Autecology of Early Goldenrod on the Northern Mixed Grass Prairie

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The autecology of Early goldenrod (Missouri goldenrod), *Solidago missouriensis* Nutt., is one of the prairie plant species included in a long ecological study conducted at the NDSU Dickinson Research Extension Center during 67 growing seasons from 1946 to 2012 that quantitatively describes the changes in growth and development during the annual growing season life history and the changes in abundance through time as affected by management treatments for the intended purpose of the development and establishment of scientific standards for proper management of native rangelands of the Northern Plains. The introduction to this study can be found in report DREC 16-1093 (Manske 2016).

Early goldenrod (Missouri goldenrod), *Solidago missouriensis* Nutt., is a member of the aster (sunflower) family, Asteraceae, and is a native, short lived perennial, warm season, dicot, herb that is moderately drought tolerant, tolerant of partial shade, and intolerant of extremely acidic and saline conditions. The first North Dakota record is Bergman 1911. Early goldenrod is highly variable throughout its range. Early aerial growth consists of petioled basal leaves with long oblanceolate blade arising from woody crown (caudex). Annual aerial growth has single or group of erect or ascending unbranched smooth reddish stems 30-60 cm (11.8-23.6 in) tall. Stem (cauline) leaves are alternate, simple, lance-elliptic to linear 6-15 cm (2.4-5.9 in) long, 1-3 cm (0.4-1.2 in) wide decreasing upward, stiff, 3 ribbbed, and sessile. Stems and leaves are hairless (glabrous). The root system has both shallow and deep roots. Clusters of short or repeatedly branched roots 0.5-3 mm in diameter are produced from the crown and rhizome nodes that end in the top 30.5-61.0 cm (1-2 ft) of soil. The larger main lateral roots are white cord-like with a horizontal radial spread of 30.5-50.8 cm (12-20 in) and descend in an unequal, open (not compact) pattern to 1.7 m (5.5 ft) with some to 2.1 m (7 ft) and a few can descend to 3.4 m (11 ft) in loose soil. The roots at all depths are vigorous absorbers. An extensive system of rhizomes develops from the crown 5.1-30.5 cm (2-12 in) long, 3-8 mm in diameter that become woody with age forming large open patches that sometimes can become dense colonies. Under some conditions, rhizomes can arise from adventitious buds on the main lateral roots. Regeneration is by vegetative and sexual reproduction. Vegetative growth is by annual sprouts from the subterranian woody crown, by offset shoots from crown branches, and by sprouts from the extensive rhizome system. Inflorescence has numerous heads on one side of recurved branches in a pyramid shaped panicle. Flowers are perfect with corolla of yellow disk and ray florets appearing during mid July to September. Pollination by bees, wasps, beetles, and other insects. Fruit is tiny one seeded cylindrical achene with pappus of numerous white bristles. Aerial parts are not eaten by livestock and are totally consumed by fire. Damage to aerial stems before senescence activates vigorous regrowth of sprouts from the affected rhizomes. This summary information on growth development and regeneration of early goldenrod was based on works of Weaver 1954, 1958; Stevens 1963, Zaczkowski 1972, Great Plains Flora Association 1986, Walsh 1994, Stubbendieck et al. 2003, Larson and Johnson 2007, Pavek 2011, and Stubbendieck et al. 2011.

Procedures

The 1955-1962 Study

Early goldenrod plant growth in height was determined by measuring ungrazed stems from ground level to top of leaf or to the tip of the inflorescence of an average of 10 plants of each species at approximately 7 to 10 day intervals during the growing seasons of 1955 to 1962 from early May until early September. Dates of first flower (anthesis) were recorded as observed. These growth in height and flower data were reported in Goetz 1963.

The 1969-1971 Study

The range of flowering time of Early goldenrod was determined by recording daily observations of plants at anthesis on several prairie habitat type collection locations distributed throughout 4,569 square miles of southwestern North Dakota. The daily observed flowering plant data collected during the growing seasons of 1969 to 1971 from April to August were reported as flower sample periods with 7 to 8 day duration in Zaczkowski 1972.

