AN EVALUATION OF METHODS FOR DETERMINING PASTURE AND HAY PRODUCTION ON RECLAIMED SURFACE MINES[1]

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Abstract--Before releasing a reclamation bond, regulatory agencies must estimate plant cover and aboveground biomass on the reclaimed site and compare it to a reference area to determine if acceptable vegetation exists. While most state regulatory agencies have adopted some method for measuring plant cover, no state has adopted a method for measuring vegetative or forage production (aboveground biomass). Nine methods for evaluating plant cover, composition, and aboveground biomass were selected to determine which, if any, of the methods would provide a simple, unbiased, repeatable, and accurate way of assessing aboveground biomass. Five of the methods involved visual estimation of certain plant parameters (Rennie-Farmer Cover, Quadrat Cover, Grass %, Legume %, Estimated Yield, and Quadrat Height), two methods indirectly measured aboveground biomass (Disk Meter and Probe), and one method directly measured aboveground biomass by clipping small plots (Quadrat Weight). The five visually-estimated methods were almost always significantly different among three observers when done on eight reclaimed sites in West Virginia. The vegetation on these sites differed in the amount of dead plant material, and species composition and density. Because of the unique characteristics of the vegetation on each site, some methods provided better estimates of aboveground biomass on particular sites than other methods. Quadrat Height (average height of the vegetation), Quadrat Weight (the weight of clipped forage in quadrats), and the Disk Meter were the three methods that showed high correlation with large clipped plots (Transect Weight). Estimated Yield showed good correlation to Transect Weight, while Rennie-Farmer Cover, Quadrat Cover, Grass %, Legume %, and the Probe showed poor correlation to Transect Weight. Since the Disk Meter correlated well to the weight of forage in mowed transects and does not involve visual estimation, it should be studied in more detail as a method for evaluating aboveground biomass on reclaimed surface mines.

[1]Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA. Published with the approval of the Director of the West Virginia Agricultural and Forestry Experiment Station as Scientific Article #2103. This research was supported with funds granted from the Office of Surface Mining Reclamation and Enforcement under contract number EC68-36306.

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INTRODUCTION

Revegetation Standards

Standards for determining successful revegetation of mined lands are set by Federal regulations as follows: "Success of revegetation shall be judged on the effectiveness of the vegetation for the approved postmining land use, . . . Ground

Proceedings America Society of Mining and Reclamation, 1988 pp 277-284

DOI: 10.21000/JASMR88020277

cover, production, or stocking shall be considered equal to the approved success standard when they are not less than 90 percent of the success standard. The sampling techniques for measuring success shall use a 90 percent statistical confidence interval (i.e., one-sided test with a 0.10 alpha error). For areas developed for use as grazing land or pasture land, the ground cover and production of living plants on the revegetated areas shall be at least equal to that of a reference area or such other success standards approved by the regulatory agency." (USDI 1983)

Evaluation of Ground Cover

By law, ground cover by plants must be measured for evaluating revegetation success on mined lands. Various methods are used by states with approved regulatory programs. The Office of Surface Mining Reclamation and Enforcement (OSMRE) conducted a field study to evaluate eight methods of determining ground cover (OSMRE 1987). Most of the methods used in the study were those that are approved in state regulatory programs in the eastern United States. The researchers found that all eight methods gave similar results. Some of the methods, however, were simpler and easier to understand than others. While the researchers did not make specific recommendations, it appears from their study that parts of different methods could be combined to increase sampling accuracy, precision, and effectiveness. The method for evaluating ground cover in West Virginia is called the Modified Rennie-Farmer procedure (explained in Methods), and has several advantages: 1) the method is simple, 2) the data are collected quickly, 3) the results are easily calculated, and can be analyzed statistically.

Evaluation of Plant Biomass

Determining aboveground biomass of plants on reclaimed land is a difficult task for regulatory agencies. Measurement of plant aboveground biomass is usually accomplished by clipping all the plant material in plots of predetermined dimensions (25 x 25 cm, 1 x 1 m, etc.). The plant material is placed in a paper bag, dried in a forced-air convection oven at 60°C to a constant weight, and weighed. The estimate of aboveground biomass is calculated by converting the dry weight of the material in the plot to kilograms per hectare. By clipping numerous plots, an average weight per unit area and a standard error can be calculated to determine the accuracy and precision of the sampling technique. This method has long been an accepted and effective practice for measuring aboveground biomass in hay fields, pastures, and rangeland.

