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First Year Soil Impacts of Well-Pad Development and Reclamation on Wyoming's Sagebrush Steppe

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ABSTRACT

In recent years, natural gas extraction activities have disturbed thousands of acres of arid and semiarid regions in Wyoming's sagebrush steppe ecosystem. Thin, nutrient poor topsoils, combined with subsoils potentially high in salts, limit the resilience of these arid and semiarid soil systems. Stripping, stockpiling, and respreading topsoil stimulates decomposition and loss of soil organic matter (SOM) by breaking apart soil structure and eliminating inputs of plant residues,which can result in reduced SOM content When the soil structure is disturbed organic matter can rapidly decompose, releasing mineral nutrients that are mobile and can be lost to weeds, leaching, erosion, or volatilization.The purpose of this study is to gain an understanding of how natural gas development and reclamation activities impact soil properties, plant growth re-establishment, and the ability of disturbed sagebrush ecosystems to recover over time. Soil samples were collected from stockpiles,respread topsoil and adjacent undisturbed areas from three natural gas fields located in Western Wyoming. Results suggest that soil organic matter needed for plant growth becomes mineralized or released when the soil is disturbed. The data show a small increase in plant-available mineral nitrogen (N) concentrations after stripping and stockpiling compared to undisturbed soils, and then a large increase in available N following respreading for reclamation. This suggests that easily decomposable organic matter exposed by destruction of soil structure during stripping is conserved in deep stockpiles but then rapidly decomposed upon re-exposure to air and moisture with respreading. The spike in mineral N likely originates from organic compounds that,in undisturbed conditions,hold and slowly release N and other nutrients. It represents a significant potential loss of this important "time-release" nutrient pool. The spike in mineral nutrients probably stimulates prolific weed production often observed on reclaimed sites. Weeds that stay and decompose on site may conserve and recycle the nutrients, but the data suggest a need for a better way to accomplish this.

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INTRODUCTION

Much ecological disturbance in the western U. S. is related to natural gas production, coal mining, or other energy development and is located in arid and/or semi-arid regions. These ecoregions that occupy much of the western landscape are difficult to reclaim once they are disturbed (Bunting and others 2003; Whisenant 1999). Low soil fertility and organic matter contents, slow-growing and difficult-to-establish vegetation, saline or sodic conditions, and other constraints related to low rainfall create fragile conditions, with low resistance to and resilience after disruption. In recent years, natural gas extraction activities have disturbed thousands of acres of arid and semiarid regions in Wyoming's sagebrush steppe ecosystem. The extraction of natural gas is a short but drastic perturbation to soil processes and the terrestrial ecosystem. In addition because of the infrastructure associated with wells (i.e. well pads, roads, and pipelines) energy development potentially influences ecoregions indirectly by exotic plant establishment or directly by the loss of wintering and breeding habitat for wildlife as well as migration barriers for ungulates (Berger 2003, 2004; Lyon and Anderson 2003). During natural gas well pad development, topsoil, which provides the majority of nutrients essential for plant growth, is typically stripped, stockpiled, and respread for reclamation. Vegetation and topsoil are removed using heavy operating equipment and stockpiled on the well pad until drilling is complete and then respread and seeded for reclamation. We speculate that stripping, stockpiling, and respreading of topsoil disrupts soil structure that protects labile organic carbon (C) and N. Labile organic C and N are protected from degradation within soil aggregates, but become mineralized when disturbed which may result in a shift in the C and N dynamics that exist in SOM pools. Soil organic matter is an important nutrient pool that plays a critical role in ecosystem stability, including nutrient cycling, soil structure formation, soil water holding capacity, energy for microorganisms, and essential nutrients required for plant growth.

There has been much research conducted on energy related disturbance impacts to soil, however, this study investigates the immediate (<1 yr) effects that occur on the redistribution of the SOM pools during the different phases (stripping, stockpiling, and respreading) of well pad development. Understanding how disturbance alters SOM pools will contribute to greater reclamation success and ecosystem recovery. The objectives of this study are to 1) determine effects of stockpiling depths on C and N dynamics and 2) quantify effects of stripping, stockpiling, and respreading on soil C and N dynamics.

