Dickinson
Research Extension Center
2022 Annual Report

Range-Forage-Livestock-Agronomy-Soils
Outreach

NDSU Research and Extension Staff Involved with the Dickinson Research Extension Center

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Current Staff - 2022

Chris Augustin	Director/Soil Scientist
Ryan Buetow	Cropping Systems Specialist
Cristin Heidecker	Administrative Secretary
Doug Landblom	Associate Research Extension Center Specialist
Llewellyn Manske	Scientist of Rangeland Research
Glenn Martin	Research Specialist
Dean Nelson	Ag Research Technician
Phyllis Okland	Administrative Assistant
Garry Ottmar	Livestock Research Specialist
Wanda Ottmar	Research Technician
Robert Paluck	Ag Research Technician
Sheri Schneider	Information Processing Specialist
Michael Strode	Computer Technician
Lee Tisor	Research Specialist

2022 Seasonal/Temporary Employees

John Urban
Eve Sticka
Karalyn Buetow
Adele Speelmon
Michele Stoltz
Jon Sticka
Breanna Hosman
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RESEARCH EXTENSION CENTER

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Variety Trials Destroyed by Hail

On June 20, 2022 the Dickinson Research Center was hit with an afternoon storm. It began as heavy rain, strong winds, lightning and thunder, and then the hail came. It wasn't much bigger than marble sized, but there was more than I'd ever seen at one time. I've never seen a hail drift until today, but there were some a foot tall. Hail overflowed gutters and cascaded like waterfalls below. Crops and gardens were wiped out. The noise was indescribable. The Dickinson Research Center was hit hard. Due to this storm DREC will have a limited amount of Variety Trials for the year 2022. The picture shown is from the following day.

2022 Chickpea - Recrop	Dickinson, ND

Variety	Days to Flower	Days to Mature	Plant Height	1000 seed weight	Seeds per Pound	Test Weight	Seed Size (mm) >8	Yield
			in	gm		lbs/bu	%	lbs/ac
CDC Frontier	55	121	13	404	1,122	61.7	67	1,177
CDC Orion	53	122	12	451	1,006	61.4	83	1,188
ND Crown	55	121	13	439	1,036	62.0	80	1,106
Royal	60	121	11	578	786	61.1	95	516
Sawyer	58	121	11	447	1,014	61.5	81	535
Sierra	57	121	10	500	907	60.5	92	470
Trial Mean	56	121	12	470	979	61.4	83	832
CV %	3.6	1.0	13.8	3.0	2.8	0.9	3.4	14
LSD 0.05	3	2	2	21	41	0.9	4	171
LSD 0.10	2	1	2	18	34	0.7	3	141

Planting Date: May 10, 2022
Harvest Date: September 26, 2022
Previous Crop: Cover Crop

2022 Field Pea - Recrop Dickinson, ND

Variety	cotyledonType	Brand	Days to Flower	Days to Mature	1000 Seed Weight	Seeds per Pound	Plant Height	Test Weight	Protein	--Grain Yield-- 2020	2021	2022	Average Yield 2 Year	3 Year
					gm		in	lbs/bu	%	--------bu/ac--------			--bu/ac--	
Yellow Types														
AAC Chrome	Y	Valesco Genetics	52	85	272	1,676	23	65.7	25.9	26.1	13.8	42.3	28.0	27.4
AAC Julius	Y	Valesco Genetics	53	81	225	2,024	23	65.0	26.9	--	15.5	45.2	30.3	--
Agassiz	Y	Meridian Seeds	49	83	275	1,664	23	64.6	27.1	24.4	14.8	41.8	28.3	27.0
CDC Amarillo	Y	Meridian Seeds	52	84	240	1,892	24	65.7	26.9	34.5	14.0	39.1	26.6	29.2
CDC Inca	Y	Meridian Seeds	51	84	272	1,711	23	66.4	27.3	29.2	16.3	41.4	28.8	29.0
CDC Spectrum	Y	Meridian Seeds	52	84	259	1,751	21	65.3	27.7	29.5	15.1	39.3	27.2	28.0
CP5222Y	Y	Winfield United	49	80	293	1,552	18	64.3	29.2	--	--	41.2	--	--
CP5244Y	Y	Winfield United	49	84	248	1,832	22	65.8	26.3	--	--	39.6	--	--
DS Admiral	Y	Pulse USA	50	82	245	1,857	24	65.6	27.5	30.4	16.3	43.8	30.1	30.2
MS GrowPro	Y	Meridian Seeds	50	84	323	1,418	22	65.3	29.1	--	14.6	31.9	23.3	--
ND Dawn	Y	NDSU	50	74	244	1,865	21	64.5	26.1	25.8	16.1	39.9	28.0	27.3
Salamanca	Y	Valesco Genetics	50	81	277	1,643	23	64.0	29.1	25.7	15.1	39.1	27.1	26.7
Green Types														
Aragorn	G	Pulse USA	49	79	237	1,937	18	62.8	28.1	23.4	11.4	34.6	23.0	23.1
Arcadia	G	Pulse USA	50	80	230	1,994	17	64.3	26.0	33.6	14.8	40.6	27.7	29.7
CDC Striker	G	Pulse USA	50	83	263	1,728	20	65.1	29.7	23.2	14.8	43.7	29.2	27.2
MS-20G1	G	Meridian Seeds	54	86	278	1,631	25	66.4	26.8	--	--	39.9	--	--
ND Victory	G	NDSU	54	88	204	2,222	25	64.1	27.0	--	--	32.0	--	--
Shamrock	G	Valesco Genetics	51	83	235	1,931	21	65.7	26.9	32.8	13.0	32.2	22.6	26.0
Trial Mean			51	82	257	1,796	22	65.0	27.4	28.4	14.3	39.3	--	--
CV %			2.4	5.0	9.1	8.0	7.9	1.3	1.7	17.1	17.6	9.8	--	--
LSD 0.05			2	6	33	203	2	1.2	0.7	6.8	3.5	5.5	--	--
LSD 0.10			1	5	28	170	2	1.0	0.5	5.7	2.9	4.6	--	--

Planting Date: May 12, 2022 Harvest Date: August 12, 2022 Previous Crop: cover crop forage

Seeding Rate: 325,000 live seeds/ac Grain protein percentages reported on 0% moisture basis

2022 Glen Ullin Barley - Recrop **Dickinson, ND**

Variety	Seeds per Pound	KWT	Test Weight	% Plump	Protein	------Grain Yield------ 2020	2021	2022	Average Yield 2 Year	3 Year
		g/1000	lbs/bu	>6/64	%	--------bu/ac--------			----bu/ac----	
Six Row										
Tradition	11,397	39.9	45.8	95	11.7	76.1	65.5	41.0	53.3	60.9
Two Row										
AAC Connect	10,427	43.6	44.4	88	11.3	--	--	62.1	--	--
AAC Synergy	9,748	46.7	46.0	93	10.6	106.8	74.6	56.9	65.7	79.4
ABI Cardinal	10,098	45.0	47.1	95	11.2	--	80.6	68.3	74.4	--
Brewski	10,177	44.6	45.4	95	9.8	--	69.6	74.0	71.8	--
CDC Fraser	10,150	44.7	45.8	96	11.5	--	--	63.8	--	--
ND Genesis	10,187	44.6	45.4	94	9.6	102.8	72.0	67.6	69.8	80.8
Trial Mean	10,232	44.5	45.7	94	10.7	95.4	69.1	60.7	--	--
CV %	4.0	3.8	1.3	2.0	4.0	7.6	11.3	8.3	--	--
LSD 0.05	602	2.5	0.9	3	0.6	10.8	11.5	7.4	--	--
LSD 0.10	498	2.1	0.7	2	0.5	9.9	9.5	6.1	--	--

Planting Date: May 16, 2022
Harvest Date: August 26, 2022
Seeding Rate: 1.2 million live seeds/ac
Grain protein percentages reported on a 0% moisture basis

2022 Glen Ullin Spring Wheat - Recrop **Dickinson, ND**

Variety	Seeds per Pound	KWT	Test Weight	Protein	--------- Grain Yield--------- 2020	2021	2022	Average Yield 2 Year	3 Year
		g/1000	lbs/bu	%	----------bu/ac----------			----bu/ac----	
Ascend-SD	16,667	27.3	60.6	11.5	--	--	43.7	--	--
CP3188	14,384	31.6	59.9	10.4	--	--	49.2	--	--
Dagmar	13,724	33.1	60.6	12.3	--	--	41.8	--	--
LCS Ascent	16,220	28.0	61.7	11.0	--	--	40.3	--	--
Lanning	13,764	33.0	59.8	12.6	46.1	41.2	40.3	40.8	42.5
MN Rothsay	14,258	31.8	61.4	11.9	--	--	48.3	--	--
MN-Torgy	14,953	30.4	61.2	11.7	57.7	39.2	40.6	39.9	45.8
MS Cobra	15,378	29.5	60.8	12.2	--	--	43.5	--	--
ND Frohberg	13,700	33.1	61.4	12.1	47.0	40.4	36.4	38.4	41.3
ND Heron	14,792	30.8	61.5	11.9	--	--	39.2	--	--
SY Longmire	13,492	33.6	61.6	12.3	48.9	44.7	39.7	42.2	44.4
Trial Mean	14,836	30.7	60.7	11.9	48.1	41.2	41.4	--	--
CV %	4.0	3.4	0.8	3.3	8.1	8.2	10.1	--	--
LSD 0.05	723	1.5	0.7	0.6	5.6	4.9	6.0	--	--
LSD 0.10	602	1.2	0.6	0.5	4.6	4.1	5.0	--	--

Planting Date: May 16, 2022
Harvest Date: August 26, 2022
Seeding Rate: 1.2 million live seeds/ac

2022 Lentil - Recrop **Dickinson, ND**

Variety	Days to Flower	Days to Mature	1000 Seed Weight	Seeds per Pound	Plant Height	Test Weight	protein	----Grain Yield---- 2019	2020	2022	Average Yield 2 Year	3 Year
			gm		in	lbs/bu	%	-----lbs/ac-----			---lbs/ac---	
Avondale	51	120	40	11,503	13	51.8		--	1034	1381.2	1,207	--
CDC Grandora	49	122	53	8,549	15	48.4		--	--	973.9	--	--
CDC Greenstar	52	122	51	8,923	14	47.5		--	1276	1100.9	1,189	--
CDC Kermit	59	120	32	14,293	14	57.0		--	1386	1531.5	1,459	--
CDC Richlea	59	120	42	10,894	14	53.9		1,400	1269	1526.6	1,398	1,399
ND Eagle	49	120	34	13,521	13	54.5		1,226	1332	1464.7	1,398	1,341
Trial Mean	53	121	42	11,281	14	52.2		1,400	1,310	1,330	--	--
CV %	14.8	0.0	4.1	4.4	5.6	2.0		12.7	13.8	12.2	--	--
LSD 0.05	12	0	3	747	1	1.6		257	316	245	--	--
LSD 0.10	10	0	2	614	1	1.3		214	260	201	--	--

Planting Date: May 10, 2022
Harvest Date: September 26, 2022
Previous Crop: Cover Crop
Seeding Rate: 600,000 live seeds/ac
Grain protein percentages reported on 0% moisture basis

2022 Lupin - Recrop Dickinson, ND

Variety	Days to Flower	Days to Mature	Plant Height	1000 seed weight	Seeds per Pound	Test Weight	Yield
			in	gm		lbs/bu	lbs/ac
Blu 25	60	115	20	415	1,094	55.9	697
Blu 31	52	114	25	443	1,026	55.9	1,261
LND0127	46	105	19	375	1,214	55.3	1,105
LND0212	47	106	19	383	1,191	54.7	1,001
LND0228	48	105	19	350	1,299	56.2	1,301
LND0229	48	105	19	353	1,289	55.5	1,329
LND0431	47	107	20	379	1,198	55.6	1,309
LND0603	48	105	19	346	1,315	54.8	1,602
LND0605	48	107	19	376	1,208	54.6	1,653
LND0614	48	105	19	356	1,279	55.0	1,412
LND0617	48	103	19	360	1,261	55.2	1,237
LND0619	48	103	19	352	1,294	55.6	1,333
LND0621	47	103	19	362	1,256	54.8	1,360
LND0705	48	106	20	367	1,244	55.3	1,592
LND0727	48	105	19	348	1,304	55.1	1,350
LNDa210	47	107	20	361	1,255	54.4	1,263
Lupro 2085	48	105	18	368	1,233	55.0	1,703
NR55-Baer	48	107	22	417	1,092	53.8	1,574
Trial Mean	49	107	20	373	1,225	55.1	1338
CV %	1.1	2.0	7.3	4.4	4.4	1.2	14.5
LSD 0.05	1	4	2	27	90	1.1	322
LSD 0.10	1	3	2	23	75	0.9	268

Planting Date:	May 16, 2022
Harvest Date:	September 26, 2022

2022 Organic Ancient Grains - Recrop				**Dickinson, ND**
Variety	Days to Head	Plant Height	Test Weight	Grain Yield
		in	lbs/bu	lbs/ac
CDC Aixe einkorn	55	34	29.6	2061
CDC Marvel einkorn	56	33	28.6	1892
CDC Silex spelt	61	38	29.3	2291
Jim spelt	66	38	29.7	3005
CDC Tatra emmer	59	34	32.2	2559
CDC Yon emmer	58	36	32.0	2495
Lucille emmer	59	37	35.1	2889
Trial Mean	59	36	30.9	2456
CV %	0.3	4.1	3.4	12.6
LSD 0.05	0	2	1.6	459
LSD 0.10	0	2	1.3	379

Planting Date:	May 17, 2022
Harvest Date:	August 22, 2022

Previous Crop: Oat Hay

2022 Organic Hard Red Spring Wheat - Recrop Dickinson, ND

Variety	Days to Head	Seeds per Pound	KWT	Plant Height	Test Weight	Protein	Grain Yield
			g/1000	in	lbs/bu	%	bu/ac
Barlow	53	16,450	27.7	31	61.1	14.6	58.4
Bolles	56	16,853	27.3	31	57.1	16.2	48.8
Ceres	55	16,292	27.9	39	59.6	15.1	52.9
Dagmar	53	15,943	28.5	30	60.2	14.9	66.8
Dapps	54	16,101	28.3	36	58.6	15.6	54.9
Driver	55	17,372	26.1	30	58.8	14.6	51.9
Elgin-ND	53	17,901	25.4	33	58.6	14.5	52.8
FBC Dylan	54	15,113	30.3	31	59.4	14.5	59.2
Faller	55	16,318	28.0	31	58.4	13.8	59.9
Glenn	53	16,125	28.3	32	62.4	15.0	56.3
Lang-MN	55	16,714	27.2	31	61.1	14.6	62.1
Lanning	55	15,808	28.8	30	58.2	14.4	61.7
Linkert	53	15,734	28.9	28	59.6	15.4	55.2
MN Washburn	55	16,848	27.0	30	59.1	14.3	54.2
MN-Torgy	55	15,990	28.5	31	61.0	14.2	69.0
Mida	55	13,483	34.0	40	59.7	15.3	45.8
ND Frohberg	53	16,346	27.8	31	58.7	15.2	51.6
ND Heron	52	15,675	29.1	30	61.8	14.2	63.3
ND VitPro	53	15,946	28.5	30	62.3	14.9	62.2
Prosper	53	14,499	31.3	31	60.6	14.4	68.0
Red Fife	58	13,357	34.1	42	59.7	14.9	51.6
Shelly	55	17,590	25.8	30	59.1	13.7	59.6
Trial Mean	54	16,020	28.6	32	59.8	14.7	57.5
CV %	0.8	7.3	7.4	3.1	2.2	3.5	14.1
LSD 0.05	1	1,663	3.0	1	1.8	0.7	11.5
LSD 0.10	1	1,389	2.5	1	1.5	0.6	9.6

Planting Date: May 17, 2022
Harvest Date: August 22, 2022
Protein adjusted to 12% moisture
Previous Crop: Oat Hay
Seeding Rate: 1.5 million live seeds/ac

The Age of Grasses has Recently Doubled to 113 Million Years

Llewellyn L. Manske PhD
Scientist of Rangeland Research
North Dakota State University
Dickinson Research Extension Center
Report DREC 22-1198

Three recent studies have discovered grass microfossils from the Cretaceous that have doubled the age of ancestral grasses. The evolutionary development of the grasses is still poorly understood. Grass plant fossilization rates are extremely low. For a geologic time scale of the Cretaceous period and Cenozoic era, see table 1. The oldest unequivocal grass macrofossils are from the Paleocene-Eocene boundary, 56 Ma (million years ago), from the Wilcox Formation in western Tennessee (Kellogg 2001, Poinar 2004, Piperno and Sues 2005). Fossil grass pollen is a little older and relatively more abundant. Grass pollen is distinctive with nearly spherical shape that has a single pore and has minute channels or holes that penetrate the outer wall, but not the inner wall, unfortunately, pollen is only diagnostic to the family level, Poaceae, and the oldest known is from the Paleocene, 66-56 Ma (Kellog 2001). Before 2005, by default, the origin of grasses had been designated to be no older than the Cenozoic era and no one suspected that herbivorous dinosaurs ate grass. Perplexingly, by the Early Cenozoic the known grasses were relatively well developed and most likely had to have much older ancestors.

Cretaceous Grass Microfossils

During the past two decades, three astonishing paleontological studies have discovered grass microfossils that have doubled the age of fossil grasses, from the Cenozoic, 56 Ma, all the way back to the Cretaceous, 113 Ma. These three groups of resourceful scientists have been able to collect and identify microscopic grass phytoliths and segments of leaf epidermis from Cretaceous deposits.

The first paleontological study was from India, Prasad et al. (2005, 2011), with a group of ten scientists, described grass phytoliths extracted from coprolites (fossilized feces) ascribed to titanosaur sauropods and segments of fossil grass epidermis from related matrix sediments, from the Maastrichtian age, 67-65 Ma, Late Cretaceous, Gondwana, recovered from the Lameta Formation consisting of alluvial to limnic sediments associated with the Deccan Traps (Southern Stairs) Volcanics in central India. Eight new grass species were named from the wide diversity of described diagnostic phytolith morphotypes. For a list of grass subfamilies, see table 2. The authors ascribed four new species to subfamilies as follows: Subfamily Pueliodeae, Pipernoa pearsalla; Subfamily Oryzoideae, Matleyite indium; Subfamily Bambusoideae, Vonhueneites papillosum; Subfamily Pooideae, Chitaleya deccana; and ascribing subfamily to four of the other new species was ambiguous because the phytolith morphologies overlapped with other more modern subfamilies. Two new grass species were named from epidermal cell structure and 3-D embedded grass silica short cell (GSSC) phytoliths. The authors ascribed these two species to one subfamily as follows: Subfamily Oryzoideae, Changii indicum, and Tateokai deccana. This study documented that titanosaur sauropods, the prominent terrestrial plant eater in Gondwana, consumed grass as part of their diet. The wide diversity of diagnostic phytoliths in this study represented samples from later diverging poaceae taxa (not primitive enough to be from ancestral taxa) that had emerged and may have spread across Gondwana before 80 Ma, which would be much earlier than previously thought, and the dispersion may have been affected by the interactions of herbivorous dinosaurs.

The second paleontological study was from Myanmar, Poinar (2004, 2011) described a grass spikelet and a leaf fragment with silica bodies (phytoliths) and Poinar et al. (2015), with a group of three scientists, described an ergot sclerotia infecting a grass floret; all three separate specimens were embedded in Burmese amber from a resin-producing araucarian tree growing in a tropical-subtropical forested area from Upper Albian, 110-100 Ma, late Early Cretaceous, on the Burma Plate of Laurasia, occurring in deposits of lignitic seams in sandstone-limestone and mined from the Summit Site in the Hukawng Valley, southwest of Maingkhwan in the state of Kachin, Myanmar. The primitive spikelet was laterally compressed, had two basal sterile glumes, a series of six lemmas and one observed palea, and the remains of three stamen (males parts) and a gynoecium (female parts). The lemma had several domed papillae (bumps of unpointed prickles). Adjacent to the spikelet were several spherical, monoporate pollen grains, which are diagnostic grass family characteristics. The spikelet was given the new grass name of

Programinis burmitis. The grass leaf fragment epidermis contained stomata with guard cells, rows of long and short cells, and several domed papillae with the same shape and size as those on the spikelet lemma. The leaf fragment was given the new grass name of Programinis laminates. The author (2004) suggested that the primitive characteristics of the spikelet and leaf fragment and the occurrence in tropical forested habitat indicated these fossils to be ancient herbaceous bamboo with affinity to the Subfamily Bambusoideae. The second report (2011) restudied the silica bodies (phytoliths) in the leaf fragment in greater detail under 800X magnification. The silica bodies (phytoliths) were located in columns of short epidermal cells. The silica bodies had nine general unspecialized rondel or elongated quadrate morphotypes that were similar to the phytoliths that occur in grasses from the Subfamilies of Bambusoideae, Panicoideae, Arundinoideae, and Chloridoideae.

The third report (2015) described a second grass floret with two basal glumes and six lemma that had similar primitive characters as the first grass spikelet named Programinis burmitis, however, this infected spikelet did not have enough observable characters to assign a new name. The infecting ergot was erect, protruding from and above the grass floret, with black flattened outgrowths composed of thick, branching, intertwining hyphae in the sclerotium. This fossil fungus was morphologically clearly separate from all extant species of Clavicipitaceae. The ergot was given the new fungal name of Palaeoclaviceps parasiticus. This study documented that fungal-grass symbioses was occurring during the late Early Cretaceous of Laurasia.

The third paleontological study was from China, Wu, You, and Li (2018), as a group of three scientists, described two silicified epidermal pieces and three slightly bilobate phytoliths of grass fragments extracted from dentition of two maxillary teeth of a basal (beginning) hadrosauroid, Equijubus normani (duck billed dinosaur), from the Albian age, 113-101 Ma, late Early Cretaceous of Laurasia, recovered from the Zhonggou Formation of Gongpoquan Basin, Mazongshan area, Gansu Province in north-western China. The two silicified epidermal pieces showed the presence of short cells intervening between long cells which is a basal characteristics shared by Joinvilleaceae (a grass-like ancestral outgroup family that produced berries) (Blackhall-Miles 2016) and Anomochlooideae (the oldest known basal subfamily of true grass), in addition, the epidermal pieces also had short-cell pairs, which first appeared in Anomochlooideae, which means that the Mazongshan specimens are a synapomorphy (an evolutionary trait shared by several species that can be grouped into a clade) of basalmost (oldest) Poaceae, most likely Anomochlooideae. This study documented that hadrosaur dinosaurs consumed grass as part of their diet. The authors suggested that ancestral grasses must have existed before the early Aptian, 125 Ma, and that deep-diverging grasses could have gained broad distribution across both Laurasian and Gondwanan continents, except for North America, during the Barremian, 129-125 Ma, mid Early Cretaceous.

Grass Phytoliths

All three of these astonishing Cretaceous paleontological studies used grass phytolith microfossils as a significant part of their fossil grass identification. Phytoliths (plant-stones) are rigid, microscopic structures made of silica, located mostly in the epidermal plant tissue (Anonymous 2021c).

Plants absorb silica from soil dissolved in groundwater in the form of monosilicic acid, $Si(OH)_4$. The rate and quantity of silica uptake is genetically controlled by the plant. Silica uptake requires a small expenditure of energy for metabolic active transport by the xylem sap to the epidermal cells and to be laid down as silicon dioxide, SiO_2, to form the phytoliths. Silica is not an essential nutrient for plants. The most likely function of silica phytoliths is to provide structural rigidity to plants in order to increase light interception and energy manufacture. The energy cost to the plant to incorporate silica phytoliths is only 3.7% of that to incorporate lignin and only 6.7% of the cost to incorporate structural carbohydrates (Shakoor et al. 2015).

All grasses have some phytoliths, upland grasses have very few, and wet meadow grasses (slough hay) have a huge amount, enough to wear down livestock teeth. Early hypothesis suspected the function of phytoliths was to deter herbivory (grazing). Phytoliths can be detected by insects and small mammals and they can avoid high-silica plants, however, medium to large herbivorous mammals cannot differentiate between plants based on phytolith content (Stromberg et al. 2016).

Silicon phytoliths are nearly indestructible, are resistant to oxidation, and are not subject to decay by microorganisms. Phytoliths can survive for millions of years in fossil coprolites, embedded in amber, stuck on herbivorous dinosaur teeth, and in fossil leaf epidermis fragments in deposits of fossil related sediments. Every sample of grassland soil contains prodigious quantities of microscopic silica phytoliths. In grasses, living and fossil, the numerous different characteristic shapes and sizes of the silica phytoliths are taxonomically diagnostic to the subfamily, tribe, and sometimes to the genus level. Several comprehensive guides of grass phytoliths have been correlated to grass taxon (Piperno and Pearsall 1998). Research paleontologists can use these reference collections of comparative grass phytoliths to aid in the identification of their collected microscopic fossil grass phytoliths. These silicon phytoliths are the key to identifying all additional Cretaceous fossil grasses.

Cretaceous Age for Ancestral Grasses

The ages of the three recently published Cretaceous grass fossil specimens were used by two large groups of phylogenetic scientists (Consortium 2018, Orton et al. 2021) to perform phylogenomic analysis (Anonymous 2022g) of the subfamily Pooideae that changed the divergence date estimation calibration points with the upper bound set at 110 Ma and the lower bound set to the fossil age. Genetic information from plastomes is maternally inherited and less complicated than that from the nucleus which is a mixture of male and female genetics. The divergence data analysis was run on the Bayesian evolutionary analysis sampling trees (BEAST 1.8 and BEAST 2). Pooideae was selected because it is the largest grass subfamily with nearly 4,000 species with a number of economically significant crop, pasture, and lawn grasses that dominate the northern temperate regions. The ages of the PACMAD clade changed from 41-28 Ma to 95.1-32.2 Ma; the BOP clade changed from 50-41 Ma to 100.1-89.8 Ma; and the APP clade changed to 109.9-105.8 Ma. The adjusted ages for the tribes of the Pooideae subfamily are on table 3.