The 1983-2012 Study

A long-term study on change in abundance of Early goldenrod was conducted during active plant growth of July and August each growing season of 1983 to 2012 (30 years) on native rangeland pastures at the Dickinson Research Extension Center ranch located near Manning, North Dakota. Effects from three management treatments were evaluated: 1) long-term nongrazing, 2) traditional seasonlong grazing, and 3) twice-over rotation grazing. Each treatment had two replications, each with data collection sites on sandy, shallow, and silty ecological sites. Each ecological site of the two grazed treatments had matching paired plots, one grazed and the other with an ungrazed exclosure. The sandy, shallow, and silty ecological sites were each replicated two times on the nongrazed treatment, three times on the seasonlong treatment, and six times on the twice-over treatment.

During the initial phase of this study, 1983 to 1986, the long-term nongrazed and seasonlong treatments were at different locations and moved to the permanent study locations in 1987. The data collected on those two treatments during 1983 to 1986 were not included in this report.

Abundance of Early goldenrod was determined with plant species stem density by 0.1 m^2 frame density method and with plant species basal cover by the ten-pin point frame method (Cook and Stubbendieck 1986).

The stem density method was used to count individual stems of each plant species rooted inside twenty five 0.1 m^2 quadrats placed along permanent transect lines at each sample site both inside (ungrazed) and outside (grazed) each exclosure. Stem density per 0.1 m^2 quadrat, relative stem density, percent frequency, relative percent frequency, and importance value were determined from the stem density data. Plant species stem density data collection was 1984, 1986 to 2012 on the twice-over treatment and was 1987 to 2012 on the long-term nongrazed and seasonlong treatments. However, stem density data was not collected during 1991, 1993 to 1997 on the sandy, shallow, and silty ecological sites of all three management treatments, stem density data was not collected during 1992 on the sandy ecological site of all three management treatments, and stem density data was not collected during 1999 on the sandy and silty ecological sites of the long-term nongrazed treatment.

The point frame method was used to collect data at 2000 points along permanent transect lines at each sample site both inside (ungrazed) and outside (grazed) each exclosure. Basal cover, relative basal cover, percent frequency, relative percent frequency, and importance value were determined from the ten-pin point frame data. Point frame data collection period was 1983 to 2012 on the twice-over treatment and was 1987 to 2012 on the long-term nongrazed and seasonlong treatments. However, point frame data was not collected during 1992 on the sandy ecological sites of all three treatments.

During some growing seasons, the point frame method or the stem density method did not document the presence of a particular plant species which will be reflected in the data summary tables as an 0.00 or as a blank spot.

The 1983-2012 study attempted to quantify the increasing or decreasing changes in individual plant species abundance during 30 growing seasons by comparing differences in the importance values of individual species during multiple year periods. Importance value is an old technique that combines relative density or relative basal cover with relative frequency producing a scale of 0 to 200 that ranks individual species abundance within a plant community relative to the individual abundance of the other species in the community during a growing season. Density importance value ranks the forbs and shrubs and basal cover importance value ranks the grasses, upland sedges, forbs, and shrubs in a community. The quantity of change in the importance value of an individual species across time indicates the magnitude of the increases or decreases in abundance of that species relative to the changes in abundance of the other species.

