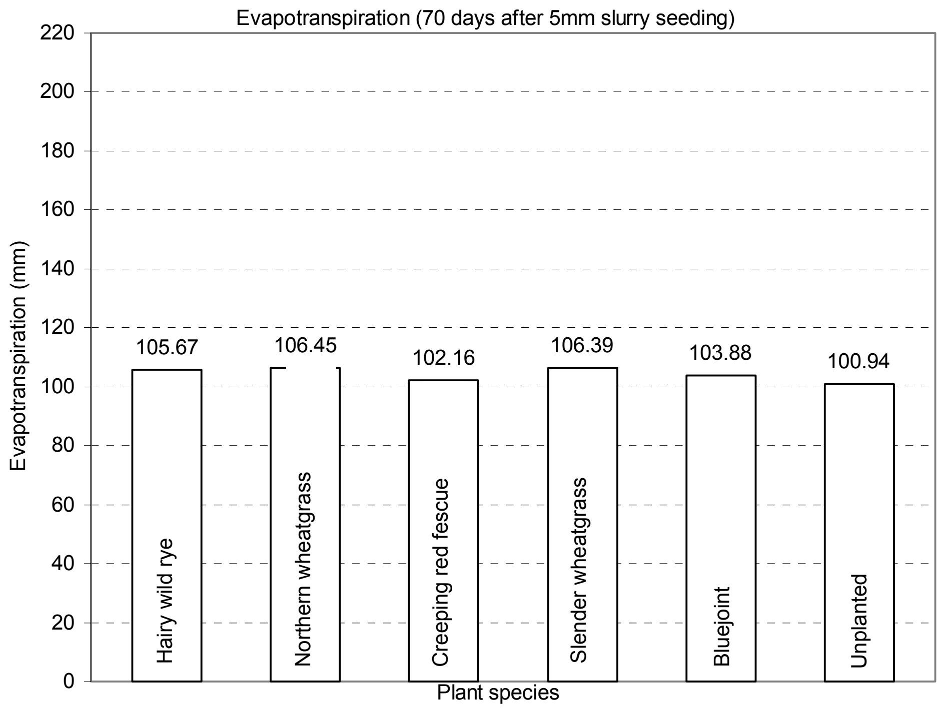


Figure C-41 Evapotranspiration and Evaporation 70 days after seeding in treatment-4

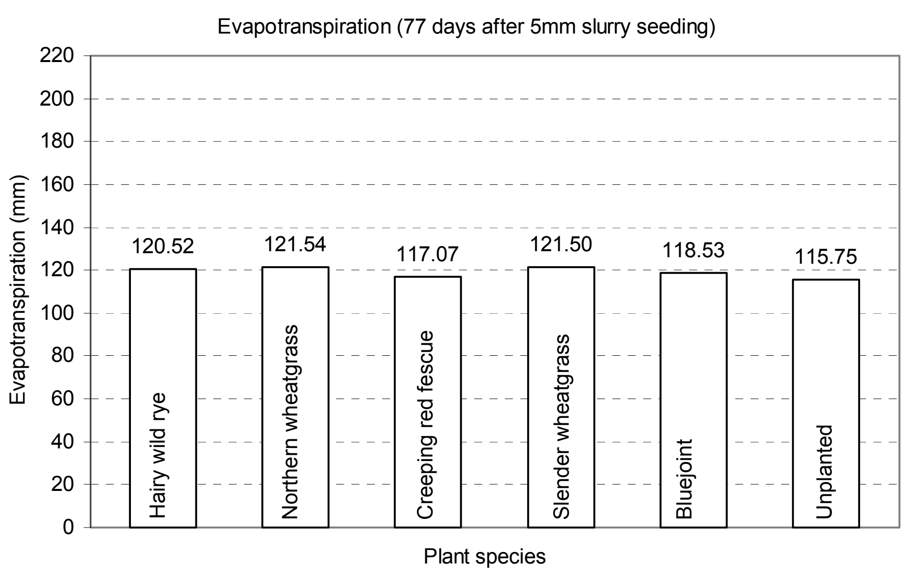


Figure C-42 Evapotranspiration and Evaporation 77 days after seeding in treatment-4

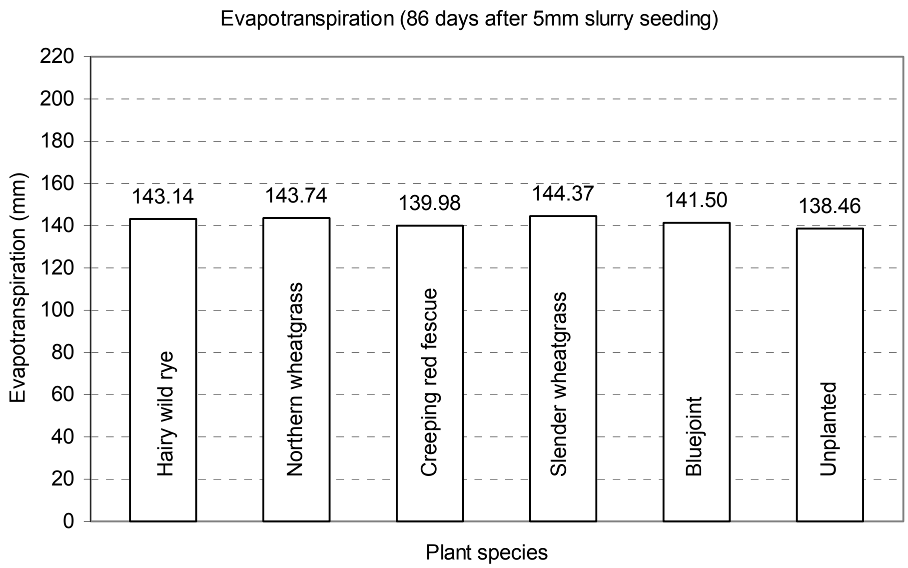


Figure C-43 Evapotranspiration and Evaporation 86 days after seeding in treatment-4

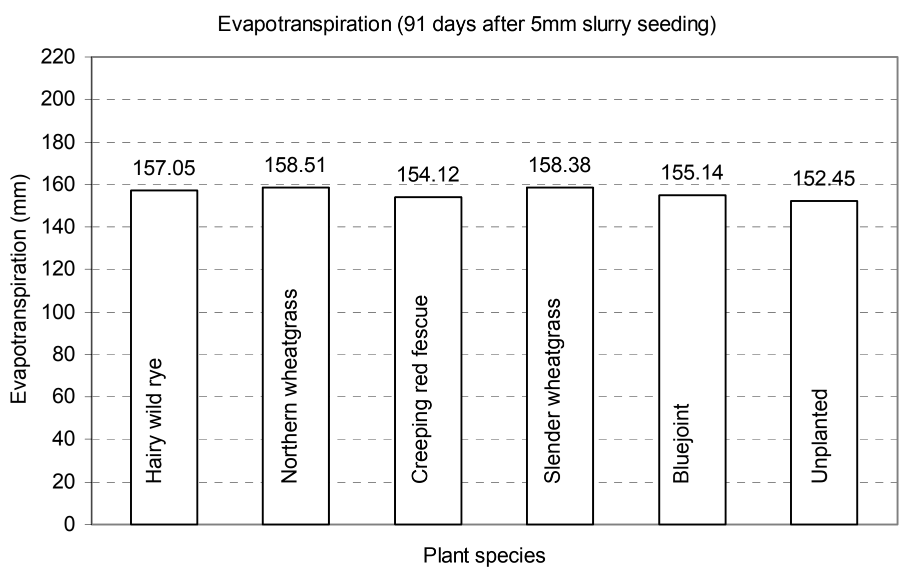


Figure C-44 Evapotranspiration and Evaporation 91 days after seeding in treatment-4

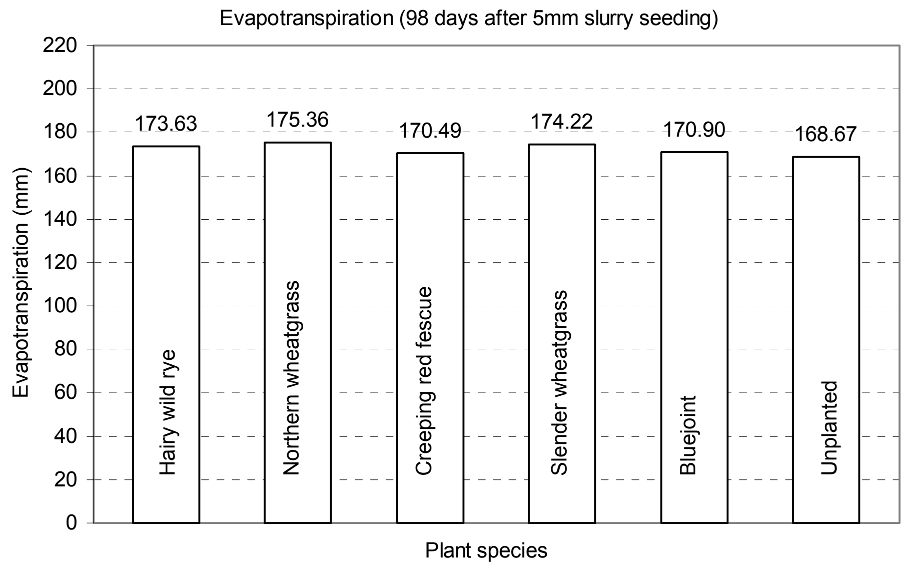


Figure C-45 Evapotranspiration and Evaporation 98 days after seeding in treatment-4

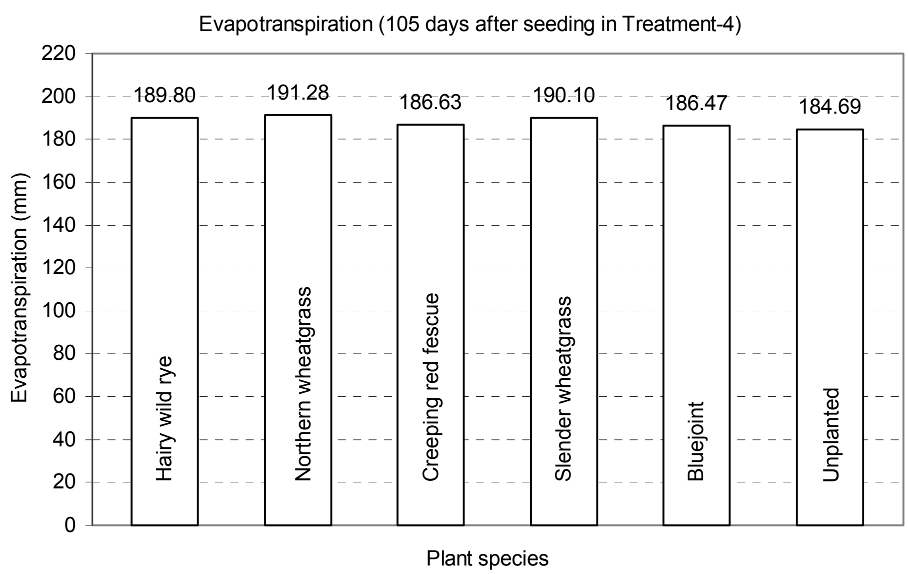


Figure C-46 Evapotranspiration and Evaporation 105 days after seeding in treatment-4