Movement of Tectonic Plates

Plate tectonics changed the environment that affected grass evolution. Gondwana was a large southern continent that included on the west, South America, Africa, and Arabia, and on the east, Madagascar, India, Antarctica, and Australia (Anonymous 2021f). Laurasia was a large northern continent that included North America, Greenland, Europe, Baltica, Siberia, North and South China, and Indochina (Anonymous 2022b). Eastern North America, Spain, and France collided with northeastern Africa around 300 Ma that uplifted the Appalachian and Atlas mountains and folded land in Spain and France (Correia and Murphy 2020). North America and Africa separated in 200 Ma and opened the Central Atlantic Ocean. During most of the Late Cretaceous, North America was divided north to south by the Western Interior Seaway that covered about one third of the continent. The seaway receded following the Laramide orogeny that uplifted the Rocky mountains during a period around 70 Ma. South America and Africa spread from south to north during 190-100 Ma that opened the Southern Atlantic Ocean. Greenland and Norway separated in 57 Ma, which opened the North Atlantic Ocean between Europe and North America (Prothero 2006). Madagascar and India, and Antarctica and Australia separated from Africa around 175 Ma. Australia moving north split from Antarctica moving to the South Pole in 80 Ma. Madagascar and India separated in 68 Ma and caused the eruption of the Deccan basaltic flows that occurred for 800 K years (Anonymous 2022a). India collided with Asia in 50 Ma forming the Himalaya mountains. Western Antarctica separated from southern South America around 33 Ma which opened the Southern Ocean and permitted the cold circumpolar currents to develop causing sea temperature to drop 10°C (18°F) and the global climate became much colder, while Antarctica became frigid and covered with ice. Glacial advances occurred 25-23 Ma on Antarctica (Retallack 2004).

Changes in Cretaceous Vegetation

Vegetation had major changes during the Cretaceous. The flora of early Cretaceous consisted primarily of gymnosperm (naked seed) trees of Cycadaceae (cycad), Ginkgoaceae (ginkgo), Gnetaceae (gnetum), Araucariceae (araucaria), Podocarpaceae (podocarp), Taxaceae (yew), Cupressaceae (cedar and metasequoia), and ferns Pteridospermales (seed fern), and Polypodioaceae (small understory fern) (Anonymous 2022d, e, f).

Basal angiosperms (flowering plants) originated during the early Jurassic between 198-178 Ma. The evolution of the ancestral line of seed plants and angiosperms is the result of two or three events of whole genome duplication during 319 Ma, 192 Ma, and 160 Ma. The earliest angiosperm macrofossils are from 125 Ma and the oldest reticulated monosulcate (net-veined with one longitudinal groove) pollen are from 140 Ma. During early development, the angiosperms underwent rapid genome downsizing which allowed for faster rates of cell division and smaller cells that facilitated higher rates of leaf gas exchange for photosynthesis and transpiration and faster rates of growth resulting in a huge competitive advantage (Anonymous 2021d). Rapid diversification and great radiation of angiosperms occurred during mid Cretaceous, 140-100 Ma, coincident with the decline of the previously dominant gymnosperms. Flowering deciduous trees of Lauraceae (laurel and sassafras), Fagaceae (beech and oak), Aceraceae (maple), Magnoliaceae (magnolia), and Moraceae (fig) became dominant along with diversification of Polypodiales (small understory fern).

During the Late Cretaceous most of the earth was warm but only a small part was wet subtropical-tropical rain forests. There were mountains with cooler climates that had light frost. All the continents had northern temperate zones and warm zones with warm temperate between. There were both open and closed habitats. The angiosperm radiation was dominant and moving northward. Dense vegetation of angiosperm trees were along rivers and open habitats of angiosperm shrubs, and herbs with low growing ferns occurring further out. The gymnosperm vegetation had greatly reduced, however, ginkgo and gymnosperm trees persisted in contracting areas along with cycad shrublands. Sequoia, metasequoia, and pinus trees were growing in some northern latitudes (Krassilov 1981, Butler et al. 2009).

Insects diversified during the Cretaceous with early butterflies, moths, wasps, and bees appearing before flowers, grasshoppers appearing before grasslands, ants appearing before picnics, and cockroaches appearing before New York apartments.

Pines Evolve with Fire Regimes

The delayed origin of the Pinus genus in the gymnospermae family Pinaceae occurred during the Late Jurassic in 150 Ma. The diversification of the pines overlaped with the evolution and competition of the angiosperms during the Cretaceous and with the change in fire regimes during the Late Cretaceous (Singh et al. 2018).

Deposits of carbon provided evidence of fire as an ecological disturbance driver during the Cretaceous. Fire frequency typically has not been the same for different regions. Fire frequency was determined to be relatively low during the Early Cretaceous when the slow growing gymnosperms were dominant and fire frequency increased during the Late Cretaceous when rapid growing angiosperms were dominant. This change in fire regimes caused the pines to differentiate into two lineages. The fire-adapted pines, subgenus Diploxylon, developed in productive environments of temperate and subtropical regions outside of the tropical rain forests and the fire-avoiding pines, subgenus Haploxylon, developed in drier and colder regions or other extreme environments with low fire frequency.

The fire-adapted pines, Diploxylon, formed three different sets of traits. The fire-tolerator pines have thick bark that protects the cambium from extreme heat, the trees have a tall height and self prune dead branches to reduce crown fires, large quantities of seeds are produced that germinate better in bare soil after a surface fire, seedlings have a long juvenile stage when deep roots are produced and long needles protect the apical buds against fire. The fire-embracing pines retain dead wood of lower branches that promote crown fire that intensify the temperature enough to consume and decimate competing plants which advances postfire regeneration by their serotinous seeds that are delayed because the cones do not open until after a fire. The fire-refugia pines have thick bark that protects the cambium, however, they retain dead branches in the crown and they lack cone serotiny, their stressed environment is fire-prone with relatively high fire frequency, except the fine fuel load is low.

The fire-avoiding pines, Haploxylon, occur in stressful environments prone to drought and low available nutrients, they can close stomata at relatively higher water potential and are capable of hydrolytic lift, they have lower nutrient requirements than competing plants, pine needle litter buildup modifies soil by changing the pH, increasing nutrient availability and have allelopathic effects, they produce high quantities of seeds with relatively high germination rates for vigorous regeneration, and they have well developed ectomycorrhizal association that produce enzymes which enable access to organic nitrogen and that transport soil water (Singh et al. 2018).

Stages of Grass Evolution

Evolution of grasses has occurred over an extremely long time. The flowers of grasses evolved by reduction in several steps from plants that had showy flowers and were insect pollinated. Typical grass florets (flowers) are wind pollinated and are composed of reduced structures of an androecium (male parts) of three stamens each with an anther and filament, and a gynoecium (female parts) of a single chambered ovary with two stigmas at the top for pollen reception, and a pair of lodicules at the base. The androecium and gynoecium organs are covered and protected by hardened internally located palea and an externally located lemma (Anonymous 2021b). At anthesis, the lodicules become turgid (swollen) and force the floret open. If pollen reaches the stigma, each floret has the potential to produce a single fruit which is uniquely a caryopsis (grain). One or more florets are attached to a rachilla (stalk) that is subtended by a pair of glumes (bracts) comprising a spikelet, and one or more spikelets comprise an inflorescence (Stanley 1999, Kellogg 2001).

Reductions of Grass Flowers

All grass relatives are wind pollinated which would mean that insect pollination and sticky pollen were lost before ancestral grasses evolved. Wind pollination of grasses has several problems; wind moves pollen for relatively short distances, the florets are open for a few hours, and the pollen is viable for only a short period. Grass ancestors had six stamen, ovaries of three fused carpels, and a large perianth of petals and sepals. As grass ancestors evolved through numerous steps of reduction, three of the stamen were lost, two of the ovules aborted, and the perianth was greatly reduced with two modified petals becoming the lodicules, and two modified sepals becoming the palea and lemma (Stanley 1999, Kellogg 2001).

Grazing Defense Mechanisms

Two of the three astonishing Cretaceous paleontological studies documented that herbivorous dinosaurs, titanosaurs and hadrosaurs, ate grass plants as part of their diet. These two scientific data points will completely change the previous concepts of how grass evolution occurred. These new data have doubled the grass evolutionary time line back to 110 Ma and placed ancestral grasses at the beginning of the Late Cretaceous when other major changes were occurring world wide. The angiosperms were rapidly developing and radiating.

The extent and abundance of ancestral grasses during the Cretaceous will probably not be known for some time. Coincidental with the rapid radiation of angiosperms and an improvement in available forage quantity and quality during the mid Cretaceous, there was an extensive explosion of new herbivorous dinosaurs. Grasses were most likely not a major portion of the dinosaurs diet during the early stages, but a result of curiosity feeding. Even so, herbivorous dinosaur grazing was an important driver that influenced the development of ancestral grass growth mechanisms. The ancestral grasses would have been subjected to intensified curiosity feeding which would have forced grasses to develop grazing defensive mechanisms. Modern perennial grasses with both C_3 and C_4 photosynthesis in several subfamilies from two clades possess the same four primary defoliation resistance mechanisms. These four mechanisms of improved water use efficiency, compensatory physiological processes, vegetative reproduction by tillering, and nutrient resource uptake competitiveness are activated by partial defoliation by grazing. The development of these resistance mechanisms must have occurred at an early stage of ancestral grass during the association with Cretaceous herbivorous dinosaurs.

The grazing pressure from herbivorous dinosaurs would require ancestral grasses to produce a low growing point below grazing height, to produce double the herbage biomass greater than the leaf area needed for photosynthesis, to develop the structures and hormone systems in order to greatly improve water use efficiency, to develop a complex system for compensatory physiological growth of replacement tissue from basal and intercalary meristem and rejuvenated meristematic tissue that can rapidly assimilate newly fixed carbon and microbial mineral nitrogen into new leaf and stem structures, to develop a highly competitive belowground system with symbiotic endomycorrhizal and ectomycorrhizal fungi for uptake of soil water and nutrients, to produce axillary buds consisting of meristamatic tissue and a controlling hormone feedback system for vegetative reproduction of tillers that maintain active growth for two growing seasons with a juvenile vegetative stage and a mature stage for sexual reproduction, and to shed the ability to produce antiherbivory toxic substances (Manske 2018).

Adaptive Mechanisms to Dry Open Conditions

Ancestral grasses to the PACMAD clade and the Pooideae subfamily shifted from relatively wet environments with no water stress to drier open habitats with variable degrees of water stress. This shift to open habitats required the development of deep branching fibrous roots with a symbiotic relationship of arbuscular mycorrhizal fungi to absorb water and nutrients from the soil and the mechanisms to control the rate of water loss in order to prevent cellular dehydration and for the control of gas exchange. These grasses needed to develop an elaborate vascular tissue system, complex leaves with waterproof cuticles, and complex stomata with dumbbell shaped guard cells and lateral subsidiary cells. The grasses developed bulliform cells to roll or fold the leaf to reduce water loss. These improved structures provided fast action response to environmental changes in water balance resulting in improved water use efficiency permitting grasses to live in open, water deficient environments and still maintain significant biomass production. These grasses also developed mechanisms and phytohormones to repair and recover from the tissue damage caused by water deficient conditions (Wang and Chen 2020).

Cold Tolerance Mechanisms

The average temperature during the Cretaceous was warmer than the present. The mountains had cool temperatures where a few lineages in the Pooideae subfamily developed adaptations to cold temperatures. However, all the rest of the ancestral grass lineages did not develop cold tolerance mechanisms during the Cretaceous.

Grasses that moved to the temperate zones had to develop mechanisms for cold tolerance and to survive winter dormancy periods. The earth experienced cooling events during the late Eocene and Oligocene, 47.5-26 Ma. Grasses share a common ancestral trait to prevent cellular dehydration which is also beneficial in the development of cold acclimation responses. Enhancement of freezing tolerance was provided by a genetically controlled Poaceae specific inhibitor of ice recrystallization by production of a protein (IRIP) which helps prevent cell rupture by ice crystal development. Grasses developed a seasonal phenology cycle with vernalization responsiveness that allows synchronization of flowering with favorable conditions of spring and activation of autumal senescence for termination of growth activity before damaging freezing temperatures and for the translocation of synthesized compounds from cells downwards to the crown for respiration during the winter period to maintain life in crown cells and meristematic tissue (Preston and Sandve 2013, Korner 2016).

Surviving Drought and Fire

Perennial grasses living in temperate zones are known to have high survival rates during environmental stressful conditions of drought and fire. However, perennial grasses have no measurable mechanisms activated by either drought or fire events. The high survival rates during drought or fire conditions are attributed to the grass mechanisms that have evolved for adaptation to grazing defoliation, shifting to open habitats, and cold temperature tolerance.

Intensified Grazing Pressure from Herbivorous Dinosaurs

The increase in angiosperm development and radiation also occurred in North America, however, fossil Cretaceous grasses have not been found yet. The huge increase in new herbivorous dinosaurs did occur (table 4).

The Thyreophoras and Nodosaurids were heavy set critters fully covered with armor. They had small heads with small leaf shaped teeth for grinding leaves picked from low lying plants in open habitats. The Hadrosaurs, Pachycephalosaurs, Neornithischians, and Ceratopsians were Ornithopods (bird foot) that had comparatively small replaceable teeth for grinding leaves grazed from plants close to the ground or browsed from low plant branches and they had cheeks that kept the food in their mouths while chewing. The Hadrosaurs (duck billed) and Ceratopsians (horn faced) were large quadrapeds that lived in open habitats and traveled in large herds with young and old individuals. The Pachycephalosaurs (thick dome heads) and Neornithischians (wondrous lizard) were moderate sized bipeds that lived in open habitats and may have traveled in small groups. The last large long necked sauropod roaming in western North America was one of the giant Titanosaurs; Alamosaurus was one of the largest, with an adult estimated to be 98 feet long, 25 feet tall, and at a weight of 70-80 tons. This large animal lived near tall trees and had a relatively small head with rod shaped teeth for stripping the leaves from branches, it had no large teeth for oral processing of the leaves, instead, it had a large muscular gizzard containing stones to mechanically breakdown the food (Barrett et al. 2006, Mallon et al. 2013, MacLaren et al. 2017, Takahashi 2019).

Mass Extinction by Asteroid

At the end of the Cretaceous, a massive asteroid 6 miles wide impacted the earth at Chicxulub Mexico on the coast of the Yucatan Peninsula in 66.043 Ma (Anonymous 2021a). The asteroid created a 112 mile wide crater that ejected vaporized granite rocks into the atmosphere that formed into minute spherules of crystallized droplets of molten rock which fell back to earth. The impact set off a global firestorm that denuded the land and put 16.5 billion tons of soot into the atmosphere which blocked sunlight from reaching the earth for 1 to 2 years. The temperature of the ocean dropped 20° F and on land it dropped 50° F. Freezing temperatures at the middle latitudes lasted for 3 to 4 years (Bardeen et al. 2017, Anonymous 2022h).

This asteroid impact caused the Cretaceous-Paleogene (K-Pg) mass extinction event. All of the non-avian dinosaurs plus the mosasaurs, plesiosaurs, and pterosaurs became extinct (Anonymous 2021a). The shallow sea coral, belemnoids, and ammonoids also became extinct. Surprisingly, many ocean animals survived, 90% of the boney fish, 66% of the sharks, and 69% of the skates and rays.

Many land animals survived, 80% of the turtles, most of the snakes, lizards, crocodiles, birds, and the mammals smaller than the size of a racoon. Almost all of the plants in the southern hemisphere survived. In North America, 43% of all terrestrial plants survived (Anonymous 2022h). All of the plants that survived this asteroid impact were polyploidy, containing more than two sets of chromosomes (Lohaus and Van de Peer 2016). Angiosperms, Poaceae, and Pinus emerged from the Cretaceous as the dominant plant forms.

Saprotrophic fungi became the dominant living organisms because they can live on dead organic material without sunlight. When the sunlight returned, two species of ferns recolonized the entire planet and were dominant for 1,000 years. How or where the terrestrial plants and animals survived two years without sunlight and four years of extreme cold is not explained in the literature.

Survival After Mass Extinction

Ancestral grasses from twelve subfamilies survived the K-Pg extinction event, 66 Ma. The number of grass subfamilies that did not survive extinction is not known. Evidence of grasses remained obscure for 10 million years after the K-Pg boundary. Nevertheless, by Early Eocene, 56-46 Ma, grass fossils had nearly a world wide distribution (Stromberg 2011). Following the K-Pg extinction, North American vegetation was dominated by evergreen gymnosperm and deciduous dicotyledonous trees with an abundant understory of palms and bamboo grass (Stromberg 2011). Some regions increased in aridity causing large openings to occur in the forest canopy permitting “desert” (arid) bunch grasslands to form during the Late Eocene-Early Oligocene, 33 Ma (Retallack 2004). These grasses were identified by their phytoliths as stipoid pooids and PACMAD clade grasses (Stromberg 2005). Areas of open grass dominated habitats appeared and started to be used as forage by large and medium sized herbivorous mammals during the Late Oligocene to Early Miocene, 25-19 Ma (Stebbins 1981, Semprebon et al. 2019). Open grasslands of C_3 pooids and PACMAD formed into wide savanna woodlands following the reduction of trees during Early Miocene, 19-15.5 Ma (Retallack 2004, Stromberg 2005, 2011). Open grasslands with C_3 grasses increased rapidly during the Middle to Late Miocene, 15-5 Ma (Stromberg 2005, 2011). There is no known fossil charcoal to indicate fire occurrence during the long period of grassland development in North America (Retallack 2004, Stromberg 2011).

C_3 and C_4 Photosynthetic Pathways

The C_3 photosynthetic pathway converts carbon dioxide and water into complex molecules by using the Calvin-Benson cycle which is the most primitive photosynthetic process in terrestrial plants. The C_3 photosynthesis process originated 2500 Ma when the atmosphere had very high CO_2 levels and much lower O_2 content. The product is a three carbon sugar (C_3), for every three molecules of CO_2 fixed, six 3C sugars are produced. However, in an atmosphere with higher levels of O_2, the process is disadvantaged because the high levels of oxygen expose some of the product to photorespiration which reduces the concentration of CO_2 that decreases the potential photosynthetic rate by up to 30%-40% (Tipple and Pagani 2007).

The C_4 photosynthetic pathway has increased effectiveness by adding a series of preliminary biochemical reactions that concentrate the CO_2 into a four carbon acid (C_4) in the leaf mesophyll cells that is then moved into nearby large bundle sheath cells resulting in a much higher rate of carbon assimilation during the Calvin-Benson cycle (Tipple and Pagani 2007).

The earliest C_4 grasses evolved during the early Oligocene, 32-30 Ma, when atmospheric CO_2 concentrations dropped to low levels (Stromberg and McInerney 2011, Christin et al. 2014). The oldest C_4 grass macrofossils date to 12.5 Ma in the Middle Miocene (Kellog 2001). The C_4 photosynthetic trait has evolved from C_3 grasses 22 to 24 times, but this has only occurred in four subfamilies that are in the PACMAD clade, Chloridoideae, Panicoideae, Aristidoideae, and Micrairoideae. The C_3 plants that have evolved into C_4 plants had to have a specific arrangement of suitable leaf anatomy with greater than 15% proportion of vascular bundle sheath tissue and with only a very short distance to the large bundle sheath cells (Christin et al. 2013).

Grassland Development

Grasslands dominated with C_4 grasses primarily from the Chloridoideae subfamily expanded during the period of Late Miocene to Early Pliocene, 7-4 Ma (Tipple and Pagani 2007, Osborne 2008, Stromberg and McInerney 2011, Christin et al. 2013, Fox et al. 2018, Kirshner and Hoorn 2020). The late Miocene grasslands in North America, Africa, Argentina, Ukraine, China, and Pakistan were extensive enough to sequester sufficient quantities of carbon dioxide to reduce the Cenozoic greenhouse conditions and cool the global temperature (Prothero 2006). Continuation of the North American expansion during the Early Pliocene, 5 Ma, created an extensive treeless grassland between the Rocky Mountains and the Appalachian Mountains (Holliday 1987, Fredlund and Tieszen 1997, Dyke 2005).

Global cooling began when Antarctica moved over the south pole and the Southern Ocean had unhindered circulation around the continent about 33 Ma, causing decreases in forest density (Retallack 2004). A global ice age intensified during late Pliocene, 3.5 Ma, with the formation of multiple continental glaciers. The largest glacier was on North America, which experienced at least 20 discrete glacial-interglacial cycles. The greatest advance occurred about 2.4 Ma in North America covering nearly all of Canada and most of the northern tier of states west of the Great Lakes, extending south along the Mississippi River to the confluence of the Ohio River, and extending east to Long Island. The land ahead of advancing glaciers and adjacent to receding glaciers was a herb tundra with sedges, grasses, and shrub willow and in some places permafrost developed. A white spruce savanna extended about 200 km (124 mi) out from the glacier with open woodlands of aspen, ash, and birch forming along lake margins and grasses covered upland areas (Holliday 1987, Fredlund and Tieszen 1997).

The old literature based on palynological studies described a spruce forest that covered the United States south of glacial margins during the Pleistocene ice age (Holliday 1987). Identification of ancient biomes from pollen analysis is hugely biased towards trees and against grasses and sedges. Trees produce much greater quantities of pollen, tree pollen moves further by wind, tree pollen has greater preservation, and tree pollen can be identified down to the genus level and be an indication of environmental conditions (Holliday 1987). Grass pollen is cosmopolitan and present at relatively low percentages in virtually all pollen samples. Grass pollen can only be identified to the family level and thus does not indicate environmental conditions. Graminoid dominated ecosystems can not be identified by pollen analysis. Phytoliths have better resolution than pollen for graminoid taxa. Phytoliths accumulate over more local areas and are remarkably durable in dry acidic conditions and can be used to identify graminoid communities (Anonymous 2021c).

The central portion of the United States south of the glacial margins was actually a grass dominated community with scattered spruce and aspen that was highly variable during the changeable conditions of the Pleistocene Epoch (Fredlund and Tieszen 1997, Dyke 2005). This age of megamammals included large quantities of mammoths, horses, zebras, asses, camels, llamas, pronghorns, oxen, and bison that depended on grasses for forage and grasslands for habitat and their predators of wolves, bears, and cats (table 5).

The last glacier melted around 11,500 years ago. The areas that had been glaciated had the previous vegetation completely destroyed and were revegetated by migrating plants from the south that developed dynamic communities in place. The current North American biomes have existed for only the last 5000 years. No new plant species have originated in the previously glaciated regions.

Synopsis of Cretaceous age ancestral grasses

The age of ancestral grasses has recently been doubled and moved back to the Cretaceous, 113 Ma, by three astonishing paleontological studies that used grass silica short cell phytoliths to identify Cretaceous ancestral grass microfossils. This was possible because grass phytoliths are nearly indestructible and they have unique morphotypes that are taxonomically diagnostic to subfamily, tribe, and to some genera. This major scientific advancement opens the path for future studies to use grass phytolith microfossils to help explain grass species evolution in greater detail and to describe the historical development of grasslands more precisely.

Pushing the age of ancestral grasses back to the Cretaceous implicates herbivorous dinosaurs as the driving force for the development of the same four grazing defense mechanisms in most temperate perennial grasses. Today, grasslands are the primary forage source for the livestock production industry because of what grazing herbivorous dinosaurs did to ancestral grasses one hundred million years ago.

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Table 1. Geologic Time Scale of the Grasses during the Cretaceous and Cenozoic.

Epoch	Age	Ma	Epoch	Age	Ma
	Cenozoic Era			Cretaceous Period	
		now			66
Holocene		0.012		Maastrichtian	
Pleistocene	Calabrian	1.8			
	Gelasian	2.6		Campanian	72
Pliocene	Piacenzian	3.6			
	Zanclean	5.3			
Miocene	Messinian	7.2	Late		84
	Tortonian			Santonian	86
		12		Coniacian	90
	Serrarallian	14		Turonian	94
	Langhian	16		Cenomanian	
	Burdignlian				
		20			100
	Aquitanian	23		Albian	
Oligocene	Chattian				
		28			
	Rupelian				
		34			113
Eocene	Priabonian			Aptian	
		38			
	Bartonian				
		41			
	Lutetian		Early		125
				Barremian	
		48			129
	Ypresian			Hauterivian	133
				Valanginian	
		56			
Paleocene	Thanetian	59			139
	Selandian	62		Berriasian	
	Danian	66			145

Data from the Geological Society of America, V.5.0. 2018.

Table 2. Classification of the worldwide family Poaceae (Gramineae), the Grasses.

Clade	Subfamily	Tribe	Genera	Species
	Chloridoideae	5	124	1602
	Danthonioideae	1	19	292
	Micrairoideae	3	8	184
PACMAD				
	Arundinoideae	2	14	40
	Panicoideae	13	247	3241
	Aristidoideae	1	3	367
	Pooideae	15	202	3968
BOP	Bambusoideae	3	125	1670
	Oryzoideae	4	19	115
	Puelioideae	2	2	11
APP	Pharoideae	1	3	12
	Anomochlooideae	2	2	4
3	12	52	768	11,506

Data from Soreng et al. 2017. Oldest to Youngest, Bottom to Top.

Table 3. Adjusted ages of grass tribes in subfamily Pooideae using calibration points of fossils from three new Cretaceous studies.

