EFFECTS OF MICRO SITES AND AMENDMENTS ON NEAR SURFACE SOIL TEMPERATURE AND VOLUMETRIC WATER CONTENT TO ENHANCE REVEGETATION

by

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ABSTRACT

Land reclamation requires successful germination, emergence and establishment of desired plant species. Seed and micro sites, often lacking in disturbed ecosystems, can be limiting factors for germination and plant establishment. Micro sites, or safe sites, are required to reduce or prevent soil and seed desiccation, especially in exposed soils common on early reclamation sites. Micro sites can provide heterogeneous conditions to favour germination and survival for a variety of native plant species. Even small changes in near surface soil temperature and water content can influence seed germination and plant establishment.

Micro sites (mounds, pits, flat areas) were evaluated with addition of amendments (hydrogel, manure, blanket, straw, grass, control) to determine their effects on near surface soil temperature and volumetric water content. Near surface soil temperature and near surface soil water content were recorded with half an hour frequency to quantify the modification from micro sites and amendments. Research sites were established in Alberta, Canada, two in parkland and one in grassland.

Near surface soil temperature and volumetric water content were modified with greater heterogeneity provided by micro sites and amendments relative to flat areas. Mounds consistently lowered near surface soil temperature in winter while raising near surface soil temperature in other seasons. The opposite occurred in pits. The amendments provided greater heterogeneity and thus higher variability in near surface soil temperature. Mulch treatments lowered near surface soil temperature. Both micro sites and amendments were associated with higher heterogeneity and variability in soil volumetric water content. Pits had higher near surface soil water contents than mounds. Micro sites and amendments modified soil conditions with more availability of favourable sites for native plant species in land reclamation.

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I. INTRODUCTION

1. BACKGROUND

Increasing economic development and world population growth have been accelerating land use changes related to agricultural intensification, infrastructure development, oil and gas extraction, mining and industrial and urban expansion, which continually decrease the area and health of many global ecosystems (Holechek et al. 2004, Foote and Krogman 2006, Young et al. 2006). These rapidly changed land areas are more likely to be invaded with non-native plant species that result in significant changes to the native plant community composition (Henderson and Naeth 2005, Stover 2013).

For example, in the Aspen Parkland of central Alberta, most of the grassland outside protected areas has been impacted by anthropogenic disturbances, primarily through cultivation, afforestation (Young et al. 2006) and oil and gas extraction. Dry mixed grass prairie has been reduced to only 43 % of its original area in Alberta (Adams et al. 2005). These ecosystems still support a wide diversity of vegetation and wildlife, including rare and protected species, and produce high quality forage for livestock grazing among the many environmental services they provide. Conservation and reclamation of the diminishing natural areas are thus of critical importance to maintain biodiversity that supports ongoing ecosystem services.

2. MICRO SITE IMPACTS ON VEGETATION

Land reclamation requires successful germination, emergence and establishment of desired plant species. However, efforts to reclaim and restore native grasslands and other plant communities through seeding in central and southern Alberta, such as after oil and gas disturbances (e.g. well sites, pipelines, batteries), often result in poor establishment of native plant species (Elsinger 2009, Desserud et al. 2010, Desserud 2011). Particularly in environments with low productivity, both seed and micro sites can be limiting factors for seed germination and plant establishment (Eskelinen and Virtanen 2005). Increased seed germination and subsequent plant establishment may be achieved through the creation of favourable micro sites and through seeding a diversity of plant species (Naeth unpublished data, Cohen Fernandez 2012).

Micro sites are small variations in topography (lower or higher), ranging from millimetres to metres in size. Micro sites can have positive effects on seeds and seedlings by protecting them from predators and the elements, reducing evaporation, increasing soil water, increasing snow cover, stabilizing soil, reducing near surface soil temperature fluctuations, reducing exposure to harsh sunlight and providing mycorrhizae necessary for seedling establishment (Carlsson and Callaghan 1991, Eldridge et al. 1991, Forbes and Jefferies 1999, Maher and Germino 2006, Stevens 2006, Naeth and Wilkinson 2011, Drozdowski et al. 2012, Naeth and Wilkinson 2014, Rotundo et al. 2015).

Seedling establishment can be impacted if there is a lack of suitable micro sites, especially with exposed soils, such as those in newly revegetated sites (Galatowitsch 2008). Areas with high micro site diversity might facilitate establishment of a more diverse suite of species (Lundholm and Larson 2003). Studies suggest spatial variability at the micro environmental scale can increase community density and species richness during establishment and that incoming seed diversity has positive effects on community density, particularly during early succession (Sterling et al. 1984, Richardson et al. 2012, Naeth and Wilkinson 2014). Seed response to micro topography can be species specific and thus the number of species that establish may be directly related to the various micro sites available (Harper et al. 1965).

Naeth and Wilkinson (2010) found that in the first year following reclamation, plants were more likely to germinate and establish near shelter, even at the micro topographic scale. Substrates creating surface variability had greater germination and establishment (Kwiatkowski 2007). The success of gravel treatments may result from surface roughness sheltering plants from wind and water erosion (Naeth and Wilkinson 2010). Plant cover and density at reclamation sites tend to be higher in depressions, crevices and adjacent to large rocks (Naeth and Wilkinson 2011, Naeth and Wilkinson 2014).

Manipulation of micro topography and further modification of micro habitat with amendments may result in increased heterogeneity and in favourable changes to soil water, light and nutrient availabilities. This may favour woody species establishment of naturally dispersed trees and shrubs onto sites with higher surface soil water and nutrient contents (Kochy and Wilson 2005, Partel and Helm 2007). Patchiness or spatial heterogeneity can greatly increase the potential for the coexistence of various organisms and species (Chesson 1985, Chesson 2000, Walker and del Moral 2003, Questad and Foster 2008). The decline of micro topographic features has resulted in reduction of native plant abundance in some environments (Werner and Zedler 2002). Micro site heterogeneity is associated with plant species richness (Lundholm and Larson 2003). Particularly in harsh environments, depressions and concave surfaces may increase soil water content and provide shelter (Marteinsdottir et al. 2013).

In dry mixed grass prairie and other xeric grasslands, micro sites that result in more available soil water and buffered soil temperature will be very important for early plant establishment (Oomes and Elberse 1976, Lauenroth et al. 1994), and therefore for reclamation success. They will reduce or prevent desiccation of seed and seedlings. Factors that affect regeneration of micro habitats include abiotic and biotic factors, such as species specific needs, extent of vegetation or cryptogamic cover, predators, facilitation, competition and physical and chemical interactions (Anderson and Bliss 1998, Kuuluvainen and Juntunen 1998, Ostendorf and Reynolds 1998, Battaglia et al. 2000).

Fine scale physical differences between sites may result in large scale gradients in vegetation types (Kuntz and Larson 2006). For example, a technique that has positively affected plant communities of various ecosystems in both short and long terms is the construction of mounds (Huenneke and Sharitz 1986, Hough-Snee et al. 2011). Seedlings can colonize mound micro sites differently, with xeric species favouring mound tops and windward sides and mesic ones favouring north-east sites (Hough-Snee et al. 2011).

One study found mounding had a positive effect on the growth and survival of several species seeded for a grassland restoration of a landfill (Ewing 2002). This study also showed effects of pits. Another study examining pits and mounds found that even fine scale micro sites can lead to differences in plant species colonization, which maintains the diversity of the plant community in woodland (Peterson et al. 1990). Rangeland species are thought to prefer pits because they provide suitable near surface soil temperature and soil water conditions (Evans and Young 1972). However, mounding and pitting do not consistently increase native species composition and survival in the long term (Biederman and Whisenant 2011).

Erosion control blankets improved seedling establishment in eroded dunes (Maun and Krajnyk 1989). Manure decreased basal area of short grasses and either did not affect tall grasses or increased their vegetation cover (Smoliak et al. 1972). Manure amendment additions can modify the botanical composition of northern Great Plains prairies (Smoliak et al. 1972). Mackenzie and Naeth (2010) found LFH mineral soil mix had more vegetation emerging than peat, partially due to more micro sites created from woody debris and organic materials. Hydrophilic polymers (hydrogels) can be used in revegetation in areas with low precipitation or poor soil-water retention to increase soil water holding capacity (Galatowitsch 2008, Williamson et al. 2011). Hydrophilic polymers have inconsistent effects on plant growth and survival being positive (Huttermann et al. 1999), slightly positive (Rowe et al. 2005) and neutral (Williamson et al. 2011). One recent study found that seedling establishment in semiarid prairie sites under reclamation can be facilitated by mulch due to its effects on seedbed conditions, with low mulch rates increasing native plant establishment during the critical first year of prairie reclamation as they were able to overcome micro site limitations (Mollard et al. 2014).

Although the research to date clearly shows positive and negative impacts of micro sites on plants through changes in soil properties, these impacts are not well understood from a reclamation perspective. Manipulation of micro topography and further modification of micro habitat with amendments may result in increased heterogeneity and beneficial effects for seeds and seedlings. It is necessary to understand what components of this heterogeneity are most important for plant establishment when reclaiming mixed grassland and how favourable ranges of soil water, temperature and nutrients can be achieved at constructed micro sites for a variety of plant species and ecosystems.

3. MICRO SITE IMPACTS ON SOIL PROPERTIES

One study reviewed the research on revegetation of arctic sites after anthropogenic disturbance (Forbes and Jefferies 1999). Natural disturbance often reduces organic matter on the soil surface, changing heat flux between the soil surface and the atmosphere, leading to rough and porous soil surfaces and higher surface soil temperatures. Differences in surface soil temperature between areas with and without micro sites were found by various researchers.

Mounds are usually drier, lower in nutrients and organic matter, have lower cation exchange capacity, litter and snow cover and greater seasonal surface soil temperature fluctuations than depressions (Beatty 1984, Price et al. 1998). Mounds can have high surface soil temperatures, increasing decomposition rates and nutrient availability (Walker and del Moral 2003, Bruland and Richardson 2005).

One study characterized the distribution patterns of vascular plant species within micro sites (cryptogamic crust covers, symmetrical geometric nets and strips) of a polar desert on Devon Island in northern Canada (Anderson and Bliss 1998). At 5 cm depths in soil, maximum temperatures were higher in the center of flat ground than in transition micro sites (between flat ground and the stone board of patterned ground) by as much as 1 to 2 °C. Studies of micro sites (mounds and pits) in a forest caused by a wind throw in the Coweeta Basin, North Carolina (Clinton and Baker 2000) and the distribution pattern of understory plants within micro sites in a maple beech forest in New York (Beatty 1984), found mounds were warmer in summer and cooler in winter than pits. Greatest differences were often between the pit bottom and the mound top (Clinton and Baker 2000). There were no significant differences in surface soil temperature between micro sites of mounds and pits combined with hemlock (Beatty 1984).

Micro site surface soil temperature differences can affect early plant development. Forbis et al. (2004) studied the impact of gopher mounds on seedling establishment in the Niwot Ridge, Colorado. Seedling establishment on gopher mounds decreased at the beginning of the study up to five years, then increased to a higher level than that of the undisturbed area and finally decreased back to the same level of the undisturbed area after twenty years. Surface soil temperature of the mound top had no effect on seed germination (Forbis et al. 2004). Pits were expected to have more species richness and cover than mounds because pits offer more favourable growing conditions (moderate surface soil temperature) than mounds (Beatty 1984). The greatest micro site differences in soil water were between pit bottom and mound top (Clinton and Baker 2000). Soil water was generally higher in pits than in mounds (Beatty 1984, Clinton and Baker 2000).

Diversity of soil micro topography can significantly affect uptake of soil water in plant seedling establishment (Harper et al. 1965). Soil water content had an effect on seed germination and seedling longevity and saturated soil was required for germination of most arctic species (Oberbauer and Miller 1982). As pits provide greater available soil water in summer, more species established in pits (Beatty 1984).

Mulch can help to conserve soil water (Chakraborty et al. 2008, Balwinder-Singh et al. 2011). Mulch can alter the response of the soil surface to atmospheric energy and water fluxes. By affecting the mass transfer of water vapour, mulch can make the beneficial effects of a rainfall event last longer. In northern great plain grasslands, a matted layer of dead grass is important in maintaining a cool, humid environment (Ripley and Redman 1976). In the cool temperate prairies high amounts of litter can improve soil water retention and could be an effective drought management strategy (Willms et al. 1986, Willms et al. 1993, Naeth et al. 1991, Deustch et al. 2010). Litter effectiveness is usually reduced when soil water is not available or in good supply from precipitation (Willms et al. 1993).

The use of hydrogels, which are synthetic acrylic polyacrylamides with a salt base, may enhance soil water retention capacity and plant available water. This will assist plant germination and establishment, especially in arid environments (Akhter et al. 2004). Hydrogels have shown considerable positive effects for revegetation in northern arctic areas after mining (Kidd and Rossow 1998). Various researchers found similar positive effects on revegetation in other areas (Sarvaš et al. 2007).

Various types of physical disturbances often lead to mineral soil exposure and to soil chemical property changes (Forbes and Jefferies 1999). In other research, mounds were usually more acidic than were pits (Beatty 1984), which may affect acid sensitive plant species. Pits provided a more moderate pH than did mounds and therefore generally had greater plant species richness and cover (Beatty 1984).

4. GENERAL RESEARCH OBJECTIVES

The goal of this research program was to determine what components of micro sites are most important for plant establishment when reclaiming grasslands and to determine how favourable ranges of soil water, surface soil temperature and nutrients can be achieved at constructed micro sites. This research quantifies the effects of micro sites on selected soil properties which increase germination, emergence and establishment of selected native species.

Specific research program objectives were as follows.

- To quantify the relationship between 24 hours and seasonal near surface soil temperature and micro sites.
- To quantify the relationship between soil water (volumetric water content) and micro sites.
- To quantify the relationships between soil properties and micro sites.
- To determine the effect of selected soil properties (near surface soil temperature, volumetric water content and electrical conductivity) in micro sites on germination, emergence and persistence of select native plant species.

This MSc research project specifically focused on the first two objectives. Another research study by post doctoral fellows addressed the effects on vegetation. The research results on near surface soil temperature and soil water content are presented in the following two chapters.

II. MICRO SITE AND AMENDMENT EFFECTS ON NEAR SURFACE SOIL TEMPERATURE

1. INTRODUCTION

Micro sites and amendments can be used in land reclamation to mitigate the harsh conditions that have been created with disturbance. Most anthropogenic disturbances and even natural disturbance can reduce organic matter content of the soil surface, changing heat flux between the soil surface and the atmosphere, leading to rough and porous soil surfaces and higher surface soil temperatures (Forbes and Jefferies, 1999). These conditions can create unfavourable conditions for revegetation and plant community development.

Topography differences that cause surface soil temperature differences are well documented. Anderson and Bliss (1998) characterized the distribution patterns of vascular plant species within micro sites (cryptogamic crust covers, symmetrical geometric nets and strips) of a polar desert on Devon Island in northern Canada. At 5 cm depths in soil, maximum temperatures were higher in the center of flat ground than in transition micro sites between flat ground and the stone board of patterned ground by as much as 1 to 2 °C. Studies evaluating the micro sites (mounds and pits) in a forest caused by a wind throw in the Coweeta Basin, North Carolina (Clinton and Baker 2000) and quantifying the distribution pattern of understory plants within micro sites (mounds, pits and undisturbed area) in a maple-beech forest in New York (Beatty 1984) provided quantitative information on effects of micro sites on surface soil temperature. Mounds were warmer in summer and cooler in winter than pits (Beatty 1984, Clinton and Baker 2000), with the greatest differences often between the pit bottom and the mound top (Clinton and Baker 2000). However, there were no significant differences in surface soil temperature between micro sites of mounds and pits combined with hemlock (Beatty 1984).

Mounds are usually drier, lower in nutrients and organic matter, have lower cation exchange capacity, litter and snow cover and greater seasonal surface soil temperature fluctuations than depressions (Beatty 1984, Price et al. 1998). Mounds can have high surface soil temperatures, increasing decomposition rates and nutrient availability (Walker and del Moral 2003, Bruland and Richardson 2005).

Micro site surface soil temperature differences can affect early plant development. One study found impacts of gopher mounds on seedling establishment in the Niwot Ridge, Colorado (Forbis et al. 2004). Seedling establishment on gopher mounds decreased within the first five years, then increased to a higher level than that of the undisturbed area and then decreased again to the same level of the undisturbed area after twenty years. Surface soil temperature of the mound top had no effect on seed germination. Pits were expected to have more species richness and cover than mounds because pits provide more favourable growing conditions (moderate surface soil temperature) than mounds (Beatty 1984).

A combination of micro sites and amendments can be useful to employ in land reclamation. In harsh climates, in particular, such as dry grassland and northern tundra types, even small amounts of increased soil water can have a significant and positive effect on seed germination and on seedling establishment and survival. Since a rapid establishment of cover in these reclamation scenarios is important and necessary micro sites and amendments may facilitate successful revegetation.

2. RESEARCH OBJECTIVES AND HYPOTHESES

2.1 Objectives

The objectives of this research were to determine whether micro topography and amendments affected near surface soil temperature. Specific research objectives were as follows.

- To quantify effects of micro topography (flat, pit and mound) on near surface soil temperature.
- To quantify effects of amendments (control, hydrogel, manure, blanket, straw and grass) on near surface soil temperature.
- To quantify interactions among micro topography and amendments on near surface soil temperature.
- To quantify effects of mound aspects on near surface soil temperature.

2.2 Hypotheses

For soil surface temperature, there are several major influencing environmental factors such as air temperature, soil background temperature and sun light. Soil surface volumetric water content can also affect surface soil temperature due to higher heat capacity of water than of soil, thus influencing soil temperature.

During the hot season, especially the summer, near surface air temperature average would be expected to be lower for soil background than that for air. During the cold season, especially winter, the opposite is true. Thus in summer pits would be expected to be lower in near surface soil temperature than mounds because pits are closer to the surrounding soil and mainly affected by soil background values. Mounds are farther from the surrounding soil and thus mainly affected by air temperature. Higher soil water content in pits can further lower near surface soil temperature in summer more than in the mounds. In winter, the opposite should be true. Greater snow cover in pits can increase the insulation effect of snow and thus further block the energy and matter exchange between air and soil. The insulation effect should further increase the temperature of pits.

Erosion control blankets and grass and straw cover amendments can decrease the near surface soil temperature during hot seasons, especially summer, because these amendments are covers on top of soil, physically blocking sun light and providing shade for soil. Hydrogel and manure should be lower in surface soil temperature due to higher soil water content of these two amendments.

3. MATERIALS AND METHODS

3.1. Research Sites

Multiple locations were required for the research to determine the effect of local environmental conditions on micro sites. The Mattheis Ranch site (hereafter called Mattheis) was in grassland and the other two sites, Elk Island National Park (hereafter called Elk Island) and the Devonian Botanic Garden (hereafter called Devonian), were in the parkland of Alberta. These areas represent those requiring revegetation from multiple disturbances, such as overgrazing, oil and gas exploration and development and mining.

3.1.1. Mattheis Ranch

The Mattheis Ranch study site is located near Brooks, Alberta, 430 km south of Edmonton, Alberta, in the Dry Mixedgrass Natural Subregion. Average elevation is 800 m above sea level (575 to 1100 m) (Natural Regions Committee 2006). Soils are mainly Brown Chernozems. Native vegetation is dominated by low growing, drought tolerant, mixed grass communities including *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama grass) and *Hesperostipa comata* (Trin. & Rupr.) Barkworth (needle and thread grass), *Koeleria macrantha* Schult (june grass) (Ledeb.) Schultes and *Pascopyrum smithii* (Rydb.) Á. Löve (western wheat grass) with numerous forbs. According to data from the closest weather station, at Brooks (50°33'00.000" N, 111°51'00.000" W), maximum air temperature was 40 °C, and averaged 12.4 °C during the growing season (April to October) (Environment Canada 2010). Average annual precipitation is 347.6 mm.

The study site is in the southern portion of the W10 paddock, an old pivot irrigation area. The land was farmed for many years then seeded with *Bromus inermis* Leyss. (smooth brome grass) to provide a forage cover when farming ceased. Native grassland species have since established naturally at the site. The area was recently characterized as having 60 % plant cover and 40 % bare ground. Soil texture is loamy sand.

3.1.2. Elk Island National Park

Elk Island National Park is located approximately 45 km east of Edmonton on Highway 16, in the Dry Mixed Wood Natural Subregion. Average elevation is 600 m (225 to 1225 m) (Natural Regions Committee 2006). Soils are mainly Orthic Gray Luvisols and Dark Gray Luvisols. Vegetation is characterized by forests of *Populus tremuloides* Michx. (trembling aspen) and *Picea glauca* (Moench) Voss (white spruce). Common herbaceous vegetation includes *Stipa spartea* Hitchc. (porcupine grass), *Koeleria macrantha* and *Elymus trachycaulus* (Link) Gould ex Shinners (slender wheat grass). According to data from the closest weather station at Elk Island National Park Point (53°53'00.000" N, 111°04'00.000" W), average air temperature in the growing season (April to October) was 10.4 °C and average maximum air temperature was 38.9 °C (Environment Canada 2010). Average annual precipitation is 482.5 mm.

The site is located in the northern portion of the park at NW-13-54-20-W4M. It is 13.9 km from the park entrance at Highway 16 and positioned approximately 300 m east of the parkway, directly across from the golf course equipment shop. The entire site encompasses approximately 480 m^2. Trees border the east, west and south sides of the site and an open meadow is located north of the site.

The research site was a historical landfill created in the 1930s and decommissioned in the early 1970s. Refuse was initially covered with soil and untouched until summer 1997 when Park staff reclaimed landfills that had some surface dumping and refuse buried beneath a shallow layer of topsoil. The landfill was decommissioned in August 1997. The site was denuded of vegetation for an MSc research project by cutting and herbicide (Van Bostelen 2003). The landfilled material was removed and a heavy equipment operator used the bucket on the front end loader to contour the sub soil at the site to predisturbance levels. Topsoil was not replaced and soil compaction resulted from the use of heavy equipment. When the landfilled sites were cleaned out, soil testing was done by O'Connor Associates to ensure there were no contaminants in the landfills. All of the soil laboratory analyses indicated the sites met the required government criteria (Van Bostelen 2003).

3.1.3. Devonian Botanic Garden

The Devonian Botanic Garden site is 42.3 km southwest of Edmonton, Alberta, in the Central Parkland Subregion. Average elevation of the Central Parkland Natural Subregion is 750 m (500 to 1250 m) (Natural Regions Committee 2006). Soils are mainly Black Chernozems with some Dark Gray Chernozems and significant occurrences of Solonetzic soils. Vegetation is characterized by forest interspersed with prairie associated with hummocky till or eolian materials. Common vegetation includes *Corylus cornuta* Marsh (beaked hazelnut), *Cornus canadensis* L. (bunch berry), *Maianthemum canadense* L. (wild lily of the valley) and *Aralia nudicaulis* L. (wild sarsaparilla). According to data from the closest weather station at Edmonton Woodbend (53°25' N, 113°45' W), maximum air temperature was 35.5 °C in the growing season (April to October) with averages of 10.7 °C (Environment Canada 2010). Average annual precipitation is 508.0 mm.

The site is an abandoned well site of Imperial Oil Ltd. The oil well started production in 1947 and was closed in 1993 according to official records. Before industrial development, the Devonian Botanic Garden Orchid Club used the site to grow plants. In 2012 field observation showed organic matter had been added with tillage. The site is surrounded by forest and wetlands and was likely covered by forest before well site establishment and development.

3.2. Experimental Design And Site Establishment

The experiment was a completely randomized design at each of the research sites. Three micro topographic treatments consisted of mounds, pits and flat land. These treatments were assessed in combination with four micro site amendments proven successful in various reclamation treatments in other sites (Naeth various) and an unamended control. The amendments were erosion control blankets, weed free straw, fresh grass debris or hay, manure mix and hydrogel. The design is 3 micro topography treatments x 6 amendments x 5 replicates = 90 plots per site.

All vegetation was removed from each site prior to establishment of the treatments, using glyphosate at a rate of 8 L/ha applied by a tractor pulled crop sprayer at Mattheis in mid May and a backpack sprayer at Elk Island and Devonian in late May. Soil was rototilled to a depth of 15 cm; 10 days later at Mattheis and 7 days later at Elk Island and Devonian.

Plant species selected for study were native components of the plant community of the area. Grass species were *Hesperostipa comata*, *Elymus trachycaulus*, *Koeleria macrantha*, *Bromus ciliatus* L. (fringed brome grass) and *Bouteloua gracilis* Lag. ex Griffiths (blue grama grass).

Forb species were *Linum lewisii* Pursch (wild blue flax), *Geum triflorum* Pursch (prairie smoke), and *Astragalus canadensis* L. (Canada milk vetch).

Each site was seeded at least two weeks after herbicide application by hand broadcasting at a rate of 350 pure live seed m^{-2} for the mix. This rate was based on previous research by Dr Naeth and her research team. Individual species were each included in the mix at an equal rate. The 2 m x 2 m plot was divided into a center 1 m x 1 m plot and a surrounding buffer zone. The center plot was seeded by hand with 50 seeds counted individually for each plot. The buffer zone was seeded at 50 seeds per m^2 based on weight of number of seeds. Seeding was completed in 2012, June 22 and 23 at Elk Island, June 28 at Devonian and June 8 at Mattheis.

To avoid the impacts from herbivores, all research sites were fenced. Research areas were fenced with a standard four strand electric and barb wire fence at Mattheis, and with game fence at Elk Island and Devonian. The Devonian and Elk Island game fences were 2.4 m high with 12 gauge wire with 0.15 m x 0.10 m cells.

3.3. Soil Micro Topography And Amendment Treatments

Treatment plots were randomly distributed at each of the study sites. Plots were 2 m x 2 m at Mattheis and Elk Island. Due to the smaller area available for research at Devonian, plots were smaller, at 1.5 m x 1.5 m.

