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Distribution and Reproductive Potential of Kudzu (*Pueraria lobata*, Fabaceae) in Illinois, USA

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ABSTRACT

Kudzu [*Pueraria lobata* (Willd.) Ohwi] was planted widely in the southeastern United States in the late 1930s to early 1940s, and now covers an estimated 3 million ha. The objective of this study was to evaluate the distribution and reproductive potential of kudzu seeds in Illinois. First collected in Illinois in 1941, a total of 78 populations of kudzu from 28 Illinois counties were recorded by 1997. In the southern third of the state, 75% of the populations were found, although one was located in Rock Island County (40° 30' N), about 110 km south of the Wisconsin border. Of the populations examined, most were very small with a mean area of 1.6 ha for all populations, although one exceeded 16 ha. All populations flowered during the summer of 1997, and mature fruit containing seeds were observed in six populations. Two color types of kudzu seeds (mottled vs. uniformly colored) were found, with the mottled seeds having greater mass than the uniform ones. Both scarified and nonscarified seeds of the two color types germinated over a series of constant temperatures ranging from 20° to 35°C; percentage germination was highest (94-100%) for scarified/mottled seeds at all temperatures. Vigorous seedlings developed from kudzu seeds, especially if the seeds were scarified and mottled, indicating that kudzu has the potential to reproduce from seed in Illinois.

INTRODUCTION

Pueraria lobata (Willd.) Ohwi (kudzu), a climbing woody vine of the family Fabaceae, is native to eastern Asia. Some authors consider the scientific name of this taxon to be *Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & Almeida (Ward, 1998). This taxon was introduced into the southeastern United States in the 1870s when it was used as an ornamental, as a forage crop, and for its edible root. By the late 1930s and early 1940s, it was being planted extensively throughout the southeastern United States for erosion control (Shurtleff and Aoyagi, 1977). Since its introduction, kudzu has extended its range into the northeastern United States, and now occurs in New York,

Massachusetts, New Jersey, Ohio and Pennsylvania (Sorrie and Perkins, 1988; Frankel, 1989; Watson, 1989; Gleason and Cronquist, 1991). Mohlenbrock (1986) reported that kudzu occasionally was adventive in the southern half of Illinois.

Kudzu is identified easily by its large, alternately arranged, trifoliate leaves with ovate to subrotund, often slightly palmately lobed leaflets, and by its racemes of fragrant reddish-purple flowers that develop in late summer and early fall (Gleason and Cronquist, 1991). Its fruits are 4-12 cm long legumes with papery pubescent valves that contain 1-9 seeds having a thick, hard seed coat. The seeds may remain viable within the soil for several years before germinating (Everest et al., 1991).

Seed viability may relate to seed polymorphism where seeds of a species exhibit two or more distinctly different morphologies in size, shape, or color (Baskin and Baskin, 1998). These morphologic differences may be due to genetics or to the preconditioning environment during seed development. Seed polymorphism occurs in other legume species, including *Senna obtusifolia* (Baskin et al., 1998). Reports of seed polymorphism in kudzu were not found. Seeds of the same species with different polymorphs also may differ in their germination and their needs to break seed dormancy (Baskin and Baskin, 1998; Baskin et al., 1998).

Kudzu has a hard, leathery seed coat and requires scarification for maximum germination (Tabor, 1949; Tsugawa et al., 1979; Baskin and Baskin, 1998; Susko et al., 1999). For seeds collected in Raleigh, North Carolina, Susko et al. (1999) reported that scarified seeds germinated over a wide range of alternating temperatures (15°/6° to 35°/25°C with 12 hours at each temperature in continuous darkness) with no differences between dark vs. light/dark photoperiods. Optimal pH for germination was between 5.4 and 7 with decreased germination at lower or higher pH (Susko et al., 1999). Seeds germinated best at planting depths of 0.5-4.0 cm in well-watered, but not flooded, conditions (Susko et al., 1999).

