Impact of Geological and Meteorological Factors on the Disjunct Distribution of *Lesquerella ludoviciana* in Illinois

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Introduction

Lesquerella ludoviciana (Nutt.) S. Wats. (silvery bladderpod) is an endangered plant in Illinois where it occurs at the easternmost edge of its geographic range (Rollins and Shaw, 1973; Herkert and Ebinger, 2002). The only extant population in Illinois is at the Henry Allan Gleason Nature Preserve (HAGNP) where three colonies are found (Beach *et al.*, 2001; Herkert and Ebinger, 2002). The colonies are scattered and disjunct occurring with very adverse conditions in blowouts on vegetated sand dunes (i.e., sand prairies). Other areas apparently similar to HAGNP occur in Illinois. Parameters that influence why it occurs in some areas and not in others are not understood. The primary focus of this research was to understand how soil and other environmental parameters are associated with the presence of *L. ludoviciana* in localized areas within this nature preserve. The significance of this research is that it will allow a fuller understanding of the interaction between the biological, geological, and climatological factors affecting the survival and distribution of endangered species such as *L. ludoviciana,* as well as the functioning of blowouts within sand prairie habitats, and will provide information necessary for the long-term management of this species and other sand prairie species.

Research Objectives

The overall goal of this research was to understand what environmental parameters are associated with the disjunct distribution of *L. ludoviciana* in Illinois. The specific objectives were measurement and analysis of geological and meteorological parameters at the Henry Allan

Gleason Nature Preserve (HAGNP) in areas where *L. ludoviciana* is present and adjoining areas where it is absent from the community structure.

Site Description

The H. A. Gleason Nature Preserve is located in Mason County, Illinois, at 40° 23' N, W 89° 56' W (Figure 1), about 3 km to the ESE of the Illinois River. The surficial geological formation of the Preserve is the Parkland Sand, for which the source material was deposited by the Kankakee Torrent and reworked by wind (Wanless, 1957; Labotka and Hester, 1971). The outstanding geological feature of the preserve is a high, stabilized sand dune called Devil's Mound, which extends to an elevation of about 165 m, about 20 m above the surrounding, relatively flat regions to the east and west (Figure 1). A stabilized blowout immediately west of and below the peak of the dune is the location of the largest colonies of *L. ludoviciana.* This colony is referred to here as the North Colony, Lower Bowl. A shallower, smaller stabilized blowout immediately south of the peak of the dune is the location of one of the two smaller colonies, which is referred to here at North Colony, Upper Bowl. The third colony is located in another stabilized blowout on the side of a smaller dune about 0.5 km to the SSW which is referred to here as the South Colony.

The soil in which the *L. ludoviciana* colonies are found at HAGNP is the Plainfield sand, a mixed, mesic Typic Udipsamment, which is excessively well-drained, high in permeability and low in available water content and organic matter (Calsyn, 1995). In the stabilized blowouts where the colonies are found, the A horizon (topsoil) is absent.

Research Methodology

A. Soil geological properties

Soil samples of approximately 200 cm^3 were collected from the top 20 cm in triplicate from seven sites on 17 June 2003 from each of the three colonies and at four areas outside the colonies. See Figure 2 and Table 1 for locations and descriptions of sampling sites. These 21 samples were sent to A&L Labs, Memphis, TN, for analysis. One additional sample was taken from each location for soil grain size analysis, which was performed using the facilities of the Geology / Geography Department at EIU.

B. Soil meteorological properties

Two each soil temperature probes and capacitance-type soil moisture probes (ECH_2O model EC-20, manufactured by Decagon Devices, Inc., Pullman, WA) were purchased and buried, one each, at depths of 17 and 45 cm in the soil at the center of the North Colony, Lower Bowl on 20 May 2003. They were attached to a HOBO Weather Station datalogger (Onset Computer Corporation, Bourne, MA) and sampled at one-minute intervals, of which five-minute averages were saved by the datalogger. These operated quite reliably until late September 2003 when an animal, probably deer, chewed through the wires connecting the sensors to the datalogger. This damage necessitated digging up the sensors and returning them to the manufacturer for repair. They were re-installed in March 2004 at the same depth and at approximately the same location. Before re-installation, the soil moisture probes were calibrated using the technique recommended by the manufacturer.