Tribe	Age Ma (mega-annum)		Geologic Age
	Range	Mean	
Brachyelytreae	93.2-76.3	84.8 [2]	Turonian
Nardeae	69.4-55.4	62.4 [1]	Maastrichtian
Lygeeae			
Duthieeae	64.4-50.3	57.3 [1]	Danian
Phaenospermateae	81.7-38.3	60.0 [2]	Campanian
Brylkinieae	61.3-47.2	54.3 [1]	Selandian
Meliceae			
Ampelodesmeae	62.8-48.7	55.9 [1]	Danian
Stipeae			
Diarrheneae	57.6-43.5	50.6 [1]	Thanetian
Brachypodieae	55.6-41.6	48.4 [1]	Ypresian
Poeae	62.4-47.8	55.1 [2]	Danian
Littledaleeae	52.4-38.8	45.5 [1]	Ypresian
Bromeae			
Triticeae			

Data determined by BEAST v 1.8[1] or BEAST 2[2]
Data from Consortium 2018 and Orton et al. 2021.

Table 4. Herbivorous Dinosaurs Living in Western North America during the Late Cretaceous, 100-66 Ma.

Thyreophora	**Hadrosaurs**	**Ceratopsian**	**Sauropoda Titanosaur**
Ankylosaurus	Augustynolophus	Achelousaurus	
Borealopelta	Brachylophosaurus	Anchiceratops	Alamosaurus
Euoplocephalus	Corythosaurus	Arrhinoceratops	
Zuul	Edmontosaurus	Avaceratops	
	Gryposaurus	Brachyceratops	
Nodosaurid	Hypacrosaurus	Bravoceratops	
	Kritosaurus	Centrosaurus	
Denversaurus	Lambeosaurus	Chasmosaurus	
Edmontonia	Maiasaura	Coronosaurus	
Glyptodontopelta	Parasaurolophus	Crittendenceratops	
Nodosaurus	Prosaurolophus	Diabloceratops	
Panoplosaurus	Saurolophus	Einiosaurus	
		Eotriceratops	
		Judiceratops	
	Pachycephalosauria	Kosmoceratops	
		Leptoceratops	
	Acrotholus	Machairoceratops	
	Pachycephalosaurus	Medusaceratops	
	Sphaerotholus	Mercuriceratops	
		Montanoceratops	
		Nasutoceratops	
	Neornithischian	Pachyrhinosaurus	
		Pentaceratops	
	Parksosaurus	Regaliceratops	
	Thescelosaurus	Styracosaurus	
		Terminocavus	
		Torosaurus	
		Triceratops	
		Utahceratops	
		Vagaceratops	
		Wendiceratops	
		Xenoceratops	

Data from Anonymous 2021 g, h, i; 2022 i, j, k, l, m, n, o, p.

Table 5. Pleistocene Grassland Megafauna Herbivores and Predators in North America, 1.9-0.011 Ma.

Grassland Herbivores	
Mammuthus	**Mammoth**
M. imperator	Imperial mammoth
M. columbi	Columbian mammoth
M. jeffersonii	Jefferson's mammoth
M. primigenius	Woolly mammoth
Equus	**Horse**
E. conversidens	Mexican horse
E. giganteus	Giant horse
E. niobrarensis	Niobrara horse
E. occidentalis	Western horse
E. scottii	Scott's horse
E. (Asinus) calobatus	Stilt legged onager/ass
E. (Plesippus) simplicidens	American Plains zebra
Camelidae	**Camel/Llama**
Camelops hesternus	Western camel
C. minidakae	Minidak camel
Titanotylopus spatula	Giant camel
Hemiauchenia macrocephala	Long legged llama
Bison	**Bison**
B. latifrons	Giant bison
B. alaskensis	Alaska bison
B. alleni	Long horn bison
B. antiquus	Ancient bison
B. occidentalis	Western bison
B. bison bison	Plains bison (extant)
Bos	**Oxen**
Euceratherium collinum	Shrub oxen
Antilocapridae	**Pronghorn**
Capromerix minor	Small four horned pronghorn
Tetramerix irvingtonensis	Large four horned pronghorn
T. shuleri	Four horned pronghorn
Antilocapra americana	American pronghorn (extant)

Table 5 (cont). Pleistocene Grassland Megafauna Herbivores and Predators in North America, 1.9-0.011 Ma.

Platygonus	**Peccary**
P. compressus	LeContes peccary
P. vetus	Flat head peccary
Tapirus	**Tapir**
T. haysii	Giant Hays tapir
Grassland Predators	
Canis	**Wolf**
C. edwardii	Edward’s wolf
C. armbrusteri	Armbruster’s wolf
C. dirus	Dire wolf
C. lupus	Gray wolf (extant)
C. latrans	Coyote (extant)
Ursidae	**Bear**
Arctodus pristinus	Lesser short faced bear
A. simus	Giant short faced bear
Ursus arctos	Grizzly bear (extant)
Felidae	**Cat**
Smilodon gracilis	Saber toothed cat
S. populator	Saber toothed cat
Homotherium serum	Scimitar toothed cat
Miracinonyx trumani	American cheetah
Panthera atrox	American lion
P. onca	Jaguar (extant)
Felis cancolor	Puma (extant)

Data from Hibbard 1958, Bell et al. 2004, Dyke 2005.

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Botanical Description of Lesser Spikemoss (Clubmoss) on the Prairie of the Northern Great Plains

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Reclassification

Lesser spikemoss, *Selaginella densa*, has a designated common name different from the familiar standard name of clubmoss. The Pteridophytes (vascular cryptogams) were recently reclassified by the Pteridophyte Phylogeny Group 1 (PPG1) (2016). The Lycopodiophyta (clubmoss) were separated into three orders of Lycopodiales (clubmoss), Isoetales (quillworts), and Selaginellales (spikemoss) (table 1) and these were divided from the divisions of Sphenophyta (horsetails), and the Pterophyta (ferns).

The plants that have had the common name of clubmoss for a long time are the Lycopods; in Greek, Lyco means wolf, and pod means foot, thus the name wolf foot, but they were called clubmoss, as were all the other plants that had been lumped under the old category of Lycophytes. The plants that were called clubmoss but currently have the designated common name of lesser spikemoss is Selaginella densa. In Latin, densa means thick, ella means diminutive or small, and selagin actually does mean clubmoss, thus this name means thick, small, clubmoss. Stevens (1963) called Selaginella densa, small clubmoss. O.A. Stevens knew the classical languages that pertained to plant names. Unfortunately, to the replacement botanists, plant common names do not follow their classical meanings.

Origin

Selaginella are an ancient primitive diminutive evergreen, appearing delicate but tough, perennial herbaceous nonflowering plant. These were among the first land plants to successfully develop basic vascular tissue and absorbing true roots. This group of plants originated more than 350 million years ago that dominated the earth during the Carboniferous period and helped form the worlds hard coal (anthracite) deposits (Burns 1974). Most of the plants from this group are extinct. All of the surviving extant members are rather small and often go unnoticed. Living in North America for over 350 million years is quite a remarkable accomplishment. Not many organisms have done that and survived three major mass extinction events.

Morphology

Selaginella densa Rydb. has several prostrate creeping stems that are 2 to 6 in (5 to 15 cm) long, with numerous erect branches, densely packed, that are seldom more than 1 in (2.5 cm) in height, forming thick cushionlike mats. The branches are completely covered with tiny lanceshaped leaves (microphylls) 1.7-2.5 mm long, 0.2-0.3 mm wide in ranks of four pressed close to the branch. The lower leaves are a little longer than the upper leaves, which have minute whitish setae (bristles) that change color with age and form conspicuous tufts at the branch tips. Roots are very fine about 0.008 in (0.2 mm) in diameter, are minutely branched and have small root hairs and a root cap. They do not extend deeper than 0.78 to 2.0 in (2-5 cm) below the soil surface. All of the roots are adventitious arising at intervals along the horizontal stems and from special short stem branches called rhizophores. The extensive tangle of roots may comprise a high percentage of the plants total dry matter (Stevens 1963, Looman and Best 1979, GPFA 1986, Crane 1990, Anonymous 2021).

As a result of the extremely shallow root system, growth is limited to periods of the year when moisture is available at shallow depths. Vegetative growth and rate of spreading is slow. Under normal conditions, measured growth was about 0.4 in (1 cm) per year. Under dry conditions, growth was less than 0.2 in (5 mm) in 5 years (Crane 1990). If growth occurs radially at equal rates, it would require 15 years to grow 6 inches, with normal rainfall.

The stems contain no pith. The very simple primary vascular tissue of xylem and phloem collectively are called the stele that is separated from the cortex in a cylindrical cavity arranged in many platelike zones that are suspended by trabeculae (modified elongate endodermal cells) that have Casparian strips on their lateral wall. The Casparian strips secrete salts into the vascular tissue that helps develop a lower hydrostatic pressure in the plant. The stele structure, in cross section, forms a plectostele type vascular system that is continuous with the roots. A single unbranched vein develops from the central stele for each microleaf and has no leaf gap (Burns 1974).

Selaginella dry weight is comprised of 16.5% silica, which is very high (Crane 1990). Silica has no nutritional qualities for the plant and would be a great deterrent for any animals to eat it. Livestock do not eat it and there is no documented evidence that any wildlife eat it. Silica is used by plants to increase the rigidity of stems and branches (Shakoor et al. 2015). Selaginella has a very primitive vascular system that most likely provides poor turgor. Turgor is the hydrostatic pressure on cell walls that result from transpiration of soil water through the leaves causing more advanced plants to be rigid. Selaginella must have to use high quantities of silica to compensate for the low turgor produced by its vascular tissue. Using lignin or structural carbohydrates to produce rigidity has a much greater biological cost to plants than using silica (Shakoor et al. 2015).

Reproduction

Selaginella produces neither flowers nor seeds during its reproductive processes. Reproduction is sporiferous from the production of spores. Selaginella plants are heterosporous and produce two different sizes of spores, the megaspores are the female gametes and the microspores are the male gametes. A four-angled strobili that is 1 to 2 cm or up to 3.5 cm long, is a conelike cluster of sporophylls (leaflike structures of the strobili) that form at the tip of a branch. The megasporangia are the structures that produce the female megaspores and are attached to the axis of the branch towards the lower portions of the strobili. A megasporophyll is a leaflike structure to protect the megasporangia from the outside. A ligule, that is a small flap of tissue, is located between the base of the sporangium and the base of the sporophyll. The microsporangia are the structures that produce the male microspores and are attached to the axis of the branch towards the upper portions of the strobili. A microsporophyll is a leaflike structure to protect the microsporangia from the outside. A ligule, that is a small flap of tissue is located between the base of the sporangium and the base of the sporophyll (Burns 1974, GPFA 1986, Crane 1990).

At maturity, the microspores produce microscopic flagellated male sperm cells that are released when there is available water to swim to the female egg cells. Tissue surrounding the fertilized egg can photosynthesize carbohydrates for the developing embryo. A young sporeling consists of a root, a stem, and two young leaves or cotyledons. When there is available water, the developed sporelings are released to fall to the ground. If conditions are perfect, the sporelings are successful (Burns 1974, Crane 1990).

Management of the Problem

In the northern Great Plains, Selaginella densa var. densa primarily grows on shallow grassland sites and usually increase on grasslands managed by traditional seasonlong grazing. Selaginella has no identifiable advantageous characteristics, it provides no forage for livestock or wildlife, it provides no protective cover for ground nesting prairie birds, and it occupies space that forage plants could grow. Clubmoss is generally considered to be a problem plant. After decades of research, there are no direct control treatments from mechanical, chemical, fertilizer, or fire practices that have demonstrated repeatable successful results at reducing clubmoss (Crane 1990).

Management of clubmoss needs a different approach. What if Selaginella were not a problem plant but a symptom of a poor soil functionality problem. Typically, shallow grassland soils managed by traditional practices have low microbial activity, low available mineral nitrogen, and extremely low water holding capacity. Selaginella has lower water and nutrient requirements than grasses and it has greater capabilities for complete or nearly complete summer dormancy and can regulate its recovery rate from partial to full depending on amounts of precipitation received.

Grass plants have not developed drought mechanisms. Grasses have developed mechanisms to live in dry open habitats, grazing defense mechanisms, and cold tolerance mechanisms (Manske 2022). When grasses transform into summer dormancy because of the lack of soil water, it is not complete dormancy, they appear to maintain the same quantity of active tissue as during winter dormancy. On shallow sites, when the small amount of soil water is used up and the interval between rain events is long, a greater percent of the grass biomass dies compared to the percent of biomass of Selaginella. The growth rate of Selaginella is very slow. The open spaces left by the dead grass plants are not back filled by Selaginella in one or two years. It takes decades for clubmoss to become a problem.

The old traditional style management should be changed to biologically effective management that was designed to increase soil microbial activity by transferring the surplus carbohydrates produced by vegetative lead tillers through the roots to the soil microbes, the resulting increase in microbial activity would increase the quantity of available mineral nitrogen that would activate the internal grass growth mechanisms that would replace the lost grass stems and leaves. Also the increased microbial activity would improve soil aggregation that would increase the water holding capacity of shallow soils. These improved changes in soil functionality would give grass plants a competitive advantage over the clubmoss and gradually decrease the land area occupied by Selaginella, producing greater quantities of forage and better cover for ground nesting prairie birds (Manske 2018).

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Table 1. Pteridophyte Phylogeny Group 1 Classification, 2016.

Kingdom:	Plaintae	Multicellular, photosynthetic	
Phylum:	Tracheophyta	Vascular plants	
Division:	Lycopodiophyta/Lycophytes	Seedless, spore bearing	
Class:	Lycopodiopsida	Bartl. PPG1 2016 modern classification	
	Order: Lycopodiales	DC	1 family, 16 genera
	Family: Lycopodiaceae	P. Beauv.	Clubmoss
	Order: Isoetales	Prantl.	1 family, 1 genera
	Family: Isoetaceae	Dumort.	Quillwort
	Order: Selaginellales	Prantl.	1 family, 1 genera
	Family: Selaginellaceae	Willk.	Spikemoss
	Genus: Selaginella	P. Beauv.	small clubmoss
	Species: S. densa	Rydb.	dense spikemoss
	Variety 1: S. densa var. densa	lesser spikemoss	
		prairies of northern Great Plains	
	Variety 2: S. densa var. scopulorum	Rocky Mountain spikemoss	
		northern Rocky Mountains	
	Variety 3: S densa var. standleyi	Standley’s spikemoss	
		only above timberline	

Data from PPG1 (2016), Crane 1990.

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Ancestral Grass Development of Survival Mechanisms

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Ancestral grasses developed in the late Early Cretaceous, with the oldest microfossils, to date, at 113 Ma (Wu, You, and Li 2018). These early ancestral grasses developed in closed canopy forests that had a relatively wet habitat with no water deficiencies. These ancestral grasses had already evolved through numerous stages of reduction, were wind pollinated, had three male stamens, a single female ovary, and the remaining remnant perianth had been greatly reduced and modified (Stanley 1999, Kellog 2001). Even with some transformation, these ancestral grasses were still comparatively vulnerable. They did have a common trait that prevented cellular dehydration, but they could not survive very long in direct sunlight, or low temperatures, and they could not fully repair physical damage to leaves, stems, or roots. In order for grasses to progress and become a worldwide dominant plant type, they had to develop several complex survival mechanisms.

The vegetation during the early half of the Cretaceous consisted primarily of gymnosperm (naked seed) trees of Cycadaceae (cycad), Ginkgoaceae (ginkgo), Gnetaceae (gnetum), Araucariceae (araucaria), Podocarpaceae (podocarp), Taxaceae (yew), Cupressaceae (cedar and metasequoia), and ferns, Pteridospermales (seed fern), and Polypodioaceae (small understory fern) (Anonymous 2022d, e, f), these were greatly reduced after mid Cretaceous.

The temperature was much warmer than the present. During the Early Cretaceous there were wet subtropical-tropical rain forests which were greatly reduced by Late Cretaceous. All the continents had moderate northern temperate zones and very warm zones, with warm temperate between (Krassilov 1981). During Early Cretaceous most of the forests were closed habitats but by mid Cretaceous open habitats were greatly increasing. There were mountains with cooler climates with some areas receiving light frost. The angiosperm radiation was dominant during mid to late Cretaceous with dense angiosperm trees along rivers and open habitats of angiosperm shrubs and herbs with low growing ferns increasing.

Mechanisms for Adaptation to Dry Open Habitats

With open habitats increasing, the ancestral grasses of the PACMAD clade and the Pooideae subfamily from the BOP clade (table 1) shifted from the relatively wet environments of closed habitats with no water stress to drier open habitats with variable degrees of water stress. This huge shift in habitat conditions required the development of adaptive mechanisms to dry open habitats. These grasses developed deep branching fibrous roots with symbiotic arbuscular mycorrhizal fungi to absorb water and nutrients from the soil. They had to develop mechanisms to control the rate of water loss in order to prevent cellular dehydration but they had to have enough flexible responsiveness to be able to regulate and control gas exchange. These grasses also developed an elaborate vascular tissue system, complex leaves with water proof cuticles, and complex stomata with dumbbell shaped guard cells and lateral subsidiary cells. The grasses developed bulliform cells to roll or fold the leaves to reduce water loss. These improved structures provided fast action response to environmental changes in water balance resulting in improved water use efficiency permitting grasses to live in open habitats, with water deficient environments and still maintain significant biomass production. These grasses also developed mechanisms and phytohormones to repair and recover from tissue damage caused during water deficient conditions (Wang and Chen 2020).

Grazing Defense Mechanisms

Coincidental with the rapid diversification and great radiation of angiosperms came a huge improvement in the quantity and quality of available forage during the mid Cretaceous which resulted in an extensive explosion of new herbivorous dinosaurs. Grasses were most likely not a major portion of the dinosaurs diet during the early stages, but a result of curiosity feeding. But in a short period, the intensified grazing pressure on grass ancestors from herbivorous dinosaurs became an important driver that influenced the development of grazing defense mechanisms. The grazing pressure from herbivorous dinosaurs required ancestral grasses to produce a low growing point below grazing height, to produce double the herbage biomass greater than the leaf area needed for photosynthesis, to develop the structures and hormone systems to greatly improve water use efficiency, to develop a complex system for compensatory physiological growth from meristematic tissue that can rapidly assimilate newly fixed carbon and microbial mineral nitrogen to replace grazed leaf and stem structures, to develop a highly competitive belowground system with symbiotic fungi for uptake of soil water and nutrients, to produce meristematic tissue in axillary buds and a controlling hormone feedback system for vegetative reproduction of tillers, and to shed the ability to produce anthiherbivory toxic substances (Manske 2018).

Modern C_3 perennial grasses from the Pooideae subfamily of the BOP clade and grasses with both C_3 and C_4 photosynthesis from several subfamilies of the PACMAD clade (table 1) possess these same grazing defense mechanisms which means that the development of these mechanisms must have occurred at a very early stage of ancestral grass during the late Early Cretaceous. The development of these grazing defense mechanisms from grazing pressure by herbivorous dinosaurs permit existent grasslands to be the primary forage source for todays livestock production industry.

Cold Tolerance Mechanisms

Ancestral grasses developed in a world of the late Early Cretaceous that was much warmer than the present and grasses did not need cold tolerance mechanisms. The earth started to become cooler during the late Eocene and the Oligocene, 48 to 26 Ma. The dinosaurs had been gone for at least 20 million years. Antarctica had broken away from Gondwana and was moving to the South Pole. Around 33 Ma, the newly opened Southern Ocean permitted the cold circumpolar currents to cause ocean temperatures to drop. Antarctica became frigid and covered with ice, and the global climate became much colder (Retallack 2004).

Grasses that lived in the Temperate Zones had several million years to develop their cold tolerance mechanisms. All grasses shared a common ancestral trait that prevented cellular dehydration, which was also beneficial in the development of cold acclimation responses.

Enhancement of freezing tolerance was provided by a genetically controlled, Poaceae specific, inhibitor of ice recrystallization, by production of a protein (IRIP), which helps prevent cell rupture by ice crystal development (Preston and Sandve 2013, Korner 2016).

Grasses also developed a seasonal phenological cycle with vernalization responsiveness that allows synchronization of vegetative growth and flowering with favorable conditions of spring and activation of autumnal senescence for termination of growth activity before damaging freezing temperatures. Autumnal senescence permits translocation of synthesized compounds from cells downwards to be stored in the crown (Preston and Sandve 2013, Korner 2016). These changes in spring and fall phenological activities are controlled by the local photoperiod (changes in the length of daylight) which is detected by photoreceptors in specialized plant cells.

Perennial grass plants live for, at least, 27 to 43 years (that is the longest time period that data have been collected). With proper management, grass plants could live for an extremely long time. Each grass tiller developed by vegetative growth of axillary buds lives two growing seasons and one winter season. The maintenance of life in grass plant cells during the winter period depends on stored carbohydrates that are assimilated during the winter hardening process that occurs during mid August to hard frost. The carbohydrates are used for respiration that provides energy for perpetuation of all necessary crown cells, carryover leaves and stems, and the meristematic tissue until they can be reactivated for growth during the following spring. Grass growth outside of the Tropical Zones would not be possible without the development of the cold tolerance mechanisms.

Survival of Drought and Fire Events

Perennial grass plants living in temperate zones are known to have relatively high survival rates following environmental stressful conditions of drought and fire. However, perennial grasses have no measurable mechanisms activated by either drought or fire events. These usually high survival rates during drought or fire conditions are attributed to the development of mechanisms that have evolved for grass adaptation to living in dry open habitats, to the defense of defoliation by grazing, and to tolerate cold temperatures.

Ancestral grasses developed several complex survival mechanisms which have permitted grasses to become the dominant plant type that humans could not survive without.

Acknowledgment

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

Table 1. Classification of the worldwide family Poaceae (Gramineae), the Grasses.

Clade	Subfamily	Tribe	Genera	Species
	Chloridoideae	5	124	1602
	Danthonioideae	1	19	292
	Micrairoideae	3	8	184
PACMAD				
	Arundinoideae	2	14	40
	Panicoideae	13	247	3241
	Aristidoideae	1	3	367
	Pooideae	15	202	3968
BOP	Bambusoideae	3	125	1670
	Oryzoideae	4	19	115
	Pueliodeae	2	2	11
APP	Phariodeae	1	3	12
	Anomochlooideae	2	2	4
3	12	52	768	11,506

Data from Soreng et al. 2017. Oldest to Youngest, Bottom to Top.

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Grasses of the Northern Plains According to Phylogenetic Classification

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Recently, the worldwide phylogenetic classification of grasses (Family=Poaceae) based on molecular DNA was updated (Soreng et al. 2017). Phylogenetic classification determines the relationships of the genetic structure in grasses using the matK and ndhF plastid DNA markers which permits the arrangement of grass genera into a graded series based on the degrees of closeness to a common ancestor and in the possession of a combination of derived traits that are in conformity with evolutionary history. The updated classification technology has determined that the world has 11,506 grass species in 768 genera, with 90 subtribes, 52 tribes, and 12 subfamilies in 3 clades (table 1).

As of yet, there are no flora treatises for the Northern Plains that include the updated phylogenetic classification of the grasses. This report arranges the grasses of the Northern Plains by clade, subfamily, tribe, subtribe, current genus and species according to the updated phylogenetic classification criteria, and includes a common name. The grasses are also separated into categories of, native, domesticated, introduced weedy, and cereal grasses of the Northern Plains. Using this classification system, the Northern Plains has 150 grass species in 66 genera, with 31 subtribes, 14 tribes, and 7 subfamilies in parts of 2 clades. The Northern Plains has no grasses from the subfamilies of Anomochlooideae, Pharoideae, and Puelioideae in the APP clade, Bambusoideae in the BOP clade, and Micrairoideae in the PACMAD clade. The Northern Plains does have grasses from the subfamilies of Oryzoideae consisting of 2 species in 2 genera with 2 subtribes and 1 tribe, and Pooideae consisting of 99 species in 40 genera with 14 subtribes and 5 tribes in the BOP clade, and Aristidoideae consisting of 1 species in 1 genus with 1 tribe, Panicoideae consisting of 18 species in 10 genera with 8 subtribes and 2 tribes, Arundinoideae consisting of 1 species in 1 genus with 1 subtribe and 1 tribe, Danthonioideae consisting of 3 species in 1 genus with 1 tribe, and Chloridoideae consisting of 26 species in 11 genera with 6 subtribes and 3 tribes in the PACMAD clade.

The native grasses of the Northern Plains are comprised of 104 species in 52 genera with 27 subtribes, 14 tribes, and 7 subfamilies in 2 clades (table 2). The domesticated grasses of the Northern Plains are comprised of 21 species in 13 genera with 6 subtribes, 3 tribes, and 1 subfamily in 1 clade (table 3). The introduced weedy grasses of the Northern Plains are comprised of 17 species in 11 genera with 9 subtribes, 5 tribes, and 3 subfamilies in 2 clades (table 4). The cereal grasses of the Northern Plains are comprised of 8 species in 5 genera with 2 subtribes, 3 tribes, and 2 subfamilies in 2 clades (table 5). Regional flora guidebooks from Stevens 1963, Looman and Best 1979, GPFA 1986, Barkworth et al. 2003, 2007, Johnson and Larson 2007, and Larson and Johnson 2007 were consulted to verify that each grass entry had documented existence in the Northern Plains, albeit, under different scientific names and classification descriptions.

Acknowledgment

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

Table 1. Classification of the worldwide family Poaceae (Gramineae), the Grasses.

Clade	Subfamily	Tribe	Subtribe	Genera	Species
PACMAD	Chloridoideae	5	26	124	1602
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	Arundinoideae	2	2	14	40
	Panicoideae	13	19	247	3241
	Aristidoideae	1	0	3	367
BOP	Pooideae	15	26	202	3968
	Bambusoideae	3	15	125	1670
	Oryzoideae	4	2	19	115
APP	Puelioideae	2	0	2	11
	Pharoideae	1	0	3	12
	Anomochlooideae	2	0	2	4
3	12	52	90	768	11,506

Data from Soreng et al. 2017. Oldest to Youngest, Bottom to Top.

Table 2. Northern Plains Native Grasses.