Once established, kudzu vines have extraordinary growth rates with growth of 18 m in a single growing season being common (Shurtleff and Aoyagi, 1977). Vines originate from large tuberous roots that can grow to a depth of 3.5 m, and sometimes weigh 90-140 kg (Miller and Edwards, 1983). Numerous vines may grow from a single root crown. Vines spread in all directions and often root at nodes in contact with the soil, thereby forming new plants (Miller and Edwards, 1983). Kudzu can grow on a variety of soil types, achieving maximum growth on deep loamy soils (Everest et al., 1991).

Kudzu now covers an estimated 3 million ha of land in the United States, resulting in high economic losses by decreasing productivity on agricultural and forest lands (Bartlow et al., 1996; Pappert et al., 2000). Kudzu occasionally is responsible for disruption of electrical power, since it readily climbs over utility poles and power lines (Flint, 1983). Kudzu forms thick dense mats of vines that smother underlying vegetation. As a consequence, kudzu prevents the growth of other plant species, decreases plant species diversity, and also decreases the amount and variety of food available for wildlife (Miller and Edwards, 1983).

Kudzu was first reported and collected in Illinois in 1941 at the Trail of Tears State Forest, Union County (collected by G.D. Fuller #590, 24 Oct. 1941). Jones and Fuller (1955) reported kudzu from Jackson and Union Counties, while Mohlenbrock and Ladd (1978) found kudzu in seven counties, mostly in southern Illinois. The present study was conducted to determine the current distribution of kudzu in Illinois, and to assess the ability of kudzu to reproduce by seed obtained from one Illinois population.

MATERIALS AND METHODS

Kudzu populations in Illinois were located using information provided by natural heritage biologists, foresters, and other personnel in the Illinois Department of Natural Resources and the Illinois Natural History Survey, and by examining herbarium specimens from most of the state herbaria. All known kudzu populations in Illinois were visited during late summer and fall of 1997, at which time the location, total area, and the habitat were recorded. For each kudzu population observed, the total area of the population size was estimated by determining the distance along one side and estimating the distance through the middle of the population. The size of large populations was estimated visually from a helicopter. At five sites, two or three of the largest stems encountered were cut and their ages determined by counting growth rings.

Mature fruits were collected from six populations in central (Fayette and Jefferson Counties) and southern (Jackson and Union Counties) Illinois. Fruit production was generally low, and at five sites all fruits found attached to the vines were collected. At one site (Union County Fish and Wildlife Area) fruits were numerous, and 9-15 were selected randomly from each of 84 inflorescences from one vine. Fruit length, fruit width, and the number of seeds per fruit were determined from 25 randomly selected fruits from each population. The seeds exhibited two distinct types of seed coat color, one white to light gray with black markings (mottled), and the other a solid light brown without markings (uniformly colored). Thus seeds were sorted into two types based upon these visual differences.

Only the seeds from the Union County Fish and Wildlife Area were used to assess seed size, germination, and seedling characteristics. The two seed color types were kept separate and stored at 3°C until subjected to germination trials in spring 1998 and emergence trials in spring 1999. Seed mass and volume were determined for 100 seeds of each color type (four replications of 25 seeds each). Lots of 25 seeds were used rather than single seeds to improve precision in measurement. Percentage of floating vs. sinking seeds was determined for 100 seeds of each color type with no replication to give an indication of seed viability. More specific replicated tests of seed vigor were done via evaluations of germination over time and seedling development.

