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**Assisted lodgepole pine regeneration on reclamation sites using logging slash
as both a mulch and natural seed source**

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Draft

9 Abstract

10 In this study we tested the efficacy of establishing lodgepole pine (*Pinus contorta* Dougl.) from
11 seed using woody mulch produced from slashed tree tops from a pine harvesting site; this mulch
12 contained the closed serotinous cones of the lodgepole pine. Mulch was spread on prepared
13 reclamation sites at 0, 1, 3 and 5 cm depth. Broadcast seeding of pine was also done at 0 and 1
14 cm of mulch depth. Mulch cover that was 1 cm thick was the preferred treatment as it produced
15 17,000 seedlings ha⁻¹ by year 3 after treatment while being similar in seedling density to the 3
16 and 5 cm treatments. When 50,000 seeds ha⁻¹ were added, seedling density went up more on the
17 sites with 1 cm of mulch than the 0 cm sites. Soil temperature was lower and temperature
18 extremes were reduced under the mulch layer compared to the control plot. The plots with 1 cm
19 mulch also had higher soil moisture in the mineral layer than the plots with 0 cm of mulch. A
20 thin layer of woody mulch therefore, provided both a source of pine seed and the covering of the
21 ground provided a more benign environment for the establishment of pine germinants.

22 Keywords: lodgepole pine, mulch, reclamation, regeneration, recruitment.

23

24 Introduction

25 Lodgepole pine (*Pinus contorta* Dougl.) populations dominate much of the landscape in the
26 lower foothills ecoregion of Alberta (Ecological Stratification Working Group 1996), where they
27 are subjected to multiple forms of disturbance including timber harvesting, mountain pine beetle
28 outbreaks, and oil and gas exploration. Abandoned roads, drilling pads, and other severely
29 disturbed sites in the boreal and montane forests of Alberta regularly need to be restored to pine
30 forests in order to meet regulatory requirements of woody vegetation on reclaimed forest sites
31 (ESRD 2013). This is particularly important for recovering biodiversity as well as habitat for
32 sensitive wildlife species (Eldridge et al. 2012). The conditions left by such human activity
33 however, are at best sub-optimal for the successful establishment of lodgepole pine and other
34 conifers, particularly when bare mineral soil is exposed (Wang et al. 2005; Kembell et al. 2006);
35 without adequate site preparation many conifer germinants would fail (Lanini and Radosevich
36 1986).

37 Some of the advantages of re-contouring the subsoil along with returning the topsoil to the
38 surface have been well documented for disturbed sites such as drill pads (Campbell et al. 2008;
39 Larney and Angers 2012). The de-compaction of the surface layers is also necessary in many
40 cases to promote soil aeration and root penetration (Startsev and McNabb 2009). Additionally,
41 there is also a benefit to adding organic soil amendments in some circumstances (Larney and
42 Angers 2012). All these practices can improve growing conditions by reducing soil strength and
43 increasing soil temperature, along with improving water holding capacity for planted seedlings
44 (Bulmer et al. 2007). They can also be effective in reducing competition from nutrient-
45 demanding weeds, for example when C-rich sawdust is added (Speigelberger et al. 2009). In

some cases this has resulted in increased growth rates of planted trees (Sanborn et al. 2004) while in other cases only small changes have been observed (Bulmer et al. 2008).

As a serotinous pine species, lodgepole pine trees keep large amounts of viable seed in closed cones in the canopy, with virtually no seedbank available in the forest floor (Corns and La Roi 1976). Greater than 20 years of closed cones accumulate in the crown of the trees, containing up to 30×10^6 seeds ha^{-1} (Teste et al. 2011a). These cones are typically opened by the heat of wildfire, which is the main disturbance associated with stand regeneration for this species (Muir and Lotan 1985). The resin bonds sealing the cone scales soften and let the scales separate when exposed to temperatures higher than 45 °C (Perry and Lotan 1977). Forest managers have scarified sites using drags made of ship anchor chains to both reduce the thickness of duff to create seed beds, and to open the cones of the serotinous pines (Landhäusser 2009). The heavy drags reposition the cones close to the ground surface, where temperatures may sometimes reach 50° C, which is warm enough to open the cone scales.