For purposes of comparison (and because budget limitations did not permit the purchase of additional sensors), additional data were obtained from two nearby weather stations operated by the Illinois State Water Survey (ISWS): the Illinois Climate Network (ICN) (Hollinger et al., 1994) station at Kilbourne, located at 40° 10' N, 90° 5' W, about 25 km SSW from HAGNP, from which air and soil temperatures and precipitation were obtained, and the soil moisture monitoring station (Hollinger and Isard, 1994) at Topeka, located at 40° 18' N, 89° 54' W, about 10 km SSE from HAGNP from which the neutron probe soil moisture was obtained. The soil moisture monitoring site at Topeka has, like the site at HAGNP, a reported soil type of Plainfield sand.

Results & Discussion

A. Soil geological properties

Soil properties showed some clear differences between areas where *Lesquerella ludoviciana* was present (group a) and areas where vegetation was sparse (group b) while areas having vegetation but lacking *L. ludoviciana* were intermediate (Table 1). The statistical significance of the differences may be assessed by considering the variability of the average values over the three samples taken in each area, which is expressed in Table 2 as a coefficient of variation (CV). This table shows that the variability between the three samples taken in each area is usually much smaller than the differences between the groups of areas. Notice also the tendency for a large inter-sample variability at the intermediate site. Areas with *L. ludoviciana* tended to be higher in calcium, magnesium, manganese, zinc, soluble salts, nitrate-nitrogen, and cation exchange capacity, but lower in phosphorus and sulfur than areas with sparse vegetation. Areas with *L. ludoviciana* also had neutral soil pH (salt) whereas those with sparse vegetation were more acidic (including neutralizable acidity). These differences may relate to the fact that areas with sparse vegetation are the flatter areas that were farmed in the past, but also may be an indicator for why *L. ludoviciana* occurs in disjunct areas. Soil samples should be collected in other natural sand areas to expand comparisons.

Sand size did not differ greatly in areas with and without *L. ludoviciana* (Table 3). Most sand was medium to fine in size regardless of area where sampled. Hence sand size did not appear to be associated with where *L. ludoviciana* was found.

B. Soil meteorological properties

Soil temperature and moisture fluctuated throughout the growing season (Figures 3 and 4). Soil temperature was highest from mid-June through August when it was usually above 25°C and sometimes exceeded 30°C in the North Colony, Lower Bowl at HAGNP. During spring and summer at HAGNP, soil temperatures were higher at the shallower depth (17 cm) than at the deeper one (45 cm), implying a downward flux of heat in the soil, and suggesting (by extrapolation) an even higher soil surface temperature. Soil temperatures were also higher at HAGNP than the Kilbourne site, especially during summer. Over the period observed, air temperatures at Kilbourne were usually somewhat lower than the soil temperatures there, implying, as would be expected, a positive sensible heat flux from the soil surface. This air-soil temperature difference should occur at HAGNP as well, but it was not possible to observe it.

Soil moisture levels in the sandy soil at HAGNP were low, with volumetric water contents (VWCs) usually in the range of 0.05 to 0.15 during the summer of 2003 and 0.05 to 0.10 during the summer of 2004, and were lowest in July and August when precipitation also was lowest and soil temperatures the highest. The differences between 2003 and 2004 at HAGNP may have been affected by the damage and repair of the sensors; the calibration used was performed after the sensors' repair. Soil moisture typically was higher at 17 cm than at 45 cm, except after extended periods with limited rainfall when the reverse was true. The soil moisture at Topeka, measured intermittently by the ISWS with a different type of probe, was typically higher than what was observed at HAGNP, despite being located in the same soil. This may be due to several factors, including the type of probe and differences in soil properties (recall at HAGNP, the topsoil is lacking) and in vegetation.