Pits, approximately 10 cm deep and 25 cm wide, were created by digging a hole in the ground with a shovel in the center of each of plot. Mounds were formed in the center of each plot using the soil extracted from the depression and buffer areas outside the plots, and molded with a flexible pipe. Mounds were round in shape, approximately 20 cm in height, with a 40 cm base width in the center of each of plot. Flat micro topography treatments served as the control to mounds and depressions.

Erosion control blankets were Nilex SC150BN made with coconut and straw. They were anchored with industrial grade staples and spread over the entire plot, after seeding was completed. Manure mix was applied at a rate of 39 Mg ha^{-1} and incorporated into the soil. One year old wheat straw was applied as a cover at a low rate of 0.5 kg m^{-2} at Mattheis. At Elk Island and Devonian straw was applied at 0.25 kg m^{-2} after deciding that 0.5 kg m^{-2} seemed to too high for the area and could hamper emergence. Native fresh grass, consisting of grass and forb leaves and stems and plant litter, was cut by hand and harvested two days later from adjacent areas at Mattheis. It was applied on the surface. Certified weed free hay was applied at Elk Island and Devonian. Hydrogel (Soil Moist), a synthetic acrylic polyacrylamide with a potassium salt base, was mixed with soil water and applied according to manufacturer's instructions (337.5 kg $ha^{-1)}$ to increase plant available soil water.

3.4. Research Site Instrumentation

The research sites were each instrumented for documentation of environmental conditions. Near surface soil volumetric water content, electrical conductivity and temperature were measured with 5TE soil water sensors (Decagon Devices, United States) and Em50 digital/analog data loggers (Decagon Devices, United States). Soil sensors were installed after the manure mix and hydrogel were incorporated into the soil and before seeding and placement of straw, grass and hay. A 4 to 5 cm deep clear cut was dug at the sensor installation spot. The sensor cable was placed at a depth of 4 to 5 cm and length varied according to the distance of the sensor installation spot to the data logger. Sensors were installed horizontally as shown in the appendix at a 2 to 3 cm depth by positioning them into the soil in the trenches. Cables of sensors were anchored with staples to keep them stable. The positions of the sensors were in the center of the plot for flat and pit micro sites and in each of the northern, eastern, southern and western parts of the mound for mound micro sites. Positions of sensors were marked with coloured tape, with different colours for different directions (pink for north, orange for east, green for south, yellow for west). After installation, soil sensors were connected to data loggers.

Data for near surface soil temperature, electrical conductivity and volumetric water content were recorded in 30 minute intervals for each sensor for the duration of the study. The 5TE sensor measures soil volumetric water content by measuring soil dielectric permittivity, measures soil temperature by a thermistor and measures soil electrical conductivity by measuring the resistance between two electrodes. Data loggers were downloaded every two months before winter in 2012 and each month from May through October in 2013. Data from the winter period were downloaded in spring 2013 and 2014. Data loggers ran relatively well but there were minor amounts of missed data due to the malfunction of individual sensors.

One weather station (T HOBO U30-NRC Weather Station by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532) was installed for each site, at Mattheis on June 17 2012, Elk Island on June 22 2012 and Devonian on June 26 2012. Wind was measured by a wind speed smart sensor (S-WSA-M003 by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532) and a wind direction smart sensor (S-WDA-M003 by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532). Precipitation was measured by a rain gauge smart sensor (S-RGA-M002 by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532). Air temperature and relative humidity were measured by temperature/RH smart sensors (S-THB-M00X by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532). Light level was measured by a silicon pyranometer smart sensor (S-LIB-M003 by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532).

3.5. Soil Sampling And Analyses

One soil sample for general site characterization from three randomly selected plots per microsite-amendment treatment was collected after plot preparation and before seeding. Samples were taken from a corner of the plot to a depth of 10 cm. Samples were only taken in amendment treatments at Mattheis Ranch.

Samples were sent to a commercial laboratory for determination of soil properties, which are presented in Tables 2.1, 2.2 and 2.3. Particle size distribution was measured by hydrometer method (Carter and Gregorich 2008). Organic and inorganic carbon were measured by gravimetric loss of CO_2 (Loeppert and Suarez 1996). Total carbon and total nitrogen were measured by combustion with a Carbo-Erba NA 1500 (Nelson and Sommers 1996). Electrical conductivity was measured by conductivity meter and pH was measured by pH meter; both in a saturated paste (Carter and Gregorich 2008). Saturation percent was by calculation in saturated paste (Carter and Gregorich 2008).

3.6. Statistical Analyses

Statistical analyses were conducted using two way analysis of variance (ANOVA) with R software (R Development Core Team 2012). The tukey's post hoc pairwise comparison test was used following a significant main effect. The shapiro Wilks test was used in testing normality of distribution. Homogeneity of variance was tested with the Bartlett's test.

4. RESULTS AND DISCUSSION

4.1. Soil Properties

Devonian and Elk Island surface soils were sandy loam in texture (Tables 2.1, 2.2) and Mattheis surface soil was sand in texture (Table 2.3). Soil pH was near neutral at all three of the research sites, lowest at Mattheis. Total nitrogen was highest at Elk Island and lowest at Mattheis, with Devonian similar to Elk Island. According to the soil quality criteria for reclamation (Alberta Soils Advisory Committee 1987), the surface soils were rated good at all three sites for pH, electrical conductivity, calcium carbonate equivalent and saturation %. Organic carbon content was rated good at Elk Island and Devonian and fair at Mattheis. Thus soils posed no problems for reclamation or for revegetation.

Amending the surface soil with manure increased electrical conductivity at all sites (Tables 2.1, 2.2, 2.3), but it was still rated good by surface soil reclamation criteria. Manure amendment increased total organic carbon and total nitrogen at Mattheis, increased total organic carbon at Devonian, and slightly reduced both total carbon and total nitrogen at Elk Island. Amending with straw increased total organic carbon and total nitrogen at Devonian and decreased it at Elk Island. Inorganic carbon at Elk Island was twice as high as at the other sites.

4.2. Site Meteorological Conditions

Meteorological conditions at the three sites were similar with 2012 being warmer than 2013 (Tables 2.4, 2.5, 2.6). Devonian had more precipitation in 2013 than in 2012, Elk Island had more in 2012 and Mattheis had similar precipitation in both 2012 and 2013. Values for precipitation and air temperature were similar to long term climate normals for the regions (Government of Canada 2015).

The precipitation and air temperature data showed the differences between parkland (Devonian and Elk Island) and grassland (Mattheis) ecosystems (Tables 2.4, 2.5, 2.6). Precipitation was lower in the parkland relative to the forests. Wind was much stronger in the grassland than the parkland. Air temperature was similar among the three sites throughout the whole year.

4.3. General Treatment Trends For Near Surface Soil Temperature

Near surface soil temperature patterns for treatments at Devonian and Elk Island were generally similar from an overview perspective for the duration of the study (Figures 2.1, 2.2). Near surface soil temperature patterns could be generally divided into three periods, spring to fall (generally mid May to the end of September), winter (generally started at the end of October to the end of April) and transition periods (between the spring and fall and winter periods). At Mattheis, with fewer data points, the pattern was still similar to that of the other two sites (Figure 2.3) from May to August.

The spring to fall period was the most dynamic (Figures 2.1, 2.2, 2.3). During this period, near surface soil temperature in each treatment rose and fell with the greatest frequencies and magnitude throughout the whole year. The differences among treatments were also highest.

The winter period (Figures 2.1, 2.2, 2.3) was the most inactive period of the year. Each treatment showed a nearly constant near surface soil temperature. The differences among treatments were smallest but there was a clear order from highest to lowest treatment which remained unchanged throughout this period.

The transition period (Figures 2.1, 2.2, 2.3) was the shortest period. However, near surface soil temperature change was greatest in the whole year which happened within two to three weeks.

4.4. Micro Topography Effects On Near Surface Soil Temperature

There was a clear response of soil near surface soil temperature to micro site treatments at all three sites (Tables 2.7, 2.8, 2.9, 2.10, 2.11). Flat control and mound micro sites often had significantly higher near surface soil temperatures in warm summer months and significantly lower near surface soil temperatures in cooler winter months than the pit micro sites. Near surface soil temperatures in mounds and flat controls were not significantly different at any of the study sites. At Elk Island, mound near surface soil temperatures were not significantly different than pit near surface soil temperatures in June and July 2012 (Table 2.9). These treatment responses are more visibly obvious in Figures 2.4, 2.5, 2.6, 2.7, 2.8, 2.9 and 2.10. Near surface soil temperatures in transition periods were similar among treatments at all sites.

Near surface soil temperatures in pits were lowest, as they would likely be more influenced by the background near surface soil temperatures of surrounding soil than by air temperature and sun radiation. The opposite would be true for near surface soil temperatures of flats and mounds. Air temperature would be higher than soil background temperatures in spring, summer and fall, and lower in winter. Transition seasonal near surface soil temperatures would be expectedly dynamic since topography effects are strongly influenced by seasonal change specially changes into and out of winter.

The obvious zippier response of near surface soil temperature in the summer weeks relative to that of the winter weeks would likely be due to other environmental factors influencing near surface soil temperature, such as vegetation. This has been shown in other studies. For example, vegetation in woodland was able to modify the under story and surrounding micro environment, decreasing the near surface soil temperature through blocking of the sun radiation (Breshears et al. 1998).

Similar to other studies in other types of environments (e.g. Peterson et al. 1990) near surface soil temperature response to micro sites was site specific and year specific. For example, the Devonian site had only one month in the transition period between winter and the other seasons, while Elk Island had two months between winter and the other seasons. Mattheis was not studied long enough to see if that pattern occurred. Elk Island near near surface soil temperatures were significantly different from June to August 2012, with no significant differences in near surface soil temperature in that same period in the following year of 2013.

4.5. Amendment Effects On Near Surface Soil Temperature

Response of soil near surface soil temperature to the amendments was not as significant as response of temperature to micro sites in either year of study. Although there were significant differences among the amendment treatments, there were few clear patterns of near surface soil temperature response at the three research sites (Tables 2.7, 2.8, 2.9, 2.10, 2.11) (Figures 2.11, 2.12, 2.13, 2.14, 2.15, 2.16, 2.17).

A few minor patterns were notable in near surface soil temperature response to amendments. At Devonian near surface soil temperatures in the erosion control blanket treatment tended to be lowest (Tables 2.7, 2.8) (Figures 2.11, 2.12, 2.13, 2.14, 2.15, 2.16, 2.17). Near surface soil temperatures in manure amendment treatments were often highest in summer. This response to erosion control blankets was similar at Elk Island in 2012 but not 2013, and was not evident at Mattheis (Tables 2.9, 2.10, 2.11, 2.12) (Figures 2.14, 2.15, 2.16, 2.17).

The lower near surface soil temperatures often found in the erosion control blanket treatment were not unexpected. Erosion control blankets form a thicker and denser cover than the other amendments do and hence can have a more remarkable effect on moderating temperatures. Covers can act as shade providers from direct sun radiation; thus lowering the temperature or preventing heat loss.

Response to amendments may be lowered as the amendments age and degrade, explaining some differences seen in 2012 but not 2013. The first month after soil sensors were set up showed more differences between amendments, perhaps due to much shorter time period and effects from installing of sensors.

The lack of clear significant amendment treatment effects may be due to the major background effects and application rate of amendments. All amendment effects were site specific, likely less influenced by seasons, but by so many other factors which may include sun radiation, wind and evaporation.

4.6. Micro Topography And Amendment Interactions On Near Surface Soil Temperature

Unexpectedly there were few significant interactions between micro sites and amendments (Tables 2.7, 2.8, 2.9, 2.10, 2.11). Perhaps, due to the constant effects of micro sites over riding the lower effects of the amendments. It may also be due to the application rate of the amendments, which may have been too low to have a major effect.

4.7. Mound Aspect Effects On Near Surface Soil Temperature

Although near surface soil temperature varied with mound aspect, there were no significant treatment effects (Data not shown). South facing aspects, as expected, had the numerically highest near surface soil temperature, west was lower in near surface soil temperature than south, followed by east, while north was the lowest. Although differences with aspects were very low numerically, they may be high enough to affect seed germination.

4.8. Applications To Reclamation

Although the near surface soil temperature differences with micro sites were small numerically, they may be sufficiently different to affect seed germination and seedling survival and establishment. Often as little as a 1 ^{o}C change in temperature can affect germination, moving germination rates from optimum to sub optimum (Baskin and Baskin 2014). These values are expected to be very sensitive for native plant species (Naeth personal communication).

For example at Devonian in the first year, mound south manure and mound south grass had the highest near surface soil temperatures while mound straw had the lowest, among which the difference was 4 to 7.5 °C. In the second year, mound control had the highest near surface soil temperature while pit blanket and mound straw had the lowest, among which the difference was 2 to 6.5 °C. At Elk Island in the first year, flat manure had the highest near surface soil temperature while mound straw and pit hydrogel had the lowest, among which the difference was 2 to 5 °C. In the second year, mound control and mound manure had the highest near surface soil temperature while pit blanket and mound straw were lowest, among which the difference was 2 to 6 °C. These treatment differences were clearly high enough to affect seed germination and seedling survival.

Roberts (1988) clearly discussed ambient environmental temperature and seed germination relationships. Once seeds lost dormancy their rate of germination (reciprocal of the time taken to germinate) showed a positive linear relationship between base ambient environmental temperature (at and below which the germination rate is zero) and optimum environment temperature (at which the germination rate is maximal); and a negative linear relation between optimal environmental temperature and the ceiling environmental temperature (at and above which the germination rate is zero).

Mollard and Naeth (2014) and Mollard et al. (2014) showed that for some prairie plant species commonly used in reclamation, mulch affected seedbed temperatures and significantly filtered photosynthetically active radiation irradiance. For some treatments photosynthesis or photomorphogenesis of shaded seedlings were thought to have been light limited. These light effects on near surface soil temperature may in turn affect germination.

Baskin and Baskin (2014) discussing the various effects of environment temperature on seed germination, found some species had higher germinating seeds when the seeds are produced at higher environment temperatures. Although data for native species often used in reclamation are hard to find, studies on other plant groups clearly show seed germination response to environment temperature.

Thus small changes in near surface soil temperature may affect the germination rate of hard to establish plant species in reclamation. The ability to have heterogeneous micro sites in reclamation may affect which species will germinate and establish and which will not.

In a counterpart research project in this research program, Naeth et al. (2014) found that micro sites alone did not have as pronounced an effect on grass and forb seedling emergence and establishment as expected. Soil water and near surface soil temperature at a specific site and in a given year relative to other site factors such as non native plant species and erosion potential, likely played a key role in determining effect of micro sites on plant response. The responses of native grasses and forbs to micro sites vary, supporting the need for a diversity of micro sites on a reclamation site to accommodate species specific requirements and annual variability in precipitation and near surface soil temperature.

5. CONCLUSIONS

Micro sites had a significant effect on near surface soil temperature. These temperatures in flat areas and mounds were generally lower than those in pits in winter and higher at other times of the year. Amendments had little significant effect on near surface soil temperature. The only clear pattern among amendments was a slightly lower value with erosion control blankets.

Although differences in near surface soil temperatures among treatments were small in magnitude, they may be large enough to affect near temperature sensitive species for seed germination and seedling survival. Generally, micro sites and amendments can create heterogeneous conditions to meet potential soil temperature requirement of seeds.

Table 2.1. Mean soil surface properties at Devonian Botanic Garden.

	Inorganic Carbon (%)	Organic Carbon (%)	CaCO3 Equivalent (%)	Total Carbon (%)	Electrical Conductivity (dS m^{-1})	Saturation (%)	Total Nitrogen (%)	PH	Sand (%)	Silt (%)	Clay (%)
Micro Site											
Flat	0.09 (0.02)	1.98 (0.25)	0.72 (0.15)	2.03 (0.23)	0.7 (0.2)	40.5 (2.7)	0.21 (0.03)	7.5 (0.1)	62 (4)	25 (3)	13 (1)
Mound	0.06 (0.01)	2.07 (0.25)	0.50 (0.10)	2.10 (0.24)	0.5 (0.1)	41.6 (0.8)	0.22 (0.02)	7.6 (0.0)	60 (5)	26 (3)	14 (1)
Pit	0.05 (0.00)	2.27 (0.25)	0.47 (0.07)	2.28 (0.21)	0.5 (0.1)	42.4 (2.2)	0.21 (0.03)	7.6 (0.0)	56 (5)	29 (4)	15 (1)
Amendment											
Blanket	0.05 (0.00)	1.97 (0.20)	0.40 (0.00)	1.97 (0.20)	0.4 (0.0)	38.0 (2.1)	0.22 (0.02)	7.5 (0.1)	62 (8)	25 (6)	14 (2)
Control	0.07 (0.02)	1.74 (0.32)	0.59 (0.19)	1.80 (0.31)	0.5 (0.0)	39.6 (2.4)	0.16 (0.02)	7.6 (0.0)	66 (7)	22 (6)	12 (2)
Grass	0.07 (0.02)	2.18 (0.39)	0.72 (0.16)	2.23 (0.39)	0.5 (0.0)	40.2 (1.9)	0.19 (0.06)	7.6 (0.0)	60 (6)	26 (5)	14 (1)
Hydrogel	0.08 (0.03)	2.04 (0.28)	0.66 (0.26)	2.10 (0.26)	0.4 (0.0)	40.3 (2.6)	0.21 (0.02)	7.5 (0.1)	60 (7)	27 (6)	14 (2)
Manure	0.07 (0.02)	2.43 (0.53)	0.60 (0.20)	2.47 (0.49)	1.2 (0.3)	47.9 (3.5)	0.25 (0.05)	7.5 (0.2)	53 (9)	32 (7)	15 (3)
Straw	0.05 (0.00)	2.27 (0.23)	0.40 (0.00)	2.27 (0.23)	0.4 (0.0)	42.9 (1.4)	0.28 (0.02)	7.6 (0.0)	56 (5)	29 (3)	15 (2)
P Value											
Micro Site	0.115	0.684	0.250	0.724	0.709	0.807	0.728	0.505	0.939	0.952	0.678
Amendment	0.828	0.771	0.681	0.763	0.002	0.13	0.858	0.784	0.272	0.58	0.839

Numbers are means, with standard error of the mean in brackets.

Blanket = erosion control blanket

Table 2.2. Mean soil surface properties at Elk Island National Park.

	Inorganic Carbon (%)	Organic Carbon (%)	CaCO3 Equivalent (%)	Total Carbon (%)	Electrical Conductivity (dS m^{-1})	Saturation (%)	Total Nitrogen (%)	PH	Sand (%)	Silt (%)	Clay (%)
Micro Site											
Flat	0.15	2.63	1.24	2.78	0.9	59.5	0.28	7.3	54	28	18
	(0.03)	(0.32)	(0.26)	(0.33)	(0.1)	(3.3)	(0.04)	(0.1)	(1)	(1)	(1)
Mound	0.13	3.01	1.04	3.13	1.0	61.9	0.34	7.2	52	29	19
	(0.02)	(0.30)	(0.15)	(0.32)	(0.2)	(2.2)	(0.02)	(0.1)	(0)	(1)	(1)
Pit	0.14	3.60	1.17	3.72	1.1	63.0	0.35	7.1	55	29	16
	(0.03)	(0.42)	(0.28)	(0.38)	(0.2)	(3.6)	(0.04)	(0.1)	(1)	(2)	(2)
Amendment											
Blanket	0.12	2.95	0.95	3.03	0.8	65.4	0.35	7.2	53	28	19
	(0.04)	(0.21)	(0.31)	(0.27)	(0.1)	(3.0)	(0.02)	(0.1)	(1)	(1)	(2)
Control	0.09	3.77	0.76	3.83	0.8	63.6	0.39	7.1	54	32	14
	(0.02)	(0.61)	(0.18)	(0.56)	(0.0)	(5.7)	(0.06)	(0.1)	(1)	(1)	(1)
Grass	0.11	3.75	0.91	3.83	0.8	65.7	0.39	7.2	54	31	16
	(0.03)	(0.45)	(0.27)	(0.38)	(0.1)	(2.8)	(0.02)	(0.1)	(3)	(1)	(3)
Hydrogel	0.20	2.25	1.64	2.47	0.8	53.7	0.21	7.3	54	27	19
	(0.04)	(0.19)	(0.35)	(0.15)	(0.1)	(3.4)	(0.05)	(0.1)	(1)	(1)	(1)
Manure	0.17	3.28	1.39	3.47	1.8	60.5	0.31	7.3	55	26	19
	(0.03)	(0.81)	(0.28)	(0.85)	(0.2)	(6.0)	(0.06)	(0.0)	(1)	(2)	(1)
Straw	0.15	2.48	1.24	2.63	1.0	59.8	0.30	7.1	53	27	20
	(0.05)	(0.15)	(0.43)	(0.22)	(0.0)	(1.0)	(0.02)	(0.1)	(1)	(0)	(1)
P Value											
Micro Site	0.822	0.181	0.843	0.185	0.741	0.718	0.367	0.188	0.057	0.826	0.326
Amendment	0.432	0.183	0.402	0.237	< 0.001	0.346	0.089	0.471	0.875	0.021	0.178

Numbers are means, with standard error of the mean in brackets.

Blanket = erosion control blanket

Table 2.3. Mean soil surface properties at Mattheis Ranch.

	Inorganic Carbon (%)	Organic Carbon (%)	CaCO3 Equivalent (%)	Total Carbon (%)	Electrical Conductivity (dS m^{-1})	Saturation (%)	Total Nitrogen (%)	PH	Sand (%)	Silt (%)	Clay (%)
Amendment											
Blanket	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Control	0.05	1.09	0.4	1.07	0.4	40.4	0.17	6.2	90	8	3
	(0.00)	(0.15)	(0.00)	(0.13)	(0.0)	(0.7)	(0.02)	(0.1)	(1)	(1)	(0)
Grass	0.05	1.05	0.4	1.03	0.5	41.7	0.12	6.4	84	11	5
	(0.00)	(0.04)	(0.00)	(0.03)	(0.1)	(2.4)	(0.00)	(0.1)	(4)	(3)	(2)
Hydrogel	0.05	1.25	0.4	1.27	0.7	42.4	0.15	6.7	87	10	3
	(0.00)	(0.13)	(0.00)	(0.12)	(0.1)	(1.6)	(0.01)	(0.1)	(1)	(1)	(0)
Manure	0.05	1.48	0.4	1.50	1.1	44	0.20	6.7	87	10	3
	(0.00)	(0.10)	(0.00)	(0.12)	(0.5)	(1.8)	(0.01)	(0.3)	(1)	(1)	(0)
Straw	0.05	1.32	0.4	1.33	0.6	40.5	0.12	6.3	87	10	3
	(0.00)	(0.04)	(0.00)	(0.07)	(0.2)	(0.9)	(0.02)	(0.1)	(1)	(1)	(0)
P Value											
Amendment	0.452	0.071	0.452	0.044	0.312	0.533	0.003	0.166	0.53	0.574	0.448

Numbers are means, with standard error of the mean in brackets.

Blanket = erosion control blanket.

NA = Not applicable.

Table 2.4. Meteorological conditions at Devonian Botanic Garden.

	Air Temperature (°C)			Precipitation (mm)	Wind Speed (m / s)		
	Mean	Max	Min	Total	Mean	Max	Min
2012							
June	16.82	27.70	3.83	0.20	0.26	2.27	0.00
July	18.16	33.68	4.69	144.4	0.13	2.27	0.00
August *	17.38	28.99	3.17	30.4	0.06	1.01	0.00
September	11.44	27.65	-1.13	21.6	0.22	2.52	0.00
October	0.80	20.25	-12.53	21.4	0.25	2.77	0.00
November	-7.92	10.00	-26.31	12.6	0.11	3.27	0.00
December	-15.62	2.05	-30.48	0.20	0.02	2.01	0.00
2013							
January	-10.06	10.27	-28.92	17.4	0.20	2.52	0.00
February	-4.79	10.17	-18.92	14.0	0.25	3.78	0.00
March	-6.80	11.90	-27.46	17.6	0.23	2.27	0.00
April	0.57	20.44	-21.92	18.6	0.49	3.02	0.00
May	13.10	31.66	-7.25	29.2	0.43	2.52	0.00
June	14.50	29.44	3.27	91.0	0.13	2.27	0.00
July	16.06	35.21	2.24	85.8	0.11	1.51	0.00
August	16.30	28.54	3.43	44.4	0.03	1.01	0.00
September	12.04	31.69	-6.11	3.8	0.09	2.27	0.00
October	4.02	19.10	-12.42	11.6	0.15	2.52	0.00
November	-7.70	10.74	-30.90	16.4	0.05	1.26	0.00

* Data were lost from August 8 to 28 2012.

Numbers are means.

Table 2.5. Meteorological conditions at Elk Island National Park.

	Air Temperature (°C)			Precipitation (mm)	Wind Speed (m / s)		
	Mean	Max	Min	Total	Mean	Max	Min
2012							
June	17.13	26.74	7.97	12.0	0.34	2.01	0.00
July	18.27	33.26	7.87	133.6	0.23	2.01	0.00
August	16.35	30.62	5.75	2.6	0.14	1.76	0.00
September	12.29	26.40	0.47	0.2	0.29	2.52	0.00
October	0.73	19.25	-16.20	15.8	0.47	3.02	0.00
November	-8.32	10.00	-21.92	16.4	0.21	2.52	0.00
December	-14.78	1.37	-28.86	0.0	0.12	2.52	0.00
2013					0.26		
January	-10.44	7.04	-30.48	22.8	0.34	2.77	0.00
February	-5.15	10.32	-17.60	10.6	0.41	3.02	0.00
March	-6.62	12.51	-19.89	10.2	0.51	3.27	0.00
April	0.10	17.84	-17.00	23.6	0.79	4.53	0.00
May	13.20	30.39	-11.04	30.0	0.62	4.78	0.00
June	14.11	28.30	4.79	63.0	0.23	2.27	0.00
July	15.61	32.61	3.35	15.6	0.18	2.27	0.00
August	16.46	28.72	6.41	2.6	0.06	1.51	0.00
September	12.65	30.42	-1.99	4.4	0.23	2.01	0.00
October	4.39	17.30	-11.54	13.4	0.29	3.02	0.00
November	-7.48	9.31	-29.19	16.8	0.14	1.76	0.00

Numbers are means.