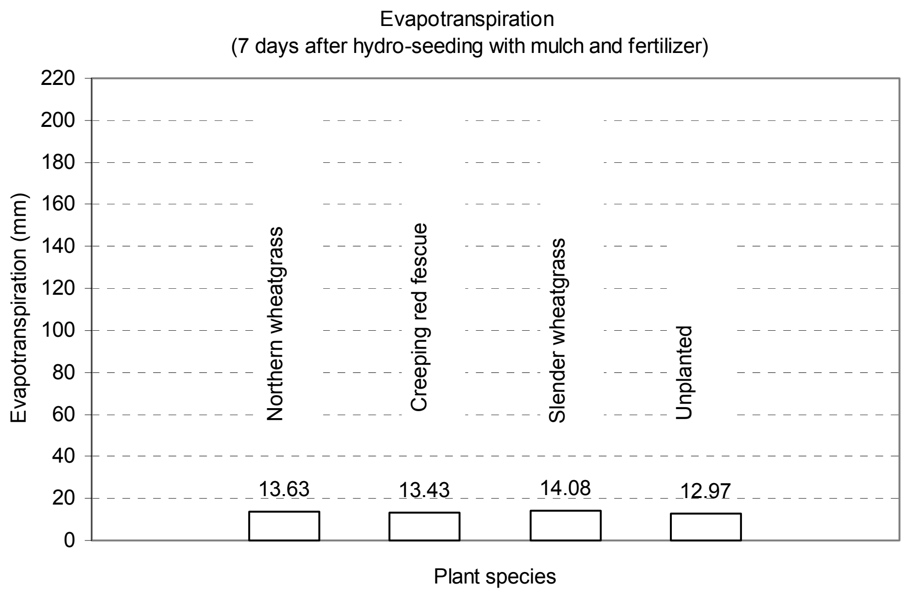


Figure C-47 Evapotranspiration and Evaporation 7 days after seeding in treatment-5

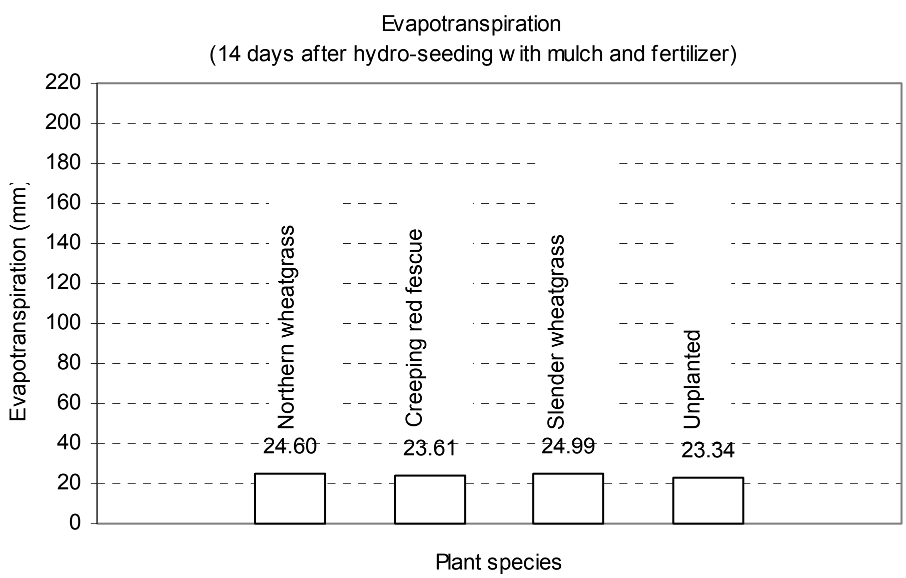


Figure C-48 Evapotranspiration and Evaporation 14 days after seeding in treatment-5

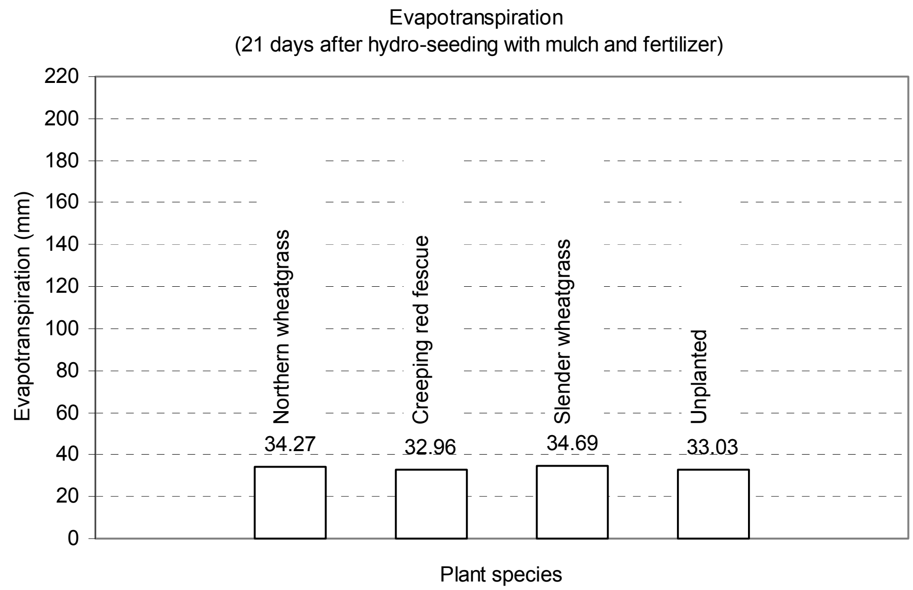


Figure C-49 Evapotranspiration and Evaporation 21 days after seeding in treatment-5

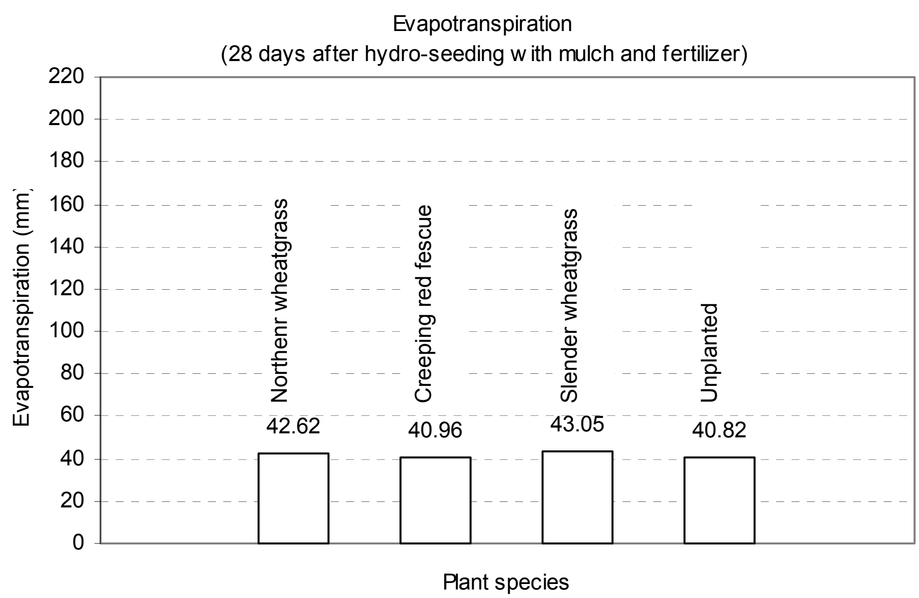


Figure C-50 Evapotranspiration and Evaporation 28 days after seeding in treatment-5

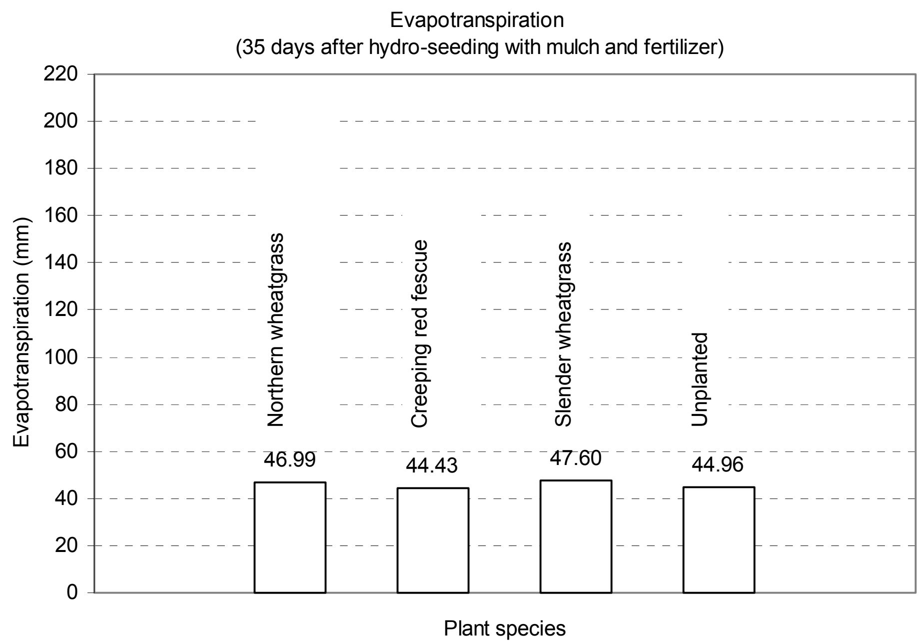


Figure C-51 Evapotranspiration and Evaporation 35 days after seeding in treatment-5

