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Peatland establishment on mineral soils: Effects of water level, amendments, and species after two growing seasons

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ABSTRACT

Recent surveys of peatland initiation that occurred over the past 10,000 years in northeastern Alberta have revealed that most peatlands initiated by paludification, or swamping of upland soils. Peatland ecologists have long known the importance of the paludification process, but it has not been transferred to peatland restoration methodologies. We initiated this study to determine if wetland structure and function could be re-established on two well sites established with mineral fill within a peatland complex. At two well sites near Peace River, AB, the mineral material was lowered to near the water level of the surrounding peatland. We placed 288 plots of 2 m × 2 m in size using a series of fertilizer, water level, cultivation, and amendment treatments and then introduced a suite of wetland plants. Four questions are addressed: – (1) Will locally available peatland vascular plant species establish on these wet, compacted, mineral soils? If so: (2) are species responses affected by these treatments? (3) are plants that we did not introduce in the planting regime (weeds) a concern? and (4) will the surrounding bog water chemistry have an effect on water in contact with mineral soils? Results after two growing seasons are – (1) *Carex aquatilis* and *Salix lutea* have all successfully established at both well sites; (2) *C. aquatilis* plants (ramets) have increased to an average of 58.5 per plot, up from the 16 original genets planted; (3) the plant responses to amendments are not significantly different from the control plots; (4) weed abundance is significantly different among some amendment types; and (5) pad ditch water chemistry is affected by the surrounding bog waters.

1. Introduction

Of the total global oil reserves of 1342 billion barrels, about 13.3% (178 billion barrels) are in Canada, with Canada ranking 2nd in reserves [source: http://www.eia.doe.gov/emeu/ international/reserves.html]. In Canada, much of the oil and gas exploration and development has occurred in boreal, continental regions where the dominant landscape is characterized by peatland ecosystems that can cover 50–100% of the land area (Vitt et al., 2000).

Oil and gas exploration, production, and processing represent major disturbances to peatland ecosystems (Schneider and Dyer, 2006). During traditional oil/gas exploration and production, as well as in SAGD operations in peatland regions, roads must be built to construct and access production pads on which oil/gas (or steam injection) wells are developed. In Canada, these roads and pads are constructed by the placement of clay and/or gravel fill directly onto the peatland surface. Peatlands are characterized by thick deposits (up to several meters) of water-saturated peat, with very gently sloping water table levels positioned at or near the peat surface. When roads transect peatlands and have minimal installation of culverts, as is typically the case in Alberta, upslope flooding and downslope water table drawdown can extend to considerable distances away from the road (Gignac et al., 1994). The extent of this disturbance is readily observable on the ground, as well as from aerial photographs.

The spatial extent of oil/gas/SAGD production pads and road building in Alberta is considerable. Between 1963 and 2008, in Alberta alone, there have been about 370,000 oil/gas wells drilled, with 140,000 of these currently abandoned and only 90,000 or so reclaimed (most of these in upland or prairie areas) [source: http://www.environment.alberta.ca/02862.html]. Each well site has an access road, and perhaps as many as 40% of these are located in pristine peatlands.

Oil/gas production wells are developed on both organic and inorganic soils. Organic soils must be amended by placing 1–2 m of mineral fill on top of the peat. The mineral fill raises the pad surface above the surrounding peatland, stabilizes the pad, and allows

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production wells to be accessed for the 20 or so years life cycle of the well. Following decommissioning of the production well, the relatively dry mineral fill is highly compacted and wetland vegetation is unable to re-colonize the pad surface. Historically, reclamation has consisted of planting grasses, legumes, and occasionally deciduous trees (*Populus* spp.) on the pad area, although some have advocated removal of the entire pad leaving a large pond of open water. Neither of these options returns the pad area to structural and functional similarity of pre-disturbance.

Peatland ecosystems are characterized by substantial accumulation of organic soil and in boreal regions mosses are often the dominant peat-forming plants (Vitt and Wieder, 2008). Since the most recent glacial retreat, boreal peatland ecosystems in the northern hemisphere have accumulated about 455 Pg (1 Pg = 10^{15} g) of carbon (about 1/3 of the global soil carbon; see Vasander and Kettunen (2008) for other estimates of the peatland carbon pool) despite occupying only 3–4% of the global land surface, and as such have represented a major long-term net sink for atmospheric CO_2 (Gorham, 1991). Roads and oil/gas production well sites located within peatlands eliminate the carbon accumulation abilities of these ecosystems and prohibit carbon sequestration. Additionally, decomposition of the underlying anaerobic peat provides a carbon source to the atmosphere.

Recent surveys of peatland initiation during the past 10,000 years in northeastern Alberta have revealed that nearly all peatlands, regardless of whether they are currently bogs and fens, were initiated by paludification, or swamping of upland soils. Basal sediments often include charcoal, wood, woody debris, and sometimes species of *Carex* (Bloise, 2007). Terrestrialization (or infilling of water bodies) rarely, if ever, was involved in the initiation of peatlands across the mid-boreal of Canada; however, even at that time the rather shallow pools contained a set of characteristic plants, including shrubby *Betula* species, *Carex* species, and *Typha* (Kuhry et al., 1992, 1993).

We initiated this study to determine if wetland structure and function could be re-established on mineral gas/oil pads (well sites) that were originally placed on organic peatland soils. We attempted to emulate the paludification process by removing mineral material to an elevation near the surrounding peatland natural water level and introducing a suite of wetland plants to the rewetted mineral soils. In this paper, we address the four questions: (1) will locally available peatland vascular plant species establish on these wet, compacted, mineral soils; if so (2) are species responses affected by water levels, amendments, cultivation, and fertilization treatments; (3) are plants that were not introduced (weeds) a concern in these re-establishment trials; and (4) will the surrounding bog water chemistry have an effect on water in contact with the mineral soils?

2. Methods

2.1. Study area

The study area is located about 50 km east of Peace River, Alberta at 56°23′N latitude and 116°46′W longitude at 571 m elevation. The climate of the region is boreal with cool, moist summers and cold, dry winters. Long-term climatic data (1970–2000) record an average annual temperature of 1.2 °C and annual total precipitation of 402 mm, of which 119 mm falls as snow. Temperatures for the 6-month growing season (May–October) in 2007–2009 were typical with the average 6-month temperature of 11.3, 12.1, and 11.3 °C for the three years, respectively (compared to 11.3 °C long term average). The 6-month precipitation total for 2007 of 304 mm and 2008 of 296 (compared to 293 mm long term) were also fairly typical, however 2009 was an extremely dry year with only 187 mm of precipitation for the six months. [Source: www.climate.weatheroffice.ec.gc.ca].

