New Technology for Estimating Seed Production of Moist-Soil Plants

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ABSTRACT Waterfowl biologists estimate seed production in moist-soil wetlands to calculate duck-energy days (DEDs) and evaluate management techniques. Previously developed models that predict plant seed yield using morphological measurements are tedious and time consuming. We developed simple linear regression models that indirectly and directly related seed-head area to seed production for 7 common moist-soil plants using portable and desktop scanners and a dot grid, and compared time spent processing samples and predictive ability among models. To construct models, we randomly collected approximately 60 plants/species at the Tennessee National Wildlife Refuge, USA, during September 2005 and 2006, threshed and dried seed from seed heads, and related dry mass to seed-head area. All models explained substantial variation in seed mass ($R^2 \geq 0.87$) and had high predictive ability ($R^2_{\mathrm{predicted}} \geq 0.84$). Processing time of seed heads averaged 22 and 3 times longer for the dot grid and portable scanner, respectively, than for the desktop scanner. We recommend use of desktop scanners for accurate and rapid estimation of moist-soil plant seed production. Seed predictions per plant from our models can be used to estimate total seed production and DEDs in moist-soil wetlands. (JOURNAL OF WILDLIFE MANAGEMENT 73(7):1229–1232; 2009)

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Waterfowl biologists estimate food resources in wetlands located along migration routes and at wintering sites to calculate duck-energy days (DEDs; Reinecke and Loesch 1996). Duck-energy days are the number of dabbling ducks (tribe: *Anatini*) that potentially can be sustained energetically in a wetland for a specified duration (Reinecke et al. 1989, Miller and Eadie 2006). Food resources in wetlands include seed and aquatic invertebrates (Baldassarre and Bolen 2006). Most often, available seed is estimated for DED calculations, because dabbling ducks primarily consume this food resource during migration and winter (Delnicki and Reinecke 1986, Anderson and Smith 1999, Anderson et al. 2000, Heitmeyer 2006).

Moist-soil wetlands are low-lying areas dominated by annual and perennial herbaceous hydrophytes (Fredrickson and Taylor 1982). Seed production in moist-soil wetlands can be >1,000 kg/ha (Kross et al. 2008) and is greatest when wetlands are in early succession and dominated by annual plants (Gray et al. 1999*c*). Waterfowl biologists use natural and mechanical disturbance and water-level manipulations to manage plant succession and maintain high seed production (Fredrickson and Taylor 1982). Estimating seed production in moist-soil wetlands is one way to monitor succession and evaluate management (Gray et al. 1999*c*). Thus, obtaining accurate estimates of seed production is important in calculating DEDs, monitoring plant succession, and evaluating waterfowl management.

Prediction models have been used to estimate seed production of moist-soil plants (Laubhan 1992). The first studies developed multiple linear-regression models to predict seed yield using multiple plant morphological measurements (e.g., plant ht, inflorescence diam; Laubhan and Fredrickson 1992, Gray et al. 1999*b*, Sherfy and Kirkpatrick 1999). Waterfowl biologists were reluctant to use these models because measuring multiple plant parts was tedious and time consuming. Gray et al. (1999*a*, *b*) also reported that multiple regression models could produce biased predictions outside the region where they were developed and noted they were subject to multicollinearity. Gray et al. (1999*a*) proposed a new method for predicting seed production of moist-soil plants using one simple variable, the number of dots on a grid covered by seed on an inflorescence. Models developed using the dot-grid method predicted seed production accurately within and outside the Southeast region (Gray et al. 1999*a*, Anderson 2006). However, similar to previous models, few biologists used dot-grid models because counting dots was tedious and time consuming.

Counting number of dots on a grid covered by seed is an index of seed-head area. Portable and desktop scanners are used frequently by the forestry industry to estimate leaf area and presumably could be used to quantify area of a seed head. Given that the scanning resolution is high (1 mm^2) and scans can be performed rapidly, this technology may facilitate easy and efficient estimation of seed production in moist-soil wetlands. Our objectives were to 1) develop models that predicted seed production using portable and desktop scanners and the dot grid developed by Gray et al. (1999*a*) and 2) compare predictive ability and time spent processing samples among models.

