EVALUATION OF METHODS TO DETERMINE PLANT PRODUCTIVITY FOR BOND RELEASE[1]

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Abstract. State regulatory authorities (SRAs) must evaluate the amount of 1) plant cover and 2) production on revegetated areas and compare them to reference areas or a technical standard to determine if acceptable vegetation exists for reclamation bond release. While most SRAs have adopted a method to evaluate ground cover by plants, only a few SRAs have established a method for determining production. In this study, six methods for predicting aboveground biomass were used to determine if one or more methods would provide an accurate way of assessing aboveground biomass. Correlations were determined between five methods (visual estimation methods were quadrat cover, estimated yield, and average height; indirect methods were disk height and probe) and the dry weight of forage clipped from small (0.25 m^2) and large (62 m^2) plots on eight reclaimed sites in West Virginia. Forage weight from small plots was also compared to forage weight from large plots. The visual estimations were made by three individuals and their estimates were analyzed for variance. Results showed significant differences among the observer's estimates indicating that these estimation methods would not be dependable for determining revegetation success. Disk height, and averages of average height and estimated yield were significantly correlated with forage dry weight from small and large plots ($r = 0.74$ to 0.87), while cover and probe readings had r values of 0.43 and 0.51, respectively. Small plot clipping was highly correlated to field yields ($r = 0.85$) and especially on five out of eight sites, but overestimated field yields by 35%. Disk height and small plot clipping are the only two methods used in this study that can be recommended for evaluating aboveground biomass for revegetation success.

Additional Key Words: Revegetation, reclamation, aboveground biomass determination, phase II bond release

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Introduction

Standards for determining successful revegetation of mine lands require that both cover and production

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of living plants on revegetated areas shall not be less than 90 percent of a reference area or other success standard approved by the regulatory authority (USDI 1983). Most states with approved regulatory programs have adopted some method for evaluating ground cover and, in a recent study by OSMRE (1987), eight of these methods were compared and gave similar results. However, determining production or aboveground biomass of the ground cover on reclaimed land for bond release is more difficult for state regulatory agencies (SRAs), and few SRAs have adopted a method.

Aboveground biomass can be determined by mowing an entire field, baling the material, and calculating the weight of the forage. More commonly, assessment of aboveground biomass is done by clipping the plant material in a number of small plots, drying, and weighing. By clipping numerous plots, an average weight per unit area and a standard error can be calculated. This method has long been an accepted practice for estimating aboveground biomass in hay fields, pastures, and rangeland (Stoddard et al. 1975). Three disadvantages of the method cited by SRAs are: 1) the time required to clip a number of plots is excessive, 2) the labor involved is intensive, tiresome, and tedious, and 3) special facilities are needed to dry and weigh the plant material.

A quicker method involves visually estimating the fresh weight of aboveground biomass in a plot followed by clipping and weighing some of the plots (Pechanec and Pickford 1937). Typically, the worker estimates the weight of ten successive plots, then after the visual estimate is made on the tenth plot, the worker "calibrates" his estimates by clipping and weighing the aboveground plant material in the tenth plot. Many individuals become proficient in making reasonably accurate weight estimates while others do not make reliable estimates (Mueller-Dumbois and Ellenberg 1974, Stoddard et al. 1975).

Double sampling techniques measure plant characteristics and correlate these attributes with clipped weights. Ground cover has been shown to range from no correlation ($r = -0.16$) to good correlation ($r = 0.70$) with biomass (Griggs and Stringer 1988, Pasto et al. 1957). Sward height of alfalfa in Pennsylvania was highly correlated ($r = 0.89$) with aboveground biomass (Griggs and Stringer 1988), and a correlation coefficient of 0.81 was determined between sward height and biomass of a mixed sward in Australia (Michalk and Herbert 1977). Similar relationships have been found in other studies with height, and when combining cover and height as a variable (Alexander et al. 1962, Evans and Jones 1958, Heady 1957, Pasto et al. 1957, Shrivastava et al. 1969, Whitney 1974).

