Greenhouse Establishment of Alfalfa in Three Soil Materials Associated with Arizona Coal Mining[1]

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Abstract

The effects of three soil materials, three mulching treatments, and two moisture treatments on the growth and forage production of 'Vernal' alfalfa (*Medicago sativa* L.) for use in coal mine waste reclamation were studied in a 3-year experiment in the greenhouse at Tucson, Arizona. The three soil materials were: (1) Gila loam, (2) Unmined soil, and (3) Coal mine soil. The three mulching treatments were: (1) No mulch, (2) Barley (*Hordeum vulgare* L.) straw, and (3) Russian thistle (*Salsola kali* L.). The two soil moisture treatments were: (1) Optimum (60 cm total) and (2) Stressed (30 cm total).

Significant differences were observed in number of stems per pot, plant height, and forage yield between soil materials, mulching treatments, and soil moisture treatments. The greatest number of stems per pot, the tallest plants, and the highest forage yield were produced in the Gila loam, barley straw mulch, and optimum soil moisture treatment. Use of a soil mulch (incorporated organic matter mulch) produced better plant growth and more forage than when soils were not mulched. Barley straw was a more effective mulching material than was Russian thistle. Within soil materials and within mulching treatments forage yields were significantly higher with optimum soil moisture than they were when moisture was limited.

Additional Index Words: Mine Spoils, Revegetation, Stabilization, Disturbed Land, Environmental Pollution.

Introduction

As the demand for energy increases each year, an alternative source of energy is needed to relieve the dependency on oil. Coal takes a strong lead as this alternative source of energy due to its availability and relative abundance. However, as more pressure is placed on the coal industry to supply this commodity, increased pressure is also placed on the strip mines to minimize the deleterious effects of the mine wastes produced. Reclamation of these wastes, especially in semiarid regions where rainfall averages less than 25 cm per year, is needed to stabilize the waste material against wind and water erosion and to return the mined land to a productivity level equal to or greater than the original productivity level prior to mining.

Literature Review

The practice of applying mulch as a reclamation amendment has been utilized for many years. The application of mulch has many purposes: to help conserve moisture, to reduce surface temperature, and to control erosion (Barth, 1977). In addition, a mulch serves to build organic matter in the soil, to improve the soil structure, and increase resistance to surface crusting (Luellen, 1977). Hardwood bark mulch has been very effective in curtailing erosion (Franz, 1975). Sarles and Emanuel (1977) compared hardwood bark mulch with straw mulch and found the bark to be intermediate between straw and unmulched soil in the production of vegetative cover. Jones et al. (1975) found that by planting a fast growing species, such as wheat (*Triticum aestivum* L. em Thell.) or barley (*Hordeum vulgare* L.), disturbed land can be quickly stabilized with a ground cover while providing an "in-place" mulch for seeding permanent grasses and legumes.

While the feasibility of using Russian thistle as an "in-place" mulch may be studied, its desirability as a permanent reclamation ground cover would be questionable. In a semi-arid region such as northeastern Arizona, other plant species such as grasses and legumes, either native or introduced, would be more desirable. Power et al. (1978) reported that viable seed of native grasses is not readily available and when used may require over 3 years to become established on a disturbed site. They also reported that introduced species are easier to establish and often more tolerant of adverse conditions during establishment and initial growth; however, they may require more preparation to become established. Holechek (1981) has shown good initial establishment of alfalfa (*Medicago sativa* L.) as an introduced legume in mine spoils on the Northern Great Plains. Alfalfa has also produced high yields in sand tailings (Mislevy et al., 1981) and pyritic uranium tailings (Murray and Moffett, 1977). In addition to providing a high yielding vegetative cover, alfalfa has been shown to contribute to the nitrogen economy of disturbed soil when used on china clay wastes (Marrs et al., 1980).

The objectives of this research were to compare the growth and yield for Vernal alfalfa grown in three soil materials, with three mulching treatments, and with two soil moisture treatments in the greenhouse.

Materials and Methods

Research was conducted in the greenhouse at Tucson, Arizona from 1979 through 1981 to compare the effects of three soil materials, three mulching treatments, and two soil moisture levels on the growth and yield of 'Vernal' alfalfa.

The following soil materials were evaluated for their effect on the growth and yield of 'Vernal' alfalfa.