STUDY AREA

We conducted our study on the Duck River Unit of the Tennessee National Wildlife Refuge (Universal Transverse

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Mercator zone 16 [North American Datum 27], 413191 E, 3981387 N) near New Johnsonville, Tennessee, USA. United States Fish and Wildlife Service biologists managed approximately 570 ha of moist-soil wetlands in this unit for waterfowl (U.S. Fish and Wildlife Service 2005). Management was typical for the Southeast, where draw-downs occurred April–June and soil was periodically disked to set back succession (Strader and Stinson 2005, U.S. Fish and Wildlife Service 2005).

METHODS

In September 2005 and 2006, we randomly collected mature inflorescences with intact seed for 7 moist-soil plant species located across 5 impoundments in the Duck River Unit: redroot flatsedge (*Cyperus erythrorhizos*), barnyard grass (*Echinochloa crusgalli*), Walter's millet (*E. walteri*), red sprangletop (*Leptochloa panicea* subsp. *brachiata*), rice cutgrass (*Leersia oryzoides*), fall panicum (*Panicum dichotomiflorum*), and curlytop knotweed (*Polygonum lapathifolium*). We collected these plant species because they were common and their seed is consumed by dabbling ducks (Anderson et al. 2000, Heitmeyer 2006). We collected approximately 30 inflorescences/plant species each year. We placed seed heads in separate plastic bags, transported them to the lab, and placed them immediately in a plant press (31 × 46 cm). We pressed seed heads such that pedicels did not overlap and we stored them in a dry location at room temperature until processing.

For each plant, we estimated seed-head area using the dot grid described in Gray et al. (1999*a*) and a portable and desktop scanner. The dot grid was 20 × 15 cm with 9 dots/cm^2 (Fig. 1). To facilitate counting, we created a transparency of the grid and overlaid it on the seed head. We counted the number of dots partially or entirely in contact with seed per se. We did not count dots covered by other plant parts. We used an ADC AM300 portable scanner (Fig. 1; ADC BioScientific Ltd., Hoddesdon, United Kingdom; US$6,000 in 2008). This scanner had a 22 × 12-cm surface area for scanning. We set the contrast level at 5 for all species, except rice cutgrass, which we scanned at contrast level 3. We used a LI-3000 desktop scanner (Fig. 1; LI-COR Inc., Lincoln, NE; US$9,000 in 2008), which could accommodate seed heads up to 25 cm in width; there was no restriction on seed-head length. Scanners could not differentiate between seed and other plant parts; thus, they provided an estimate of inflorescence area not seed area per se. If a seed head was too large for the dot grid or scanners, we cut it and summed estimates of area across parts. Scanning resolution for the portable and desktop scanners was 1 mm^2; thus, the dot grid and scanners estimated seed-head area for similar scales. We calibrated scanners prior to use and recorded processing time for each method. Following area estimates, we measured seed production per plant by threshing seeds from each inflorescence and removing chaff. We oven-dried samples at 50° C for 24 hours and weighed seed mass per plant to the nearest 0.0001 g (Laubhan and Frederickson 1992).

Figure 1. Dot grid (top left), ADC AM300 portable scanner (top right; ADC BioScientific Ltd., Hoddesdon, England), and LI-COR LI-3000 desktop scanner (bottom; LI-COR Inc., Lincoln, NE) used to estimate seed-head area for predicting seed production of moist-soil plants, Tennessee National Wildlife Refuge, USA, September 2005 and 2006.

Predictor variables included number of dots for the dot-grid method and area (cm^2) for scanners; the response variable was mass of seed per plant. We used simple linear regression to build prediction models for each plant species and method, combining years for more robust parameter estimates (Myers 1990, Gray et al. 1999*b*). We used weighted least-squares regression for red sprangletop (desktop model) and fall panicum (all models), because plots of residuals against predicted values revealed nonconstant variance (Myers 1990). We calculated normal (R^2) and predicted (R^2_{pred}) coefficients of determination as measures of model precision and predictive ability, respectively (Gray et al. 1999*a*). We calculated the statistic R^2_{pred}, a cross-validation procedure, using the predicted sum-of-squares (Myers 1990). We tested for differences in amount of time spent processing samples among methods using an analysis of variance (ANOVA) and used Tukey's Honestly Significant Difference test to determine pair-wise differences when the ANOVA was significant (Zar 1999). We did not test residual normality because sample size was large ($n \geq 58$; Zar 1999). We performed all statistical analyses using the SAS® system (PROC REG; SAS Institute, Cary, NC) at $\alpha = 0.05$ (Littell et al. 1991).