Even though widely-used and accepted, clipping plots for estimating aboveground biomass by regulatory agencies has several disadvantages in terms of inspection and enforcement of laws related to revegetation of surface-mined lands. The three largest disadvantages of the method are: 1) the time required to clip 25 to 50 plots is excessive (this number of plots is usually necessary to obtain an adequate statistical sample), 2) the labor involved is intensive, tiresome, and tedious, and 3) special facilities are needed to dry and weigh the plant material.

An approach developed to reduce the time and effort required to clip all plots involves visually estimating the weight of aboveground biomass followed by clipping and weighing a portion of the plots. Typically, the worker estimates the weight of ten successive plots. After the visual estimate is made on the 10th plot, the worker "calibrates" his estimates by clipping and weighing the aboveground plant material in the plot. The value determined by clipping and weighing is compared to the estimated value, and the worker then makes adjustments to his estimates. By routinely clipping every 10th plot and "calibrating" the weight estimate, many individuals can become quite proficient in making reasonably accurate weight estimates. Others, however, are never quite able to make weight estimates with any degree of reliability (Mueller-Dombois and Ellenberg 1974, Stoddard et al. 1975). This method is particularly difficult for individuals who do not use it frequently. In the case of surface mine inspection, estimating forage biomass once or twice a month (even with calibration clippings) would produce results that would be variable, and possibly refutable by the coal operator.

An approach for measuring aboveground biomass without clipping plots is the disk meter (Baker et al. 1981). The governing principle of the disk meter is that aboveground biomass is highly correlated with height and density of the vegetation. The disk meter consists of a circular board or steel plate (up to 80-cm diameter) which freely slides up and down on a steel pipe. When the disk meter is dropped from a standard height onto the vegetation, the board is supported by the vegetation and its height on the steel pipe is measured. A limited number of plots are clipped and regression equations then relate the height of the disk meter to aboveground biomass.

Baker et al. (1981) studied the use of the disk meter on 40 mixed swards cut for hay in West Virginia. They divided the swards into 14 different categories corresponding to different proportions of grasses, legumes, and weeds in the sward. The researchers reported the slopes of the regression lines for the different cate gories were not significantly different. However, questions have been raised con cerning the disk meter's suitability for measuring aboveground biomass on mined lands. Mined lands produce vegetation with wide variations in species composition, density and height.

Palazzo and Lee (1986) used two different sized disk meters (45 and 60 cm diameter) to predict plant biomass of a pure stand of K-31 tall fescue (*Festuca arundinaceae* Schreb.) and a pure stand of sericea lespedeza (*Lespedeza cuneata* (Dumont) G. Don.) on reclaimed mined lands. The disk meter height to biomass weight relationship was highly variable, and was best within individual sampling days. Across all seasons, the linear correlation (r) between disk meter height and biomass was 0.61 for lespedeza stands and 0.78 for tall fescue stands.

Capacitance meters have been used for biomass estimates for many years and are another method for measuring aboveground biomass. These meters are based upon electrical principles. The term "capacitance" describes the amount of electrical charge stored by two conductors (or plates) separated by an insulator (or dielectric). The amount of capacitance is determined by the surface area of the conductors and the resistance of the insulator.

The Pasture Probe™ is a portable, microprocessor-controlled capacitance meter, designed to measure and record pasture biomass in practical field applications (Design Electronics LTD 1985). In the Pasture Probe™ the central earth spike and the outer aluminum tube are the two plates of the capacitor, and the air and the perspex spacer (in the aluminum tube) form the dielectric. The device introduces an electric charge (or capacitance) into the circuit. An air reading provides a reference level of capacitance against the reading of the probe when it is placed on the ground. Changes in capacitance (due to the surface area and amount of green vegetation and biomass) cause the frequency of the signal to change. The change in frequency is converted to biomass through mathematical relationships.