1. Gila loam soil without mulch (control).
2. Gila loam soil mulched with barley straw (control).
3. Gila loam soil mulched with Russian thistle (control).
4. Unmined soil without mulch.
5. Unmined soil mulched with barley straw.
6. Unmined soil mulched with Russian thistle.
7. Coal mine soil without mulch.
8. Coal mine soil mulched with barley straw.
9. Coal mine soil mulched with Russian thistle.

The Gila loam soil material used as a control was previously prepared by combining Gila loam soil with peat moss to improve its organic content in a ratio of 1:1 and pasteurizing by heating to 72°C. Gila loam soil is a member of the sandy-loam, mixed (calcareous), thermic Typic Torrifluvents. It is an excellent agricultural soil and is frequently used as a "check-soil" in greenhouse experiments.

The unmined soil was obtained from the surface of areas adjacent to but not included in the strip mining operations at Black Mesa Coal Mine near Kayenta, Arizona. This soil (Fruitland soil series), which belongs to the soil family of coarse-loamy, mixed (calcareous), mesic Typic Torriorthents, had experienced overgrazing and supported a sparse vegetative cover of native grasses, saltbush, and sagebrush on less than 25 cm of annual precipitation.

The coal mine soil was also obtained from the Black Mesa Coal Mine near Kayenta, Arizona. This soil was collected from freshly contoured strip mine overburden and consisted of particles ranging in size from silt to crushed sedimentary rock fragments 15 cm in diameter. At the time of collection, this overburden supported no vegetation.

Dried Russian thistle was gathered from representative surface mined areas at the Black Mesa Coal Mine. The Russian thistle and barley straw were reduced in size by a hammer mill with a 6 mm screen for use as an incorporated organic mulch material.

The mulched soil materials were prepared by adding one part of mulch to two parts of soil on a volume basis. The soil materials were placed in 20-cm clay pots. Vernal alfalfa was planted in each pot and thinned to four plants per pot after establishment. A watering schedule was maintained after establishment and for the duration of the experiment that insured that those pots that received optimum moisture (a total of 60 cm at the end of the experiment) were never stressed for soil moisture. The quantity of water applied and the frequency of application was such that the soil was not allowed to completely dry between waterings and the plants never showed signs of moisture stress.

Those pots that received insufficient soil moisture (a total of 30 cm at the end of the experiment) were maintained with only 50% of the optimum moisture levels. This lesser quantity of water applied did allow the soil to dry between waterings and the plants did show signs of moisture stress between applications.

The experimental design was a split-split-plot with soil materials as main plots, mulching treatments as sub-plots, and soil moisture treatments as sub-sub-plots with four replications. The plot size was one pot. At periodic intervals during the 3-year experiment, the forage in the pots was harvested and data were recorded. All data were analyzed using the standard analysis of variance and means were compared using the Student-Newman-Keuls' Test as described by Steel and Torrie (1960).

Results and Discussion

Analyses of the three soil materials used are given in Table 1. The pH of coal mine soil was lower than the pH of unmined soil or Gila loam soil. Plants that grow well in a less alkaline environment may be better adapted to this specific coal mine soil than plants that grow best under alkaline conditions. The ESP in all three soils was virtually non-existant, indicating that sodium should not present any problems. The total soluble salts in coal mine soil was much higher than in Gila loam or unmined soil. Salt sensitive plant species may be injured when grown in coal mine soil at the level of salt indicated. The nitrogen content (nitrate nitrogen) of coal mine soil was much higher than the nitrogen content of Gila loam and unmined soil. Lower nitrogen fertilizer applications would be needed for plants growing in coal mine soil than would be necessary for plants produced on unmined soil. The total amount of phosphorus in coal mine soil was lower than the phosphorus content of the other two soils. All three soils contained similar amounts of potassium which is sufficient for the growth of most plants. The organic matter of coal mine soil was higher than that of unmined soil, although lower than Gila loam. This higher figure may be the result of residual coal in the overburden from which the coal mine soil was derived.

Stems per pot, plant height, green forage yield, and dry forage yield for Vernal alfalfa grown in the greenhouse in three soil materials, with three mulching treatments, and with two soil moisture treatments are reported in Table 2.

