ORGANIC MATTER DYNAMICS ON RECLAIMED COAL MINES IN THE CANADIAN ROCKIES [1]

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Abstract. Development of self-sustaining plant communities on harsh reclamation sites in the Rocky Mountains has often proven difficult. This paper describes the organic matter cycles of three grass species and the influences of fertilization and topsoiling. The study took place on an abandoned coal mine on the eastern slope of the Rocky Mountains near Hinton, Alberta, Canada. The role of species selection and topsoil addition in assisting the development of a stable nutrient cycle is quantified and the effectiveness of various revegetation strategies was evaluated.

Species selection and, to a lesser extent, topsoil addition controlled reclamation success. Successful native and agronomic species were identified. Successful grasses, both native and agronomic had characteristic patterns of organic matter accumulation, retention and loss.

Additional key words. Organic matter dynamics, species selection, rocky mountains, reclamation.

Introduction

In the Canadian Rockies revegetation of reclaimed mined land generally aims to initiate an herbaceous plant community which will be capable of supporting itself either indefinitely or until successfully colonized by the indigenous plant communities. Either way, the reclamation plant community is expected to control erosion, ameliorate site microclimatic and soil conditions, to propagate itself for some time and finally to do so without artificial assistance. Failure results in retrograde community development, bare ground, soil erosion and the liability of a second round of site reclamation. These reclaimed mine sites present a novel opportunity to characterize organic matter dynamics during primary succession.

Reclaimed mines in this region often appear successful for the first several years then deteriorate as surface cover diminishes and erosion occurs. Identification of the factors which control a plant community's persistence will shed light not only on the mechanisms for plant community and soil development but help to identify reclamation techniques which favor long-term success.

When revegetating raw spoil, fertilization is usually applied to initiate a mobile pool of plant nutrients. Also, legumes may contribute significant amounts of N to the site. Under optimal conditions the added nutrients remain mobile and maintenance fertilization can be terminated leaving a healthy plant community which slowly accumulates nutrients and ultimately assimilates with the surrounding native vegetation types. Otherwise, nutrient cycling is curtailed and the site

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deteriorates.

Organic and Mineral Cycling. In cold environments decomposition of dead plant material is the major restriction on nutrient mobility. Decomposition is restricted by low temperatures, drying of surface materials, high C:N:P ratios and low decomposer populations. In-plant transfer supplies a portion of the plant's needs and may be particularly critical in the spring, releasing the plant from even greater dependence on detritus-supplied nutrients. This strategy appears to be prominent in most tundra and grassland vegetation. Plants in these areas consistently exhibit high proportions of root mass to shoot mass (Aleksandrova, 1970; Bliss, 1963; Dennis and Johnson, 1970; Rehder 1976; Thilenius, 1975).

Many reclamation studies in the Arctic, Alpine and Subalpine have reported good initial growth but poor persistence (Brown et al. 1976; Hull, 1974; Younkin, 1976). The decline in vigor is often matched by an accumulation of dead plant material on the soil surface (Younkin, 1976). Frequently, this decline in vigor coincides with the withdrawal of fertilization. While other factors undoubtedly contribute to this deterioration, mineral nutrition is critical due to the depression of decomposition and nutrient cycling in cold regions. Consequently, repeated fertilization is often required (Brown, et al., 1978).

Techniques developed in nutrient cycling studies permit isolation of the structural components within a plant community (e.g. Batzli 1974). Organic matter dynamics among the principal compartments (shoot, detritus, root) illustrate functional relationships (e.g., net production, carbohydrate partitioning, decomposition). These values comprised the dependent variables in this study. The independent variables were two of the principal treatments available to the reclamation planner: soil reconstruction and species selection.

Study Site

In 1978 the Alberta Forest Service established a series of revegetation test plots at the Cadomin surface mine near Hinton, Alberta. The mine was abandoned in 1952. The Cadomin mine lies about 40 km south of Hinton, Alberta. The elevation of the site is 1675 m ASL, at the upper margin of subalpine plant communities. The surrounding mountains rise to the west toward the Jasper National Park boundary. The upper limit of tree growth in this area is about 1980 m above sea level. The abandoned mine remains nearly unvegetated except for isolated pockets of vegetation under the lee of several steep spoil banks (Takyi, 1985).

The site was chosen for its exceptional harshness. The spoil surface consisted of sandstone, coal, ironstone and shale fragments. The mine is subject to chinook winds throughout the winter. These winds can reach velocities in excess of 160 kph and are responsible for removing much of the winter snow cover (Root, 1976).