The disk meter is another method of measuring aboveground biomass without clipping many plots (Baker et al. 1981, Bransby et al. 1977) and has shown a high correlation with height and density (bulk) of the vegetation. It is necessary to clip a limited number of plots and develop regression equations between disk height and aboveground biomass on each site for each season (Karl and Nicholson 1987, Palazzo and Lee 1986). Baker et al. (1981) reported that the slopes of the regression lines for disk height and biomass on 40 mixed swards in West Virginia were not significantly different. Palazzo and Lee (1986) found that disk height correlations to biomass on reclaimed sites were best within individual sampling days. Linear correlation (r) between disk height and biomass was 0.61 for sericea lespedeza (_Lespedeza cuneata_ (Dumont) G. Don.) stands and 0.78 for tall fescue (_Festuca arundinacea_ Schreb.) stands.

Capacitance meters (probes) are based on electrical principles and have been used for biomass estimates for many years (Neal and Neal 1973). Crosbie et al. (1985) compared a single probe capacitance meter with other methods of measuring biomass and reported that the probe readings were sensitive and could delineate between pasture grazing treatments (Richardson 1984). Currie et al. (1987), however, found the values obtained from a single probe capacitance meter to be quite variable and the probe appeared to respond to vegetation attributes other than surface area. They also found that a single regression equation did not relate probe readings to aboveground biomass as had been suggested by others (Vickery et al. 1980).

Because methods for determining production to evaluate revegetation success on mine sites have not been established, this research study compares several methods for estimating aboveground biomass on eight reclaimed surface mine sites in West Virginia. The objectives were to determine the accuracy of six techniques for predicting aboveground biomass for use by SRAs in determining revegetation success for bond release.

Study Sites and Methods

Eight surface mines in West Virginia were selected as research sites (Table 1). All sites had been seeded with a pasture seed mix composed of tall fescue, orchardgrass (_Dactylis glomerata_ L.), ryegrass (_Lolium perenne_ L.), birdsfoot trefoil (_Lotus corniculatus_ L.), and clovers (_Trifolium_ spp.); they

Table 1. Characteristics of eight reclaimed surface-mine sites in West Virginia.

	SITES							
Characteristic	(CM) Camden	(DP) Dippel	(GR) Garlow	(GS) Gumspring	(KK) King Knob	(LR) Laurita	(HD) Hodrag	(HO) Hobold
Location (County)	Lewis	Monongalia	Monongalia	Monongalia	Monongalia	Monongalia	Boone	Boone
Coal seam	Redstone	Waynesburg	Sewickley	Freeport	Waynesburg	Sewickley	Stockton	Stockton
Overburden composition[1]	SH = 50% SS = 30% MS = 15% LS = 5%	MS = 30% SS = 70%	SH = 50% SS = 40% LS = 10%	SS = 80% SH = 20%	SS = 80% SH = 20%	SH = 50% SS = 40% LS = 10%	SS = 50% MS = 50%	SS = 50% MS = 50%
Date mined	1979	1978	1973	1982	1978	1979	1983	1980
Mine method[2]	B - L	B - L	Drag	B - L	B - L	B - L	Drag	B - L
Date reclaimed	1981	1980	1976	1985	1980	1981	1985	1982

[1]LS = limestone, MS = mudstone, SH = shale, SS = sandstone
[2]B - L = bulldozers and front-end loaders, Drag = dragline.

had not been grazed or mowed prior to the study. Lime and fertilizer had been applied according to soil test recommendations. Most mining companies wait until near the end of the growing season to obtain the maximum forage accumulation before requesting a revegetation evaluation by the SRA for bond release. Therefore, all sites in this study were sampled in September 1987.

Four transects of 100 m were randomly located on each site. Every 10 m along the transect line, visual estimates were made by three observers. Each observer carried a separate data sheet for recording his/her estimates, and no discussion took place during visual estimates. The observers were two agronomy graduate students and a professor. They all had experience in making vegetation evaluations before the project started. After estimates were made, probe and disk readings were taken, followed by clipping. To reduce error, the same individual performed the same task on all the sites (i.e., one person placed the quadrat, stick, and disk; another person took all readings with the probe; and one individual did all the clipping). The measurements were conducted in the following order these specifications:

1) Quadrat cover

A quadrat measuring 50 x 50 cm (0.25 m^2) was placed on the left side of the transect line. Each observer visually estimated the percent of ground cover by plants inside the quadrat.

