RECLAMATION RESEARCH AT QUINTETTE OPERATING CORPORATION

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ABSTRACT

A comprehensive research program was initiated at Quintette in 1986. Research trials ranging from site preparation treatments to native species selection and establishment methods were implemented and assessed. Results of many of the trials are now being applied operationally.

INTRODUCTION

Reclamation at Quintette, like other mines, requires background information to guide operational practices. Because of the occurrence of disturbances in several biogeoclimatic zones and the wide variability in growth media, area of disturbance and differences in end land-use objectives, several trials were initiated between 1986 and 1993.

Surface disturbances at Quintette were categorized by location and type: (1) low elevation tailings and coarse refuse (BWBS), (2) low-elevation waste dumps (SBS), (3) mid-elevation waste dumps (ESSF) and (4) high-elevation (AT). Each location and type required differential attention. Therefore, several research categories (site preparation, agronomic and native species selection, seed mixes, establishment methods, fertilizer applications), were proposed at the outset and these are described in the following text.

SITE PREPARATION

Seedbed ecology is an important determinant of revegetation success and appropriate site preparation is essential. Based on economic constraints and available literature, two trials were established to examine site preparation requirements.

Low Elevation - Shikano:

To determine optimum site preparation practices on the available growth materials in Shikano ('mud' or waste rock), a harrowing/ripping trial was set up during the fall of 1991. Two 8x100m contiguous panels were treated, one by harrowing, the other by ripping, and then cyclone seeded and fertilized. Five 2m² replicates were randomly positioned within each panel and percent cover recorded annually from 1991 to 1994. Vegetation cover increased each year, and in 1994, mean cover was 31% for the ripped treatment and 4% for the harrowed treatment. The significant difference was due to 'mud' crusting problems. The results showed that where 'mud' is used, deep ripping of material or coordinated seeding/harrowing is necessary.
Waste dump resloping, where necessary, represents a significant portion of reclamation costs. In the fall of 1986, an experiment was established to determine whether there was a significant difference in plant establishment and persistence on different waste dump slope angles and aspects. Three slope angles (37°, 32°, 28°) on two aspects (northwest and southwest) were seeded with the equivalent of 100 kg/ha of Creeping Red Fescue (cv. Boreal), Slender Wheatgrass (cv. Revenue), Alpine Bluegrass, Timothy (cv. S-50) and Alfalfa (cv. Anile). The treatments were fertilized once with the equivalent of 400 kg/ha of N₀P₄₅K₀ and 800 kg/ha of N₅P₂₀K₂₀. Six replicates were randomly established in each treatment. Percent vegetation cover was assessed visually from 1987 through 1993. Mean percent cover increased from 1987 until 1989 but in the absence of fertilization, declined thereafter. Significant differences in cover between the resloped and non-resloped treatments were only recorded in 1989. Differences in material type confounded treatment effects with this trial. The results indicated the need for maintenance fertilization.

AGRONOMIC SPECIES SELECTION

Establishment of agronomic species is important for short-term erosion control and, in some cases, for permanent end land-use objectives. Therefore, evaluation of agronomic species performance is a prerequisite for revegetation. Since there are significant site and material differences at Quintette, several trials were established.

Low Elevation - Tailings:

Three material types are potentially available for operational reclamation in the tailings and coarse refuse dump areas. Therefore, three completely randomized designs were established on each of these material types. Twenty-four agronomic grasses and legumes (three replicates per species) were seeded in the fall of 1990. On tailings material, mean percent cover was highest for Cicer milkvetch (100%), Hard Fescue (92%), Canada Bluegrass (88%), Creeping Red Fescue (cv. Boreal) (83%) and Alfalfa (cv. Garst) (80%). On coarse refuse, the best species were Cicer Milkvetch (100%), Creeping Red Fescue (cv. Boreal) (85%), Hard Fescue (82%), Alfalfa (cv. Garst) (80%), Redtop (76%) and Canada Bluegrass (72%). On till material, the best species were Birdsfoot Trefoil (cv. Leo) (100%), Cicer milkvetch (100%), Creeping Red Fescue (cv. Boreal) (93%), Orchardgrass (cv. Napier) (93%), Redtop (92%), Slender Wheatgrass (cv. Revenue) (90%) and Tall Fescue (90%). Greatest overall performance for all species was achieved on till material. Percent cover and seed heads consistently increased from 1991 to 1994.