The experimental site was located on a series of species adaptability trials which had been established in June, 1978. These test plots were located on both east and west facing 15 degree slopes. The experimental plots had been seeded with a variety of native and agronomic grass and legume species.

More than 70% of the top 15 cm of spoil material was larger than 2 mm. The porous nature of the spoil coupled with the high prevailing wind makes it likely that drought conditions pertained at least sporadically through the growing season. On some plots the surface material contained significant coal fragments. This material is termed spoil. Non-coaly materials are termed overburden (mindful that, in fact, both materials are spoils). Topsoil, consisting of the A and B horizons of a nearby forested Entisol was applied at a thickness of 20 cm to one half of the plots. Table 1 summarizes the chemical properties of the spoil, overburden and topsoil.

Table 1. Some properties of the spoil, overburden and mineral soil used for topdressing at the Cadomin Test Site.

AGRONOMIC SPECIES PLOTS

	SPOIL	SOIL
pH	8.8	6.9
Ec (mS/cm)	0.3	0.1
AVAIL. NUTRIENTS (ppm)		
NH4-N	5.6	4.5
N03-N	0	1
P	0	10
K	186	214
TOTAL N (%)	0.13	0.07
T.E.C. (me/100 g)	6.6	13.2

NATIVE SPECIES PLOTS

	OVERBURDEN	SOIL
pH	8.9	6.5
Ec (mS/cm)	0.3	0.1
AVAIL. NUTRIENTS (ppm)		
NH4-N	3.7	4.1
N03-N	0	0
P	0	12
K	235	219
TOTAL N (%)	0.03	0.07
T.E.C. (me/100 g)	6.4	12.7

By 1982 the Alberta Forest Service had maintained and monitored the agronomic and maintenance fertilization plots for four years while the native species plots had been maintained for three years. Results of these studies are reported in Takyi and

Islam, 1985 and Takyi, 1985. It was agreed that, in addition to their intended purpose, the plots could supply valuable information about the influence of topsoil and species selection on development of stable, self sufficient plant communities.

Methods

Two of the experiments were selected for this study:

1. Agronomic Species Adaptability,

2. Native Species Adaptability

Duplicate experiments had been established on both topsoil and spoil. The Agronomic Species Adaptability experiment was established on coaly spoil while the Native Species Adaptability experiment had been established on non coal spoil.

The individual Agronomic Species Adaptability plots measured 2.5 m by 6 m. A number of commercially available grasses and legumes were seeded at a rate of 60 kg/ha in June 1978. Immediately after seeding the plots were fertilized with 60 kg/ha N, 30 kg/ha P and 62 kg/ha K. The plots received the same rate of maintenance fertilization until the 1981 growing season. Two species were chosen for this project: red fescue (Festuca rubra L.) and crested wheatgrass (Agropyron cristatum (L.) (Gaertn.).

Red fescue was chosen because it is consistently the most successful agronomic grass for revegetation in the mountains of Western Canada and crested wheatgrass was chosen because it is consistently unsuccessful in the mountains. Success is defined as the ability of a species to become established, to persist and to colonize new sites. While crested wheatgrass generally establishes well, individual plants begin dying off within a few years. It almost never reseeds a second generation of individuals in the mountains. The comparison of red fescue's and crested wheatgrass's carbon budgets should shed some light on successful versus unsuccessful allocation strategies.

The Native Species Adaptability Trial was duplicated on spoil and on spoil capped with 20 cm of the same mineral soil used in the Agronomic Species Adaptability plots. Each species was seeded to provide 5000 viable seeds per square meter. All plots were fertilized by hand to provide 71-50-65 kg/ha of N, P and K, respectively. The plots received maintenance rates of fertilization up to and including the 1981 growing season. Individual plots measured 2 m X 2 m.

The native Slender Wheatgrass (Agropyron caninum L.) was also selected for the study. It was a variety which had been collected near the study site and propagated at the University of Alberta by R. Sadisivaiah and D.G. Walker. It is a common component of native subalpine grasslands in the region.