Two recent studies (Crosbie et al. 1985, Richardson 1984) have been conducted with the Pasture Probe™. Crosbie et al. (1985) compared the Pasture Probe™ with other direct and indirect methods of measuring dry matter and reported the following conclusions:

1) the probe readings were sensitive enough to delineate between pasture grazing treatments;

2) the precision of the probe was at least as good as that of other methods currently used;

3) large labor savings were evident when the probe was used instead of direct methods such as mowing and quadrat cutting.

There is a need to assess the use of direct (quadrat clipping) and indirect methods (cover estimates, height estimates, biomass estimates, disk meter, and Pasture Probe™) in measuring aboveground biomass on surface-mined lands. In order to demonstrate the application, effectiveness, and accuracy of these methods in predicting aboveground biomass on surface-mined lands, a research project was conducted using eight reclaimed sites in WV. The objective of this investigation was to determine the precision and suitability of each technique for predicting aboveground biomass in order to assist regulatory agencies in determining revegetation success and granting bond release.

MATERIALS AND METHODS

Study Sites

Eight surface-mined areas in West Virginia were selected as research sites based on location, coal seam, overburden, date mined and reclaimed, mining method, length of time since seeding, and revegetation techniques (lime, fertilizer, and seeded species). This was done to obtain a cross-section and variety of mined areas and reclamation techniques.

Sampling Methods and Analyses

Four transects of 100 m were randomly located on each site. Every 10 m along the transect, eight measurements or estimates were made by three observers. Each observer carried a separate data sheet for recording estimates, and no discussion took place during visual estimates (methods 1 through 5). The observers were agronomy and forestry graduate students with good backgrounds in plant identification. The measurements were made in the following order.

1) Rennie-Farmer Cover

A round, 1-cm diameter, 113-cm long dowel with 20 equally-spaced ring marks was placed perpendicular to the transect line and inserted into the vegetation. Each of three observers recorded the number of "hits" at each sampling point. A hit occurred when living vegetation was found directly above, below, or touching the mark on the dowel. A count of 20 was possible at every sampling point.

2) Quadrat Cover

A quadrat measuring 50 x 50 cm (0.25 m^2) was placed on the left side of the transect line, and each observer visually estimated the total amount of plant cover in percent.

3) Quadrat Botanical Composition

In the same 0.25 m^2 quadrat as in (2), each observer estimated the botanical composition. The categories were Grass %, Legume %, and Weed %.

4) Estimated Yield

In the quadrat, each observer visually estimated the fresh weight of the plant material inside the quadrat. (After the material in the quadrat was clipped as described in Method 8, the fresh plant material in every third quadrat was weighed with a portable scale and observers were able to "calibrate" their visual biomass estimates).

5) Quadrat Height

A meter stick was placed in the center of the quadrat which each observer used to estimate the average height of the vegetation in the quadrat.

6) Pasture Probe™ Reading

Pasture Probe™ readings were taken in 10 places in a systematic grid pattern within each quadrat which gave an average corrected meter reading for each quadrat. This average reading was recorded.

7) Disk Meter Reading

The disk meter (50-cm diameter) was placed in the center of the quadrat and dropped onto the vegetation. The height of the disk was recorded in cm.

8) Quadrat Weight

After all estimates and readings had been taken, all biomass 1 cm above ground level in the quadrat was clipped and placed in a labelled paper bag.

A 65-cm wide swath of vegetation was mowed at approximately 1 cm above ground level along each 100-m transect line with a sickle-type mower. The plant material mowed in this swath was raked together and placed in labelled gunny sacks. The weight of forage collected in these mowed transects (called Transect Weight) was used as the target weight or control to which all other methods were evaluated.

All plant material clipped in quadrats or mowed along transects was transported to large drying ovens and dried at 60°C for 3 to 4 days and weighed to determine dry weight.

Cover, botanical composition, height and yield estimates by each observer were analyzed by analysis of variance to determine the variability among observers for estimated parameters (Rennie-Farmer Cover, Quadrat Cover, Grass %, Legume %, Estimated Yield, and Quadrat Height). After analyzing for differences among observers, the estimates were averaged for each quadrat and the average value for each visually estimated method were combined into a data set with the other methods (Pasture Probe™, Disk Meter, and Quadrat Weight) for analysis of variance, multiple regression, stepwise regression, and correlation with Transect Weight. The analysis was conducted using the Statistical Analysis System (SAS) at West Virginia University.