2) Estimated yield

Each observer visually estimated the fresh weight (g) of the plant material inside each quadrat. (After the material in the quadrat was clipped as described in Method 6, the fresh plant material in every third quadrat was weighed with a portable metric scale and observers were able to "calibrate" their visual estimated yields).

3) Average height

A meter stick was placed in the center of the quadrat. Each observer used the meter stick to estimate the average height (cm) of the vegetation in the quadrat.

4) Probe

Probe readings were taken by one individual in 10 systematic places within each quadrat that gave an average corrected meter reading (CMR) for each quadrat.

5) Disk

A disk meter (50 cm diameter and 1.9 kg) was placed in the center of the quadrat and dropped onto the vegetation by one individual. The height of the disk (cm) was read.

6) Quadrat weight

After all estimates and readings had been taken, all biomass 1 cm above ground level in the quadrat was hand clipped, dried at 60°C for three

Table 2. Significance of differences among three observers in their visual estimates of quadrat cover, estimated yield, and average height on eight reclaimed sites in West Virginia.

	Site							
Method	CM	DP	GR	GS	HD	HO	KK	LR
Quadrat cover	NS	*	**	NS	NS	NS	**	NS
Estimated yield	**	**	*	*	**	NS	*	**
Average height	**	**	*	**	**	**	**	**

NS = non significant, * = $P < 0.05$, ** = $P < 0.01$.

days, and weighed.

Visual estimates of cover, yield, and height were analyzed by analysis of variance to determine the variability among observers. The three visual estimates were then averaged for each quadrat, combined into a data set with probe and disk height readings, and linear regression was used to fit the relationships between quadrat weights and values obtained by the five methods.

Forage from large areas (65 m^2) along the side of each transect on each site was also harvested with a sickle-type mower, raked together, and placed in large gunny sacks. The material from the large plots was also dried and weighed, and linear regression was used to compare the values obtained from the five methods and small plot forage weights to large plot weights. Correlation coefficients for each relationship were also determined (Ray 1982).

Results and Discussion

Variation Among Observers

Estimates made by three observers for quadrat cover, estimated yield, and average height were significantly different on most study sites (Table 2). The estimates of quadrat cover showed the least variation among observers in our study. Variation in visual estimates was expected but not to the degree that was found in the study. Reasons for such high variation among observers are not totally clear, especially when considering that the observers were looking at the same small plot at the same time and making their judgments. For example, when estimating average height of vegetation in the quadrat, the observer needed to account for all vegetation in the quadrat and assign one average height value. It was evident that different types of vegetation, bare areas, and the observer's location in relation to the quadrat surely introduced subjectivity into the estimate. Estimated yield was also very subjective, and the estimates made by the observers were often not accurate compared to the weight of clipped forage as shown in the examples in Table 3. These results demonstrate that visual estimates, even when made on the same vegetation in a small plot, were highly variable among individuals. Considerable variation existed even when the observers had frequent chances to "calibrate" their estimates and experience that should have helped them make accurate estimates.

The fact that the estimates made by the observers resulted in significantly different values suggests that methods which require estimation to predict aboveground biomass for bond release are not very reliable. Reliability and repeatability are two criteria that are necessary when selecting a method to determine revegetation success. In order to assess the accuracy of these estimation methods in predicting clipped forage weights, the average of the three observer's values were calculated for each quadrat and compared to the clipped weights.

Comparison Among Methods

Relationships between each method of measuring aboveground biomass and the dry weight of clipped forage in small 0.25 m^2 plots are shown in Figure 1 using the data from all sites ($n = 320$). Average height ($r = 0.81$), disk height ($r = 0.76$), and estimated yield ($r = 0.74$) showed the highest correlations ($p < 0.01$) with the dry weight of clipped forage in small plots. Quadrat cover and the probe showed significant but lower correlations ($p < 0.05$) with quadrat weight ($r = 0.43$ and 0.48, respectively). The same trends were evident when the data was correlated to the forage weight from large plots ($n = 32$) (Figure 2).