BOP Clade				
Oryzoideae	C_3	subfamily		
Oryzeae		tribe		
Oryzinae		subtribe		
Leersia			oryzoides	Rice cutgrass
Zizaniinae		subtribe		
Zizania			aquatica	Wildrice
Pooideae	C_3	subfamily		
Meliceae		tribe		
Glyceria			grandis	Tall mannagrass
			striata	Fowl mannagrass
			borealis	Boreal mannagrass
Schizachne			purpurascens	False melic
Stipeae		tribe		
Achnatherum			nelsonii	Nelson's needlegrass
			richardsonii	Richardson's needlegrass
			hymenoides	Indian ricegrass
Piptatherum			canadense	Canada ricegrass
			pungens	Northern ricegrass
			micrantherum	Little ricegrass
			racemosum	Blackseed ricegrass
Hesperostipa			comata	Needle and Thread
			curtiseta	Western needlegrass
			spartea	Porcupinegrass
Oryzopsis			asperifolia	Roughleaf ricegrass
Nassella			viridula	Green needlegrass
Bromeae		tribe		
Bromus			porteri	Nodding brome
			pubescens	Canada brome
			ciliatus	Fringed brome
Triticeae		tribe		
Hordeum			pusillum	Little barley
			jubatum	Foxtail barley
Pseudoroegneria			spicata	Bluebunch wheatgrass
Elymus			virginicus	Virginia wildrye
			villosus	Hairy wildrye
			canadensis	Canada wildrye
			hystrix	Bottlebrush grass
			elymoides	Squirreltail
			trachycaulus, trachycaulus	Slender wheatgrass

Table 2 cont. Northern Plains Native Grasses.

Pooideae (cont)		
Triticeae (cont)		
Elymus	trachycaulus, subsecundus	Bearded wheatgrass
	lanceolatus	Thickspike wheatgrass
Pascopyram	smithii	Western wheatgrass
Poeae	tribe	
Aveninae	subtribe	
Sphenopholis	obtusata	Prairie wedgegrass
	intermedia	Slender wedgegrass
Koeleria	macrantha	Prairie Junegrass
Phalaridinae	subtribe	
Phalaris	arundinacea	Reed canarygrass
Anthoxanthinae	subtribe	
Anthoxanthum	hirtum	Hairy sweetgrass
Agrostidinae	subtribe	
Agrostis	gigantea	Redtop
	stolonifera	Creeping bent
	scabra	Ticklegrass
Calamagrostis	montanensis	Plains reedgrass
	canadensis	Bluejoint reedgrass
	stricta, inexpansa	Northern reedgrass
Scolochloinae	subtribe	
Scolochloa	festucacea	Whitetop
Aristaveninae	subtribe	
Deschampsia	cespitosa	Tufted hairgrass
Loliinae	subtribe	
Festuca	hallii	Plains rough fescue
	idahoensis	Idaho fescue
Vulpia	octoflora	Sixweeks fescue
Coleanthinae	subtribe	
Puccinellia	nuttaliana	Nuttall’s alkali grass
Catabrosa	aquatica	Brookgrass
incertae sedis		
Avenula	hookeri	Spike oatgrass
Poinae	subtribe	
Poa	cusickii	Cusick’s bluegrass
	palustris	Fowl bluegrass
	interior	Inland bluegrass
	compressa	Canada bluegrass
	secunda	Sandberg bluegrass
	arida	Plains bluegrass
Beckmanniinae	subtribe	
Beckmannia	syzigachne	American sloughgrass

Table 2 cont. Northern Plains Native Grasses.

Poeae (cont)			
Cinninae	subtribe		
Cinna		latifolia	Drooping woodreed
Alopecurinae	subtribe		
Alopecurus		aequalis	Shortawn foxtail
		geniculatus	Marsh foxtail
		carolinanus	Tufted foxtail
PACMAD Clade			
Aristidoideae	subfamily		
Aristideae	tribe		
Aristida		purpurea, longiseta	Red Threeawn
Panicoideae	subfamily		
Paniceae	tribe		
Dichantheliinae	subtribe		
Dichanthelium C_3		leibergii	Leiberg's panicgrass
		oligosanthes, scribnerianum	Scribner's panicgrass
		wilcoxianum	Wilcox's panicgrass
Boivinellinae	subtribe		
Echinochloa		muricata	American barnyardgrass
Panicinae	subtribe		
Panicum		capillare	Witchgrass
		virgatum	Switchgrass
Cenchrinae	subtribe		
Cenchrus		longispinus	Mat sandbur
Andropogoneae C_4	tribe		
Saccharinae	subtribe		
Sorghastrum		nutans	Indiangrass
Andropogoninae	subtribe		
Andropogon		gerardii	Big bluestem
		hallii	Sand bluestem
Schizachyrium		scoparium	Little bluestem
Arundinoideae C_3	subfamily		
Molinieae	tribe		
Moliniinae	subtribe		
Phragmites		australis	Common reed
Danthonioideae C_3	subfamily		
Danthonieae	tribe		
Danthonia		spicata	Poverty oatgrass
		intermedia	Timber oatgrass
		parryi	Parry's oatgrass

Table 2 cont. Northern Plains Native Grasses.

Chloridoideae		subfamily		
Eragrostideae	C_4	tribe		
Eragrostidinae		subtribe		
Eragrostis			hypnoides	Creeping lovegrass
			pectinacea	Tufted lovegrass
			spectabilis	Purple lovegrass
Zoysieae	C_4	tribe		
Sporobolinae		subtribe		
Sporobolus			neglectus	Small dropseed
			compositus	Tall dropseed
			airoides	Alkali dropseed
			cryptandrus	Sand dropseed
			heterolepis	Prairie dropseed
Calamovilfa			longifolia	Prairie sandreed
Spartina			gracilis	Alkali cordgrass
			pectinata	Prairie cordgrass
Cynodonteae	C_4	tribe		
Boutelouinae		subtribe		
Bouteloua			curtipendula	Sideoats grama
			gracilis	Blue grama
			hirsuta	Hairy grama
Buchloe			dactyloides	Buffalograss
Monanthochloinae		subtribe		
Distichlis			spicata	Inland saltgrass
Muhlenbergiinae		subtribe		
Muhlenbergia			racemosa	Green muhly
			glomerata	Spike muhly
			cuspidata	Plains muhly
			richardsonis	Mat muhly
			asperifolia	Scratchgrass
			pungens	Sandhill muhly
Redfieldia			flexuosa	Blowout grass
Schedonnardus			paniculatus	Tumble grass
Scleropogoninae		subtribe		
Munroa			squarrosa	False buffalograss

Table 3. Northern Plains Domesticated Grasses.

BOP clade				
Pooideae	C_3	subfamily		
Bromeae		tribe		
Bromus			inermis	Smooth brome
			riparius	Meadow brome
Triticeae		tribe		
Agropyron			cristatum	Crested wheatgrass
			fragile	Siberian wheatgrass
			desertorum	Desert wheatgrass
Leymus			angustus	Altai wildrye
			cinereus	Great Basin wildrye
Psathyrostachys			juncea	Russian wildrye
Thinopyrum			intermedium, intermedium	Intermediate wheatgrass
			intermedium, barbulatum	Pubescent wheatgrass
			ponticum	Tall wheatgrass
Poeae		tribe		
Phalaridinae		subtribe		
Phalaris			canariensis	Annual canarygrass
Loliinae		subtribe		
Festuca			rubra	Red fescue
			trachyphylla	Hard fescue
Lolium			perenne	Perennial ryegrass
			multiflorum	Italian ryegrass
Schedonorus			pratensis	Meadow fescue
Dactylidinae		subtribe		
Dactylis			glomerata	Orchardgrass
Poinae		subtribe		
Poa			pratensis	Kentucky bluegrass
Phleinae		subtribe		
Phleum			pratensis	Timothy
Alopecurinae		subtribe		
Alopecurus			arundinaceus	Creeping meadow foxtail

Table 4. Northern Plains Introduced Weedy Grasses

BOP Clade				
Pooideae	C_3	subfamily		
Bromeae		tribe		
Bromus			tectorum	Cheatgrass
			japonicus	Japanese brome
			squarrosus	Squarrose brome
Triticeae		tribe		
Elymus			repens	Quackgrass
Poeae		tribe		
Aveninae		subtribe		
Avena			fatua	Wild oats
Loliinae		subtribe		
Lolium			persicum	Persian darnel
Coleanthinae		subtribe		
Puccinellia			distans	European alkali grass
Poinae		subtribe		
Poa			annua	Annual bluegrass
			bulbosa	Bulbous bluegrass
Alopecurinae		subtribe		
Alopecurus			pratensis	Meadow foxtail
PACMAD clade				
Panicoideae		subfamily		
Paniceae		tribe		
Anthephorinae		subtribe		
Digitaria			ischaemum	Smooth crabgrass
Boivineliinae		subtribe		
Echinochloa			crus-galli	Barnyardgrass
Cenchrinae		subtribe		
Setaria			viridus	Green foxtail
			verticillate	Bristly foxtail
			pumila	Yellow foxtail
			italica	Foxtail millet
Chloridoideae		subfamily		
Eragrostideae		tribe		
Eragrostidinae		subtribe		
Eragrostis			cilianensis	Stinkgrass

Table 5. Northern Plains Cereal Grasses.

BOP clade				
Pooideae	C_3	subfamily		
Triticeae		tribe		
Hordeum			valgaria	Barley
Secale			cereale	Rye
Triticum			dicoccum	Emmer wheat
			durum	Durum wheat
			aestivum	Wheat
			spelta	Spelt
Poeae		tribe		
Aveninae		subtribe		
Avena			sativa	Oats
PACMAD clade				
Panicoideae		subfamily		
Andropogoneae	C_4	tribe		
Tripsacinae		subtribe		
Zea			mays	Corn

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Range Plant Growth Related to Climatic Factors of Western North Dakota, 1982-2022.

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Introduction

Successful long-term management of grassland ecosystems requires knowledge of the relationships of range plant growth and regional climatic factors. Range plant growth and development are regulated by climatic conditions. Length of daylight, temperature, precipitation, and water deficiency are the most important climatic factors that affect rangeland plants (Manske 2011).

Light

Light is necessary for plant growth because light is the source of energy for photosynthesis. Plant growth is affected by variations in quality, intensity, and duration of light. The quality of light (wavelength) varies from region to region, but the quality of sunlight does not vary enough in a given region to have an important differential effect on the rate of photosynthesis. However, the intensity (measurable energy) and duration (length of day) of sunlight change with the seasons and affect plant growth. Light intensity varies greatly with the season and with the time of day because of changes in the angle of incidence of the sun's rays and the distance light travels through the atmosphere. Light intensity also varies with the amount of humidity and cloud cover because atmospheric moisture absorbs and scatters light rays.

The greatest variation in intensity of light received by range plants results from the various degrees of shading from other plants. Most range plants require full sunlight or very high levels of sunlight for best growth. Shading from other plants reduces the intensity of light that reaches the lower leaves of an individual plant. Grass leaves grown under shaded conditions become longer but narrower, thinner (Langer 1972, Weier et al. 1974), and lower in weight than leaves in sunlight (Langer 1972). Shaded leaves have a reduced rate of photosynthesis, which decreases the carbohydrate supply and causes a reduction in growth rate of leaves and roots (Langer 1972). Shading increases the rate of senescence in lower, older leaves. Accumulation of standing dead leaves ties up carbon and nitrogen. Decomposition of leaf material through microbial activity can take place only after the leaves have made contact with the soil. Standing dead material not in contact with the soil does not decompose but breaks down slowly as a result of leaching and weathering. Under ungrazed treatments the dead leaves remain standing for several years, slowing nutrient cycles, restricting nutrient supply, and reducing soil microorganism activity in the top 12 inches of soil. Standing dead leaves shade early leaf growth in spring and therefore slow the rate of growth and reduce leaf area. Long-term effects of shading, such as that occurring in ungrazed grasslands and under shrubs or leafy spurge, reduce the native grass species composition and increase composition of shade-tolerant or shade-adapted replacement species like smooth bromegrass and Kentucky bluegrass.

Day-length period (photoperiod) is one of the most dependable cues by which plants time their activities in temperate zones. Day-length period for a given date and locality remains the same from year to year. Changes in the photoperiod function as the timer or trigger that activates or stops physiological processes bringing about growth and flowering of plants and that starts the process of hardening for resistance to low temperatures in fall and winter. Sensory receptors, specially pigmented areas in the buds or leaves of a plant, detect day length and night length and can activate one or more hormone and enzyme systems that bring about physiological responses (Odum 1971, Daubenmire 1974, Barbour et al. 1987).

The phenological development of rangeland plants is triggered by changes in the length of daylight. Vegetative growth is triggered by photoperiod and temperature (Langer 1972, Dahl 1995), and reproductive initiation is triggered primarily by photoperiod (Roberts 1939, Langer 1972, Leopold and Kriedemann 1975, Dahl 1995) but can be slightly modified by temperature and precipitation (McMillan 1957, Leopold and Kriedemann

1975, Dahl and Hyder 1977, Dahl 1995). Some plants are long-day plants and others are short-day plants. Long-day plants reach the flower phenological stage after exposure to a critical photoperiod and during the period of increasing daylight between mid April and mid June. Generally, most cool-season plants with the C3 photosynthetic pathway are long-day plants and reach flower phenophase before 21 June. Short-day plants are induced into flowering by day lengths that are shorter than a critical length and that occur during the period of decreasing day length after mid June. Short-day plants are technically responding to the increase in the length of the night period rather than to the decrease in the day length (Weier et al. 1974, Leopold and Kriedemann 1975). Generally, most warm-season plants with the C4 photosynthetic pathway are short-day plants and reach flower phenophase after 21 June.

The annual pattern in the change in daylight duration follows the seasons and is the same every year for each region. Grassland management strategies based on phenological growth stages of the major grasses can be planned by calendar date after the relationships between phenological stage of growth of the major grasses and time of season have been determined for a region.

Temperature

Temperature is an approximate measurement of the heat energy available from solar radiation. At both low and high levels temperature limits plant growth. Most plant biological activity and growth occur within only a narrow range of temperatures, between 32° F (0 C) and 122° F (50° C) (Coyne et al. 1995). Low temperatures limit biological reactions because water becomes unavailable when it is frozen and because levels of available energy are inadequate. However, respiration and photosynthesis can continue slowly at temperatures well below 32° F if plants are "hardened". High temperatures limit biological reactions because the complex structures of proteins are disrupted or denatured.

Periods with temperatures within the range for optimum plant growth are very limited in western North Dakota. The frost-free period is the number of days between the last day with minimum temperatures below 32° F (0° C) in the spring and the first day with minimum temperatures below 32° F (0° C) in the fall and is approximately the length of the growing season for annually seeded plants. The frost-free period for western North Dakota generally lasts for 120 to 130 days, from mid to late May to mid to late September (Ramirez 1972). Perennial grassland plants are capable of growing for periods longer than the frost-free period, but to continue active growth they require temperatures above the level that freezes water in plant tissue and soil. Many perennial plants begin active growth more than 30 days before the last frost in spring and continue growth after the first frost in fall. The growing season for perennial plants is considered to be between the first 5 consecutive days in spring and the last 5 consecutive days in fall with mean daily temperature at or above 32° F (0° C). In western North Dakota the growing season for perennial plants is considered to be generally from mid April through mid October. Low air temperature during the early and late portions of the growing season greatly limits plant growth rate. High temperatures, high evaporation rates, drying winds, and low precipitation levels after mid summer also limit plant growth.

Different plant species have different optimum temperature ranges. Cool-season plants, which are C_3 photosynthetic pathway plants, have an optimum temperature range of 50° to 77°F (10° to 25°C). Warm-season plants, which are C_4 photosynthetic pathway plants, have an optimum temperature range of 86° to 105°F (30° to 40°C) (Coyne et al. 1995).

Water (Precipitation)

Water, an integral part of living systems, is ecologically important because it is a major force in shaping climatic patterns and biochemically important because it is a necessary component in physiological processes (Brown 1995). Water is the principal constituent of plant cells, usually composing over 80% of the fresh weight of herbaceous plants. Water is the primary solvent in physiological processes by which gases, minerals, and other materials enter plant cells and by which these materials are translocated to various parts of the plant. Water is the substance in which processes such as photosynthesis and other biochemical reactions occur and a structural component of proteins and nucleic acids. Water is also essential for the maintenance of the rigidity of plant tissue and for cell enlargement and growth in plants (Brown 1977, Brown 1995).

Water Deficiency

Temperature and precipitation act together to affect the physiological and ecological status of range plants. The biological situation of a plant at any time is determined by the balance between rainfall and potential evapotranspiration. The higher the temperature, the greater the rate of evapotranspiration and the greater the need for rainfall to maintain homeostasis. When the amount of rainfall received is less than potential evapotranspiration demand, a water deficiency exists. Evapotranspiration demand is greater than precipitation in the mixed grass and short grass prairie regions. The tall grass prairie region has greater precipitation than evapotranspiration demand. Under water deficiency conditions, plants are unable to absorb adequate water to match the transpiration rate, and plant water stress develops. Range plants have mechanisms that help reduce the damage from water stress, but some degree of reduction in herbage production occurs.

Plant water stress limits growth. Plant water stress develops in plant tissue when the rate of water loss through transpiration exceeds the rate of water absorption by the roots. Water stress can vary in degree from a small decrease in water potential, as in midday wilting on warm, clear days, to the lethal limit of desiccation (Brown 1995).

Early stages of water stress slow shoot and leaf growth. Leaves show signs of wilting, folding, and discoloration. Tillering and new shoot development decrease. Root production may increase. Senescence of older leaves accelerates. Rates of cell wall formation, cell division, and protein synthesis decrease. As water stress increases, enzyme activity declines and the formation of necessary compounds slows or ceases. The stomata begin to close; this reaction results in decreased rates of transpiration and photosynthesis. Rates of respiration and translocation decrease substantially with increases in water stress. When water stress becomes severe, most functions nearly or completely cease and serious damage occurs. Leaf and root mortality induced by water stress progresses from the tips to the crown. The rate of leaf and root mortality increases with increasing stress. Water stress can increase to a point that is lethal, resulting in damage from which the plant cannot recover. Plant death occurs when meristems become so dehydrated that cells cannot maintain cell turgidity and biochemical activity (Brown 1995).

Study Area

The study area is the region around the Dickinson Research Extension Center (DREC) Ranch, Dunn County, western North Dakota, USA. Native vegetation in western North Dakota is the Wheatgrass-Needlegrass Type (Barker and Whitman 1988, Shiflet 1994) of the mixed grass prairie.

The climate of western North Dakota has changed several times during geologic history (Manske 1999). The most recent climate change occurred about 5,000 years ago, to conditions like those of the present, with cycles of wet and dry periods. The wet periods have been cool and humid, with greater amounts of precipitation. A brief wet period occurred around 4,500 years ago. Relatively long periods of wet conditions occurred in the periods between 2,500 and 1,800 years ago and between 1,000 and 700 years ago. Recent short wet periods occurred in the years from 1905 to 1916, 1939 to 1947, and 1962 to 1978. The dry periods have been warmer, with reduced precipitation and recurrent summer droughts. A widespread, long drought period occurred between the years 1270 and 1299, an extremely severe drought occurred from 1863 through 1875, and other more recent drought periods occurred from 1895 to 1902, 1933 to 1938, and 1987 to 1992. The current climatic pattern in western North Dakota is cyclical between wet and dry periods and has existed for the past 5,000 years (Bluemle 1977, Bluemle 1991, Manske 1994a).

Procedures

Daylight duration data for the Dickinson location of latitude 46 48' N, longitude 102 48' W, were tabulated from daily sunrise and sunset time tables compiled by the National Weather Service, Bismarck, North Dakota.

Temperature and precipitation data were taken from historical climatological data collected at the Dickinson Research Extension Center Ranch, latitude 47° 14' N, longitude 102° 50' W, Dunn County, near Manning, North Dakota, 1982-2022.

A technique reported by Emberger et al. (1963) was used to develop water deficiency months data from historical temperature and precipitation data. The water deficiency months data were used to identify months with conditions unfavorable for plant growth. This method plots mean monthly temperature (° C) and monthly precipitation (mm) on the same axis, with the scale of the precipitation data at twice that of the temperature data. The temperature and precipitation data are plotted against an axis of time. The resulting ombrothermic diagram shows general monthly trends and identifies months with conditions unfavorable for plant growth. Water deficiency conditions exist during months when the precipitation data bar drops below the temperature data curve and plants are under water stress. Plants are under temperature stress when the temperature curve drops below the freezing mark (0° C).

Results and Discussion

Light

The tilt of the earth's axis in conjunction with the earth's annual revolution around the sun produces the seasons and changes the length of daylight in temperate zones. Dickinson (figure 1) has nearly uniform day and night lengths (12 hours) during only a few days, near the vernal and autumnal equinoxes, 20 March and 22 September, respectively, when the sun's apparent path crosses the equator as the sun travels north or south, respectively. The shortest day length (8 hours, 23 minutes) occurs at winter solstice, 21 December, when the sun's apparent path is farthest south of the equator. The longest day length (15 hours, 52 minutes) occurs at summer solstice, 21 June, when the sun's apparent path is farthest north of the equator. The length of daylight during the growing season (mid April to mid October) oscillates from about 13 hours in mid April, increasing to nearly 16 hours in mid June, then decreasing to around 11 hours in mid October (figure 1).

Temperature

The DREC Ranch in western North Dakota experiences severe, windy, dry winters with little snow accumulation. The springs are relatively moist in most years, and the summers are often droughty but are interrupted periodically by thunderstorms. The long-term (41-year) mean annual temperature is 42.2° F (5.7° C) (table 1). January is the coldest month, with a mean temperature of 15.0° F (-9.5° C). July and August are the warmest months, with mean temperatures of 69.7° F (20.9° C) and 68.5 F (20.3° C), respectively. Months with mean monthly temperatures below 32.0° F (0.0° C) are too cold for active plant growth. Low temperatures define the growing season for perennial plants, which is generally from mid April to mid October (6.0 months, 183 days). During the other 6 months each year, plants in western North Dakota cannot conduct active plant growth. Soils are frozen to a depth of 3 to 5 feet for a period of 4 months (121 days) (Larson et al. 1968). The early and late portions of the 6-month growing season have very limited plant activity and growth. The period of active plant growth is generally 5.5 months (168 days).

Western North Dakota has large annual and diurnal changes in monthly and daily air temperatures. The range of seasonal variation of average monthly temperatures between the coldest and warmest months is 55.0° F (30.5 C), and temperature extremes in western North Dakota have a range of 161.0° F (89.4° C), from the highest recorded summer temperature of 114.0° F (45.6° C) to the lowest recorded winter temperature of -47.0° F (-43.9° C). The diurnal temperature change is the difference between the minimum and maximum temperatures observed over a 24-hour period. The average diurnal temperature change during winter is 22.0° F (12.2° C), and the change during summer is 30.0° F (16.7° C). The average annual diurnal change in temperature is 26.0° F (14.4° C) (Jensen 1972). The large diurnal change in temperature during the growing season, which has warm days and cool nights, is beneficial for plant growth because of the effect on the photosynthetic process and respiration rates (Leopold and Kriedemann 1975).

Precipitation

The long-term (41-year) annual precipitation for the Dickinson Research Extension Center Ranch in western North Dakota is 17.10 inches (434.34 mm). The long-term mean monthly precipitation is shown in table 1. The growing-season precipitation (April to October) is 14.46 inches (366.88 mm) and is 84.56% of annual precipitation. June has the greatest monthly precipitation, at 3.07 inches (78.02 mm).

The seasonal distribution of precipitation (table 2) shows the greatest amount of precipitation occurring in the spring (7.18 inches, 41.99%) and the least amount occurring in winter (1.60 inches, 9.36%). Total precipitation received for the 5-month period of November through March averages less than 2.65 inches (15.50%). The precipitation received in the 3-month period of May, June, and July accounts for 47.19% of the annual precipitation (8.07 inches).

The annual and growing-season precipitation levels and percent of the long-term mean for 41 years (1982 to 2022) are shown in table 3. Drought conditions exist when precipitation amounts for a month, growing season, or annual period are 75% or less of the long-term mean. Wet conditions exist when precipitation amounts for a month, growing season, or annual period are 125% or greater of the long-term mean. Normal conditions exist when precipitation amounts for a month, growing season, or annual period are greater than 75% and less than 125% of the long-term mean. Between 1982-2022, 5 drought years (12.20%) (table 4) and 7 wet years (17.07%) (table 5) occurred. Annual precipitation amounts at normal levels, occurred during 29 years (70.73%) (table 3). The area experienced 5 drought growing seasons (12.20%) (table 6) and 7 wet growing seasons (17.07%) (table 7). Growing-season precipitation amounts at normal levels occurred during 29 years (70.73%) (table 3). The 6-year period (1987-1992) was a long period with near-drought conditions. The average annual precipitation for these 6 years was 12.12 inches (307.89 mm), only 70.88% of the long-term mean. The average growing-season precipitation for the 6-year period was 9.97 inches (253.11 mm), only 68.95% of the long-term mean (table 3).

Water Deficiency

Monthly periods with water deficiency conditions are identified on the annual ombrothermic graphs when the precipitation data bar drops below the temperature data curve. On the ombrothermic graphs, periods during which plants are under low-temperature stress are indicated when the temperature curve drops below the freezing mark of 0.0° C (32.0° F). The long-term ombrothermic graph for the DREC Ranch (figure 2) shows that near water deficiency conditions exist for August, September, and October. This finding indicates that range plants generally may have a difficult time growing and accumulating herbage biomass during these 3 months. Favorable water relations occur during May, June, and July, a condition indicating that range plants should be able to grow and accumulate herbage biomass during these 3 months.

The ombrothermic relationships for the Dickinson Research Extension Center Ranch in western North Dakota are shown for each month in table 8. The 41-year period (1982 to 2022) had a total of 246 months during the growing season. Of these growing-season months, 75.0 months had water deficiency conditions, which indicates that range plants were under water stress during 30.5% of the growing-season months (tables 8 and 9): this amounts to an average of 2.0 months during every 6.0-month growing season range plants have been limited in growth and herbage biomass accumulation because of water stress. The converse indicates that only 4.0 months of an average year have conditions in which plants can grow without water stress.