Results

Early goldenrod resumes annual aerial growth with an early basal rosette of long petioled leaves arising from a woody caudex, followed by growth of an erect unbranched smooth reddish stem. An extensive system of rhizomes 5.1-30.5 cm (2-12 in) long develops from the caudex. A shallow and a deep root system develop. Repeatedly branched roots cluster from the caudex and rhizomes nodes occupy the top 61.0 cm (2 ft) of soil. White cord-like large main lateral roots spread radially out to 30.5 to 50.8 cm (12-20 in) then turn downward and descend to 1.7-3.4 cm (5.5-11 ft) deep in loose soil. All the roots are vigorous absorbers. Numerous composite heads with yellow disk and ray florets develop on one side of recurved branches forming a pyramid shaped

panicle. On the fall grazed pastures of the 1955-1962 study, the earliest first flowers appeared 5 July, the mean first flowers occurred on 19 July, and a 7 week long flower period from mid July, through August and into the first week of September (table 1) (Goetz 1963, Zaczkowski 1972). A mean mature stem height of 21.0 cm (8.3 in) with an annual variance in height from 12.0 cm (4.7 in) to 31.0 cm (12.2 in) was reached during August (table 2) (Goetz 1963). The reported normal mature stem height in the Northern Plains ranged from 30.0 cm (11.8 in) to 60.0 cm (23.6 in) tall. The mature stem heights measured during the 1955-1962 study were mostly short of the normal stem height for the Northern Plains. The shorter heights of Early goldenrod were not caused directly by grazing effects but was caused by low quantities of available mineral nitrogen below the threshold levels of 100 lbs/ac in the soil as a result of detrimental effects from traditional management practices.

Plant species composition in rangeland ecosystems is variable during a growing season and dynamic among growing seasons. Early goldenrod was found to have low abundance in sandy ecological sites. Patterns in the changes of individual plant species abundance was followed for 30 growing seasons during the 1983-2012 study on the shallow and silty ecological sites of the long-term nongrazed, traditional seasonlong, and twice-over rotation management treatments.

On the shallow site of the nongrazed treatment, Early goldenrod was not present where basal cover data were collected and was present during 5.3% of the years that density were collected with a mean 0.022 stems/m^2 density during the total 30 year period. During the early period (1983-1992), Early goldenrod was present during 20.0% of the years with a mean 0.10 stems/m^2 density. During the later period (1998-2012), Early goldenrod was not present with density decreasing to 0.0 stems/m^2. Basal cover data was not present during the total 30 year period. The percent present for density data and stem density decreased to zero on the shallow site of the nongrazed treatment over time (tables 3 and 5).

On the shallow site of the ungrazed seasonlong treatment, Early goldenrod was present during 5.0% and 3.9% of the years that density and basal cover data were collected with a mean 0.025 stems/m^2 density and a mean 0.003% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Early goldenrod was not present on the shallow site of the ungrazed seasonlong treatment. During the later period (1998-2012), Early goldenrod was present during 6.7% and 6.7% of the years with a mean 0.033 stems/m^2 density and a mean 0.005% basal cover, respectively. Early goldenrod was not present during the early period and all observations were made during the later period indicated low abundance.

On the shallow site of the grazed seasonlong treatment, Early goldenrod was present during 40.0% and 23.1% of the years that density and basal cover data were collected with a mean 0.63 stems/m^2 density and a mean 0.03% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Early goldenrod was present during 40.0% and 33.3% of the years with a mean 1.48 stems/m^2 density and a mean 0.11% basal cover, respectively. During the later period (1998-2012), Early goldenrod was present during 40.0% and 26.7% of the years with a mean 0.35 stems/m^2 density and a mean 0.009% basal cover, respectively. The percent present for density data remained the same, and percent present for basal cover data, stem density, and basal cover decreased on the shallow site of the grazed seasonlong treatment over time (tables 3, 4, and 5). The percent present, stem density, and basal cover were all greater on the shallow site of the grazed seasonlong treatment than those on the shallow site of the ungrazed seasonlong treatment.

On the shallow site of the ungrazed twice-over treatment, Early goldenrod was present during 72.7% and 65.5% of the years that density and basal cover data were collected with a mean 1.90 stems/m^2 density and a mean 0.08% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Early goldenrod was present during 28.6% and 55.6% of the years with a mean 0.43 stems/m^2 density and a mean 0.003% basal cover, respectively. During the later period (1998-2012), Early goldenrod was present during 93.3% and 93.3% of the years with a mean 2.59 stems/m^2 density and a mean 0.14% basal cover, respectively. The percent present, stem density, and basal cover all increased greatly on the shallow site of the ungrazed twice-over treatment over time (tables 3, 4, and 5).