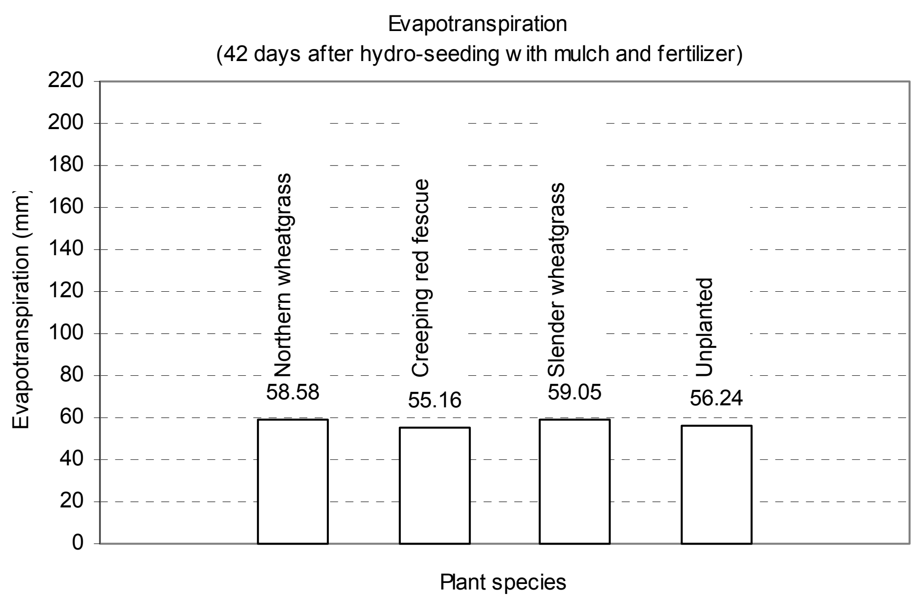


Figure C-52 Evapotranspiration and Evaporation 42 days after seeding in treatment-5

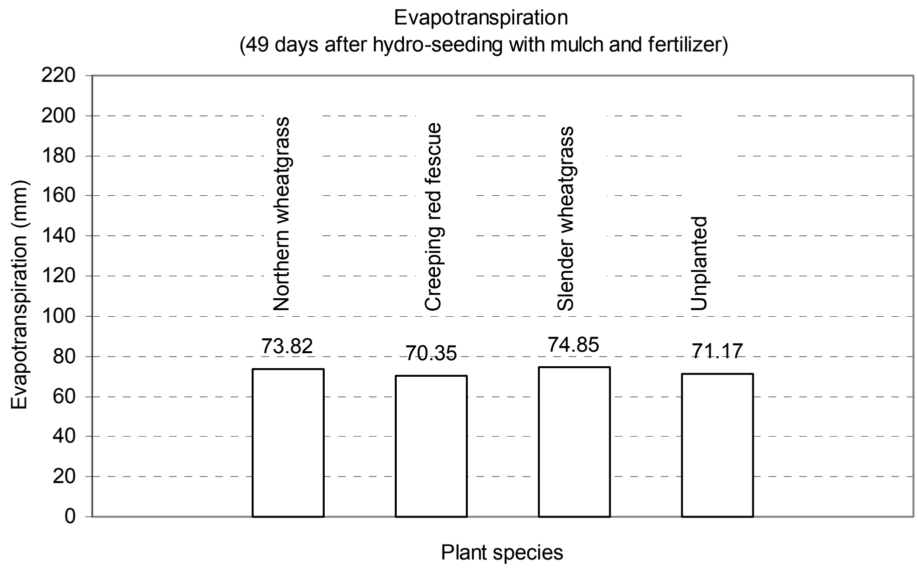


Figure C-53 Evapotranspiration and Evaporation 49 days after seeding in treatment-5

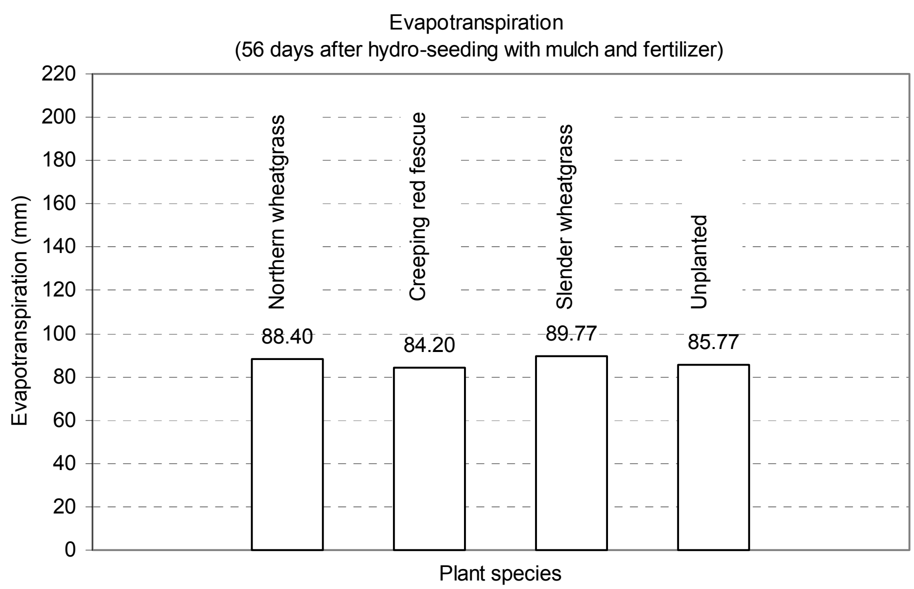


Figure C-54 Evapotranspiration and Evaporation 56 days after seeding in treatment-5

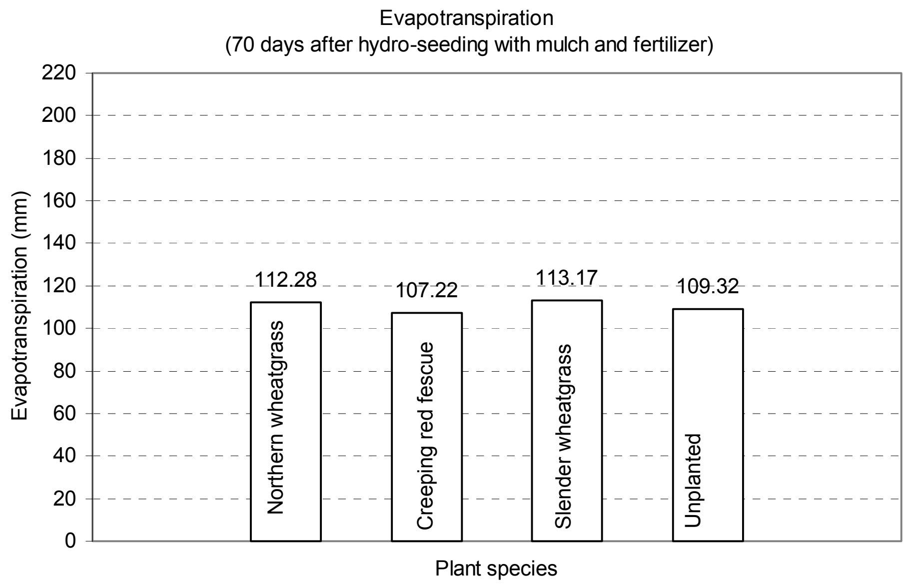


Figure C-55 Evapotranspiration and Evaporation 70 days after seeding in treatment-5

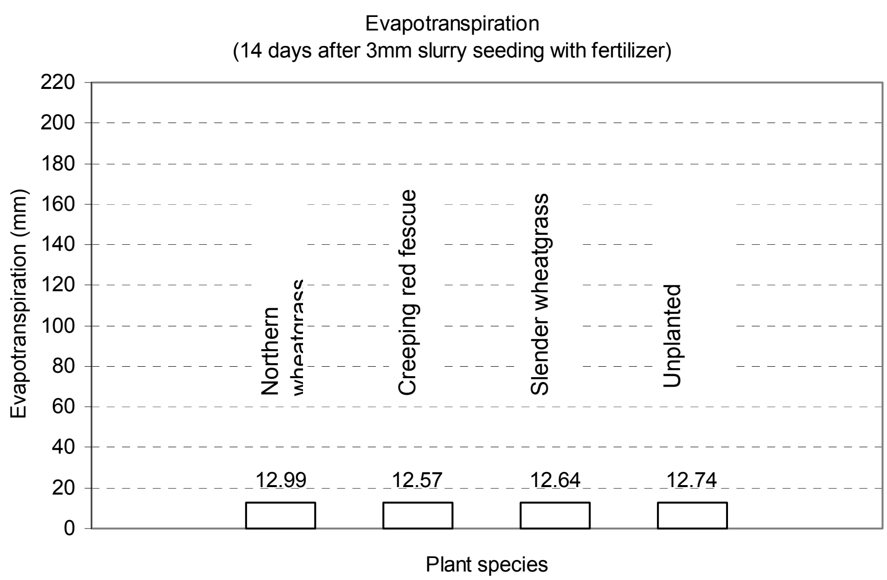


Figure C-56 Evapotranspiration and Evaporation 14 days after seeding in treatment-6

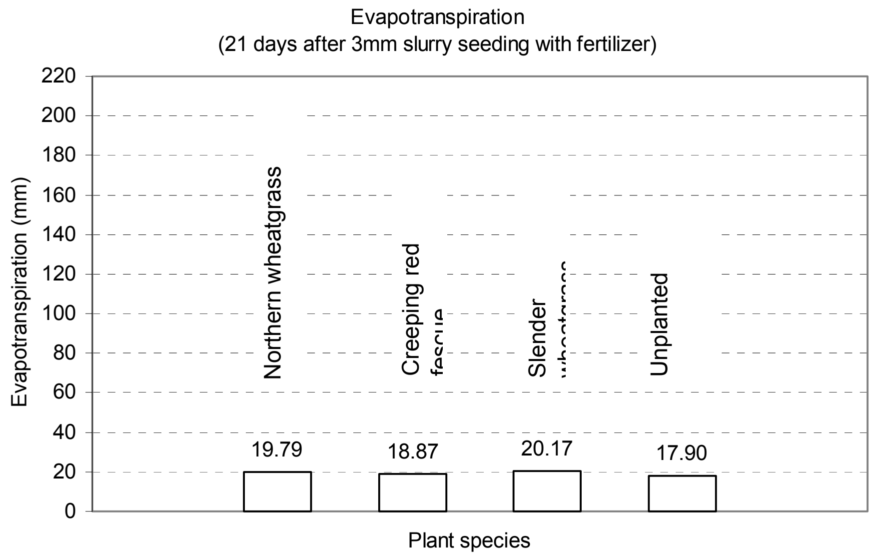


Figure C-57 Evapotranspiration and Evaporation 21 days after seeding in treatment-6