The study area lies at the junction of the Central Mixedwood and Dry Mixedwood natural subregions of Alberta, both within the Boreal Mixedwood ecological area (Beckingham and Archibald, 1996). This area is characterized by a mosaic of uplands dominated by *Populus tremuloides* and *Picea alba* and peatlands composed of a mixture of rich fens usually with a bryophyte layer of brown mosses (e.g., *Hamatocaulis vernicosus*, *Tomenthypnum nitens*, *Campylium stellatum*) a sedge layer of *Carex aquatilis* and *Carex lasiocarpa*, a shrub layer of *Salix pedicellaris*, *S. lutea*, and *Betula glandulifera*, and a tree layer of *Larix laricina*; and bogs dominated by species of *Sphagnum*, ericaceous shrubs, and the tree species, *Picea mariana*.

2.2. Experimental design and block setup

Our overall experimental design is hierarchical, in our case a split–split–split–split split plot design, with planting nested within amendment, within cultivation, within water level, within pad. One of the pads was fertilized and the other was not; as such we do not have replication at the pad (fertilization level). Amendments were arrayed across pads in a Latin rectangle design to account for the possibility that spatial gradients prevailed across each pad. As Hurlburt (1994) points out, "replication is often impossible or undesirable when very large-scale systems . . . are studied. When gross effects of a treatment are anticipated, or when only a rough estimate of effect is required, or when the cost of replication is very great, experiments involving unreplicated treatments may also be the only or best option." Our experimental design with only two pads was determined by two important factors. Not only were there two (and only two) decommissioned pads available and accessible at Shell's Peace River Complex, but also Shell was enthusiastic about supporting the research, contributing the heavy machinery (bulldozers) and personnel to prepare the pads for the research. The total cost of Shell's site-preparation for the two pads was over $200,000.00 (Rob Gray, personal communication).

The split-plot design was adopted as it permits the efficient use of factors that require large experimental units in combination with other factors that require smaller experimental units, recognizing that a consequence of the design is lower precision of the estimate of the variance component for the larger experimental units such that large differences may not be significant, and increasing precision on successively divided levels of the split-plot design, such that differences in the lowest level of splitting may be significant even though they may be of no practical significance (SAS, 2005). Of the main effects, we were most interested in the effects of amendments and planting, the lowest levels of the hierarchical design, where the experimental design affords the greatest precision. However, our overall design does allow for the assessment of all treatments and their interactions, using the appropriate error variances.

During the summer of 2007, we selected two 20-year old mineral-filled well sites located within a peatland complex at Shell Canada's Peace River Carmin Creek *in situ* plant (designated as pad 12 and pad 16 by Shell). These pads were decommissioned in the early 2000s and are approximately 100 m × 100 m and have between 1 and 2 m of clay fill placed on top of bog organic soil. Previously the pads were planted with *Melilotus alba* and *M. officinalis*. In August of 2007, an area along one side of each pad – about 30 m × 100 m – was leveled to near natural water table elevation of the bog. Following this rough grading, the 30 m × 100 m areas on each pad were divided into two 30 m × 50 m areas and one graded to 4–6 cm (here termed wet) above seasonal water level and the other to about 15 cm (termed dry) above water level. Within each of these water level treatment areas, three ditches (about 20 cm

Fig. 1. Photograph of pad 12-dry after final leveling and ditching, fall 2007. Natural bog in background.

deep) were dug in order to increase water contact with the mineral soils (Fig. 1). Soils were saturated and inundated by shallow waters during spring runoff.

The four water level treatment areas (two on each pad) were left to over-winter without further treatment. The following spring (June 1–5, pad 12; June 24–29, pad 16) we installed 192 2 m × 2 m plots on each pad; each separated by a distance of 1 m, and installed boardwalks between all plots. Each water level was then divided into a cultivated and not-cultivated block (each with 48 plots). The 2 m × 2 m plots were treated with one of six amendments (Table 1), each replicated six times within each water level/cultivation block. Thus each amendment had 24 replicates on each of the two pads – yielding a total of 144 amendment plots, with 48 plots left for future experiments (Fig. 2). On pad 16, each plot was treated with 30 g of 10:10:10 fertilizer in the spring of 2008 and again in spring 2009.

Each 2 m × 2 m plot was subdivided into four 1 m × 1 m subplots and planted with the following suites of species: (A) control with no plants; (B) nine evenly spaced individuals of *C. aquatilis*; (C) four individuals of *C. aquatilis* and five of *Salix lutea*; and (D) three individuals of *C. aquatilis*, three of *S. lutea*, and three of *L. laricina*.

For the purposes of this paper, the data for each species are lumped together for each 2 m × 2 m plot with data only presented for *C. aquatilis* (16 individuals) and *S. lutea* (8 individuals). Mature, healthy plants (genets) of *C. aquatilis* were extracted at nearby fen locations, *S. lutea* individuals were obtained from rooted cuttings (each from 0.7 to 1.2 cm diameter twigs cut 25–30 cm long) taken in early spring of 2008 at the surrounded fen area, and *L. laricina* seedlings (2–3 dm high) were grown from seeds collected in north-eastern Alberta (data for *Larix* are not included here). The plots were cultivated using a rototiller with the amendment tilled into the upper 4–6 cm of mineral soil (shovels were used for the slough hay amendment). All amendments and cultivation were completed in June of 2008 (Fig. 3).

Water levels were assessed by assigning a wetland index value to each 1 m × 1 m subplot with values as follows: −2 = surface dry; −1 = surface moist no standing water; 0 = water at the surface, some surface only moist; +1 = water above soil surface, depth ranging from 0 to 3 cm; +2 = water above soil surface, depth ranging from 3 to 6 cm; +3 = water above soil surface, depth greater than 6 cm. Means were calculated for the plots ($n = 4$) and used in the statistical analysis.

Table 1
Amendments applied to the 2 m × 2 m plots in June, 2008.