Overall, as would be expected from the sandy soil and sparse vegetation, the soil climate at the North Colony, Lower Bowl at HAGNP is hot and dry during summer, as compared to nearby monitoring sites with similar conditions. These conditions point to adaptations of *L. ludoviciana* to such conditions, and suggest something of the uniqueness of the site where it is found. However, other apparently similar sand areas exist in Mason County. Precise characterization of their soil climates would be of interest.

The datalogger worked well to monitor soil temperature and moisture, with problems from animals being prevented by covering wires with PVC pipes.

Conclusions

Two years of investigations of soil geological and meteorological properties in around the sites where *L. ludoviciana* is found at H. A. Gleason Nature Preserve in Mason County, Illinois, were conducted. These studies show significant differences in some soil geological properties depending on vegetation cover within HAGNP, with the vegetated sites have higher levels of many mineral nutrients, as well as higher (neutral) rather than acidic pH, while soil grain size distributions did not differ significantly. Differences in soil meteorology (temperature and moisture) as compared to nearby sites outside HAGNP monitored by others, with soil at HAGNP being hotter and drier, were also observed. Additional monitoring of similar sites would be necessary in order to determine if these properties can explain the disjunct distribution of *L. ludoviciana* in Illinois.

References

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Figures

1. Map showing the location of H. A. Gleason Nature preserve in Illinois and the surface deposits of Illinois.

2. Map showing location of *L. ludoviciana* colonies and soil sampling locations within H. A. Gleason Nature Preserve, Mason County, Illinois.

3. Graphs showing daily average soil and air temperatures at H. A. Gleason Nature Preserve site and at the Illinois Climate Network site at Kilbourne: (a) May through September 2003, (b) March through November, 2004.

4. Graph showing calibrated soil moisture (as expressed as volumetric water content (VWC), which is the volume of water per unit volume of soil) and precipitation at H. A. Gleason Nature Preserve site and at the Illinois soil moisture monitoring site at Topeka: (a) May through September 2003, (b) March through November, 2004.

Table 1. Results of soil tests: Averages over three samples. [Abbreviations: LB: North Colony, Lower Bowl, LBW: West of Lower Bowl, UB: North Colony, Upper Bowl, NCS: South of North Colony, OS: Open Sand, SC: South Colony, OM: Organic Matter, OM-ENR: Estimated Nitrogen Release from Organic Matter, Neut. Acid: Neutralizable Acidity, CEC: Cation Exchange Capacity]

	Averages over the three samples							Group Behavior	
Site:	1-LB	2-LBW	3-UB	4-NCS	5-OS	6-Flats	7-SC		
Group:	(a)	(a)	(a)	inter-mediate	(b)	(b)	(a)	(a)	(b)
Constituent									
pH (Salt)	6.60	6.87	6.53	5.30	4.43	4.13	6.83	neutral	acid
Buffer pH	7.00	7.00	6.99	6.77	6.78	6.57	6.98		
P (ppm)	2.00	7.67	7.33	26.3	30.7	40.3	8.67	low	high
K (ppm)	28.3	37.0	34.3	49.3	15.0	32.3	36.3		
Ca (ppm)	1917	1163	1769	491	23.0	125	1064	high	low
Mg (ppm)	106	116	119	74.7	7.00	8.33	147	high	low
S (ppm)	5.67	7.67	9.00	11.33	11.33	16.33	7.00	low	high
B (ppm)	0.47	0.60	0.60	0.53	0.30	0.43	0.60		
Cu (ppm)	1.33	1.43	1.33	1.20	1.10	1.27	1.43		
Fe (ppm)	50.3	41.3	52.7	71.0	47.7	77.7	52.3		
Mn (ppm)	41.7	40.7	41.7	26.7	7.00	10.7	50.3	high	low
Zn (ppm)	1.50	2.57	1.97	1.93	0.50	0.90	2.03	high	low
Na (ppm)	5.00	4.33	4.33	9.33	2.67	7.33	8.67		
Soluble Salts (mmhos/cm)	0.12	0.13	0.14	0.09	0.03	0.07	0.10	high	low
OM (%)	0.83	1.10	1.33	1.17	0.27	1.17	0.80		
OM-ENR (ppm)	30	33	35	34	24	34	30		
NO3-N (ppm)	22.3	25.3	21.0	12.3	5.67	9.67	15.7	high	low
Neut. Acid (meqH/100g)	0.00	0.03	0.10	2.30	2.17	4.33	0.17	low	high
CEC (meq/100g)	8.47	5.60	8.07	4.27	1.70	3.70	5.60	high	low
%K	0.83	1.63	1.07	2.90	2.17	2.13	1.60		
%Ca	89.4	81.5	86.3	43.7	5.33	13.6	73.9	high	low
%Mg	9.57	16.57	11.63	12.70	3.20	1.73	21.17	high	low
%H	0.00	0.33	0.80	40.23	89.4	81.8	2.07	low	high
%Na	0.27	0.37	0.23	0.97	0.67	0.90	0.67		
K:Mg	0.08	0.10	0.09	0.37	0.69	1.24	0.08	low	high