Table 2.6. Meteorological conditions at Mattheis Ranch.

	Air Temperature (°C)			Precipitation (mm)	Wind Speed (m / s)		
	Mean	Max	Min	Total	Mean	Max	Min
2012							
July	20.95	34.44	5.28	13.6	1.81	8.31	0.00
August	18.01	34.12	2.66	45.4	1.56	7.55	0.00
September	13.11	29.84	-3.39	8.0	1.66	13.60	0.00
October	2.62	26.16	-15.83	15.8	2.45	11.08	0.00
November	-7.05	10.81	-27.96	5.0	1.92	10.83	0.00
December	-14.74	5.57	-32.29	5.4	1.43	8.06	0.00
2013							
January	-10.52	6.00	-28.47	0.8	2.28	11.08	0.00
February	-6.58	6.66	-19.75	1.6	1.75	11.08	0.00
March	-7.86	14.22	-24.88	4.6	2.16	12.09	0.00
April	2.35	24.00	-12.16	17.0	2.68	10.07	0.00
May	12.88	29.49	-9.61	61.2	2.41	10.07	0.00
June	15.62	30.37	2.18	117.6	2.08	10.07	0.00
July	17.94	34.28	3.38	48.2	1.80	7.55	0.00
August	18.29	33.31	3.14	8.2	1.43	6.80	0.00

Numbers are means.

Table 2.7. Mean near surface soil temperature (^{o}C) at Devonian Botanic Garden in 2012.

	June	July	August	September	October	November	December
Micro Site							
Flat	20.86^{a}	21.35^{a}	19.63^{a}	13.10	3.51^{b}	-0.02^{b}	-0.37^{b}
Mound	20.20^{a}	20.83^{a}	19.21^{a}	12.76	3.36^{b}	-0.05^{b}	-0.36^{b}
Pit	18.26^{b}	19.52^{b}	17.86^{b}	12.06	4.27^{a}	0.80^{a}	0.31^{a}
Amendment							
Blanket	18.76^{b}	19.62^{b}	18.38	12.40	4.04^{ab}	0.42^{ab}	-0.03
Control	20.68^{a}	21.12^{ab}	19.07	12.58	3.27^{b}	0.00^{c}	-0.33
Hay	19.35^{ab}	20.32^{ab}	18.78	12.83	4.14^{a}	0.45^{a}	-0.01
Hydrogel	19.85^{ab}	20.82^{ab}	19.07	12.99	3.62^{ab}	0.10^{bc}	-0.31
Manure	20.90^{a}	21.50^{a}	19.68	12.96	3.46^{ab}	0.11^{bc}	-0.17
Straw	19.09^{ab}	20.01^{ab}	18.43	12.07	3.76^{ab}	0.38^{ab}	0.01
P value							
Micro Site	< 0.01	< 0.01	< 0.01	0.14	< 0.01	< 0.01	< 0.01
Amendment	0.01	0.01	0.35	0.78	0.02	< 0.01	0.06
Micro Site * Amendment	0.98	0.98	0.99	0.96	0.83	0.66	0.85

Means with the same letters in each column, for each of micro sites and amendments, are not significantly different.

In data sets with no letters, there are no significant differences.

Table 2.8. Mean near surface soil temperature (^{o}C) at Devonian Botanic Garden in 2013.

	January	February	March	April	May	June	July	August
Micro Site								
Flat	-0.24^{b}	0.05^{b}	0.23^{b}	1.28	14.70^{a}	16.90^{a}	19.64^{a}	18.34^{a}
Mound	-0.20^{b}	0.09^{b}	0.25^{b}	1.24	13.99^{a}	16.85^{a}	19.61^{a}	18.36^{a}
Pit	0.23^{a}	0.36^{a}	0.50^{a}	1.07	12.04^{b}	15.36^{b}	18.28^{b}	17.13^{b}
Amendment								
Blanket	-0.03	0.20	0.35	1.13	12.17^{b}	15.84	18.54	17.69
Control	-0.21	0.05	0.24	1.12	14.39^{a}	16.44	19.21	18.02
Hay	0.03	0.26	0.39	1.28	13.61^{ab}	16.54	19.25	18.04
Hydrogel	-0.21	0.05	0.24	1.23	14.07^{ab}	16.50	19.23	18.08
Manure	-0.04	0.18	0.33	1.31	14.29^{a}	16.73	19.70	17.87
Straw	0.03	0.25	0.39	1.09	12.95^{ab}	16.17	18.82	17.83
P value								
Micro Site	< 0.01	< 0.01	< 0.01	0.48	< 0.01	< 0.01	< 0.01	0.01
Amendment	0.18	0.32	0.54	0.94	0.01	0.16	0.59	0.97
Micro Site * Amendment	0.86	0.79	0.80	0.88	0.91	0.81	0.73	0.84

Means with the same letters in each column, for each of micro sites and amendments, are not significantly different.

In data sets with no letters, there are no significant differences.

Table 2.9. Mean near surface soil temperature (^{o}C) at Elk Island National Park in 2012.

	June	July	August	September	October	November	December
Micro Site							
Flat	19.88^{a}	21.29^{a}	19.43^{a}	13.37	4.08	0.84^{b}	0.56^{b}
Mound	19.48^{ab}	20.85^{ab}	19.04^{a}	13.07	3.55	0.94^{b}	0.62^{b}
Pit	18.91^{b}	20.41^{b}	18.63^{b}	13.07	4.12	1.32^{a}	0.99^{a}
Amendment							
Blanket	18.68^{b}	19.88^{c}	18.53^{b}	13.08	3.72	1.13^{ab}	0.68
Control	20.06^{a}	21.48^{a}	19.25^{ab}	13.32	4.23	0.83^{ab}	0.65
Hay	19.24^{ab}	20.61^{bc}	19.04^{ab}	13.05	4.14	1.29^{a}	0.86
Hydrogel	19.26^{ab}	21.08^{ab}	18.93^{ab}	13.17	3.27	0.70^{b}	0.52
Manure	20.16^{a}	21.68^{a}	19.59^{a}	13.48	3.59	0.90^{ab}	0.69
Straw	19.14^{ab}	20.40^{bc}	18.87^{ab}	12.93	4.54	1.29^{a}	0.89
P value							
Micro Site	0.01	< 0.01	< 0.01	0.33	0.41	< 0.01	< 0.01
Amendment	0.01	< 0.01	0.01	0.58	0.43	0.01	0.18
Micro Site * Amendment	0.64	0.66	0.70	0.41	0.65	0.55	0.40

Means with the same letters in each column, for each of micro sites and amendments, are not significantly different.

In data sets with no letters, there are no significant differences.

Table 2.10. Mean near surface soil temperature (^{o}C) at Elk Island National Park in 2013.

	January	February	March	April	May	June	July	August
Micro Site								
Flat	0.51^{b}	0.49^{b}	0.47^{b}	1.00	13.64	16.53^{a}	18.31	17.27
Mound	0.58^{b}	0.57^{b}	0.53^{b}	0.99	12.47	16.31^{ab}	17.54	16.90
Pit	0.82^{a}	0.74^{a}	0.69^{a}	0.94	12.17	15.74^{b}	17.65	16.87
Amendment								
Blanket	0.59	0.59^{ab}	0.58^{ab}	0.96	12.43	16.17	17.20	16.99
Control	0.54	0.50^{ab}	0.48^{ab}	0.86	11.55	16.91	18.08	17.12
Hay	0.77	0.72^{ab}	0.65^{ab}	0.97	13.25	16.16	18.22	17.03
Hydrogel	0.45	0.45^{b}	0.44^{b}	0.75	12.58	16.10	18.01	16.99
Manure	0.63	0.56^{ab}	0.53^{ab}	1.18	13.97	15.99	17.70	16.77
Straw	0.80	0.75^{a}	0.69^{a}	1.10	12.57	15.89	17.77	17.09
P value								
Micro Site	< 0.01	< 0.01	< 0.01	0.83	0.06	0.04	0.18	0.38
Amendment	0.08	0.02	0.01	0.17	0.06	0.26	0.61	0.98
Micro Site * Amendment	0.28	0.20	0.07	0.88	0.55	0.11	0.71	0.96

Means with the same letters in each column, for each of micro sites and amendments, are not significantly different.

Table 2.11. Mean near surface soil temperature (^{o}C) at Mattheis Ranch in 2013.

Factor	2013			
	May	June	July	August
Micro Site				
Flat	14.79^{a}	17.73	20.98^{a}	20.20^{a}
Mound	14.41^{a}	17.63	20.68^{a}	20.04^{a}
Pit	13.26^{b}	16.26	19.28^{b}	18.74^{b}
Amendment				
Blanket	13.78^{c}	17.01	20.63^{a}	19.59^{ab}
Control	14.73^{ab}	17.77	20.77^{a}	20.08^{a}
Hay	14.16^{bc}	17.29	20.28^{a}	19.59^{ab}
Hydrogel	14.80^{a}	17.86	20.63^{a}	19.98^{a}
Manure	14.92^{a}	17.85	20.70^{a}	19.92^{a}
Straw	12.28^{d}	15.42	18.79^{b}	18.67^{b}
P value				
Micro Site	< 0.01	< 0.01	< 0.01	< 0.01
Amendment	< 0.01	< 0.01	< 0.01	0.01
Micro Site * Amendment	0.13	0.08	0.07	0.08

Means with the same letters in each column, for each of micro sites and amendments, are not significantly different.

In data sets with no letters, there are no significant differences.

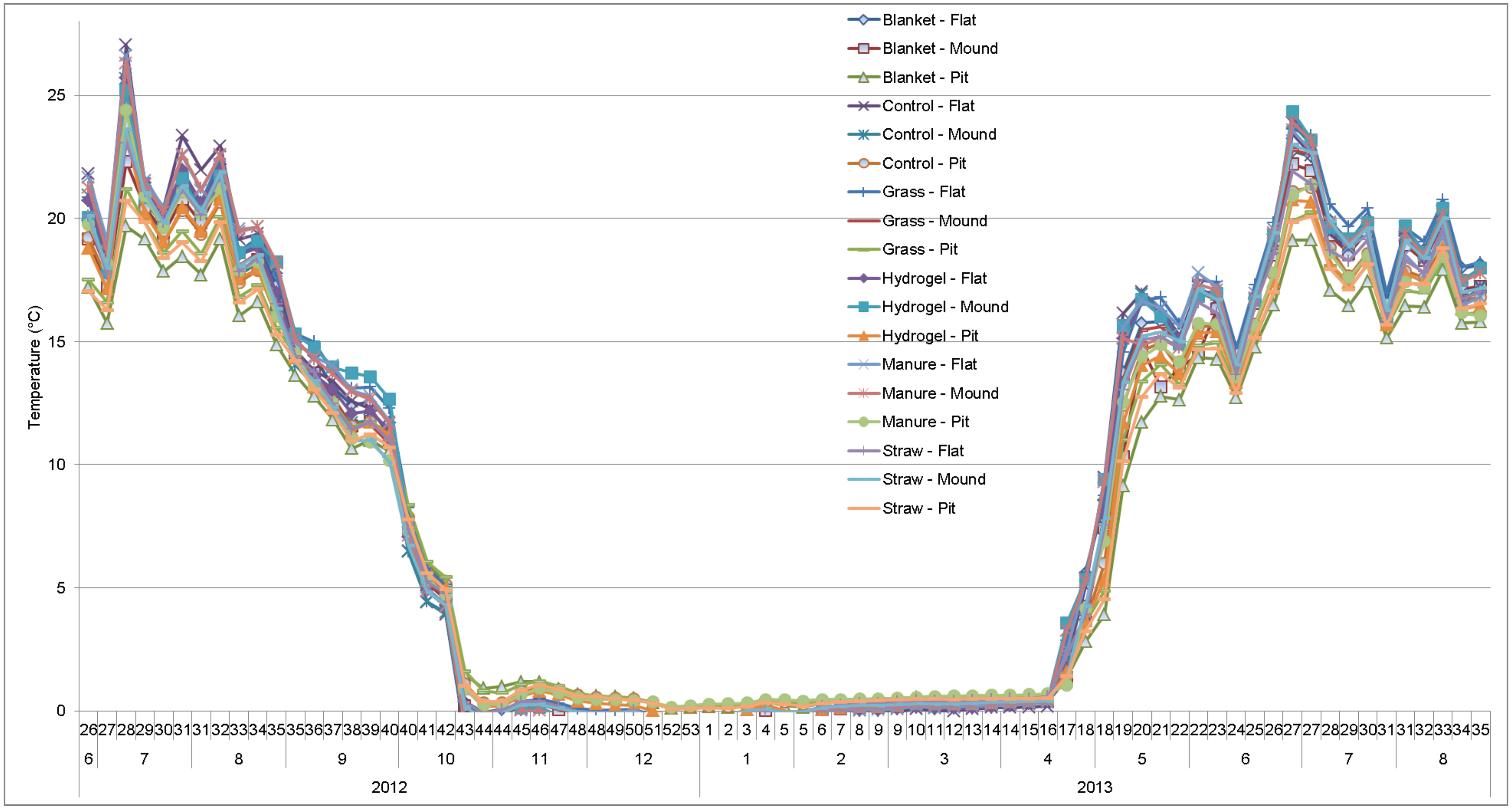

Figure 2.1. Mean weekly near surface soil temperature in all treatments at Devonian Botanic Garden throughout the study period. Numbers above years refer to months (6-12, 1-8), then weeks (26-53, 1-35) of the year.

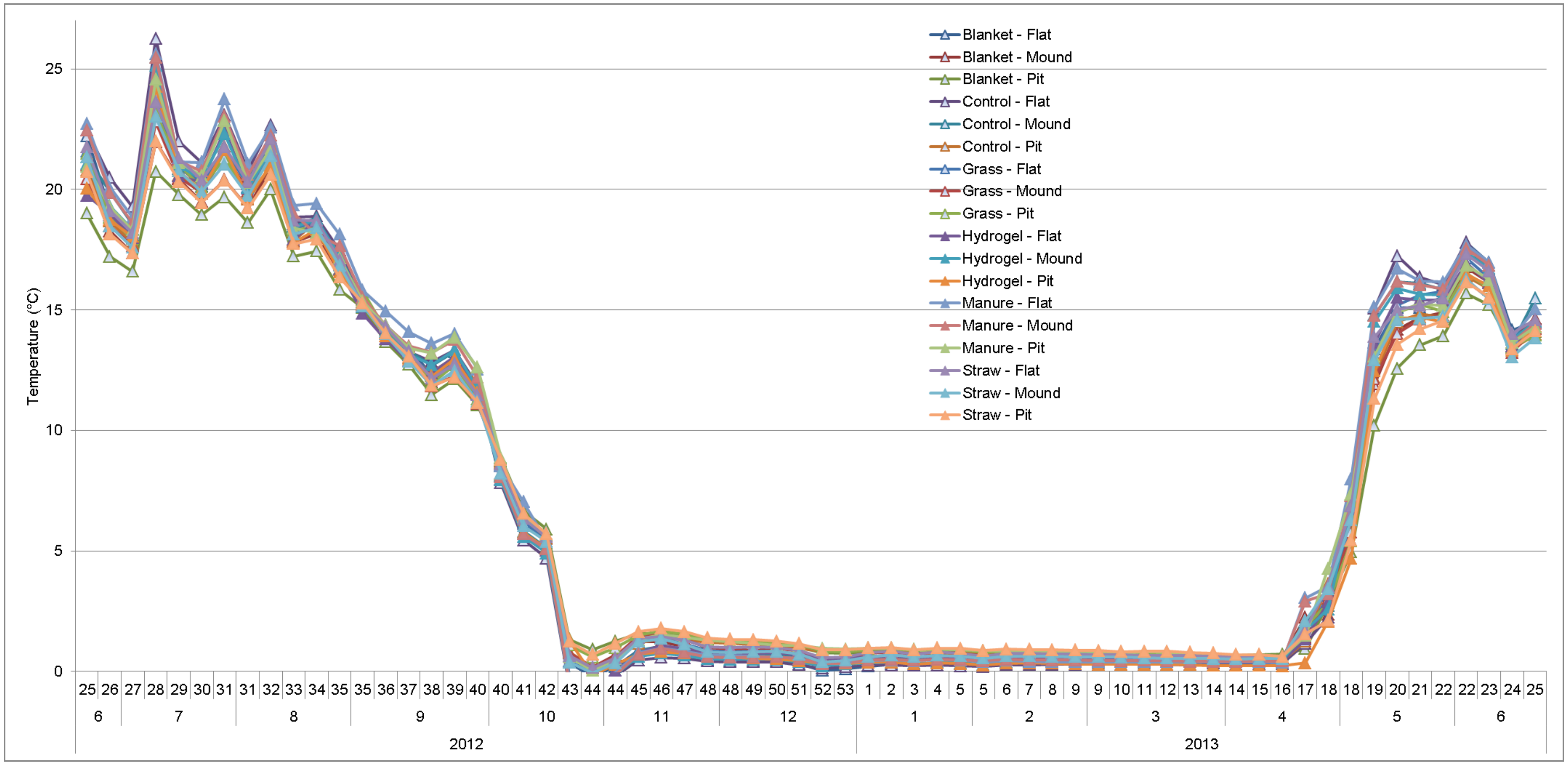

Figure 2.2. Mean weekly near surface soil temperature in all treatments at Elk Island National Park throughout the study period. Numbers above years refer to months (6-12, 1-8), then weeks (26-53, 1-25) of the year.

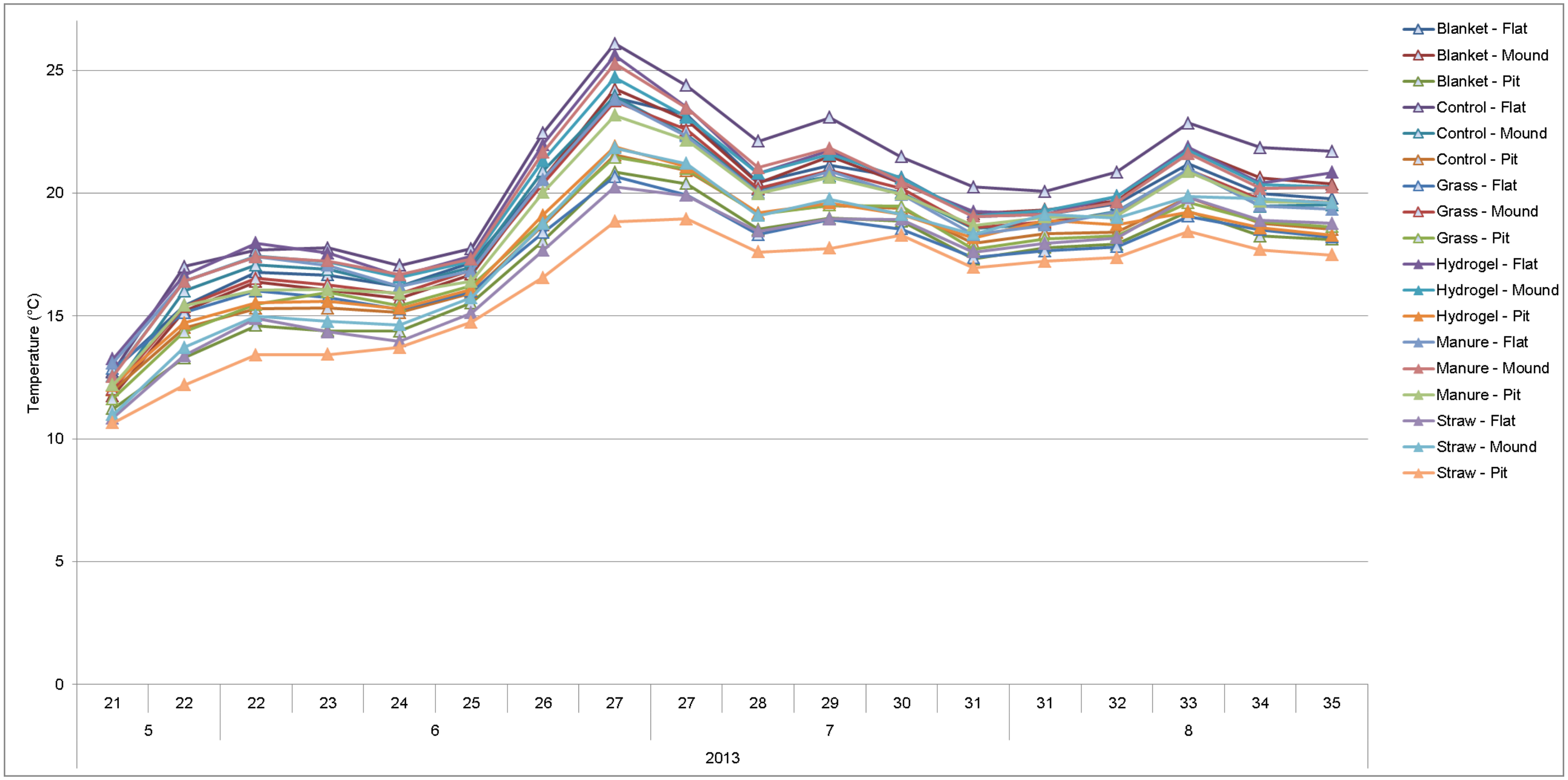

Figure 2.3. Mean weekly near surface soil temperature in all treatments at Mattheis Ranch throughout the study period. Numbers above years refer to months (5-8), then weeks (21-36) of the year.

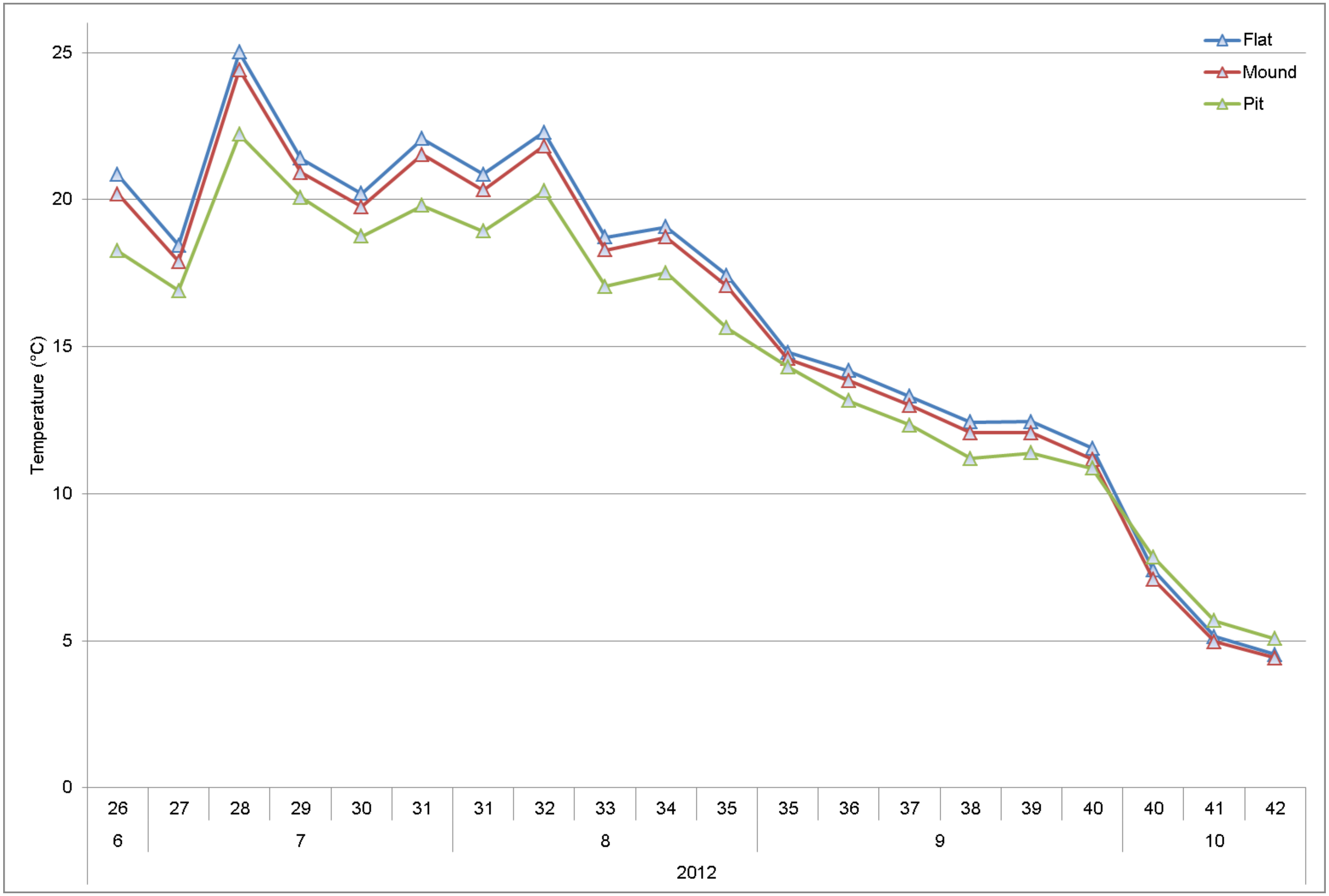

Figure 2.4. Mean weekly near surface soil temperature for micro sites at Devonian Botanic Garden in 2012 growing season. Numbers above years refer to months (6-10), then weeks (26-42) of the year.

Figure 2.5. Mean weekly near surface soil temperature for micro sites at Devonian Botanic Garden in 2012-2013 winter season. Numbers above years refer to months (10-12, 1-4), then weeks (43-53, 1-16) of the year.

