Autecology of Rough Pennyroyal on the Northern Mixed Grass Prairie

Llewellyn L. Manske PhD
Research Professor of Range Science
North Dakota State University
Dickinson Research Extension Center
Report DREC 16-1115

The autecology of Rough pennyroyal, *Hedeoma hispida*, 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).

Rough pennyroyal, *Hedeoma hispida* Pursh, is a member of the mint family, Lamiaceae, and is a native, small annual, dicot, herb that has low ecological rank, even though, it has wide occurrence, it has low numbers. The first North Dakota record is Bolley 1891. Aerial growth has a single simple, 4 angled square stem, sometimes branched near base, 10-15 cm (3.9-5.9 in) tall. Leaves are opposite, simple, spreading, sessile, narrowly elliptic to linear-lanceolate, 10-15 mm, long, 1-2 mm wide. Stem and underside of leaves are covered with downward curved (retrorse) hairs. The root system is shallow with one main descending root and with several lesser roots arising from a crown. All roots have short lateral roots. Rarely does the main root extend past 5.1 cm (2 in) deep. Regeneration is by sexual reproduction. Inflorescence is a cymule of 3 to 6 flowers in a whorl at all leaf nodes except for a few lower nodes (verticillasters) forming a compound cyme. Flowers are perfect on pedicels 1.5-4 mm long with bluish purple corolla 5 mm long that are of 2 types; the chasmogamous flowers open before cross fertilization appearing during early June to mid August, and the cleistogamous flowers are self fertilized without opening. Fruit is a dry, indehiscent schizocarp that splits into 4, 1 seeded segments (carpels) at maturity. Nutlets are yellow brown or darker 1-1.3 mm long. Aerial parts are not eaten by livestock and are totally consumed by fire. This summary information on growth development and regeneration of Rough pennyroyal was based on the works of Weaver and Fitzpatrick 1934, Stevens 1963, Zaczkowski 1972, Great Plains Flora Association 1986, and Stubbendieck et al. 2003.

Procedures

The 1969-1971 Study

The range of flowering time of Rough pennyroyal 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 1984-1985 Study

Rough pennyroyal plant growth in height was determined by measuring stems from ground level to top of stem or leaf or to the tip of the inflorescence of 12 ungrazed specimens randomly selected on each of the three replications of grazed sandy, shallow, silty, and clayey ecological sites biweekly during June, July, and August of the growing seasons of 1984 and 1985. Phenological growth stage of each specimen was recorded as vegetative, budding, anthesis, seed developing, seed shedding, or mature. Percentage of stem dryness of each specimen was recorded as 0, 0-2, 2-25, 25-50, 50-75, 75-98, or 100 percent dry. Mean stem weight was determined by clipping at ground level 80 specimens at typical phenological growth stages at biweekly sample dates on separate grazed areas of the sandy, shallow, silty, and clayey ecological sites. Clipped stems at each sample site were placed in separate labeled paper bags of known weight, oven dried at 62° C (144° F), and weighed in grams.

The 1983-2012 Study

A long-term study on change in abundance of Rough pennyroyal 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 Rough pennyroyal 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 that 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 values 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

Rough Pennyroyal is a small annual mint that develops from a seed, however, it does not develop every year. During the growing seasons that it germinates and develops, the tiny blue flowers appear during early June to mid August, from the 1969-1971 study (table 1) (Zaczkowski 1972), and during early June to late July, from the 1984-1985 study (tables 3, 4, 5, and 6). The mean mature stem height of 6.8 cm (2.7 in) tall was reached in August, from the 1984-1985 study (table 2). The tallest stems were on the sandy site at 8.1 cm (3.2 in), the shortest stems were on the shallow and clayey sites at 6.0 cm (2.4 in) and 6.2 cm (2.4 in), respectively, and the middle height stems were on the silty sites at 7.1 cm (2.8 in) (table 2). The reported normal mature stem height in the Northern Plains ranged from 10 cm to 15 cm (3.9-5.9 in). The range of measured mature stem heights was 6.0-8.1 cm (2.4-3.2 in), which was shorter than the reported normal heights. These lower mature stem heights of Rough pennyroyal on the 1984-1985 study were not caused directly by grazing effects but were caused by low available mineral nitrogen below the threshold quantity of 100

lbs/ac that resulted from the traditional management practices conducted prior to the start of this study.

Changes in phenological growth stages from the 1984-1985 study are summarized on tables 3, 4, 5, and 6. A total of 3,747 Rough pennyroyal stems were sampled during this study with, 776 stems (20.71%) from the sandy sites, 866 stems (23.11%) from the shallow sites, 1225 stems (32.69%) from the silty sites, and 880 stems (23.49%) from the clayey sites. Rough pennyroyal can grow on the sandy, shallow, silty, and clayey ecological sites, however, it is more plentiful on the silty ecological sites than on the sandy ecological sites.

During the growing season, almost all of the Rough pennyroyal stems developed through anthesis and the mature phenological growth stages and less than 0.1% of the stems remained at vegetative growth stages until the end of the growing season and died (tables 3, 4, 5, and 6).