On the shallow site of the grazed twice-over treatment, Early goldenrod was present during 86.4% and 50.0% of the years that density and basal cover data were collected with a mean 1.46 stems/m^2 density and a mean 0.04% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Early goldenrod was present during 71.4% and 50.0% of the years with a mean 1.03 stems/m^2 density and a mean 0.06% basal cover, respectively. During the later period (1998-2012), Early goldenrod was present during 93.3% and 66.7%

of the years with a mean 1.67 stems/m^2 density and a mean 0.03% basal cover, respectively. The percent present for density data, percent present for basal cover data, and stem density increased and basal cover decreased on the shallow site of the grazed twice-over treatment over time (tables 3, 4, and 5). The percent present, stem density, and basal cover were fairly similar on the shallow site of the ungrazed and grazed twice-over treatments.

On the silty site of the nongrazed treatment, Early goldenrod was not present during the total 30 year period.

On the silty site of the ungrazed seasonlong treatment, Early goldenrod was present during 30.0% and 15.4% of the years that density and basal cover data were collected with a mean 0.03 stems/m^2 density and a mean 0.003% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Early goldenrod was present during 20.0% and 50.0% of the years with a mean 0.40 stems/m^2 density and a mean 0.09% basal cover, respectively. During the later period (1998-2012), Early goldenrod was present during 33.3% and 6.7% of the years with a mean 0.23 stems/m^2 density and a mean 0.003% basal cover, respectively. The percent present for density data increased and percent present for basal cover data, stem density, and basal cover decreased on the silty site of the ungrazed seasonlong treatment over time (tables 3, 4, and 5).

On the silty site of the grazed seasonlong treatment, Early goldenrod was present during 10.0% and 19.2% of the years that density and basal cover data were collected with a mean 0.03 stems/m^2 density and a mean 0.015% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Early goldenrod was present during 20.0% and 16.7% of the years with a mean 0.08 stems/m^2 density and a mean 0.04% basal cover, respectively. During the later period (1998-2012), Early goldenrod was present during 6.7% and 20.0% of the years, with a mean 0.007 stems/m^2 density and a mean 0.005% basal cover, respectively. The percent present for basal cover data increased, and percent present for density data, stem density, and basal cover decreased on the silty site of the grazed seasonlong treatment over time (tables 3, 4, and 5). The percent present for basal cover data were fairly similar, and percent present for density data, stem density, and basal cover were greater on the silty site of the ungrazed seasonlong treatment than those on the silty site of the grazed seasonlong treatment.

On the silty site of the ungrazed twice-over treatment, Early goldenrod was present during 13.6% and 3.5% of the years that density and basal cover data were collected with a mean 0.04 stems/m^2 density and a mean 0.001% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Early goldenrod was present during 14.3% and 11.1% of the years with a mean 0.04 stems/m^2 density and a mean 0.002% basal cover, respectively. During the later period (1998-2012), Early goldenrod was present during 13.3% and 0.0% of the years with a mean 0.03 stems/m^2 density and a mean 0.0% basal cover, respectively. The percent present for density data and stem density remained fairly similar and percent present for basal cover data and basal cover decreased greatly on the silty site of the ungrazed twice-over treatment over time (tables 3, 4, and 5).

On the silty site of the grazed twice-over treatment, Early goldenrod was not present where basal cover data were collected and was present during 18.2% of the years that density data were collected with a mean 0.07 stems/m^2 density during the total 30 year period. During the early period (1983-1992), Early goldenrod was present during 28.6% of the years with a mean 0.19 stems/m^2 density. During the later period (1998-2012), Early goldenrod was present during 13.3% of the years with a mean 0.013 stems/m^2 density. Basal cover data was not present during the total 30 year period. The percent present for density data and stem density decreased on the silty site of the grazed twice-over treatment over time (tables 3 and 5). The percent present, stem density, and basal cover were fairly similar on the silty site of the ungrazed and grazed twice-over treatment.