Percent seed germination was determined at four constant temperatures (20°, 25°, 30° and 35° C) using 50 seeds (five replications with 10 seeds each) for each of four treatments (scarified/mottled, scarified/uniform, nonscarified/mottled, nonscarified/uniform) at each temperature regime. Thus, the design included 4 temperatures X 2 seed types X 2 scarification treatments. All seeds were soaked initially in a 10% sodium hypochlorite (Clorox®) solution for 10 minutes, and rinsed. After the rinse, half of the seeds of each seed coat color type were scarified with a razor blade by nicking the seed coat on the side

opposite the hilum. Then seeds were placed in glass petri dishes on three sheets of filter paper (Whatman #1) moistened with 5 ml water. Dishes were arranged randomly inside a clear Rubbermaid® container (35 cm x 24 cm x 12 cm) and placed in a dark growth chamber at appropriate temperature. Germinated seeds were counted daily for 14 days. A seed was considered germinated when the radicle emerged from the seed coat by ≥ 2 mm.

For seedling characteristics, seeds were soaked in a 10% Clorox® solution for 10 minutes, rinsed and planted to a depth of 1 cm in a standard greenhouse soilless mix (1:1:1 of peat/vermiculite/perlite) in plastic trays (27 cm x 19 cm x 6 cm). Each of five trays (replications) included four rows of planted seeds with 10 seeds/row. Individual rows contained seeds from one of four scarification/seed color treatments: scarified/mottled, scarified/uniform, nonscarified/mottled and nonscarified/uniform. Thus, the design included 2 seed types X 2 scarification treatments. Seeds were planted 1.75 cm apart within the row and rows were separated by a distance of 5.5 cm. Trays were placed initially in a growth chamber at a constant temperature of 25°C with a light intensity of 250 umol/s/m^2 which was the maximum intensity available in the chamber. Trays were moved to a growth room where temperatures ranged from 15.5° to 22.4°C, light intensity was 145 umol/s/m^2 (which was maximum intensity available within room), and relative humidity ranged from 32 to 46% as measured with a hygrothermograph. A photoperiod of 16-hrs light/8-hrs dark was maintained in both the chamber and the growth room. All trays were watered as needed with equal volumes. Plants were grown for one month (12 February to 12 March 1999). Growth was considered to begin at the start of imbibition when the seeds were first watered. Emergence, height of the stems (from soil surface to terminal bud on main stem), number of nodes, total leaf area (using a Li-Cor Model 3100 leaf area meter), fresh mass of shoots and dry mass of shoots (dried at 75°C for 48 hrs) were measured at the end of the experiment.

Data were analyzed using Excel (2002) or CoStat (1995). Means and standard deviations or standard errors were calculated. Where replicated data were available, analysis of variance was used to determine which means were significantly different.

RESULTS

A total of 78 kudzu populations from 28 counties were found in Illinois, 75% of which were located in the southern third of the state (Table 1 and Fig. 1). One population was found in Rock Island County (40° 30' N), about 110 km (70 miles) south of the Wisconsin border, and 110 km northwest of the closest known population in Peoria, Illinois (Fig. 1). Populations varied in size from 0.1 ha to more than 16 ha with an average of 1.6 ha.

Although most of the kudzu populations examined rarely exceeded 1 ha in size, one population that was located in Pope County, Illinois, in the extreme southern part of the state, exceeded 16 ha. This population from the Shawnee National Forest covered a 6 ha field that originally contained wildlife food plots and 10 ha within an adjacent mature pine plantation and oak/hickory forest. The field was impassible due to a tangle of kudzu vines. As many as 30 stems were counted rising from one tuberous crown. One stem found growing on the forest floor exceeded 50 m in length. It had rooted at some of the nodes and had developed aerial stems that grew into the canopy. No mature fruits were found at this site.

In our study, stems with a diameter at breast height (dbh) of 6 cm were encountered with 7 growth rings. These large stems were from the kudzu population in the Shawnee National Forest, but stems in excess of 3 cm dbh, with 2-4 growth rings, also were found in Schuyler County in west-central Illinois.

Most kudzu populations were found along roadsides, in successional fields, around farm ponds, in strip-mined areas, around home sites and other disturbed areas, indicating many had been planted or established as a result of earth moving and road building activities (Table 1). Of 17 land owners interviewed, one obtained young plants from the Soil Conservation Service, four got plants or cuttings from established populations, five were planted along township roads for erosion control, and seven were not sure where or how the populations became established.