Low Elevation - Coarse Refuse:

In 1987, a section of angle of repose coarse refuse dump was till capped. This, and an adjacent unamended section, were seeded with Creeping Red Fescue (cv. Boreal), Hard Fescue (cv. Durar), Kentucky Bluegrass and Slender Wheatgrass (cv. Revenue). These panels were assessed each year from 1988 to 1994. Establishment and persistence was very poor on the unamended section while those on the till amended portion were favorable.
Low Elevation - Shikano:

Twenty-four agronomic grass and legume species (three replicates/species) were sown in a completely randomized design during the fall of 1990. Percent cover, seed head production and vigor were assessed from 1991 to 1994 with increases in percent cover and seed head production recorded each year. In 1994, the species with the greatest percent cover were Cicer milkvetch (100%), Creeping Red Fescue (cv. Boreal) (88%), Hard Fescue (82%), Sainfoin (90%), Slender Wheatgrass (cv. Revenue) (100%) and Western Wheatgrass (cv. Walsh) (90%).

Mid-Elevation:

Thirty agronomic grass and legume species (three replicates/species) were sown in a completely randomized design on the P1 1660m dump failure during the fall of 1991. Percent cover, seed head production and vigor were assessed from 1992 to 1994. Generally, percent cover and seed head production increased each year. In 1994, the grass species with the greatest percent cover were Slender Wheatgrass (cv. Revenue) (80%), Northern Wheatgrass (70%), Sheep's Fescue (68%), Sheep's Fescue (cv. Nakiska) (67%), Hard Fescue (53%) and Smooth Bromegrass (52%). Cicer milkvetch (32%) and Sainfoin (30%) were the best performing legume species.

High Elevation:

Thirty agronomic grass and legume species (three replicates/species) were hand sown in a completely randomized design on the Wolverine South 1850m dump during the fall of 1991. Percent cover, seed head production and vigor were assessed from 1992 to 1994. Percent cover and seed head production for only a few species increased each year. In 1994, the grass species with the greatest percent cover were Slender Wheatgrass (cv. Revenue) (42%), Sheep's Fescue (cv. Nakiska) (32%), Sheep's Fescue (13%), Hard Fescue (13%) Northern Wheatgrass (12%) and Alpine Bluegrass (11%). Persistence of the agronomic legumes was extremely low.

In 1993, an additional two trials were established to determine the viability of seed produced by the agronomic species. Most agronomics are unable to persist at high elevations and those that can survive may not be able to produce viable seeds. Thirty-nine agronomic grass and legume species, three replicates each, were hand seeded in a completely randomized design (500 seeds/species/m²) in the spring. In addition, a separate identical design using 14 local provenance and ecovar grasses was established in the fall. Percent cover, vigor and seed head production were assessed. As well, samples were collected from those plants which produced seeds. The samples were processed and seed germinated where produced. Percent cover was greatest for Northern Wheatgrass (28%), Orchardgrass (cv. Arctic) (20%), Sheep's Fescue Common (33%), Sheep's Fescue (cv. Nakiska) (32%), Slender Wheatgrass (cv. Revenue) (25%), Smooth Bromegrass (18%), Timothy (cv. Alma) (30%) and Timothy (cv. Korpa) (18%).

None of the agronomics flowered during the first year of growth. During the second year, Canada Bluegrass, Creeping Red Fescue (cv. Boreal), Hard Fescue, Meadow Foxtail, Sheep's Fescue (cv. Nakiska), Slender Wheatgrass (cv. Revenue), Smooth Bromegrass, Sweet Clover, Tufted Hairgrass, Timothy (cv. Alma), Timothy (cv. Korpa) and Western Wheatgrass (cv. Walsh)
flowered. However, only three species produced seed, of which, the mean germination percentages were Hard Fescue (35%), Sheep's Fescue (cv. Common) (43%) and Sheep's Fescue (cv. Nakiska) (28%).