Most growing seasons have months with water deficiency conditions. In only 5 of the 41 years (table 8) did water deficiency conditions not occur in any of the six growing-season months. In each growing-season month of 1982, 2013, 2015, 2016, and 2019, the amounts and distribution of the precipitation were adequate to prevent water stress in plants. Twenty years (48.78%) had water deficiency for 0.5 to 2.0 months during the growing season. Fifteen years (36.59%) had water deficiency conditions for 2.5 to 4.0 months during the growing season. One year (2.44%), 1988, had water deficiency conditions for 5.0 months during the growing season. None of the 41 years had water deficiency conditions for all 6.0 months of the growing season (table 8). The 6-year period (1987-1992) was a long period with low precipitation; during this period, water deficiency conditions existed for an average of 3.1 months during each growing season, which amounts to 51.33% of this period's growing-season months (table 8).

May, June, and July are the 3 most important precipitation months and therefore constitute the primary period of production for range plant communities. May and June are the 2 most important months for dependable precipitation. Only 4 (9.76%) of the 41 years had water deficiency conditions during May, and 6 years (14.63%) had water deficiency conditions during June. One year (2017) had water deficiency conditions in both May and June. Fourteen (34.15%) of the 41 years had water deficiency conditions in July (table 9). Only one year (2017) has had water deficiency conditions during May, June, and July (table 8b).

Most of the growth in range plants occurs in May, June, and July (Goetz 1963, Manske 1994b). Peak aboveground herbage biomass production usually occurs during the last 10 days of July, a period that coincides with the time when plants have attained 100% of their growth in height (Manske 1994b). Range grass growth coincides with the 3- month period of May, June, and July, when 47.19% of the annual precipitation occurs.

August, September, and October are not dependable for positive water relations. August and September had water deficiency conditions in 46.34% and 53.66% of the years, respectively, and October had water deficiency conditions in 34.15% of the years (table 9). Visual observations of range grasses with wilted, senescent leaves in August indicate that most plants experience some level of water stress when conditions approach those of water deficiency. August, September, and/or October had water deficiency conditions during 82.93% of the growing seasons in the previous 41 years (table 8). These 3 months make up 42% of the growing season, and they had water deficiency conditions on the average of 45% of the time (table 9). The water relations in August, September, and October limit range plant growth and herbage biomass accumulation.

Over the last 41 years, drought years occurred 12.2% of the time. Drought growing seasons occurred 12.2% of the time. Water deficiency months occurred 30.5% of the time. Water deficiency occurred in May and June 9.8% and 14.6% of the time, respectively. July had water deficiency conditions 34.1% of the time. August, September, and October had water deficiency conditions more than 45% of the time. Water deficiency periods lasting for a month place plants under water stress severe enough to reduce herbage biomass production. These levels of water stress are a major factor limiting the quantity and quality of plant growth in western North Dakota and can limit livestock production if not considered during the development and implementation of long-term grazing management strategies.

The ombrothermic procedure to identify growing season months with water deficiency treats each month as an independent event. Precipitation during the other months of the year may buffer or enhance the degree of water stress experienced by perennial plants during water deficiency months. The impact of precipitation during other months on the months with water deficiency can be evaluated from annual running total precipitation data (table 10). Water deficiency conditions occurred during 2.0 months in 2022 (table 10).

Conclusion

The vegetation in a region is a result of the total effect of the long-term climatic factors for that region. Ecologically, the most important climatic factors that affect rangeland plant growth are light, temperature, water (precipitation), and water deficiency.

Light is the most important ecological factor because it is necessary for photosynthesis. Changes in time of year and time of day coincide with changes in the angle of incidence of the sun's rays; these changes cause variations in light intensity. Daylight duration oscillation for each region is the same every year and changes with the seasons. Shading of sunlight by cloud cover and from other plants affects plant growth. Day-length period is important to plant growth because it functions as a trigger to physiological processes. Most cool-season plants reach flower phenophase between mid May and mid June. Most warm-season plants flower between mid June and mid September.

Plant growth is limited by both low and high temperatures and occurs within only a narrow range of temperatures, between 32° and 122° F. Perennial plants have a 6-month growing season, between mid April and mid October. Diurnal temperature fluctuations of warm days and cool nights are beneficial for plant growth. Cool-season plants have lower optimum temperatures for photosynthesis than do warm-season plants, and cool-season plants do not use water as efficiently as do warm-season plants. Temperature affects evaporation rates, which has a dynamic effect on the annual ratios of cool-season to warm-season plants in the plant communities. A mixture of cool- and warm-season plants is highly desirable because the grass species in a mixture of cool- and warm-season species have a wide range of different optimum temperatures and the herbage biomass production is more stable over wide variations in seasonal temperatures.

Water is essential for living systems. Average annual precipitation received at the DREC Ranch is 17.1 inches, with 84.6% occurring during the growing season and 47.2% occurring in May, June, and July. Plant water stress occurs when the rate of water loss through transpiration exceeds the rate of replacement by absorption. Years with drought conditions have occurred 12.2% of the time during the past 41 years. Growing seasons with drought conditions have occurred 12.2% of the time.

Water deficiencies exist when the amount of rainfall received is less than evapotranspiration demand. Temperature and precipitation data can be used in ombrothermic graphs to identify monthly periods with water deficiencies. During the past 41 years, 30.5% of the growing-season months had water deficiency conditions that placed range plants under water stress: range plants were limited in growth and herbage biomass accumulation for an average of 2.0 months during every 6-month growing season. May, June, and July had water deficiency conditions 9.8%, 14.6%, and 34.1% of the time, respectively. August, September, and October had water deficiency conditions 46.3%, 53.7% and 34.1% of the time, respectively. One month with water deficiency conditions causes plants to experience water stress severe enough to reduce herbage biomass production.

Most of the growth in range grasses occurs in May, June, and July. In western North Dakota, 100% of range grass leaf growth in height and 86% to 100% of range flower stalk growth in height are completed by 30 July. Peak aboveground herbage biomass production usually occurs during the last 10 days of July, a period that coincides with the time during which plants are attaining 100% of their height. Most range grass growth occurs during the 3-month period of May, June, and July, when 47.2% of the annual precipitation occurs.

Grassland management should be based on phenological growth stages of the major grasses and can be planned by calendar date. Management strategies for a region should consider the climatic factors that affect and limit range plant growth.

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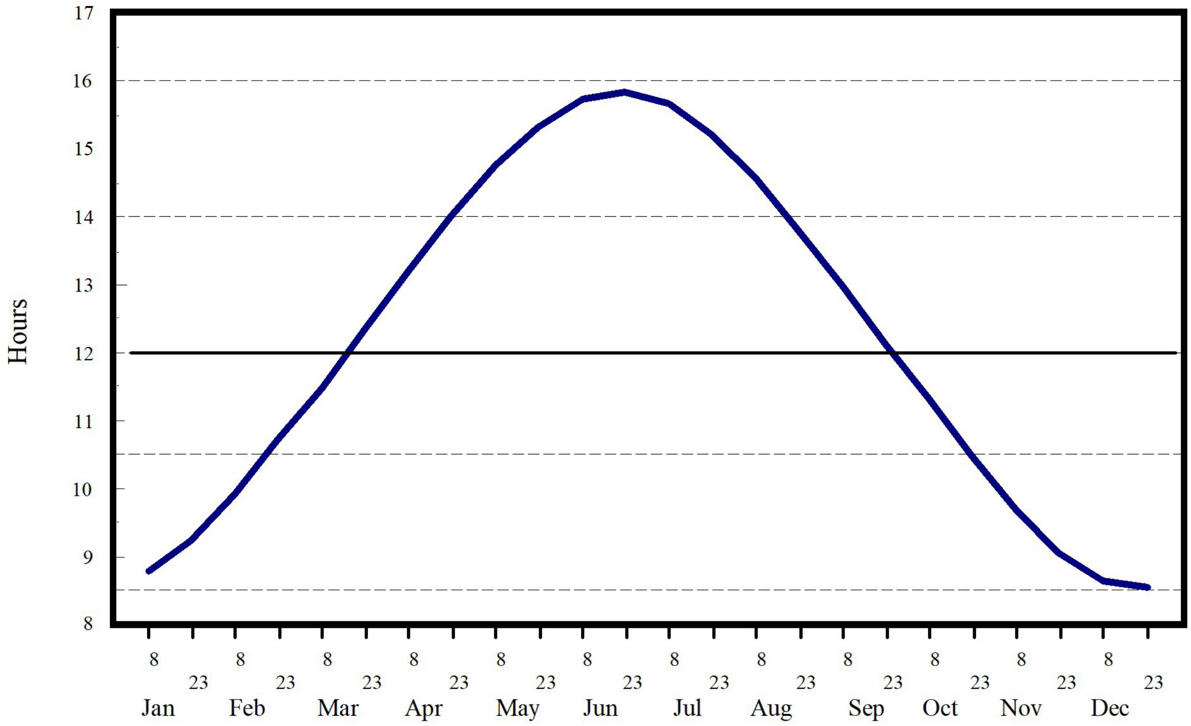

Figure. 1. Annual pattern of daylight duration at Dickinson, North Dakota.

Table 1. Long-term mean monthly temperature and monthly precipitation, 1982-2022.

	°F	**°C**	**in.**	**mm**
Jan	14.91	-9.49	0.43	10.86
Feb	18.05	-7.75	0.44	11.16
Mar	29.44	-1.42	0.73	18.62
Apr	41.26	5.14	1.45	36.72
May	53.46	11.92	2.66	67.46
Jun	63.24	17.36	3.07	78.02
Jul	69.71	20.95	2.34	59.44
Aug	68.45	20.25	1.96	49.68
Sep	56.50	14.04	1.63	41.35
Oct	43.77	6.54	1.35	34.21
Nov	29.16	-1.58	0.56	14.29
Dec	17.95	-7.80	0.49	12.53
	MEAN		**TOTAL**	
	42.16	**5.68**	**17.10**	**434.34**

Table 2. Seasonal precipitation distribution, 1982-2022.

Season	**in.**	**%**
Winter (Jan, Feb, Mar)	1.60	9.36
Spring (Apr, May, Jun)	7.18	41.99
Summer (Jul, Aug, Sep)	5.93	34.68
Fall (Oct, Nov, Dec)	2.40	14.04
TOTAL	**17.10**	

Table 3. Precipitation in inches and percent of long-term mean for perennial plant growing season months, 1982-2022.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2022	1.45	2.66	3.07	2.34	1.96	1.63	1.35	14.46	17.10
1982	1.37	2.69	4.30	3.54	1.75	1.69	5.75	21.09	25.31
% of LTM	94.48	101.13	140.07	151.28	89.29	103.68	425.93	146.01	148.01
1983	0.21	1.53	3.26	2.56	4.45	0.86	0.72	13.59	15.55
% of LTM	14.48	57.52	106.19	109.40	227.04	52.76	53.33	94.09	90.94
1984	2.87	0.00	5.30	0.11	1.92	0.53	0.96	11.69	12.88
% of LTM	197.93	0.00	172.64	4.70	97.96	32.52	71.11	80.93	75.32
1985	1.24	3.25	1.58	1.07	1.84	1.69	2.13	12.80	15.13
% of LTM	85.52	122.18	51.47	45.73	93.88	103.68	157.78	88.62	88.48
1986	3.13	3.68	2.58	3.04	0.46	5.29	0.18	18.36	22.96
% of LTM	215.86	138.35	84.04	129.91	23.47	324.54	13.33	127.11	134.28
1987	0.10	1.38	1.15	5.39	2.65	0.78	0.08	11.53	14.13
% of LTM	6.90	51.88	37.46	230.34	135.20	47.85	5.93	79.82	82.63
1988	0.00	1.85	1.70	0.88	0.03	0.73	0.11	5.30	9.03
% of LTM	0.00	69.55	55.37	37.61	1.53	44.79	8.15	36.69	52.81
1989	2.92	1.73	1.63	1.30	1.36	0.70	0.96	10.60	13.07
% of LTM	201.38	65.04	53.09	55.56	69.39	42.94	71.11	73.39	76.43
1990	2.03	2.39	3.75	1.13	0.31	0.68	0.85	11.14	11.97
% of LTM	140.00	89.85	122.15	48.29	15.82	41.72	62.96	77.12	70.00
1991	1.97	1.16	3.95	1.43	0.55	2.17	1.31	12.54	13.30
% of LTM	135.86	43.61	128.66	61.11	28.06	133.13	97.04	86.82	77.78
1992	0.81	0.68	1.59	2.70	2.02	0.72	0.16	8.68	11.23
% of LTM	55.86	25.56	51.79	115.38	103.06	44.17	11.85	60.09	65.67
1993	1.41	1.71	4.57	5.10	1.24	0.18	0.05	14.26	17.36
% of LTM	97.24	64.29	148.86	217.95	63.27	11.04	3.70	98.73	101.52
1994	0.86	1.46	4.51	1.07	0.31	1.08	4.58	13.87	16.14
% of LTM	59.31	54.89	146.91	45.73	15.82	66.26	339.26	96.03	94.39

Table 3 (cont). Precipitation in inches and percent of long-term mean for perennial plant growing season months, 1982-2022.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2022	1.45	2.66	3.07	2.34	1.96	1.63	1.35	14.46	17.10
1995	1.01	4.32	0.68	4.62	3.16	0.00	0.67	14.46	16.24
% of LTM	69.66	162.41	22.15	197.44	161.22	0.00	49.63	100.11	94.97
1996	0.14	3.07	1.86	2.55	1.72	2.51	0.09	11.94	15.97
% of LTM	9.66	115.41	60.59	108.97	87.76	153.99	6.67	82.66	93.39
1997	2.89	0.95	5.02	5.41	0.76	1.75	0.78	17.56	18.61
% of LTM	199.31	35.71	163.52	231.20	38.78	107.36	57.78	121.57	108.83
1998	0.40	1.51	5.98	2.11	4.60	0.71	4.38	19.69	22.42
% of LTM	27.59	56.77	194.79	90.17	234.69	43.56	324.44	136.32	131.11
1999	1.10	4.93	1.59	1.80	2.70	2.40	0.00	14.52	15.56
% of LTM	75.86	185.34	51.79	76.92	137.76	147.24	0.00	100.53	90.99
2000	1.26	1.90	3.77	2.77	2.74	1.09	1.46	14.99	20.23
% of LTM	86.90	71.43	122.80	118.38	139.80	66.87	108.15	103.78	118.30
2001	2.70	0.53	6.36	4.87	0.00	1.94	0.00	16.40	18.03
% of LTM	186.21	19.92	207.17	208.12	0.00	119.02	0.00	113.54	105.44
2002	1.14	2.18	5.40	4.27	4.24	0.74	0.88	18.85	21.88
% of LTM	78.62	81.95	175.90	182.48	216.33	45.40	65.19	130.50	127.95
2003	1.30	4.34	1.42	2.03	0.82	2.37	0.74	13.02	19.12
% of LTM	89.66	163.16	46.25	86.75	41.84	145.40	54.81	90.14	111.81
2004	0.89	1.31	1.65	2.30	0.93	2.57	3.10	12.75	16.51
% of LTM	61.38	49.25	53.75	98.29	47.45	157.67	229.63	88.27	96.55
2005	0.96	6.01	6.05	0.60	1.52	0.50	1.96	17.60	21.51
% of LTM	66.21	225.94	197.07	25.64	77.55	30.67	145.19	121.85	125.79
2006	2.78	2.82	2.13	0.96	2.87	1.42	2.01	14.99	17.70
% of LTM	191.72	106.02	69.38	41.03	146.43	87.12	148.89	103.78	103.51
2007	1.58	4.64	1.80	1.05	0.78	0.76	0.26	10.87	13.94
% of LTM	108.97	174.44	58.63	44.87	39.80	46.63	19.26	75.26	81.52

Table 3 (cont). Precipitation in inches and percent of long-term mean for perennial plant growing season months, 1982-2022.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2022	1.45	2.66	3.07	2.34	1.96	1.63	1.35	14.46	17.10
2008	0.61	2.79	4.02	1.06	1.02	1.04	1.68	12.22	14.88
% of LTM	42.07	104.89	130.94	45.30	52.04	63.80	124.44	84.60	87.02
2009	1.49	2.47	3.84	3.24	0.95	1.15	1.95	15.09	17.89
% of LTM	102.76	92.86	125.08	138.46	48.47	70.55	144.44	104.47	104.62
2010	1.43	3.70	3.50	1.94	1.39	4.09	0.13	16.18	19.03
% of LTM	98.62	139.10	114.01	82.91	70.92	250.92	9.63	112.02	111.29
2011	1.66	6.87	2.15	2.33	2.70	1.76	0.44	17.91	21.28
% of LTM	114.48	258.27	70.03	99.57	137.76	107.98	32.59	123.99	124.44
2012	2.38	1.58	4.31	1.98	0.82	0.21	2.35	13.63	15.46
% of LTM	164.14	59.40	140.39	84.62	41.84	12.88	174.07	94.36	90.41
2013	1.05	7.55	2.23	2.13	2.81	2.44	3.35	21.56	23.22
% of LTM	72.41	283.83	72.64	91.03	143.37	149.69	248.15	149.26	135.79
2014	1.41	3.73	3.38	0.37	8.84	1.03	0.59	19.35	21.11
% of LTM	97.24	140.23	110.10	15.81	451.02	63.19	43.70	133.96	123.45
2015	0.60	1.65	4.68	2.87	1.69	1.35	1.96	14.80	17.01
% of LTM	41.38	62.03	152.44	122.65	86.22	82.82	145.19	102.46	99.47
2016	3.44	2.26	1.96	3.61	1.86	2.66	1.80	17.59	19.70
% of LTM	237.24	84.96	63.84	154.27	94.90	180.95	133.33	121.78	115.20
2017	1.30	0.84	1.27	0.72	2.67	2.28	0.08	9.16	10.55
% of LTM	89.66	31.58	41.37	30.77	136.22	139.88	5.93	63.42	61.70
2018	0.48	1.22	4.23	2.01	0.55	1.84	0.66	10.99	14.39
% of LTM	33.10	45.86	137.79	85.90	28.06	112.88	48.89	76.09	84.15
2019	1.35	2.52	2.60	1.61	4.70	9.10	1.26	23.14	25.88
% of LTM	93.10	94.74	84.69	68.80	239.80	558.28	93.33	160.20	151.34
2020	0.59	1.45	1.10	2.67	2.56	0.86	0.26	9.49	11.01
% of LTM	40.69	54.51	35.83	114.10	130.61	52.76	19.26	65.70	64.39

Table 3 (cont). Precipitation in inches and percent of long-term mean for perennial plant growing season months, 1982-2022.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1982-2022	1.45	2.66	3.07	2.34	1.96	1.63	1.35	14.46	17.10
2021	0.26	5.07	1.07	1.03	1.63	0.14	2.70	11.90	13.75
% of LTM	17.93	190.60	34.85	44.02	83.16	8.59	200.00	82.39	80.41
2022	4.16	3.17	2.02	3.71	0.28	0.93	1.84	16.11	20.16
% of LTM	286.90	119.17	65.80	158.55	14.29	57.06	136.30	111.53	117.89

Table 4. Years with annual precipitation amounts of 75% or less of the long-term mean (LTM).

	Year	**%LTM**
1	1988	52.81
2	2017	61.70
3	2020	64.39
4	1992	65.67
5	1990	70.00

Table 5. Years with annual precipitation amounts of 125% or more of the long-term mean (LTM).

	Year	**%LTM**
1	2019	151.34
2	1982	148.01
3	2013	135.79
4	1986	134.28
5	1998	131.11
6	2002	127.95
7	2005	125.79

Table 6. Years with growing-season precipitation amounts of 75% or less of the long-term mean (LTM).

	Year	%LTM
1	1988	36.69
2	1992	60.09
3	2017	63.42
4	2020	65.70
5	1989	73.39

Table 7. Years with growing-season precipitation amounts of 125% or more of the long-term mean (LTM).

	Year	%LTM
1	2019	160.20
2	2013	149.26
3	1982	146.01
4	1998	136.32
5	2014	133.96
6	2002	130.50
7	1986	127.11

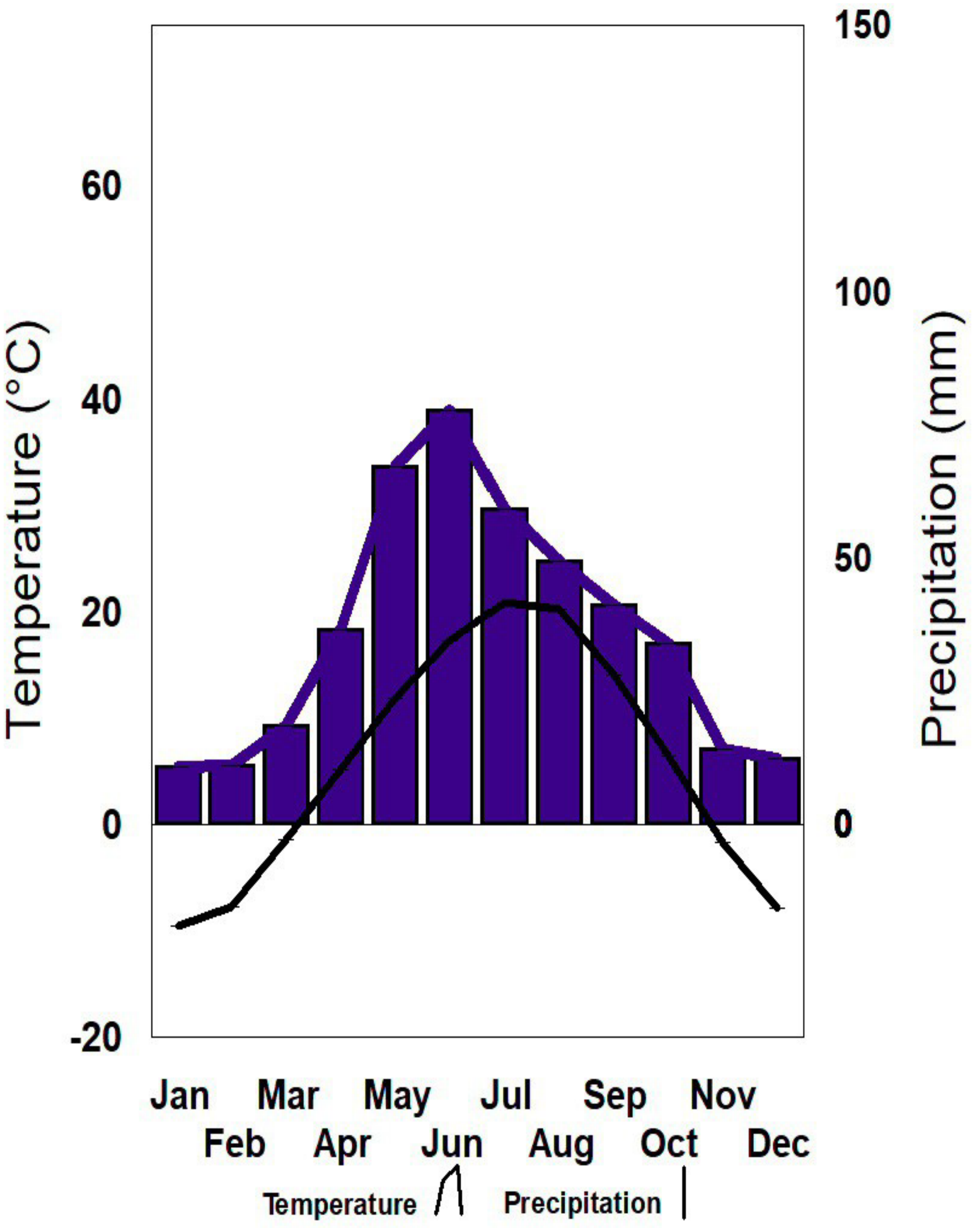

Figure 2. Ombrothermic diagram of long-term mean monthly temperature and monthly precipitation at the DREC Ranch, western North Dakota, 1982-2022.

Table 8a. Growing season months with water deficiency conditions that caused water stress in perennial plants (1982-1989, 1990-1999).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
1980								-	-
1981	-	-				■		-	-
1982								0.0	0
1983	■					■		1.5	25
1984		■		■		■		3.0	50
1985				■				1.0	17
1986					■		■	1.5	25
1987	■		■			■	■	3.0	50
1988	■		■	■	■	■	■	5.0	83
1989				■	■	■		3.0	50
								18.0	**38**
1990				■	■	■		3.0	50
1991				■	■			2.0	33
1992		■				■	■	2.5	42
1993					■	■	■	2.5	42
1994				■	■	■		3.0	50
1995			■			■		2.0	33
1996	■						■	1.0	17
1997					■			1.0	7
1998	■					■		1.5	25
1999							■	0.5	8
								19.0	**32**

Table 8b. Growing season months with water deficiency conditions that caused water stress in perennial plants (2000-2009, 2010-2019).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
2000						▨		1.0	17
2001		▨			▨		▨	2.5	42
2002						▨		1.0	17
2003					▨			1.0	17
2004					▨			1.0	17
2005				▨	▨	▨		3.0	50
2006				▨				1.0	17
2007				▨	▨	▨	▨	3.5	58
2008				▨	▨	▨		3.0	50
2009					▨	▨		2.0	33
								19.0	**32**
2010					▨		▨	1.5	25
2011							▨	0.5	8
2012					▨	▨		2.0	33
2013								0.0	0
2014				▨		▨	▨	2.5	42
2015								0.0	0
2016								0.0	0
2017		▨	▨	▨			▨	3.5	58
2018					▨			1.0	17
2019								0.0	0
								11.0	**18**

Table 8c. Growing season months with water deficiency conditions that caused water stress in perennial plants (2020-2029, 2030-2039).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
2020			▨			▨	▨	2.5	42
2021	▨		▨	▨		▨		3.5	58
2022					▨	▨		2.0	33
2023									
2024									
2025									
2026									
2027									
2028									
2029									
								8.0	**44**
2030									
2031									
2032									
2033									
2034									
2035									
2036									
2037									
2038									
2039									

Table 9. Growing season months with water deficiency, 1982-2022.