Amendment	Source	Comments
Commercial peat (P)	Sungro	Spread at a depth of 4–6 cm
Field peat (T)	Local fen/bog peat stockpiled for several years, peat was a mixture of woody material and Sphagnum peat	Spread at a depth of 4–6 cm
Slough hay (H)	A mixture of wetland sedges and grasses combined locally	Spread at a depth of 4–6 cm
Woodchips (W)	Aspen chips each ca. 2 cm × 3 cm	Spread with a single layer of chips
Landscape fabric (L)	Futerra F4 netless	Single layer covering plot
Control (C)	No amendments	–

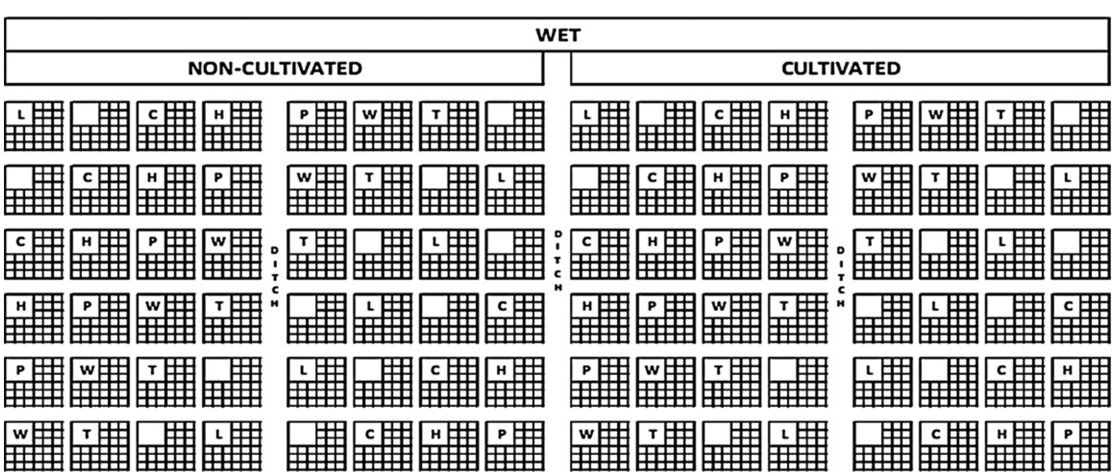

Fig. 2. Latin square design for pad 16-wet. Each amendment (commercial peat, control, field peat, landscape fabric, slough hay, woodchips,) is replicated six times for each water level/cultivation combination (block). Each lettered square is a 2 m × 2 m plot, which is subdivided into four 1 m × 1 m subplots. The left upper corner subplot was not planted. Plots without a letter were not utilized in this experiment. Pad 16-dry, pad 12-wet, and pad 12-dry were treated identically. P = commercial peat, C = control, T = field Peat, L = landscape fabric, H = slough hay, W = woodchips.

Fig. 3. Overall aspect of pad 12-wet immediately after plot setup and planting of the species, June 2008.

2.3. Plant responses

Responses of *C. aquatilis* were assessed in two ways: first we assessed asexual reproductive success by counting the number of offspring (ramets) produced from tillers, and second we assessed overall performance using a scale of 1–10 (Table 2). For *S. lutea* performance, we tallied the number of cuttings that survived and the number of branches produced by each cutting. Tallies were done in late May, June, and July 2009.

We define 'weed' as a plant species that we did not introduce into the plots. Nearly all of these species in our study are widespread upland annuals. There were no bog/fen species discovered in the plots within this time frame. We surveyed each 2 m × 2 m plot for weed occurrence first by determining the number of plant species additional to those we planted within the plots and secondly by counting the number of individuals of each species as a measure of abundance. The weed survey we report on here was done in July of 2009.

Surface water chemistry (measured in the ditches) was assessed by *in situ* measurement of pH and electrical conductivity in spring and mid summer of 2009. Conductivity (reduced) values were modified by subtracting the conductivity present from hydrogen ion following Sjörs (1952) and corrected for temperature at 20 °C.

2.4. Statistical analysis

The reproductive success and performance of *C. aquatilis* and performance of *S. lutea* were analyzed for pad (fertilization), water level, cultivation, and amendment with time as a repeated factor in SAS 9.1.3. The diversity and abundance of weed species were analyzed for pad (fertilization), water level, cultivation, and amendment for July 2009 only. Wherever there are significant effects, a post hoc multiple means comparisons with Bonferroni correction was performed. Trends in pH and reduced conductivity were assessed through non-linear regression.

3. Results

3.1. Water level treatment blocks

We initially engineered the two pads to each have a relatively wet treatment area (4–6 cm above autumn water level) and a relatively dry treatment area (15 cm above autumn water level) and after construction we assessed whether our engineering achieved these results. Our construction elevations did achieve significantly different wet and dry areas on each pad. We also found high variation of water table throughout the season on one pad (pad 12)

Table 2
Performance scale for *Carex aquatilis*. The mean values for all 16 individuals in each 2 m × 2 m plots were used for statistical analyses.

Scale	Performance	Color	Height	Plantlets/seeds
1	Dead	Brown	N/A	None
2	Alive/weak	Greenish-yellow	<6 inch	None
3	Alive/weak/fruiting	Greenish-yellow	<6 inch	With seeds, no plantlets
4	Alive/weak/with plantlets	Greenish-yellow	<6 inch	Plantlets
5	Alive/weak/fruiting	Green plantlets	<6 inch	Both seeds and with plantlets
6	Plantlets only	Bluish-green	<6 inch	No adults
7	Alive/growing	Greenish-yellow	>6 inch	No plantlets
8	Alive/fruiting	Greenish-yellow	>6 inch	Seeds
9	Alive/with plantlets	Greenish-yellow	>6 inch	Plantlets
10	Alive/fruiting/with plantlets	Green	>6 inch	Both seeds and plantlets