Sampling. The test plots were sampled to permit partitioning of the organic component into shoot, root and detritus compartments. This allowed examination of the major pathways of intra and extra-plant organic matter accumulation, storage and loss. Both shoot and detritus samples were obtained by clipping. The shoot compartment contained all above-ground living tissues. The detritus sample included dead standing and fallen shoot materials as well as other surface organic matter longer than 5 mm. Root samples were obtained to a maximum depth of 15 cm from a soil core sampler. Roots were separated from soil by immersion of the entire sample in a beaker of water, stirring and repeatedly removing the floating roots. Soil materials on the study plots, even the "topsoiled" plots were nearly devoid of organic matter prior to the study. So, separation of root material from soil organic matter was not a problem and virtually complete root recovery was possible. Core depth was noted for each sample. All plant and detritus samples were dried for 48 hours at 50C immediately after collection. Root samples were additionally separated then dried and massed.

This study required destructive sampling over a 14-month period on small plots. It imposed several constraints on sampling. Primarily, both clipping samples and root cores had to be small to avoid damaging the plots during the study yet sufficiently intense to yield reasonably precise estimates of means.

The plots were sampled on six dates: 2 June 1988, 7 July 1982, 9 Aug. 1982, 20 Sept. 1982, 9 June 1983 and 17 Aug. 1983. Five shoot and detritus samples were clipped each within a 30 X 15 cm frame and five 8 cm diameter root cores were taken and processed. From the smaller Native Species plots only three samples were taken. This level of sampling yielded estimates whose standard deviations of the mean to mean ratio ranged from 20 to nearly 100%. The process of collecting a complete set of samples took two days.

Calculation of Organic Matter Transfers. Within each plant community changes in organic matter within compartments were estimated by adding gains and losses between each of the sample dates. In characterizing this organic matter flux three parameters were of interest: Percent Retention, Percent Total Transfer Per Compartment and Total Transfer. The following equations define the derivation of each of the parameters of interest:

$$\text{Total Transfer} = T_t = \sum_{i=1}^{c} \sum_{j=1}^{n_i} |\Delta_i|_j$$

$$\text{Compartmental Transfer} = T_c = \sum_{j=1}^{n} |\Delta|_j$$

$$\text{Net Change} = N_c = \sum_{j=1}^{n} \Delta_j$$

$$\text{\% Total Transfer per compartment} = \frac{T_c}{T_t} \times 100$$

$$\text{\% Retention} = \frac{N_c}{T_c} \times 100$$

where:

T = Organic matter transfer (Flux) in g/m2/year
N = Net change in organic matter level
t = total (e.g. all compartments)
c = compartment (e.g. shoot, detritus, root)
n = sampling intervals

Results and Discussion

The following discussion focusses on the changes during the period 9 August 1982 and 17 August 1983 in each organic matter compartment and on estimates of the total organic matter flux per compartment and per species.

Performance of Various Grasses.

Slender Wheatgrass. At the end of the first growing season after cessation of maintenance fertilization (August 1982) the standing crop was evenly distributed between the detritus and root compartments (between 44 and 50%). About 7% of the standing crop was in the shoots (Table 2). Within a year, however, the ratio had shifted strongly toward the roots (about 80%) while detritus contained between 20 and 14% and the shoots contained 5% or less of the standing crop.

This shift of organic matter toward the root system was reflected in organic matter flux during the August 1982 to August 1983 period. Table 2 illustrates that the bulk of organic matter transfers occurred in the roots and to a much lesser extent in the detritus and shoots.

Topsoil apparently enhanced the proportion of standing crop and organic matter flux through the root compartment. Slender Wheatgrass communities on both topsoil and spoil increased their standing crops after withdrawal of maintenance fertilization. Almost all of the gain was in root mass (Table 3). Root gains were more pronounced on the topsoiled plots.

Red Fescue. At the end of both growing seasons standing crop was strongly concentrated in root mass (about 80%) while detritus and shoots recorded about 15 and 5% respectively (Table 2). Total standing crop was nearly double that of the Slender Wheatgrass. Most of the difference was in the root masses. Again, organic matter flux through various compartments reflected the distribution of standing crop. Ratios of root, detritus and shoot flux were around 75, 19, and 7%, respectively.

Topsoil had little effect on the proportion of standing crop and organic matter flux in the three compartments.

Red Fescue communities on the topsoiled plots lost some standing crop particularly the shoots and roots (Table 3). The Red Fescue plots on spoil showed a gain in the detritus and particularly the root compartments though the total mass was still less than on the topsoiled plots.