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
TOTAL	6	4	6	14	19	22	14	75.0	30.5
% of 41 **YEARS**	14.6	9.8	14.6	34.1	46.3	53.7	34.1		

Table 10. Monthly precipitation and running total precipitation compared to the long-term mean (LTM), 2022.

	Monthly Precipitation (in)			Running Total Precipitation (in)		
Months	LTM 1982-2020	Precipitation 2021	% of LTM	Running LTM 1982-2020	Running Precipitation 2021	% of LTM
Jan	0.43	0.15	34.88	0.43	0.15	34.88
Feb	0.44	0.22	50.00	0.87	0.37	42.53
Mar	0.74	0.48	64.86	1.61	0.85	52.80
Apr	1.38	4.16	301.45	2.99	5.01	167.56
May	2.64	3.17	120.08	5.63	8.18	145.29
Jun	3.10	2.02	65.16	8.73	10.20	116.84
Jul	2.31	3.71	160.61	11.04	13.91	126.00
Aug	2.00	0.28	14.00	13.04	14.19	108.82
Sep	1.65	0.93	56.36	14.69	15.12	102.93
Oct	1.33	1.84	138.35	16.02	16.96	105.87
Nov	0.54	1.51	279.63	16.56	18.47	111.53
Dec	0.46	1.69	367.39	17.02	20.16	118.45
Total	17.02	20.16	118.45			

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Surface Lime Impacts on No-Till North Dakota Soils

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Objective

Soils become acidic from the mineralization of ammonium-based fertilizers. No-till soils are particularly susceptible to acidification from the lack of mixing subsurface alkaline products and the tendency to apply ammonium-based fertilizers at or near the soil surface. As a result, the zone of acidification is at the depth of fertilizer placement (Blevins et al., 1982; Dick, 1983).

Soil pH controls chemical weathering and soil solution chemical activity. Phosphorus (P) and aluminum (Al) are two elements that greatly impact crop production and are dependent on soil pH. Phosphorus is most readily plant available when the soil pH is approximately six to seven. When soil pH is less than 5.5, Al becomes soluble, binds to P, and renders P unavailable to plants. Additionally, Al can have a toxic effect to plants that stunt and deform root growth and reduces seed germination. Free Al in the soil solution hydrolyzes water which further acidifies the soil (Lindsay, 2001). Soil pH less than 5.5 can reduce bacteria activity and cause crop nitrogen deficiencies (Graham, 1992).

Calcium-carbonate (lime) neutralizes acidity and is a common liming amendment (Sims and Lamb, 2010). Agriculture lime is not readily available in North Dakota. However, a waste product of the sugarbeet refining process (SBWL) is comprised of lime (Sims, 1996).

Lime requirement recommendations have not been developed for North Dakota (Sims, 1996). Soil acidity is new and growing issue to North Dakota soils. This project investigated the impacts of surface applied SBWL on acidic no-till soils in North Dakota.

Methodology

Eleven sites (Figure 1) were established in April/May of 2021 after planting. Soil pH at the 0-3 in depth was less than 5.5. Collaborating producers planted and managed their crop. Experimental design was a randomized complete block design.

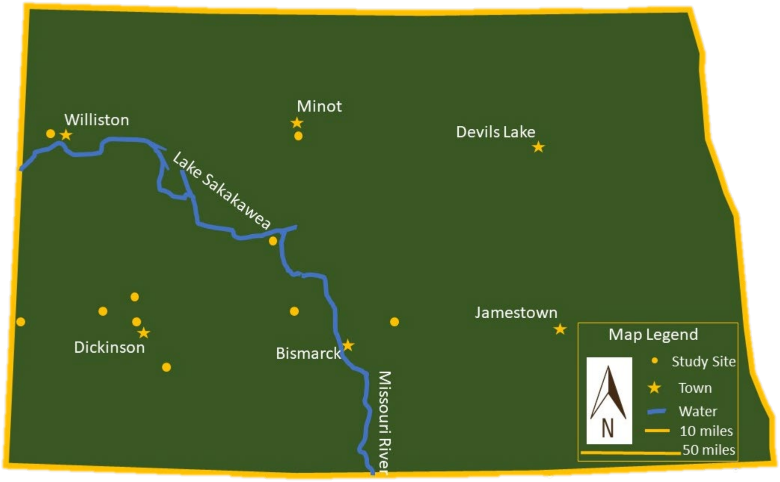

Figure 1. Locations of experimental sites in North Dakota (Google LLC, 2022).

Plastic hoops with a 36 in diameter were placed in the field and spaced at least 10 ft away from adjacent hoops. Soils were collected within 1 ft outside of the hoop. Soil was sampled by a hand probe at the 0-3, 3-6, and 0-6 in depths. Sugarbeet waste lime treatments were hand applied within the hoop after initial soil sampling. Treatments were 0, 2, 4, 8, and 16 tons lime/ac. The SBWL contained 0.6 lbs nitrate/ton, 5.2 lbs P/ton, 0.9 lbs potassium/ton, 75.5 % calcium carbonate equivalence, and 14% moisture.

Post harvest, October/November, soil samples were collected by a hand probe within the hoop at the 0-3, 3-6, and 0-6 in depths.

Soils were analyzed for nitrate, Olsen P, potassium, calcium carbonate equivalent, pH, buffer pH, salinity, organic matter, cation exchange capacity, zinc, sodium, manganese, magnesium, aluminum. Soil analysis was completed by AGVISE LABORATORIES (2022). Comparison of means and regression analysis was conducted by Statistical Analysis Software (SAS Institute Incorporated, 2019).

Results

Sugarbeet waste lime treatments increased the soil pH of the 0-3 and 0-6 in depths. Lime applications of 4, 8, and 16 tons/ac increased the 3-6 in soil depth (Table 1).

The regression analysis procedure produced statistically significant polynomial regressions from all, except the 6.3 and 7.1 buffer pH soil environments (Table 2).

Sugarbeet waste lime treatments impacted salinity, P, Ca, Mn, Al, and calcium-carbonate-equivalent (Table 3). However, SBWL treatments did not impact soil organic matter (p-value 0.955), nitrate (p-value 0.703), potassium (p-value 0.983), magnesium (p-value 0.799), zinc (p-value 0.888), sodium (p-value 0.698), and cation exchange capacity (p-value 0.995). The 4, 8, and 16 tons lime/ac treatments increased soil salinity (Table 3).

Table 1. Beet lime impacts on soil pH at various depths.

Lime	0-3in	3-6in	0-6in
tons/ac*	----------pH----------		
0	5.4e	6.0d	5.7e
2 (2.6)	6.0d	6.0d	5.9d
4 (5.3)	6.4c	6.2c	6.3c
8 (10.6)	6.7b	6.4b	6.7b
16 (21.2)	7.0a	6.7a	6.9a
P-value	<0.001	<0.001	<0.001
Variance	0.609	0.461	0.528
C.V.	4.28	6.5	5.3

*Applied as tons of lime/ac. Parentheses values are tons of SBWL/ac.

Table 2. Regression analysis and predicted lime needed to raise soil pH at the 0-3 inch depth.

Buffer pH‡	Desired pH (0-3 in depth)			Equation**	r^2
	5.5	6	6.5		
	Tons of Calcium Carbonate/Acre				
6.2 n=5†	5.6	9.5	14	$y = 1.271x^2 - 6.8828x + 5.0276$	0.99*
6.3 n=7	10	11	8.5	$y = -7.0431x^2 + 82.954x - 233.15$	0.6
6.4 n=20	0.7	3.4	8.6	$y = 5.1047x^2 - 53.374x + 139.86$	0.81*
6.5 n=24	2.7	5.2	8.6	$y = 1.5829x^2 - 13.1x + 26.826$	0.60*
6.6 n=29	2	4.5	8.1	$y = 2.0756x^2 - 18.833x + 26.826$	0.67*
6.7 n=19	1.5	5.5	9.2	$y = -0.6377x^2 + 15.394x - 63.884$	0.57*
6.8 n=27	0.9	2.4	5.1	$y = 2.3551x^2 - 24.025x + 61.806$	0.54*
6.9 n=22	0.1	1.2	3.8	$y = 2.9871x^2 - 32.222x + 86.998$	0.61*
7.0 n=16	-0.1	0.5	2.5	$y = 2.9062x^2 - 32.259x + 89.428$	0.59*
7.1 n=5	1.1	4.2	7.3	$y = -0.1207x^2 + 7.6291x - 37.184$	0.56

*r^2 was significant at the 0.05 level.

**x variable is desired soil pH at the 0-3 in depth. y variable is tons of lime/ac.

†n is the number of samples from each soil environment.

‡Sikora, 2006.

Table 3. Beet lime impacts on soil nutrients at the 0-6 inch depth.

Lime	Salts	Phosphorus (Olsen)	Calcium	Manganese	Aluminum	Calcium Carbonate Equivalence
tons/ac*	mmhos/cm		ppm			%
0	0.3b**	18d	1781c	18a	5a	0.6c
2(2.6)	0.3b	19d	1999c	14ab	2b	0.6c
4 (5.3)	0.4ab	20c	2286c	11ab	2b	0.8b
8 (10.6)	0.5a	23b	3096b	9b	2b	1.0b
16 (21.2)	0.5a	26a	4143a	9b	1b	1.5a
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Variance	1.18	56.7	1,480,729	54.56	15.1	0.28
C.V.	39.4	33	32.8	54.5	157.3	44.5

*Applied as tons of lime/ac. Parentheses values are tons of SBWL lime/ac.

**Different letters indicate statistical differences at the 0.05 level.

Conclusions & Implications

- Surface applied SBWL could improve crop yields from by increasing the soil pH and by reducing Al and Mn.
- The regression equations (Table 2) based on the initial buffer pH (Sims, 1996) can be used to guide producers on lime recommendations. Soil buffer pH values of 6.1 or less and 7.2 or greater were not collected in this study.
- All pH buffer tests were greater than 6.3 and indicates that the reserve acidity pool is relatively small (Sims, 1996). Liming these soils to desirable pH levels (i.e. pH 6) could be required once a decade or more. Saskatchewan research suggests that similarly cropped, fertilized, and limed soils acidify in 18 years (Curtin and Ukrainetz, 1997).
- Olsen P soil tests increased from SBWL applications (Table 3). Sugarbeet waste lime in an acid soil environment might serve as P fertilizer.
- Soil salinity increased from SBWL (Table 3). However all treatments were less than 0.5 mmhos/cm and likely would not negatively impact North Dakota crop yields (Franzen et al., 2019).
- Calcium increased from SBWL applications (Table 3). Manganese and soil extractable Al levels decreased from SBWL treatments. Lime increased the soil pH and likely rendered Mn and Al insoluble (Lindsay, 2001).
- Two and 0 tons of lime/ac treatments both had 0.6% calcium-carbonate equivalence (Table 3). This suggests that the 2 tons of lime/ac reacted with the soil in one growing season.

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Surface Applied Lime Impacts on North Dakota No-till Soils

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Objective

Soils become acidic from the mineralization of ammonium-based fertilizers. No-till soils are particularly susceptible to acidification from the lack of mixing subsurface alkaline products and the tendency to apply ammonium-based fertilizers at or near the soil surface. As a result, the zone of acidification is at the depth of fertilizer placement[2,4].

Soil pH controls chemical weathering and soil solution chemical activity. Phosphorus (P) and aluminum (Al) are two elements that greatly impact crop production and are dependent on soil pH. Phosphorus is most readily plant available when the soil pH is approximately six to seven. When soil pH is less than 5.5, Al becomes soluble, binds to P, and renders P unavailable to plants. Additionally, Al can have a toxic effect to plants that stunt and deform root growth and reduces seed germination (Figure 1). Free Al in the soil solution hydrolyzes water which further acidifies the soil[8]. Soil pH less than 5.5 can reduce bacteria activity and increase nitrogen deficiencies[6].

Calcium-carbonate (lime) neutralizes acidity and is a common liming amendment[11]. Agriculture lime is not readily available in North Dakota. However, a waste product of the sugarbeet refining process (SBWL) is comprised of lime[11].

Lime requirement recommendations have not been developed for North Dakota[11]. Soil acidity is new and growing issue to North Dakota soils. This project investigated the impacts of surface applied SBWL on acidic no-till soils in North Dakota.

Methodology

Eleven sites (Figure 2) were established in April/May of 2021. Soil pH at the 0-3 in depth was less than 5.5. Collaborating producers planted and managed their crop. Experimental design was a randomized complete block design.

Plastic hoops with a 36 in diameter were placed in the field and spaced at least 10 ft away from adjacent hoops. Soils were collected within 1 ft outside of the hoop. Soil was sampled by a hand probe at the 0-3, 3-6, and 0-6 in depths . Sugarbeet waste lime treatments were hand applied (Figure 3) within the hoop after initial soil sampling. Treatments were 0, 2, 4, 8, and 16 tons lime/ac. The SBWL contained 0.6 lbs nitrate/ton, 5.2 lbs P/ton, 0.9 lbs potassium/ton, 75.5 % calcium carbonate equivalence, and 14% moisture.

Post harvest, October/November, soil samples were collected by a hand probe within the hoop at the 0-3, 3-6, and 0-6 in depths.

Soils were analyzed for nitrate, Olsen P, potassium, calcium carbonate equivalent, pH, buffer pH, salinity, organic matter, cation exchange capacity, zinc, sodium, manganese, magnesium, aluminum. Soil analysis was completed by AGVISE Labs[1]. Comparison of means and regression analysis was conducted by Statistical Analysis Software[9].

Figure 3. Hand application of SBWL.

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Figure 1. Aluminum toxic canola (top) with soil pH of 4.5 and 51 ppm Al. Healthy canola (bottom) with a soil pH of 5.8 and 3 ppm Al.

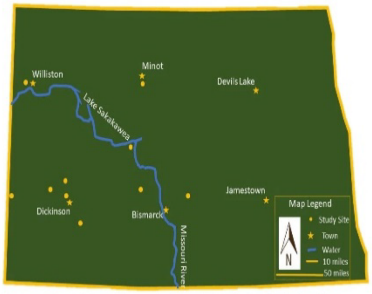

Figure 2. Locations of experimental sites in North Dakota[7].

Table 2. Regression analysis and predicted lime needed to raise soil pH at the 0-3 in depth.

Buffer pH[10]	Desired pH (0-3 in depth)			Equation**	r^2
	5.5	6	6.5		
	Tons of Calcium Carbonate/Acre				
6.2 n=5†	5.6	9.5	14.0	$y = 1.271x^2 - 6.8828x + 5.0276$	0.99*
6.3 n=7	10.0	11.0	8.5	$y = -7.0431x^2 + 82.954x - 233.15$	0.60
6.4 n=20	0.7	3.4	8.6	$y = 5.1047x^2 - 53.374x + 139.86$	0.81*
6.5 n=24	2.7	5.2	8.6	$y = 1.5829x^2 - 13.1x + 26.826$	0.60*
6.6 n=29	2.0	4.5	8.1	$y = 2.0756x^2 - 18.833x + 26.826$	0.67*
6.7 n=19	1.5	5.5	9.2	$y = -0.6377x^2 + 15.394x - 63.884$	0.57*
6.8 n=27	0.9	2.4	5.1	$y = 2.3551x^2 - 24.025x + 61.806$	0.54*
6.9 n=22	0.1	1.2	3.8	$y = 2.9871x^2 - 32.222x + 86.998$	0.61*
7.0 n=16	-0.1	0.5	2.5	$y = 2.9062x^2 - 32.259x + 89.428$	0.59*
7.1 n=5	1.1	4.2	7.3	$y = -0.1207x^2 + 7.6291x - 37.184$	0.56

*r^2 was significant at the 0.05 level.

**x variable is desired soil pH at the 0-3 in depth. y variable is tons of lime/ac.

†n is the number of samples from each soil environment.

Table 3. Beet lime impacts on soil nutrients at the 0-6 in depth.

Lime	Salts	Phosphorus (Olsen)	Calcium	Manganese	Aluminum	Calcium Carbonate Equivalence
tons/ac*	mmhos/cm	ppm				%
0	0.3b**	18d	1,781c	18a	5a	0.6c
2(2.6)	0.3b	19d	1,999c	14ab	2b	0.6c
4 (5.3)	0.4ab	20c	2,286c	11ab	2b	0.8b
8 (10.6)	0.5a	23b	3,096b	9b	2b	1.0b
16 (21.2)	0.5a	26a	4,143a	9b	1b	1.5a
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Variance	1.18	56.70	1,480,729	54.56	15.10	0.28
C.V.	39.4	33	32.8	54.5	157.3	44.5

*Applied as tons of lime/ac. Parentheses values are tons of SBWL lime/ac.

**Different letters indicate statistical differences at the 0.05 level.

Results

Sugarbeet waste lime treatments increased the soil pH of the 0-3 and 0-6 in depths. Lime applications of 4, 8, and 16 tons/ac increased the 3-6 in soil depth (Table 1).

The regression analysis procedure produced statistically significant polynomial regressions from all, except the 6.3 and 7.1 buffer pH soil environments (Table 2).

Sugarbeet waste lime treatments impacted salinity, P, Ca, Mn, Al, and calcium-carbonate-equivalent (Table 3). However, SBWL treatments did not impact soil organic matter (p-value 0.955), nitrate (p-value 0.703), potassium (p-value 0.983), magnesium (p-value 0.799), zinc (p-value 0.888), sodium (p-value 0.698), and cation exchange capacity (p-value 0.995). The 4, 8, and 16 tons lime/ac treatments increased soil salinity (Table 3).

Table 1. Beet lime impacts on soil pH at various depths.

Lime	0-3in	3-6in	0-6in
tons/ac*		pH	
0	5.4e	6.0d	5.7e
2 (2.6)	6.0d	6.0d	5.9d
4 (5.3)	6.4c	6.2c	6.3c
8 (10.6)	6.7b	6.4b	6.7b
16 (21.2)	7.0a	6.7a	6.9a
P-value	<0.001	<0.001	<0.001
Variance	0.609	0.461	0.528
C.V.	4.28	6.50	5.30

*Applied as tons of lime/ac. Parentheses values are tons of SBWL/ac.

Conclusions & Implications

- Surface applied SBWL could improve crop yields from by increasing the soil pH and by reducing Al and Mn.
- The regression equations (Table 2) based on the initial buffer pH[11] can be used to guide producers on lime recommendations. Soil buffer pH values of 6.1 or less and 7.2 or greater were not collected in this study.
- All pH buffer tests were greater than 6.3 and indicates that the reserve acidity pool is relatively small[11]. Liming these soils to desirable pH levels (i.e. pH 6) could be required once a decade or more. Saskatchewan research suggests that similarly cropped, fertilized, and limed soils acidify in 18 years[3].
- Olsen P soil tests increased from SBWL applications (Table 3). Sugarbeet waste lime in an acid soil environment might serve as P fertilizer.
- Soil salinity increased from SBWL (Table 3). However all treatments were less than 0.5 mmhos/cm and likely would not negatively impact North Dakota crop yields[5].
- Calcium increased from SBWL applications (Table 3). Manganese and soil extractable Al levels decreased from SBWL treatments. Lime increased the soil pH and likely rendered Mn and Al insoluble[8].
- Two and 0 tons of lime/ac treatments both had 0.6% calcium-carbonate equivalence (Table 3). This suggests that the 2 tons of lime/ac reacted with the soil in one growing season.

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Dickinson Research Extension Center Hops Demonstration

Hop Variety	Place of Origin	2015-2020 average yield per plant in air dried ounces	2015-2020 average yield pounds per acre	2016 -2019 Average Percent Alpha Acid
Brewers Gold	Manitoba, Canada	4.4	245	7.5
Galena	Manitoba, Canada	3.5	193	13.0
Magnum	Manitoba, Canada	2.0	112	12.0
Newport	Manitoba, Canada	1.6	87	8.8
Fuggle	England	1.4	78	2.3
Glacier	France x Canada	1.1	58	4.6
Hallertau	Germany	1.0	57	3.2
Golding	England	0.5	26	3.5
Mt. Hood	Germany	0.4	20	2.7
Average yield of hops in the Yakima, WA area is 1900 pounds per acre				

Assessment of early planting and early-maturing hybrids as tools in management of the red sunflower seed weevil

Jarrad Prasifka: USDA-ARS, Fargo
Ryan Buetow: NDSU Dickinson REC

The red sunflower seed weevil has long been considered a key pest of sunflowers in North Dakota. The weevil has one generation per year, with adults emerging from the soil during early summer (Figure 1). Because females need to feed on pollen to complete development of their eggs (Korman & Oseto 1989), adult weevils move among plants within an area, leaving plants on which pollen shed is complete and landing on plants still in bloom. Female weevils lay eggs through the sunflower hull onto developing seeds, where larvae remain until they are mature. At maturity, larvae chew through the hull and drop, burrowing into the soil to overwinter. Though feeding of each weevil larva damages only a single seed, it reduces seed weight and oil (Oseto & Branness 1980). National Sunflower Association sunflower production survey data from 2017–2021 suggest red seed weevil is currently the most serious insect pest of sunflowers. Specifically, damage from the red seed weevil was detected in 46% of the 164 samples submitted in 2021, with damage as high as 76% of seeds in a sample. In some counties, damage has been bad enough that reportedly no confection contracts were offered in 2023.

Chemical management alone has not been shown to be effective in some regions so it is important to use all of the tools in the pest management toolbox. By utilizing cultivar maturity and earlier planting dates we can add a layer of avoidance to our pest management strategy. Previous research in both South Dakota (Gednalske and Walgenbach 1983) and North Dakota (Oseto et al. 1987, Prasifka et al. 2016) show that early planting can prevent much of the damage by red sunflower seed weevils. This was repeated in Dickinson in 2022 even with weather conditions delaying the earliest planting dates. Across planting dates a clear trend emerged of increasing damage with later plantings and evidence that the use of early-maturity hybrids can have an additional benefit for avoiding seed weevil damage (Figure 2). This research is under consideration to be repeated in 2023 at multiple locations with an emphasis on impact of planting date and cultivar maturity on weevil damage and yield.

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Acid soil management update

Ryan Buetow

No-till practices paired with heavy nitrogen (N) use have acidified the soil surface on many acres in the Northern Great Plains. Acid soil where the pH drops below 5.5 has an impact on nutrient availability, soil microbial activity, herbicide efficacy, stunted roots from aluminum (Al) toxicity and other plant/soil interactions. These areas can be improved from surface liming or lime incorporation; however, liming can be costly. We are continuing efforts to collect data on surface applications of lime at different rates in different environments and soil types. With incorporation of lime we can see a faster and deeper reaction of lime, however this tillage can negate the hard built efforts of no-till management. In a trial we have in Hettinger county, ND it was shown early in the growing season that our tillage pass was looking nice and green with all of the moisture we had, but as drought set in the tilled area dried out much faster and yield was greatly impacted. There are many factors that will go into decisions on how to manage these acid areas of fields and in some cases whole fields. Each management system is different and with each system comes different challenges. All management systems have trade-offs and you will need to decide what is best for your operation, but without lime application the acidity issue will continue to worsen. For many producers facing this issue, especially those working rented land, there is a search for alternative options to reduce yield loss on acid ground. Research has been conducted in western North Dakota on adaptive management strategies for mitigating the symptoms of aluminum toxicity and soil acidity including variety selection, in-furrow fertilizer application, and seed treatments. Variety selection showed a significant difference in yield (Table 1). Calcium in-furrow did not have an impact on yield (Table 2). Across HRSW varieties a yield bump of 1.5 bushel in 2021 and 9.3 bushels in 2022 was shown from seed placed P (0-45-0) applied at high rates (60 lb P_2O_5/ac) (Table 3). In 2021 we tried a wide range of seed treatments and foliar applications on wheat in acid soils including PGR's and biologicals that showed no response across 2 locations. The data suggests use of tolerant varieties along with in-furrow P fertilizer can be used to alleviate yield reduction of small grains on an acid soil. Ideally producers should be applying tons of lime to bring the pH above 5.5 because the variety and fertilizer may fix the yield loss but does not fix issues with pesticide breakdown and carryover, soil microbiological activity, and nutrient tie-up; all issues caused by acid soil. The implications of soil acidity reach much farther than an impact on yield but an overall attack on the ability to profitably mange your inputs. There are 3 main components in yield; plants per acre, seeds per plant, and seed size. Acidity in one way or another has an impact on all three of those components. The impacts on stand can be great as seen by many facing this issue. As seen in Figure 1 stand loss is often found in acid soils. The area to the left of the photo had an average pH of 4.8 with some spots showing a pH of 3.9 and the right side of the photo had an average pH of 5.1. A tissue analysis showed that the plants on the right had much less stress from aluminum toxicity with less than half the accumulated Al than the plants with reduced stand on the left with ppm of Al of 40.8 and 98.0 respectively. Not only did this show on the tissue samples but also manifested with shorter stressed plants with smaller heads. With each passing year more N is added to the system further acidifying the soil. As pH drops, Al becomes more soluble in soil solution. To fix this we need to add tons of lime and potentially reevaluate our fertilizer management.

Table 1. HRSW variety across fertilizer treatments, Dickinson 2021 and 2022.

	Yield	
Variety	2021	2022
SY Soren (susceptible)	19.6b	47.5b
Lanning (tolerant)	22.3a	65.4a
LSD (0.05)	1.2	3.2

Table 2. Calcium fertilizer yields of HRSW across other treatments, Dickinson 2021 and 2022.