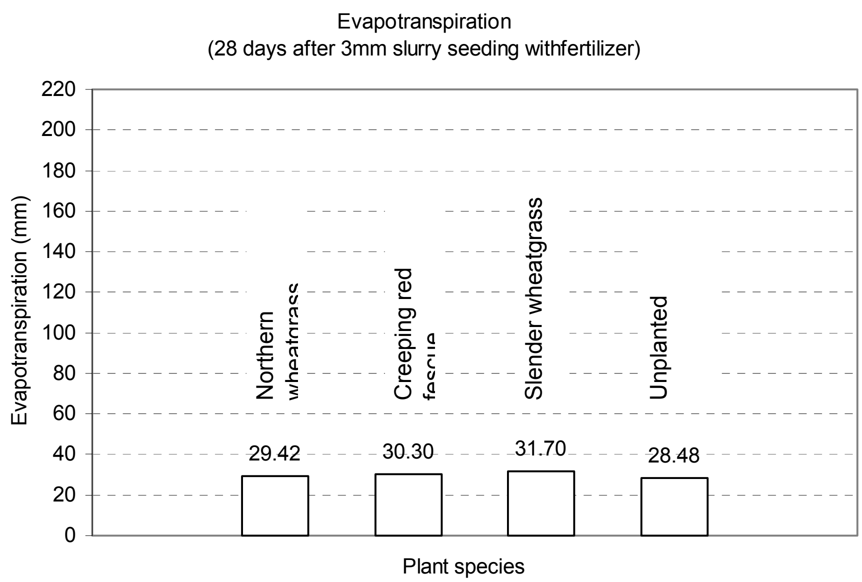


Figure C-58 Evapotranspiration and Evaporation 28 days after seeding in treatment-6

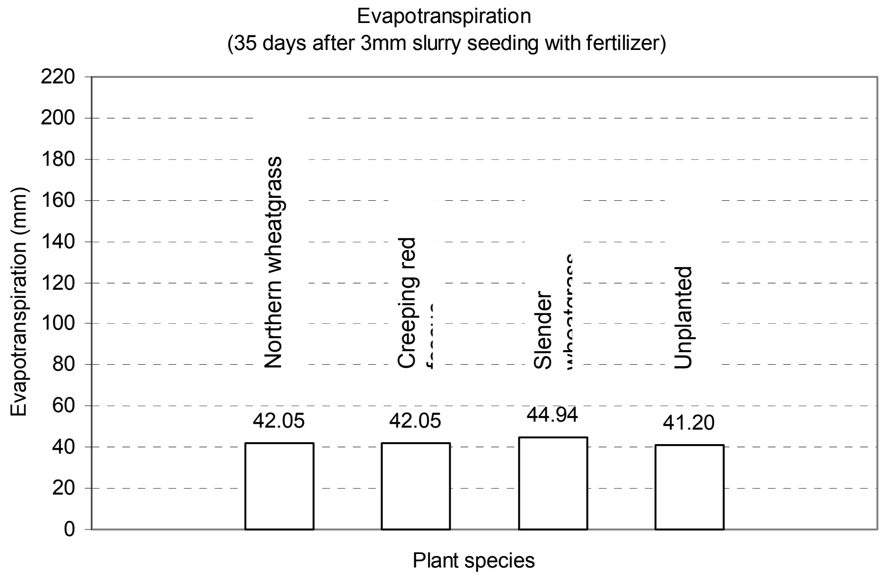


Figure C-59 Evapotranspiration and Evaporation 35 days after seeding in treatment-6

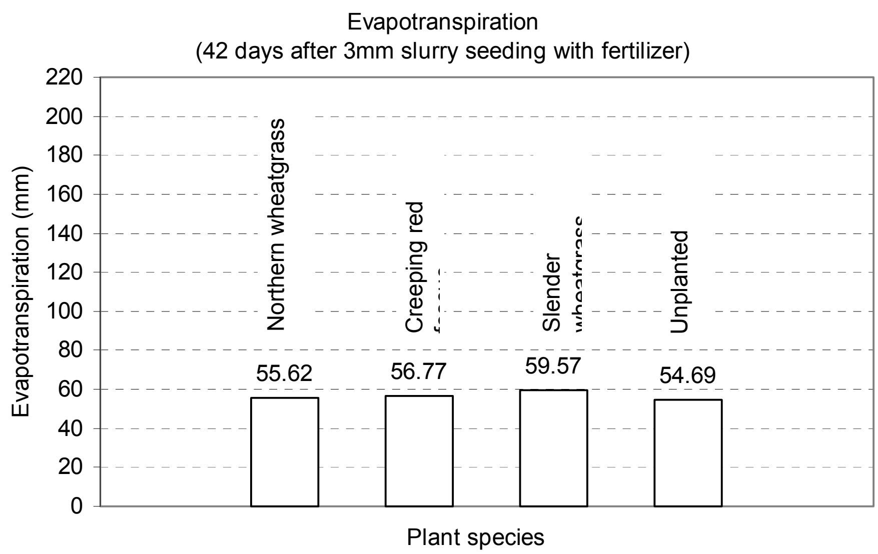


Figure C-60 Evapotranspiration and Evaporation 42 days after seeding in treatment-6

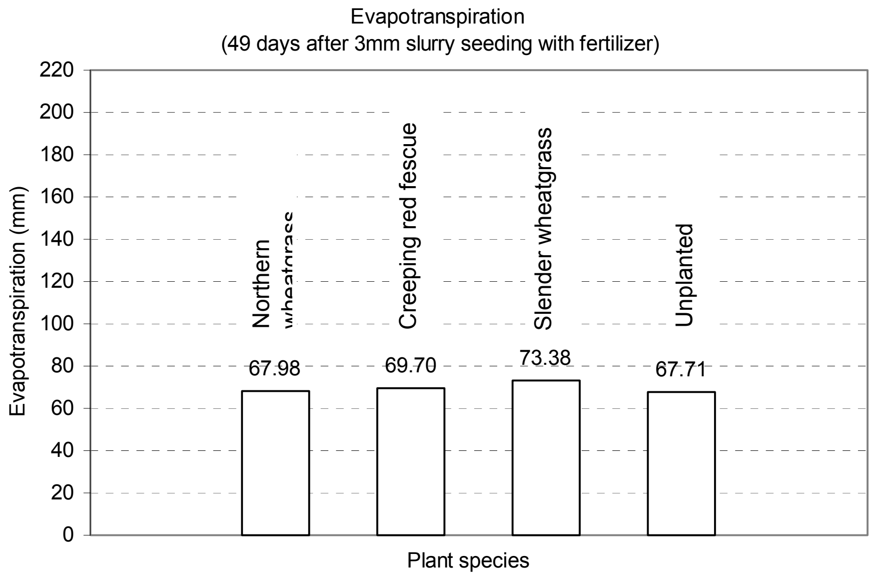


Figure C-61 Evapotranspiration and Evaporation 49 days after seeding in treatment-6

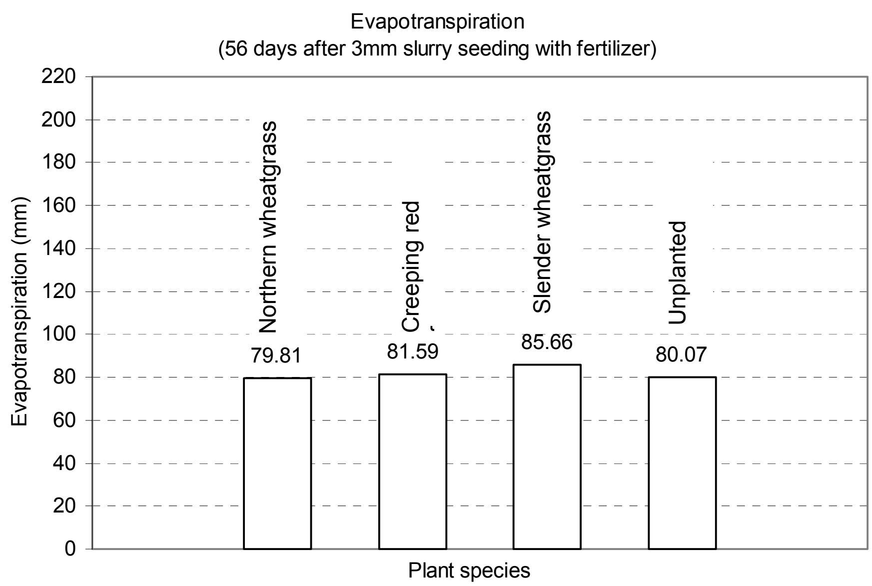


Figure C-62 Evapotranspiration and Evaporation 56 days after seeding in treatment-6

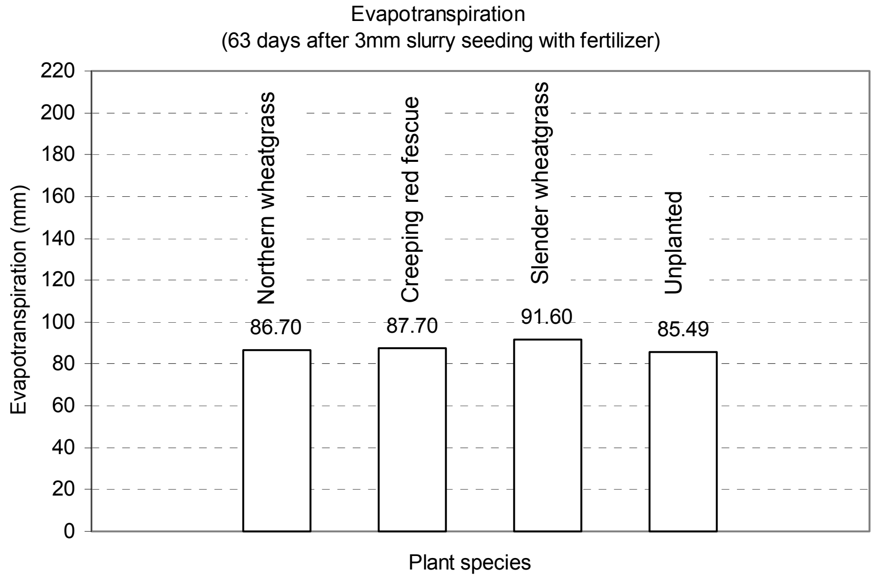


Figure C-63 Evapotranspiration and Evaporation 63 days after seeding in treatment-6