Lodgepole pine regeneration on bare reclamation sites is limited primarily by a deficiency of seeds (Corns and La Roi 1976), but fully open sites also have easy access to feeding animals, intense radiation, rapid drying of the surface layer, and micro-erosion liable to shift the germinating seeds before effective root anchoring (Elmarsdottir et al. 2003). The lack of a seed bank may be easily overcome by broadcasting seed, but the poor habitat of these exposed sites can make this practice ineffective. Woody mulch layers could alleviate some of these concerns on reclamation sites but they have not been tested to determine their influence on conifer tree regeneration. In this study we examined the establishment of lodgepole pine (*Pinus contorta*

Dougl.) using mulch produced from logging slash that would be normally burned as waste at the logging site.

The objective of this work was to assess the effectiveness of rough-chipped mulch from lodgepole pine logging slash, applied at different depths, as an assisted–natural regeneration strategy for lodgepole pine. This was compared to broadcast spreading of pine seed, with and without a thin layer of mulch. We also tested if there are regeneration benefits of tilling-in larger quantities of pine mulch into the soil. Soil temperature, moisture and nutrient availability were also assessed in relation to mulch thickness.

Methods

Six drill pads (natural gas wells) about 1 ha in size were constructed in 2009 and 2010 in the Upper Foothills zone of the boreal forest on sandy clay loam in Brunisolic and Orthic Gray Luvisols of the upper foothills ecoregion — specifically ‘d’ and ‘e’ ecosites (Beckingham et al. 1996). In the construction phase, the topsoil consisting of the L, F, H, and A soil horizons was stripped and stockpiled off the site. The average depth of the topsoil before removal was 10 cm, across all sites. The pads were leveled and drilled and a production facility was established in the centre of the pad. In August of 2011, the outer ring of each pad (~2/3 of the pad area) was re-contoured with subsoil as much as possible. The stored mixed topsoil was spread back onto this outer ring and this area was disked to 40 cm with a breaking disc to alleviate soil compaction. Some amount of mixing of the topsoil and the subsoil took place as a result of disking. In October of 2011 the area around each active well installation was subdivided into 8 treatment plots, each plot 200 m² in area (10 × 20 m). The plots were given the combinations of treatments listed in Table 1.

Woody debris for mulching was obtained from local forestry harvesting operations in areas dominated by lodgepole pine. Whole trees were skidded to the roadside where a processor removed tops and branches containing many closed cones of lodgepole pine. This slash was piled and then mulched with a Peterson 4710B horizontal grinder (Peterson Pacific Corp, Eugene, Oregon, U.S.A.). The chipping screens were removed from the grinder that would otherwise have produced uniformly small chips. This resulted in more desirable irregular pieces of debris that were between 1 and 4 cm in width and 2 to 15 cm in length, while mostly less than 1.5 cm thick. The debris contained many completely intact and partially shattered cones of the serotinous lodgepole pine which was the expected outcome of the chipper screens removal (as opposed to having entirely shattered cones).

The coarse mulch was applied with a manure spreader after tests were done to determine the speed of travel necessary to produce the treatment depths: 1, 3 and 5 cm of mulch as outlined in Table 1. The mulch depths corresponded to mulch material wet weights of 3.32, 9.96, and 16.6 kg m⁻² for 1, 3, and 5 cm respectively (Table 1). The control treatment consisted of the spreader being driven on the plots without producing output (0 cm of mulch). Additional plots with 3 or 5 cm of mulch were disked after application such that the mulch was partly incorporated into the soil. Some of the plots were also supplemented with lodgepole pine seed from a local source. The supplementary seeding treatment was applied during the first week of May 2012 (i.e. after mulch had been applied) using a cyclone seeder at walking speed that was calibrated to deliver ~50,000 viable seeds per hectare. This allowed a period of natural cold-wet stratification before normal germination in June.