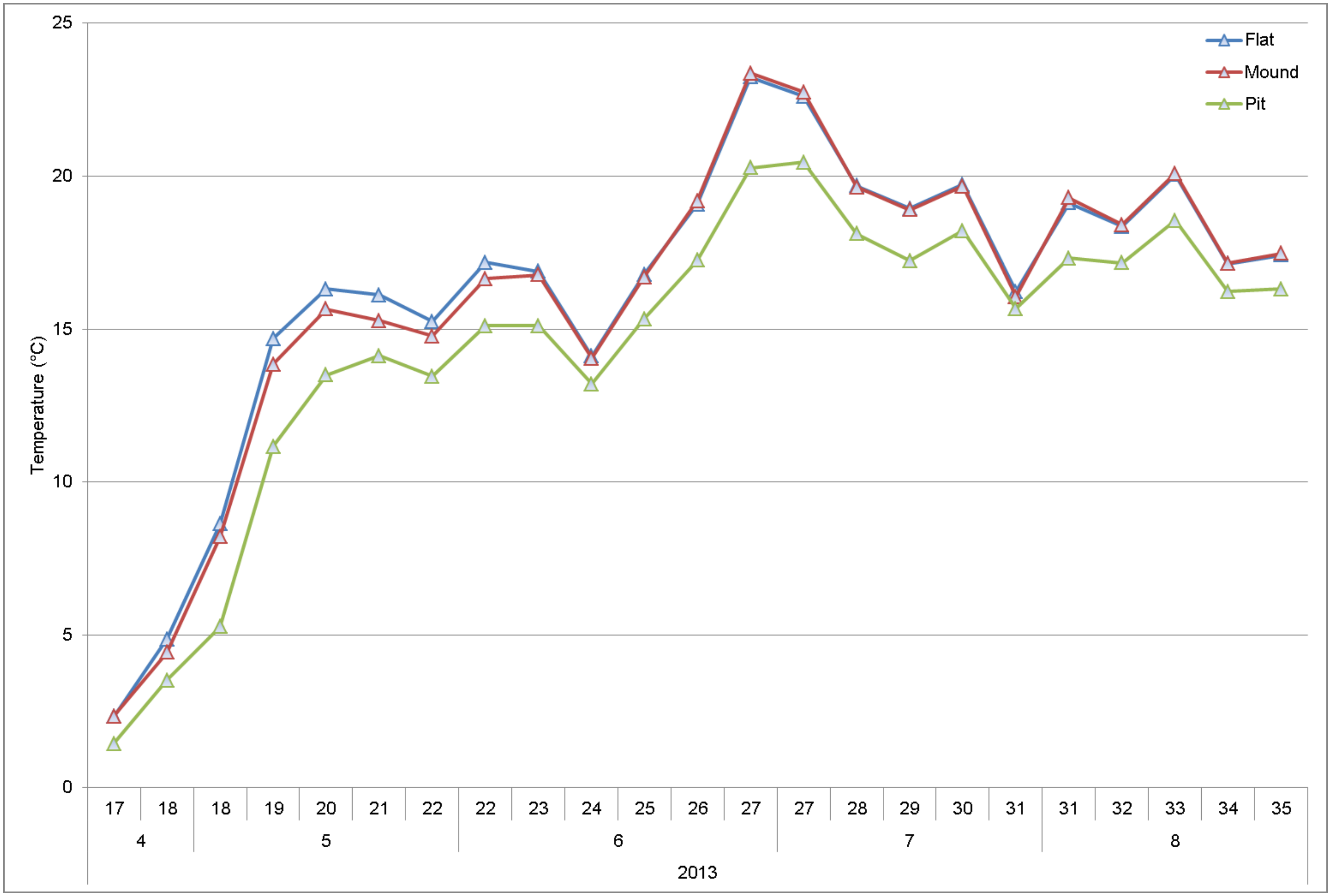

Figure 2.6. Mean weekly near surface soil temperature for micro sites at Devonian Botanic Garden in 2013 growing season. Numbers above years refer to months (4-8), then weeks (17-35) of the year.

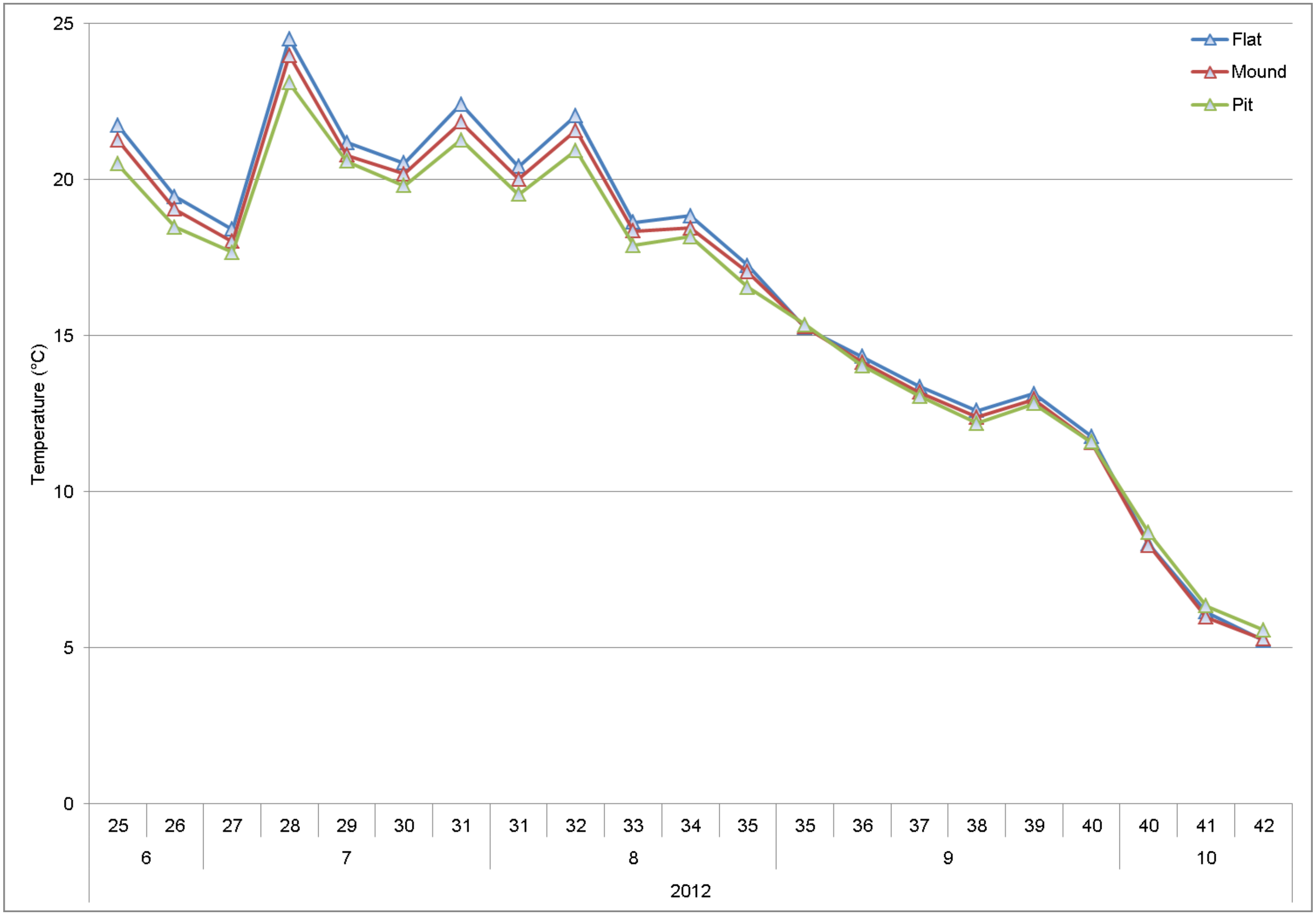

Figure 2.7. Mean weekly near surface soil temperature for micro sites at Elk Island National Park in 2012 growing season. Numbers above years refer to months (6-10), then weeks (25-42) of the year.

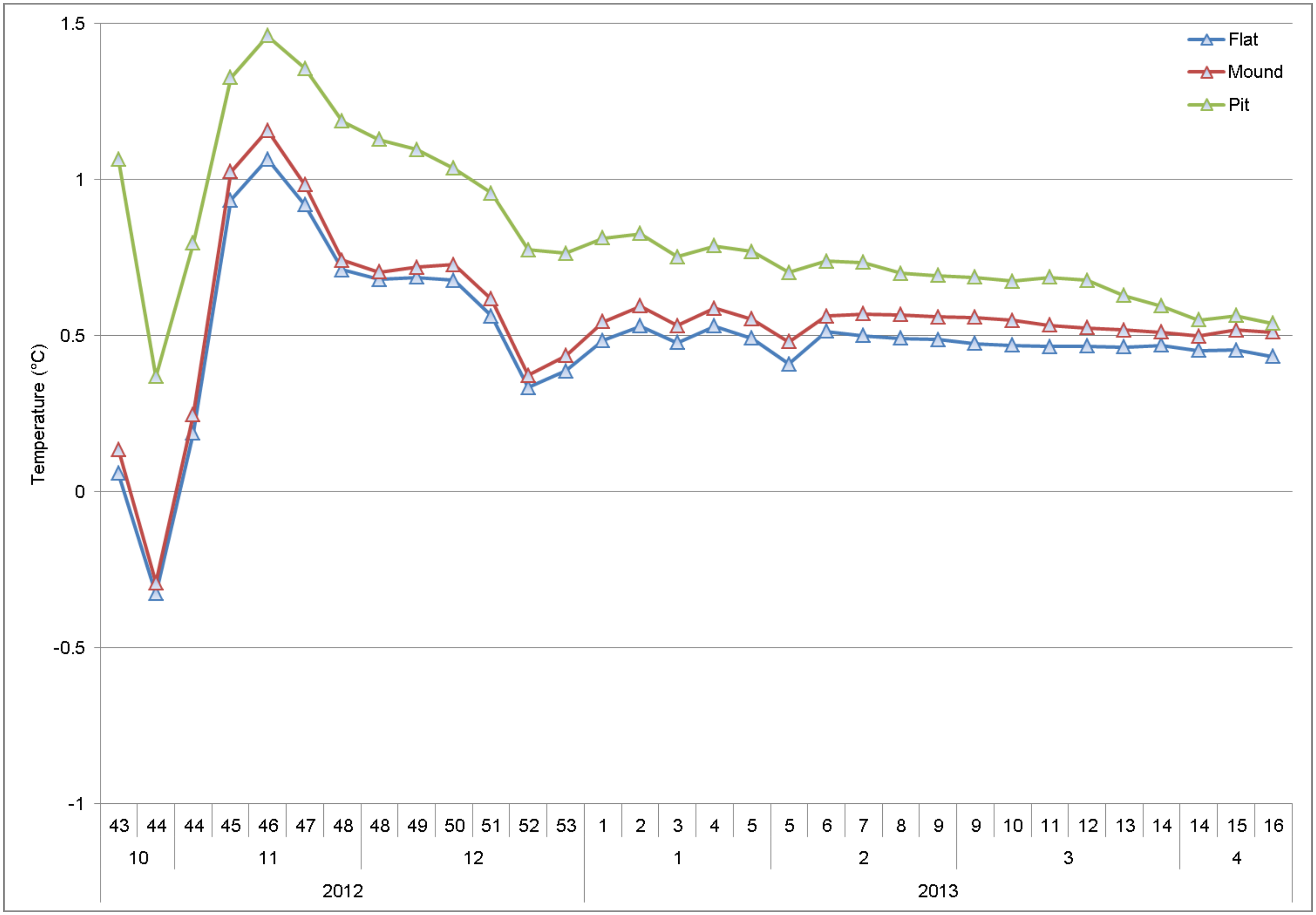

Figure 2.8. Mean weekly near surface soil temperature for micro sites at Elk Island National Park in 2012-2013 winter season. Numbers above years refer to months (10-12, 1-4), then weeks (43-53, 1-16) of the year.

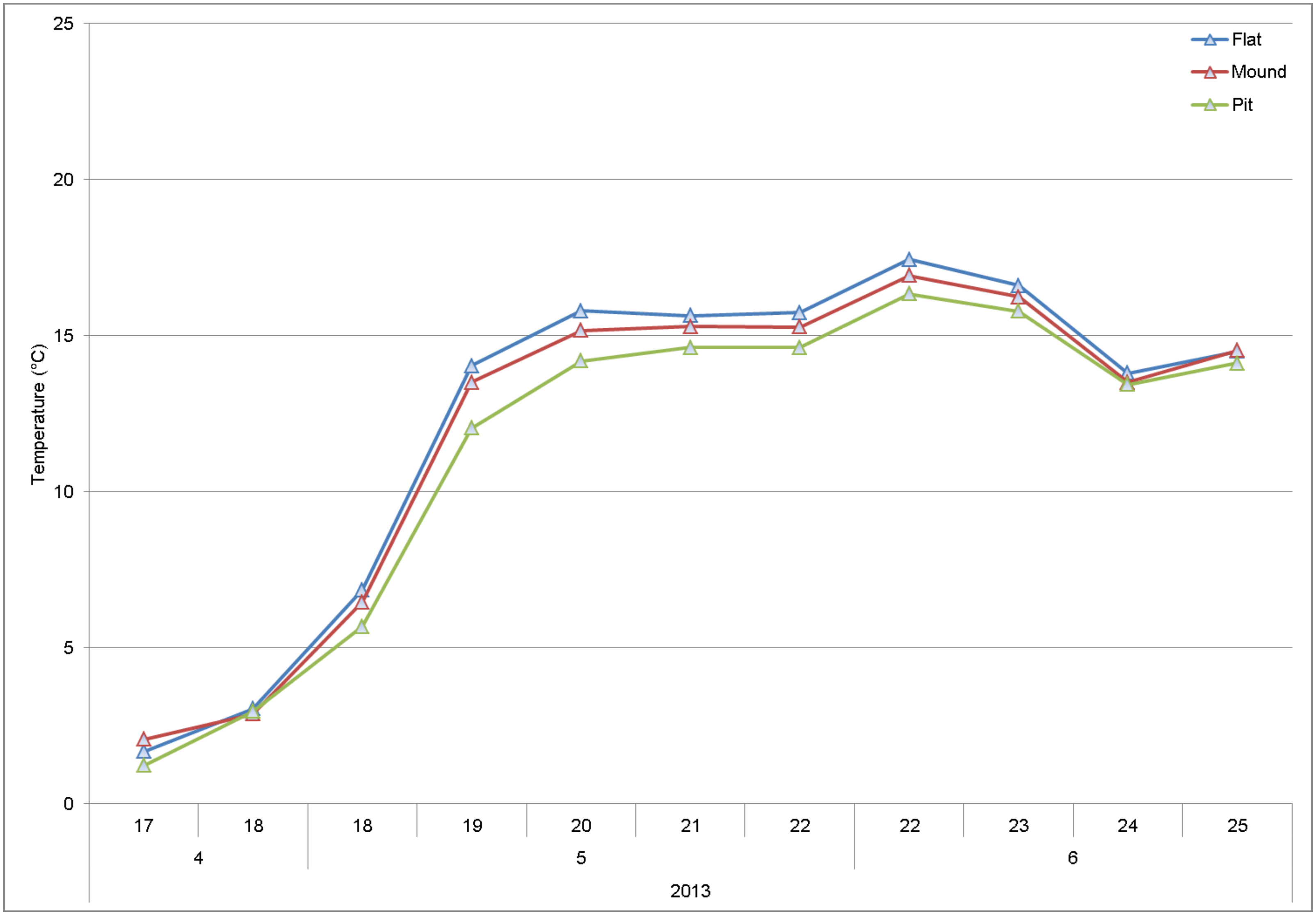

Figure 2.9. Mean weekly near surface soil temperature for micro sites at Elk Island National Park in 2013 growing season. Numbers above years refer to months (4-6), then weeks (17-25) of the year.

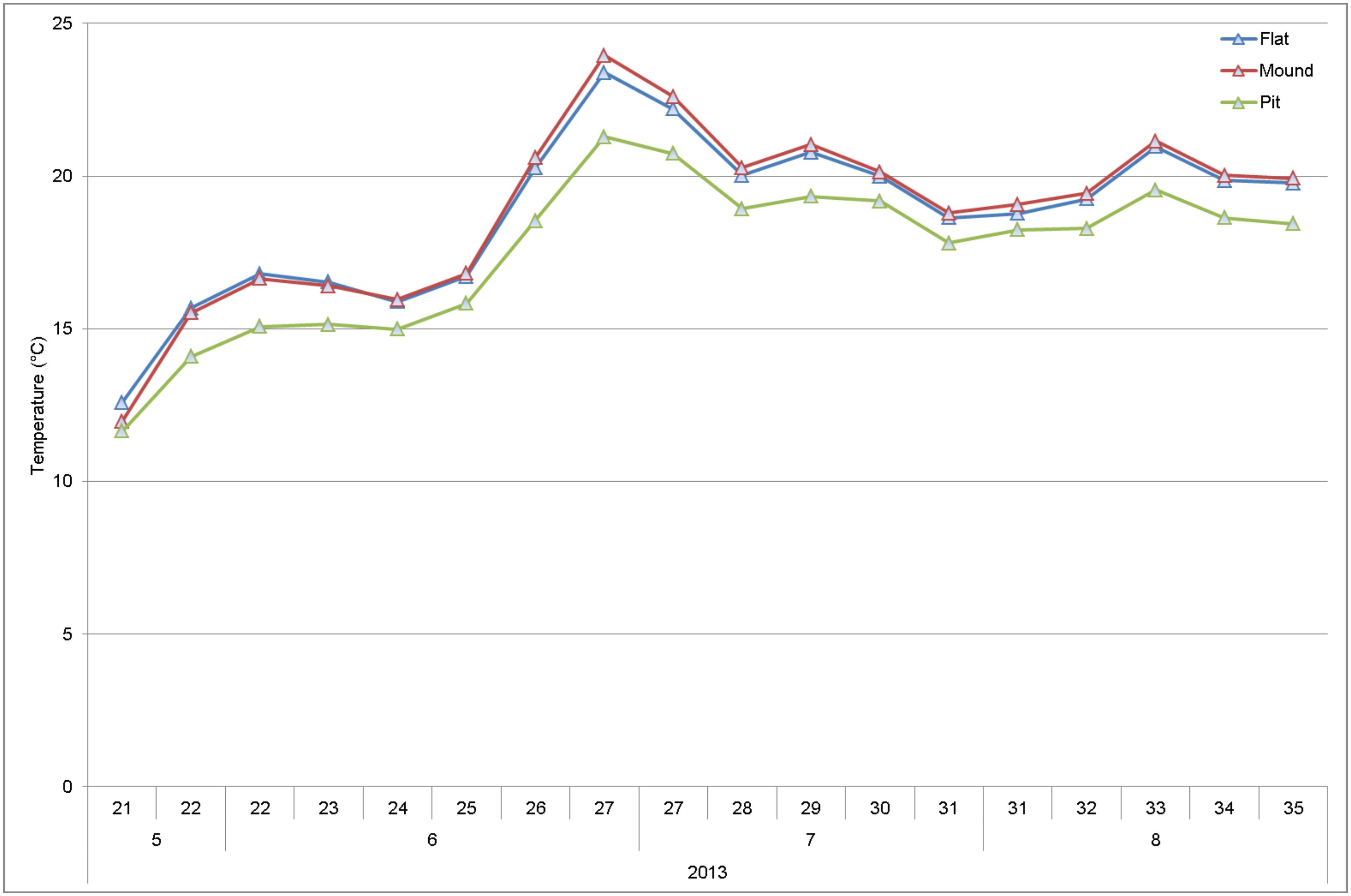

Figure 2.10. Mean weekly near surface soil temperature for micro sites at Mattheis Ranch 2013 growing season.

Numbers above years refer to months (5-8), then weeks (21-35) of the year.

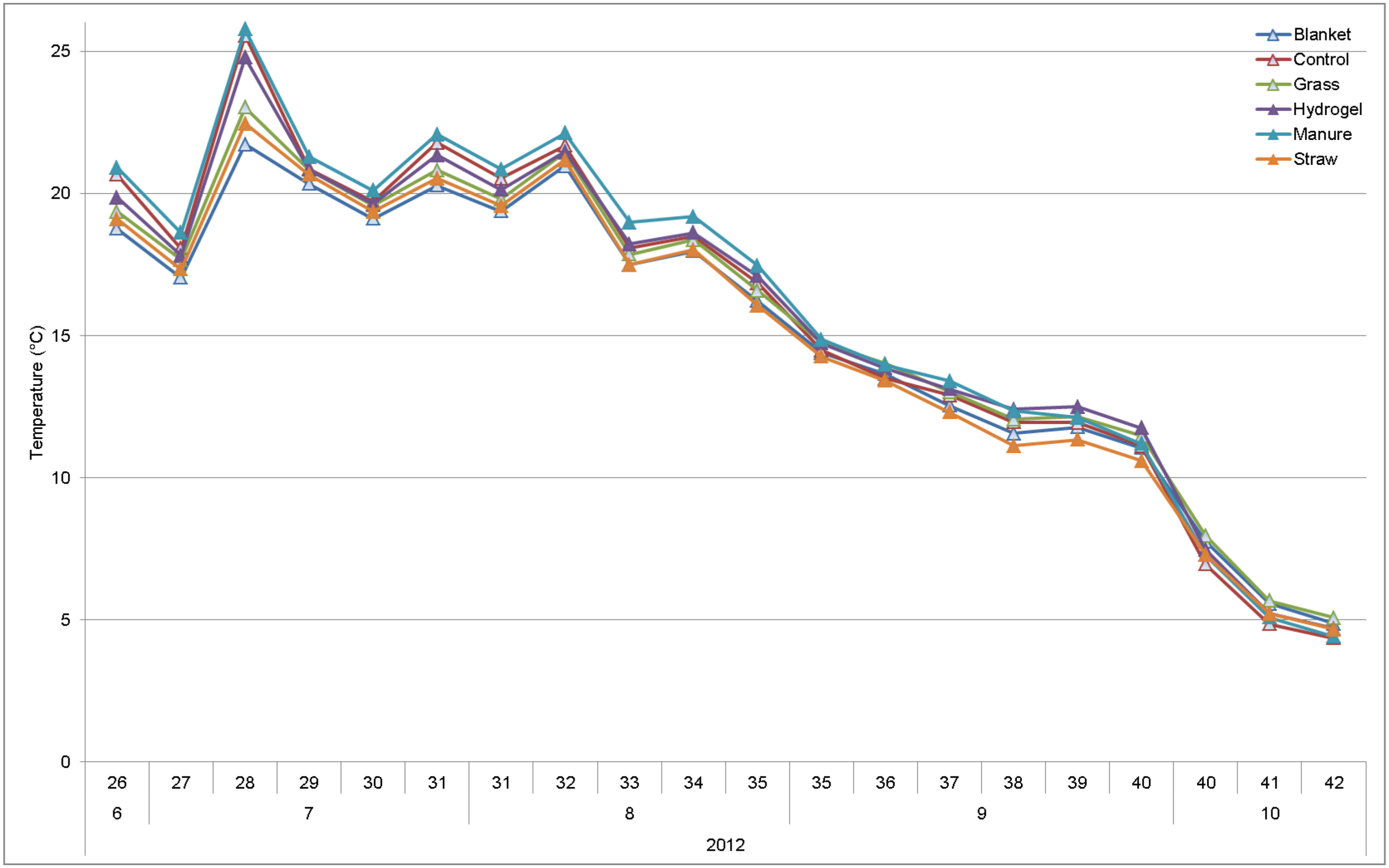

Figure 2.11. Mean weekly near surface soil temperature for amendments at Devonian Botanic Garden in 2012 growing season. Numbers above years refer to months (6-10), then weeks (26-42) of the year.

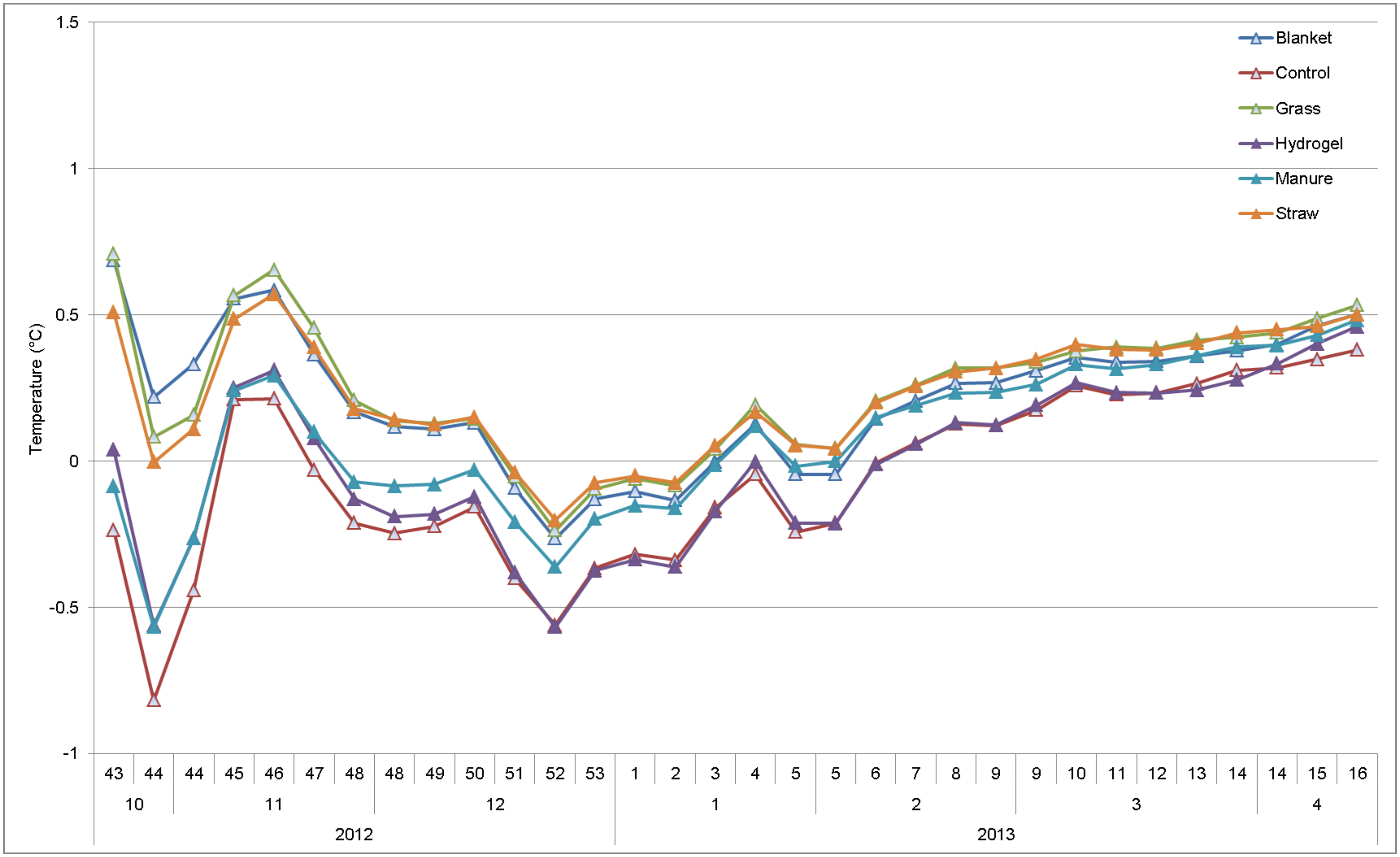

Figure 2.12. Mean weekly near surface soil temperature for amendments at Devonian Botanic Garden in 2012-2013 winter season. Numbers above years refer to months (10-12, 1-4), then weeks (43-53, 1-16) of the year.