Establishment of the native grasses and ecovars was slow during the first growing season. Mean percent cover for the best performing *Sitanion hystrix* (4%), *Festuca brachyphylla* (3%), *Festuca saximontana* (3%), *Agropyron trachycaulum* (cv. AEC Highlander) (3%) and *Festuca saximontana* (ev. Rocky Mt. Fescue) (2%). None of the species flowered in 1994.

**Toxicology:**

As part of the agronomic species selection process and permit compliance, a toxicology study was initiated in 1992. Seven grasses and five legumes were selected based on a preliminary evaluation of species performance. Seed from these species was sown in a replicated randomized block design on tailings, coarse refuse and till. Comparison of the laboratory results with published literature indicated that foliage metal levels did not appear to be problematic. However, Creeping Red Fescue (cv. Boreal) had high levels of cadmium, lithium (coarse refuse) and managanese (till) while Redtop had high levels of lithium and managanese (till). All of the legumes had high levels of boron and molybdenum. Only three legume species had additional elemental problems. Alsike Clover (cv. Tetra) had an elevated level of zinc when grown on tailings and coarse refuse, Cicer Milkvetch had an elevated level of nickel when grown in coarse refuse and Sainfoin had an elevated level of selenium in tailings and coarse refuse.

**NATIVE SPECIES SELECTION**

Seeding or transplanting of native species is necessary to achieve end land-use objectives at Quintette. Native species are important for increasing biotic and structural diversity. However, the availability of plant materials (seed or seedlings) is limited, particularly for alpine and subalpine disturbances. Therefore, native species establishment has been an important aspect of the Quintette research program.

Native species research focused on three areas: (1) autecology and horticulture (nursery production), (2) establishment success on disturbances and (3) spatial relationships (wildlife habitat requirements and seed dispersal). Initially, information describing the suitability of native species was derived from literature reviews and anecdotal observations of performance in early successional habitats such as exploration disturbances within the Quintette lease.

**Seed Collection:**

From 1987 to 1994, seed collection, processing and storage information was collected on 138 species. For each species, at least three seed collection locations (accessions) were chosen. Frequent phenophase monitoring at each collection location was essential, particularly for wind dispersed species. Seed collection began usually during the second week of July and continued until the third week of September. Portable gas powered vacuums were used for species such as
Dryas, Oxytropis, Populus and Salix species and gas powered Seed Strippers™ were used for the grasses, sedges and the remaining forbs. Seed for shrubs and trees were collected by hand.

The native high elevation grasses were relatively easy to collect and process mechanically (Hance Mini-Vac seed processor) while several forbs required additional preparation prior to screening. Many forbs required tumbling prior to separation and cleaning while Astragalus alpinus, Oxytropis podocarpa and Potentilla diversifolia required an additional blending step. For the latter species, the blender blades were protected with surgical rubber. Shrub species were generally blended with water and dried prior to screening and blowing.

In terms of native seed acquisition, reconnaissance and processing times represented the greatest costs. Therefore, to reduce costs, a seed multiplication area was set up. The multiplication area consisted of several rows or patches of suitable native species. Species rows were established either by transplanting or direct seeding. Seed was collected from this area beginning in 1993, and seed quality, seed volume and collection efficiency has been good. However, seed from this facility cannot replace 'wild' population seed. Therefore, 'wild' and multiplication seed has been 'blended' to ensure sufficient genetic variability of the re-established species populations. Phenophase development was advanced over the 'wild' collection locations, so seed collection timing at this location was generally advanced one month.

Nursery Production:

Transplant establishment of several native species is required for three reasons: (1) establishment difficulties with direct seeding, (2) low in situ inoculum densities of requisite microbiological populations and (3) strict establishment spatial patterns. Therefore, the horticultural properties of several native species, particularly those of high elevation, were studied. The specific areas of research were container type, soil mix, fertilizer application, seed germination and seedling growth.

Nursery setup (maintenance, seeding, cuttings propagation) was usually complete by the end of April. Seed pre-treatments were required for several species, particularly shrubs. With the exception of the shrubs and trees, most species did not require greenhouse conditions in order to achieve transplantable size based on plug rooting density and shoot growth. Most grasses, sedges and forbs required only one growing season in the nursery. In general, cuttings propagation of such species as Arctostaphylos uva ursi, Salix arctica, Salix barclayi and Salix prolixa required two growing seasons to develop adequate root systems. 'Lifting' of seedlings occurred immediately prior to transplanting. All species were dormant when transplanted.