110 Temperature data loggers (HOBO[®], Onset, Cape Cod, Massachusetts, United States of America)
111 were buried at 10 cm from the surface of the soil on June 23rd of 2012 and removed on
112 September 12th of the same year. On the same days, ion exchange probes (PRS[®] probes, Western
113 Ag, Saskatoon, Saskatchewan, Canada) were installed (and removed) at an average depth of 5
114 cm into the mineral soil. One ion exchange probe per plot was used, including plots where mulch
115 was incorporated. Both temperature and ion exchange probes were placed approximately at the
116 centre of each plot.

117 Seedlings counts were made in mid-August of 2013 and 2014 inside 10 circular sampling plots
118 within each treatment plot; each sampling plot being 2 m² in area. The frequency of sampling
119 plots with at least one seedling was also assessed as a measurement of distribution (converted to
120 percent stocking). Soil samples of the top 10 to 15 cm, excluding mulch, were collected and
121 bagged on August 27th, 2014. Soil water content was determined gravimetrically by weighing
122 before and after oven-drying the samples at 70 °C and verifying constant dry weight. Regional
123 precipitation at Grande Prairie was 4.7% below normal for April to September in 2012, 15.0%
124 below normal in 2013, and 25% below normal in 2014 (Government of Canada 2015).

125 Statistical analyses were performed in R version 3.2.3 “Wooden Christmas-Tree” (R Core Team
126 2015) on a Linux platform. All the functions used to perform data calculations and statistical
127 analyses were from the included packages in the base R installation. The data were analyzed as
128 three separate experiments. Experiment 1 tested the effects of mulch depth on seedling
129 establishment success (0, 1, 3 and 5 cm depth) and it was analysed with a factorial one-way
130 ANOVA. Multiple comparisons were done using Tukey’s test. Experiment 2 tested whether
131 there was a benefit to supplementing the natural seed supply in control plots (0 cm of mulch) and

in plots with a shallow layer of mulch (1 cm). A 2×2 factorial ANOVA was used to analyse experiment 2. The third and final experiment tested the effects of heavy addition of mulch without seed supplementation and the possible benefits of tilling the mulch into the soil (3 and 5 cm of mulch with and without tilling) and compared to plots where mulch had not been incorporated using a 2-way factorial ANOVA. In addition, the effect of mulch depth on soil nutrient levels was also analysed as a one-way factorial design. All ANOVA tables are combined in Table 2. Prior each analysis, boxplots were used to visually compare the variance between treatments and a formal Bartlett's test was conducted to corroborate homogeneity. Normal Q-Q plots were used to corroborate that the residuals followed a normal distribution. Data transformation was not necessary in any case.

Results

Seedling density was nearly 10 times higher in plots with cone-bearing mulch cover than in plots without cover ($p < 0.05$). However, plots with no cover seemed to continue recruitment into the third year of treatment, whereas in plots with mulch there was a net mortality rate of 14% on average between the second and third years. There were no significant differences in seedling density among mulch treatments, with a combined average of 18,000 seedlings ha⁻¹ in the second year (Fig. 1). Seeding improved seedling density (seeding effect $p \ll 0.01$) and there was benefit of the addition of 1 cm of mulch (mulch effect $p \ll 0.01$). The benefit of adding seed, however, was larger in the 1 cm mulch (seeding × mulch interaction $p \approx 0.07$); here seeding into cone-bearing mulch increased density to 27,000 seedlings ha⁻¹ (Fig. 2), an increase of ~10,000 seedlings vs. ~5000 increase by seeding onto bare soil. Tilling-in the mulch resulted in 3,000 seedlings ha⁻¹ (data not shown) and was comparable to the unseeded control plot.

154 The frequency of the 2 m² plots with pine seedlings (i.e. stocking) tended to be higher in plots
155 with 1 cm of mulch than in plots without mulch ($p < 0.05$, Fig. 3). However, the sites with 3 and
156 5 cm of cone-bearing mulch were not significantly different from the non-covered plots albeit
157 showing higher frequency. As there was distinct clustering of seedlings around some of the
158 cones, stocking was not always related to overall seedling density.