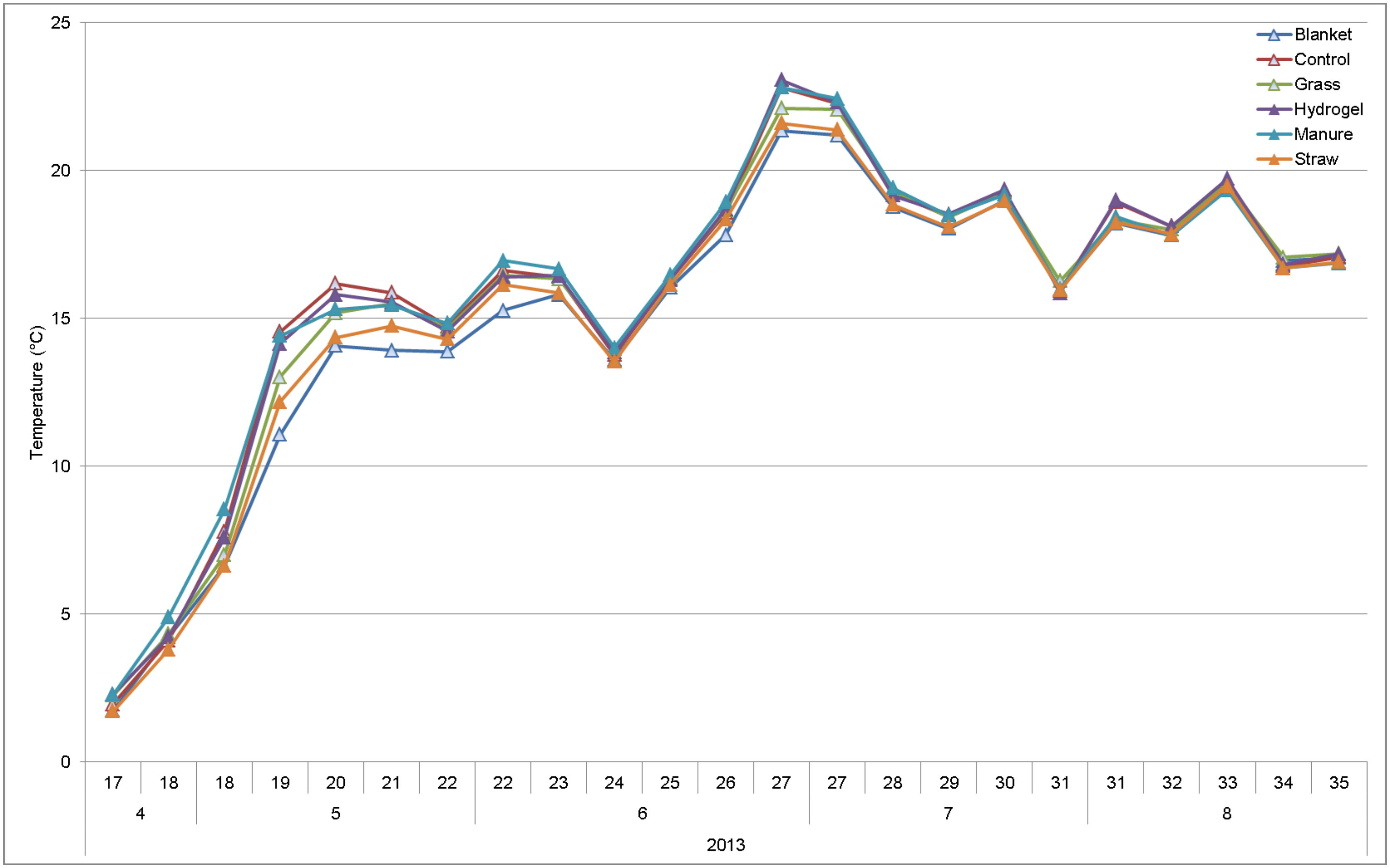

Figure 2.13. Mean weekly near surface soil temperature for amendments at Devonian Botanic Garden in 2013 growing season. Numbers above years refer to months (4-8), then weeks (17-35) of the year.

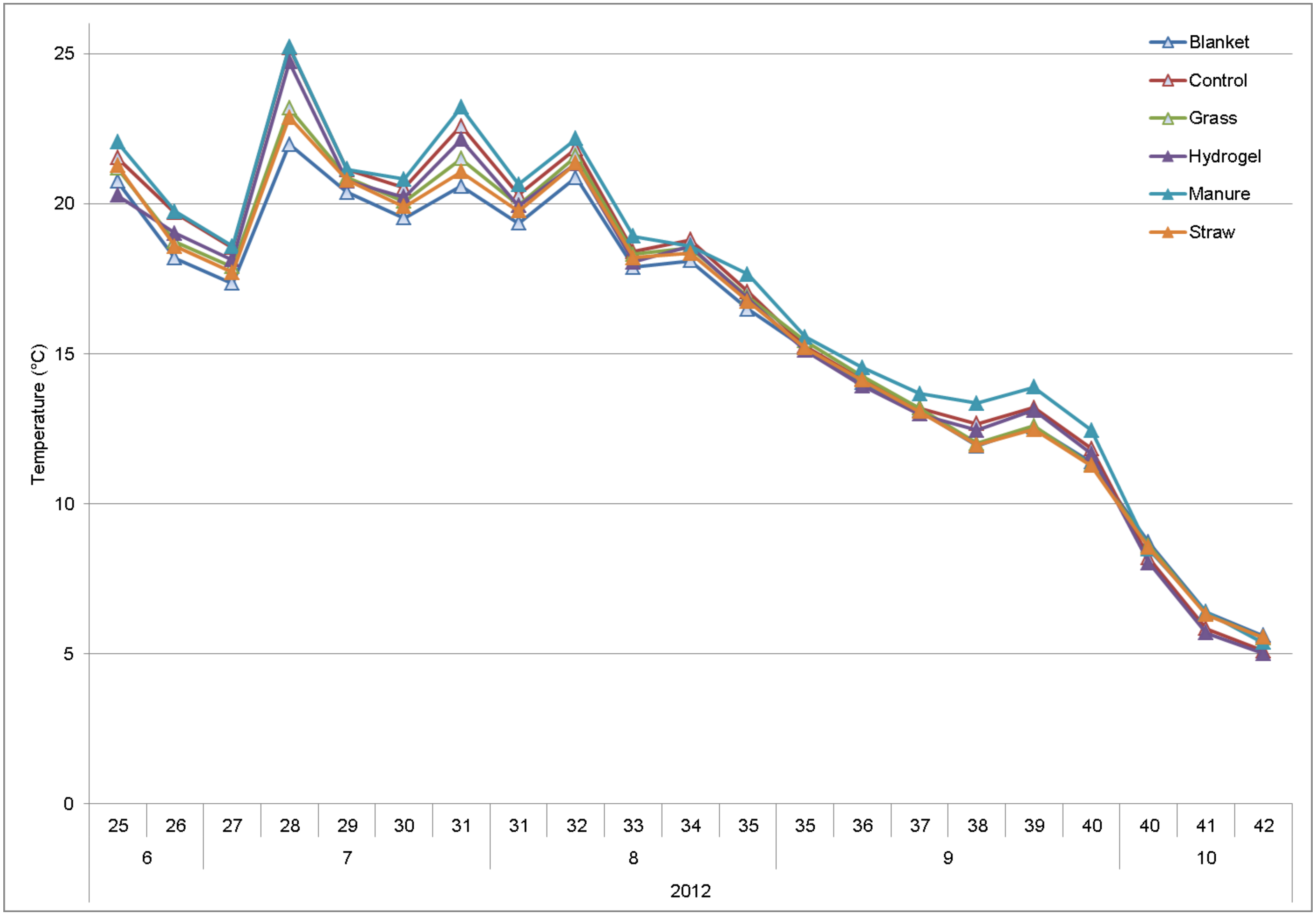

Figure 2.14. Mean weekly near surface soil temperature for amendments at Elk Island National Park in 2012 growing season. Numbers above years refer to months (6-10), then weeks (25-42) of the year.

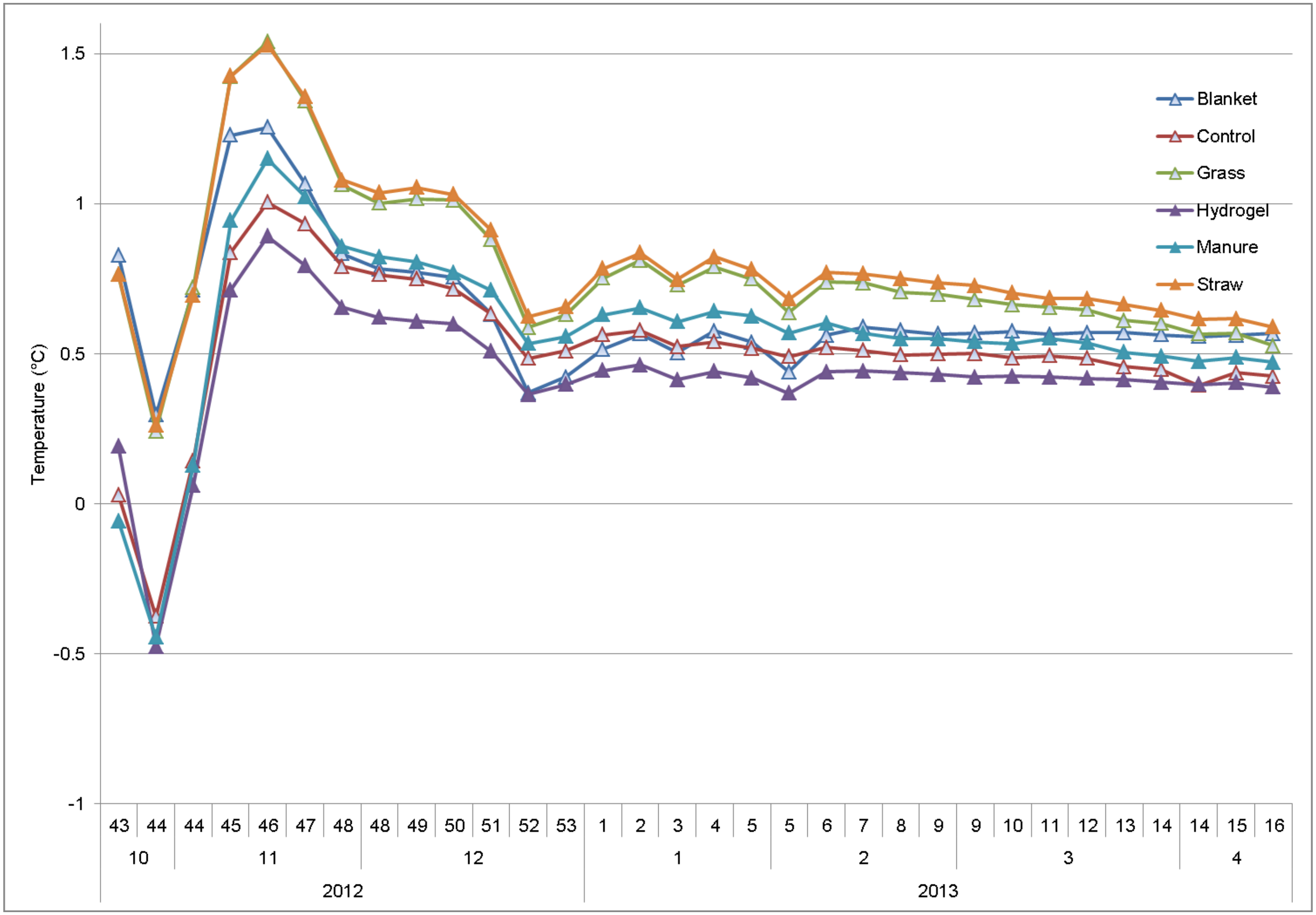

Figure 2.15. Mean weekly near surface soil temperature for amendments at Elk Island National Park in 2012-2013 winter season. Numbers above years refer to months (10-12, 1-4), then weeks (43-53, 1-16) of the year.

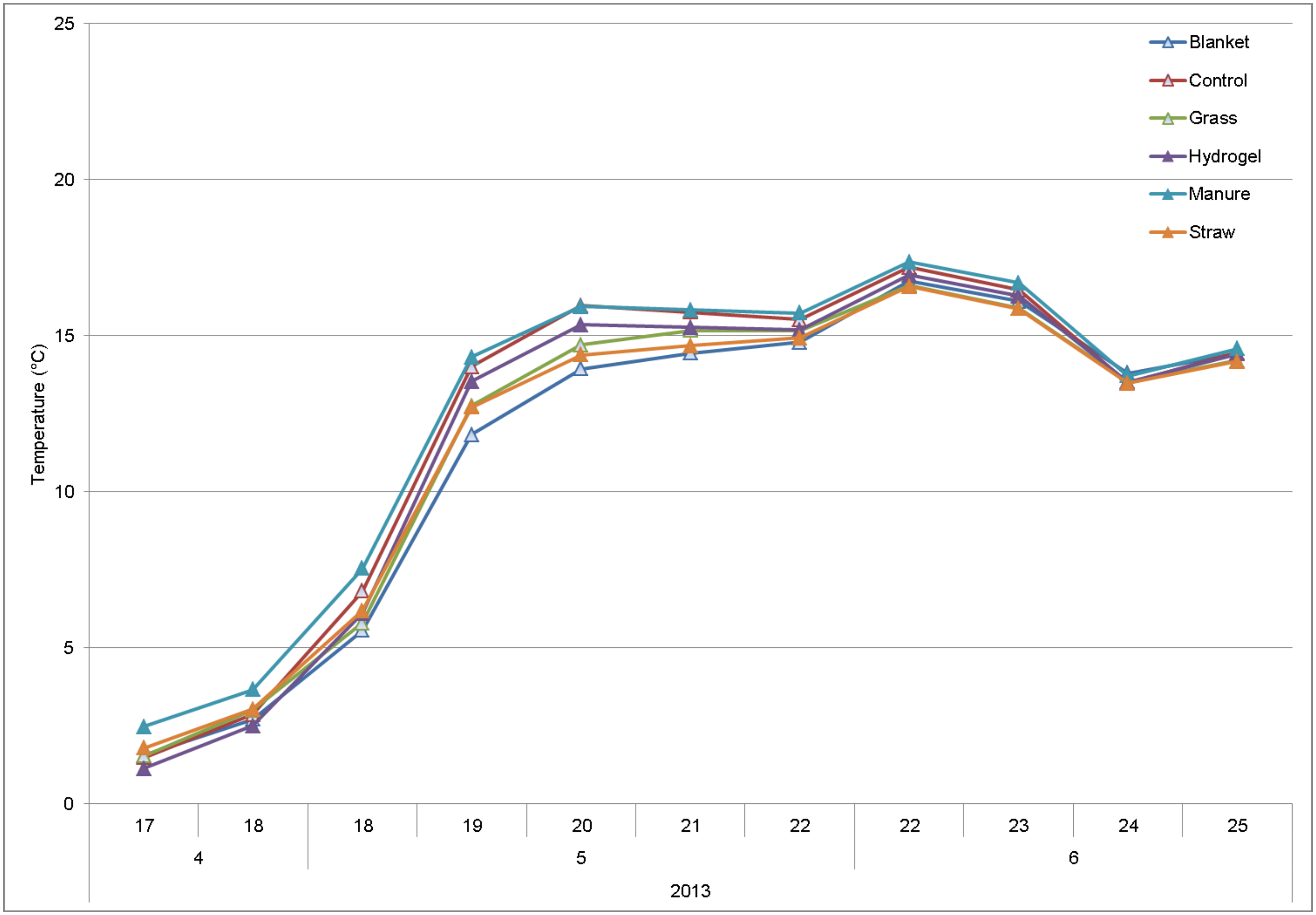

Figure 2.16. Mean weekly near surface soil temperature for amendments at Elk Island National Park in 2013 growing season. Numbers above years refer to months (4-6), then weeks (17-25) of the year.

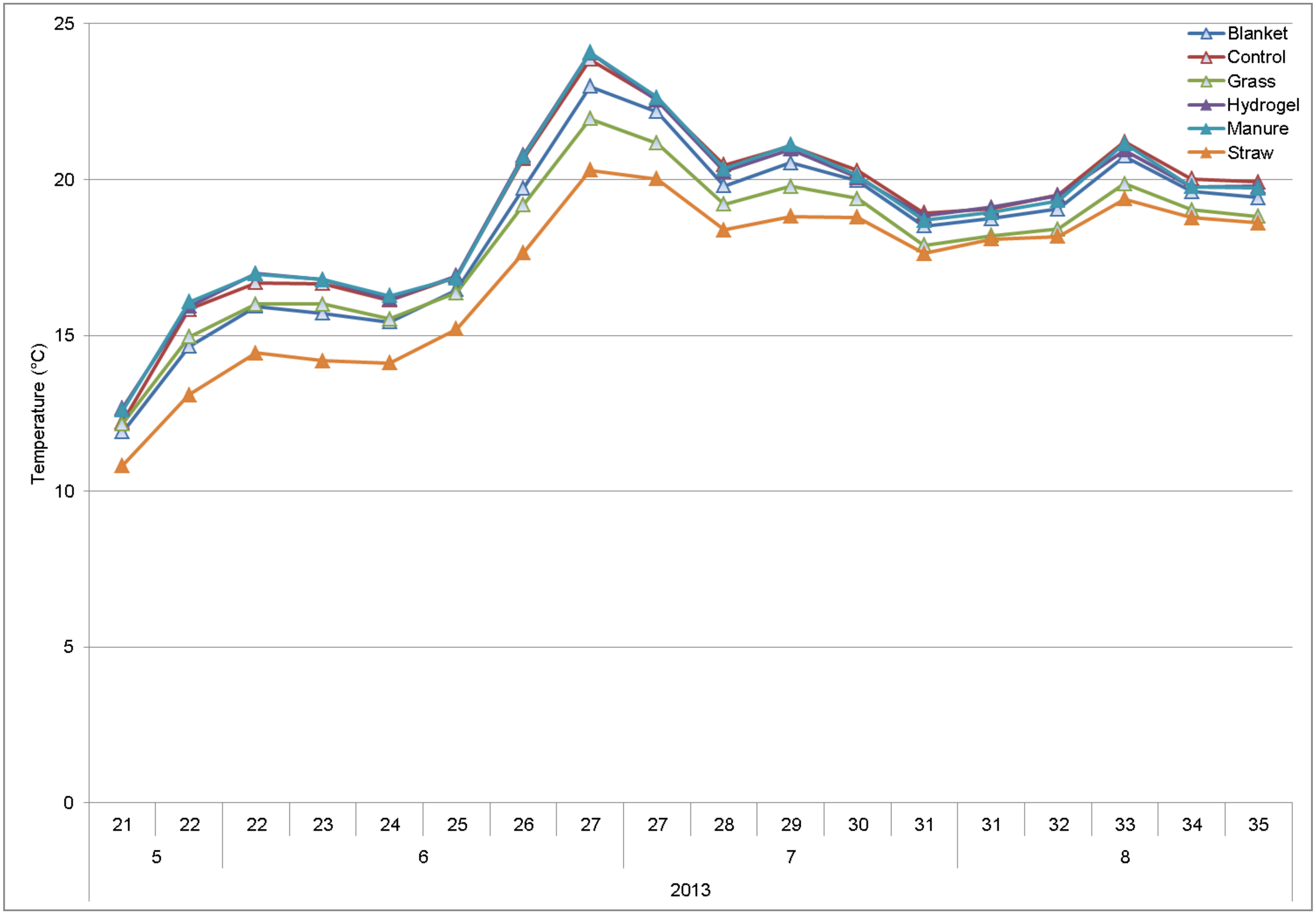

Figure 2.17. Mean weekly near surface soil temperature for amendments at Mattheis Ranch 2013 growing season.

Numbers above years refer to months (5-8), then weeks (21-35) of the year.

III. MICRO SITE AND AMENDMENT EFFECTS ON NEAR SURFACE SOIL VOLUMETRIC WATER CONTENT

1. INTRODUCTION

Micro sites and amendments can be used in land reclamation to mitigate the harsh conditions that have been created with various types of disturbances. Most anthropogenic disturbances, and even natural disturbances, can reduce organic matter content of the soil surface, reducing soil water holding capacity, and other hydrologic properties of the soil such as infiltration, percolation and soil water content. Many severely disturbed areas have exposed soil surfaces leading to high erosion of soil from them. The conditions of the soil created by the severe disturbances can in turn lead to unfavourable conditions for revegetation and for plant community development.

Topographic differences in the landscape, even at the micro scale, can result in soil water content differences. Diversity of soil micro topography can significantly affect uptake of soil water in plant seedling establishment (Harper et al. 1965). Soil water content can in turn have an effect on seed germination and seedling longevity (Oberbauer and Miller 1982). Significant differences in soil water content can be found in micro site such as pit bottoms and mound tops (Clinton and Baker 2000), with soil water was generally higher in pits than in mounds (Beatty 1984, Clinton and Baker 2000). As pits provide greater available soil water in summer, more species established in pits (Beatty 1984).

Applications of amendments can modify soil properties that in turn will modify soil water. Mulch can help to conserve soil water (Chakraborty et al. 2008, Balwinder-Singh et al. 2011). Mulch can affect soil surface to atmosphere energy and water fluxes. By affecting the mass transfer of water vapour, mulch can make the beneficial effects of a rainfall event last longer. In northern great plain grasslands, a matted layer of dead grass is important in maintaining a cool, humid environment (Ripley and Redman 1976). In the cool temperate prairies high amounts of litter can improve soil water retention and could be an effective drought management strategy (Willms et al. 1986, Naeth et al. 1991, Deustch et al. 2010). Litter effectiveness is reduced when soil water is not available or in good supply from precipitation (Willms et al. 1993). The use of hydrogels, synthetic acrylic polyacrylamides with a salt base, may enhance soil water retention capacity and plant available soil water. This will assist plant germination and establishment, especially in arid environments (Akhter et al. 2004).

A combination of micro sites and amendments can be useful to employ in land reclamation. In harsh climates, in particular, such as dry grassland and northern tundra types, even small amounts of increased soil water can have a significant and positive effect on seed germination and on seedling establishment and survival. Since a rapid establishment of cover in these reclamation scenarios is important and necessary micro sites and amendments may facilitate successful revegetation.

2. RESEARCH OBJECTIVES AND HYPOTHESES

3.1 Objectives

The objectives of this research were to determine whether micro topography and amendments affected near surface soil water content. Specific research objectives were as follows.

- To quantify effects of micro topography (flat, pit and mound) on near surface soil volumetric water content.
- To quantify effects of amendments (control, hydrogel, manure, blanket, straw and grass) on near surface soil volumetric water content.
- To quantify interactions among micro topography and amendments on near surface soil volumetric water content.
- To quantify effects of mound aspects on near surface soil volumetric water content.

3.2 Hypotheses

For near soil surface water content, there are several major influencing environmental factors. Some of these environmental factors are soil background water content, wind presence and intensity and sun light presence and intensity. Soil surface temperature can also affect near surface soil volumetric water content due to higher surface soil temperatures which will lead to higher evaporation rates.

Pits are expected to have higher near surface soil volumetric water content than that found in mounds because of lower wind and less sunlight in pits than in mounds. Erosion control blankets and grass and straw amendments can increase near surface soil surface water content. This is due to the shade provided by these amendments since they cover the soil and reduce sunlight and heat. Hydrogel can increase near surface soil surface water content by increasing near surface soil water holding capacity. Manure as an amendment can increase near surface soil volumetric water content because of the high organic carbon contents that are found in manure.

3. MATERIALS AND METHODS

3.1. Research Sites

Multiple research locations were utilized to determine the effect of local environmental conditions on micro sites. The Mattheis Ranch site (hereafter called Mattheis) was in grassland and the other two sites, Elk Island National Park (hereafter called Elk Island) and the Devonian Botanic Garden (hereafter called Devonian), were in the parkland of Alberta. These areas represent those requiring revegetation from multiple disturbances, such as overgrazing, oil and gas exploration and development and mining.