Our results compared favorably to

Table 3. An example of the estimated yields of forage in 0.25 m^2 quadrats made by three observers, and the average of the three estimates compared to the measured fresh weight after clipping of selected quadrats on two reclaimed sites in West Virginia.

Location	Estimated yield Observer 1	2	3	Ave	Actual fresh weight
S-T-Q[1]	g/.25m^2				
CM-1-3[2]	280	340	285	301	440
1-6	220	280	100	200	140
1-9	200	180	185	188	180
2-3	260	130	140	177	165
2-6	180	190	130	167	160
2-9	120	100	140	120	130
3-3	90	125	90	102	110
3-6	130	110	130	123	130
3-9	140	120	130	130	120
4-3	80	80	95	85	85
4-6	110	140	100	117	105
4-9	80	50	100	77	70
Ave	158	154	135	149	153
HO-1-3	50	25	50	42	35
1-6	40	35	45	40	60
1-9	90	110	95	98	130
2-3	40	35	80	52	30
2-6	160	130	120	139	150
2-9	210	280	325	272	310
3-3	300	230	275	268	140
3-6	200	290	220	237	200
3-9	240	160	190	197	105
4-3	100	75	60	78	60
4-6	180	165	130	158	120
4-9	60	45	150	85	125
Ave	139	132	145	137	126

[1]Site-Transect-Quadrat

[2]Differences among observers were significantly different on CM but not on HO.

many studies in the literature using similar techniques. Ground cover by plants was not closely correlated to clipped weights in this study which agreed with other studies (Griggs and Stringer 1988, Pasto et al. 1957), while sward height has generally shown a much better relationship to aboveground biomass (Michalk and Herbert 1977). Probe readings were not highly correlated to clipped forage in this study, and Currie et al. (1987) found correlation coefficients ranged from 0.50 to 0.80 between probe readings and forage weights on Montana rangelands. It is not clear why the probe did not predict aboveground biomass better in this study, but it should be noted that the probe showed higher correlations with clipped weights on sites where the plant material was less than 15 cm tall.

The disk meter has been used in many places and under many conditions to predict aboveground biomass, and our results revealed that the method worked reasonably well on surface mine sites. Table 4 gives the linear regression equation and correlation coefficient for our eight sites in West Virginia. Correlation of disk height with forage weight from small plots resulted in accurate estimates of aboveground biomass on almost all of our sites. Note that the correlation coefficients were all above .50 except for the KK site.

When comparing disk height measurements to the forage weight obtained from large plots, the same pattern was evident (Table 4). Disk heights from three of the sites did not