Mature fruits were found in six of the 78 populations. Most of the fruits contained at least one seed, although occasionally fruits lacked seeds (Table 2). Fruit size ranged from 34-104 mm long, and 4.5 to 9.3 mm wide (Table 2). Fruits from Union County Fish and Wildlife Area were longest and contained the most seeds (Table 2). Two distinct seed coat color types (mottled vs. uniform) were found in the fruits from two-thirds of the populations producing fruit. The frequency of mottled seeds varied from 0 to 80% (Table 2). In the Union County Fish and Wildlife population, where numerous seeds were available, mottled seeds possessed a greater mass than uniform ones (for 25 seeds), although volumes were similar for both seed types (Table 3). A smaller percentage of mottled seeds floated when placed in water than did uniform seeds (3 vs. 73%) in an unreplicated trial. This difference indicated that mottled seeds were more apt to be viable than uniform ones. Intermediate forms that were light brown with black mottling were very rare (less than 1%), while the placement of mottled and uniform seed in the fruits was random (personal observations).

Mottled/scarified kudzu seeds from the Union County Fish and Wildlife Area population displayed germination percentages in excess of 90% at all four temperatures. For scarified seeds, mottled seed germination percentages were significantly higher than those for uniform seeds (Table 4). Nonscarified seeds had relatively poor germination, always less than 33%. Germination of nonscarified seeds was not significantly correlated to mottling except at 30ºC. Scarification significantly improved germination for mottled seeds, but had no significant impact upon uniform seeds (Table 4). Germination rates declined at 35ºC relative to other temperatures tested (Fig. 2). Most seeds germinated within 3 days of imbibition (Fig. 2). Overall, kudzu seeds that were uniform or nonscarified had lower germination.

Seedling characteristics were studied for plants grown from seed collected at the Union County Fish and Wildlife Area (Table 5). The number of surviving seedlings present at one month after planting was highest for scarified/mottled seeds (76%), lower for nonscarified/mottled seeds (32%) and lowest for uniform seeds regardless of scarification treatment. Heights, node numbers, leaf areas, fresh masses and dry masses were greatest for seedlings derived from scarified/mottled seeds (Table 5). For all seedling parameters measured, plants started from mottled seeds were more vigorous than those from uniform seeds. For seedlings from mottled seeds, plants from scarified seeds grew better than

from nonscarified seeds. The young seedlings from scarified/mottled seeds had relatively short main stems with an average length of 13.9 mm at day 30, while the shoots formed a carpet-like covering of leaves (area of 39.6 cm^2) in the trays. In contrast, seedlings of nonscarified/mottled seeds had main stems that were only 8.8 mm long, and a leaf area of only 5.1 cm^2. For mottled seeds, average shoot masses of seedlings from scarified seeds also were significantly higher than for nonscarified seeds. Thus, vigorous seedlings were produced.

DISCUSSION

Many assumptions have been made concerning the capability of kudzu to grow in the northern United States. Sorrie and Perkins (1988) suggested that above-ground die-back may be important in preventing the spread of this taxon in New England. Flint (1983) also suggested that vines of this species were killed back by cold winter temperatures in Illinois, Indiana, Ohio and Pennsylvania. Our observations indicate, however, that kudzu vines do not die-back every winter in Illinois as stems with as many as 7 growth rings were found.

Fernald (1950), Sinclair et al. (1987) and Sorrie and Perkins (1988) stated that kudzu plants rarely produce fruits and viable seeds in the northern part of the United States. During the present study, fruits with seeds were found in six populations from central and southern Illinois (Table 2). Only small quantities of seeds (<60 seeds) were found in five of these populations, but a population at the Union County Fish and Wildlife Area produced large quantities (4500 seeds) with a high percentage of them viable (Table 4).