Crested Wheatgrass. At the beginning of the study the ratios of standing crop in the root, detritus and shoot compartments were similar to those of Slender Wheatgrass and Red Fescue at the end of the study: 78-13-9 on the topsoil plot and 63-23-15 on the non-topsoiled plot. However, by the end of the study the ratios had reverted to a nearly equal distribution between the roots and detritus (about 45% each) with the remainder in the shoot compartment (Table 2). Total community standing crop by August 1983 had fallen sharply to levels well below those of Slender Wheatgrass and Red Fescue with most of the loss in the root system.

Organic matter flux reflected the initial standing crop levels. However, most of the changes were negative (Table 3). Only the detritus compartment showed an increase.

The rate of organic matter loss was greatest on the topsoiled plots, though by August 1983 it still contained more organic matter than the spoil plot.

Organic Matter Retention. Organic matter retention is expressed as a ratio of net annual change to the annual flux through a compartment. It represents a significance index for gains and losses in each compartment. For example, red fescue on topsoil and crested wheatgrass without topsoil lost 178 and 180 g/m2 of root mass respectively (Table 3). For the red fescue, this represented only 9% of the organic matter which moved through the root compartment during the year. However, for crested wheatgrass it indicates that 26% of the organic matter which moved through the roots was lost. It is unlikely that losses of this magnitude can be maintained for more than a few years.

TABLE 2. Distribution of organic matter within shoot, detritus and root compartments in August 1982 and August 1983, and organic matter flux between these dates.

	STANDING CROP (G/M^2)				FLUX (G/M^2/YR)	
SLENDER WHEATGRASS TOPSOIL	AUG 82	% TOTAL	AUG 83	% TOTAL	AUG-AUG	% TOTAL
SHOOT	39	7	41	4	68	6
DETRITUS	270	49	142	14	128	11
ROOT	247	44	824	82	939	83
TOTAL	556	100	1007	100	1135	100
SLENDER WHEATGRASS NO TOPSOIL	AUG 82	% TOTAL	AUG 83	% TOTAL	AUG-AUG	% TOTAL
SHOOT	27	6	2	0	45	6
DETRITUS	216	45	202	21	266	33
ROOT	242	50	740	78	498	62
TOTAL	485	100	944	100	809	100
RED FESCUE TOPSOIL	AUG 82	% TOTAL	AUG 83	% TOTAL	AUG-AUG	% TOTAL
SHOOT	172	8	109	5	259	9
DETRITUS	252	11	297	15	609	21
ROOT	1806	81	1628	80	2092	71
TOTAL	2230	100	2034	100	2960	100
RED FESCUE NO TOPSOIL	AUG 82	% TOTAL	AUG 83	% TOTAL	AUG-AUG	% TOTAL
SHOOT	80	7	4	0	120	6
DETRITUS	177	16	286	17	351	17
ROOT	835	76	1418	83	1631	78
TOTAL	1092	100	1708	100	2102	100
CRESTED WHEATGRASS TOPSOIL	AUG 82	% TOTAL	AUG 83	% TOTAL	AUG-AUG	% TOTAL
SHOOT	182	9	42	5	214	10
DETRITUS	264	13	376	48	130	6
ROOT	1603	78	365	47	1712	83
TOTAL	2049	100	783	100	2056	100
CRESTED WHEATGRASS NO TOPSOIL	AUG 82	% TOTAL	AUG 83	% TOTAL	AUG-AUG	% TOTAL
SHOOT	94	15	64	12	150	14
DETRITUS	146	23	228	44	222	21
ROOT	407	63	227	44	698	65
TOTAL	647	100	519	100	1070	100

TABLE 3. Net change in organic matter standing crop and per cent retention for the shoot, detritus and root compartments.

	NET CHANGE (G/M^2/YR)	% RETENTION
SLENDER WHEATGRASS TOPSOIL		
SHOOT	2	3
DETRITUS	-128	-100
ROOT	577	61
TOTAL	451	40
SLENDER WHEATGRASS NO TOPSOIL		
SHOOT	-25	-56
DETRITUS	-14	-5
ROOT	498	100
TOTAL	459	57
RED FESCUE TOPSOIL		
SHOOT	-63	-24
DETRITUS	45	7
ROOT	-178	-9
TOTAL	-196	-7
RED FESCUE NO TOPSOIL		
SHOOT	-76	-63
DETRITUS	109	31
ROOT	583	36
TOTAL	616	29
CRESTED WHEATGRASS TOPSOIL		
SHOOT	-140	-65
DETRITUS	112	86
ROOT	-1238	-72
TOTAL	-1266	-62
CRESTED WHEATGRASS NO TOPSOIL		
SHOOT	-30	-20
DETRITUS	82	37
ROOT	-180	-26
TOTAL	-128	-12

Even more severe losses were noted on the topsoiled crested wheatgrass plot, where root retention was -72%. Root retention on the non-topsoiled red fescue plot and both slender wheatgrass plots were strongly positive ranging from 31 to 100%.