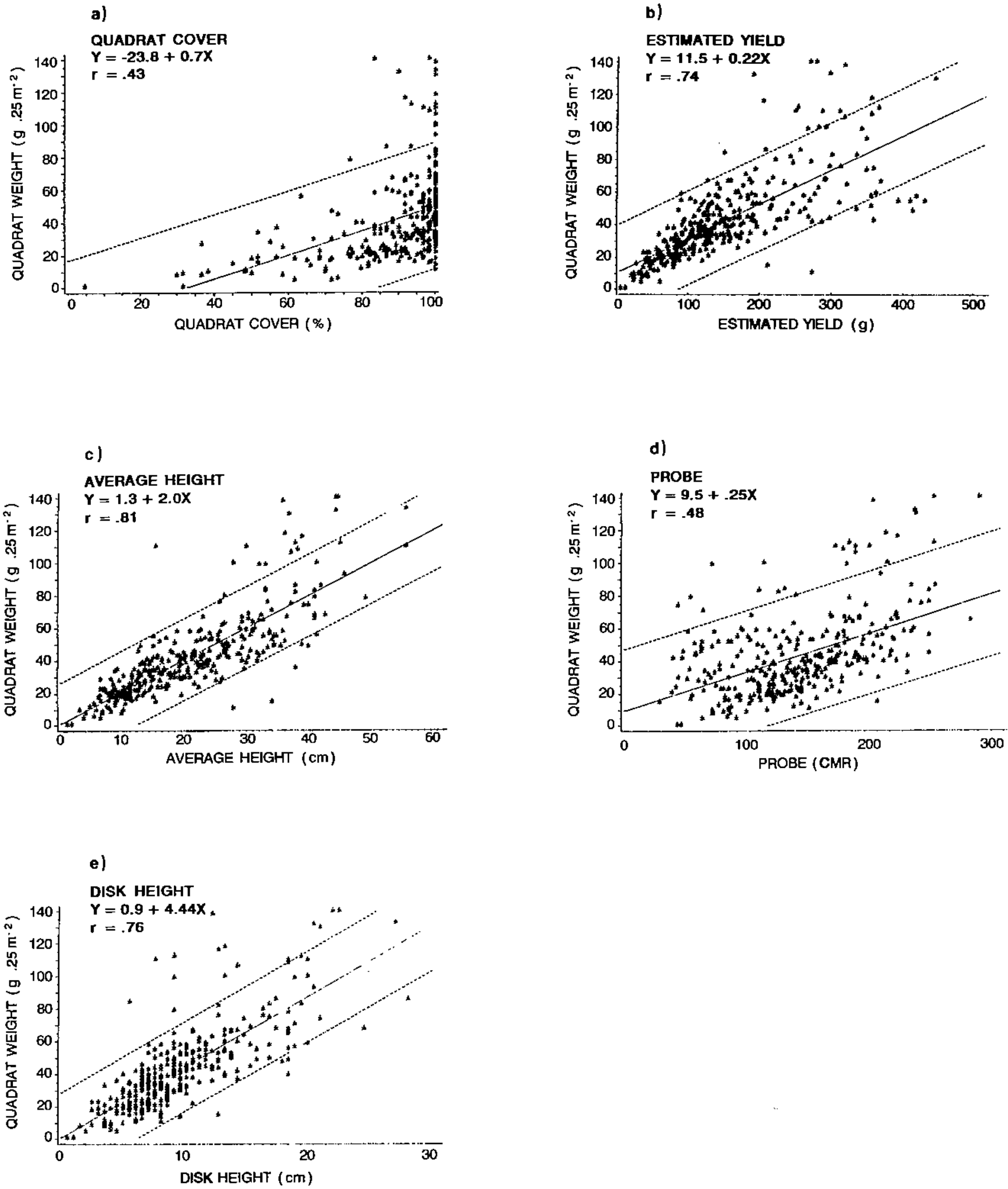

Figure 1 a-e. Relationship between clipped forage weight in small plots quadrat weight) and a) quadrat cover, b) estimated yield, c) average height, d) probe, and e) disk height (n = 320). Dashed lines indicated 90% confidence intervals.