Most Illinois populations of kudzu were planted intentionally or became established with vegetative tissues as a result of human activities, such as being transported by construction and mowing equipment. Kudzu stems commonly root at the nodes when touching the ground, forming adventitous roots, and soon an elongated fleshy root (Miller and Edwards, 1983). These stems can be transported easily by construction equipment, and once buried, can continue to grow.

During the present study, seed germination and seedling establishment were highest with scarified/mottled seeds (Tables 4 and 5). The two seed coat colors observed during the present study (mottled vs. uniform) were not discussed by previous authors. These differences may be the result of early cessation of development with the mottled seeds having completed development before the fruits were killed by frost. The uniform seeds were smaller, and may have been immature, i.e., not fully developed. Additional studies are needed to investigate this speculation. Other environmental variations during seed development also might have influenced the appearance and vigor of these seeds (Baskin and Baskin, 1998). The mottled seeds had a harder seed coat and were more difficult to scarify than uniform seeds. Kudzu seeds from Illinois germinated at a wide range of temperatures and responded well to mechanical scarification for breaking dormancy. These responses are similar to previous reports for other legumes (Baskin et al., 1998) and for kudzu from other locations (Tabor, 1949; Tsugawa et al., 1979; Baskin and Baskin, 1998; Susko et al., 1999). The range of temperatures where kudzu seed germinated, indicate that it has the potential to become a major plant pest at least throughout the southern half of Illinois where seed was produced.

This study shows that viable seeds capable of producing vigorous seedlings are produced in Illinois at least during some growing seasons. It is therefore possible that some kudzu populations in Illinois were established from local seed sources rather than from vegetative tissues. Presently kudzu is uncommon in Illinois but population sizes and numbers have increased slowly during the last 50 years. This continual increase, coupled with an effective seed dispersal agent, could result in a population explosion, particularly in southern Illinois. This species is not expected to achieve the same degree of invasiveness in Illinois as in the southern United States. However, if not controlled, it has the potential of becoming a local problem, causing concern for rural landowners.

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Table 1. Location of known kudzu populations in Illinois, habitat of occurrence, and total area by county (ha).

County	Total Sites	Habitat Type						Total Area (ha)
		Roadside	Open Field	Woods	Home Site	Stripmine	Water Edge	
Alexander	3	2	1	-	-	-	-	15.0
Crawford	1	-	-	1	-	-	-	0.3
Fayette	2	2	-	-	-	-	-	1.0
Fulton	2	-	1	-	-	1	-	6.0
Gallatin	1	1	-	-	-	-	-	2.5
Greene	1	-	-	1	-	-	-	1.0
Hardin	2	1	-	-	-	1	-	2.0
Jackson	8	5	1	1	1	-	-	17.0
Jefferson	3	3	-	-	-	-	-	1.8
Jersey	2	-	-	2	-	-	-	2.0
Johnson	3	3	-	-	-	-	-	1.0
Madison	3	1	2	-	-	-	-	2.5
Massac	1	-	-	-	-	1	-	1.0
Monroe	2	2	-	-	-	-	-	1.0
Peoria	1	1	-	-	-	-	-	0.3
Perry	1	-	1	-	-	-	-	1.5
Pike	1	-	-	1	-	-	-	2.0
Pope	5	1	1	1	2	-	-	22.0
Pulaski	2	2	-	-	-	-	-	6.0
Randolph	3	-	3	-	-	-	-	14.0
Rock Island	1	-	-	1	-	-	-	0.3
Saline	5	-	1	-	-	4	-	6.0
Schuyler	1	-	-	-	1	-	-	0.5
Shelby	1	-	-	-	-	-	1	0.5
St. Clair	2	-	1	-	-	1	-	1.0
Tazewell	1	-	-	1	-	-	-	1.0
Union	8	3	-	4	-	-	1	4.4
Williamson	12	4	-	-	-	7	1	13.0
Totals	78	31	12	13	4	15	3	126.6

Table 2. Means and standard deviations for kudzu fruit length, fruit width, and number of seeds/fruit for selected Illinois populations. Ranges are in parentheses. Percent of mottled seeds is based on the total of mottled plus uniform seeds.