Several container types were tried (Cone-Tainers, Styroblocks and Spencer-Lemaires) but overwintering success and 'lifting' problems precluded the use of all but the Spencer-Lemaire Hillson containers for forbs and shrubs. Copperblock™ styro-containers were only used for production of non-commercially available conifers such as Abies lasiocarpa, Larix lariciana, Picea mariana and high elevation provenances of Pinus contorta. Growing media was standardized with a 2 peat: 1 vermiculite: 1 perlite and Nutricote™.
Fertilizer application was standardized with an initial addition of N\textsubscript{14}P\textsubscript{14}K\textsubscript{14} Nutricote\textsuperscript{TM} to the growing media followed by weekly liquid fertilizer applications. Liquid N\textsubscript{10}P\textsubscript{32}K\textsubscript{10} fertilizer was applied during May and June, and liquid N\textsubscript{20}P\textsubscript{20} K\textsubscript{20} in July. Liquid fertilizer application was discontinued and watering frequency decreased in August.

Based on the nursery results, all of the grass and most of the forb species were considered suitable for nursery production or direct seeding. Due to difficulties in propagation, several species have, at this point in time, limited capacity for nursery production. However, direct seeding is an option open for those species in this category which are considered essential for wildlife habitat.

Several native species trials were established between 1991 and 1993. These trials are described in the following sections.

**Low Elevation - Tailings:**

Shrubs and trees provide browse and habitat structure for wildlife species at low elevations in the Quintette lease area. Consequently, several trials were established to evaluate native shrub and tree performance on the available growth materials at low elevation.

To begin with, a transplant trial with 1+0 seedlings of four conifer species was established during the fall of 1992. The trial consisted of three randomized blocks on each material type with three replicate rows (n=10) per species. In 1994, mean survivorship was greatest for *Larix laricina* (98%) and lowest for *Picea mariana* (69%). Survivorship of *Finns contorta* was greatest on coarse rejects but for all other species, till material was best. Annual growth increments (height) in all species increased in 1994 over that of 1993, and were greatest for *Larix laricina* (80%). Annual growth increments were generally greater on till material. However, mean growth increments of *Finns contorta* were greatest on coarse refuse (89%).

Twelve deciduous shrub and tree species were transplanted into three growing materials (tailings, coarse refuse, till) during the fall of 1993. Three replicates per species (n=10) were established. Examination of first year results revealed, as expected, that survivorship varied with species and growth material. Survivorship and growth was greatest for *Populus balsamifera*, *Ribes hudsonianum*, *Rosa acicularis*, *Salix planifolia* and *Salix prolixa*. Growth was greatest on the till and tailings materials.

**Low Elevation - Shikano:**

Several grass, forb and shrub transplant trials were established also on 'mud' amended spoil on the 895m Shikano Common dump during 1990. For each species, three replicate rows were transplanted. Survivorship, growth and seed head production were assessed from 1991 to 1994. Herbaceous species which performed well were *Achillea millefolium* (90%), *Astragalus aboriginum* (58%), *Astragalus eucosmus* (42%), *Elymus innovatus* (60%) *Hedysarum alpinum* (58%), *Oxytropis campestris* (46%), *Sitaition hystrix* (40%) and *Taraxacum officinale* (87%). Woody species with high survivorship and growth were *Amelanchier alnifolia* (93%), *Eleagnus commutata* (55%), *Populus balsamifera* (100%), *Rosa acicularis* (83%) and *Salix scouleriana*. 
Transplanted conifer species did not perform well on the 'mud' material and a blending trial of this material and coarse refuse is being considered at present.