3.1.1. Mattheis Ranch

The Mattheis Ranch study site is located near Brooks, Alberta, 430 km south of Edmonton, Alberta, in the Dry Mixedgrass Natural Subregion. Average elevation is 800 m above sea level (575 to 1100 m) (Natural Regions Committee 2006). Soils are mainly Brown Chernozems. Native vegetation is dominated by low growing, drought tolerant, mixed grass communities including *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama grass) and *Hesperostipa comata* (Trin. & Rupr.) Barkworth (needle and thread grass), *Koeleria macrantha* Schult (june grass) (Ledeb.) Schultes and *Pascopyrum smithii* (Rydb.) Á. Löve (western wheat grass) with numerous forbs. According to data from the closest weather station, at Brooks (50°33'00.000" N, 111°51'00.000" W), maximum air temperature was 40 °C, and averaged 12.4 °C during the growing season (April to October) (Environment Canada 2010). Average annual precipitation is 347.6 mm.

The study site is in the southern portion of the W10 paddock, an old pivot irrigation area. The land was farmed for many years then seeded with *Bromus inermis* Leyss. (smooth brome grass) to provide a forage cover when farming ceased. Native grassland species have since established naturally at the site. The area was recently characterized as having 60 % plant cover and 40 % bare ground. Soil texture is loamy sand.

3.1.2. Elk Island National Park

Elk Island National Park is located approximately 45 km east of Edmonton on Highway 16, in the Dry Mixed Wood Natural Subregion. Average elevation is 600 m (225 to 1225 m) (Natural Regions Committee 2006). Upland soils are mainly Orthic Gray Luvisols and Dark Gray Luvisols. Vegetation is characterized by forests of *Populus tremuloides* Michx. (trembling aspen) and *Picea glauca* (Moench) Voss (white spruce). Common herbaceous vegetation includes

Stipa spartea Hitchc. (porcupine grass), *Koeleria macrantha* and *Elymus trachycaulus* (Link) Gould ex Shinners (slender wheat grass). According to data from the closest weather station at Elk Island National Park Point (53°53'00.000" N, 111°04'00.000" W), average air temperature in the growing season (April to October) was 10.4 °C and average maximum air temperature was 38.9 °C (Environment Canada 2010). Average annual precipitation is 482.5 mm.

The site is located in the northern portion of the park at NW-13-54-20-W4M. It is 13.9 km from the park entrance at Highway 16 and positioned approximately 300 m east of the parkway, directly across from the golf course equipment shop. The entire site encompasses approximately 480 m^2. Trees border the east, west and south sides of the site and an open meadow is located north of the site.

The research site was a historical landfill created in the 1930s and decommissioned in the early 1970s. Refuse was initially covered with soil and untouched until summer 1997 when Park staff reclaimed landfills that had some surface dumping and refuse buried beneath a shallow layer of topsoil. The landfill was decommissioned in August 1997. The site was denuded of vegetation for an MSc research project by cutting and herbicide (Van Bostelen 2003). The landfilled material was removed and a heavy equipment operator used the bucket on the front end loader to contour the sub soil to predisturbance levels. Topsoil was not replaced and compaction resulted from the use of heavy equipment. When the landfilled sites were cleaned out, soil testing was done by O'Connor Associates to ensure there were no contaminants in the landfills. All of the analyses indicated the sites met the required government criteria (Van Bostelen 2003).

3.1.3. Devonian Botanic Garden

The Devonian Botanic Garden site is 42.3 km southwest of Edmonton, Alberta, in the Central Parkland Subregion. Average elevation of the Central Parkland Natural Subregion is 750 m (500 to 1250 m) (Natural Regions Committee 2006). Soils are mainly Black Chernozems with some Dark Gray Chernozems and significant occurrences of Solonetzic soils. Vegetation is characterized by forest interspersed with prairie associated with hummocky till or eolian materials. Common vegetation includes *Corylus cornuta* Marsh (beaked hazelnut), *Cornus canadensis* L. (bunch berry), *Maianthemum canadense* L. (wild lily of the valley) and *Aralia nudicaulis* L. (wild sarsaparilla). According to data from the closest weather station at Edmonton Woodbend (53°25' N, 113°45' W), maximum air temperature was 35.5 °C in the growing season (April to October) with averages of 10.7 °C (Environment Canada 2010). Average annual precipitation is 508.0 mm.

The site is an abandoned well site of Imperial Oil Ltd. The oil well started production in 1947 and was closed in 1993 according to official records. Before industrial development, the Devonian Botanic Garden Orchid Club used the site to grow plants. In 2012 field observation showed organic matter had been added with tillage. The site is surrounded by forest and wetlands and was likely covered by forest before well site establishment and development.

3.2. Experimental Design And Site Establishment

The experiment was a completely randomized design at each of the research sites. Three micro topographic treatments consisted of mounds, pits and flat land. These treatments were assessed in combination with four micro site amendments proven successful in various reclamation treatments in other sites (Naeth various) and an unamended control. The amendments were erosion control blankets, weed free straw, fresh grass debris or hay, manure mix and hydrogel. The design is 3 micro topography treatments x 6 amendments x 5 replicates = 90 plots per site.

All vegetation was removed from each of the research sites prior to establishment of the research treatments, using glyphosate at a rate of 8 L/ha applied by a tractor pulled crop sprayer at Mattheis in mid May and a backpack sprayer at Elk Island and Devonian in late May. Soil was rototilled to a depth of 15 cm; 10 days after herbicide application at Mattheis and 7 days after herbicide application at Elk Island and Devonian.

Plant species selected for the study were native components of the plant community of the area. Grass species were *Hesperostipa comata*, *Elymus trachycaulus*, *Koeleria macrantha*, *Bromus ciliatus* L. (fringed brome grass) and *Bouteloua gracilis* Lag. ex Griffiths (blue grama grass). Forb species were *Linum lewisii* Pursch (wild blue flax), *Geum triflorum* Pursch (prairie smoke), and *Astragalus canadensis* L. (Canada milk vetch).

Each site was seeded at least two weeks after herbicide application, by hand broadcasting the mix at a rate of 350 pure live seed m^{-2}. This rate was based on previous research by Dr Naeth and her research team. Individual plant species were each included in the mix at an equal rate. The 2 m x 2 m plot was divided into a center 1 m x 1 m plot and a surrounding buffer zone. The center plot was seeded by hand with 50 seeds, counted individually for each plot. The buffer zone was seeded at 50 seeds per m^2 based on weight of the number of seeds. Seeding was completed; June 22 and 23 at Elk Island, June 28 at Devonian and June 8 at Mattheis in 2012.

To avoid the impacts of from herbivores, all research sites were fenced. Research areas were fenced with a standard four strand electric and barb wire fence at Mattheis, and with game fence at Elk Island and Devonian. The Devonian and Elk Island game fences were 2.4 m high with 12 gauge wire with 0.15 m x 0.10 m cells.

3.3. Soil Micro Topography And Amendment Treatments

Treatment plots were randomly distributed at each of the study sites. Plots were 2 m x 2 m at Mattheis and Elk Island. Due to the smaller area available for research at Devonian, plots were smaller, at 1.5 m x 1.5 m.

Pits, approximately 10 cm deep and 25 cm wide, were created by digging a hole in the ground with a shovel in the center of each plot. The mounds were formed in the center of each of the research plots using the soil extracted from the depression and buffer areas outside of the plots, and molded with a flexible pipe. The mounds were round in shape, and were approximately 20 cm in height, with a 40 cm base width in the center of each of plot. Flat micro topography treatments served as the control to mounds and to the depressions.

Erosion control blankets were Nilex SC150BN made with coconut and straw. They were anchored with industrial grade staples and spread over the entire plot after seeding was completed. Manure mix was applied at a rate of 39 Mg ha^{-1} and incorporated into the soil. One year old wheat straw was applied as a cover at a low rate of 0.5 kg m^{-2} at Mattheis. At Elk Island and Devonian straw was applied at 0.25 kg m^{-2} after deciding that 0.5 kg m^{-2} seemed too high for the area and could potentially hamper seedling emergence. Native fresh grass, consisting of grass and forb leaves and stems and plant litter, was cut by hand and harvested two days later from adjacent areas at Mattheis. It was applied on the surface. Certified weed free hay was applied at Elk Island and Devonian. Hydrogel (Soil Moist), a synthetic acrylic polyacrylamide with a potassium salt base, was mixed with water and applied according to manufacturer's instructions (337.5 kg ha$^{-1)}$ to increase plant available soil water.

3.4. Research Site Instrumentation

The three research sites were each instrumented for ongoing documentation of environmental conditions. Near surface soil volumetric water content, electrical conductivity and temperature were measured with 5TE soil water sensors (Decagon Devices, United States) and Em50 digital/analog data loggers (Decagon Devices, United States). Soil sensors were installed after the manure mix and hydrogel were incorporated into the soil and before seeding and placement of covers of straw, grass and hay. A 4 to 5 cm deep clear cut was dug at the sensor installation spot. The sensor cable was buried 4 to 5 cm deep and length varied according to the sensor installation spot to data logger. Sensors were installed horizontally as shown in the appendix at a 2 to 3 cm depth by positioning them into the soil in the trenches. Cables of sensors were anchored with staples to keep them from moving. The positions of the sensors were in the center of the plot for flat and pit micro sites and in each of the northern, eastern, southern and western parts of the mound for mound micro sites. Positions of sensors were marked with coloured tape, with different colours for different directions (pink for north, orange for east, green for south, yellow for west). After installation, soil sensors were connected to data loggers.

Data for near surface soil temperature, electrical conductivity and volumetric water content were recorded in 30 minute intervals for each sensor for the duration of the study. The 5TE sensor measures soil volumetric water content by measuring soil dielectric permittivity, measures soil temperature by a thermistor and measures soil electrical conductivity by measuring the resistance between two electrodes. Data loggers were downloaded every two months before winter in 2012 and each month from May through October in 2013. Data from the winter period were downloaded in spring 2013 and 2014. Data loggers ran relatively well but there were minor amounts of missed data due to the malfunction of individual sensors. These missing data did not affect results and their interpretation.

One weather station (T HOBO U30-NRC Weather Station by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532) was installed for each site, at Mattheis on June 17 2012, Elk Island on June 22 2012 and Devonian on June 26 2012. Wind was measured by wind speed smart sensors (S-WSA-M003 by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532) and wind direction smart sensors (S-WDA-M003 by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532). Precipitation was measured by rain gauge smart sensors (S-RGA-M002 by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532). Air temperature and relative humidity were measured by temperature/RH smart sensors (S-THB-M00X by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532). Light level was measured by silicon pyranometer smart sensors (S-LIB-M003 by Onset Computer Corporation, 470 MacArthur Blvd., Bourne, MA 02532).

3.5. Soil Sampling And Analyses

One soil sample for general site characterization from three randomly selected plots per microsite-amendment treatment was collected after plot preparation and before seeding. Samples were taken from a corner of the plot to a depth of 10 cm. Samples were only taken in amendment treatments at Mattheis Ranch.

Samples were sent to a commercial laboratory for determination of soil properties, which are presented in Tables 2.1, 2.2 and 2.3. Particle size distribution was measured by hydrometer method (Carter and Gregorich 2008). Organic and inorganic carbon were measured by gravimetric loss of CO_2 (Loeppert and Suarez 1996). Total carbon and total nitrogen were measured by combustion with a Carbo-Erba NA 1500 (Nelson and Sommers 1996). Electrical conductivity was measured by conductivity meter and pH was measured by pH meter; both in a saturated paste (Carter and Gregorich 2008). Saturation percent was by calculation in saturated paste (Carter and Gregorich 2008).

3.6. Statistical Analyses

All of the statistical analyses were conducted using two way analysis of variance (ANOVA) with R software (R Development Core Team 2012). The Tukey's post hoc pairwise comparison test was used following all significant main effects. The Shapiro Wilks test was used for testing normality of distribution of all of the data. Homogeneity of variance of the data was tested with the Bartlett's test.

4. RESULTS AND DISCUSSION

4.1. Soil Properties

Devonian and Elk Island surface soils were sandy loam in texture (Tables 3.1, 3.2) and Mattheis surface soil was sand in texture (Table 3.3). Soil pH was near neutral at all three of the research sites, lowest at Mattheis. Total nitrogen was highest at Elk Island and lowest at Mattheis, with Devonian similar to Elk Island. According to the soil quality criteria for reclamation (Alberta Soils Advisory Committee 1987), the surface soils were rated good at all three sites for pH, electrical conductivity, calcium carbonate equivalent and saturation %. Organic carbon content was rated good at Elk Island and Devonian and fair at Mattheis. Thus soils posed no problems for reclamation and or for revegetation.

Amending the surface soil with manure increased near surface soil electrical conductivity at all sites (Tables 3.1, 3.2, 3.3), but it was still rated good by surface soil reclamation criteria. Manure amendment increased near surface soil total organic carbon and total nitrogen at Mattheis, increased total organic carbon at Devonian, and slightly reduced both total carbon and total nitrogen at Elk Island. Amending with straw increased total organic carbon and total nitrogen at Devonian and decreased it at Elk Island. Near surface soil norganic carbon at Elk Island was twice as high as at the other sites.

4.2. Site Meteorological Conditions

Meteorological conditions at the three sites were similar with 2012 being warmer than 2013 (Tables 3.4, 3.5, 3.6). Devonian had more precipitation in 2013 than in 2012 while Elk Island had more in 2012. Mattheis had similar precipitation in both 2012 and 2013. Values for precipitation and air temperature were similar to long term climate normals for the regions (Government of Canada 2015).

The precipitation and air temperature data showed the differences between parkland (Devonian and Elk Island) and grassland (Mattheis) ecosystems. Precipitation was lower in the parkland relative to the forests. Wind was much stronger in the grassland than the parkland. Air temperature was similar among the three sites throughout the whole year.

4.3. General Treatment Trends For Near Surface Soil Volumetric Water Content

Near surface soil volumetric water content patterns for treatments at Devonian and Elk Island were generally similar from an overview perspective for the duration of the study (Figures 3.1, 3.2). Soil water content patterns could be generally divided into three periods, spring to fall, winter and transition periods. At Mattheis, with fewer data points, the pattern was still similar to that of the other two sites (Figure 3.3) from May to August.

The spring to fall period was the most dynamic. It generally occurred from mid May to the end of September. During this period, soil water content in each treatment rose and fell with the greatest frequencies and magnitude throughout the whole year, clearly following precipitation events. The differences between treatments were also highest during this growing season time.

The winter period generally started at the end of October and finished at the end of April and it was the most inactive period of the year. Each treatment at each of the three sites showed a nearly constant soil water content throughout the study. The differences among treatments were the smallest during this time.

The transition period occurred between the spring to fall and winter periods. It was the shortest period but had dynamic soil water content changes, particularly in spring. This is expected as it is often the time of greatest rainfall in spring and would have been associated with the time of spring snow melt.

There was a small difference in soil water between grassland (Mattheis) and parkland areas (Devonian and Elk Island). Grassland had much lower soil water content due to lower annual rain fall, higher evaporation and higher light penetration (Coupland 1979).

The more dramatic differences in soil water content with pits and mounds in other treatments is likely related to the larger size of pits and mounds in other studies. In this study, sensors were very close to the soil surface and hence may have been more susceptible to evaporation and other drying effects.

4.4. Micro Topography Effects On Near Surface Soil Volumetric Water Content

Near surface soil volumetric water content response to micro site treatments was similar at all three sites, with few significant effects (Tables 3.7, 3.8, 3.9, 3.10, 3.11). Soil water content was similar at Devonian and Elk Island and slightly lower at Mattheis. Although the treatment effects were sometimes statistically significant, the range of values was unlikely to have any practical significant effect on vegetation, except perhaps at the time of seed germination. Small treatment responses are more visibly obvious in Figures 3.4, 3.5 and 3.6.

When treatment effects were significant, soil water content was mostly higher in pit treatments than in flats and mounds. This is expected due to the protective topographic lows of the pits where near surface soil temperatures were slightly lower than in the mounds and flats and less evaporation would take place.

Near surface soil water was likely more influenced by rainfall than micro sites. Although soil water content capacity was expected to be affected by micro sites due to their different exposure intensities to evaporation, the fact that the soil surface is very dynamic and responsive to evaporation and potentially evapotranspiration, may negate that expected effect.

4.5. Amendment Effects On Near Surface Soil Volumetric Water Content

Near surface soil volumetric water content response to amendment treatments was similar at all three sites with very few significant effects (Tables 3.7, 3.8, 3.9, 3.10, 3.11). Soil water content was very similar at Devonian and Elk Island and slightly lower at Mattheis. Although the treatment effects were sometimes statistically significant the range of values was unlikely to have any practical significant effect on vegetation. Small treatment responses are more visibly obvious in Figures 3.7, 3.8 and 3.9.

Although there were a few significant differences among amendment treatments, there were no clear patterns of response of soil volumetric water content at the three study sites (Tables 3.7, 3.8, 3.9, 3.10, 3.11) (Figures 3.7, 3.8, 3.9). Even though data were statistically significant, the treatment differences would have very little practical impact, except perhaps for small seed germination responses.

The lack of response to amendments for near surface volumetric water content was initially surprising since many studies show clear response of soil water content to amendments, particularly organic amendments. However, the soil surface is highly dynamic and the small amounts of amendments used may have minimized their effect on soil water. The research sites are also at a very early stage of reclamation, meaning they have significant amounts of bare ground, which are prone to evaporation.

4.6. Micro Topography And Amendment Interactions On Near Surface Soil Volumetric Water Content

Unexpectedly there were few significant interactions between micro sites and amendments (Tables 3.7, 3.8, 3.9, 3.10, 3.11). This may be due to the constant effects of micro sites over riding the lesser effects of the amendments and the fact that there were few effects of micro sites or amendments in general.

There was a significant interaction between micro site and amendment in June 2013 at Mattheis. Different amendments showed different trends among micro sites in near surface soil temperature. For straw, control and grass, near surface soil temperature was lowest in mounds. With erosion control blankets, mounds had highest soil water contents.

4.7. Mound Aspect Effects On Near Surface Soil Volumetric Water Content

Aspect of the mounds had no significant effect on soil water content (Data not shown). South facing aspects, as expected, were numerically highest, west was lower than south, followed by east and north was the lowest.

4.8. Applications To Reclamation

Although the near surface soil water content differences with micro sites were small numerically, they were likely sufficiently different to affect seed germination and seedling survival and establishment. Often very small differences in soil water content can affect germination, moving germination rates from optimum to sub optimum (Baskin and Baskin 2014). These values are expected to be very sensitive for native plant species (Naeth personal communication).

In a counterpart research project in this research program, Naeth et al. (2014) found that micro sites alone did not have as pronounced an effect on grass and forb seedling emergence and establishment as expected. The relative importance of soil water and near surface soil temperature at a specific site and in a given year relative to other site factors such as non native plant species and erosion potential played a key role in determining effect of micro sites on plant response. The responses of native grasses and forbs to micro sites vary, supporting the need for a diversity of micro sites on a reclamation site to accommodate species specific requirements and annual variability in precipitation and near surface soil temperature.

5. CONCLUSIONS

Micro sites had very little effect on near surface soil water content. Soil water content was marginally higher in pits than in flat areas and mounds. Amendments had little significant effect on near surface soil water content. There were no clear patterns among the amendments in their effect on near surface soil water content.

Although the differences in soil water content among the treatments were small in magnitude, they may be large enough to affect sensitive species for seed germination and seedling survival. Generally, micro sites and amendments are good ways to create heterogeneous conditions to meet the potential soil water requirement of seeds from different species.

Table 3.1. Mean soil surface properties at Devonian Botanic Garden.

	Inorganic Carbon (%)	Organic Carbon (%)	CaCO3 Equivalent (%)	Total Carbon (%)	Electrical Conductivity (dS m^{-1})	Saturation (%)	Total Nitrogen (%)	PH	Sand (%)	Silt (%)	Clay (%)
Micro Site											
Flat	0.09 (0.02)	1.98 (0.25)	0.72 (0.15)	2.03 (0.23)	0.7 (0.2)	40.5 (2.7)	0.21 (0.03)	7.5 (0.1)	62 (4)	25 (3)	13 (1)
Mound	0.06 (0.01)	2.07 (0.25)	0.50 (0.10)	2.10 (0.24)	0.5 (0.1)	41.6 (0.8)	0.22 (0.02)	7.6 (0.0)	60 (5)	26 (3)	14 (1)
Pit	0.05 (0.00)	2.27 (0.25)	0.47 (0.07)	2.28 (0.21)	0.5 (0.1)	42.4 (2.2)	0.21 (0.03)	7.6 (0.0)	56 (5)	29 (4)	15 (1)
Amendment											
Blanket	0.05 (0.00)	1.97 (0.20)	0.40 (0.00)	1.97 (0.20)	0.4 (0.0)	38.0 (2.1)	0.22 (0.02)	7.5 (0.1)	62 (8)	25 (6)	14 (2)
Control	0.07 (0.02)	1.74 (0.32)	0.59 (0.19)	1.80 (0.31)	0.5 (0.0)	39.6 (2.4)	0.16 (0.02)	7.6 (0.0)	66 (7)	22 (6)	12 (2)
Grass	0.07 (0.02)	2.18 (0.39)	0.72 (0.16)	2.23 (0.39)	0.5 (0.0)	40.2 (1.9)	0.19 (0.06)	7.6 (0.0)	60 (6)	26 (5)	14 (1)
Hydrogel	0.08 (0.03)	2.04 (0.28)	0.66 (0.26)	2.10 (0.26)	0.4 (0.0)	40.3 (2.6)	0.21 (0.02)	7.5 (0.1)	60 (7)	27 (6)	14 (2)
Manure	0.07 (0.02)	2.43 (0.53)	0.60 (0.20)	2.47 (0.49)	1.2 (0.3)	47.9 (3.5)	0.25 (0.05)	7.5 (0.2)	53 (9)	32 (7)	15 (3)
Straw	0.05 (0.00)	2.27 (0.23)	0.40 (0.00)	2.27 (0.23)	0.4 (0.0)	42.9 (1.4)	0.28 (0.02)	7.6 (0.0)	56 (5)	29 (3)	15 (2)
P Value											
Micro Site	0.115	0.684	0.250	0.724	0.709	0.807	0.728	0.505	0.939	0.952	0.678
Amendment	0.828	0.771	0.681	0.763	0.002	0.13	0.858	0.784	0.272	0.58	0.839

Numbers are means, with standard error of the mean in brackets.

Blanket = erosion control blanket

Table 3.2. Mean soil surface properties at Elk Island National Park.

	Inorganic Carbon (%)	Organic Carbon (%)	CaCO3 Equivalent (%)	Total Carbon (%)	Electrical Conductivity (dS m^{-1})	Saturation (%)	Total Nitrogen (%)	PH	Sand (%)	Silt (%)	Clay (%)
Micro Site											
Flat	0.15	2.63	1.24	2.78	0.9	59.5	0.28	7.3	54	28	18
	(0.03)	(0.32)	(0.26)	(0.33)	(0.1)	(3.3)	(0.04)	(0.1)	(1)	(1)	(1)
Mound	0.13	3.01	1.04	3.13	1.0	61.9	0.34	7.2	52	29	19
	(0.02)	(0.30)	(0.15)	(0.32)	(0.2)	(2.2)	(0.02)	(0.1)	(0)	(1)	(1)
Pit	0.14	3.60	1.17	3.72	1.1	63.0	0.35	7.1	55	29	16
	(0.03)	(0.42)	(0.28)	(0.38)	(0.2)	(3.6)	(0.04)	(0.1)	(1)	(2)	(2)
Amendment											
Blanket	0.12	2.95	0.95	3.03	0.8	65.4	0.35	7.2	53	28	19
	(0.04)	(0.21)	(0.31)	(0.27)	(0.1)	(3.0)	(0.02)	(0.1)	(1)	(1)	(2)
Control	0.09	3.77	0.76	3.83	0.8	63.6	0.39	7.1	54	32	14
	(0.02)	(0.61)	(0.18)	(0.56)	(0.0)	(5.7)	(0.06)	(0.1)	(1)	(1)	(1)
Grass	0.11	3.75	0.91	3.83	0.8	65.7	0.39	7.2	54	31	16
	(0.03)	(0.45)	(0.27)	(0.38)	(0.1)	(2.8)	(0.02)	(0.1)	(3)	(1)	(3)
Hydrogel	0.20	2.25	1.64	2.47	0.8	53.7	0.21	7.3	54	27	19
	(0.04)	(0.19)	(0.35)	(0.15)	(0.1)	(3.4)	(0.05)	(0.1)	(1)	(1)	(1)
Manure	0.17	3.28	1.39	3.47	1.8	60.5	0.31	7.3	55	26	19
	(0.03)	(0.81)	(0.28)	(0.85)	(0.2)	(6.0)	(0.06)	(0.0)	(1)	(2)	(1)
Straw	0.15	2.48	1.24	2.63	1.0	59.8	0.30	7.1	53	27	20
	(0.05)	(0.15)	(0.43)	(0.22)	(0.0)	(1.0)	(0.02)	(0.1)	(1)	(0)	(1)
P Value											
Micro Site	0.822	0.181	0.843	0.185	0.741	0.718	0.367	0.188	0.057	0.826	0.326
Amendment	0.432	0.183	0.402	0.237	< 0.001	0.346	0.089	0.471	0.875	0.021	0.178

Numbers are means, with standard error of the mean in brackets.

Blanket = erosion control blanket

Table 3.3. Mean soil surface properties at Mattheis Ranch.