Table 2: Results of soil tests: Variability among three samples. [Abbreviations: CV: coefficient of variation (standard deviation / mean), undef.: undefined; see Table 1 for other abbreviations.]

	CVs						
Group:	(a)	(a)	(a)	inter-mediate	(b)	(b)	(a)
	1-LB	2-LBW	3-UB	4-NCS	5-OS	6-Flats	7-SC
pH (Salt)	5%	1%	2%	22%	1%	3%	4%
Buffer pH	0%	0%	0%	3%	1%	2%	0%
P	0%	27%	44%	51%	13%	19%	47%
K	14%	10%	15%	21%	7%	22%	15%
Ca	7%	27%	17%	65%	19%	41%	33%
Mg	4%	14%	18%	84%	29%	30%	28%
S	10%	8%	22%	22%	5%	4%	14%
B	12%	0%	17%	11%	0%	13%	17%
Cu	4%	8%	9%	8%	0%	5%	11%
Fe	8%	4%	5%	27%	11%	9%	22%
Mn	10%	1%	1%	44%	14%	24%	23%
Zn	27%	21%	41%	30%	20%	19%	36%
Na	20%	35%	27%	33%	43%	8%	13%
Soluble Salts	14%	9%	21%	34%	0%	14%	6%
OM (%)	18%	0%	37%	20%	22%	18%	12%
OM - ENR	5%	0%	14%	7%	4%	6%	3%
NO3-N	17%	36%	25%	103%	20%	16%	21%
Neut. Acid	undef.	173%	100%	77%	16%	30%	69%
CEC	6%	22%	14%	13%	18%	28%	22%
%K	14%	19%	27%	31%	17%	11%	29%
%Ca	1%	5%	4%	53%	12%	46%	13%
%Mg	8%	31%	32%	72%	25%	15%	39%
%H	undef.	173%	94%	79%	2%	8%	66%
%Na	22%	16%	25%	32%	31%	19%	23%
K:Mg	12%	20%	0%	90%	23%	25%	15%

Table 3. Sand Size. [See Table 1 for abbreviations.]

Sieve Size (mm)	**Percent Not Passing Sieve**							
	1-LB	**2-LBW**	**3-UB**	**4-NCS**	**5-OS**	**6-FLATS**	**7-SC**	**Avg.**
1 (Very Coarse Sand)	0.1	0.2	0.1	0.2	0.0	0.3	0.2	0.2
0.5 (Coarse Sand)	3.7	4.0	3.6	4.7	3.6	4.3	2.4	3.8
0.25 (Med. Sand)	56.1	56.3	56.0	56.7	64.5	55.4	54.3	57.1
0.125 (Fine Sand)	30.1	30.1	31.2	29.4	28.7	31.1	33.0	30.5
0.063 (Very Fine Sand)	8.4	7.3	7.5	6.4	2.8	7.7	7.8	6.8
< 0.063 (Silt)	1.6	2.1	1.6	2.3	0.4	1.2	2.3	1.6