In 1992, a conifer fertilizer trial was set up on the Shikano South Dump slide area to assess species survival and growth on 'mud' material. Two hundred and sixteen seedlings of *Picea interior* and *Pinus contorta* were transplanted into each of three treatment rows (control, Gromax™, Agriform™). Treatments were assigned randomly to each row. Seedling survival and vigor was assessed in both 1993 and 1994. In 1994, cumulative proportion surviving was low for all species and treatments. In each treatment, *P. contorta* had the highest survivorship; the control treatment was the best for both species, and Growmax™ the poorest. Fertilizer type, pH, 'soil' texture and protective cover were considered to be the important determinants of seedling survival. In 1993, the above species were transplanted into both 'mud' and waste rock to compare species performance.

**Mid-elevation:**

On the 1660m Dump Failure, sixteen shrub and tree species were transplanted in 1992. In 1994, survivorship was greatest for *Populus balsamifera*, *Pinus contorta*, *Rosa acicularis*, *Salix arctica* and *Salix planifolia*. However, survivorship results were affected by the confounding effects of wildlife browsing. Survivorship of *Betula glandulosa*, *Lonicera involucrata* and *Ribes hudsonianum* were browsed heavily by moose.

Direct seeding may be a cost effective method of establishing shrubs and trees. To examine this alternative approach, a randomized complete block design with three replicates per species was hand seeded in the fall of 1993. Germination was not observed in 1994.

**High-elevation:**

Several herb and shrub transplanting and seeding trials were established in 1991 and 1992. Two sets of native species transplant trials were established, one on the Wolverine South 1850m dump and one on the Wolverine North 1765m dump. A total of 46 native grass, sedge, forb and shrub species were transplanted. In 1994, the grass and sedge species with the greatest survivorship were *Agropyron caninum*, *Agrostis scabra*, *Carex haydeniana*, *Carex phaeocephala*, *Festuca brachyphylla*, *Poa alpina*, *Poa arctica*, *Poa pattersonii*, *Sitanion hystrix* and *Trisetum spicatum*. The forbs with the greatest survivorship were *Achillea millefolium*, *Androsace septentrionalis*, *Astragalus alpinus*, *Astragalus aboriginum*, *Cerastium beeringianum*, *Erigeron compositus*, *Minuartia rubella*, *Oxytropis sericea*, *Potentilla diversifolia*, *Potentilla nivea*, *Solidago multiradiata*, *Stellaria longipes* and *Taraxacum officinale* while the best shrub species were *Arctostaphylos uva-ursi*, *Betula glandulosa* and *Dryas integrifolia*. However, forbs such as *Papaver kluanensis* and shrubs such as *Ribes hudsonianum*, *Salix arctica* and *Salix bare lay i* may also be suitable candidates.
Recruitment from seed was extensive for all of the grass species and several forbs (*Androsace septentrionalis*, *Cerastium beeringianum*, *Crepis nana*, *Minuartia rubella*). Vegetative reproduction was also observed for *Stellaria longipes*.

In 1992, a legume inoculation trial was established to assess inoculation requirements and practices for the selected native legumes. Four treatments, (1) nitrogen - no inoculum (+NNI), (2) nitrogen - inoculum (+NI), (3) no nitrogen and no inoculum (-NNI) and (4) no nitrogen plus inoculum (-NI) were established in a randomized block design. Fifty seeds of eight legume species were combined and hand sown into each of the three treatment replicates. Abundance, percent cover, vigor and seed head production were assessed annually. Percent cover was consistently higher on the -NI treatment. The best performing species were *Astragalus aboriginum*, *Astragalus alpinus* and *Oxytropis sericea*. Initial performance of *Lupinus arcticus* was good but high 1993/1994 winter mortality was recorded.

**SEED MIXES**

Several species mix trials were established in the Shikano dump area. Percent cover on the west aspect mud (<2%) and spoil (18%) comparison trial was poor (18%). The poor performance on the mud covered slopes was due primarily to crusting on the mud material. In contrast, vegetation cover on the mud covered bench platform (80%) and north east spoil aspect (21%) were better.

In the fall of 1987, a southeast slope of the 1765m Wolverine North Dump was seeded with an agronomic grass/legume seed mix at the equivalent of 100 kg/ha. The area was only fertilized with the equivalent of 400 kg/ha of N₀P₄₀K₀ and 800 kg/ha of N₅P₂₀K₂₀ in the spring of 1988. Ten 2m² plots were established in 1988 and percent cover recorded annually. Mean percent cover increased until 1992 (26%) and declined thereafter. The dominant species each year were Creeping Red Fescue and Slender Wheatgrass. The results indicate that a maintenance fertilizer program is necessary for this material.