RESULTS AND DISCUSSION

Differences between three observers was significant with most methods and on many of the sites (table 1). The methods showing the least variation among observers in this study were the estimates of Grass % and Quadrat Cover. The methods that produced the most variable values among observers were Quadrat Height and

Table 1--Significance of differences between three observers in their visual estimates of cover and aboveground biomass using six methods on each reclaimed site.

	Site							
Method	CM	DP	GR	GS	KK	LR	HD	HQ
Rennie-Farmer	NS[1]	**[2]	*	**	**	NS	*	**
Quadrat Cover	NS	*	**	NS	**	NS	NS	NS
Grass %	NS	NS	NS	NS	NS	NS	*	NS
Legume %	**	NS	NS	*	NS	*	**	**
Estimated Yield	**	**	*	*	*	**	**	NS
Quadrat Height	**	**	*	**	**	**	**	**

[1]Values estimated by three observers were not significantly different between observers.

[2]Values estimated by the three observers were significantly different at $p < 0.05$ (*) or $p < 0.01$ (**).

Estimated Yield. Since the vegetation on the sites differed in the amount of standing dead plant material, dead plant material lying on the ground, and the composition and density of living vegetation, it is not surprising that variation was high among observers. This finding demonstrates that visual estimates (even when looking at the same vegetation in a particular plot) are highly variable among individuals. Considerable variation existed even when the observers had good scientific backgrounds.

Because characteristics of the vegetation were different for each site, each method was independently compared to Transect Weight on each site (table 2). Some methods on certain sites predicted Transect Weight well, while other methods did not. For example, aboveground biomass as determined by mowing on Camden (CM) was best predicted by Estimated Yield, Quadrat Weight, and the Disk Meter. Prediction of Transect Weight by these methods on Gumspring (GS) was similar to CM. However, no method adequately predicted Transect Weight on Dippel (DP) and Laurita (LR). Five methods correlated well with Transect Weight on the Hodrag (HO) site. Estimated Yield, the Disk Meter, and Quadrat Weight correlated well with Transect Weight on three sites, while Rennie-Farmer Cover, Quadrat Height, and the Probe correlated well with forage weight in mowed transects on two sites.

Table 3 shows a matrix of partial correlation coefficients (r) between each pair of methods. There are several meaningful relationships. For example, the data show a high correlation (.74) between Estimated Yield and Quadrat Height. Other high positive correlations involve Quadrat Height with the Disk Meter (.67), and with Quadrat Weight (.70). The Disk Meter and Quadrat Weight are also related (.63). Estimated Yield is also related to Quadrat Weight (.68).

In order to find an appropriate method of measuring aboveground biomass for bond release, it is critical that the method be applicable to a wide range of sites. It has already been shown that only three methods correlated well with Transect Weight on three or more sites. It is important to determine the relationship of each method to Transect Weight across all sites.

Quadrat Height, Quadrat Weight, the Disk Meter, and Estimated Yield show high correlation with Transect Weight in this study (table 4). Although the correlation coefficient (r) for each of these four methods is 0.80 or higher, a demonstration calculating predicted values of aboveground biomass and its variation for several of the methods should be done, and compared to actual Transect Weight.

The equations are taken from table 4.

Predicted aboveground biomass = 982.4 + 296.7 (Quadrat Height)

Predicted aboveground biomass = -439.4 + 792.1 (Disk Meter Height)

Predicted aboveground biomass = -5213.6 + 135.7 (Quadrat Cover)

Calculating aboveground biomass is based on the average value across all sites and are 20.5 cm Height, 9.5 cm for Disk Meter. and 90.4% on Quadrat Cover. Predicted biomass values are 7065, 7085, 7053 g/transect, respectively. Multiplying these numbers by .15385 will convert from g in

Table 2--Coefficient of determination (r^2) between the values from each method for predicting aboveground biomass and the weight of forage in mowed transects (Transect Weight) on each reclaimed site.