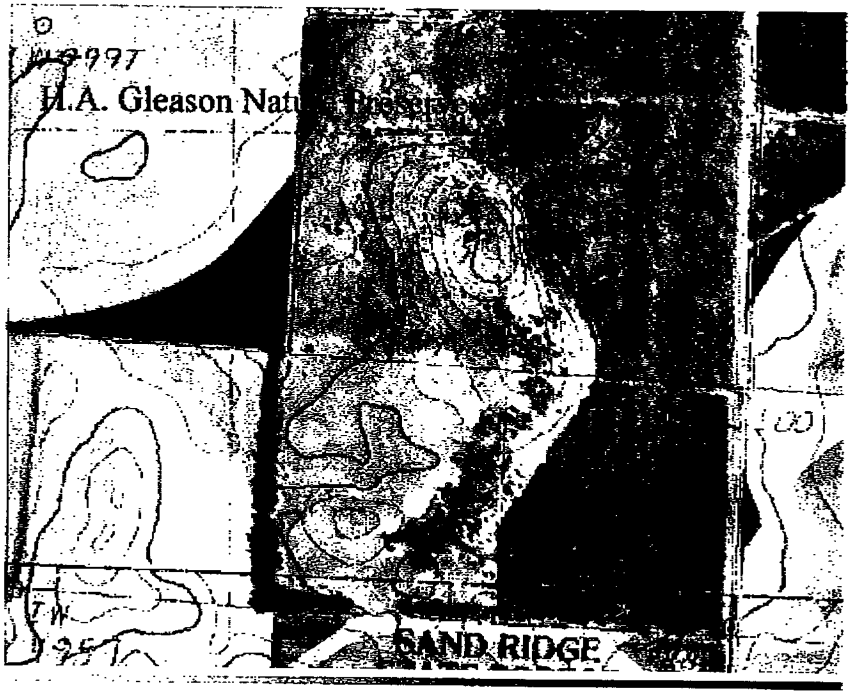


Figure 1.