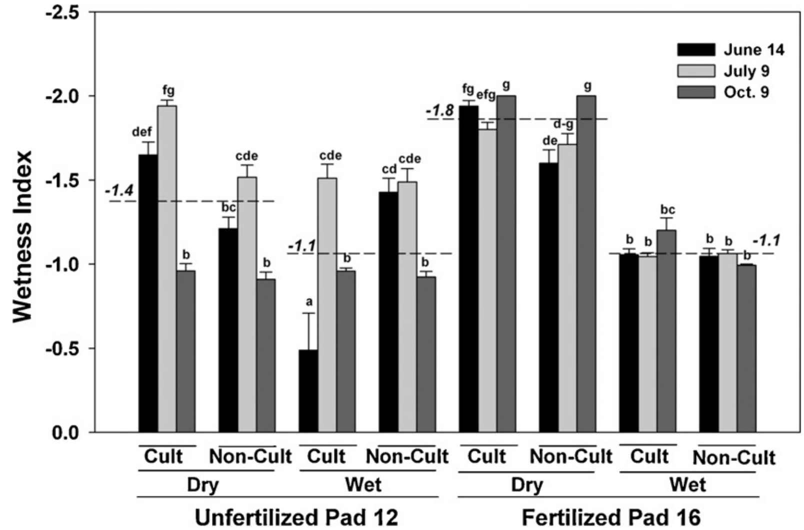

Fig. 4. Variation in wetland index during the 2008 growing season for the treatment blocks. Variation shown is from 0.0 (wet) to −2.0 (dry). Means shown by dashed line ($n = 96$). Different letters indicate significant differences by Tukey–Kramer multiple comparisons ($p = 0.05$).

and nearly no seasonal variation on the other (pad 16 – Fig. 4) (significant fertilization × water level × cultivation × time interaction, $p = 0.0002$).

3.2. Water chemistry

Mean pH values of the natural bog waters were about 4.5 with less than 20 μS reduced conductivity. Values at the bog/pad junction were considerably higher ranging from around 7.3 and 600 μS for pad 12 and 6.5 and 430 μS for pad 16, and gradually increasing along the ditches to values of 8.0 and 1000 μS for the interior of both pads (Fig. 5). Bog waters near the pad were not affected by waters from the pad (readings taken at 3 m from pad edge).

3.3. Plant responses

3.3.1. *Carex aquatilis*

C. aquatilis asexual reproduction, as quantified by the total number of plantlets (ramets) per plot, was considerable across all combinations of treatments; from the 16 individuals initially planted in each plot in 2008, by July 2009 the number of plants per plot had risen to 58.5 ± 2 (mean ± standard error; $n = 286$) (Fig. 6). Asexual reproduction in *C. aquatilis* exhibited a 5-way interaction (fertilizer × water level × cultivation × amendment × sampling date; $p = 0.034$). Few patterns are visually evident except that plantlets continued to be produced throughout the summer and generally the wet blocks had more plants than the dry ones.

Performance of *C. aquatilis*, assessed using the scale defined in Table 2, averaged 5.4 ± 0.1 (mean ± standard error; $n = 286$) in July 2009, and exhibited a 4-way interaction (fertilizer × cultivation × water level × sampling date; $p = 0.048$). On the fertilized pad, performance was significantly lower in the dry, cultivated section of the pad and overall was consistently lower in the dry blocks (Fig. 7). These patterns were less evident on the unfertilized pad, where there was strong seasonal variation in the water table levels (Fig. 4). A significant 3-way interaction of water level × cultivation × amendment also was present ($p = 0.0163$), reflecting the somewhat lower but variable performance for plants in the dry block control and plants in the landscape fabric amendment in the wet, non-cultivated block (Fig. 8).

3.3.2. *Salix lutea*

Initial survival of our willow cuttings differed between the two pads (Figs. 9 and 10). On pad 12 (not fertilized and planted on June 4–5), 67.6% of the cuttings survived, compared to pad

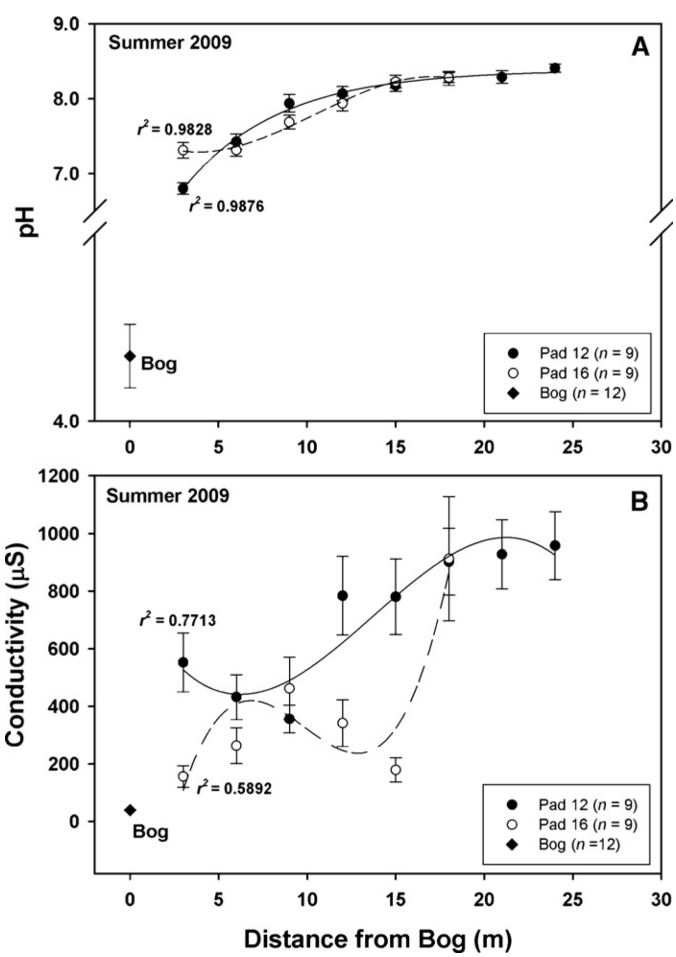

Fig. 5. pH (A) and reduced conductivity (B) taken from surface waters of ditches of pads 12 and 16 as a function of distance to the edge of nearby bog. The nearby bog values are shown as a reference.