159 Total soil exchangeable N levels were not significantly different among treatments with mulch
160 added to the surface. Ammonium levels however, were significantly higher in plots with 3 and 5
161 cm of surface mulch compared with plots without cover ($p < 0.05$). Plots with 1 cm of mulch
162 also tended to have higher NH_4^+ levels than bare plots, but the difference was not significant
163 (Table 3). Exchangeable Fe was significantly higher in plots with greater mulch cover but Fe was
164 reduced when chips were tilled into the mineral soil. Tilling reduced the amount of NH_4^+ ($p <$
165 0.05), and P while other nutrients were mostly unchanged (Table 3).

166 Soil temperature and soil moisture were affected by the presence of surface mulch. Daily mean
167 temperatures of soil during summer were 14.4 °C in the plots with mulch cover and 16.0 °C in
168 non-covered plots (Fig. 4). This difference was statistically significant between 0 cm plots and
169 the 1, 3, and 5 cm plots combined but there were no differences among the mulched plots ($p <$
170 0.05). Daily thermal amplitude was also markedly lower in the mulch treatments with an average
171 of 4.0 °C compared to 8.2 °C in uncovered plots ($p < 0.05$). Soil water content was higher in plots
172 with mulch than in plots without mulch ($p = 0.03$), without major differences among mulch
173 treatments (Fig. 5).

174 We performed regression analyses on the seedling density response to soil temperature and to
175 each of the macronutrients N, P, K, and S as well as the micronutrient Fe (not shown). None of

these regressions pointed clearly to a relationship between seedling density and soil temperature or nutrition, having non-significant slopes and poor goodness-of-fit.

Discussion

The addition of a sparse layer of cone-bearing mulch along with seed supplementation was the most effective treatment both to obtain a high seedling density and to promote an even distribution of the seedlings. The importance of mulch for seedling establishment is eminently clear even without seed supplementation. In the non-seeded condition, seedling density was an order of magnitude greater by having any level of mulch cover on the ground compared to bare soil. The success of establishment in the mulch-covered plots was likely from two reasons: firstly, the non-seeded plots with mulch cover had a large number of seedlings originating from seeds present in whole or shattered cones that were part of the mulch, since the mulch had come from harvest debris with tree tops of lodgepole pine. Secondly, the mulch provided shelter for seedlings especially in the germination phase where roots need to penetrate soil to locate stable water supplies. Shelter and organic soil cover has been shown to be beneficial for conifer establishment (Kemball et al. 2006; Wang et al. 2005), even for shade intolerant species like jack pine (*P. banksiana* Lamb.). It is likely that the mulch also provided some level of protection against soil erosion during germination. Although the 3 and 5 cm mulch treatments had more seed delivered to the plots, they showed no significant increases in density or frequency over the 1 cm thick mulch. Thick mulch layers could in fact be detrimental in relation to the number of microsites suitable for successful germination since there is a higher chance for seeds to remain caught in the mulch material without reaching the soil surface.

198 Plots corresponding to the non-seeded 0-cm mulch treatment had a few pine seedlings that may
199 have come from different sources such as airborne seed from surrounding forests and seed or cone
200 movement from adjacent plots, either by wind or animals. Increasing the seed density with an
201 additional 50,000 seeds per hectare contributed about 5,000 seedlings ha⁻¹ when applied to bare
202 soil. Comparatively, seeding onto 1 cm thick mulch improved seedling density by 10,000
203 seedlings per hectare over the mulch alone, highlighting the benefit to early germination success
204 by the mulch cover on the ground. Similar benefits of increased soil moisture with an organic
205 cover have been reported in relation to various other conifers (Kemball et al. 2006; Wang et al.
206 2005). Indeed roughening the surface layers and providing sheltered microsites has also been
207 shown to increase seeding success in drier environments, particularly when precipitation is
208 below average (Eldridge et al. 2012).