	Inorganic Carbon (%)	Organic Carbon (%)	CaCO3 Equivalent (%)	Total Carbon (%)	Electrical Conductivity (dS m^{-1})	Saturation (%)	Total Nitrogen (%)	PH	Sand (%)	Silt (%)	Clay (%)
Amendment											
Blanket	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Control	0.05 (0.00)	1.09 (0.15)	0.4 (0.00)	1.07 (0.13)	0.4 (0.0)	40.4 (0.7)	0.17 (0.02)	6.2 (0.1)	90 (1)	8 (1)	3 (0)
Grass	0.05 (0.00)	1.05 (0.04)	0.4 (0.00)	1.03 (0.03)	0.5 (0.1)	41.7 (2.4)	0.12 (0.00)	6.4 (0.1)	84 (4)	11 (3)	5 (2)
Hydrogel	0.05 (0.00)	1.25 (0.13)	0.4 (0.00)	1.27 (0.12)	0.7 (0.1)	42.4 (1.6)	0.15 (0.01)	6.7 (0.1)	87 (1)	10 (1)	3 (0)
Manure	0.05 (0.00)	1.48 (0.10)	0.4 (0.00)	1.50 (0.12)	1.1 (0.5)	44 (1.8)	0.20 (0.01)	6.7 (0.3)	87 (1)	10 (1)	3 (0)
Straw	0.05 (0.00)	1.32 (0.04)	0.4 (0.00)	1.33 (0.07)	0.6 (0.2)	40.5 (0.9)	0.12 (0.02)	6.3 (0.1)	87 (1)	10 (1)	3 (0)
P Value											
Amendment	0.452	0.071	0.452	0.044	0.312	0.533	0.003	0.166	0.53	0.574	0.448

Numbers are means, with standard error of the mean in brackets.

Blanket = erosion control blanket

Table 3.4. Meteorological conditions at Devonian Botanic Garden.

	Air Temperature (°C)			Precipitation (mm)	Wind Speed (m / s)		
	Mean	Max	Min	Total	Mean	Max	Min
2012							
June	16.82	27.70	3.83	0.20	0.26	2.27	0.00
July	18.16	33.68	4.69	144.4	0.13	2.27	0.00
August *	17.38	28.99	3.17	30.4	0.06	1.01	0.00
September	11.44	27.65	-1.13	21.6	0.22	2.52	0.00
October	0.80	20.25	-12.53	21.4	0.25	2.77	0.00
November	-7.92	10.00	-26.31	12.6	0.11	3.27	0.00
December	-15.62	2.05	-30.48	0.20	0.02	2.01	0.00
2013							
January	-10.06	10.27	-28.92	17.4	0.20	2.52	0.00
February	-4.79	10.17	-18.92	14.0	0.25	3.78	0.00
March	-6.80	11.90	-27.46	17.6	0.23	2.27	0.00
April	0.57	20.44	-21.92	18.6	0.49	3.02	0.00
May	13.10	31.66	-7.25	29.2	0.43	2.52	0.00
June	14.50	29.44	3.27	91.0	0.13	2.27	0.00
July	16.06	35.21	2.24	85.8	0.11	1.51	0.00
August	16.30	28.54	3.43	44.4	0.03	1.01	0.00
September	12.04	31.69	-6.11	3.8	0.09	2.27	0.00
October	4.02	19.10	-12.42	11.6	0.15	2.52	0.00
November	-7.70	10.74	-30.90	16.4	0.05	1.26	0.00

Data were lost from August 8 to 28 2012.

Numbers are means.

Table 3.5. Meteorological conditions at Elk Island National Park.

	Air Temperature (°C)			Precipitation (mm)	Wind Speed (m / s)		
	Mean	Max	Min	Total	Mean	Max	Min
2012							
June	17.13	26.74	7.97	12.0	0.34	2.01	0.00
July	18.27	33.26	7.87	133.6	0.23	2.01	0.00
August	16.35	30.62	5.75	2.6	0.14	1.76	0.00
September	12.29	26.40	0.47	0.2	0.29	2.52	0.00
October	0.73	19.25	-16.20	15.8	0.47	3.02	0.00
November	-8.32	10.00	-21.92	16.4	0.21	2.52	0.00
December	-14.78	1.37	-28.86	0.0	0.12	2.52	0.00
2013					0.26		
January	-10.44	7.04	-30.48	22.8	0.34	2.77	0.00
February	-5.15	10.32	-17.60	10.6	0.41	3.02	0.00
March	-6.62	12.51	-19.89	10.2	0.51	3.27	0.00
April	0.10	17.84	-17.00	23.6	0.79	4.53	0.00
May	13.20	30.39	-11.04	30.0	0.62	4.78	0.00
June	14.11	28.30	4.79	63.0	0.23	2.27	0.00
July	15.61	32.61	3.35	15.6	0.18	2.27	0.00
August	16.46	28.72	6.41	2.6	0.06	1.51	0.00
September	12.65	30.42	-1.99	4.4	0.23	2.01	0.00
October	4.39	17.30	-11.54	13.4	0.29	3.02	0.00
November	-7.48	9.31	-29.19	16.8	0.14	1.76	0.00

Numbers are means.

Table 3.6. Meteorological conditions at Mattheis Ranch.

	Air Temperature (°C)			Precipitation (mm)	Wind Speed (m / s)		
	Mean	Max	Min	Total	Mean	Max	Min
2012							
July	20.95	34.44	5.28	13.6	1.81	8.31	0.00
August	18.01	34.12	2.66	45.4	1.56	7.55	0.00
September	13.11	29.84	-3.39	8.0	1.66	13.60	0.00
October	2.62	26.16	-15.83	15.8	2.45	11.08	0.00
November	-7.05	10.81	-27.96	5.0	1.92	10.83	0.00
December	-14.74	5.57	-32.29	5.4	1.43	8.06	0.00
2013							
January	-10.52	6.00	-28.47	0.8	2.28	11.08	0.00
February	-6.58	6.66	-19.75	1.6	1.75	11.08	0.00
March	-7.86	14.22	-24.88	4.6	2.16	12.09	0.00
April	2.35	24.00	-12.16	17.0	2.68	10.07	0.00
May	12.88	29.49	-9.61	61.2	2.41	10.07	0.00
June	15.62	30.37	2.18	117.6	2.08	10.07	0.00
July	17.94	34.28	3.38	48.2	1.80	7.55	0.00
August	18.29	33.31	3.14	8.2	1.43	6.80	0.00

Numbers are means.

Table 3.7. Mean near surface soil volumetric water content (m^3 / m^3) at Devonian Botanic Garden in 2012.

	June	July	August	September	October	November	December
Micro Site							
Flat	0.20^{a}	0.24^{a}	0.23	0.20	0.19^{ab}	0.16^{b}	0.14^{b}
Mound	0.18^{ab}	0.22^{ab}	0.22	0.19	0.18^{b}	0.14^{b}	0.13^{b}
Pit	0.17^{b}	0.21^{b}	0.22	0.20	0.20^{a}	0.19^{a}	0.17^{a}
Amendment							
Blanket	0.19	0.24	0.23	0.20	0.20	0.18	0.16
Control	0.17	0.21	0.21	0.18	0.18	0.15	0.14
Hay	0.19	0.23	0.23	0.20	0.20	0.18	0.16
Hydrogel	0.20	0.22	0.21	0.19	0.18	0.15	0.13
Manure	0.18	0.22	0.23	0.20	0.20	0.17	0.16
Straw	0.17	0.23	0.22	0.20	0.19	0.17	0.15
P Value							
Micro Site	< 0.01	0.01	0.28	0.72	0.05	< 0.01	< 0.01
Amendment	0.22	0.11	0.28	0.40	0.32	0.03	0.08
Micro Site * Amendment	0.72	0.77	0.48	0.58	0.32	0.28	0.37

Means with the same letters in each column, within micro sites and amendments, are not significantly different.

In data sets with no letters, there are no significant differences.

Table 3.8. Mean near surface soil volumetric water content (m^3 / m^3) at Devonian Botanic Garden in 2013.

	January	February	March	April	May	June	July	August
Micro Site								
Flat	0.15^{b}	0.15^{b}	0.17^{ab}	0.23	0.19	0.22	0.19	0.19
Mound	0.14^{b}	0.14^{b}	0.16^{b}	0.22	0.18	0.21	0.17	0.16
Pit	0.17^{a}	0.18^{a}	0.19^{a}	0.23	0.20	0.22	0.19	0.23
Amendment								
Blanket	0.16	0.16	0.18	0.23	0.20	0.23	0.21^{a}	0.20
Control	0.14	0.15	0.16	0.22	0.18	0.21	0.17^{ab}	0.17
Hay	0.16	0.16	0.19	0.24	0.19	0.22	0.20^{ab}	0.21
Hydrogel	0.14	0.14	0.16	0.22	0.19	0.21	0.16^{b}	0.16
Manure	0.16	0.17	0.18	0.24	0.19	0.22	0.18^{ab}	0.17
Straw	0.15	0.15	0.17	0.22	0.19	0.21	0.18^{ab}	0.26
P Value								
Micro Site	< 0.01	< 0.01	0.01	0.41	0.16	0.10	0.04	0.29
Amendment	0.18	0.22	0.38	0.57	0.36	0.16	0.01	0.58
Micro Site * Amendment	0.29	0.29	0.38	0.63	0.49	0.50	0.56	0.61

Means with the same letters in each column, within micro sites and amendments, are not significantly different.

In data sets with no letters, there are no significant differences.

Table 3.9. Mean near surface soil volumetric water content (m^3 / m^3) at Elk Island National Park in 2012.

	June	July	August	September	October	November	December
Micro Site							
Flat	0.20	0.25	0.28	0.22^{b}	0.18^{b}	0.21^{b}	0.20^{b}
Mound	0.20	0.26	0.28	0.22^{b}	0.18^{b}	0.20^{b}	0.20^{b}
Pit	0.19	0.26	0.30	0.24^{a}	0.20^{a}	0.25^{a}	0.23^{a}
Amendment							
Blanket	0.21^{ab}	0.27	0.30	0.24^{a}	0.20^{a}	0.22	0.20
Control	0.18^{b}	0.24	0.28	0.22^{ab}	0.18^{ab}	0.22	0.22
Hay	0.20^{ab}	0.27	0.30	0.23^{ab}	0.20^{a}	0.23	0.22
Hydrogel	0.23^{a}	0.26	0.28	0.23^{ab}	0.18^{ab}	0.21	0.21
Manure	0.19^{b}	0.25	0.29	0.21^{b}	0.16^{b}	0.21	0.20
Straw	0.19^{b}	0.25	0.28	0.22^{ab}	0.20^{a}	0.22	0.21
P Value							
Micro Site	0.55	0.83	0.15	0.01	< 0.01	< 0.01	0.01
Amendment	0.01	0.33	0.58	0.01	0.01	0.60	0.67
Micro Site * Amendment	0.06	0.61	0.63	0.06	0.31	0.32	0.36

Means with the same letters in each column, within micro sites and amendments, are not significantly different.

In data sets with no letters, there are no significant differences.

Table 3.10. Mean near surface soil volumetric water content (m^3 / m^3) at Elk Island National Park in 2013.

	January	February	March	April	May	June	July	August
Micro Site								
Flat	0.20^{b}	0.22^{ab}	0.24^{b}	0.33^{b}	0.22	0.22^{b}	0.23^{b}	0.23^{b}
Mound	0.20^{b}	0.21^{b}	0.23^{b}	0.32^{b}	0.22	0.22^{b}	0.23^{b}	0.21^{b}
Pit	0.24^{a}	0.25^{a}	0.27^{a}	0.39^{a}	0.25	0.27^{a}	0.28^{a}	0.26^{a}
Amendment								
Blanket	0.20	0.22	0.24	0.32	0.24	0.25	0.26	0.24
Control	0.23	0.25	0.25	0.35	0.27	0.24	0.24	0.23
Hay	0.23	0.24	0.26	0.36	0.22	0.24	0.25	0.25
Hydrogel	0.21	0.23	0.24	0.34	0.23	0.23	0.25	0.23
Manure	0.21	0.23	0.24	0.38	0.21	0.22	0.24	0.23
Straw	0.21	0.22	0.24	0.34	0.24	0.24	0.24	0.23
P Value								
Micro Site	0.02	0.04	0.01	0.01	0.15	< 0.01	< 0.01	< 0.01
Amendment	0.74	0.76	0.75	0.59	0.38	0.20	0.43	0.63
Micro Site * Amendment	0.53	0.44	0.32	0.21	0.06	0.49	0.14	0.39

Means with the same letters in each column, within micro sites and amendments, are not significantly different.

In data sets with no letters, there are no significant differences.

Table 3.11. Mean near surface soil volumetric water content (m^3 / m^3) at Mattheis Ranch in 2013.

Factor	2013			
	May	June	July	August
Micro Site				
Flat	0.16	0.17	0.13^{ab}	0.10^{ab}
Mound	0.14	0.16	0.11^{b}	0.09^{b}
Pit	0.16	0.17	0.14^{a}	0.11^{a}
Amendment				
Blanket	0.16	0.17	0.12^{ab}	0.10
Control	0.16	0.17	0.13^{ab}	0.11
Hay	0.15	0.16	0.12^{ab}	0.09
Hydrogel	0.15	0.17	0.12^{ab}	0.09
Manure	0.13	0.15	0.10^{b}	0.08
Straw	0.18	0.19	0.16^{a}	0.13
P Value				
Micro Site	0.16	0.44	0.04	0.04
Amendment	0.06	0.08	0.02	0.09
Micro Site * Amendment	0.07	0.02	0.09	0.09

Means with the same letters in each column, within micro sites and amendments, are not significantly different.

In data sets with no letters, there are no significant differences.

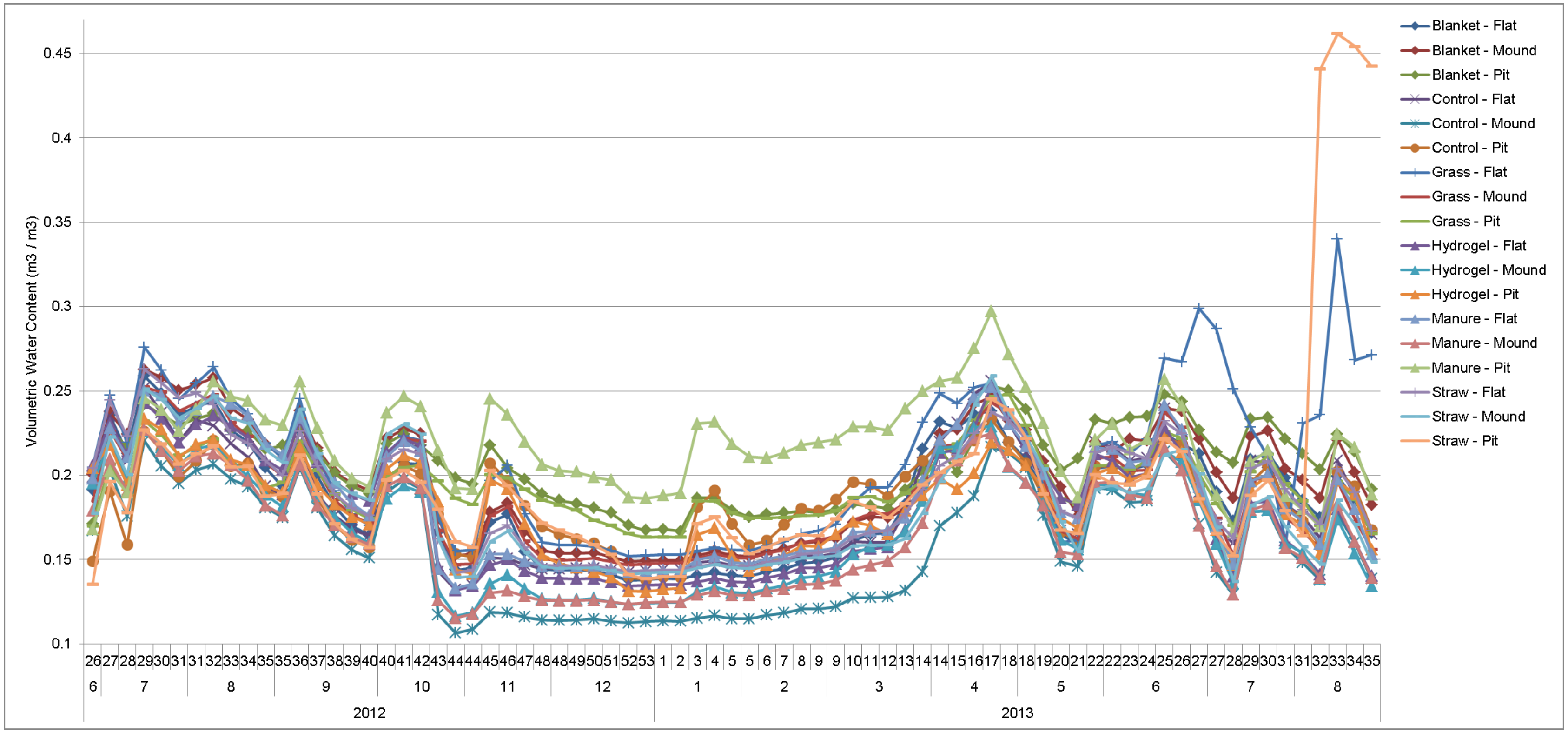

Figure 3.1. Mean weekly near surface soil volumetric water content in all treatments at Devonian Botanic Garden throughout the study period.

Numbers above years refer to months (6-12, 1-8), then weeks (26-53, 1-35) of the year.

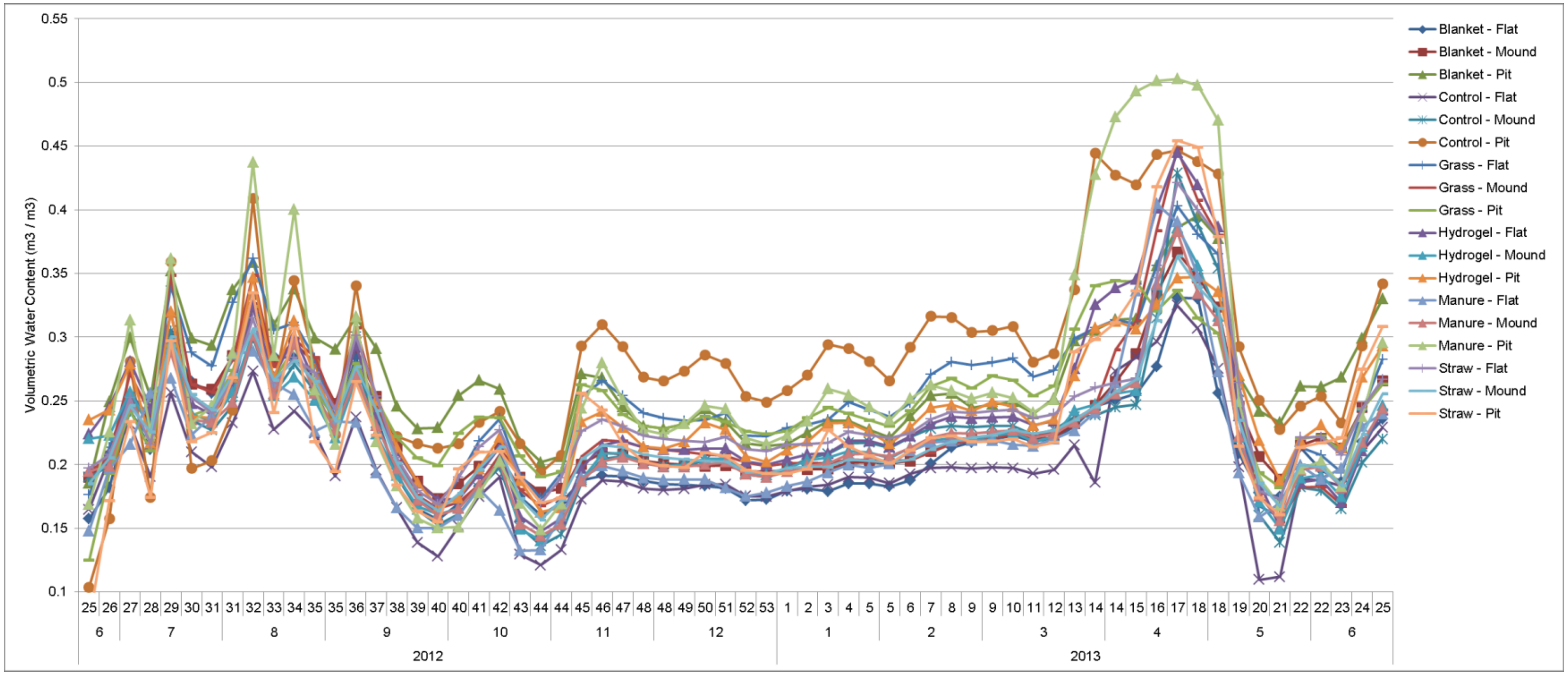

Figure 3.2. Mean weekly near surface soil volumetric water content in all treatments at Elk Island National Park throughout the study period.

Numbers above years refer to months (6-12, 1-8), then weeks (26-53, 1-35) of the year.

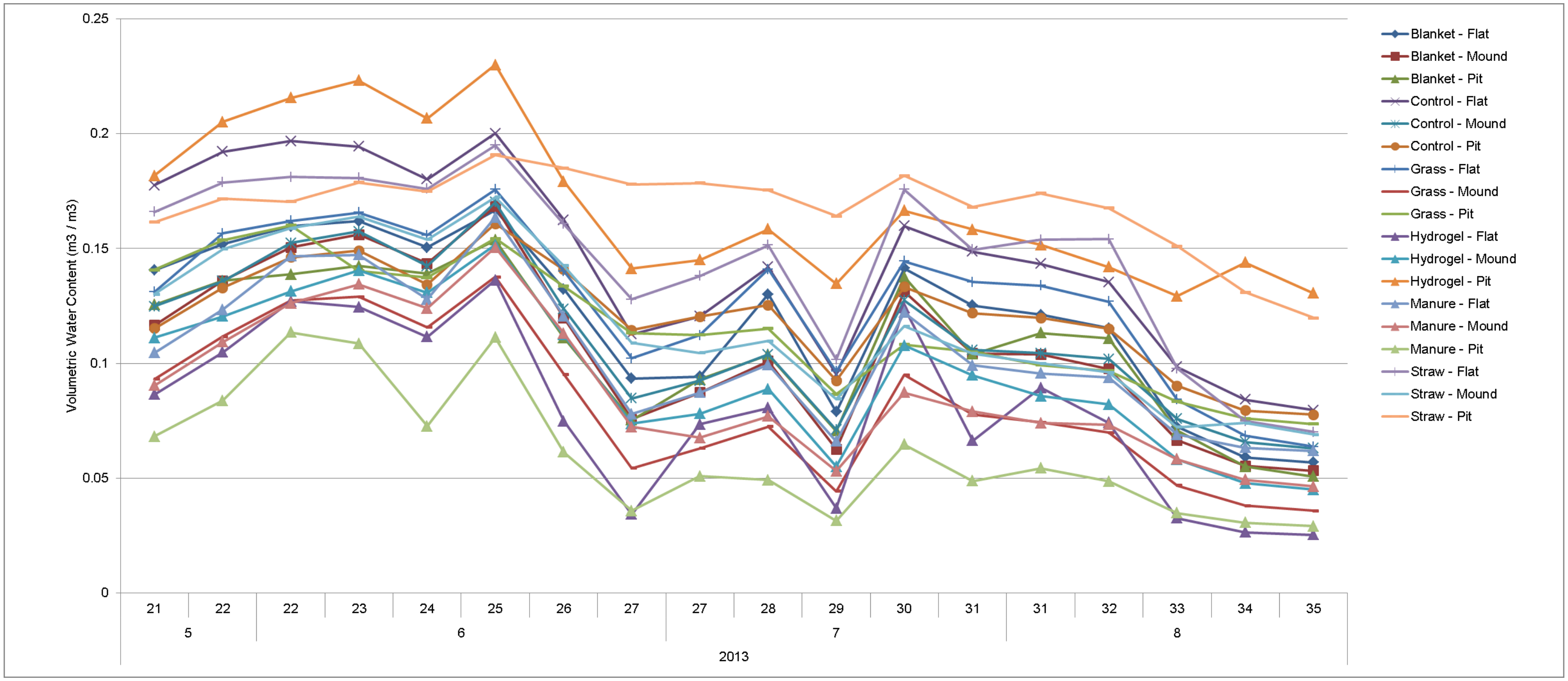

Figure 3.3. Mean weekly near surface soil volumetric water content in all treatments at Mattheis Ranch throughout the study period. Numbers above years refer to months (5-8), then weeks (21-35) of the year

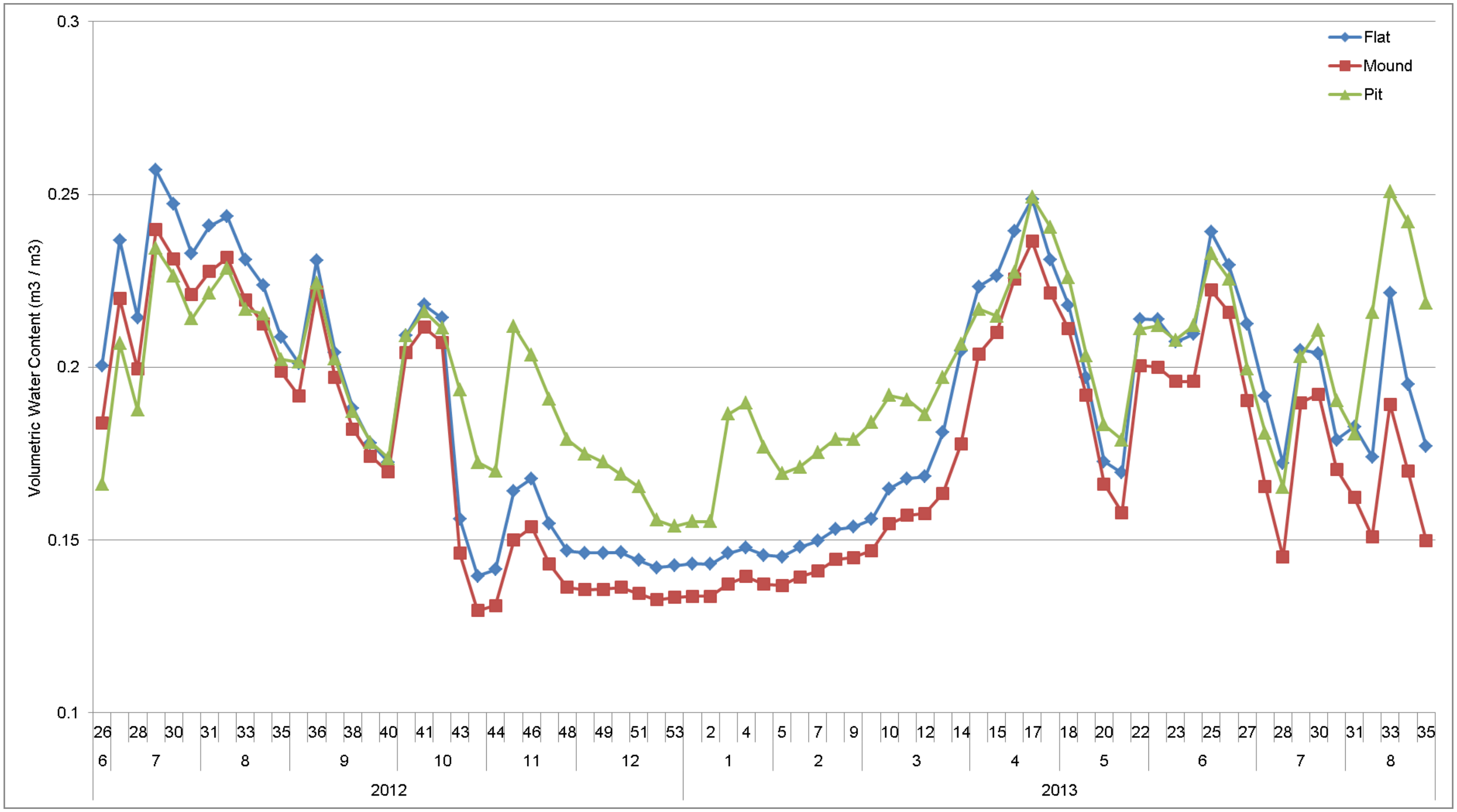

Figure 3.4. Mean weekly near surface soil volumetric water content for micro sites at Devonian Botanic Garden from June 2012 to August 2013.