Mean Rough pennyroyal stem weights were not significantly different on the four ecological sites. Stem weights were heaviest on the sandy sites at 0.05 g, were lightest on the clayey sites at 0.02 g, and were in the middle on the shallow and silty sites at 0.03 g each (tables 3, 4, 5, and 6).

Plant species composition in rangeland ecosystems is variable during a growing season and dynamic among growing seasons. Patterns in the changes in individual plant species abundance was followed for 30 growing seasons during the 1983-2012 study.

On the sandy site of the nongrazed treatment, Rough pennyroyal was present during 27.8% and 4.0% of the years that density and basal cover data were collected, with a mean 0.30 stems/m^2 density and a mean 0.006% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Rough pennyroyal was present during 0.0% and 0.0% of the years. During the later period (1998-2012), Rough pennyroyal was present during 35.7% and 5.6% of the years, with a mean 0.39 stems/m^2 density and a mean 0.008% basal cover, respectively. Both the stem density and basal cover increased on the sandy sites of the nongrazed treatment over time (tables 7, 8, and 9).

On the sandy sites of the seasonlong treatment, Rough pennyroyal was present on the ungrazed sandy site during 26.3% and 4.0% of the years, with a mean 0.33 stems/m^2 density and a mean 0.003% basal cover, and was present on the grazed sandy site during 47.4% and 12.0% of the years that density and basal cover data were collected, with a mean 0.81 stems/m^2 density and a mean 0.01% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Rough pennyroyal was present on the ungrazed sandy site during 0.0% and 0.0% of the years. During the later period (1998-2012), Rough pennyroyal was present on the ungrazed sandy site during 33.3% and 5.6% of the years, with a mean 0.42 stems/m^2 density and a mean 0.004% basal cover, respectively. Both the stem density and basal cover increased on the ungrazed sandy site of the seasonlong treatment over time. During the early period (1983-1992), Rough pennyroyal was present on the grazed sandy site during 0.0% and 0.0% of the years. During the later period (1998-2012), Rough pennyroyal was present on the grazed sandy site during 60.0% and 16.7% of the years, with a mean 1.02 stems/m^2 density and a mean 0.02% basal cover, respectively. Both the stem density and basal cover increased on the grazed sandy site of the seasonlong treatment over time. During the early period (1983-1992), Rough Pennyroyal was not present on the ungrazed and grazed sandy sites. During the later period (1998-2012), stem density and basal cover of Rough pennyroyal increased on both the ungrazed and grazed sandy sites. The increase was greater on the grazed sandy site, resulting in greater stem density and basal cover values on the grazed sandy site of the seasonlong treatment (tables 7, 8, and 9).

On the sandy sites of the twice-over treatment, Rough pennyroyal was present on the ungrazed sandy site during 33.3% and 7.1% of the years, with a mean 0.22 stems/m^2 density and a mean 0.001% basal cover, and was present on the grazed sandy site during 57.1% and 10.3% of the years that density and basal cover data were collected, with a mean 0.34 stems/m^2 density and a mean 0.01% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Rough pennyroyal was present on the ungrazed sandy site during 33.3% and 0.0% of the years, with a mean 0.05 stems/m^2 density. During the later period (1998-2012), Rough pennyroyal was present on the ungrazed sandy site during 33.3% and 11.1% of the years, with a mean 0.29 stems/m^2 density and a mean 0.002% basal cover, respectively. Both stem density and basal cover increased on the ungrazed sandy site of the twice-over treatments over time. During the early period (1983-1992), Rough pennyroyal was present on the grazed sandy site during 33.3% and 11.1% of the years, with a mean 0.08 stems/m^2 density and a mean 0.008% basal cover. During the later period (1998-2012), Rough pennyroyal was

present on the grazed sandy site during 67.7% and 11.1% of the years, with a mean 0.44 stems/m^2 density and a mean 0.01% basal cover, respectively. Both the stem density and basal cover increased on the grazed sandy site of the twice-over treatment over time. Rough pennyroyal was not present during the low precipitation period of 1988 to 1992 on both the ungrazed and grazed sandy sites. During the early period (1983-1992), Rough pennyroyal stem density and basal cover were greater on the grazed site than that on the ungrazed sandy site. When growing season precipitation returned to normal after 1992, stem density and basal cover of Rough pennyroyal increased on both the ungrazed and grazed sandy sites of the twice-over treatment (tables 7, 8, and 9).

During the 30 year period of the 1983-2012 study, on the sandy sites, the greatest stem density of 0.81 stems/m^2 and the greatest basal cover of 0.01% were on the grazed site of the seasonlong treatment.

On the shallow site of the nongrazed treatment, Rough pennyroyal was present during 21.1% and 7.7% of the years that density and basal cover data were collected, with a mean 0.56 stems/m^2 density and a mean 0.005% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Rough pennyroyal was present during 0.0% and 0.0% of the years. During the later period (1998-2012), Rough pennyroyal was present during 7.1% and 11.1% of the years, with a mean 0.76 stems/m^2 density and a mean 0.007% basal cover, respectively. Both the stem density and basal cover increased on the shallow sites of the nongrazed treatment over time (tables 7, 8, and 9).