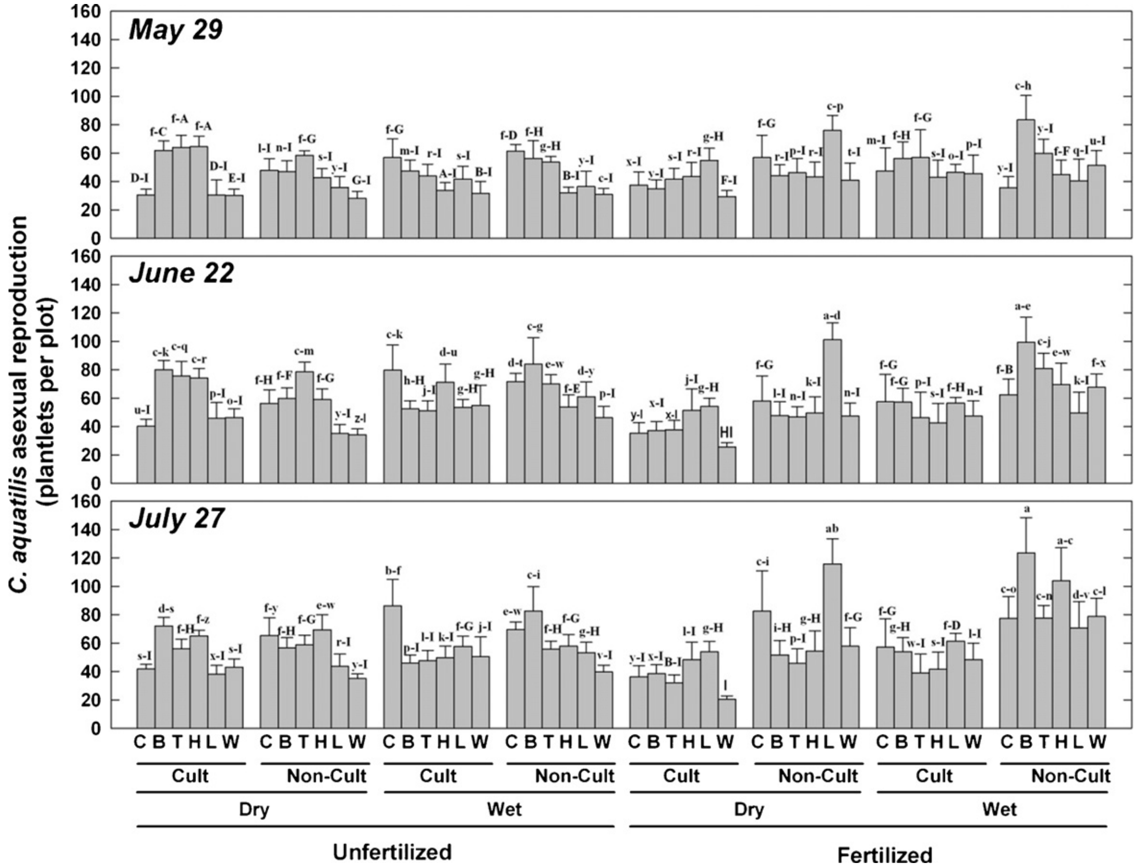

Fig. 6. *Carex aquatilis* overall reproductive success assessed by number of plantlets per 2m × 2m plots. Means ± 1 s.e.m. ($n = 6$). Different letters indicate significant differences by Bonferroni multiple comparisons ($p = 0.05$). P = commercial peat, C = control, T = field peat, L = landscape fabric, H = slough hay, W = woodchips.

16 (fertilized and planted on June 28–29) where only 30.5% of the cuttings survived. The delay in planting (heavy rainfall resulted in the flooding of pad 16, such that planting had to be delayed until late June) was almost certainly the reason, as many of the cuttings were in poor condition in late June. Performance of *S. lutea*, assessed as the number of branches produced per plot, exhibited a significant 5-way interaction (fertilizer × water level × cultivation × amendment × sampling date; $p = 0.0124$) (Fig. 10). Despite the interactions, on the fertilized pad, branch production was consistently low (average of 4.4 ± 0.2 branches per plot), with no differences between any of the treatment combinations. On the unfertilized pad, *S. lutea* branch production, in general, was lower in the landscape fabric amendment (average of 5.0 ± 0.6 branches per plot) than in the other

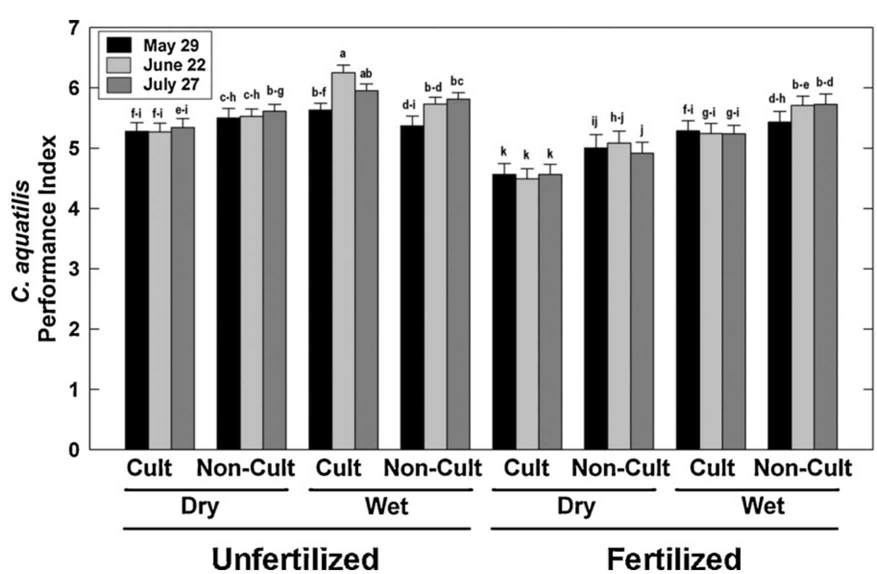

Fig. 7. Performance of *Carex aquatilis* across fertilization × water level × cultivation treatments over time. The higher the performance value, the better the performance. Means ± 1 s.e.m. ($n = 576$). Different letters indicate significant differences by Bonferroni multiple comparisons ($p = 0.05$).