Population	Fruit Length (mm)	Fruit Width (mm)	Seeds/Fruit	Percent Mottled Seeds
Central Illinois				
Fayette Co. near Laclede	54.2 ± 9.3 (42-83)	8.5 ± 0.4 (8.0-9.3)	0.8 ± 1.0 (0-4)	0
Jefferson Co. 3 km N of Harmon	52.6 ± 7.0 (39-69)	8.1 ± 0.4 (7.5-8.8)	1.8 ± 1.1 (0-4)	56
Jefferson Co. 1.5 km N of Harmon	51.2 ± 11.9 (34-80)	8.0 ± 0.6 (6.8-9.0)	2.3 ± 1.3 (1-6)	20
Southern Illinois				
Jackson Co. 8 km S of Murphysboro	55.3 ± 7.1 (41-69)	7.3 ± 0.5 (6.4-8.5)	0.9 ± 0.9 (0-3)	80
Union Co. Fish & Wildlife Area	79.0 ± 15.6 (52-104)	7.3 ± 0.5 (6.0-8.2)	4.7 ± 2.2 (1-9)	65
Union Co. State Nursery	48.8 ± 4.5 (44-60)	6.9 ± 0.5 (4.5-7.7)	0.1 ± 0.3 (0-1)	0

Table 3. Means and standard deviations for mass and volume of mottled and uniform kudzu seeds from fruits collected at the Union County Fish and Wildlife Area, southern Illinois.

Seed Type	Mass (g) for 25 seeds	Volume (ml) for 25 seeds
mottled	0.34 ± 0.01 a[a]	0.29 ± 0.02 a
uniform	0.21 ± 0.02 b	0.23 ± 0.06 a

[a] means within a column followed by different letters are significantly different at 5% level based upon ANOVA

Table 4. Means and standard deviations for germination percentages after 14 days of mottled and uniform kudzu seeds with and without scarification. Fruits were collected at Union County Fish and Wildlife Area, southern Illinois (50 seeds/test).

Seed Type	Scarified		Nonscarified		
20°C					
mottled	98 ± 4	a[a]	22 ± 18	a	*[b]
uniform	34 ± 17	b	14 ± 13	a	ns
25°C					
mottled	100 ± 0	a	20 ± 16	a	*
uniform	36 ± 11	b	24 ± 9	a	ns
30°C					
mottled	100 ± 0	a	32 ± 11	a	*
uniform	18 ± 24	b	10 ± 7	b	ns
35°C					
mottled	94 ± 5	a	16 ± 9	a	*
uniform	14 ± 17	b	10 ± 10	a	ns

[a] means within a temperature pair in a column followed by different letters are significantly different at 5% level based upon ANOVA

[b] means within a row are significantly different (*) or not significantly different (ns) at 5% level based upon ANOVA

Table 5. Means and standard deviations for seedling characteristics after one month of growth for mottled and uniform kudzu seeds with and without scarification. Seeds are from fruits collected at the Union County Fish and Wildlife Area, southern Illinois.

Seed Type	Scarified		Nonscarified		
Emergence (%)					
mottled	76 ± 19	a[a]	32 ± 8	a	*[b]
uniform	2 ± 4	b	8 ± 13	b	ns
Height (mm)					
mottled	13.9 ± 2.4	a	8.8 ± 1.5	a	*
uniform	1.8 ± 4.0	b	3.4 ± 4.6	b	ns
Number of Nodes					
mottled	7.1 ± 0.4	a	4.1 ± 1.1	a	*
uniform	1.0 ± 2.2	b	1.0 ± 2.2	b	ns
Leaf Area (cm^2)					
mottled	39.6 ± 4.9	a	5.1 ± 1.6	a	*
uniform	3.6 ± 8.2	b	0.5 ± 1.1	b	ns
Fresh Shoot Mass (g)					
mottled	0.80 ± 0.10	a	0.14 ± 0.03	a	*
uniform	0.07 ± 0.17	b	0.02 ± 0.04	b	ns
Dry Shoot Mass (g)					
mottled	0.108 ± 0.013	a	0.023 ± 0.009	a	*
uniform	0.012 ± 0.027	b	0.003 ± 0.006	b	ns