On the shallow sites of the seasonlong treatment, Rough pennyroyal was present on the ungrazed shallow site during 30.0% and 3.8% of the years, with a mean 1.49 stems/m^2 density and a mean 0.002% basal cover, and was present on the grazed shallow site during 50.0% and 7.7% of the years that density and basal cover data were collected, with a mean 0.47 stems/m^2 density and a mean 0.002% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Rough pennyroyal was present on the ungrazed shallow site during 0.0% and 0.0 % of the years. During the later period (1998-2012), Rough pennyroyal was present on the ungrazed shallow site during 40.0% and 5.6% of the years, with a mean 1.99 stems/m^2 density and a mean 0.003% basal cover, respectively. Both the stem density and basal cover increased on the ungrazed shallow site of the seasonlong treatment over time. During the early period (1983-1992), Rough pennyroyal was present on the grazed shallow site during 0.0% and 0.0% of the years. During the later period (1998-2012), Rough pennyroyal was present on the grazed shallow site during 66.7% and 11.1% of the years, with a mean 0.62 stems/m^2 density and a mean 0.003% basal cover, respectively. Both the stem density and basal cover increased on the grazed shallow site of the seasonlong treatment over time. During the early period (1983-2012), stem density and basal cover of Rough pennyroyal was not present on the ungrazed and grazed shallow sites. During the later period (1998-2012) stem density and basal cover of Rough pennyroyal increased on both the ungrazed and grazed shallow sites. The increase was greater on the ungrazed shallow site, resulting in greater stem density values on the ungrazed shallow site of the seasonlong treatment (tables 7, 8, and 9).

On the shallow sites of the twice-over treatment, Rough pennyroyal was present on the ungrazed shallow site during 59.1% and 17.2% of the years, with a mean 1.42 stems/m^2 density and a mean 0.01% basal cover, and was present on the grazed shallow site during 68.2% and 20.0% of the years that density and basal cover data were collected, with a mean 0.88 stems/m^2 density and a mean 0.02% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Rough pennyroyal was present on the ungrazed shallow site during 42.9% and 11.1% of the years, with a mean 0.13 stems/m^2 density and a mean 0.003% basal cover. During the later period (1998-2012), Rough pennyroyal was present on the ungrazed shallow site during 66.7% and 22.2% of the years, with a mean 2.02 stems/m^2 density and a mean 0.02% basal cover, respectively. Both stem density and basal cover increased on the ungrazed shallow site of the twice-over treatments over time. During the early period (1983-1992), Rough pennyroyal was present on the grazed shallow site during 28.6% and 30.0% of the years, with a mean 0.36 stems/m^2 density and a mean 0.01% basal cover. During the later period (1998-2012), Rough pennyroyal was present on the grazed shallow site during 86.7% and 16.7% of the years, with a mean 1.13 stems/m^2 density and a mean 0.02% basal cover, respectively. Both the stem density and basal cover increased slightly on the grazed shallow site of the twice-over treatment over time. During the early period (1983-1992), Rough pennyroyal stem density and basal cover was greater on the grazed site than that on the ungrazed shallow site. When growing season precipitation returned to normal after 1992, stem density and basal cover of Rough pennyroyal increased on both the ungrazed and grazed shallow sites of the twice-over treatment (tables 7, 8, and 9).

During the 30 year period of the 1983-2012 study, on the shallow sites, the greatest stem density of 1.49 stems/m^2 was on the ungrazed site of the seasonlong treatment.

On the silty site of the nongrazed treatment, Rough pennyroyal was present during 36.8% and 7.7% of the years that density and basal cover data were collected, with a mean 0.50 stems/m^2 density and a mean 0.005% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Rough pennyroyal was present during 0.0% and 0.0% of the years. During the later period (1998-2012), Rough pennyroyal was present during 50.0% and 11.1% of the years, with a mean 0.70 stems/m^2 density and a mean 0.007% basal cover, respectively. Both the stem density and basal cover increased on the silty sites of the nongrazed treatment over time (tables 7, 8, and 9).

On the silty sites of the seasonlong treatment, Rough pennyroyal was present on the ungrazed silty site during 35.0% and 15.4% of the years, with a mean 1.44 stems/m^2 density and a mean 0.03% basal cover, and was present on the grazed silty site during 55.0% and 11.5% of the years that density and basal cover data were collected, with a mean 1.63 stems/m^2 density and a mean 0.04% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Rough pennyroyal was present on the ungrazed silty site during 0.0% and 0.0 % of the years. During the later period (1998-2012), Rough pennyroyal was present on the ungrazed silty site during 46.7% and 22.2% of the years, with a mean 1.91 stems/m^2 density and a mean 0.04% basal cover, respectively. Both the stem density and basal cover increased on the ungrazed silty site of the seasonlong treatment over time. During the early period (1983-1992), Rough pennyroyal was present on the grazed silty site during 20.0% and 0.0% of the years, with a mean 0.08 stems/m^2 density. During the later period (1998-2012), Rough pennyroyal was present on the grazed silty site during 66.7% and 16.7% of the years, with a mean 2.15 stems/m^2 density and a mean 0.05% basal cover, respectively. Both the stem density and basal cover increased on the grazed silty site of the seasonlong treatment over time. During the early period (1983-2012), Rough pennyroyal was only present on the grazed silty site. During the later period (1998-2012), stem density and basal cover of Rough pennyroyal increased on both the ungrazed and grazed silty sites. The increase was greater on the grazed silty site, resulting in greater stem density and basal cover values on the grazed silty site of the seasonlong treatment (tables 7, 8, and 9).