MATERIALS AND METHODS

Site Information and Field Sampling

Study Area

Nine well pads were selected from three Wyoming natural gas fields: Pinedale Anticline (Anticline), Jonah, and Wamsutter. Each site location consisted of three stockpiles (SP), three recently reclaimed well pads (RC), and three adjacent undisturbed sites (UN). Soil samples were collected from stockpiles, respread topsoil and adjacent undisturbed sites in 2009 and 2010. For ecological site descriptions and climate data for each site location refer to Driessen and others (this volume).

Stockpile Sampling

Stockpiled topsoil soil samples were collected from <1 yr (Jonah and Wamsutter) and <5 yr (Anticline) old stockpiles. On each stockpile, three randomly located holes were augured to a depth of 250 cm. Samples were bulked by depths of 0-5 cm, 5-20 cm, 20-100 cm, 100-200 cm, and 200-250 cm for each of the nine stockpiles. An adjacent undisturbed site was also randomly sampled with an auger to serve as a reference soil. From the undisturbed site, a composite soil sample was collected from 0-20 cm to represent the topsoil stripping depth.

Reclaimed Well Pad Sampling

After the stockpiled topsoil was respread and seeded for reclamation in Fall 2009, soil samples were collected on the recently respread topsoil and adjacent undisturbed area along three transects set up on a 0.1 ha plot. Soil samples were collected from 0-5 cm, 5-20 cm, and 20-30 cm at three points along each of three 32 m transects. Soil samples were bulked by depth for each transect, thus a total of 9 samples were collected from each plot.

Laboratory Analyses

Soil samples were kept at 4°C until they were brought back to the lab for analysis. Ten grams of field moist soil was measured for gravimetric moisture content (Gardner 1986) and mineral N. Mineral N, an index of plant-available N, was extracted from 10-g subsamples with 50 mL of K_2SO_4 and run on a microplate spectrophotometer (Powerwave HT, BioTek Instruments, Vinooski, Vermont) for NH_4-N (Weatherburn 1967) and NO_3-N (Doan and Horwath, 2003). An additional 22 g of field moist soil was measured for labile organic C and N determination using aerobic incubation (Hart and others 1994; Zibiliske 1994). Samples were brought to 23 percent gravimetric moisture content prior to incubation. Aerobic incubations yielded mineralizable N and C after 14 d under optimal water and temperature conditions. Samples were incubated in sealed jars and jar lids were fitted with rubber septa for the collection of gas samples. Headspace samples (30 ml) were collected in syringes fitted with gas-tight valves after mixing the total volume by plunging the syringe up and down. Samples were collected on day 1, 4, 7, and 14 to measure potentially mineralizable C or labile organic C. All incubation jars were flushed and refilled with ambient air following each sampling. Four blank jars (no soil) were included in each experiment to control for background CO_2 concentration. Headspace samples were analyzed for CO_2 concentration using an infrared gas analyzer and calibrated with three standard gases (Model LI-820, LICOR Inc., Lincoln, Nebraska). After the 14-d incubation period, a 10-g subsample was taken from the 22-g sample to determine gravimetric moisture content after 14 d. The remaining soil was extracted with 50 mL of K_2SO_4 and analyzed for NH_4-N and NO_3-N as described for mineral N above. This represents the amount of organic N mineralized under optimal conditions after a 14-d incubation period. Potentially mineralizable N or labile organic N is achieved by subtracting the initial inorganic N content from the N content after the 14-d incubation period.

Statistical Analysis

The data were analyzed statistically using one way analysis of variance using SAS 9.1.3 SP4 (SAS Institute 2008). All statistical tests were conducted at $P < 0.05$.

RESULTS AND DISCUSSION

Stockpile Depth Effects

The stockpile data presented reflects the average midpoint of each depth interval compiled for all three site locations. Although not significant, mineral N increased slightly with increasing stockpile depth for the Jonah and Wamsutter sites (figure 1a). Mineral N for the Anticline increased with increasing depth, but declined beyond 150-cm depth. Abdul-Kareem and McRae (1984) reported that NO_3-N concentrations in stockpiles were similar to those in adjacent undisturbed soils, but NH_4-N was greater with depth in all stockpiles when compared to adjacent undisturbed soils.