	SITE							
Method	CM	DP	GR	GS	KK	LR	HD	HO
Rennie-Farmer	.41	.42	.96**[1]	.54	.41	.35	.89*	.37
Quadrat Cover	.50	.63	.40	.67	.01	.36	.90*	.50
Grass %	.23	.40	.03	.56	.60	.14	.24	.08
Legume %	.23	.33	.95**	.65	.25	.28	.16	.11
Estimated Yield	.94**	.77	.01	.43	.11	.47	.83*	.92*
Quadrat Height	.59	.54	.02	.79*	.01	.21	.33	.99**
Probe	.70	.62	.01	.22	.88*	.24	.46	.92*
Disk	.78*	.52	.11	.95**	.01	.16	.61	.97**
Quadrat Weight	.85*	.23	.01	.99**	.06	.68	.74	.98**

[1]The r^2 value is significant at this site at $p < 0.05$ (*) or $p < 0.01$ (**).

Table 3--Matrix of partial correlation coefficients (r) between each pair of methods for predicting aboveground biomass across all sites.

Method	RF	QC	G%	L%	EY	QH	P	D	QW
	Partial Correlation Coefficients[1] — Methods								
Rennie-Farmer (RF)	--	.68	-.07	.13	.26	.26	.37	.27	.29
Quadrat Cover (QC)	.68	--	-.14	.16	.51	.47	.40	.45	.50
Quadrat Grass % (G%)	-.07	-.14	--	-.87	-.11	-.05	-.05	-.05	-.08
Quadrat Legume % (L%)	.13	.16	-.87	--	.18	.08	.09	.02	.07
Estimated Yield (EY)	.26	.51	-.11	.18	--	.74	.43	.59	.68
Quadrat Height (QH)	.26	.47	-.05	.08	.74	--	.35	.67	.70
Probe (P)	.37	.40	-.05	.09	.43	.35	--	.35	.37
Disk (D)	.27	.45	-.05	.02	.59	.67	.35	--	.63
Quadrat Weight (QW)	.29	.50	-.08	.07	.68	.70	.37	.63	--

[1]Any partial correlation coefficient value greater than .113 is signiicant at the $p < 0.05$, and .148 is significant at the $p < 0.01$.

the transect to kg/ha, or 1087, 1090, and 1085 kg/ha, respectively. Confidence intervals associated with each regression equation (using the standard error for the intercept and slope) can be calculated. Once a range is calculated, the assumption is made that a particular method will predict Transect Weight at some level of confidence. For example, using the data collected from these eight sites and with a value of 20.5 cm in Quadrat Height, aboveground biomass will fall between 6588 to 7542 g/transect (1013 to 1160 kg/ha) 90% of the time. Calculating 90% confident intervals gives ranges of (using the same mean values for Disk Meter and Quadrat Cover as above), 990 to 1190 kg/ha for the Disk Meter, and 581 to 1629 kg/ha for Quadrat Cover. By comparison, the mean value for Transect Weight across all sites was 7085 g/transect or 1085 kg/ha.

A statistical procedure called Stepwise Regression (using the Statistical

Table 4--Correlation coefficients (r) between each method for predicting aboveground biomass and Transect Weight across all sites, and the linear regression equation associated with each method.

Method	r	Significance[1]	Intercept	STD Error of Intercept	Slope	STD Error of Slope
Rennie-Farmer	.43	*	-10454.3	6744.7	920.5	353.6
Quadrat Cover	.44	*	- 5213.6	4582.2	135.7	50.4
Grass %	.04	NS	6739.3	1714.2	5.6	28.6
Legume %	.02	NS	7159.8	1078.3	-2.9	26.9
Estimated Yield	.82	**	2071.6	710.2	34.2	4.4
Quadrat Height	.87	**	982.4	686.9	296.7	31.0
Probe	.51	*	771.6	1993.4	46.2	14.2
Disk	.84	**	-439.4	923.8	792.1	92.8
Quadrat Weight	.85	**	1811.0	659.0	122.2	13.9

[1]Significance is at $p < 0.05$ (*) or $p < 0.01$ (**) or not signficant (NS).