On the silty sites of the twice-over treatment, Rough pennyroyal was present on the ungrazed silty site during 63.6% and 24.1% of the years, with a mean 1.22 stems/m^2 density and a mean 0.04% basal cover, and was present on the grazed silty site during 72.7% and 36.7% of the years that density and basal cover data were collected, with a mean 3.62 stems/m^2 density and a mean 0.08% basal cover during the total 30 year period, respectively. During the early period (1983-1992), Rough pennyroyal was present on the ungrazed silty site during 28.6% and 33.3% of the years, with a mean 1.57 stems/m^2 density and a mean 0.04% basal cover. During the later period (1998-2012), Rough pennyroyal was present on the ungrazed silty site during 80.0% and 22.2% of the years, with a mean 1.05 stems/m^2 density and a mean 0.05% basal cover, respectively. Stem density decreased and basal cover increased on the ungrazed silty site of the twice-over treatments over time. During the early period (1983-1992), Rough pennyroyal was present on the grazed silty site during 28.6% and 40.0% of the years, with a mean 1.36 stems/m^2 density and a mean 0.10% basal cover. During the later period (1998-2012), Rough pennyroyal was present on the grazed silty site during 93.3% and 38.9% of the years, with a mean 4.67 stems/m^2 density and a mean 0.08% basal cover, respectively. Stem density increased and basal cover decreased on the grazed silty site of the twice-over treatment over time. During the early period (1983-1992), Rough pennyroyal stem density was greater on the ungrazed site than that on the grazed silty site and basal cover was greater on the grazed site than that on the ungrazed silty site. When growing season precipitation returned to normal after 1992, stem density decreased and basal cover increased on the ungrazed silty site, and stem density increased and basal cover decreased on the grazed silty site of the twice-over treatment (tables 7, 8, and 9).

During the 30 year period of the 1983-2012 study, on the silty sites, the greatest stem density of 3.62 stems/m^2 and the greatest basal cover of 0.08% were on the grazed site of the twice-over treatment.

Rough pennyroyal did not grow on every ecological site of each management treatment every growing season. Rough pennyroyal abundance was determined by two different techniques. Stem density data was collected by the density frame method and basal cover data was collected by the point frame method. Both methods were conducted on exactly the same permanent transect lines year after year during the same time of the growing season. The point frame method did not detect the abundance of small fine, square, stemmed forbs at the same level of

sensitivity that the stem density frame method did. However, both methods showed similar patterns of change in abundance. Rough pennyroyal tended to grow during lower percentages of the years on the nongrazed treatment and ungrazed sites of the seasonlong and twice-over treatments than the percentages of years that it grew on the grazed sites of the seasonlong and twice-over treatments. Rough pennyroyal tended to grow during lower percentages of the years on the sandy sites than on the shallow and silty sites, and grew during lower percentages of the years on the shallow sites than on the silty sites (table 10). The nongrazed treatment and the ungrazed sites tend to develop greater quantities of standing dead leaf material and litter matter than on the grazed sites. Standing dead and litter matter produce greater shading problems and absorb a portion of the precipitation, that in effect reduces the quantity of water infiltrated into the soil. Rough pennyroyal seedlings would have access to lower levels of sunlight and soil water on the nongrazed treatment and ungrazed sites resulting in lower rates of successful development than on the grazed sites. Similarly, the quantity of available soil water in the upper 5.1 cm (2 in) of soil would be progressively greater from the sandy sites to the shallow sites to the silty sites providing greater rates of successful development on the silty sites than on the shallow sites and greater development on the shallow sites than on the sandy sites (table 10).