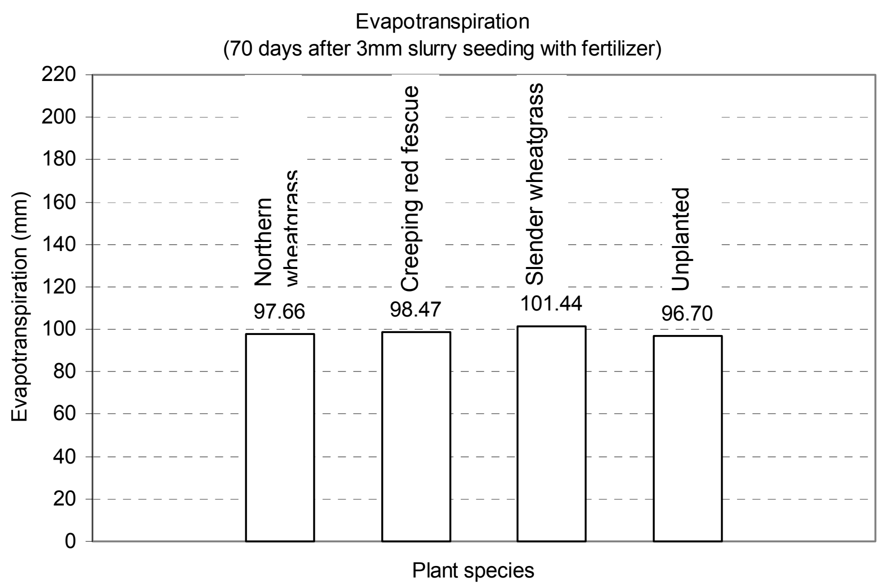


Figure C-64 Evapotranspiration and Evaporation 70 days after seeding in treatment-6

APPENDIX D

RESULTS DATA ON NATIVE PLANT SPECIES DEWATERING CAPACITY ON CT DEPOSITS

D.1 Introduction

As stated in Chapter 3, Ritchie (1968 and 1972) presented an empirical model for estimating the plant evapotranspiration in which the evaporation from soil surface and transpiration from plant are considered separately. Then, both soil evaporation (E_s) and plant transpiration (E_p) contribute to plant total evapotranspiration (E). Evapotranspiration changes the soil moisture content. From the figures shown in Appendix C, the amount of the evapotranspiration in all treatments are not significant different. New dimensionless parameter α was introduced to this experiment to evaluate native plant dewatering capacity on CT materials. Figure D-1 to D-16 presented the results data using this parameter α of native plant species transpiration alone in one growing season.

D.2 References

Ritchie, J. T. and Burnett, E.. 1968. *A precision weighting lysimeter for row crop water use studies*. Agronomy Journal, Vol. 60, pp. 545-549.

Ritchie, J. T. 1972. *Model for Predicting Evaporation from a Row Crop with Incomplete Cover*. Water Resources Research, Vol. 8, No. 5, pp. 1204-1213.