209 The lack of relationship found between seedling density and soil temperature and/or nutrient
210 status, stresses the fact that during the recruitment and seedling establishment phases of the
211 regeneration, the availability of sheltered microsites is perhaps the most important variable
212 within a wide range of conditions. Sheltering may also be important before germination since it
213 lowers the risk of the seed population being predated by birds and small mammals and during
214 seed germination it provides a more stable moisture environment for the radicle to anchor the
215 seedling. As there were about 17,000 natural seedlings in 1 cm of mulch treatment by year three
216 and density increased to 27,000 with the added seed, our data suggests that the 1 cm of woody
217 mulch from these pine logging sites added ~85,000 seeds ha⁻¹, presumably more if a proportion
218 of the seed was retained in the cones. A deficiency of seed in other woody mulches could thereby
219 be made up by the addition of supplementary seed.

The 1 cm depth of mulch was arguably the most effective at regenerating these pads. This thin layer of mulch was able to deliver a sufficient amount of seed to obtain ~17,000 seedling by year three and these seedlings were well dispersed based upon the percentage stocking values. The deeper layer of mulch would have had greater amounts of seed but this did not translate to greater seedling density, most likely due to the thicker mulch impeding seedling emergence or successful rooting. Furthermore, in the 1-cm mulch, the higher exposure of mineral soil due to micro-scale gaps between woody mulch pieces allowed germinants to take root right into the mineral soil and LFH mixture, while providing sufficient shade patches such that moisture retention during germination was improved. In the deeper layer of mulch, however, there may be future opportunities for recruitment as the closed cones buried in the mulch may release some viable seed (Teste et al. 2011b) as the covering layers of mulch are decomposed. Hellum and Linfield (1986) noted that recruitment from natural regeneration extended for a decade on pine cutover areas – likely due to this factor.

The fact that in the naturally regenerated plots, seedlings were often clustered near the partial or complete cones indicates that cones were an important seed source. As intraspecific competition would eliminate all but one of the seedlings in a cluster, however, the better dispersal of seedlings in the seeded plots would likely translate into reasonable numbers of successful seedlings. Nevertheless, the natural seed in the thin layer of mulch had good numbers of seedling and levels of stocking, without the extra expense of seeding. We estimate that the average cluster consisted of three seedlings per cone, taking into account non-clustered seedlings. If we consider the survival of one out of three seedlings in a cluster, the seedling density after competition would be just under 6,000 seedlings ha^{-1} in the 1-cm mulch treatment. This is similar to post-fire regeneration density in other lodgepole pine stands (Johnstone et al. 2004).

243 All levels of mulch cover had about the same mean soil temperature, but plots with mulch
244 showed less diurnal temperature fluctuation than non-covered soil – similar to observations of
245 cover of debris on severely disturbed sites (Bulmer et al. 2007). The cooler temperatures under
246 the mulch also resulted in higher soil moisture due to lower surface temperatures because of the
247 shielding of solar radiation; similar to the coverage of ‘hog fuel’ in Bulmer et al. (2007). We
248 caution that a single soil water sample (in time) was taken after a period of rain at the end of
249 August of 2014 and, therefore, we can only draw on the one-time link found between mulch and
250 water in this case. However, it is conceivable that thicker layers of mulch might also intercept
251 precipitation thereby actually decreasing soil moisture at depth, during periods with incidence of
252 many cycles of low precipitation. The reduction in temperature extremes under mulch could
253 potentially benefit the seedlings both during colder days and during the night since the mulch can
254 reflect back and re-emit longwave radiation, particularly when wet (Montague et al. 2000).