Rough pennyroyal plant development on the ecological sites of the management treatments had intermittent recurrence. During 4 (13%) growing seasons, Rough pennyroyal grew on every ecological site of each management treatment (table 11) and during 8 (27%) of the growing seasons it did not grow on any of the ecological sites (table 14). During the other 60% of the growing seasons, it grew on a high percentage of the ecological sites during 8 (27%) of the years (table 12) and on a low percentage of the sites during 10 (33%) of the years (table 13). This intermittent occurrence of Rough pennyroyal annual percent present on the various ecological sites of the management treatments is at least partially related to the quantity of precipitation received compared to the respective long-term mean precipitation during a critical three month growing season period between April and July starting with April or May. When the early growing season precipitation received during three consecutive months had a mean monthly equivalent of around 136.2% of the long-term mean, the annual % present of Rough pennyroyal on the ecological sites was 100% (table 11). When the early growing season precipitation received during three consecutive months had a mean monthly equivalent of around 116.3% of the long-term mean, the annual % present of Rough pennyroyal on the ecological sites was high ranging from 60% to 90% (table 12). When the early growing season precipitation received during three consecutive months had a mean monthly equivalent of around 102.9% of the long-term mean, the annual % present of Rough pennyroyal on the ecological sites was low ranging from 5% to 50% (table 13). When the early growing season precipitation received during three consecutive months had a low mean monthly equivalent of around 84.4% of the long-term mean, the annual % present of Rough pennyroyal on the ecological sites was zero (table 14).

The most plausible explanation of why Rough pennyroyal plants need 16% to 36% greater precipitation than the long-term mean during the early portion of the growing season in order for successful development of seedlings through the mature growth stages on all or most of the ecological sites of the three management treatments is that that quantity of increased water is the amount required by the seedlings to overcome the inherent negative characteristics of the sandy and shallow ecological sites and the additional problems created on the nongrazed treatment and the ungrazed sites of the seasonlong and twice-over treatments.

Rough pennyroyal plants were present on the silty ecological site of the grazed twice-over treatment during 73% of the years (table 10) which had received early season precipitation at a mean monthly equivalent of 116.1% of the long-term mean. Rough pennyroyal plants were not present on the silty ecological site of the grazed twice-over treatment during 27% of the years which had received early season precipitation at a mean monthly equivalent of 89.0% of the long-term mean.

Discussion

Rough pennyroyal, *Hedeoma hispida*, is a small inconspicuous annual forb that is intermittently present on healthy mixed grass prairie plant communities. Rough pennyroyal can grow on sandy, shallow, silty, and clayey ecological sites, however, it has greater occurrence on the silty and shallow sites than that on the clayey and sandy sites. Annual aerial growth starts early with germination from a seed, followed by rapid development through the mature growth stages. The tiny flowers appeared during a ten week flower period from early June until mid August from the 1969-1971 study, and during an eight week flower period from early June until late July from the 1984-1985 study. Erect aerial stems

reached maximum stem height during August. The mean mature stem heights collected during the 1984-1985 study were 6.8 cm (2.7 in) tall. These collected mean stem heights were shorter than the reported normal Northern Plains mature stem height of 10-15 cm (3.9-5.9 in) tall because the soils had mineral nitrogen available at less than the threshold quantity of 100 lbs/ac which resulted from the detrimental effects caused by the traditional management practices on the ecosystem biogeochemical processes and soil microorganism biomass of the prairie plant communities.

Rough pennyroyal plants were not eaten by livestock and thus the effects from partial defoliation by grazing did not directly cause annual changes in stem abundance. Rough pennyroyal % present on the ecological sites of the management treatments was highly variable and dependent on the level of inherent negative characteristics of water infiltration and water holding capacity of the top 5.1 cm (2 in) layers of soil and the degree of additional problems caused by the buildup of standing dead leaf material and litter matter related to the quantity of early season precipitation received greater than the long-term mean during three consecutive months within the critical period of April to July. The Rough pennyroyal seedlings required 16% to 36% greater early season precipitation than the long-term mean to overcome most of the problem ecological site characteristics for successful development into mature growth stages.

Acknowledgment

I am grateful to Sheri Schneider for assistance in the production of this manuscript and for development of the tables.

Table 1. Flower period of Hedeoma hispida, Rough Pennyroyal.

	Apr	May	Jun		Jul		Aug	Sep
Flower Period 1969-1971			XX	XX	XX	XX	XX	

Flower Period Data from Zaczkowski 1972.

Table 2. Changes in mean mature stem heights in cm of Hedeoma hispida, Rough Pennyroyal, on ecological sites during the growing season, 1984-1985.

Site	8 Jun	23 Jun	8 Jul	23 Jul	8 Aug	23 Aug
Sandy		7.7	6.0	7.1	8.7	7.5
Shallow	6.5	4.6	5.3	5.0	4.9	7.1
Silty	5.9	6.6	6.6	6.9	7.2	6.9
Clayey		4.9	5.1	6.2	6.3	6.1
Monthly Mean		6.0		6.0		6.8

Table 3. Phenological growth stage changes during the growing season for, Hedeoma hispida, Rough Pennyroyal, 1984-1985.