Detritus retention was positive for slender wheatgrass and negative for both red fescue and crested wheatgrass. It tended to vary inversely with shoot retention of the latter two grasses. Detritus should be retained at a high rate in the first year after terminating maintenance fertilization as the excess shoot mass begins to decompose. A healthy decomposer population is evident on the topsoiled red fescue plot where despite high inputs from the shoots (-24% shoot retention) only 7% of the detrital flux was retained.

Finally, total organic matter retention indicates the proportional change in the plot's organic matter pool. There was a slight negative retention on the topsoiled red fescue plot and strongly positive retention values for the other red fescue and both slender wheatgrass plots. The topsoiled crested wheatgrass plot lost 62% of the organic matter which cycled through it while the non-topsoiled plot lost 12%.

In summary, positive organic matter retention values indicate that the plant community is developing and successfully colonizing the site. Under the stress of termination of maintenance fertilization such development is regarded as an indication that, at least for the short term, the plants will continue to develop.

Structure and Adaptability to the Subalpine.

The results suggest plant structural adaptations which explain the observed fitness of some grasses to harsh subalpine reclamation environments. The successful grasses in this study developed an organic matter cycle in which most of the activity was below ground. All of these species seem to have a limited ability to retain structure and, by inference, carbohydrates and nutrients. Their root systems expand and contract rapidly, releasing their nutrients to the surrounding soil. In this sort of open cycle there appears to be an advantage in the capability of the root system to recapture these externally stored nutrients. Slender wheatgrass and red fescue evidently have this ability.

Species such as crested wheatgrass which expend a disproportionate amount of resources generating shoot material appear to allocate photosynthate to a compartment which cannot be supported. Thus, the tendency to accumulate detritus until shoot production fails.

Observations.

Mid August is the end of the growing season in this region. Light snow is common by this time and the native plant communities have already set seed and are approaching toward winter dormancy. By the end of the study (17 August 1983) the Slender Wheatgrass and Red Fescue appeared slightly chlorotic and the reddish cast to the leaves suggested P deficiency. However, during the growing season the plants appeared vigorous. Both species had flowered and set seed.

Crested Wheatgrass appeared unhealthy from the beginning of the 1983 growing season. This was the first growing season without maintenance fertilization. The plants failed to flower, aerial cover appeared to diminish and the plants seemed to generate an unusual amount of detritus. In short, they looked unhealthy.

Summary

A methodology was developed in this study whereby organic matter dynamics in the shoot, detritus and root compartments of grass stands were monitored and evaluated over a one year period. This approach provides insight into patterns which can predict and explain the long-term performance of grass species in harsh subalpine reclamation environments. These single species test plots were all subjected to the same experimental perturbation: withdrawal of maintenance fertilization. The following summarizes how each species responded to this perturbation.

While each grass species was affected differently by withdrawal, each supported less shoot mass by mid-August. The only exception was the slight shoot increase in slender wheatgrass grown on topsoil. Otherwise, it appears that upon withdrawal of maintenance fertilization the shoots enter fall dormancy sooner.

Slender wheatgrass and red fescue roots developed strongly during the study. The only exception was a slight decrease in the topsoiled red fescue plot. The total organic matter pools of both slender wheatgrass and red fescue also increased. Root mass and total organic matter of both crested wheatgrass plots declined sharply.

The behavior of the topsoiled red fescue plot was unique. Its organic matter pool was stable throughout the study, losing only 7% of its total flux. Except for the large drop in shoot mass the other compartments changed little relative to their initial mass. This suggests that this plot had reached a level of "maturity" and was little affected by the withdrawal of maintenance fertilization. The other red fescue plot and both slender wheatgrass plots developed rapidly after withdrawal suggesting that fertilization may have been an impediment to root development, possibly through overstimulation of shoot production.

Crested wheatgrass, however, was clearly dependent on maintenance fertilization. After its withdrawal both topsoiled and non-topsoiled plots declined in all parameters except detritus.

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