255 In addition to adding cost and time to the reclamation operations, tilling the mulch into the soil
256 negated any benefits of having a natural seed source for regeneration in the form of cones. The
257 tilling process incorporated the cones into the soil where either the cones remained closed
258 because the cones never experience the $\sim 45^{\circ}\text{C}$ needed to open these serotinous cones, or the
259 seed was buried too deep for the cotyledons to reach the surface. Moreover, incorporation of the
260 mulch left most of the surface as bare soil with little woody debris on the surface to shelter
261 germinants. In addition, the high amount of C incorporated would have promoted the growth of
262 soil microflora which can create a demand for N that will generally lower the availability of N
263 and other nutrients for plant growth (Sanborn et al. 2004). High N availability however, is more
264 likely to be a concern in regards to competition with invasive and noxious weeds, the presence of
265 which was variable across the pads.

In our study the added mulch had little consistent effect on exchangeable nutrient availability except for Fe and more weakly for P and NH_4^+ . Greater amounts of Fe in the exchangeable fraction were found with increasing amount of mulch on the surface. Redox processes in the organic matter are likely responsible for releasing Fe, which then appears in the leachate (Schuman 1988). Tilling drastically reduced available Fe which is consistent with other observations (Schuman 1985). Other studies with added woody chips showed that reduction in N availability is dependent on the rate of application (Homyak et al. 2008 and references therein). In our study, the mulch was made from tops and branches of lodgepole pine which has normally twice the concentration of N compared with mulch from large stem material (Wei et al. 1997). The high C:N values noted in wastes containing a large amount of bole material (Bulmer et al. 2007) were likely not a big factor with the mulch applied in our study. Incorporation of mulch into the soil might reduce soil bulk density in the future (Sanborn et al. 2004; Bulmer et al. 2007) but it is not clear if this is so when mulch is only spread on the surface. We did not assess the effect of mulch on soil bulk density since the sites were disked as part of the treatment.

The higher levels of NH_4^+ observed in the mulch treatments are consistent with wetter, lower temperature conditions where nitrification is less active, while the temperature of the bare plots approached the optimum for nitrification in that area (Malhi and McGill 1982). This is potentially an additional benefit of the mulch to the young seedlings once they are established, since high NH_4^+ (in relation to NO_3^-) has been associated with faster growth in coniferous species, especially in height (Nelson and Selby 1974; Margolis et al. 1988). Fast-growing seedlings are the key to a favourable competition outcome, and the mulch treatments showed conditions to support both seedling recruitment and early growth better than bare plots.

Conclusions

Seed management either by spreading of cones or artificial seeding was an effective means of establishing pine seedlings – provided there was a shallow cover of mulch to protect the seedlings. Deeper coverage of the site with mulch provided no additional benefits in the short term. Seedlings may have benefited from greater water supply in the mineral soil that is sheltered by the mulch as suggested by the water content measured at the end of August 2014, and perhaps from reduced erosion undermining anchorage of germinants during the sprouting stage. Mulching improved soil nutrients in a manner that we anticipate will be favourable for pine seedlings. Tilling of mulch into the soil is not recommended as it deeply buried the cones and seed and negated the early positive effects of surface mulch on mineral nutrients.

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389

Tables

Table 1. Experiments and treatment combinations (mulch level, tilling and seed supplementation).

Experiment #	Mulch layer thickness (cm)	Tilling	Seed supplementation
1: mulch level, 2: seed suppl.	0 (no mulch)	No	No
1: mulch level, 2: seed suppl.	1	No	No
2: seed suppl.	0 (no mulch)	No	Yes
2: seed suppl.	1	No	Yes
1: mulch level, 3: tilling	3	No	No
1: mulch level, 3: tilling	5	No	No
3: tilling	3	Yes	No
3: tilling	5	Yes	No

Table 2. ANOVA results of the three experiments and soil nutrients as affected by mulch depth.