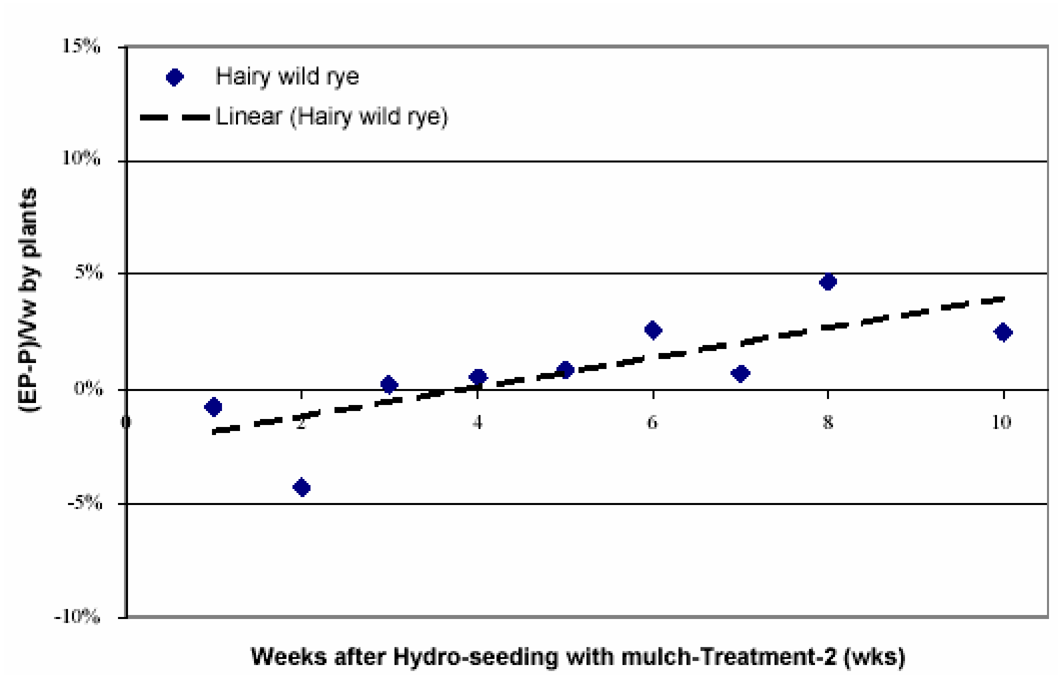


Figure D-1 Water lose percentage by Hairy wild rye in treatment-2

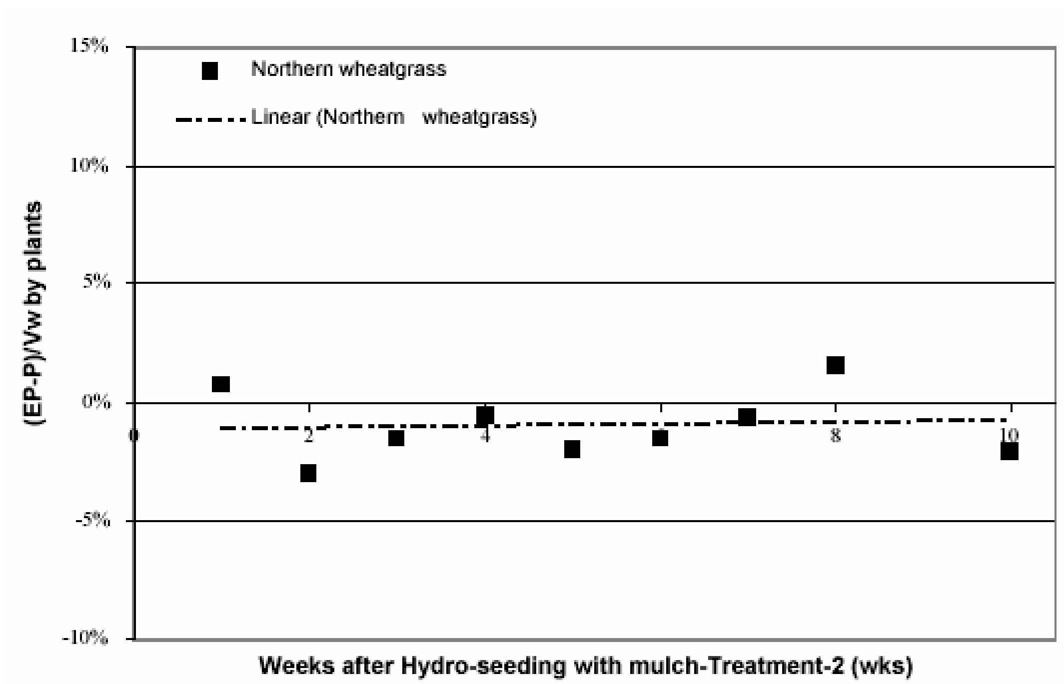


Figure D-2 Water lose percentage by Northern wheatgrass in treatment-2

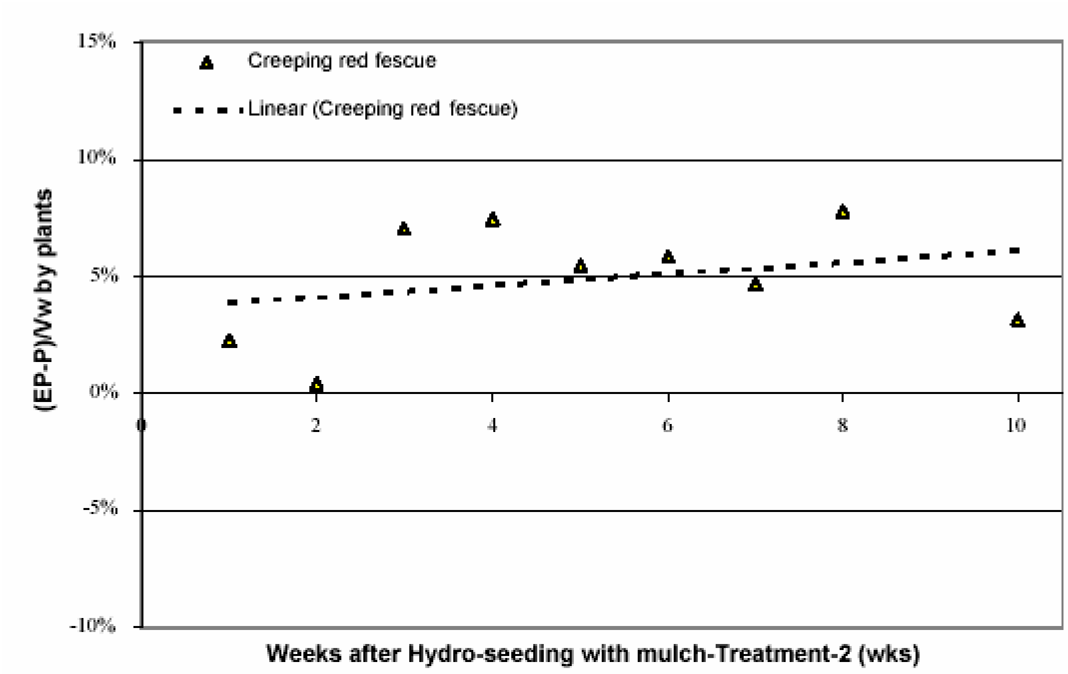


Figure D-3 Water lose percentage by Creeping red fescue in treatment-2

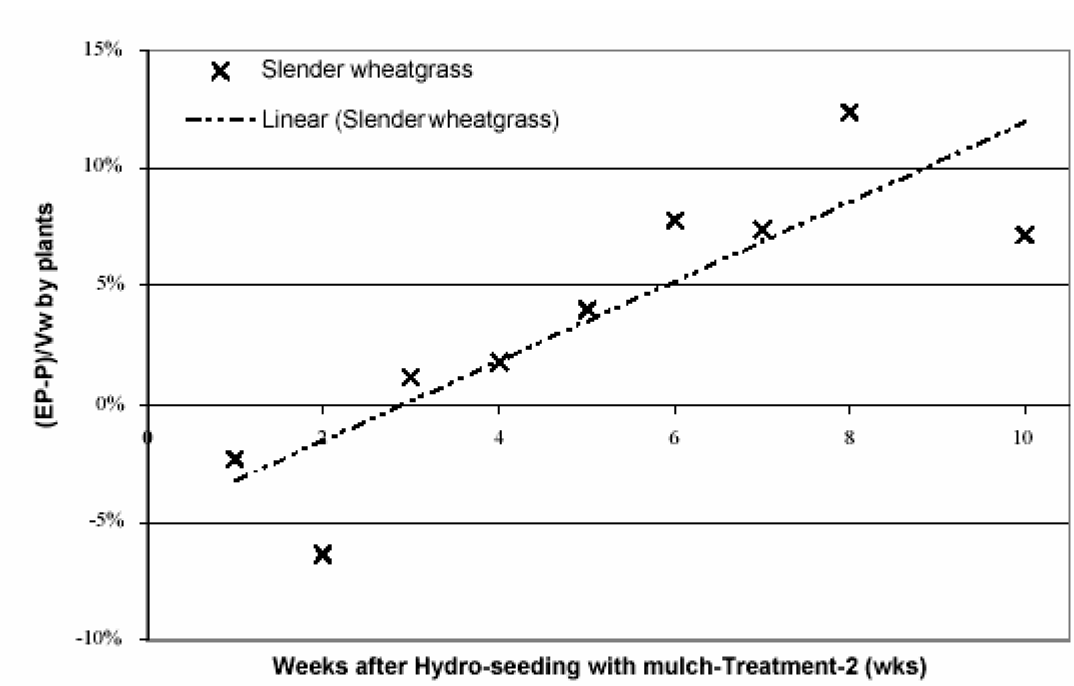


Figure D-4 Water lose percentage by Slender wheatgrass in treatment-2

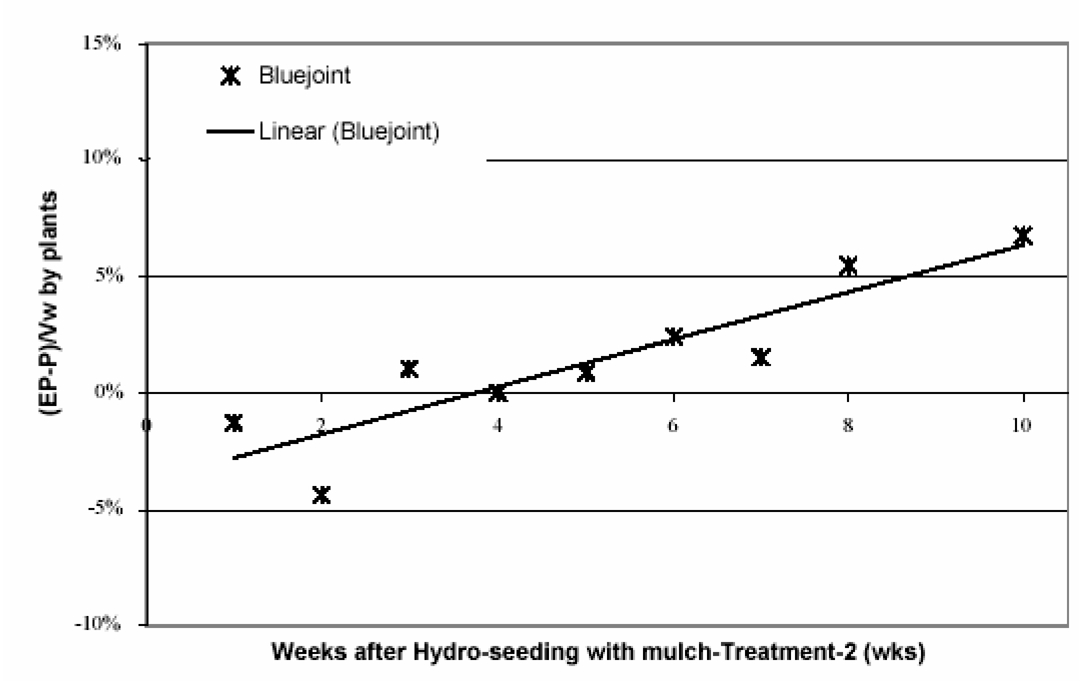


Figure D-5 Water lose percentage by Bluejoint in treatment-2

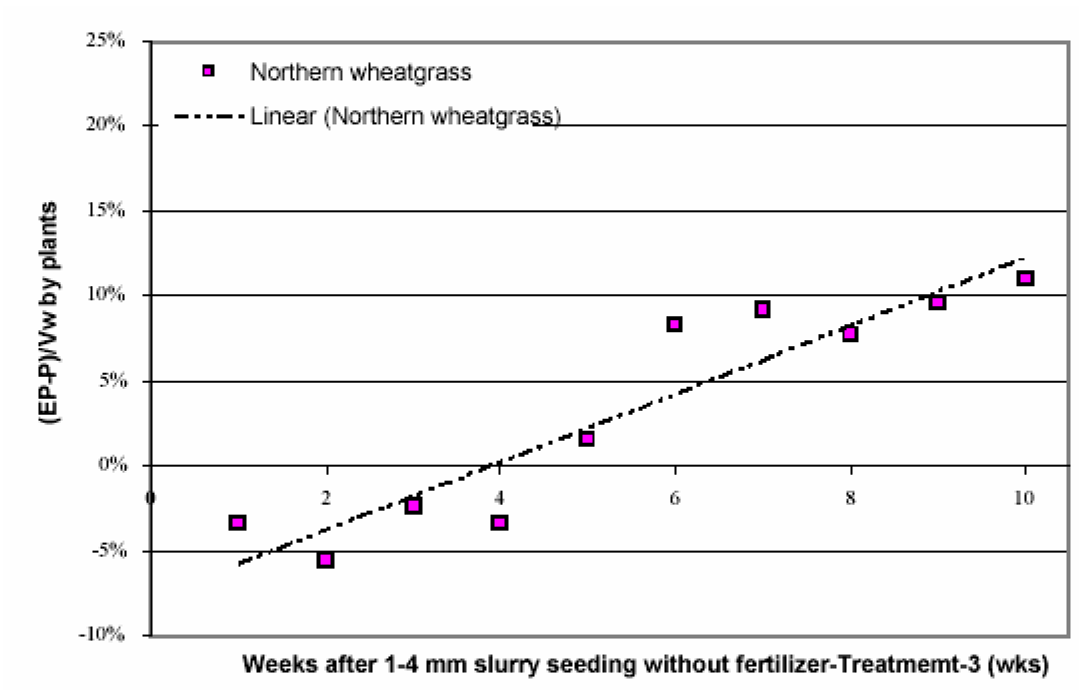