**SEEDING RATES**

Application of appropriate amounts of seed is important in ensuring cost effective operational reclamation. Therefore, due to site variability, two seeding rate trials were established. The objectives of these trials were to determine appropriate application rates, both in terms of vegetation cover and competition for shrub and trees.

**Low Elevation - Shikano:**

In Shikano, a five treatment (0, 25, 50, 75 and 100 kg/ha) seeding rate trial was established on the 880m Common dump during the fall of 1991. Three 2m² plots were randomly positioned in each panel. The trials were assessed annually from 1992 to 1994. Mean percent vegetation cover increased each year. In 1994, percent cover on the 100 and 75 kg/ha treatments, (77%) and (67%) respectively, were significantly different from that of the 50, 25 and 0 kg/ha treatments.
Since the differences between the two higher seeding rates were not significant, an operational application rate of the 75 kg/ha was chosen.

Mid-elevation:

On the 1660m Dump Failure, a set of four seeding rate treatments (0, 25, 50, 75 kg/ha) were established on a northwest aspect slope of the 1660m dump failure. A total of nine 2m² plots were established systematically in each treatment, three at each slope position location. Following seeding and fertilizing, four rows containing 32 seedlings each of 1+0 stock *Picea interior* and *Pinus contorta* were transplanted. Both percent cover and transplant survival were assessed annually. Vegetation cover increased each year and as expected, cover was greatest on the 75 kg/ha treatment in 1994. In 1994, cumulative survivorship of transplants was greatest on the 50 and 75 kg/ha treatments. Between species survivorship comparisons were not significantly different although the presence of accompanying vegetation appeared to protect the conifer seedlings.

APPLICATION METHODS

Information describing revegetation techniques is also important, particularly where there are significant differences in site conditions (growing media, slope, access). Therefore, three revegetation techniques were examined experimentally.

Low Elevation - Coarse Refuse:

Hydroseeding was evaluated experimentally on both coarse refuse and waste rock material. Two panels with different aspects (east and southwest) were hydroseeded in the spring of 1991. A systematic sampling system (n = 9) was established at each location to assess the effects of slope aspect and slope position on vegetation establishment and persistence. Vegetation cover on the coarse refuse trials in 1994 was much greater on the east aspect (5 - 23%) in comparison to the southeast aspect (<1 - 7%). On both aspects, vegetation cover was greater on the crest and mid-slopes.

Low Elevation Shikano:

Two areas in Shikano were hydroseeded with a seed mix during the spring of 1991. In 1994, mean cover values on a west facing spoil dump were highest at the crest (62%) and lowest at the toe (16%). In contrast, mean cover values on a north east facing mud dump were highest at the toe (87%) and lowest at the mid-slope (33%). In general, percent cover was greater on the north east aspect. Creeping Red Fescue (cv. Boreal), Slender Wheatgrass (cv. Revenue) and Sainfoin were the dominant species on the west aspect while Alfalfa (cv. Garst) and Creeping Red Fescue and Smooth Bromegrass were the dominants on the northeast aspect. Hydroseeding appears to be an effective method of establishment on 'mud' amended material.
Anecdotal observations, based on operational trials, demonstrated that direct seeding with bulldozers (plus harrows) and with fixed-wing or rotary-wing aircraft are effective methods of revegetation.