Site Sandy	8 Jun	23 Jun	8 Jul	23 Jul	8 Aug	23 Aug
% Population						
Veg		15.2	1.1			
Bud	100.0	68.4	23.9			
Anth		7.6	13.0	1.2		
Seed Dev		6.3	46.7	53.1	50.0	
Seed Shed		2.5	13.0	43.2	47.6	86.4
Mat			2.2	2.5	2.4	13.6
Mean Height (cm)						
Veg		2.6	0.7			
Bud	6.7	4.6	4.9			
Anth		12.2	5.1	6.9		
Seed Dev		4.3	7.1	6.8	7.3	
Seed Shed		6.6	5.9	7.7	10.0	7.5
Mat			4.9	5.9	5.9	4.9
% Dryness						
Veg		0.3	50.0			
Bud	0.0	1.8	6.6			
Anth		0.7	15.1	75.0		
Seed Dev		54.6	40.3	80.8	87.9	
Seed Shed		100.0	89.3	93.8	99.8	100.0
Mat			99.0	100.0	100.0	100.0
Mean Weight (g)	0.07	0.02	0.05	0.07	0.06	0.01

Phenological Growth Stages: Vegetative (Veg), Budding (Bud), Anthesis (Anth), Seed Developing (Seed Dev), Seed Shedding (Seed Shed), Mature (Mat).

Table 4. Phenological growth stage changes during the growing season for, Hedeoma hispida, Rough Pennyroyal, 1984-1985.

Site Shallow	8 Jun	23 Jun	8 Jul	23 Jul	8 Aug	23 Aug
% Population						
Veg	40.5	17.0	0.8			1.2
Bud	56.8	66.7	24.6			
Anth	2.7	5.2	19.7			
Seed Dev		5.2	23.8	34.2	57.5	
Seed Shed		5.9	29.5	49.5	41.4	61.7
Mat			1.6	16.2	1.1	37.0
Mean Height (cm)						
Veg	4.2	2.2	7.1			1.6
Bud	5.7	3.9	4.3			
Anth	6.5	5.6	5.6			
Seed Dev		3.8	4.5	5.7	4.4	
Seed Shed		4.3	5.7	4.2	5.3	7.1
Mat			3.0	4.5	3.4	3.3
% Dryness						
Veg	0.4	2.9	98.0			0.0
Bud	0.1	5.8	4.0			
Anth	0.0	4.1	7.4			
Seed Dev		60.7	24.9	84.4	99.6	
Seed Shed		90.2	78.1	95.9	99.8	100.0
Mat			87.5	100.0	100.0	100.0
Mean Weight (g)	0.03	-	0.02	0.02	0.01	0.05

Phenological Growth Stages: Vegetative (Veg), Budding (Bud), Anthesis (Anth), Seed Developing (Seed Dev), Seed Shedding (Seed Shed), Mature (Mat).

Table 5. Phenological growth stage changes during the growing season for, Hedeoma hispida, Rough Pennyroyal, 1984-1985.

Site Silty	8 Jun	23 Jun	8 Jul	23 Jul	8 Aug	23 Aug
% Population						
Veg	19.0	20.2	1.9			
Bud	69.8	54.3	9.7			1.8
Anth	11.1	1.7	12.3			
Seed Dev		12.1	34.2	37.5	27.1	
Seed Shed		11.0	38.7	46.9	62.7	88.5
Mat		0.6	3.2	15.6	10.2	9.7
Mean Height (cm)						
Veg	5.6	4.9	5.4			
Bud	5.3	6.0	6.9			7.3
Anth	5.9	8.4	6.6			
Seed Dev		6.4	6.9	6.5	7.5	
Seed Shed		4.9	6.3	7.2	6.9	6.5
Mat		3.5	5.1	5.3	4.5	5.5
% Dryness						
Veg	0.5	1.7	1.3			
Bud	0.3	3.2	6.2			2.0
Anth	0.3	1.3	9.8			
Seed Dev		61.8	26.0	88.7	96.1	
Seed Shed		65.6	89.8	94.4	99.8	99.8
Mat		100.0	100.0	99.9	100.0	100.0
Mean Weight (g)	0.05	0.02	0.06	0.02	0.03	0.02

Phenological Growth Stages: Vegetative (Veg), Budding (Bud), Anthesis (Anth), Seed Developing (Seed Dev), Seed Shedding (Seed Shed), Mature (Mat).

Table 6. Phenological growth stage changes during the growing season for, Hedeoma hispida, Rough Pennyroyal, 1984-1985.

Site Clayey	8 Jun	23 Jun	8 Jul	23 Jul	8 Aug	23 Aug
% Population						
Veg	53.3	18.2				
Bud	46.7	68.2	4.8			
Anth		3.0	7.2			
Seed Dev		6.1	62.7	27.5	27.6	
Seed Shed		3.0	22.9	51.3	67.2	93.4
Mat		1.5	2.4	21.3	5.2	6.6
Mean Height (cm)						
Veg	6.4	2.5				
Bud	4.8	5.1	5.5			
Anth		5.4	5.8			
Seed Dev		4.7	4.7	5.7	6.4	
Seed Shed		4.7	4.8	6.2	6.2	6.1
Mat		4.5	4.0	4.1	3.2	5.9
% Dryness						
Veg	0.4	2.1				
Bud	0.6	3.7	2.0			
Anth		12.5	9.0			
Seed Dev		37.5	16.1	80.9	99.4	
Seed Shed		50.0	92.8	95.5	99.7	99.9
Mat		98.0	100.0	100.0	100.0	100.0
Mean Weight (g)	0.04	0.01	0.02	0.01	0.01	0.03

Phenological Growth Stages: Vegetative (Veg), Budding (Bud), Anthesis (Anth), Seed Developing (Seed Dev), Seed Shedding (Seed Shed), Mature (Mat).