On the shallow site, Early goldenrod was present during 41.9% and 28.5% of the years with a mean 0.81 stems/m^2 density and a mean 0.03% basal cover. On the silty site, Early goldenrod was present during 14.4% and 7.2% of the years with a mean 0.08 stems/m^2 density and a mean 0.007% basal cover. The percent present, stem density, and basal cover were greater on the shallow site than those on the silty site.

Early goldenrod was present on the shallow site of the nongrazed treatment during 5.3% and 0.0% of the years with a mean 0.02 stems/m^2 density and a mean 0.0% basal cover. Early goldenrod was present on the shallow site of the seasonlong treatment during 22.5% and 13.5% of the years with a mean 0.33 stems/m^2 density and a mean 0.017% basal cover. Early goldenrod was present on the shallow site of the

twice-over treatment during 79.6% and 57.8% of the years with a mean 1.68 stems/m^2 density and a mean 0.05% basal cover. The percent present, stem density, and basal cover were greater on the shallow site of the twice-over treatment.

Early goldenrod on the silty site of the nongrazed treatment was not present during the total 30 year period. Early goldenrod was present on the silty site of the seasonlong treatment during 20.0% and 17.3% of the years with a mean 0.15 stems/m^2 density and a mean 0.019% basal cover. Early goldenrod was present on the silty site of the twice-over treatment during 15.9% and 1.7% of the years with a mean 0.05 stems/m^2 density and a mean 0.001% basal cover. The percent present, stem density and basal cover were greater on the silty site of the seasonlong treatment.

Discussion

Early goldenrod, *Solidago missouriensis*, is a native, late succession, perennial, warm season, dicot, forb of the aster family that is commonly present on healthy mixed grass prairie plant communities. Early goldenrod can grow on shallow and silty ecological sites. It grows better on shallow sites and grows best on shallow sites managed with the twice-over treatment. Annual aerial growth consists of an early set of basal rosette leaves with long petioles arising from a woody perennating caudex. Shortly after, one to few erect unbranched smooth reddish stems arise, and an extensive subterranean rhizome system develops. A shallow root system that occupies the top 61.0 cm (2 ft) of soil develops as repeatedly branched root clusters arising from the caudex and rhizome nodes. A deep root system develops as large main white cord-like lateral roots that spread radially before turning downward and descending to 3.4 m (11 ft) deep in loose soil. All the roots are vigorous absorbers. Flowers with yellow disk and ray florets develop on one side of recurved branches form a pyramid shaped panicle. The mean first flowers occurred on 19 July (1955-1962 study), with a 7 week flower period from mid July to early September (1969-1971 study). The mean mature stem height of 21.0 cm (8.3 in) was reached during August (1955-1962 study). Early goldenrod has low abundance on the nongrazed and ungrazed seasonlong treatments on the shallow and silty sites. Early goldenrod has a slightly greater abundance on the grazed seasonlong treatment on the shallow and silty sites and on the ungrazed and grazed twice-over treatment on the silty site and moderate abundance on the ungrazed and grazed twice-over treatment on the shallow site.

The perennating caudex, the rhizome system, and the two root systems help Early goldenrod to persist through the harsh conditions of the Northern Mixed Grass Prairie.

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Table 1. First flower and flower period of Solidago missouriensis, Early goldenrod.

	Apr	May	Jun	Jul	Aug	Sep
First Flower						
1955-1962						
Earliest			5			
Mean				19		
Flower Period						
1969-1971				XX	XX XX X	

First Flower data from Goetz 1963.
Flower Period Data from Zaczkowski 1972.

Table 2. Autecology of Solidago missouriensis, Early goldenrod, with growing season changes in mature height.