Figure D-6 Water lose percentage by Northern wheatgrass in treatment-3

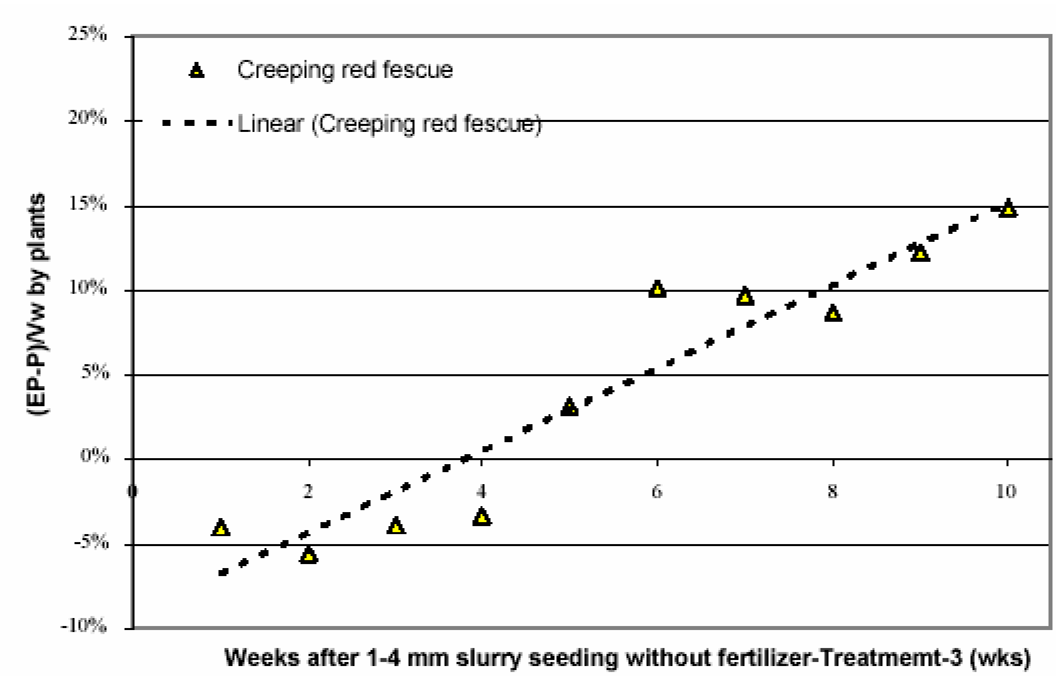


Figure D-7 Water lose percentage by Creeping red fescue in treatment-3

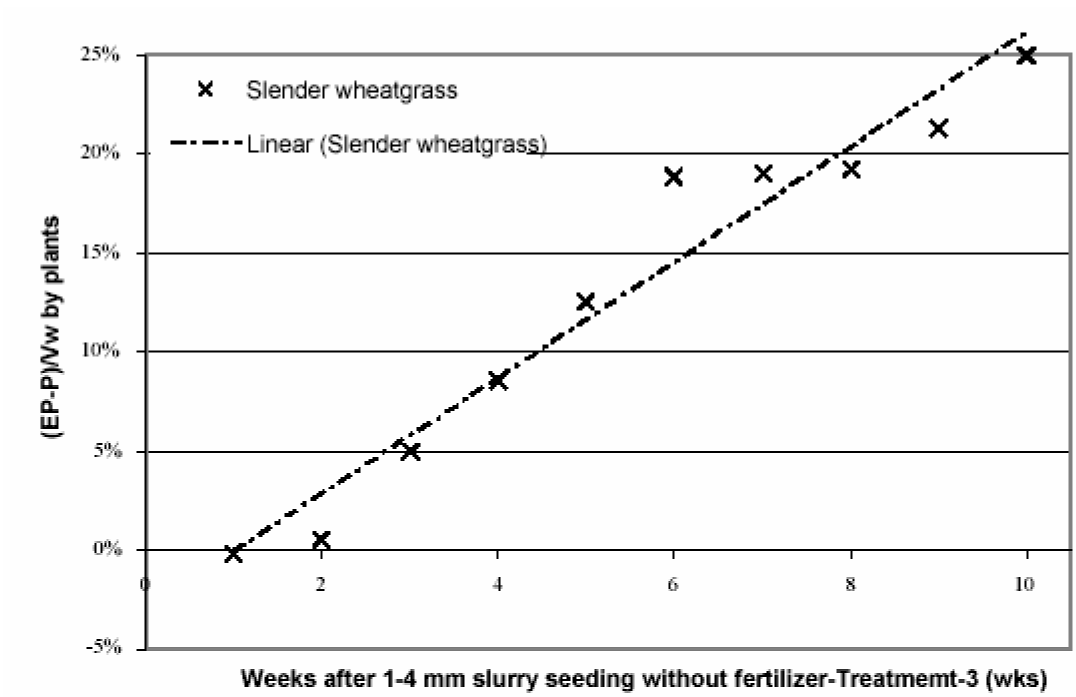


Figure D-8 Water lose percentage by Slender wheatgrass in treatment-3

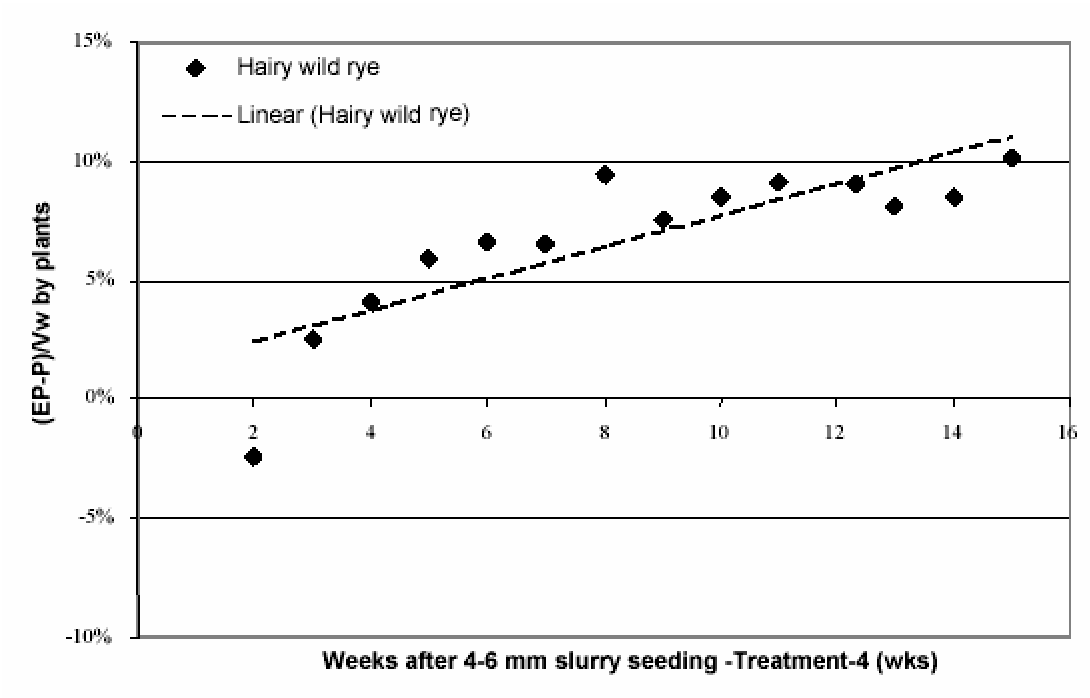


Figure D-9 Water lose percentage by Hairy wild rye in treatment-4

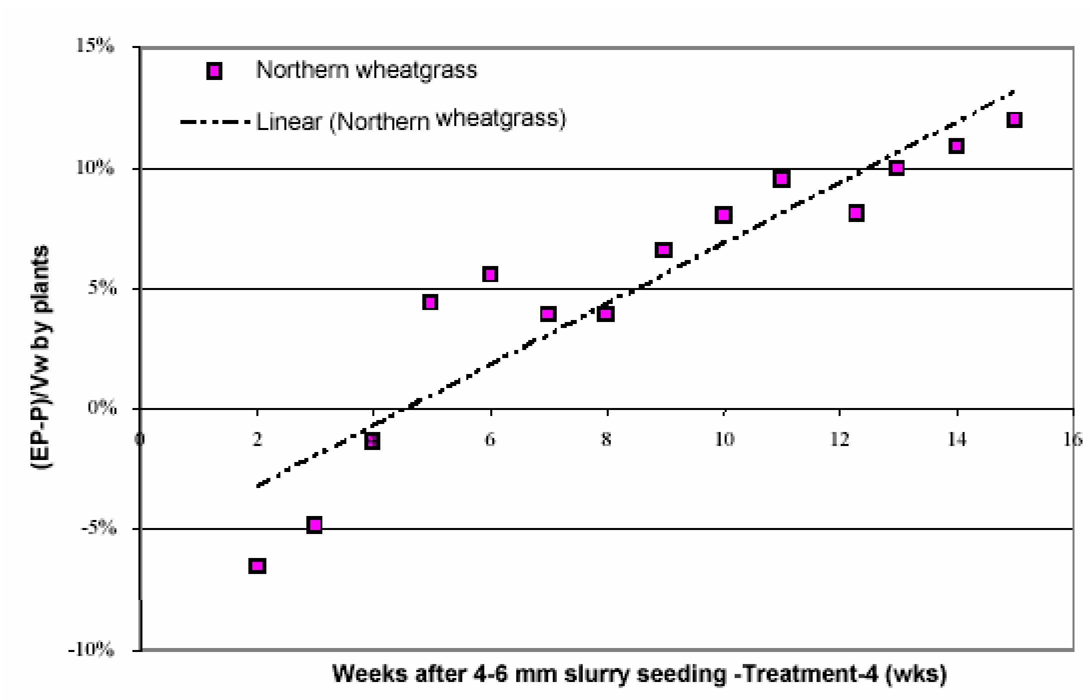


Figure D-10 Water lose percentage by Northern wheatgrass in treatment-4

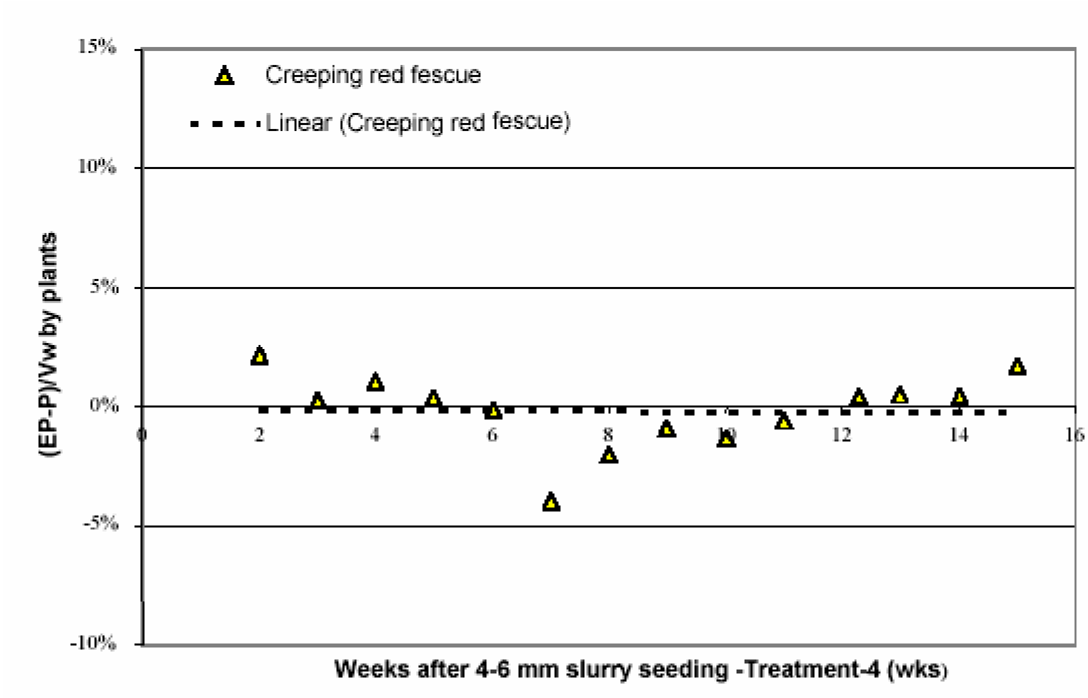