**High Elevation:**

At high elevation, the use of native species is essential for revegetation success. However, seed availability for most of the suitable species is restricted. Therefore, two research trials were undertaken to determine the efficacy of seed dispersal from ‘islands.’ In the first trial, four transects radiating from remnant patches within the Wolverine South disturbance area were established in 1991. Along each transect, twelve 1m² quadrats were positioned at 5m intervals. Species abundance was recorded for each quadrat. A rapid drop-off in colonization of all species occurred at the 45-50 m distance from colonizing source. The absence of a gradual decrease in abundance with increasing distance suggested that distance from seed source is not a determining factor until the 50m threshold. The species with the highest abundance were *Festuca brachyphylla*, *Poa alpina*, *Poa pattersonii* and *Trisetum spicatum*. In the second trial, ten 4m² quadrats were established on the Wolverine South Dumps in 1991. Twenty grass and forb species were hand seeded and fertilized. Percent cover and seedling recruitment was monitored each year. Percent cover increased each year. Seed production for many of the seeded species began in 1993. To date, recruitment within a 10 m radius of each quadrat has been limited to species such as *Androsace septentrionalis*, *Cerastium beeringianum*, *Crepis nana*, *Minuartia rubella*, *Poa alpina*, *Poa pattersonii*, *Sitanion hystrix* and *Trisetum spicatum*.

**FERTILIZER APPLICATION**

Adequate levels of nutrients are required for plant establishment and growth, and in the process of ecosystem reconstruction. Nutrient availability is low, particularly nitrogen, in all growth materials at Quintette. Therefore, several trials involving different formulations, application rates and frequencies of application were implemented at Quintette.

**Low Elevation - Tailings:**

In the tailings area, a fertilizer application rate trial was established to compare vegetation performance on different growth materials. An $N_{26}P_{10}K_{10}$ formulation was developed, based on laboratory analyses, and three treatments (0, Ix, 2x) applied. During 1991, a set of randomized blocks, three replicates per treatment, were located, one on each of the available growth materials (tailings, coarse refuse and till). Vegetation cover was assessed for three years, and during this time period cover increased consistently. Mean percent cover was greatest on the 2x till treatment (74%). In general, percent cover was greatest on till and lowest on coarse refuse.

**Low Elevation - Shikano:**

Two factorial fertilizer trials were established in the Shikano Common during 1991; the first examined agronomic species response to inorganic fertilizer ($N_{26}P_{10}K_{10}$) and the second,
agronomic/native species response to organic fertilizer (N₆P₈K₆). Fertilizer formulations were based on soil samples taken during 1990.

The agronomic mix trial involved a randomized complete block design with five 2m² replicates for 0, 1x, 2x and 3x applications of 336kg/ha of fertilizer. Vegetation cover was assessed for two years, and during this time period cover increased consistently on each treatment. In 1993, as expected, mean percent cover was lowest on the control (4%) and highest on the 3x treatment (30%). Creeping Red Fescue (cv. Boreal) and Slender Wheatgrass (cv. Revenue) were the dominant species.

The agronomic/native mix trial involved a randomized complete block design with three 5 x 5 m replicates for 0, 1x and 2x applications of 1344kg/ha of fertilizer. Vegetation cover was assessed for three years, and during this time period cover increased consistently on each treatment. In 1994, as expected, mean percent cover was lowest on the control (20%) and highest on the 2x treatment (70%). Dominance by Creeping Red Fescue (cv. Boreal), Slender Wheatgrass (cv. Revenue) and Timothy (cv. Climax) restricted growth of the native species. The best performing native species were Astragalus aboriginuni and Sitanion hystrix.

In addition to the experimental trials, anecdotal observations of vegetation cover response to N₂₇P₁₄K₁₀S₇ + micronutrients foliar fertilizer (fixed-wing aircraft application) were made. Increased vegetation cover, particularly for Alfalfa, was recorded.

Mid-Elevation:

In 1991, two trials were established on the 1660m Dump Failure to assess the long-term effectiveness of inorganic (N₂₆P₁₀K₁₀) and organic (N₆P₈N₆) fertilizers. Both experiments involved establishment of a latin square design with four 2m² replicates for each of the treatments (0, 1x, 2x, 3x). Vegetation cover was assessed annually, and during this time period, percent cover increased consistently on all treatments of each experiment. In 1994, as expected, mean percent cover was lowest on the control and highest on the 3x treatment in each experiment. Furthermore, only the control was significantly different. In general, percent cover was greater on the inorganic fertilizer experiment. Creeping Red Fescue (cv. Boreal), Sheep's Fescue (cv. Nakiska) and Redtop were the dominant species.