Table 7. Autecology of Hedeoma hispida, Rough pennyroyal, 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	0.00	0.00	0.00	0.88	1.27
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.00	0.00	0.00	0.00	0.53
1999-2003	0.00	0.26	3.59	2.68	1.99
2004-2009	6.82	4.19	5.11	1.05	3.11
2010-2012	0.42	0.00	0.33	0.51	0.79
Shallow					
1983-1987	0.00	0.00	0.00	1.40	3.05
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.00	0.00	0.00	0.00	0.00
1999-2003	2.07	0.43	1.78	5.66	3.34
2004-2009	4.47	8.39	4.96	9.01	8.09
2010-2012	0.39	3.14	2.18	2.32	2.33
Silty					
1983-1987	0.00	0.00	2.72	14.16	13.85
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.00	0.00	4.41	1.99	0.00
1999-2003	0.73	0.64	3.15	4.15	10.06
2004-2009	3.77	10.65	9.48	8.37	21.02
2010-2012	2.11	8.02	3.83	14.16	15.04

Table 8. Autecology of Hedeoma hispida, Rough pennyroyal, with growing season changes in basal cover importance value, 1983-2012.

Ecological Site Ten Year Period	Nongrazed	Seasonlong		Twice-over	
		Ungrazed	Grazed	Ungrazed	Grazed
Sandy					
1983-1987	0.00	0.00	0.00	0.00	0.07
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.28	0.11	0.47	0.15	0.29
1999-2003	0.00	0.00	0.03	0.00	0.00
2004-2009	0.00	0.00	0.02	0.01	0.06
2010-2012	0.00	0.00	0.00	0.00	0.00
Shallow					
1983-1987	0.00	0.00	0.00	0.05	0.12
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.12	0.00	0.08	0.24	0.56
1999-2003	0.00	0.00	0.00	0.03	0.00
2004-2009	0.11	0.06	0.04	0.12	0.07
2010-2012	0.00	0.00	0.00	0.00	0.00
Silty					
1983-1987	0.00	0.00	0.00	0.29	0.89
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.05	0.77	1.22	1.28	1.60
1999-2003	0.00	0.00	0.00	0.03	0.02
2004-2009	0.00	0.24	0.20	0.16	0.44
2010-2012	0.27	0.00	0.00	0.00	0.02

Table 9. Autecology of Hedeoma hispida, Rough pennyroyal, with growing season changes in density, 1983-2012.					
Ecological Site Ten Year Period	Nongrazed	Seasonlong		Twice-over	
		Ungrazed	Grazed	Ungrazed	Grazed
Sandy					
1983-1987	0.00	0.00	0.00	0.01	0.02
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.00	0.00	0.00	0.00	0.01
1999-2003	0.00	0.01	0.06	0.04	0.04
2004-2009	0.09	0.10	0.20	0.03	0.07
2010-2012	0.01	0.00	0.01	0.01	0.02
Shallow					
1983-1987	0.00	0.00	0.00	0.00	0.03
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.00	0.00	0.00	0.00	0.00
1999-2003	0.04	0.01	0.02	0.02	0.17
2004-2009	0.15	0.46	0.12	0.12	0.34
2010-2012	0.01	0.07	0.03	0.03	0.04
Silty					
1983-1987	0.00	0.00	0.04	0.37	0.32
1988-1992	0.00	0.00	0.00	0.00	0.00
1993-1998	0.00	0.00	0.07	0.02	0.00
1999-2003	0.02	0.01	0.09	0.05	0.24
2004-2009	0.13	0.36	0.37	0.15	0.85
2010-2012	0.04	0.23	0.16	0.13	0.24

Table 10. Rough pennyroyal percent present on the ecological sites of the management treatments during the years that stem density and basal cover data were collected, 1983-2012.

Management Treatment	Sandy		Shallow		Silty	
	Stem Density	Basal Cover	Stem Density	Basal Cover	Stem Density	Basal Cover
Nongrazed	27.8	4.0	21.1	7.7	36.8	7.7
Seasonlong						
Ungrazed	26.3	4.0	30.0	3.8	35.0	15.4
Grazed	47.4	12.0	50.0	7.7	55.0	11.5
Twice-over						
Ungrazed	33.3	7.1	59.1	17.2	63.6	24.1
Grazed	57.1	10.3	68.2	20.0	72.7	36.7

Table 11. Rough pennyroyal annual % present at high rates of 100% on the sites with stem density and basal cover data collected related to monthly precipitation as % of long-term mean during three consecutive months within the period of April to July, 1983-2012.