Figure D-11 Water lose percentage by Creeping red fescue in treatment-4

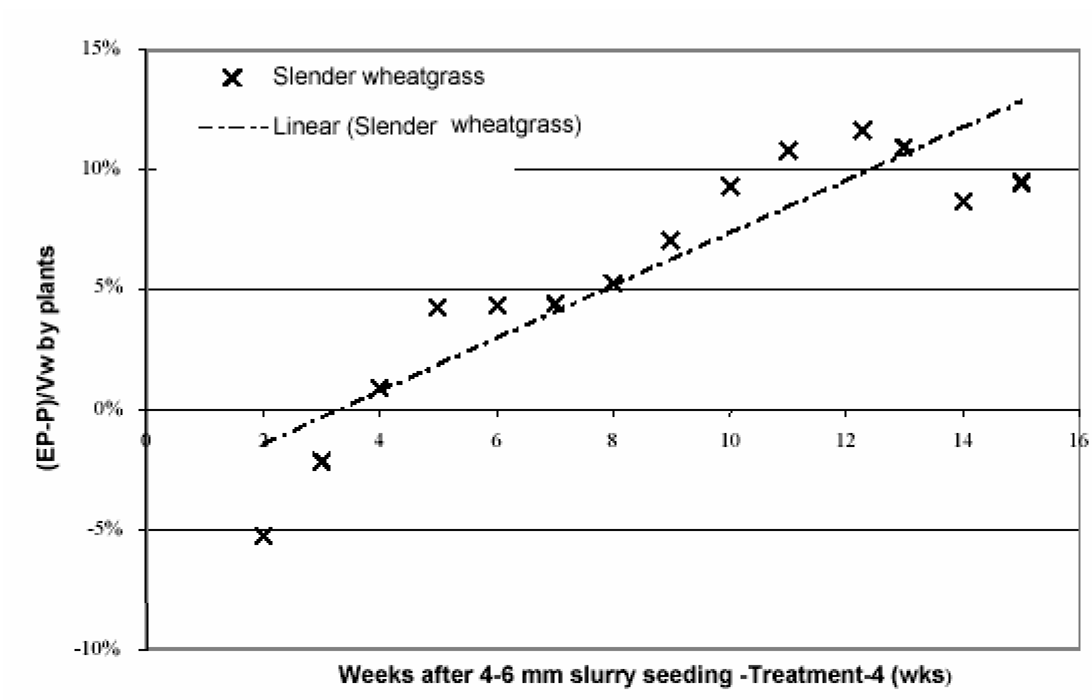


Figure D-12 Water lose percentage by Slender wheatgrass in treatment-4

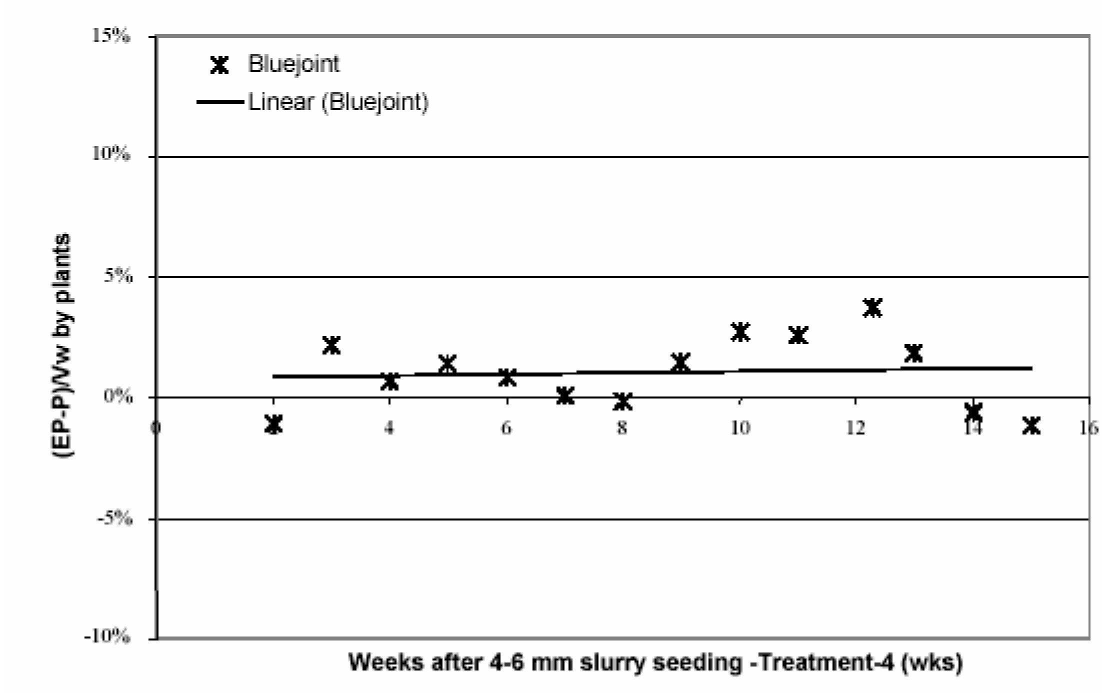


Figure D-13 Water lose percentage by Bluejoint in treatment-4

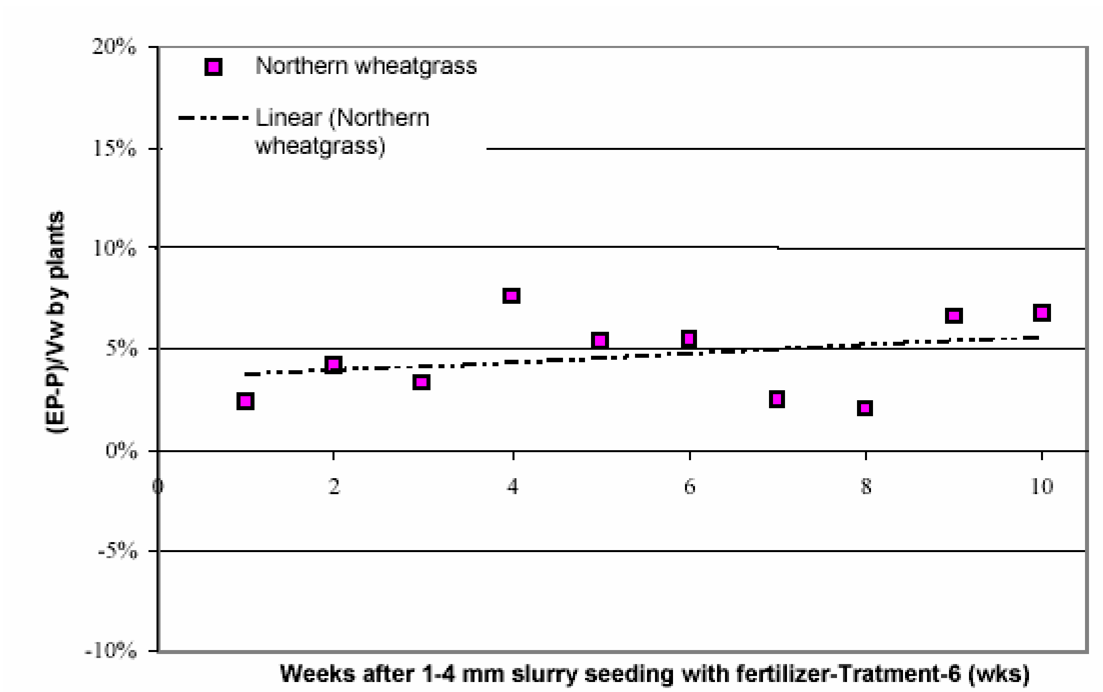


Figure D-14 Water lose percentage by Northern wheatgrass in treatment-6

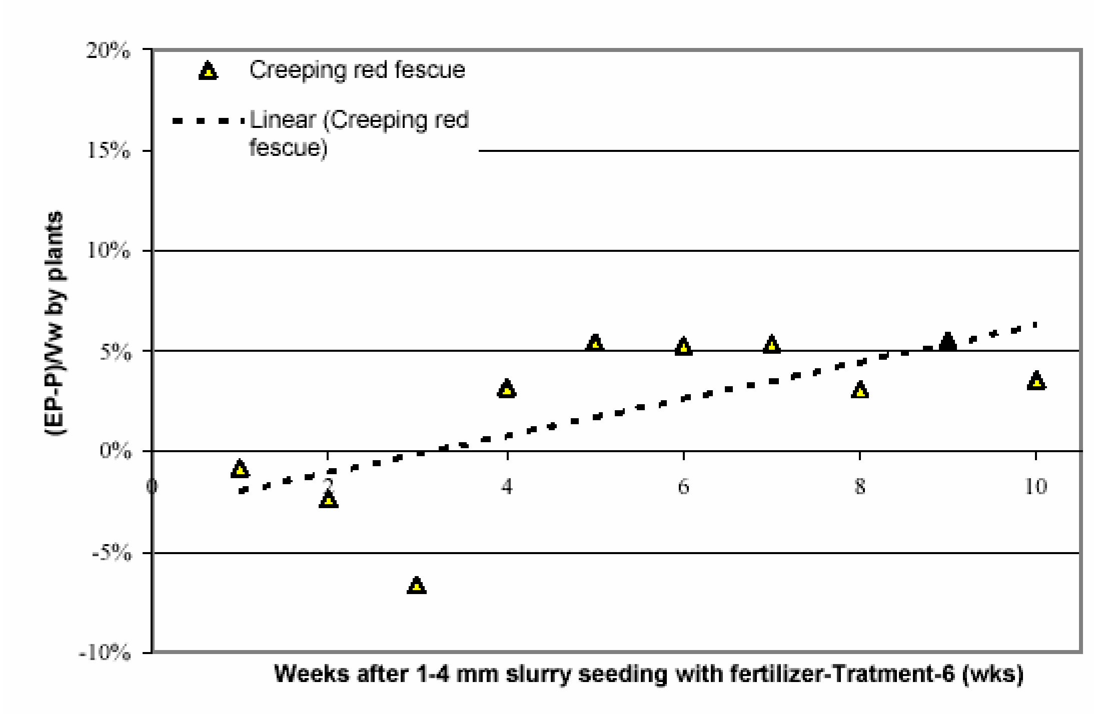


Figure D-15 Water lose percentage by Creeping red fescue in treatment-6

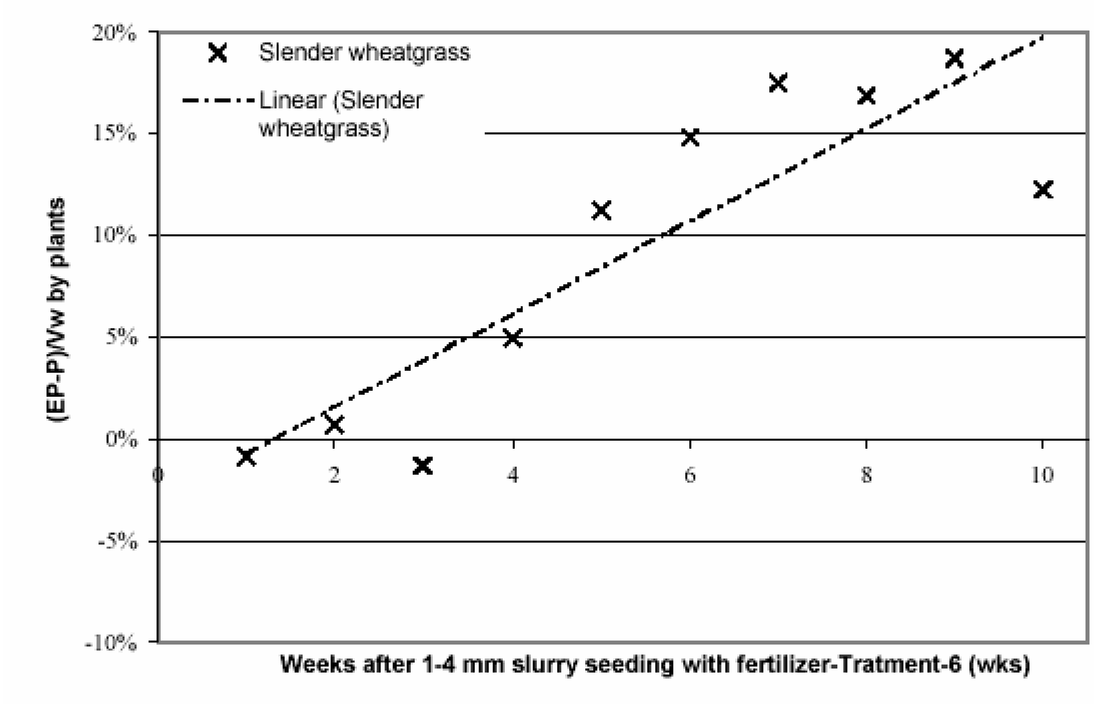


Figure D-16 Water lose percentage by Slender wheatgrass in treatment-6