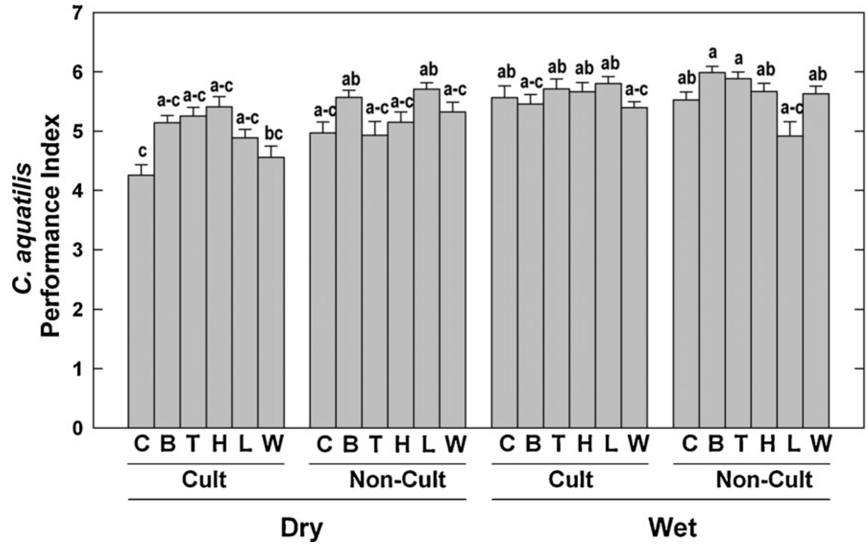

Fig. 8. Performance of *Carex aquatilis* across water level × cultivation × amendment treatments. Means ± 1 s.e.m. ($n = 576$). Different letters indicate significant differences by Bonferroni multiple comparisons ($p = 0.05$). P = commercial peat, C = control, T = field peat, L = landscape fabric, H = slough hay, W = woodchips.

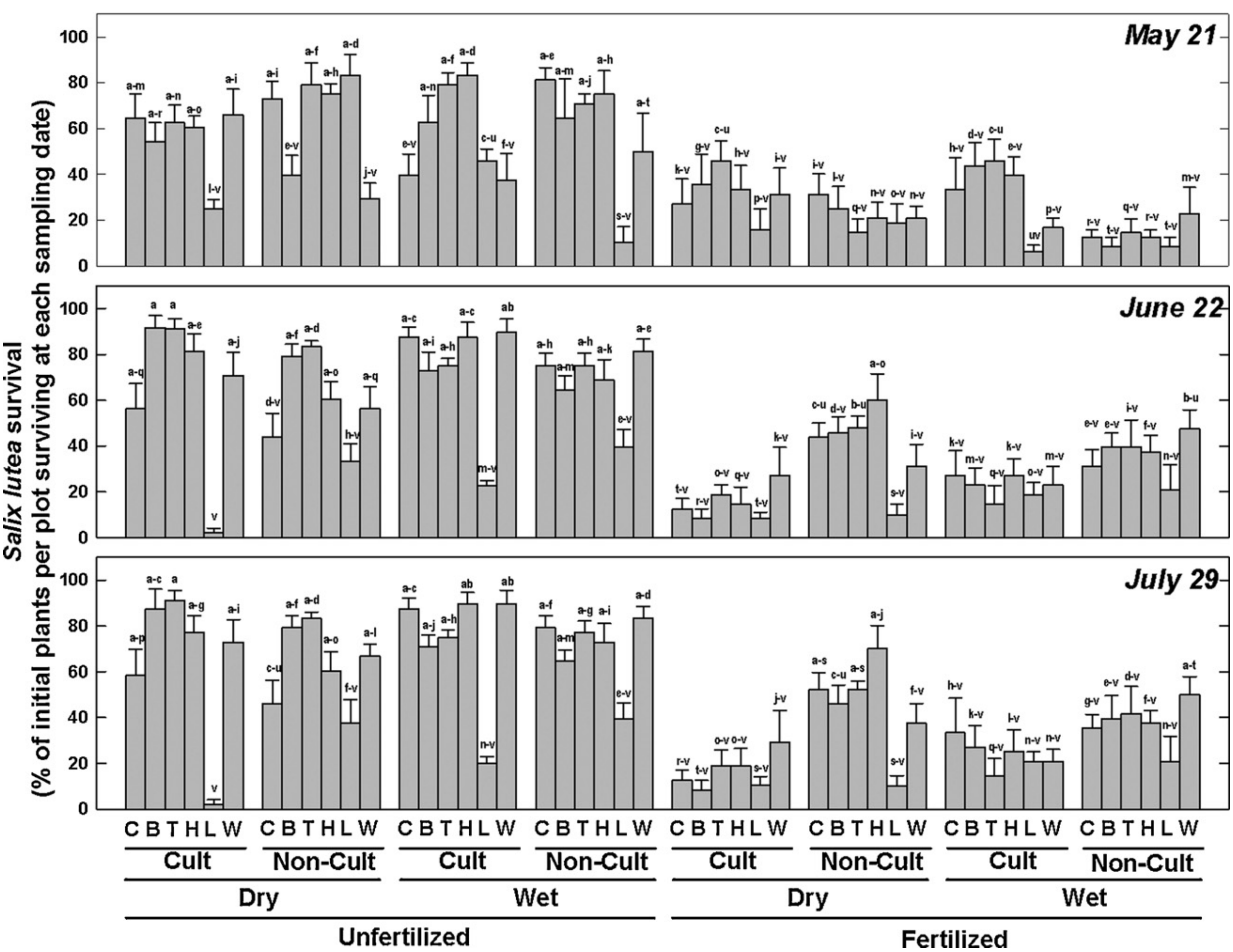

Fig. 9. Percent survival of *Salix lutea* across fertilization × water level × cultivation × amendment treatments over time. Means ± 1 s.e.m. ($n = 6$). Different letters indicate significant differences among means by Bonferroni multiple comparisons ($p = 0.05$). P = commercial peat, C = control, T = field peat, L = landscape fabric, H = slough hay, W = woodchips.