High Elevation:

At the high elevation research site, three fertilizer experiments were established in 1991. First, two agronomic trials were established on the 1820m Wolverine South Dump to assess the long-term effectiveness of single versus maintenance inorganic (N₂₆P₁₀K₁₀) fertilizer applications. Both experiments involved establishment of a latin square design with four 2m² replicates for each of the treatments (0, 1x, 2x, 3x). Vegetation cover was assessed annually. During this time period, percent cover increased in the first and second years but decreased in the third on all treatments in both experiments. In 1994, as expected, mean percent cover was lowest on the control and highest on the 3x treatments. Significant differences were recorded only between the controls and each of the 1x, 2x and 3x treatments. In 1994, percent cover on the single 3x
treatment cover was lowest on the control and highest on the 3x treatment in each experiment. Furthermore, only the control was significantly different. In general, percent cover was greater on the 3x maintenance (13%) than the 3x single application (9%). Creeping Red Fescue (cv. Boreal), Sheep's Fescue (cv. Nakiska) and Redtop were the dominant species.

Second, a native species organic fertilizer trial was established on the Wolverine South 1850m dump to evaluate the long-term effects of organic fertilizer on native species performance. Four maintenance fertilizer treatments 0, 1x, 2x, 3x (equivalent of 1344kg/ha) were established in a randomized block design. Each treatment contained five 5m² replicates of 56 species which were hand sown. Percent cover was assessed annually. In 1994, as expected, percent cover was greatest for the 3x treatment. However, the difference between the 2x (22%) and the 3x (9%) treatments were not significant. Species richness was lowest on the control and highest on the 3x treatment. However, richness was not significantly different between treatments 1x, 2x and 3x. Agropyron caninum, Agrostis scabra, Androsace septentrionalis, Astragalus aboriginum, Astragalus alpinum, Cerastium beeringianum, Festuca brachyphylla, Papaver kluanensis, Poa alpina, Poa pattersonii and Sitanion hystricx were the dominant species.

SUMMARY

Site and growing media variability required Quintette to undertake a comprehensive reclamation research program in the 1980s. Six general categories of research were required: (1) site preparation, (2) species selection, (3) seeding rates, (4) seed mixes, (5) application methods and (6) fertilizer applications. Site preparation techniques were studied and, as a result, operational practices such as harrowing, ripping and shaping were 'customized.' Agronomics were studied and several are considered suitable for different locations and on material types. Agronomic grasses such as Creeping Red Fescue (cv. Boreal), Sheep's Fescue (cv. Common) and Slender Wheatgrass (cv. Revenue) appear to be suitable for all locations while others have more site specific requirements. At present, the magnitude and frequency of viable seed production by these species at high elevations is not known. Agronomic legumes such as Alfalfa, Birdsfoot Trefoil, Cicer milkvetch and Sainfoin are suitable for the low and mid-elevation sites but do not persist at high elevations. The research undertaken in Alberta may resolve this problem.

A large number of native species have demonstrated an ability to establish and persist. At low and mid-elevations, species such as Eleagnis commutata, Pinus contorta, Populus balsamifera, Ribes hudsonianim, Rosa acicularis and Salix prolix have performed well while at high elevations, Arctostaphylos uva-ursi, Betula glandulosa, Dryas integrifolia and Salix arctica have shown promise. In addition, many native grasses, sedges and forbs such as Achillea millefolium, Astragalus aboriginum, Agropyron caninum, Festuca brachyphylla, Papaver kluanensis and Poa pattersonii have excellent potential at high elevation.

Also at high elevations, islands managed as foci for seed production and dispersal, will function as sources of native species colonists and as components of wildlife habitat. Seed for these 'islands' can be provided cost effectively if acquisition is balanced between the 'wild' populations and a multiplication area.
As well, seeding rates of 75 kg/ha appear to be optimal in terms of initial erosion control and succession facilitation. This seeding rate does not impose restrictions on future ‘biological space’ occupancy. Seed mixes must be balanced in terms of ecosystem function such as spatial and temporal resource use.

The fertilizer trials have demonstrated that a maintenance program in which application alternates every other year is appropriate for inorganic granular fertilizer. However, various formulations of organic-based fertilizers may provide benefits in terms of reduced application frequency. The use of liquid fertilizer may also be beneficial and cost effective.