Relation of Root and Shoot Morphology of Grass Seedlings

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ABSTRACT
Grass seedling establishment is dependent on adventitious root development. However, evaluating the establishment status of a seeding by excavating a population of seedlings and determining root morphology is difficult and generally will not be undertaken. Based on both field and greenhouse studies we have found that root and shoot morphological development is closely related within species, for intermediate wheatgrass, [*Thinopyrum intermedium* (Host) Barkw. and D.R. Dewey], smooth bromegrass (*Bromus inermis* Leyss.), switchgrass (*Panicum virgatum* L.), and big bluestem (*Andropogon gerardii* Vitman) seedling populations. Easily observable developmental stages of seedling shoots were related to adventitious root development. When the average stage of the population of shoots of these grasses reaches three to four collared leaves for intermediate wheatgrass and smooth bromegrass, first secondary tiller for switchgrass and the four to six collared leaf stage for big bluestem, there was an average of two to three adventitious roots which indicates the onset of seedling establishment.

KEYWORDS
Seedling establishment, intermediate wheatgrass, smooth bromegrass, switchgrass, big bluestem, shoot morphology, root morphology, adventitious roots

INTRODUCTION
The establishment process of grass seedings is often not well understood and decisions must be made regarding the establishment status throughout the first growing season. After seed germination, establishment is dependent on the interaction of environmental factors with the morphological development of seedlings. Once adventitious roots are initiated the liklihood of establishment becomes much more certain (Hyder *et al*., 1971; Newman and Moser, 1988a). Ries and Svejcar (1991) reported that blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] was considered established when seedlings had six leaves, two adventitious roots that penetrated 10 cm, and two tillers per plant. Crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult.] was considered established when seedlings had four leaves, two adventitious roots and one tiller.

Excavating seedlings and determining the number and depth of adventitious roots is difficult so the objective of this research was to develop relationships between easily observed shoot characteristics with root development so decisions regarding the developmental status of root systems could be made with confidence by observing shoot development. Aguirre and Johnson (1991) reported that there was a close association between the pattern of root and shoot development in four species of cool-season grasses. However, the relationship of seedling root and shoot development varied among grass species (Newman and Moser, 1988b) so such relationships probably must be made within grass species.

METHODS
Seedling root and shoot developmental stages of two cool-season grasses, intermediate wheatgrass and smooth bromegrass, and two warm-season grasses, switchgrass and big bluestem, were quantified using a grass seedling staging system (Moser *et al*., 1993). Both root and shoot morphological development were classified on each individual plant under both field and greenhouse conditions in a number of experiments (Table 1). Experiments were randomized complete blocks and generally were replicated four times. The experimental unit in nearly every case was a 20-seedling lot harvested consecutively starting at a random point in a row. In each experiment, seedlings were harvested at 7 to 10-d intervals and separate shoot and root index values were assigned to each plant (Moser et al., 1993). Classification ceased when plants initiated rhizomes and three or more secondary tillers were present. Data were analyzed using Proc GLM (SAS, 1990) and linear relationships established with Mean Stage Count for Roots (MSCR) as the dependent variable and Mean Stage Count for Shoots (MSCS) as the independent variable.

RESULTS AND DISCUSSION
High correlations existed between shoot and root morphological stages for all four species (Table 1). When both greenhouse and field data were combined, the MSCS and MSCR values were nearly identical throughout the developmental process for cool-season grasses but MSCR lagged MSCS by an average of 0.60 units for switchgrass and 0.95 units for big bluestem (Fig. 1). The variability of MSCR relative to MSCS prior to a MSCS of 4 was small but increased at later developmental stages. Standard errors for both slopes and intercepts were low in both greenhouse and field studies except for big bluestem under field conditions (Table 1). Smooth bromegrass tended to have higher standard errors as well. Some of this error may be explained by the lower n values for both big bluestem and smooth bromegrass. Big bluestem had a lot of variability in seedling morphology. Most seedlings developed short leaves rather quickly (short phyllochron) and some seedlings developed multiple tillers rather early. At the three-leaf stage Newman and Moser (1988a) found that big bluestem had not developed adventitious roots while switchgrass averaged one adventitious root per plant. They also reported that intermediate wheatgrass had one and smooth bromegrass had over four adventitious roots at the three-leaf stage.

By looking at the combined data (Fig. 1) it appears that establishment (development of adventitious roots) could be estimated by observing shoot development. The MSCR stage 4 (two to three adventitious roots) describes the root stage at which Ries and Svejcar (1991) indicated that both blue grama and crested wheatgrass were established. Seedling establishment becomes more certain after the onset of adventitious roots, however, considering only a single point for establishment may not be appropriate depending on the subsequent environmental conditions.