			Long-Term Mean Precipitation				
	Annual % Present		Apr	May	Jun	Jul	Three Month Total
			1.44	2.56	3.27	2.43	%Long-Term Mean
Year	Stem Density	Basal Cover	% Long-Term Mean				
1984	100	67	199.3	0.0*	162.1	*	361.4
1986	100	33	217.4	143.8	78.9		440.1
2005	100	80	66.7	234.8	185.0	*	486.5
2007	100	13	109.7	181.3	55.1	*	346.1
Mean							408.5
Month Equivalent							136.2

Growing Season % Long-Term Mean Data from Introduction to Study (Manske 2016).
* Water Deficiency Month.

Table 12. Rough pennyroyal annual % present at high rates of 60% to 90% on the sites with stem density and basal cover data collected related to monthly precipitation as % of long-term mean during three consecutive months within the period of April to July, 1983-2012.

			Long-Term Mean Precipitation				
	Annual % Present		Apr	May	Jun	Jul	Three Month Total
			1.44	2.56	3.27	2.43	%Long-Term Mean
Year	Stem Density	Basal Cover	% Long-Term Mean				
1995	-	87		168.8	20.8*	190.1	379.7
1999	75	7	76.4	192.6	48.6		317.6
2000	80	20		74.2	115.3	114.0	303.5
2003	60	7	90.3	169.5	43.4		303.2
2006	80	33	193.1	110.2	65.1	*	368.4
2009	80	7	103.5	96.5	117.4		317.4
2010	67	13	99.3	144.5	107.0		350.8
2011	67	0	115.3	268.4	65.8		449.5
Mean							348.8
Month Equivalent							116.3

Growing Season % Long-Term Mean Data from Introduction to Study (Manske 2016).
* Water Deficiency Month.

Table 13. Rough pennyroyal annual % present at low rates of 5% to 50% on the sites with stem density and basal cover data collected related to monthly precipitation as % of long-term mean during three consecutive months within the period of April to July, 1983-2012.

	Annual % Present		Long-Term Mean Precipitation				Three Month Total
			Apr	May	Jun	Jul	%Long-Term Mean
			1.44	2.56	3.27	2.43	
Year	Stem Density	Basal Cover	% Long-Term Mean				
1983	- -	50	*	59.8	99.7	105.4	264.9
1985	- -	33	86.1	127.0	48.3	*	261.4
1987	13	7	*	53.9	35.2*	221.8	310.9
1997	- -	7	200.7	37.1	153.5		391.3
1998	20	0	*	59.0	182.9	86.8	328.7
2001	27	0	187.5	20.7*	194.5		402.7
2002	20	0	79.2	85.2	165.1		329.5
2004	13	0	61.8	51.2	50.5		163.5
2008	27	0	42.4	109.0	122.9	*	274.3
2012	47	0	165.3	61.7	131.8		358.8
Mean							308.6
Month Equivalent							102.9

Growing Season % Long-Term Mean Data from Introduction to Study (Manske 2016).
* Water Deficiency Month.

Table 14. Rough pennyroyal annual % present at zero rates on the sites with stem density and basal cover data collected related to monthly precipitation as % of long-term mean during three consecutive months within the period of April to July, 1983-2012.

			Long-Term Mean Precipitation				
	Annual % Present		Apr	May	Jun	Jul	Three Month Total
			1.44	2.56	3.27	2.43	%Long-Term Mean
Year	Stem Density	Basal Cover	% Long-Term Mean				
1988	0	0	*	72.3	52.0*	36.2*	160.5
1989	0	0	202.8	67.6	49.9	*	320.3
1990	0	0	141.0	93.4	114.7	*	349.1
1991	- -	0	136.8	45.3	120.8	*	302.9
1992	0	0	56.3	26.6*	48.6		131.5
1993	- -	0	97.9	66.8	139.8		304.5
1994	- -	0	59.7	57.0	137.9	*	254.6
1996	- -	0	*	120.0	56.9	104.9	201.8
Mean							253.2
Month Equivalent							84.4

Growing Season % Long-Term Mean Data from Introduction to Study (Manske 2016).
* Water Deficiency Month.

Literature Cited

Cook, C.W., and J. Stubbendieck. 1986. Range research: basic problems and techniques. Society for Range Management, Denver, CO. 317p.

Great Plains Flora Association. 1986. Flora of the Great Plains. University of Kansas, Lawrence, KS.

Manske, L.L. 2016. Autecology of prairie plants on the Northern Mixed Grass Prairie. NDSU Dickinson Research Extension Center. Range Research Report DREC 16-1093. Dickinson, ND.

Stevens, O.A. 1963. Handbook of North Dakota plants. North Dakota Institute for Regional Studies. Fargo, ND.

Stubbendieck, J., M.J. Coffin, and L.M. Landholt. 2003. Weeds of the Great Plains. Nebraska Department of Agriculture. Lincoln, NE.

Weaver, J.E., and T.J. Fitzpatrick. 1934. The Prairie. Ecological Monographs 4(2):109-295.

Zaczkowski, N.K. 1972. Vascular flora of Billings, Bowman, Golden Valley, and Slope Counties, North Dakota. PhD. Thesis. North Dakota State University, Fargo, ND. 219 p.