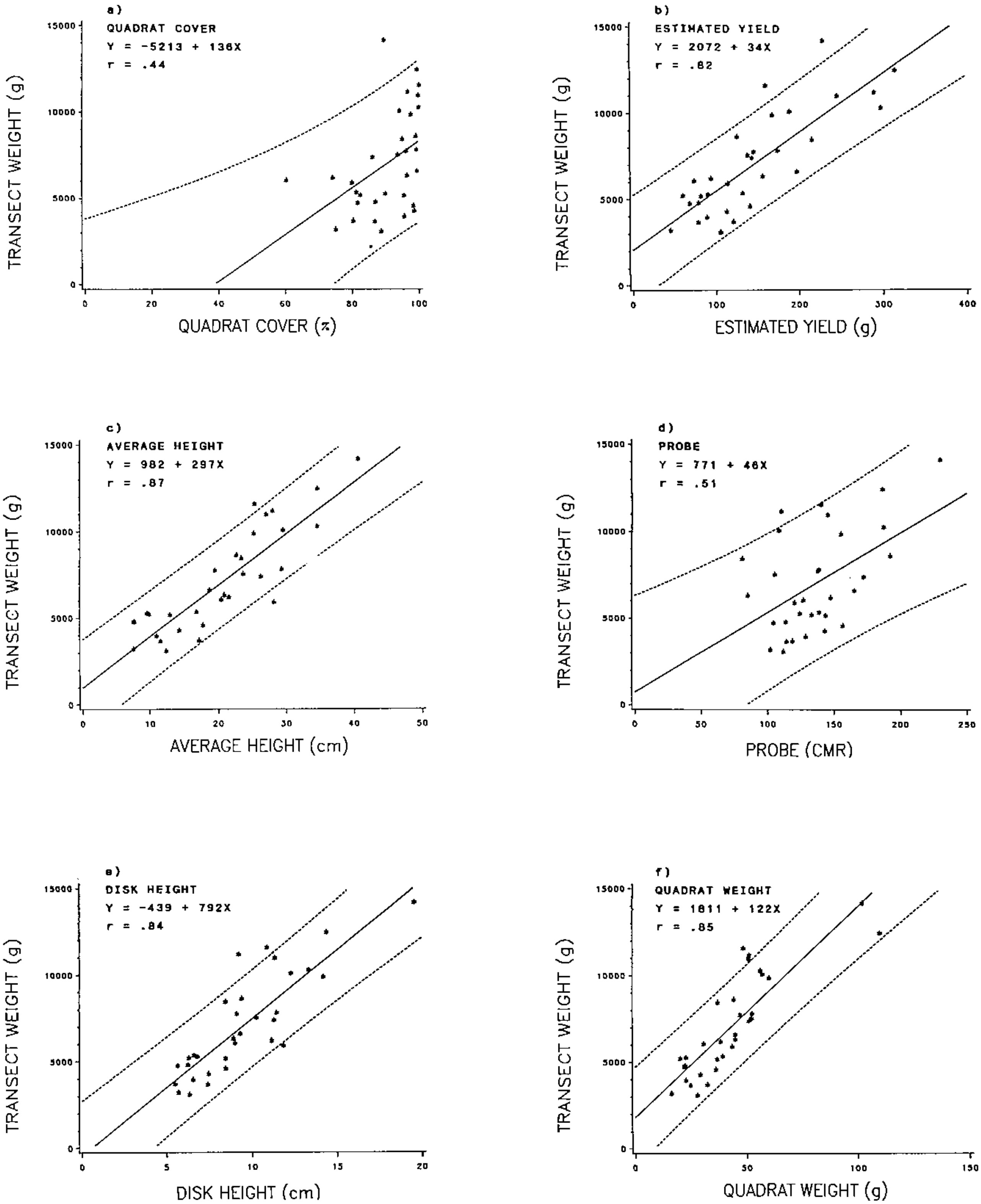

Figure 2 a-f. Relationship between clipped forage weight in large plots (transect weight) and a) quadrat cover, b) estimated yield, c) average height, d) probe, e) disk height, and f) quadrat weight (n = 32). Dashed lines indicate 90% confidence intervals.

Table 4. Linear regression equation and correlation coefficient between disk height (X) and dry weight of forage (Y) in small plots (0.25 m^2) and large plots (65 m^2) for each surface-mined site in West Virginia. Each site had n = 40, while all sites had n = 320.

SMALL PLOTS

Site	Equation	r
CM	Y = -9.2 + 5.3X	.87
DP	Y = -1.4 + 4.1X	.81
GR	Y = 17.7 + 3.0X	.51
GS	Y = 7.2 + 4.5X	.71
HD	Y = 20.5 + 3.6X	.57
HO	Y = 0.8 + 4.4X	.78
KK	Y = 12.4 + 1.6X	.34
LR	Y = 16.8 + 3.0X	.64
All Sites	Y = 0.9 + 4.4X	.76

LARGE PLOTS

Site	Equation	r
CM	Y = -2151 + 881(X)	.88
DP	Y = 3908 + 160(X)	.72
GR	Y = 3624 + 519(X)	.33
GS	Y = 17 + 730(X)	.97
HD	Y = -11892 + 1626(X)	.78
HO	Y = -1971 + 816(X)	.98
KK	Y = 2984 + 124(X)	.10
LR	Y = 7806 + 226(X)	.40
All Sites	Y = -439 + 792(X)	.84

correlate well with large plot weights (GR, KK, and LR) while the GS and HO site were highly correlated. Across all sites (n = 320), the overall correlation coefficient between disk height and small plot forage weight was 0.76, while the r value between disk height and large plot forage weight was 0.84. The use of the disk meter for predicting aboveground biomass shows good potential as a method for evaluating revegetation success. The disk method still involves calibration for correlative analysis on each site.