For intermediate wheatgrass a MSCS of 4.7 is associated with a MSCR of 4 (two to three adventitious roots). When the MSCS approached 5 nearly all plants had adventitious roots and many had two or more. At MSCS 5 intermediate wheatgrass had four to six collared leaves. Smooth bromegrass adventitious root development was a little earlier relative to shoot development than it was for intermediate wheatgrass. The MSCS of 4.4 was associated with a MSCR of 4. Again, when bromegrass seedlings approached a MSCS of 5 nearly all plants had adventitious roots.

For switchgrass a MSCS of 5 (four to six collared leaves) was associated with a MSCR of 4 so when the MSCS is above 5 a switchgrass seeding generally should be established. However, individual switchgrass seedlings often bypass the MSCS stage 5 because they generally produce a secondary tiller before they form

the fourth leaf putting them in stage 6. Certainly by the time the MSCS for switchgrass reaches 6 (first secondary tiller) most plants would have adventitious roots, some with six or more. For big bluestem a MSCS of 5.1 was associated with a MSCR of 4 so when the tiller population exceeds MSCS 5 or approaches 6 a seeding should be established.

Although there may be additional survival problems for seedling stands during the first growing season, grass seedlings pass a very critical stage when they initiate adventitious roots at the coleoptilar node. Since root morphology was closely associated with shoot morphology, quantification of the shoot population morphology should be useful in estimating the developmental status of root systems in a seedling population and seeding establishment status. For intermediate wheatgrass and smooth bromegrass MSCS values of 4.7 and 4.4, respectively, are associated with a MSCR of 4 (two to three adventitious roots) and should indicate that a seeding is established. For switchgrass and big bluestem MSCS values of 5.0 and 5.1, respectively, are associated with a MSCR of 4 and should indicate establishment of the seedling populations. Further investigations will be necessary to determine relationships for other species and possibly varieties and to refine shoot/root morphological relationships and variability caused by prevailing environmental conditions.

Figure 1
Relations Between Shoot and Root Developmental Stage for Field and Greenhouse Studies Involving: A) Intermediate Wheatgrass, b) Smooth Bromegrass, c) Switchgrass, d) Big Bluestem.

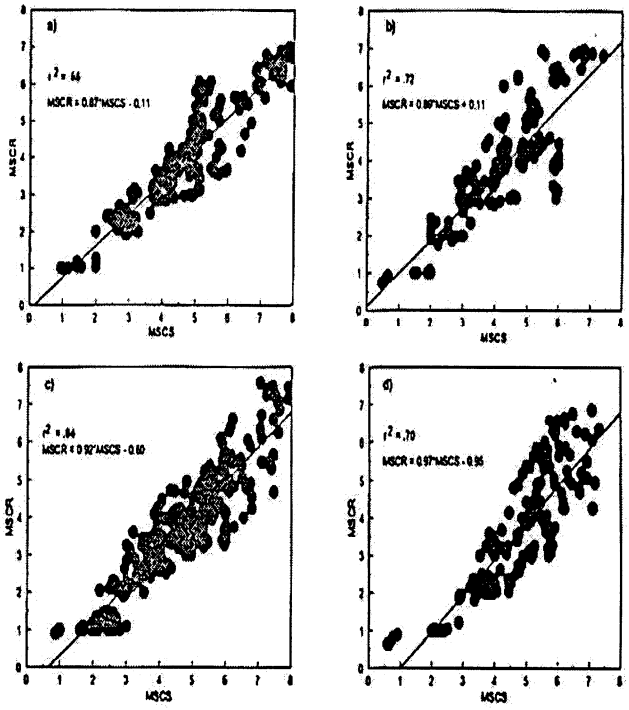

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Table 1
Relationships between mean stage count for shoots (MSCS) and mean stage count for roots (MSCR) for intermediate wheatgrass, smooth bromegrass, switchgrass, and big bluestem in field and greenhouse studies.

Grass Species	Data Set	r	R-square	b	SE(b)	intercept	SE(int)	no. of expts.	n
Big bluestem	Field	.76	.58	0.97	0.12	-0.62	0.64	2	54
	Greenhouse	.86	.74	0.89	0.05	-0.76	0.24	3	112
Switchgrass	Field	.93	.87	0.98	0.03	-0.85	0.14	3	183
	Greenhouse	.88	.78	0.79	0.04	-0.06	0.18	3	112
Int. wheatgrass	Field	.96	.92	0.86	0.03	-0.01	0.20	3	60
	Greenhouse	.85	.72	0.87	0.05	-0.11	0.21	2	112
S. bromegrass	Field	.92	.84	1.01	0.08	0.27	0.41	1	32
	Greenhouse	.83	.69	0.72	0.05	0.52	0.19	3	108