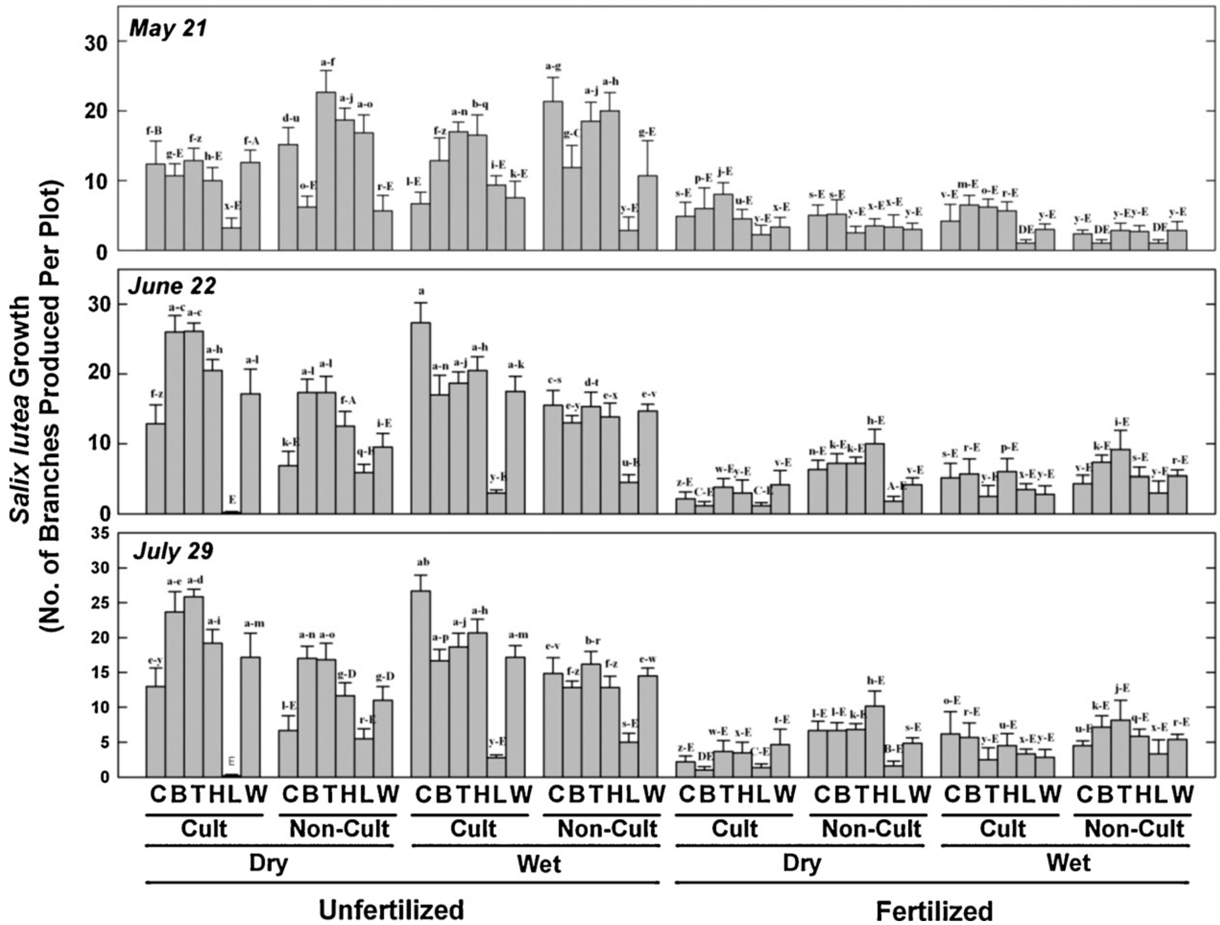

Fig. 10. Performance of *Salix lutea* across fertilization × water level × cultivation × amendment treatments over time. Mean number of branches produced per plot ± 1 s.e.m. ($n = 6$). Different letters indicate significant differences among means by Bonferroni multiple comparisons ($p = 0.05$). P = commercial peat, C = control, T = field peat, L = landscape fabric, H = slough hay, W = woodchips.

amendments combined (average of 15.7 ± 0.4 branches per plot). On the unfertilized pad, over the course of the summer the number of branches increased, remained constant, or decreased, but these changes were not consistent across the water level, cultivation, and amendment treatment combinations. In general, survival and performance of *S. lutea*, when compared to block controls with amendments, was rarely significant, and performance was only less within the landscape fabric amendment.

3.3.3. *Weeds*

Both the number of weed species per plot (richness) and weed abundance exhibited significant 3-way interactions between fertilizer, water level, and cultivation (species, $p = 0.0071$; plants, $p = 0.0176$) (Fig. 11) and between water level, cultivation, and amendment (species, $p = 0.0135$; plants, $p = 0.0089$) (Fig. 12). In addition, the number of weed species per plot had a 3-way interaction between fertilizer, cultivation and amendment ($p = 0.0004$), while the number of weed plants per plot had a 3-way interaction between fertilizer, water level, and amendment ($p = 0.0472$ not shown). The field peat amendment consistently had a greater number of weed species and weed abundance than any of the other amendments (Fig. 12). When compared to the block controls only the wood chip amendment consistently had fewer weeds. Averaged across all treatments, field peat amended plots had an average of 26.9 ± 1.4 weed plants and 7.6 ± 0.4 weed species and plots with other amendments had 4.1 ± 0.3 weed plants and 1.7 ± 0.1 weed species (means ± standard errors). In general, weeds were more speciose and abundant under drier conditions, and within three of four wetness/fertilization blocks weeds were more abundant under non-cultivated conditions, but patterns were rarely consistent.

4. Discussion

We set out to answer four questions that will lead to a better understanding of whether peat-forming wetlands can be established on mineral soils resulting from previous well site placement in boreal peatlands. Our experimental sites are surrounded by ombrotrophic bog that has acidic waters and a *Sphagnum*-dominated ground layer. The bogs of northern Alberta often are situated in a mosaic pattern along with minerotrophic rich fens, poor fens, and a variety of uplands. Fens have long been known to provide the early successional communities along a fen to bog successional trajectory. Unless the mineral substrate is naturally acidic (as on the Canadian Shield of eastern Canada), bogs form late in succession after the arrival of oligotrophic species of *Sphagnum* (Kuhry et al., 1993). Fens on the other hand can and do form on mineral soil substrates. We wondered whether we could emulate this early succession by providing conditions suitable for wetland species, especially species that naturally occur on both mineral and organic substrate so we chose three such species. The successional pattern from wet mineral soil to peat-forming communities of plants naturally takes many 100s if not 1000s of years (Bloise, 2007), so we also