Analysis System) was used to find which one or combination of methods best predicts Transect Weight. The forward selection technique in the Stepwise Regression analysis begins with no variables in the model. For each independent variable (the various methods) the analysis calculates the variable's contribution to the prediction equation when included. This analysis then adds the variable that removes the greatest amount of variation. The independent variables (or methods) are added sequentially until no variables remain (Ray 1982).

The analysis showed that 75% of the variability in Transect Weight could be explained by determining the average Height of the vegetation (table 5). Rennie-Farmer Cover was next in the model and contributed only 4% more to the prediction of Transect Weight beyond Quadrat Height alone. Quadrat Height measurements varied widely among observers (table 1) and across sites (table 2), so it was removed as a variable. Quadrat Weight was then selected by the Stepwise procedure. Clipping plots, even small quadrats, for assessing revegetation success by regulatory agencies has several disadvantages as noted earlier, so Quadrat Weight was also removed from the variable list. Stepwise then selected the Disk Meter which accounted for 70% of the variation in Transect Weight across all sites.

SUMMARY AND CONCLUSIONS

When estimating vegetation parameters in the same 0.25-m^2 quadrat, three observers were almost always significantly different in their estimates which demonstrates that visually estimated techniques for assessing aboveground biomass are highly variable. Two cover estimation

Table 5--Stepwise selection of methods used in this study to predict Transect Weight.

	Variable	Number of Variables in Equation	Partial R^2	Total R^2	Significance[1]
1.	Quadrat Height	1	.753	.753	**
2.	Rennie-Farmer	2	.040	.793	*
3.	Quadrat Grass %	3	.032	.825	*
4.	Quadrat Yield	4	.023	.848	NS
5.	Quadrat Weight	5	.009	.857	NS
6.	Probe	6	.004	.861	NS
7.	Disk	7	.003	.864	NS
8.	Quadrat Cover	8	.001	.865	NS
9.	Quadrat Legume %	9	.000	.865	NS
	Same analysis except without Quadrat Height				
1.	Quadrat Weight	1	.721	.721	**
2.	Quadrat Yield	2	.064	.785	**
3.	Disk	3	.050	.835	**
4.	Quadrat Legume %	4	.018	.853	NS
5.	Probe	5	.005	.858	NS
6.	Quadrat Cover	6	.002	.860	NS
7.	Rennie-Farmer	7	.002	.862	NS
8.	Quadrat Grass %	8	.001	.863	NS
	Same analysis except without Quadrat Height and Quadrat Weight				
1.	Disk	1	.708	.708	**
2.	Quadrat Yield	2	.125	.883	**
3.	Quadrat Legume %	3	.017	.850	NS
4.	Probe	4	.004	.854	NS
5.	Rennie-Farmer	5	.001	.854	NS
6.	Quadrat Cover	6	.001	.855	NS
7.	Quadrat Grass %	7	.001	.856	NS

[1]Significance is at $p < 0.05$ (*), $p < 0.01$ (**), or not significant (NS).

methods (Rennie-Farmer Cover and Quadrat Cover) did not correlate well with mowed transects except on one site. Estimating Grass % or Legume % was not as highly variable among observers as other estimation methods, but the methods also did not correlate with the mowed transects. Estimated Yield and Quadrat Height (both estimated by observers) were the two most variable methods among observers, but were two of the four best methods used in this study to predict Transect Weight. Quadrat Weight (clipping small quadrats) showed good correlation to Transect Weight. The Pasture Probe™ showed poor correlation to Transect Weight. The Disk Meter showed good correlation between its height and the weight of vegetation mowed in transects. Since the Disk Meter does not involve visual estimation and high observer variability, it should be studied in more detail as a method that may be adopted for aboveground biomass evaluation on reclaimed surface mines.

ACKNOWLEDGMENTS

The author gratefully acknowledges the valuable assistance of Ms. Silva Strazds throughout the course of this study. Appreciation is also extended to Drs. John Sencindiver, William Bryan, and Barton Baker of West Virginia University for serving as reviewers and making helpful suggestions. Special thanks are given to the following individuals who allowed access and use of their reclaimed surface mined lands for this study: Mr. Charlie Miller, Mr. Frank Dippel, Mr. John Garlow, Mr. Brian Osborn, Mr. Brownie Stuart, and Mr. Larry Emerson.

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