Table 1: Average pH, $EC_e \times 10^3$, ESP, total soluble salts, nitrogen (N), phosphorous (P), potassium (K), sodium (Na), and organic matter (OM) in three soil materials in the greenhouse at Tucson, Arizona, in 1978.

Soil Material	pH	$EC_e \times 10^3$	ESP	Total Soluble Salts	N	P	K	Na	OM
				(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(%)
Gila loam	7.5	1.1	0	735	30	2.8	47	11	3.2
Unmined soil	7.4	0.9	0	658	16	2.5	11	8	1.2
Coal mine soil	7.1	8.0	0.6	5607	151	1.3	17	178	2.6

Comments:
1. K and Na were obtained by water soluble extraction and N and P were obtained by CO_2 extraction; pH was obtained by the paste method.

Table 2. Average number of stems per plot, plant height, green forage yield, and dry forage yield for Vernal Alfalfa grown in three soil materials, with three mulching treatments, and with optimum and stressed soil moisture treatments in the greenhouse at Tucson, Arizona, in 1978 through 1980 (3-year average).

Soil material	Mulching treatment	Soil moisture treatment	Stems per plot at harvest	Plant height	Green forage yield	Dry forage yield (12% moisture)
			(no.)	(cm)	(g)	(g)
Gila loam	Not mulched	Optimum	42 a+	45 a	42 a	11 a
		Stressed	27 b	36 b	21 b	6 b
	Barley straw	Optimum	55 a	51 a	64 a	16 a
		Stressed	40 b	39 b	49 b	13 b
	Russian thistle	Optimum	47 a	48 a	45 a	11 a
		Stressed	30 b	36 b	23 b	7 b
Unmined soil	Not mulched	Optimum	37 a	44 a	28 a	7 a
		Stressed	19 b	32 b	15 b	4 b
	Barley straw	Optimum	47 a	48 a	39 a	10 a
		Stressed	26 b	34 b	18 b	5 b
	Russian thistle	Optimum	39 a	46 a	32 a	8 a
		Stressed	24 b	33 b	16 b	4 b
Coal mine soil	Not mulched	Optimum	13 a	37 a	10 a	4 a
		Stressed	6 b	29 b	8 b	2 b
	Barley straw	Optimum	33 a	40 a	32 a	8 a
		Stressed	14 b	32 b	14 b	4 b
	Russian thistle	Optimum	24 a	40 a	19 a	5 a
		Stressed	12 b	32 b	10 b	3 b
Significance of differences:						
Between soil materials			*	*	**	**
Between mulching treatments			*	*	**	**
Between soil moisture treatments			*	*	**	**

* = Significant at the 5% level.
** = Significant at the 1% level.
\+ = Means followed by the same letter, within soil materials, within mulching treatments, and between soil moisture treatments are not different at the 5% level of significance using the Student-Newman-Keuls' test.

In the reclamation of mine wastes, the number of stems produced per plant is important. A high number of stems is desirable for providing a more complete ground cover and producing more forage per unit area. A significant difference was observed in the number of stems per pot between soil materials, between mulching treatments, and between soil moisture treatments (Table 2). Gila loam and barley straw mulch produced the highest number of stems per pot. Within soil materials and within mulching treatments, the average number of stems per pot were higher in the optimum soil moisture treatment than in the stressed soil moisture treatment. Taller plants are desired in coal mine reclamation because they provide better soil protection and higher forage yields than do shorter plants. The plant heights observed in the experiment were greater with Gila loam and barley straw mulch than they were with the other treatments (Table 2). Within soil materials and within mulching treatments, the average plant height was greater with optimum soil moisture than it was when plants were stressed for moisture.

Significant differences were also observed for forage yields among the soil materials tested and among the mulching treatments used (Table 2). Gila loam produced the highest forage yield followed by unmined soil and coal mine soil, in decreasing order. Among the mulching treatments, barley straw produced the highest forage yield and no mulch produced the lowest yield. Within the soil materials and within

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the mulching treatments, plants grown with optimum soil moisture conditions produced higher yields than did plants stressed for soil moisture.

Experiments in the greenhouse indicate that for optimum revegetation of disturbed land in a semiarid environment, the soil material should be mulched with an organic soil mulch and the plant cover should not be stressed for soil moisture during establishment.

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