Labile organic C and N concentrations increased with increasing stockpiling depth (figure 1b and 1c), suggesting that the labile SOM pool is protected and being conserved deep in stockpiles. Other research (Abdul-Kareem and McRae 1984; Visser and others 1984; Williamson and Johnson 1990) has shown greater soil respiration rates deeper in stockpiles than at the surface of stockpiles. Management implications often recommend shallow topsoil stockpiles, but our data suggests that may not be necessary.

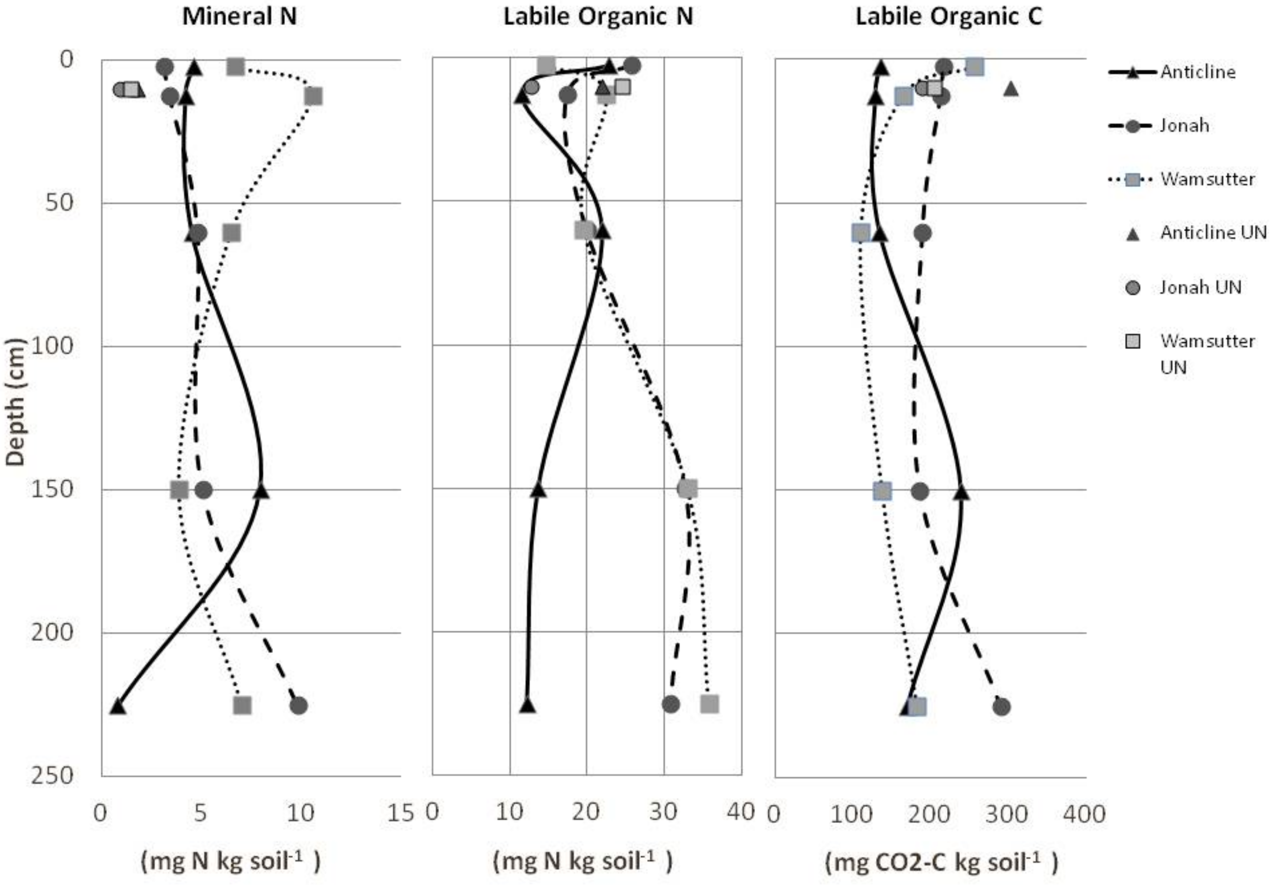

Figure 1a Figure 1b Figure 1c

Figure 1. Average mineral N(a), labile organic N (b) (mg N kg soil $^{-1}$) and labile organic C (c) concentrations (cumulative mg CO_2-C kg soil^{-1} during 14-d incubation) from stockpile depths and adjacent undisturbed from each natural gas field.