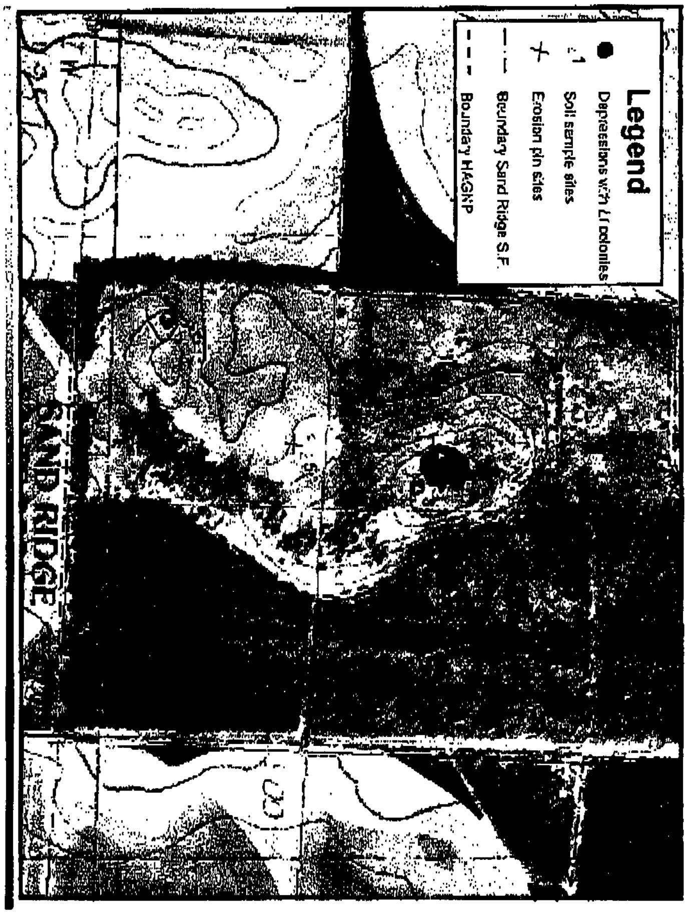
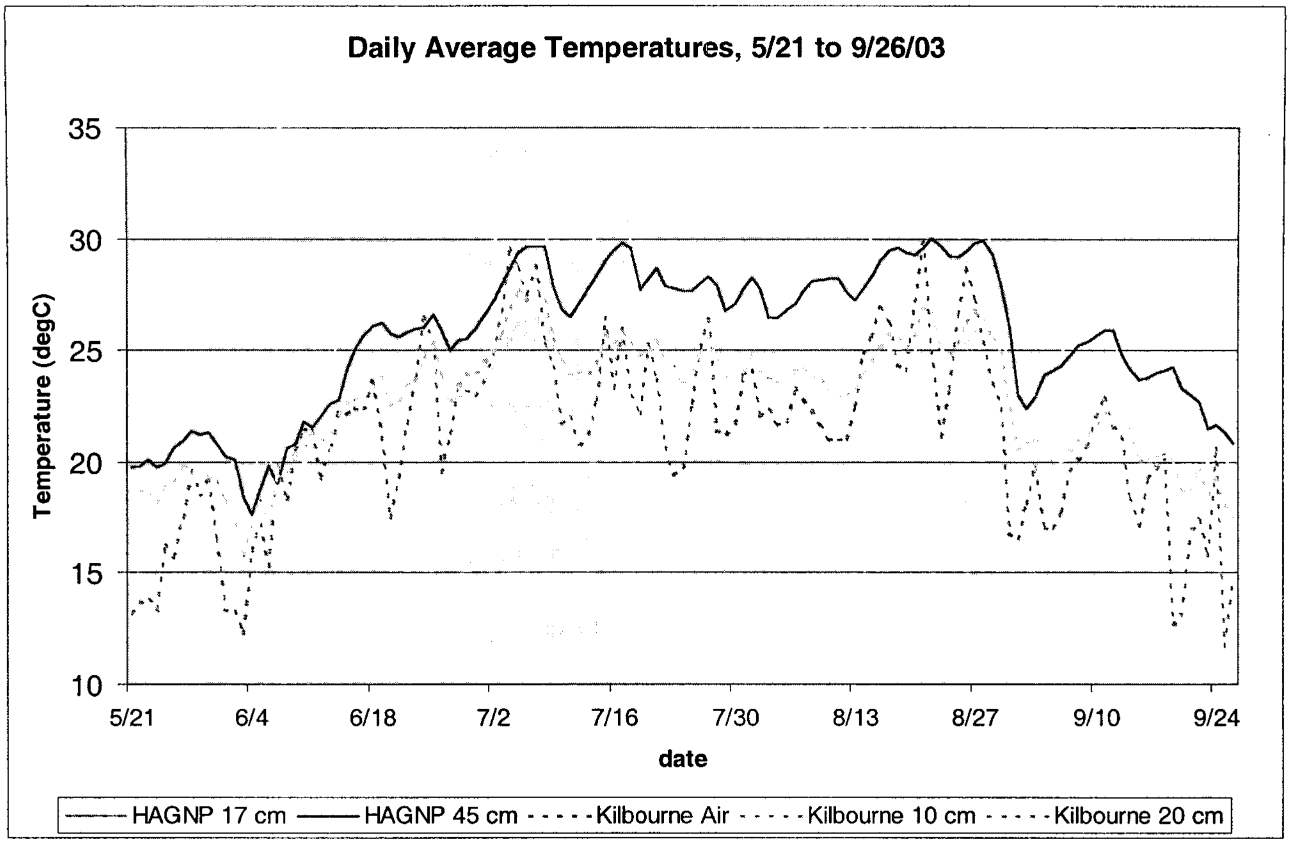

Legend
Depressions with Lr colonies
Soil sample sites
Erosion pin sites
Boundary Sand Ridge S.F.
Boundary HAGNP
SAND RIDGE