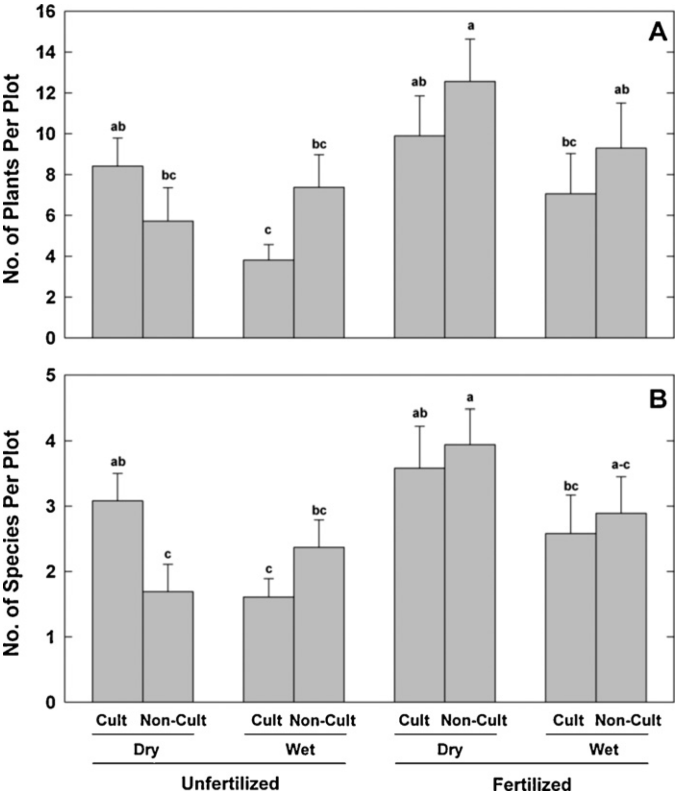

Fig. 11. Weed abundance (A) and diversity (B) across fertilization × water level × cultivation treatments. Diversity and abundance were analyzed independently. Means ± 1 s.e.m. (n = 36, 36). Different letters indicate significant differences among means by Bonferroni multiple comparisons (p = 0.05).

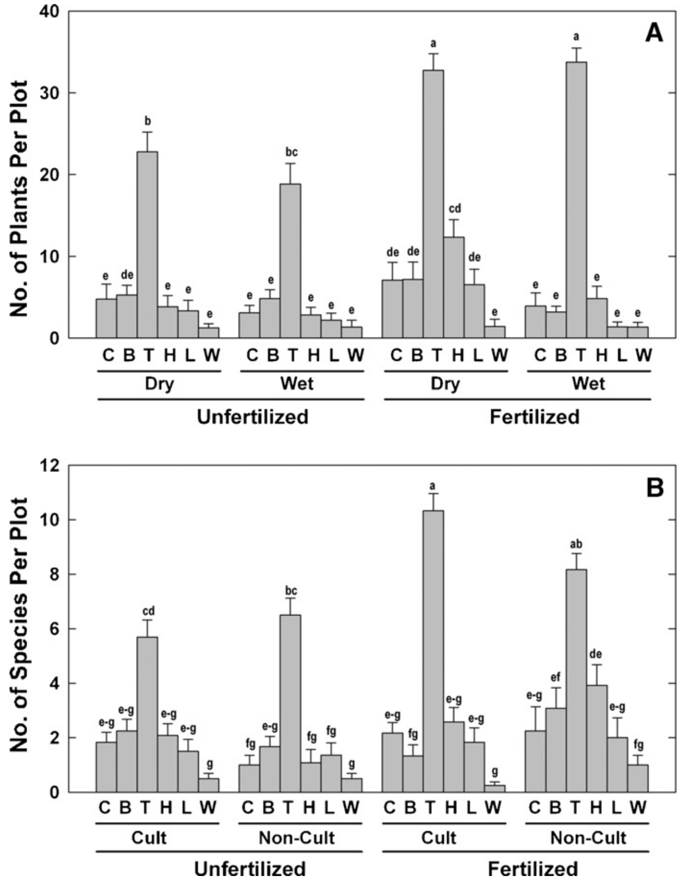

Fig. 12. Weed abundance (A) and diversity (B) across water level x cultivation x amendment treatments. Diversity and abundance were analyzed independently. Means ± 1 s.e.m. (n = 12, 12). Different letters indicate significant differences among means by Bonferroni multiple comparisons (p = 0.05).

evaluated whether various amendments could be provided to the wet mineral substrate to enhance early plant establishment and provide a faster earlier succession.

Our first question was whether locally available species would establish on these wet, compacted mineral soils? At the beginning of the second growing season, *C. aquatilis* increased its population size from the original 16 plants we planted some 3.6 fold to an average of 58 plants per plot; likewise *S. lutea* had good survival and growth success.

Our second question was centered around whether water levels, cultivation, and amendments would have an effect on species performance. There seem to be some clear conclusions to these questions. Whereas *Carex* had better performance in our wettest areas, *Salix* performed better in the mesic/dry areas. Cultivation amendments into the top 4–6 cm appeared to make no difference to the performance of either species; neither did our weak fertilization treatment. Among our five amendments none made an appreciable difference to the performance of either of our species. Rather, wood chips, and landscape fabric seemed to inhibit performance of *Carex* and *Salix*, respectively.

Weeds are in general not a source of concern, with only 2–4 species per plot; however, the use of peat stored in open field conditions did increase the number of weed species by 4.5 fold and weed abundance by 6.6 times. Additionally weeds are more speciose and more abundant in the drier non-cultivated areas.

Finally we asked if the surrounding acidic bog waters would affect the chemistry of the well-buffered pad and we conclude that even after this relatively short time frame, the highly buffered waters of the pad are affected for some distance into the pad ditches.

5. Conclusions

We have demonstrated on two abandoned well sites that wetland plants that naturally inhabit organic soils can establish on compacted mineral soils if pads are leveled to appropriate elevations. Successful establishment by the sedge, *C. aquatilis* and the shrub, *S. lutea*, was not enhanced by the five amendments we provided. Water levels are key components of early wetland development; whereas *C. aquatilis* responded better to the wetter environments, *S. lutea* responded better to the drier treatments. Cultivation of the top 2–3 cm of the mineral soil, whether with amendments or not provided no significant response by either species; fertilization effects were complicated by water level interactions for *Carex*; however, the non-fertilized area yielded a better response from *Carex*. Late planting of the *Salix* on the fertilized pad may have been a key factor in the lesser response of this species on the fertilized treatment area rather than a direct influence of the fertilizer treatment. Weeds were variable in their occurrence, differing among some treatments and water levels. One natural occurring amendment (field peat with an inherent seed bank) had greater abundance of weeds than the control or other more artificial amendments.

Based on two growing seasons and from data from only two well site pads it may be possible that early wetland plant communities can be reconstituted on abandoned well sites with rewetted mineral soils; however, it is not known whether these communities will develop into plant assemblages resembling natural analogues with comparable species richness, community structure, and carbon sequestering function. Our large-scale experiment was carried out on only two mineral pads, one fertilized and one not fertilized – our results for these two pads appear hopeful that pads such as these can be returned to wetland habitats.

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