Small plot clipping has been the standard method for estimating aboveground biomass in many places and under many conditions. As expected, forage weights from small plots correlated well to the forage weights from large plots (r = .85), especially on five of our eight sites (Table 5). However, two of the sites showed no correlation, while the other site showed only a slight correlation.

There has been some concern expressed by SRA's that the weight of forage from small plot clipping does not translate directly into actual field yields that a landowner might obtain with commercial machinery. Converting the average forage dry weight from small plots and from large plots to an equal unit of measurement (i.e., kg/ha) showed that our large plot forage weights only averaged 65% (range of 52 to 80% across sites) of the forage weight calculated from small plots (Table 6). This discrepancy occurs because workers who clip by hand generally remove more forage closer to the ground and also collect more forage than commercial hay mowing and harvesting equipment. Therefore, the amount of material harvested by hand clipping will almost always be greater than the amount harvested from the same area by commercial equipment. In cases where a reference area is not available for a forage weight comparison, the forage weight clipped from small plots must be compared to county averages under specified management. If forage weights from small plot clipping are compared to county averages, correlative analysis should be done to compensate for the overestimation of forage weight from small plot clipping. Across our sites, the compensation values averaged 35%, or about one-third of the material that was hand harvested was not harvested with our sickle-type mower or was not collected with our rake. This estimate of approximately one-third loss of

Table 5. Linear regression equation and correlation coefficient between the forage weight obtained from small plots (X) and the forage weight from large plots (Y) on eight reclaimed sites in West Virginia. Each site had n = 40, and all sites had n = 320.

Site	Equation	r
CM	Y = 945 + 117.2(X)	.92
DP	Y = 4527 + 17.8(X)	.48
GR	Y = 10877 - 40.7(X)	-.08
GS	Y = -2350 + 191.4(X)	.99
HD	Y = 4183 + 80.4(X)	.85
HO	Y = 1797 + 119.7(X)	.99
KK	Y = 4827 - 46.7(X)	-.24
LR	Y = 4104 + 125.1(X)	.82
All Sites	Y = 1811 + 122.2(X)	.85

material may be a reasonable value to use in comparing the forage weight from hand clipping of small plots to actual field yields obtained by farmers.

Visual estimations for predicting aboveground biomass were significantly different among three observers. In spite of wide variation among observers, the average values for estimated yield and average height showed high correlation to forage weight from small and large plots. Average height and estimated yield, while showing good correlation after averaging, are very subjective among individuals and would not provide reliable estimates of aboveground biomass to evaluate revegetation success. The probe was not accurate in predicting forage weight in this study, while the disk provided good correlation and accurate estimates of aboveground biomass. Forage weight from small plots showed good correlation to large plot forage weights in five out of eight sites. The disk meter and small plot clipping are the only methods used in this study suitable for measuring aboveground biomass. These two methods showed reasonable accuracy and reliability in estimating forage clipped weights and are recommended as methods that could be used by SRAs in evaluating plant production. Small plot clipping has been the standard method for estimating aboveground biomass for many years, but should be calibrated to field harvesting. In this study, approximately 35% (or about one-third) of the weight of the material from hand clipped plots should be subtracted to equate to actual field forage weights.

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Table 6. The average forage weight from small plots (0.25 m^2) and large plots (65 m^2) and these weights converted to a standard unit of measurement on eight reclaimed sites in West Virginia.

Site	Dry Weight of Forage: Small Plot g	Small Plot kg/ha	Large Plot g	Large Plot kg/ha
CM	33.3	1,330	4,842	745
DP	26.1	1,044	4,992	768
GR	48.0	1,920	8,925	1,373
GS	42.2	1,686	5,717	880
HD	67.5	2,700	9,560	1,471
HO	55.5	2,219	8,440	1,298
KK	22.4	895	3,782	582
LR	48.8	1,950	10,202	1,570
All Sites	43.0	1,720	7,047	1,084

and companies for the sites sampled in this study: Charlie Miller, Grafton Coal Company; Frank Dippel, Dippel and Dippel Coal Company; John Garlow; Brian Osborn, Laurita Energy Corporation; Brownie Stuart, King Knob Coal Company; Larry Emerson, Hobet Mining Company.

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Links were assigned numbers and links are on next page.

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