	Yield	
Treatment	2021	2022
Control	21.4	54.3
Lime in furrow	20.3	56.3
Gypsum in furrow	20.8	57.4
Calcium nitrate in furrow	N/A	57.8
LSD (0.05)	ns	ns

Table 3. P fertilizer across HRSW varieties, Dickinson 2021 and 2022.

	Yield	
Treatment	2021	2022
Control	20.1b	51.8b
60 lbs additional P	21.6a	61.1a
LSD (0.05)	1.2	3.2

Figure 1. Sunflower stand greatly reduced by soil acidity.

Integrated Systems Single Timed-AI Heifer Development

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Research Brief:

Reproduction is the most profitable single management tool for the beef cattle enterprise. Heifers that become pregnant at the first service and calve early within the first 21 days of the calving season produce more pounds of beef compared to their later calving counterparts and have a greater probability of becoming pregnant early in subsequent breeding seasons (Burris and Priode, 1958). Moreover, heifers that calve early with their first calf have greater herd longevity and lifetime productivity compared to those that calve in the second 21 days or later (Cushman et al., 2013). In addition to the importance of pregnancy and early calving, accessing elite sires artificially ensures that replacement heifers have above average production opportunity due to genomic enhanced genetic potential.

Integrated crop-livestock beef cattle systems research at the NDSU-Dickinson Research Extension Center (DREC), has shown that regardless of steer frame score extended grazing of perennial and annual forages and delayed feedlot entry supported comparable meat quality and was consistently more profitable than feedlot control steers (Senturklu et al., 2018; 2019). This previous yearling steer grazing performance would be nutritionally supportive and is an ideal management system for replacement heifer development.

First service TAI using a 14-day Controlled Internal Drug Release® (CIDR-PGF2α-GnRH) program results in consistent pregnancy rates of 50-60% (Perry et al., 2012, 2015). A principal result from the use of progesterone delivered from a CIDR is to manipulate follicular waves by preventing the negative effect of premature $PGF_{2\alpha}$ release from the uterus on corpus luteum survival (Patterson et al., 2019). For virgin heifers, a 14-d CIDR followed by $PGF_{2\alpha}$ 16 d after CIDR removal and GnRH at the time of insemination 66 hr.±2hr after $PGF_{2\alpha}$ has been a cost-effective timed artificial insemination (TAI) program. Moreover, using a single-TAI procedure produces heifers that are timed to calve early and the cost for keeping easy-calving heifer bulls year-around is eliminated.

The first objective for this long-term research and extension project is to evaluate reproductive performance comparing a traditional TAI program in which cleanup bulls are used after a single-TAI breeding and non-pregnant heifers are sold as feeder cattle after an 85-day pregnancy exam to a single-TAI program *without* cleanup bulls. Since cleanup bulls are not used, all non-pregnant heifers graze annual forages grown in multi-crop rotation and feedlot entry is delayed until fall and early-winter grazing has been completed. The finished heifers are marketed “in the meat” on a carcass grid basis.

The second project objective is to determine the economic value and efficiency of bred heifers and sale of open heifers compared to the combined values of bred heifers and non-pregnant finished heifer carcass value.

The third objective is to train students in estrous synchronization management techniques and cattle artificial insemination, and the third objective is to conduct a beef cattle producer heifer development survey comparing heifers developed in drylot compared to a pasture system.

Preliminary Results:

This is a long-term four-year research project. The first-year results presented here are preliminary and will change as subsequent year data is added.

The project is designed to compare control heifers reared in drylot (DLOT) and fed hay and supplement to heifers managed grazing either native range (NR) or a combination of native range and annual forages (winter wheat, field pea-barley, corn, cover crop) grown in a diverse cropping system (ANN), which are bred using a common single Timed-AI protocol (14d CIDR-PG-GnRH) and all non-pregnant heifers are finished for grid marketing. As such, following synchronization cleanup bulls are placed with the DLOT control heifers; however, there are no cleanup bulls placed with the grazing treatments.

Heifers in the study grazed native range and annual forages for a period of 121 days and during the period total gain per heifer was 33.7, 119.5, and 126.5 kg (*P* = 0.001), and synchronized timed-AI pregnancy rates were 59.4, 43.8, and 62.5% (*P* = 0.27) respectively, for the DLOT, ANN and NR treatments. Total pregnancy rate of 90.6% in the drylot control group was significantly greater than the ANN forage group (43.8%), and the NR total pregnancy rate of 62.5% (*P* = 0.002) did not differ from either the DLOT or ANN treatment groups.

Grazing heifer feedlot performance for the ANN forage and NR had numerical differences; however, there was no measurable difference for starting weight (452 vs 456 kg, *P* = 0.29), ending weight (610.0 vs 600.0 kg, *P* = 0.74), feedlot finishing gain (157 vs 164 kg, *P* = 0.69), ADG (1.42 vs 1.48 kg, *P* = 0.70), daily DM feed intake (15.0 vs 14.7 kg, *P* = 0.73), G:F ratio expressed as the amount of gain per unit of feed consumed (0.04298 vs 0.04554 kg, *P* = 0.42), daily feed cost ($4.38 vs $4.30, *P* = .73), feed cost/kg gain ($3.11 vs $2.95, *P* = 0.51), and feed and yardage cost/kg gain ($3.42 vs $3.24, *P* = 0.55).

Non-pregnant grazing heifers from the ANN and NR treatments were harvested at the Cargill Meat Solutions federally inspected packing plant located in Ft. Morgan, Colorado. Similar to the feedlot heifer growth performance and efficiency data, grazing heifer carcass measurements did not differ between treatments for, HCW (369 vs 365 kg, *P* = 0.83), dressing pct (60.7 vs 61.0, *P* = 0.69), marbling score (524 vs 531, *P* = 0.78), and percent Choice/Prime (100% vs 100%).

The gross pregnant heifer and gross carcass return for DLOT, ANN and NR were $1,325, $1,702, and $1,601, respectively. These data indicate that grazing systems combining bred heifer value and grid-based carcass value are competitive.

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Outreach Programming Activities:
Workshop, Conference, Professional Abstract, and Invited Speaker Events

Workshop Coordinator:
DREC Soil Health Workshop – Integrated Systems, Intercropping, and Organic Matter Management, September 14, 2022
Workshop proceedings available upon request while supplies last

Conference Coordinator:
Reproductive Strategies Conference – Replacement Heifer Synchronization and Cow Herd Management
November 10, 2022
Conference proceedings available upon request while supplies last.

Professional Meeting Abstract:
2022 American Society of Animal Science – Canadian Society of Animal Science Annual Meeting & Trade Show, Oklahoma City, OK
Forages and Pastures I
Effect of feedlot finishing compared with grass fed beef following bale grazing and delayed feedlot entry on steer performance, carcass measurement and net return
Songul Senturklu, Douglas Landblom, Steve Paisley, and Christina Stroh
Journal of Animal Science, Vol. 100:84 (Suppl 3), Abst.186
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Invited Speaker Events:
Tools for Genetic Advancement – Using Expected Progeny Difference (EPD) for Bull Selection
Presented at: NDSU Dunn County Extension Education Program, February 1, 2022
Glendive Agriculture and Trade Show (GATE), February 11, 2022

Beef Producer Synchronized Heifer Development Survey Results –
Presented at: American Breeder Service producer meetings
Golden Valley Community Center, Golden Valley, ND, February 15, 2022
Sweetwater Golf Course, Bowman, ND, February 16, 2022

Research Progress Report –
Effect of a single-TAI and delayed feedlot entry program on reproductive performance and profitability
Beef Cattle Producer Heifer Development Survey Results for 2021
Presented at: Reproductive Strategies Conference

NDSU Spring Conference –
Grazing and delayed feedlot entry effects on small-framed steer economics
Presented to: NDSU Research Extension Center faculty conference attendees, February 23, 2022

NDSU Fall EXT/REC Conference, Holiday Inn, Fargo, ND, November 1-3, 2022 –
Coordinator: Summary of Research Extension Center Research Programs presented in the REC Joint Session with ANR Agents. RE Center presenters: Colin Tobin, James Rogers, Michael Undi, and Douglas Landblom – Integrated crop and beef cattle systems research at the Dickinson Research Extension Center

Reversing Soil Acidity:
Effect of high-density stocking rate on beet lime incorporation, soil compaction, steer gain economics, soil microbial activity, and soil physical properties

Progress Report

Douglas Landblom, Songul Senturklu, Larry Cihacek, Chris Augustin,
Ryan Buetow, and Rashad Alghamdi

Measurement of soil hydrogen ion (H^+) is a function expressed logarithmically as the negative H^+ ion concentration. As soil pH declines and becomes more acidic, crop growth and productivity are negatively impacted when unhydrated aluminum (Al $(OH)_4$ becomes disassociated from the hydroxyl group result in positively charged aluminum Al^{3+} that is toxic to plants. There are soils in North Dakota that were formed on parent material that is naturally slightly acidic. Nonetheless, soil pH decline is accelerated by acids produced in soil following repetitious application of most nitrogen fertilizers, nitrate leaching and plant cation uptake, which results in anion accumulation promoting increased acidity (Cihacek et al., 2021).

Approaches to reversing soil acidity conditions include applying lime (Calcium carbonate, $CaCO_3$) sourced as a byproduct from sugar beet processing (beet lime) or municipal water treatment facilities. Beet lime is being used for this investigation. In order for elements in the soil solution to react and buffer acidic conditions some form of incorporation is necessary. Minimal soil disturbance from no-till seeding practices may not be sufficient to adequately incorporate lime into the root zone. In addition to light discing, the effect of animal hoof action during grazing of cover crops, where lime has been applied, might possibly be a mechanism for lime incorporation.

Yearling Steer Cover Crop Grazing:
A multi-specie full-season cover crop was planted early June for August grazing with yearling steers as a component in a four-crop rotation (Cover Crop, Spring Wheat, Corn, and Sunflower). To ensure adequate hoof action, a high-density stocking rate was used in which 60 crossbred steers (A x RA x Lowline x SM) grazed the study area for 21days. The grazing area of 9.478 acres was subdivided into 11 segments equaling 0.861636 acre grazing areas. Polywire electric fence was used to restrict grazing within designated high-density stocking areas and the steers were rotated to the next cover crop segment every other day. Steer average weights were 979 and 1,007 lbs. years 1 and 2, respectively, and the pounds of beef per acre was 67,160 and 70,140 lbs. years 1 and 2, respectively. Yearling steer average daily gain was 1.50 lb/day/steer both years of the study.

Beet lime cost was \$50/T plus \$10/T for custom application. Lime treatments were 0, 2, and 4 T/ac. Total cost to apply 2 T/ac was \$120 and the 4T/ac rate cost \$240/T. Although the 2-year steer ADG was similar, market price per hundredweight was \$0.26/lb greater year-2 compared to year-1 (\$1.37 vs. \$1.63). Year-1 steer gain value/steer/ac, after deductions for freight and sale barn marketing charges, was \$29.83/ac; and year-2, due to the higher market prices for yearling steers, the gain value/steer/ac was \$93.74. The two-year average lime cost/ac after accounting for steer gain value reduction was \$58.21 and \$178.21/ac for the 2 and 4Ton application rates.

Soil samples were collected on October 28, 2021, (0-3in) in corn (CN), sunflower (SF), spring wheat (SPW), and cover crop (CCRP) fields from designated sampling strips identified as A3 through A8, which included two reps from untreated check, 2T, and 4T treatment strips. Soil samples were analyzed by Ward Laboratories, Inc., Kearny, NE, for microbial biomass and arbuscular mycorrhizal fungi (AMF) using the phospholipid fatty acid (PLFA) Soil Microbial Community Analysis. Measurement units are expressed in nanograms/gram of soil. The Haney Soil Health Analysis provided results for soil pH (H^+ ion concentration; 1:1 soil:water ratio), organic matter (OM %), and nitrate-NO_3-N (ppm).

Microbial testing revealed a sharply greater microbial biomass (Fig. 1, ng/g soil) in the cover crop (CCRP) treatment strips. The CCRP check and 4T treatment strips had the highest microbial biomass. Interestingly, the CCRP check strip had the highest microbial biomass (10693 ng/g), but also a pH level of 4.85, which indicates tolerance for soil acidity. Except for the SPW 2T strip, all other crops and treatment levels were considerably lower. Likewise, arbuscular mycorrhizal fungi AMF (Fig. 2) levels mirrored the PLFA values, i.e., check strip and 4T levels were highest followed by 2T strip and the SPW 2T was also high.

The 2T and 4T beet lime applications consistently increased soil pH values (Fig 3) compared to the check strips among all crops. The 2T and 4T cover crop pH values were consistently higher than the check strip indicating that yearling steer hoof action may have been effective for lime incorporation.

Soil organic matter (Fig 4) level on the Thomas Family Farm, Mott, North Dakota, is consistently very good ranging from a low of 3.1 to 4.35%. This range of organic matter across crops demonstrates the value of a diverse crop rotation, which followed a consistent trendline from the check strip through 2T and 4T treatment levels with the exception of SF in which check strip was higher than the 4T application.

Residual nitrate levels (Fig 5) were consistently and significantly higher for CN check, 2T and 4T strips as well as the 2T SPW strip. These residual levels are consistent with the farm producers N fertilizer applications on corn.

Considering the data results, it appears that the yearling steer hoof action may have had a positive impact on the soil environment and yearling steer gain value over the first two years of the study contributed to offsetting the cost of lime and application. A third year of the long-term study will be continued during the 2023 growing season.

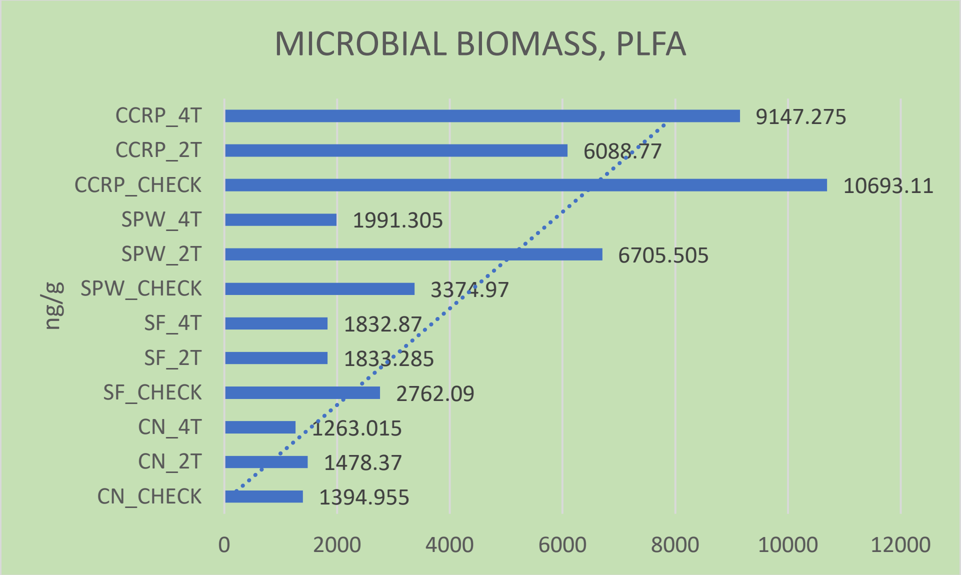
MICROBIAL BIOMASS, PLFA
ng/g
CCRP_4T
CCRP_2T
CCRP_CHECK
SPW_4T
SPW_2T
SPW_CHECK
SF_4T
SF_2T
SF_CHECK
CN_4T
CN_2T
CN_CHECK
9147.275
6088.77
10693.11
1991.305
6705.505
3374.97
1832.87
1833.285
2762.09
1263.015
1478.37
1394.955
0
2000
4000
6000
8000
10000
12000

Fig. 1

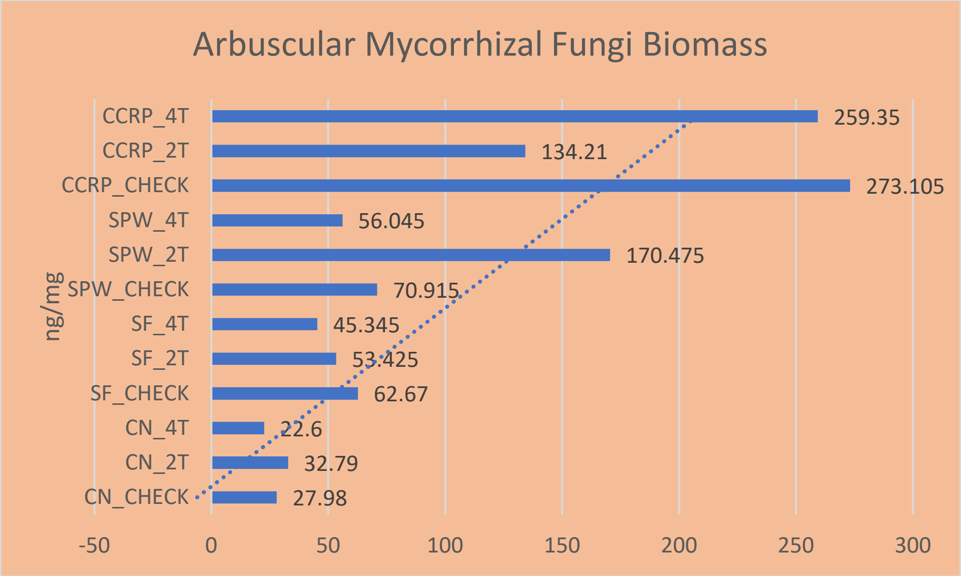
Arbuscular Mycorrhizal Fungi Biomass
ng/mg
CCRP_4T
CCRP_2T
CCRP_CHECK
SPW_4T
SPW_2T
SPW_CHECK
SF_4T
SF_2T
SF_CHECK
CN_4T
CN_2T
CN_CHECK
259.35
134.21
273.105
56.045
170.475
70.915
45.345
53.425
62.67
22.6
32.79
27.98
-50
0
50
100
150
200
250
300

Fig. 2

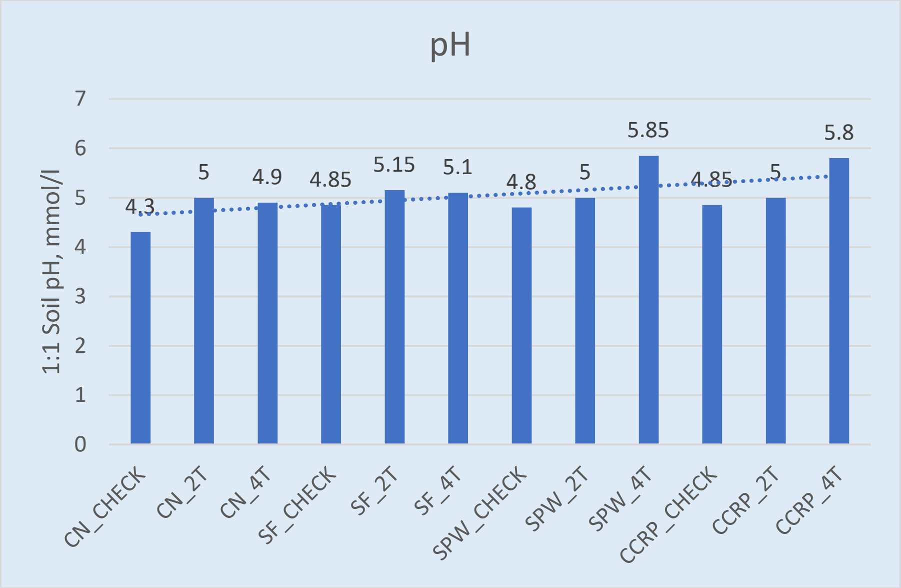
pH
1:1 Soil pH, mmol/l
7
6
5
4
3
2
1
0
4.3
5
4.9
4.85
5.15
5.1
4.8
5
5.85
4.85
5
5.8
CN_CHECK
CN_2T
CN_4T
SF_CHECK
SF_2T
SF_4T
SPW_CHECK
SPW_2T
SPW_4T
CCRP_CHECK
CCRP_2T
CCRP_4T

Fig. 3

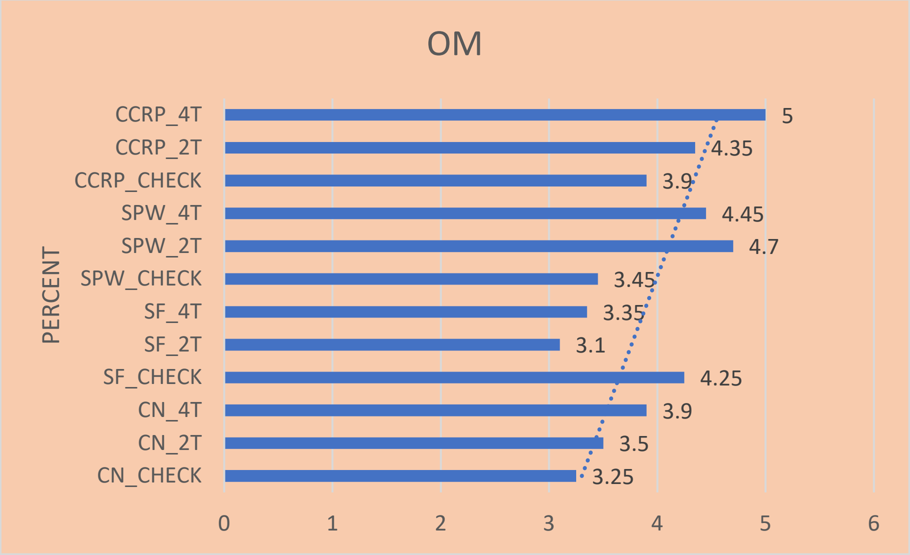
OM
PERCENT
CCRP_4T
CCRP_2T
CCRP_CHECK
SPW_4T
SPW_2T
SPW_CHECK
SF_4T
SF_2T
SF_CHECK
CN_4T
CN_2T
CN_CHECK
5
4.35
3.9
4.45
4.7
3.45
3.35
3.1
4.25
3.9
3.5
3.25
0
1
2
3
4
5
6

Fig. 4

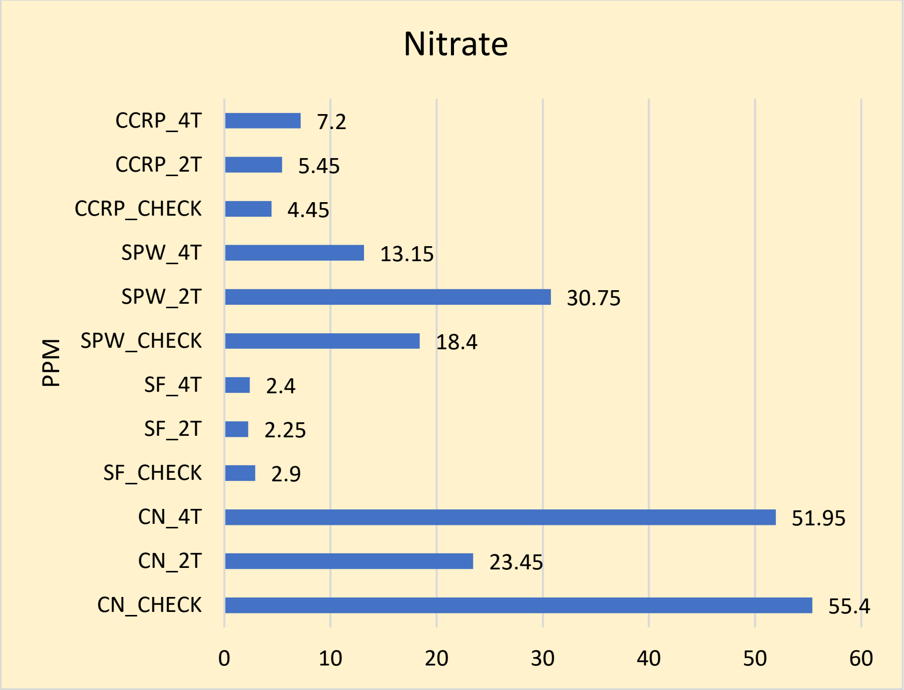
Nitrate
PPM
CCRP_4T
7.2
CCRP_2T
5.45
CCRP_CHECK
4.45
SPW_4T
13.15
SPW_2T
30.75
SPW_CHECK
18.4
SF_4T
2.4
SF_2T
2.25
SF_CHECK
2.9
CN_4T
51.95
CN_2T
23.45
CN_CHECK
55.4
0
10
20
30
40
50
60

Fig. 5

Beef cattle finishing methods: Forage-based finishing compared conventional feedlot finishing following bale grazing and delayed feedlot entry

Songul Senturklu[1,2], Douglas Landblom[1], Steve Paisley[3], and Christina Stroh[4]

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Research Brief:

In a finishing methods systems evaluation, seventy-two crossbred yearling steers (Aberdeen Angus x Red Angus x Angus) that had been wintered for modest gain (1.05 lb/day gain) were assigned to either a grass-fed annual forage (GF-ANN) or a grass-fed native range (GF-NR) systems that were compared to a native range feedlot control system (NR-FLT) in a delayed feedlot entry program. Steers in the systems were weighed and ultrasounded for initial weight, muscle and fat measurements, and turned out on native range until annual forages were suitable for grazing and grazed spring-summer-fall for total period of 176 days. After the 176-day grazing period, the GF-ANN, GF-NR, and NR-FLT steers were transitioned to free-choice cover crop baled hay feeding (Bale Grazing) and fed an average 6.81 lbs. daily of a highly digestible fiber-based supplement for 92 days. The NR-FLT control group grazed bales and received the fiber-based supplement for 69 days before transfer to the University of Wyoming, Sustainable Agriculture Research Extension Center (UWY-SAREC) for final finishing. The grass-fed (GF-ANN, GF-NR) steers continued grazing bales and receiving supplement for an additional 23-days. When forage finishing and feedlot finishing were completed, the grass-fed (GF-ANN, GF-NR) steers were harvested at a federally inspected abattoir in Green Bay, WI, and the feedlot control steers (NR-FLT) were harvested at a separate federally inspected abattoir in Ft. Morgan, CO.