Stripping, Stockpiling, and Respreading Effects

For all three site locations mineral N was significantly (Anticline p = 0.0052, Jonah p = 0.0106, Wamsutter p = 0.0018) greater for the reclaimed treatment than in the undisturbed and stockpile treatments. The data shows a small increase in mineral N concentrations after stripping and stockpiling compared to undisturbed soils, and then a large increase in available N following re-spreading for reclamation (figure 2a). Soil organic matter is decomposed upon re-exposure to air and moisture with respreading. Williamson and Johnson (1990) reported that decomposition occurred as a result of the labile organic matter and mineral N release associated with stockpile disturbance and restoration. In addition, the NH_4-N that accumulated within the stockpile was converted to NO_3-N as oxygen became available during the restoration process (Williamson and Johnson 1990).

Labile organic N concentrations were significantly (p = 0.0076) less for the stockpile and reclaimed treatments than the undisturbed reference site at the Anticline (figure 2b). Labile organic N concentrations significantly increased in the stockpile treatment compared to the reclaimed treatment for the Wamsutter (p = 0.0145) and Jonah (p = 0.0341) gas fields. In two of the three sites (Jonah and Wamsutter) labile organic N concentrations were greater in the stockpiles than in the undisturbed reference sites. Ingram and others (2005) found lower labile organic N in stockpiles than in native sites. Furthermore, Lindemann and others (1989) showed slightly lower labile organic N concentrations in stockpiled topsoil compared to fresh topsoil.

All three site locations had significantly (Jonah p = 0.0120, Anticline p = 0.0366, Wamsutter p = 0.0379) lower labile organic C concentrations in the reclaimed plots than in the undisturbed plots (figure 2c). Our data show labile organic C concentrations were less in the stockpiles than the undisturbed sites. Ingram and others (2005) reported carbon mineralization rates were greater in a 2-yr-old stockpile than native sites after 21 days of incubation. Differences in labile organic C and N concentrations between the native and reclaimed sites may be due to differences in microbial communities, break-up of microaggregrates, or the addition of new non-humified plant residues (Ingram and others 2005).Two of the three sites (Jonah and Wamsutter) showed that loss of labile organic C and N was most pronounced upon re-spreading stockpiled soil, whereas on the Anticline this loss occurred upon stockpiling. This loss probably reflects the fact that stockpiles on the Anticline were older and had been moved several times causing redisturbance and loss of labile organic C and N.