				Percent of Mature Height Attained					
Data Period	Minimum Annual Mature Height cm	Maximum Annual Mature Height cm	Mean Mature Height cm	Apr %	May %	Jun %	Jul %	Aug %	Sep %
1955-1962	12.0	31.0	21.0	3.2	28.7	47.6	88.0	100.0	

Data from Goetz 1963.

Table 3. Autecology of Solidago missouriensis, Early goldenrod, with growing season changes in density importance value, 1983-2012.					
Ecological Site Year Period	Nongrazed	Seasonlong		Twice-over	
		Ungrazed	Grazed	Ungrazed	Grazed
Sandy					
1983-1987	Few Plants Present				
1988-1992					
1993-1998					
1999-2003					
2004-2009					
2010-2012					
Shallow					
1983-1987	1.99	0.00	13.40	2.44	6.83
1988-1992	0.00	0.00	5.17	0.00	3.64
1993-1998	0.00	0.00	1.97	3.55	3.63
1999-2003	0.00	0.88	3.21	3.81	5.84
2004-2009	0.00	0.00	0.39	4.80	5.50
2010-2012	0.00	0.00	0.77	6.74	6.23
Silty					
1983-1987	0.00	2.55	2.36	0.47	1.73
1988-1992	0.00	0.00	0.00	0.00	0.17
1993-1998	0.00	1.90	0.00	1.86	0.00
1999-2003	0.00	0.92	0.00	0.13	0.00
2004-2009	0.00	0.29	0.09	0.00	0.15
2010-2012	0.00	0.00	0.00	0.00	0.00

Table 4. Autecology of Solidago missouriensis, Early goldenrod, with growing season changes in basal cover importance value, 1983-2012.					
Ecological Site Year Period	Nongrazed	Seasonlong		Twice-over	
		Ungrazed	Grazed	Ungrazed	Grazed
Sandy					
1983-1987	Few Plants Present				
1988-1992					
1993-1998					
1999-2003					
2004-2009					
2010-2012					
Shallow					
1983-1987	0.00	0.00	0.00	0.30	0.40
1988-1992	0.00	0.00	0.07	0.10	0.04
1993-1998	0.00	0.00	0.00	0.12	0.07
1999-2003	0.00	0.00	0.00	0.16	0.05
2004-2009	0.00	0.00	0.02	0.06	0.08
2010-2012	0.00	0.00	0.00	0.02	0.07
Silty					
1983-1987	0.00	1.58	2.14	1.29	1.06
1988-1992	0.00	0.11	0.12	0.00	0.00
1993-1998	0.37	0.25	0.31	0.39	0.20
1999-2003	0.00	0.03	0.20	0.58	0.54
2004-2009	0.00	0.03	0.02	0.60	0.43
2010-2012	0.00	0.05	0.00	0.07	0.28

Table 5. Autecology of Solidago missouriensis, Early goldenrod, with growing season changes in density, 1983-2012.					
Ecological Site Year Period	Nongrazed	Seasonlong		Twice-over	
		Ungrazed	Grazed	Ungrazed	Grazed
Sandy					
1983-1987	Few Plants Present				
1988-1992					
1993-1998					
1999-2003					
2004-2009					
2010-2012					
Shallow					
1983-1987	0.04	0.00	0.37	0.10	0.18
1988-1992	0.00	0.00	0.09	0.00	0.05
1993-1998	0.00	0.00	0.03	0.09	0.05
1999-2003	0.00	0.01	0.07	0.28	0.19
2004-2009	0.00	0.00	0.01	0.29	0.16
2010-2012	0.00	0.00	0.01	0.21	0.17
Silty					
1983-1987	0.00	0.20	0.04	0.01	0.04
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.00	0.07	0.00	0.04	0.00
1999-2003	0.00	0.04	0.00	0.00	0.00
2004-2009	0.00	0.01	0.00	0.00	0.00
2010-2012	0.00	0.00	0.00	0.00	0.00

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