RESULTS

All models explained significant variation (R^2 = 87–98%, $F_{1,57} \geq 190.6$, $P < 0.001$) in seed production per plant and had high predictive ability (R^2_{pred} = 84–98%, Table 1). The fall panicum models for the portable and desktop scanners explained the least amount of variation (R^2 = 87% and 92%, respectively) and had the poorest predictive capability (R^2_{pred} = 84% and 90%) among models. The dot-grid

Table 1. Models for predicting seed production of 7 common moist-soil species collected on the Tennessee National Wildlife Refuge, USA, September 2005 and 2006, using dots on a grid in contact with seed (DOTS) or seed-head area (AREA, cm^2) measured with a portable and desktop scanner as the explanatory variable.

Plant species	Method[a]	n	Model (Y = g seed/plant)[b,c]	F	R^2	R^2_{pred}
Redroot flatsedge	Dot	59	Y = (0.002 × DOTS) + 0.247	964.2	0.97	0.968
	Portable	59	Y = (0.016 × AREA) − 0.023	966.7	0.97	0.968
	Desktop	59	Y = (0.018 × AREA) − 0.209	1,070.1	0.973	0.971
Barnyard grass	Dot	60	Y = (0.004 × DOTS) − 0.044	714.7	0.96	0.956
	Portable	60	Y = (0.023 × AREA) − 0.105	968.3	0.97	0.968
	Desktop	60	Y = (0.026 × AREA) − 0.023	982.2	0.97	0.968
Walter's millet	Dot	60	Y = (0.003 × DOTS) + 0.057	1,074.0	0.973	0.971
	Portable	60	Y = (0.009 × AREA) + 0.032	1,516.8	0.981	0.98
	Desktop	60	Y = (0.010 × AREA) + 0.256	1,178.2	0.975	0.974
Red sprangletop	Dot	59	Y = (0.0009 × DOTS) + 0.373	456.2	0.939	0.933
	Portable	59	Y = (0.007 × AREA) + 0.421	395.1	0.93	0.923
	Desktop	59	Y = (0.008 × AREA) + 0.301	682.2	0.959	0.955
Rice cutgrass	Dot	59	Y = (0.001 × DOTS) − 0.007	1,653.2	0.983	0.981
	Portable	59	Y = (0.007 × AREA) + 0.021	1,273.9	0.977	0.976
	Desktop	59	Y = (0.009 × AREA) + 0.009	2,664.8	0.989	0.989
Fall panicum	Dot	58	Y = (0.002 × DOTS) − 0.213	900.2	0.969	0.964
	Portable	58	Y = (0.001 × AREA) − 0.080	190.6	0.867	0.842
	Desktop	58	Y = (0.023 × AREA) − 0.281	326.2	0.918	0.903
Curlytop knotweed	Dot	62	Y = (0.006 × DOTS) − 0.019	694.2	0.957	0.953
	Portable	62	Y = (0.045 × AREA) − 0.012	1,575.9	0.981	0.979
	Desktop	62	Y = (0.045 × AREA) − 0.059	1,067.5	0.972	0.97

[a] Dot = dot grid with 9 dots/cm^2 (Gray et al. 1999*a*); Portable = portable scanner (AM300 Leaf-area Meter; ADC BioScientific Ltd., Hoddesdon, United Kingdom); Desktop = desktop scanner (LI-3100 Area Meter; LI-COR Inc., Lincoln, NE).

[b] DOTS = no. of dots in contact with seed; AREA = area measured by scanner.

[c] We created all models using simple linear regression, except the desktop model for red sprangletop and all models for fall panicum, because of nonconstant variance; we generated these eqs using weighted least-squares regression.

model explained 97% of variation in seed production for fall panicum. The poorest performing dot-grid model was red sprangletop (R^2 = 94%, R^2_{pred} = 93%, Table 1).

For all plant species, processing time was 4–36 times greater ($F_{2,183} \geq 68.8$, $P < 0.001$) for the dot-grid method than for portable or desktop scanners (Table 2). Average processing time for the dot grid was 336 seconds across species (range = 115–808). Processing time for the portable scanner was 2–10 times longer than the desktop scanner for barnyard grass, Walter's millet, red sprangletop, and rice cutgrass. Average processing time for the portable and desktop scanners across species was 45 seconds and 15 seconds, respectively (range = 25–114 and 9–31, Table 2).