[a] means within a pair for a given measured parameter in a column followed by different letters are significantly different at 5% level based upon ANOVA

[b] means within a row are significantly different (*) or not significantly different (ns) at 5% level based upon ANOVA

Figure 1. Distribution of *Pueraria lobata* (Willd.) Ohwi in Illinois, USA.

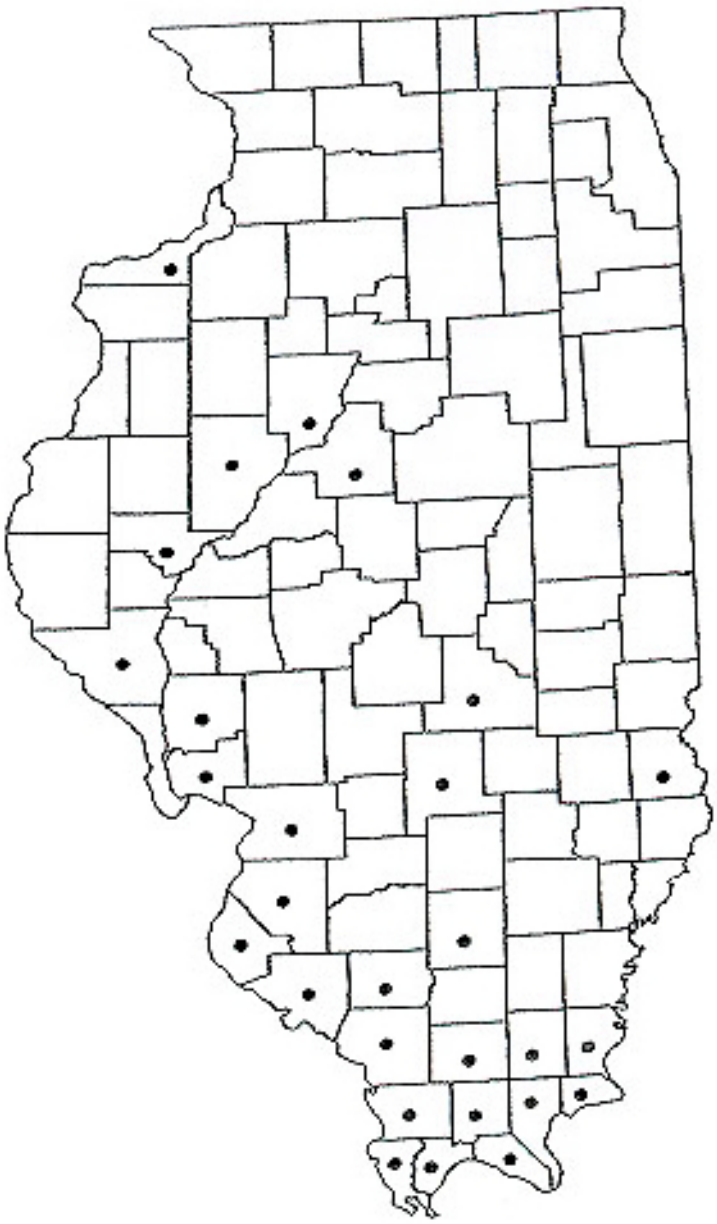

Figure 2. Means and standard deviations for percentage germination over time of mottled and uniform kudzu seeds with and without scarification. Fruits were collected at the Union County Fish and Wildlife Area, southern Illinois.