Numbers above years refer to months (6-12, 1-8), then weeks (26-53, 1-35) of the year.

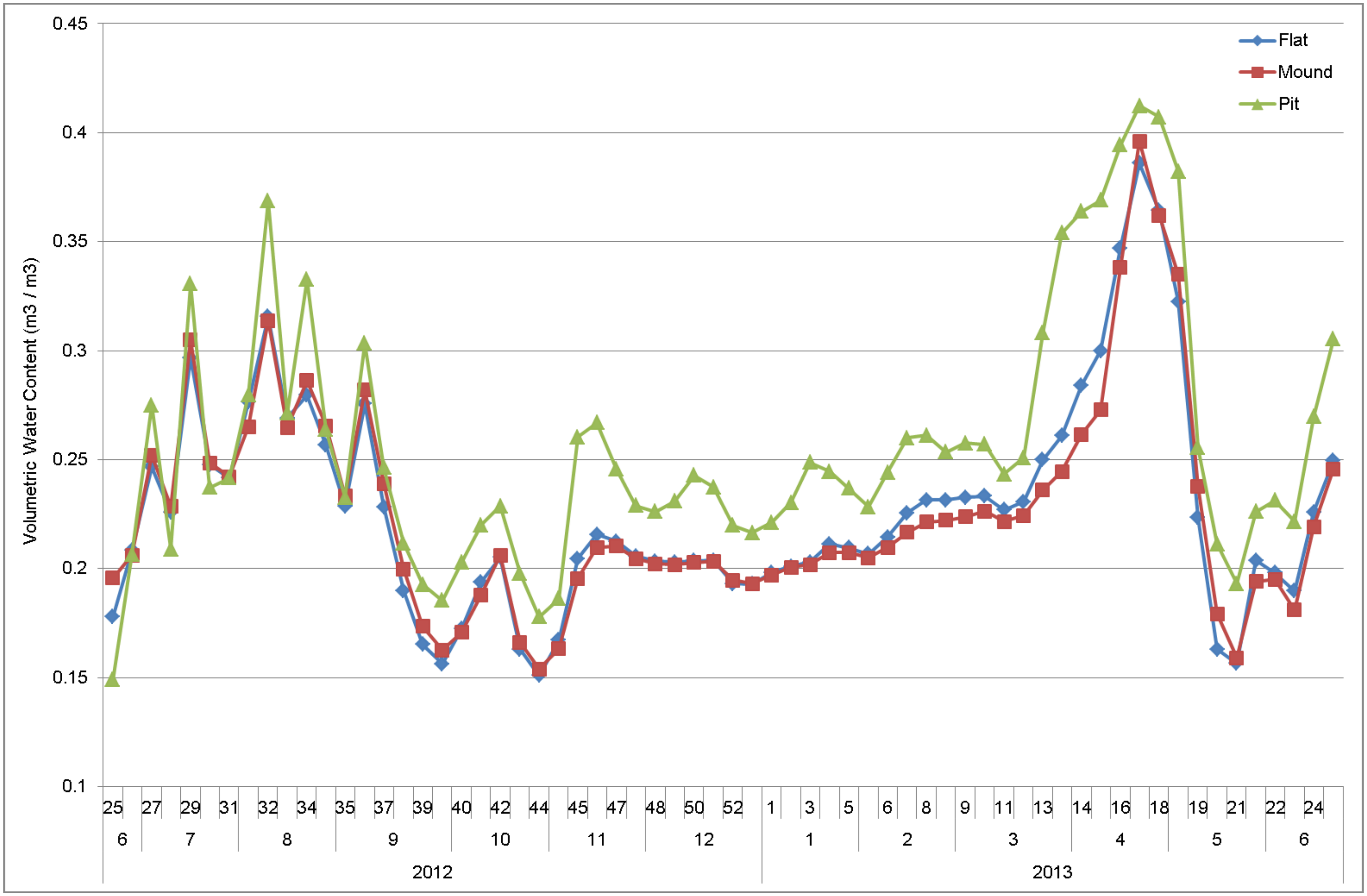

Figure 3.5. Mean weekly near surface soil volumetric water content for micro sites at Elk Island National Park from June 2012 to August 2013.

Numbers above years refer to months (6-12, 1-8), then weeks (26-53, 1-35) of the year.

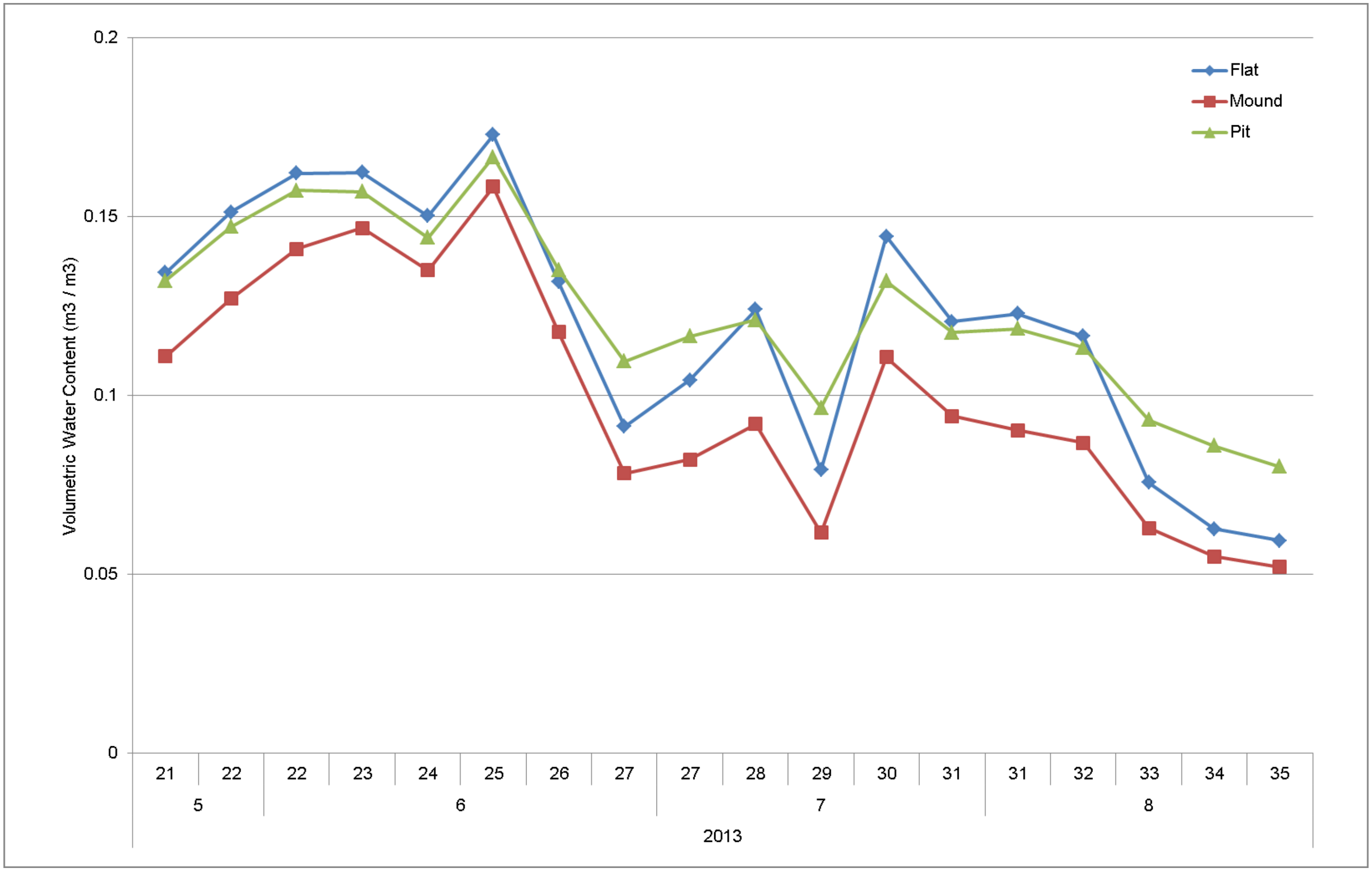

Figure 3.6. Mean weekly near surface soil volumetric water content for micro sites at the Mattheis Ranch from June 2012 to August 2013.

Numbers above years refer to months (5-8), then weeks (21-35) of the year.

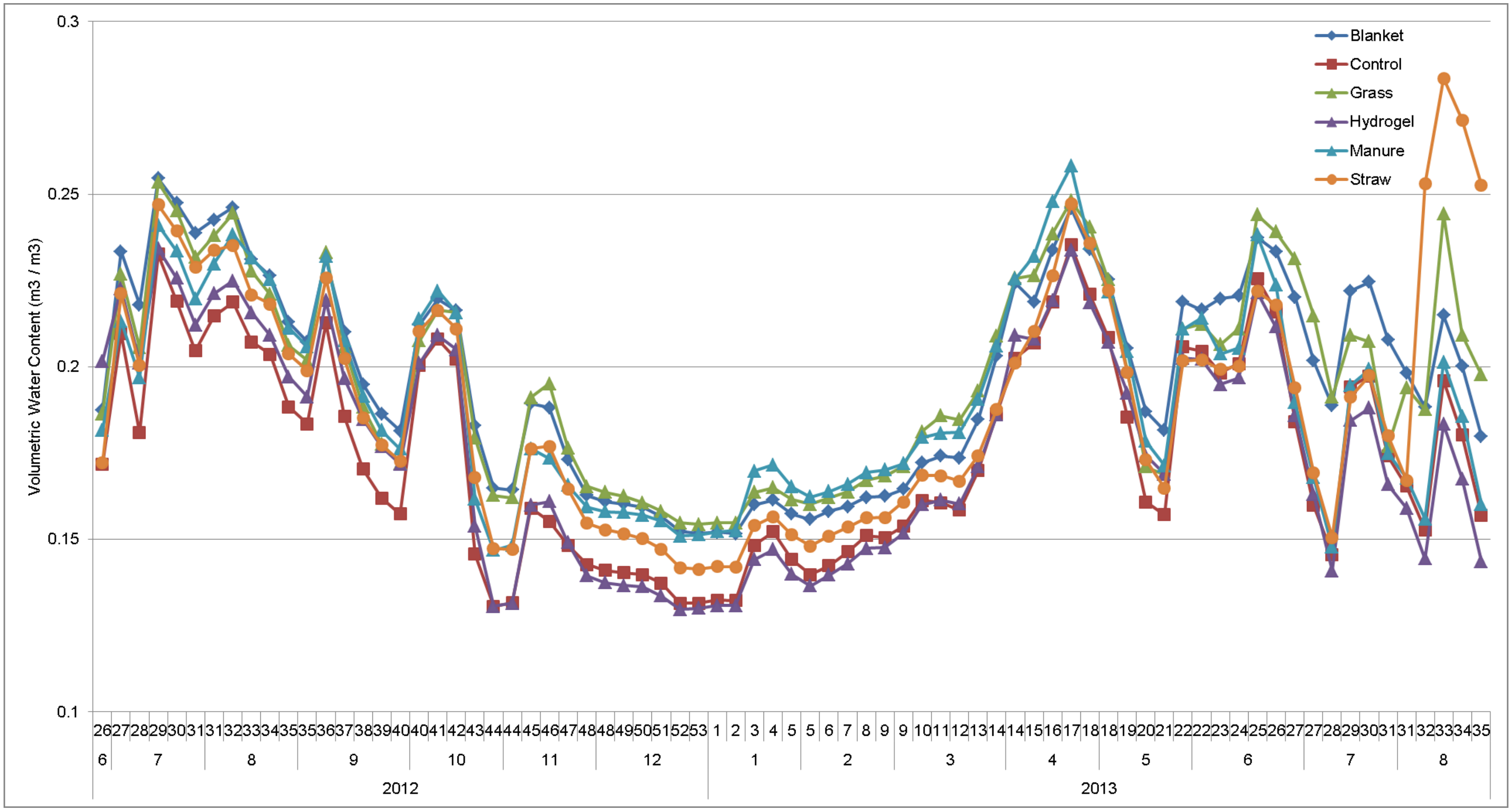

Figure 3.7. Mean weekly near surface soil volumetric water content for amendments at Devonian Botanic Garden from June 2012 to August 2013.

Numbers above years refer to months (6-12, 1-8), then weeks (26-53, 1-35) of the year.

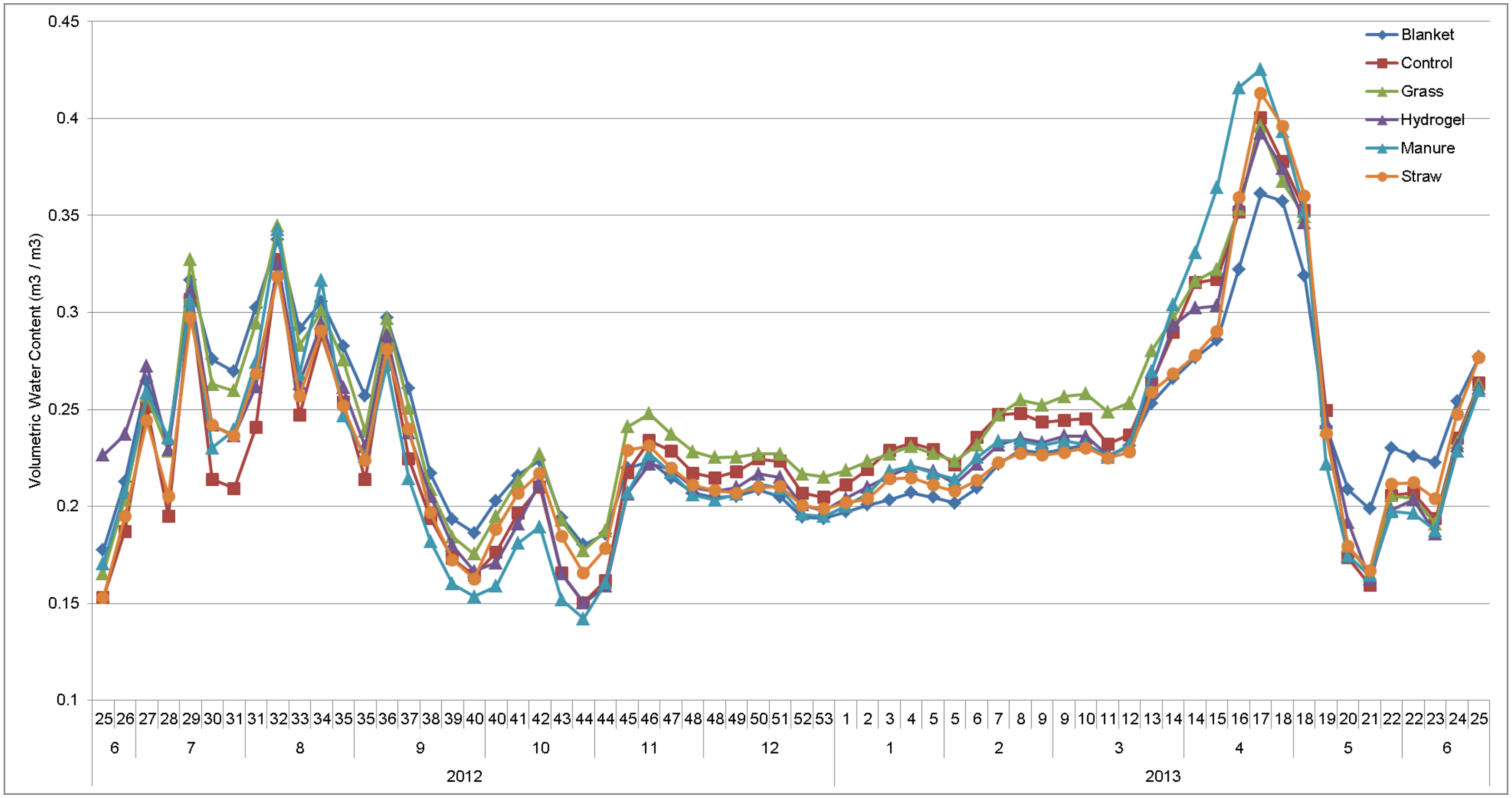

Figure 3.8. Mean weekly near surface soil volumetric water content for amendments at Elk Island National Park from June 2012 to August 2013.

Numbers above years refer to months (6-12, 1-8), then weeks (26-53, 1-35) of the year.

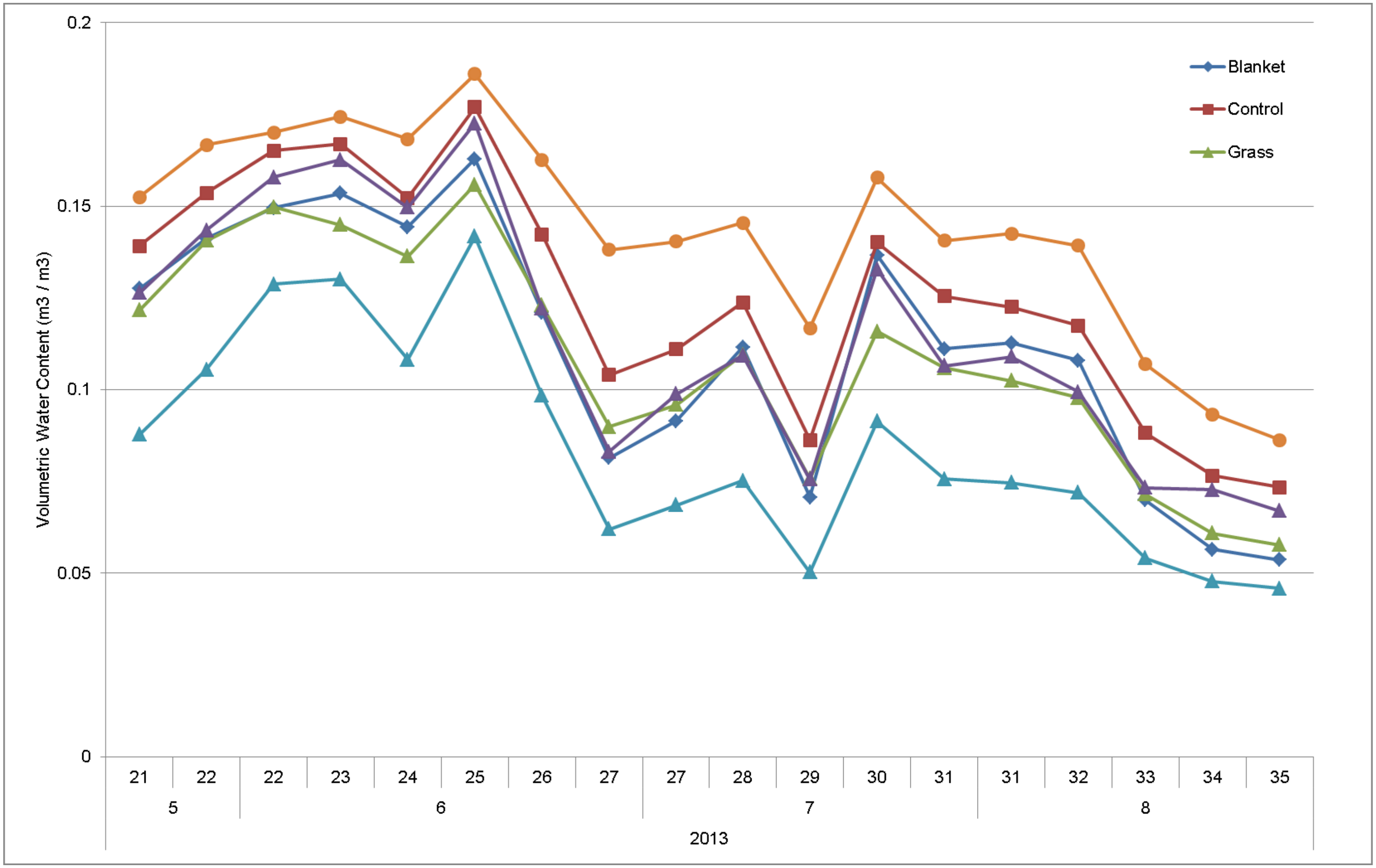

Figure 3.9. Mean weekly near surface soil volumetric water content for amendments at the Mattheis Ranch from June 2012 to August 2013.

Numbers above years refer to months (5-8), then weeks (21-35) of the year.

IV. SUMMARY, APPLICATIONS AND FUTURE RESEARCH

1. RESEARCH SUMMARY

Micro sites had a significant effect on near surface soil temperature. Near surface soil temperatures in flat areas and mounds were generally lower than near surface soil temperatures in pits in winter and higher at other times of the year. Amendments had little significant effect on near surface soil temperature. The only clear pattern among the amendments used in the study was a slightly lower near surface soil temperature with erosion control blankets.

Micro sites had very little effect on near surface soil water content. Near surface soil water content was marginally higher in pits than in flat areas and mounds. Amendments had little significant effect on near surface soil water content, with no clear trends among the amendments in their effect on soil near surface soil water content.

Although the differences in surface soil temperature and water content among the treatments were small in magnitude, they may be large enough to affect sensitive species for seed germination and seedling survival. Generally, micro sites and amendments are good ways to create heterogeneous conditions to meet the potential near surface soil temperature and water content requirements of seeds from different species.

2. APPLICATIONS FOR RECLAMATION

After plant species specific near surface soil water and near surface soil temperature requirements are known, suitable micro sites and amendments can be constructed during reclamation to meet these requirements. When propagules of plant species are known to require higher near surface soil temperature for germination and for establishment, flat or mound micro sites can be constructed during reclamation to meet the requirement. Pit micro sites will likely be more suitable for plant species requiring lower near surface soil temperatures than will mounds or flat areas.

Even if species specific requirements for near surface soil conditions are not known, using a variety of micro sites and amendments on a reclamation site can provide the heterogeneity for a multitude of plant species that may be required or desired for revegetaiton. This heterogeneity can provide small differences in soil water and surface soil temperature, that are known to affect a variety of species.

3. STUDY LIMITATIONS

Research results are specific to the study areas and to the climatic conditions of the two study years. The study was not able to incorporate different amendment rates and micro site sizes due to financial constraints and logistics. Although there were few treatments for the rates and sizes chosen for this research, other rates and sizes may have had a more significant effect.

The aging of micro sites was not designed to be quantified in this study. Micro sites are subjected to wind and water erosion, which are site specific and climate specific. The shapes of micro sites are changing along the time of the research due to these factors. Future studies can plan for examining the aging of micro sites and the effects of the aging process on various micro site characteristics.

There are no clear definitions of roughness of micro site in the literature, which make measuring the changes of micro sites from wind and water erosion difficult.

Only surface soil effects were studied as this is where the majority of seed germination takes place. However, treatment effects may have been more profound at depth.

4. RECOMMENDATIONS FOR FUTURE RESEARCH

Future studies can monitor soil infiltration and evaporation to further understand micro sites and amendment effects on near surface soil temperature and soil water.

Future studies can include dormancy factors in the experimental design. With dormancy of seeds broken, other factors that influence germination and establishment of seeds can be studied more clearly (Pavliscak et al. 2015).

Future studies can include seed sowing time in the experimental design. Seed sowing time plays an important role in restoration from seeds (Pavliscak et al. 2015).

Future studies can clearly define roughness of micro sites to assist future measuring of the changes of micro sites from wind and water erosion. To clearly define roughness, several questions need to be answered such as the purpose of roughness parameterization, the aspects of surface form, types (profile or array like) and the scale of roughness (Smith 2014).

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Appendix Figure. Soil sensor installation schematic.