Three steer grazing performance periods are shown in Table 1. The first period was the 176-day period between May 5th and October 28th, when the steers grazed native range and annual forages. The second period was the first 69-day period of bale grazing between October 29 and January 5 (Bale Graze-1, 69 days), when all three treatment groups ranged freely and grazed cover crop bales plus a fiber-based energy supplement. The third period was an additional 23-day period of bale grazing between January 6 and January 30 (Bale Graze-2, total = 92 days), after the feedlot control steers had been transferred to the UWY-SAREC feedlot. For the 176-day grazing season, GF-ANN and NR-FLT steers gained more weight than GF-NR group ($P = 0.02$). During the 69-day bale-graze-1 period the NR-FLT and GF-NR grew at a slower rate compared to the GF-ANN ($P = 0.001$). However, during the bale graze-2 period, which included feedlot finishing steers that were being fed high energy finishing diets in the feedlot, the feedlot control group (NR-FLT) steers gained 442.9 lb compared to an average 207.9 lb; 2.2 times faster than the forage-finished group.

Forage-based cover crop bale graze and feedlot finishing performance, efficiencies and economics are shown in Table 2. Forage-finishing supplement fed consisted of highly digestible fiber ingredients to include wheat-middlings (47.7%), barley malt sprouts (18.0%), soybean hulls (16.0%), beet pulp shreads (10.0%), beet molasses (5.0%), dical phosphorus (2.5%), salt (0.5%), and vitamin ADE & selenium (0.272%), and range trace minerals (0.072%). Highly digestible fiber supplements are not prone to causing bloat or rapid changes in rumen pH. However, the steers received an initial 1.50 lb/steer/day that was increased 0.50 lb every other day until an average 6.81 lbs. were fed/steer/day. During the 69-day period before transfer to the UWY-SAREC combined with the 90-day feedlot finishing period resulted in enhanced overall performance for the NR-FLT treatment steers. Hay ($90.87), supplement ($28.30), and feedlot ($381.18) costs were greater (P = 0.001) than the forage-finished GF-ANN and GF-NR. The feedlot control steer gain to feed efficiency was greater (P = 0.001) and feed cost per pound of gain was less (P = 0.001) compared to the forage-finished steers.

Forage-based cover crop bale graze and feedlot finishing carcass measurements are shown in Table 3. Selling forage-based grass-fed beef to the grass-fed beef company in Green Bay, WI, was problematic with respect to carcass measurement data received from the company. As shown in Table 3, hot carcass weight (HCW), marbling score, and gross carcass value were the only criterion provided. The company pays a base price for Select quality grade carcasses and does not reward the cattle feeder with quality grade premiums. Therefore, the steers were not fed to attain Choice and Prime quality grade premiums and as such HCW was greater for the NR-FLT steers compared to the GF-ANN and GF-NR in which HCWs were 26.0% and 34% lighter, respectively. Quality grade among the NR-FLT steer group harvested at the Cargill Meat Solutions packing plant was 0.0% Select, 83.3% Choice and 16.7% Prime.

A finishing systems marketing comparison between the forage-based grass-fed finishing system and the feedlot control system has been summarized in Table 4. The economic systems comparison considers cow costs and backgrounding expense, grazing costs, bale grazing and protein energy supplement expenses, and transportation costs. The GF-ANN forage steers lost -$88.25 per steer, which was due primarily to greater annual forage farming costs compared to native range and freight to Green Bay, WI. Compared to the GF-ANN steers' net loss, the GF-NR and NR-FLT steer net returns were $62.70 and $160.22, respectively. In the final analysis, forage finishing was not competitive with delayed entry feedlot finishing, which has repeatedly been proven to be very profitable.

Table 1. Annual, native range, and bale-grazing steer performance.

	GF-ANN	NR-FLT	GF-NR	SEM	P-Value - Trt
Spring-Summer-Fall, 176 days					
Start Wt., lb	757.0	738.7	725.3	20.69	0.13
End Wt., lb	1090.3	1076.2	1033.3	23.99	0.02
Gain, lb	333.3	337.5	308.0		
ADG, lb	1.89	1.92	1.75		
Bale Graze-1 69 days					
Start Wt., lb	1090.3	1076.2	1033.3	23.99	0.02
End Wt., lb	1243.3	1197.3	1164.7	23.93	0.002
Gain, lb	153.1	121.1	131.4	5.84	0.001
ADG, lb	2.22	1.76	1.91	0.08	0.001
Bale Graze-2 92 days					
Start Wt., lb	1243.3	1197.3	1164.7	23.93	0.002
End Wt., lb	1297.3	1558.4	1242.1	31.89	0.001
Gain, lb	207.0	442.9	208.8	9.78	0.001
ADG, lb	2.25	4.98	2.27	0.11	0.001

Table 2. Forage-based cover crop bale graze and feedlot finishing performance and economics.

	GF-ANN	NR-FLT	GF-NR	SEM	P-Value - Trt
Finish Growth					
Number steers	24	24	24		
Days on feed	92	90	92		
Start Wt., lb	1090.25	1115.5	1033.29	23.8692	0.001
End Wt., lb	1297.29	1558.42	1242.08	31.8863	<0.001
Gain, lb	207.04	442.82	208.79	9.775	<0.001
ADG, lb	2.25	4.98	2.27	0.11	<0.001
Cover Crop Hay					
Hay/steer	3280.40	2207.20	3039.13	73.92	0.0001
Hay/steer/Day	34.53	31.99	31.99	0.85	0.13
Supplement Intake					
Lb/steer	647.16	147.0	647.26		
Lb/steer/day	6.81	2.13	6.81		
Feed Cost & Efficiency					
Supplement cost/steer, $	124.57	28.30	124.57	0.00	<.001
Hay cost/steer, $	128.73	90.87	120.33	2.96	0.001
Feedlot cost/steer, $		381.18			
Hay & suppl., lb	3927.58	2354.21	3686.29	73.91	0.001
Hay, suppl. & feedlot (Fd & Ydg) cost, $	253.30	500.35	244.90	2.96	<.001
Hay, suppl. & feedlot cost/day (69 + 90 days; 159 days), $	2.67	3.15	2.58	0.03	<.001
Gain, lb	207.04	563.90	208.80	11.31	0.001
ADG, lb	2.25	3.55	2.27	0.12	<.001
Gain:Feed	0.0527	0.1551	0.0655	0.003	<.001
Feed cost/lb of gain, $	1.22	0.887	1.17	0.05	0.001

Table 3. Forage-based cover crop bale graze and feedlot finishing carcass measurements.

	GF-ANN	**NR-FLT**	**GF-NR**	**SEM**	**P-Value - Trt**
Number Steers	24	24	24		
HCW, lb	718.96	905.75	675.42	16.3287	<.001
Dressing Percent, %		60.54			
Fat depth, in		0.48			
REA, sq. in		13.7			
REA : HCW ratio, sq. in		0.0151			
Marbling score	515.0	678.33	488.75	14.7523	<.001
USDA Yield Grade					
YG2,%		25			
YG3,%		70.8			
YG4,%		4.2			
Quality Grade					
Choice, %		83.3			
Prime, %		16.7			
Grid Market Price/CWT, $		190.58			
Gross carcass value, $	1483.28	1727.34	1393.45	33.686	<.001

Table 4. Finishing system marketing comparison: Bale-graze and Delayed feedlot entry – Grass-Fed vs. Feedlot

	Grass-Fed			**Feedlot**
	GF-ANN	**GF-NR**		**NR-FLT**
Cow Cost & Backgrounding				
Annual cow cost, $	642	642		642
Winter feed cost, $	110	110		110
Total, $	**752**	**752**		**752**
Grazing Cost				
Native range pasture cost, $	115.3	207.77		207.77
Pea-barley annual forage, $	74.98			
Unharvested corn, $	108.87			
Cover crop, $	58.82			
total, $	**357.97**	**207.77**		**207.77**
Bale Grazing & Protein/Energy Supl.				
Cover crop hay cost, $	128.73	128.73		90.86
Pasture grazing supplement cost, $	21.52	20.87		
Bale grazing supplement cost, $	124.57	124.57		28.30
Feedlot feed and yardage cost, $				389.24
Total, $	**274.82**	**274.17**		**508.04**
Freight Cost to Packing Plant (Green Bay, WI)	**136.46**	**136.36**		
Freight to UWY feedlot (Lingle, WY)				69.85
Freight Cost to Packing Plant (Ft. Morgan, CO)				29.46
Total Freight	**136.46**	**136.36**		**99.31**
Total Expenses	**1521.25**	**1370.3**		**1567.12**
Gross Return				
(68,784/48 = $1,433)	1433	1433		**1727.34**
Net Return/Str, $	**-88.25**	**62.7**		**160.22**
Difference vs ANN, $		**+150.95**		**+248.47**
Difference vs GrassFed NR, $				**+97.52**

Beef Cattle Producer Synchronized Timed-AI Survey

[1]Douglas Landblom, [2]Lauren Hanna, [3]Bryon Parman, [4]George Perry,
[5]Steve Paisley, and [1,6]Songul Senturklu

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[2]North Dakota State University, Animal Science Department
[3]North Dakota State University, Department of Agribusiness and Applied Economics
[4]Texas A & M University, Agrilife Research, Overton
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Research Brief:

Reproduction is unquestionably the single most important criterion in the beef cattle enterprise, because profitability begins with new birth, which is the initiator of new wealth. It is from the American ranchers who devote their resources and every ounce of energy into producing new wealth that accompanies each newborn calf.

Replacement heifers are literally the backbone of any beef cattle operation's future performance, efficiency, and profitability. Therefore, selecting and breeding heifers to elite sires with known performance and efficiency traits is of utmost importance to the progressive cattleman. Because reproduction is the most profitable single management tool, heifers that calve early at the start of the calving season produce more pounds of beef and demonstrate greater herd longevity and lifetime productivity compared to their later calving counterparts.

For small to medium sized farm managers, access to elite sires is for the most part out of their reach financially; however, accessing the merits of elite sires artificially with known genomic enhanced genetic potential is the most rapid and efficient method to enhance genetic merit of replacement heifer offspring.

Yes, artificial insemination is labor intensive, which is why <10% of breeding age females in the U.S. beef cattle herd are bred artificially? Nonetheless, cattlemen who know the value of the enhanced genomic merit available through AI devote the labor and focused time required to breed heifers artificially by appointment. And when TAI pregnancy rates approaching 60.0% or greater are attained, breeding cost per pregnant female is reasonably priced, because bull semen cost per unit has not increased appreciably over time compared to the average herd bull cost per pregnant female.

A voluntary survey of cattle ranchers that synchronize replacement heifers for AI was initiated with the 2021 breeding season for the purpose of establishing trends and identifying areas where future research efforts can be expended. Currently, two rancher breeding seasons (2021 and 2022) have been summarized in Table 1. Without exception, environmental insult from drought, blizzards, long winter cold spells, and nutrition play a heavy role in heifer response and pregnancy rate. Drought during the 2021 breeding season and back-to-back April 2022 blizzards effected pregnancy rates. Looking ahead into 2023, brutally cold temperatures in all likelihood will have a negative effect on pregnancy rates unless nutritional energy supplementation is provided to ensure heifers are in a positive energy and gaining condition 30-days before, during, and 30-days after AI has been completed.

Looking at year-over-year change between heifer synchronization results from 2021 and 2022, costs increased for feed, vaccine, semen, and veterinary services, while pasture grazing system heifer pregnancy rates declined 17.0% due to stress resulting from the back-to-back blizzards. Thus, for the upcoming 2023 synchronized heifer breeding season, TMR diets with increased energy content and energy-based pasture supplementation will be necessary to ensure heifers affected by the recent unusually cold 2022-2023 winter are in a gaining condition before, during, and after heifers have been artificially inseminated.

Voluntary rancher heifer synchronization survey results for 2023 will be added to the database and the 3-year breeding season results will be provided in this report next year.

Table 1. Beef cattle rancher heifer synchronization survey results (2021, 2022).

	DRYLOT	**GRAZING**	**DRYLOT**	**GRAZING**
	2021	**2021**	**2022**	**2022**
Number of Systems	**3-Drylot**	**3-Grazing**	**1-Drylot**	**5-Grazing**
TMR Diet				
Lb/Hd/Day	25.7	-	35.0	-
Cost/Ton	$58.15	-	$73.42	-
Suppl/Lb/Hd/Day	2.17	-	4.0	-
Grazing				
Tame Grass & Native Range	Yes	Yes	Yes	Yes
Cost/Ac	-	$16.67	-	$14.20
Cost/Day	-	$0.90	0.70	$0.61
Pasture Yield, T/Ac	-	0.567	-	1.08
Vaccine Cost (Range $1.91 - $11.56)	$8.29	$5.88	$19.75	$17.53
Synchronization				
No. Synchronized	133	52	194	62.2
No. Inseminated Before TAI	160	2	165	65
TAI Pregnancy	56%	74%	59.0%	57.0%
Repeat Pregnancy	47.2%	-	13.0%	-
TAI + Repeat Pregnancy	75.5%	-	72.0%	-
Bull Bred	16.7%	-	18.6%	27.15%
Open	7.81%	-	10.0%	12.83%
Semen Cost				
Average Semen Cost	$21.33	$16.21	$20.00	$20.20
Average Vet Preg Check Cost	$4.83	$3.67	$6.00	$5.05

Outreach List 2022

Name	Topic	Location	Date
Chris Augustin	Soil compaction management	Mott	16-Feb-22
Chris Augustin	Cost saving soil fertility manegemtn	Center	04-Feb-22
Chris Augustin	Liming acid no-till soils	Sidney, MT	03-Mar-22
Chris Augustin	Droughty soil fertility management	Online	14-Mar-22
Chris Augustin	ND Wheat Commission soil acidity recap	Online	16-Mar-22
Chris Augustin	Liming acid no-till soils	Golva	08-Apr-22
Chris Augustin	Acid soil liming (poster presentation)	online	16-Apr-22
Chris Augustin	Pollinator garden planting (Dickinson Public Schools)	DREC	12-Apr-22
Chris Augustin	4-H communication arts judge	New England	16-May-22
Chris Augustin	Acid soil management	DREC	13-Jul-22
Chris Augustin	Garden soil testing	DREC	13-Jul-22
Chris Augustin	North Dakota acid soil management	Williston	14-Jul-22
Chris Augustin	Banquet in a field	Dickinson	19-Jul-22
Chris Augustin	Surface applied lime impacts on North Dakota no-till soils (poster)	West Palm Beach, FL	17-22-Jul-2022
Chris Augustin	Liming North Dakota acid soils	Scranton	26-Jul-22
Chris Augustin	State Land Judging	Harvey	3-4-Aug-2022
Chris Augustin	Horticulture tour	DREC	05-Aug-22
Chris Augustin	Extension agent horticulture tour	DREC	31-Aug-22
Chris Augustin	Liming acid no-till soils	Fargo	02-Nov-22
Chris Augustin	Surface applied lime impacts on North Dakota no-till soils (poster)	Fargo	02-Nov-22
Chris Augustin	Surface lime impacts of Canola	Fargo	16-Nov-22
Chris Augustin	Rural leadership	Dickinson	17-Nov-02
Chris Augustin	Nitrogen management	KX News (Television)	30-Nov-22
Chris Augustin	Acid soil management	Mandan	04-Dec-22
Chris Augustin	Carbon management	KX News (Television)	07-Dec-22
DREC Hosted	Senior NDSU geology students	DREC	2-8-Sep-2022
DREC Hosted	DSU soil genesis class	DREC	Fall 2022

Name	**Topic**	**Location**	**Date**
Llewellyn L. Manske	Biology of Grassland Workshop-33 Topics Discussed	Dickinson	4,5,6-Jan-22
Llewellyn L. Manske	Developed 8 Twice-over ranch plans	Dickinson	6-Jan-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	13-Apr-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	27-Apr-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	11-May-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	25-May-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	9-Jun-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	23-Jun-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	11-Jul-22
Llewellyn L. Manske	DREC Field Day Agronomy Tour	Dickinson	13-Jul-22
Llewellyn L. Manske	DREC Field Day Horticulture Tour	Dickinson	13-Jul-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	8-Aug-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	24-Aug-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	31-Aug-22
Llewellyn L. Manske	DSU Lecture: How Grasses Grow	Dickinson	7-Sep-22
Llewellyn L. Manske	DSU Lecture: Herbage Curves	Dickinson	9-Sep-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	12-Sep-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	26-Sep-22
Llewellyn L. Manske	DSU Class Field Tour ND Badlands	West ND	18-20-Sep-22
Llewellyn L. Manske	Seminar I: Getting more out of your pastures Pitchfork and Hoe Gathering	Valley City	30-Sep-22
Llewellyn L. Manske	Seminar II: Biologically Effective Management Pitchfork and Hoe Gathering	Valley City	1-Oct-22
Llewellyn L. Manske	DSU Lecture: Twice-over rotation system	Dickinson	5-Oct-22
Llewellyn L. Manske	DSU Lecture: Grassland ecology	Dickinson	7-Oct-22
Llewellyn L. Manske	Presentation: Twice-over rotation management system Saskatchewan Range Management Planning Meeting	Video Meeting	12-Oct-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	17-Oct-22
Llewellyn L. Manske	Fall Conference Planning Committee Meeting	Video Conference	24-Oct-22
Llewellyn L. Manske	NDSU Fall Conference	Fargo	1-3-Nov-22

Name	Topic	Location	Date
Douglas Landblom	Beef Cattle Progeny Difference with Dunn County Cattle Producers	Dunn County Commissioners Meeting Room, Manning, ND	01-Feb-22
Douglas Landblom	Beef Cattle Progeny Difference Presented to attendees at the Glendive Agriculture & Trade Exposition	Glendive, MT	11-Feb-22
Douglas Landblom	Synchronized Heifer Producer Survey Presentation and Invitation to Participate. ABS Producer meeting.	Golden Valley, ND	15-Feb-22
Douglas Landblom	Synchronized Heifer Producer Survey Presentation and Invitation to Participate. ABS Producer meeting.	Bowman, ND	16-Feb-22
Douglas Landblom	Synchronized Heifer Producer Survey Presentation and Invitation to Participate. ABS Producer meeting.	Buffalo, SD	23-Feb-22
Douglas Landblom	DREC Advisory Board Project Update	Dickinson, ND	31-Mar-22
Douglas Landblom	ND Stockmen's Assoc, Area % meeting	Amidon, ND	06-Jun-22
Douglas Landblom	DREC Advisory Board Meeting & Ranch Tour	Manning, ND	01-Jul-22
Douglas Landblom	Beef Cattle Reproductive Taskforce meeting	San Antonio, TX	29-31-Aug-22
Douglas Landblom	DREC Soil Health Workshop: integrated Syst,Intercropping, OM Management	DSU Biesiot Activities Center, Dickinson, ND DREC Ranch, Sec 19, Manning, ND	14-Sep-22
Douglas Landblom	ND Stockmen's Assoc, Annual meeting	Bismarck, ND	22-23-Sep-22
Douglas Landblom	NDSU Ext/REC Conference: Integrated Crop/Livestock Res Update for Agents	Fargo, ND	1-3-Nov-22
Douglas Landblom	DREC Reproductive Strategies Conference: Replacement heifer Synchronization and Cow Herd Management	Dickinson, ND	10-Nov-22

2022 Weekly Updates

Name	Topic	Date
Chris Augustin	Welcome	4-Jan-22
Llewellyn L. Manske	How did Kentucky bluegrass get to North America	25-Jan-22
Ryan Buetow	Soybean basics for southwest North Dakota	1-Feb-22
Doug Landblom	Grazing and delayed feedlot entry effect on small framed steer economics	8-Feb-22
Chris Augustin	Soil Testing is the number one practice to manage high fertilizer costs	15-Feb-22
Llewellyn L. Manske	"Ranching and Farming can Curb Climate Change"	22-Feb-22
Chris Augustin	Nitrogen credits maintain yields and save money	3-Mar-22
Doug Landblom	Drought: Early Weaning is a Management Option	8-Mar-22
Ryan Buetow	Acid soil band-aids	15-Mar-22
Llewellyn L. Manske	Management that can reduce mineral deficiencies	22-Mar-22
Chris Augustin	Surface Applied Lime Impacts on North Dakota No-till Soils	29-Mar-22
Doug Landblom	Is It Necessary to Apply That Much Fertilizer?	5-Apr-22
Chris Augustin	NDSU Dickinson Research Extension Center Relocates 20 trees to Accommodate Future Parking Lot	12-Apr-22
Llewellyn L. Manske	Determining Grazing Readiness of Perennial Grasses	19-Apr-22
Ryan Buetow	NSA Sunflower Survey and Drought	26-Apr-22
Doug Landblom	Drought Management Part II: Comparison of Early Weaned Calf Management Methods	3-May-22
Chris Augustin	Managing Soil Salinity that Yield Robbing White Spot	10-May-22
Llewellyn L. Manske	The Twice-Over Rotation Strategy	17-May-22
Ryan Buetow	Forage management for good times and bad	24-May-22
Doug Landblom	Principles of Soil Health	31-May-22
Chris Augustin	Diagnosing Nutrient Deficiencies	7-Jun-22
Llewellyn L. Manske	Prescribed Fire on Grasslands	14-Jun-22
Ryan Buetow	Dickinson Research Extension Center Field Day Set for July 13	16-Jun-22
Ryan Buetow	Input Efficiency	21-Jun-22
Doug Landblom	Mycorrhizal Fungi: Why are they important to agriculture?	28-Jun-22
Chris Augustin	Dickinson Research Extension Center is Looking for Your Input!	5-Jul-22
Llewellyn L. Manske	Reducing Detrimental Effects from Drought Conditions	15-Jul-22
Ryan Buetow	Lifelong Learning	19-Jul-22
Doug Landblom	Soil Health Workshop	26-Jul-22
Chris Augustin	Soil Sampling Post Small Grain Harvest	2-Aug-22
Llewellyn L. Manske	Deferred Rotation Grazing Practice History	9-Aug-22
Ryan Buetow	Goal based crop production	16-Aug-22
Doug Landblom	Soil Health Workshop	23-Aug-22
Chris Augustin	Manure Can Be Cost-effective Fertilizer	30-Aug-22

Llewellyn L. Manske	Idle Undisturbed Grasslands	6-Sep-22
Doug Landblom	Soil Health Workshop	13-Sep-22
Ryan Buetow	Acid Soil Management with Hard Red Spring Wheat	20-Sep-22
Llewellyn L. Manske	Weeds on Grasslands	4-Oct-22
Ryan Buetow	What are Ecosystem Services?	11-Oct-22
Doug Landblom	Reproductive Strategies: Replacement Heifer Synchronization and Cow Herd Management	18-Oct-22
Chris Augustin	Fall Nitrogen Recommendations	25-Oct-22
Doug Landblom	Reproductive Strategies: Replacement Heifer Synchronization and Cow Herd Management	1-Nov-22
Ryan Buetow	Buetow measurement of goals	8-Nov-22
Llewellyn L. Manske	Finding Microfossils of Ancestral Grasses with Cretaceous Age, 113 Million Years Ago	15-Nov-22
Llewellyn L. Manske	Grass Survival of Winter Cold	29-Nov-22
Ryan Buetow	Cultivar Selection	6-Dec-22
Doug Landblom	DREC Integrated Crop and Livestock Research Shows Benefits	13-Dec-22
Chris Augustin	Soil test 0-3 inches to pinpoint acidity acres	20-Dec-22
Llewellyn L. Manske	Soils of the Northern Plains	27-Dec-22

2022 Outreach List for DREC

DREC Hosted	Master Gardener Program 2022	DREC	Jan-March (every Friday)
	Meet With Area Legislator's		28-Jan-22
	Bayer Climate Fieldview Training		15-Feb-22
	West Plains Inc/AFS Software & Plains Ag Training		22-Mar-22
	Advisory Board Meeting		31-Mar-22
	DSU Appeal Hearing		20-Apr-22
	Defensive Driving Class		19-May-22
	Beef Cattle Breeding Research/Ed Program's		23-Jun-22
	Field Day 2022 Agronomy/Horticulture		13-Jul-22
	Advisory Board Meeting @ Manning Ranch		1-Aug-22
	Dickinson Public Schools meetings		1-2-Aug-22
	NAD Soybean Council		4-Aug-22
	DSU Class Soil Genesis & Survey		Fall 2022
	NDSU Geology		Sept. 2-8
	Carbon Capture meeting		13-Sep-22
	Rural Leadership ND		18-Nov-22
	4-H Club Meeting's		Nov. 2022- April 2023

Weather Summary

Monthly Temperature (°F)									
	Max Temp			Min Temp			Monthly Avg. Temp		
Month	2022	2021	2020	2022	2021	2020	2022	2021	2020
Jan	23	33	26	2	13	7	13	23	16
Feb	28	21	31	3	-4	11	16	9	21
Mar	40	51	43	18	20	22	29	36	32
Apr	43	54	51	25	26	24	34	40	38
May	64	64	66	39	38	38	51	51	52
Jun	75	82	81	50	52	51	62	67	66
Jul	24	89	83	57	58	56	41	73	69
Aug	85	83	84	56	53	55	71	68	70
Sep	78	79	72	49	47	43	64	63	57
Oct	56	60	50	34	37	26	45	48	38
Nov	31	46	46	14	22	22	22	34	34
Dec	16	27	36	-1	3	16	7	15	26

Monthly Precipitation (in)			
	Max Temp		
Month	2022	2021	2020
Jan	0.33	0.15	0.34
Feb	0.25	0.22	0.47
Mar	0.48	0.25	0.27
Apr	4.16	0.26	0.59
May	3.17	5.07	1.45
Jun	2.02	1.07	1.10
Jul	3.71	1.03	2.67
Aug	0.28	1.63	2.56
Sep	0.93	0.14	0.86
Oct	1.84	2.70	0.26
Nov	1.51	0.40	0.00
Dec	1.69	0.39	0.13