DISCUSSION

All models explained substantial variation in seed production of moist-soil plants and had high predictive ability. Average processing time of seed heads was 9–808 seconds and depended on the estimation method for seed-head area and the plant species. Processing time was longest for the dot grid and most rapid for the desktop scanner.

Strong predictive ability among our models indicates that seed-head area is a good predictor of seed production. Gray et al. (1999*a*) and Anderson (2006) provided results that support our inference. Anderson (2006) also provided evidence that the relationship between seed-head area and seed production likely is consistent among geographic regions. Thus, models developed using seed-head area as a predictor are probably more robust than models using plant morphological measurements, such as plant height and inflorescence diameter (Gray et al. 1999*a*, *b*; Anderson 2006).

The portable and desktop scanner models for fall panicum explained the least amount of variation in seed production (87% and 92%, respectively). Interestingly, the dot-grid model explained 97% of the variation in seed production for this species. Gray et al. (1999*a*) also reported that the dot-grid model explained substantial variation (97%) in seed production for fall panicum. We attribute the variability in model performance to the large number of pedicels for this plant species, which likely added variability to seed-head area estimates for the scanners. In contrast, seeds and

Table 2. Time (sec) necessary to process one seed head among 3 methods that indirectly estimate seed production for 7 common moist-soil species collected on the Tennessee National Wildlife Refuge, USA, September 2005 and 2006.

	Method[a]					
	Dot		Portable		Desktop	
Plant species	$\bar{x}$[b]	SE	$\bar{x}$	SE	$\bar{x}$	SE
Redroot flatsedge	807.9 A	42.9	33.3 B	1.2	22.5 B	0.9
Barnyard grass	186.4 A	7.3	24.9 B	2.1	9.4 C	0.3
Walter's millet	313.3 A	15.5	113.7 B	12.7	11.0 C	0.5
Red sprangletop	443.6 A	13.9	41.6 B	2.3	9.1 C	0.3
Rice cutgrass	114.8 A	4.7	26.7 B	4.2	11.9 C	1.3
Fall panicum	338.4 A	22.7	39.2 B	3.2	9.6 B	0.2
Curlytop knotweed	147.3 A	1.5	38.4 B	0.7	31.3 B	0.3

[a] Dot = dot grid with 9 dots/cm^2 (Gray et al. 1999*a*); Portable = portable scanner (AM300 Leaf-area Meter; ADC BioScientific Ltd., Hoddesdon, United Kingdom); Desktop = desktop scanner (LI-3100 Area Meter; LI-COR Inc., Lincoln, NE).

[b] Means within rows followed by unlike letters are different by analysis of variance and Tukey's Honestly Significant Difference test.

pedicels could be distinguished when counting number of dots. Others have reported poor model performance for plant species with large variability in number of pedicels per seed head (Laubhan and Fredrickson 1992, Gray et al. 1999*b*).

Processing time was longest for the dot-grid method, averaging >5 minutes/plant, with some species requiring >10 minutes. In contrast, processing time averaged 45 seconds and 15 seconds for portable and desktop scanners, respectively, across species. Average processing time of Walter's millet was nearly 2 minutes/plant for the portable scanner. For this species, we had to scan some seed heads several times because the long awns on the seed prevented a clear first scan. In general, the additional time required for the portable scanner was a result of poor initial scans or multiple scans required for seed heads that were larger than the scanning surface area. In the latter case, we cut large seed heads into multiple parts and scanned them separately. These problems did not occur with the desktop scanner.

MANAGEMENT IMPLICATIONS

We recommend that biologists use desktop scanners to predict seed yield in moist-soil wetlands, because samples can be processed rapidly and predictions are accurate. Dot models could be used if funds are unavailable to purchase a scanner, recognizing that the lower efficiency of the dot grid will require greater processing time for samples. Seed predictions per plant from our models can be multiplied by mean plant density to estimate total seed production and DEDs in moist-soil wetlands, which has been described previously (Gray et al. 1999*b*). A spreadsheet for calculating seed production per plant with our models is available at http://fwf.ag.utk.edu/mgray/. Note that estimates from our models represent aboveground seed production. Belowground seed resources are not considered (e.g., Reinecke and Hartke 2005); thus, estimates from our models may be conservative for total seed availability. We recommend that biologists continue to validate the usefulness of seed-head area models in other geographic areas and years, and with other plant species.

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