	Df	SS	MS	F	p (>F)
Exp. 1. Effect of mulch depth. Response is pine seedling density.					
Mulch	3	1.182 × 10 ⁹	0.394 × 10 ⁹	5.166	0.00676
Exp. 2. Effect of seed supplementation with (1 cm) and without mulch. Response is pine seedling density.					
Seeding	1	5.47 × 10 ⁹	5.47 × 10 ⁹	16.505	0.00006
Mulch	1	37.54 × 10 ⁹	37.54 × 10 ⁹	113.230	< 0.00001
Interaction	1	1.12 × 10 ⁹	1.12 × 10 ⁹	3.366	0.06730
Exp. 3. Effect of tilling-in two levels of mulch (3 and 5 cm). Response is pine seedling density.					
Tilling	1	1382 × 10 ⁶	1382 × 10 ⁶	24.728	0.00004
Mulch	1	29 × 10 ⁶	29 × 10 ⁶	0.519	0.47800
Interaction	1	31 × 10 ⁶	31 × 10 ⁶	0.564	0.46000
Effects of mulch depth on different nutrients. Statistics correspond to factor mulch at 4 levels.					
Response					
N	3	40.4	13.5	2.222	0.11050
NH ₄ ⁺	3	24.3	8.1	4.760	0.00893
P	3	84.4	28.1	2.203	0.10990
K	3	345.1	115.0	0.394	0.75840
Fe	3	1507256.0	502419.0	7.447	0.00081

p-values < 0.05 appear in bold type

Table 3. Soil nutrient levels of all treatment plots ($\mu\text{g cm}^{-2}$ at 10 cm depth for an 80 day period). Plots that were tilled are included for comparison but they do not form part of the ANOVA since they belong to a different experiment. Numbers in parenthesis indicate standard errors. Different letters indicate statistical differences within the same column ($p < 0.05$).

Cover (cm)	Tilling (Yes/No)	N	NH_4^+	P	K	Fe
0	N	10.4 (3.3)	3.5 (0.4) ^b	2.70 (0.7)	24.0 (4.2)	137 (51) ^c
1	N	9.1 (2.5)	4.6 (0.5) ^{ab}	4.97 (1.2)	28.4 (4.8)	453 (99) ^b
3	N	10.0 (1.3)	5.9 (0.7) ^{ab}	4.55 (1.5)	29.5 (9.9)	429 (93) ^b
5	N	8.0 (0.8)	5.4 (0.5) ^a	7.26 (1.5)	21.4 (1.7)	751 (84) ^a
3	Y	7.3 (2.5)	2.7 (0.2)	2.66 (0.5)	32.9 (5.2)	79 (28)
5	Y	10.8 (2.1)	3.4 (0.5)	2.85 (0.7)	23.9 (3.5)	92 (25)

402 List of Figures

403 Figure 1. Seedling density in plots with different levels of mulch cover and without tilling. Error
404 bars indicate standard error. Different letters indicate statistically significant differences within
405 the same year ($p < 0.05$).

406 Figure 2. Seedling density in seeded and non-seeded plots without cover and with 1-cm nominal
407 cover level. Error bars indicate standard error. Different letters indicate statistically significant
408 differences ($p < 0.05$) with comparisons being performed within cover level (not between levels).

409 Figure 3. Frequency of sampling plots with at least one seedling (% stocking). Plots of all
410 treatment levels are represented including seeded plots (0S: no cover, seeded; 1S: 1-cm chip
411 cover, seeded). Gray levels are included for visual separation of cover levels: bars with the same
412 color belong to the same level of mulch cover. Error bars indicate standard error. Different letters
413 indicate statistically significant differences ($p < 0.05$).

414 Figure 4. Soil daily mean temperature of plots with surface mulch (dashed line) and bare (solid
415 line) plots during a two-month span. On some days, maximum and minimum temperatures are
416 displayed to compare thermal amplitudes ('*' symbols for covered, '+' symbols for non-covered);
417 these points represent local maxima and minima. Measurements were taken at a depth of 10 cm
418 from the surface of the soil.

419 Figure 5. Soil water content of bare plots and all mulch cover treatments. Letters indicate small
420 differences between covered and non-covered ($0.05 < p < 0.1$). Soil samples of the first 10 to 15
421 cm of soil (excluding mulch) were collected August 27th, 2014.

Seedling density in plots with different levels of mulch cover and without tilling. Error bars indicate standard error. Different letters indicate statistically significant differences within the same year ($p < 0.05$).

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