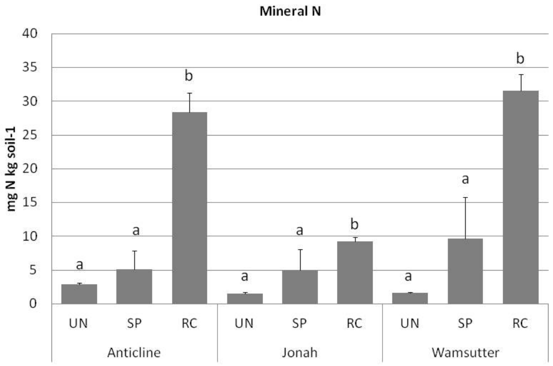

Figure 2a

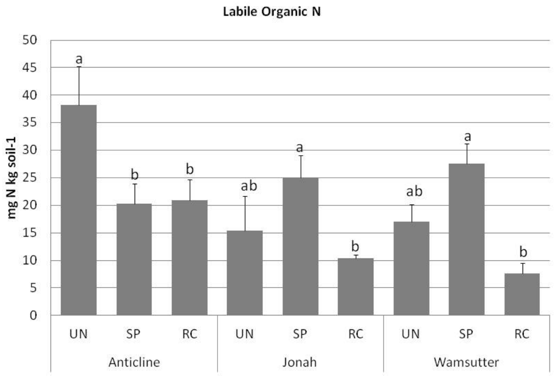

Figure 2b

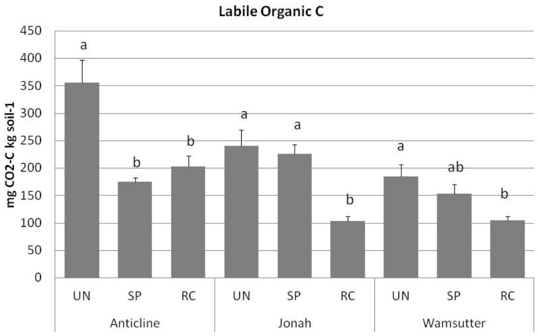

Figure 2c

Figure 2. Average Mineral N (a), labile organic N (b) (mg N kg soil^{-1}) and labile organic C (c) concentrations (cumulative mg CO_2-C kg soil^{-1} during 14-d incubation) from undisturbed, stockpile, and reclaimed plots from each natural gas field. Letters indicate significance differences ($P \leq 0.05$) between undisturbed, stockpiles, and reclaimed plots at each gas field. Error bars denote standard error.

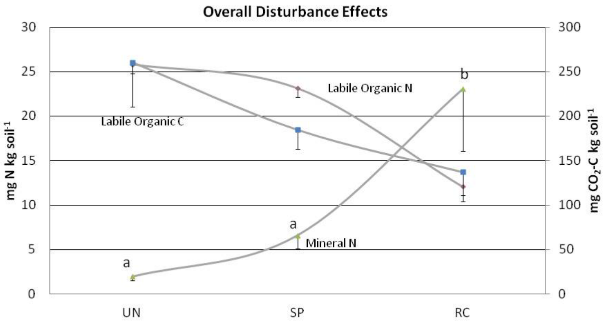

Figure 3. Average mineral N, labile organic N (mg N kg soil^{-1}) and labile organic C concentrations (cumulative mg CO_2-C kg soil^{-1} during 14-d incubation) from undisturbed, stockpile, and reclaimed plots for all site locations. Letters indicate significance differences ($P \leq 0.05$) between undisturbed, stockpiles, and reclaimed plots at all 3 gas fields. Error bars denote standard error.

Overall Disturbance Effects

The labile pool of SOM is a reservoir of time-release nutrients and is extremely important for ecosystem resiliency. The data presented in Figure 3 represents the mineral N and labile organic C and N concentrations averaged and compiled for all 3 site locations. The data show that mineral N increases or becomes available with each phase of disturbance. Mineral N is significantly greater ($p = 0.0254$) for the reclaimed treatment than the undisturbed and stockpile treatments. Although not significant, the data show that labile organic C and N are reduced with each phase of disturbance. The active pool consists of readily available nutrients where as the slow pool is less available for microbial degradation because it is protected in the micro- and macro-aggregates. Thus breaking soil aggregates releases a labile organic material (Beare and others 1994; Kristensen and others 2000), changing nutrient pools (Chapin and others 2002).

CONCLUSION

The SOM that is needed for plant growth becomes mineralized and released when the soil is disturbed. The destruction of soil aggregates stimulates mineralization and decomposition resulting in reduced C and N (Chapin and others 2002; Ingram and others 2005; Wick and others 2009) and SOM (Abdul-Kareem and McRae 1984). Our data indicate that the initial stripping of topsoil disrupts the soil structure causing an increase in the labile organic C and N when compared to the undisturbed reference site. Once the topsoil is stockpiled the labile organic C and N is protected from mineralization deep within the stockpile. However, labile organic C and N concentrations are reduced when stockpiled and re-spread for reclamation, suggesting that the protected pool is being mineralized and lost to the environment. Losses in labile organic C and N are greatest just beneath the surface where moisture, temperature, and aeration are probably optimal for mineralization during the time soil is stockpiled. Mineralization increases with each disturbance activity, but is greater when the topsoil is respread and tilled for seeding. The spike in mineral N originates from organic compounds that, in undisturbed conditions, hold and slowly release N and other nutrients. The spike in mineral nutrients probably stimulates prolific weed production often observed on reclaimed sites.

The data suggest there is a loss of valuable SOM in soils and an untimely release of nutrients. The data indicates a need for alternative handling and/or management methods that conserve labile SOM and mineral nutrients, such as less destructive stripping/spreading methods that conserve soil structure, and cover crops or C additions that immobilize mineral N and keep it on site. Stahl and others (2002) stated that successful restoration of a disturbed area is dependent on maintenance of soil quality and minimizing the human footprint to soil resources could prevent further site degradation and facilitate site restoration.

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