Figure 2.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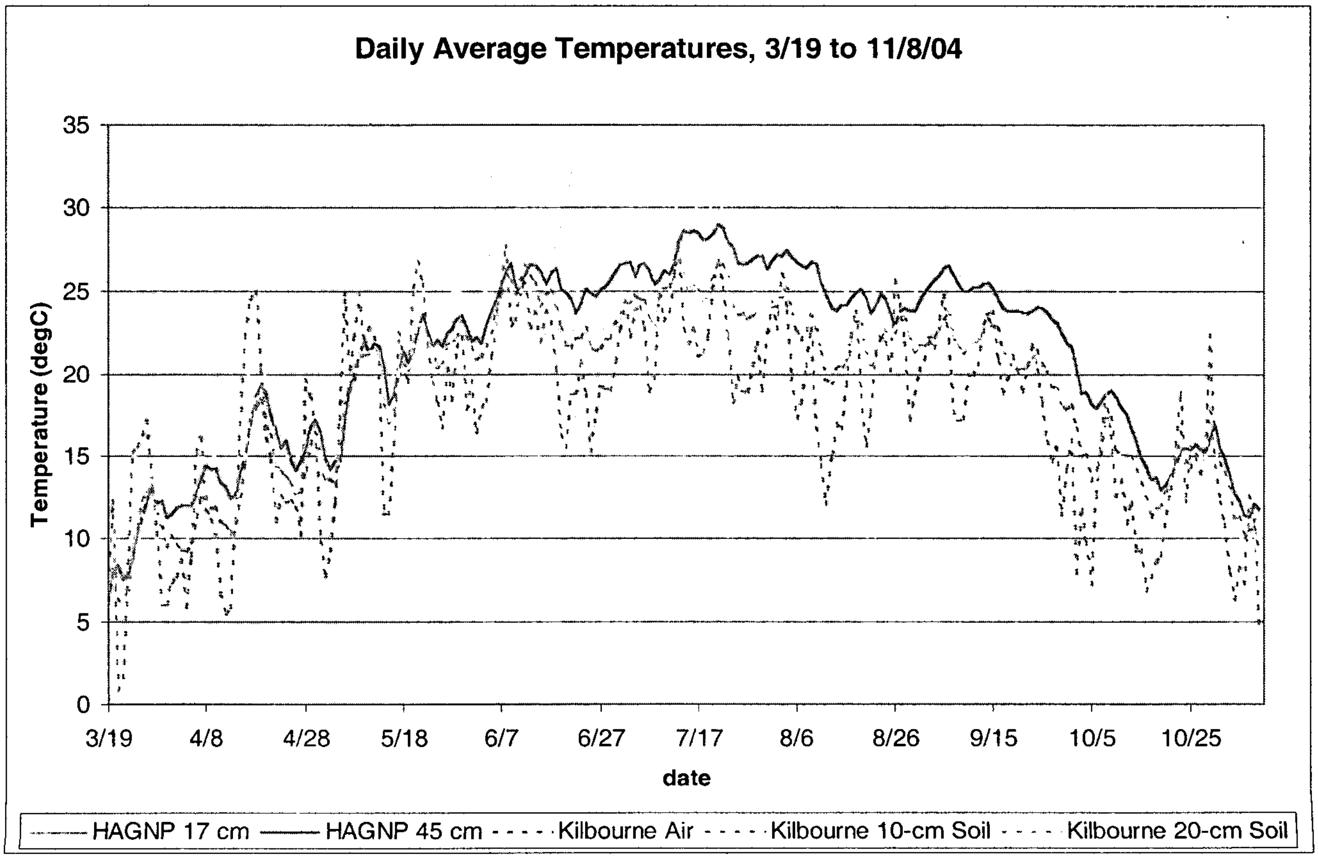
Temperature (degC)
35
30
25
20
15
10
5/21
6/4
6/18
7/2
7/16
7/30
8/13
8/27
9/10
9/24
date
HAGNP 17 cm
HAGNP 45 cm
Kilbourne Air
Kilbourne 10 cm
Kilbourne 20 cm


Daily Average Temperatures, 3/19 to 11/8/04
Temperature (degC)
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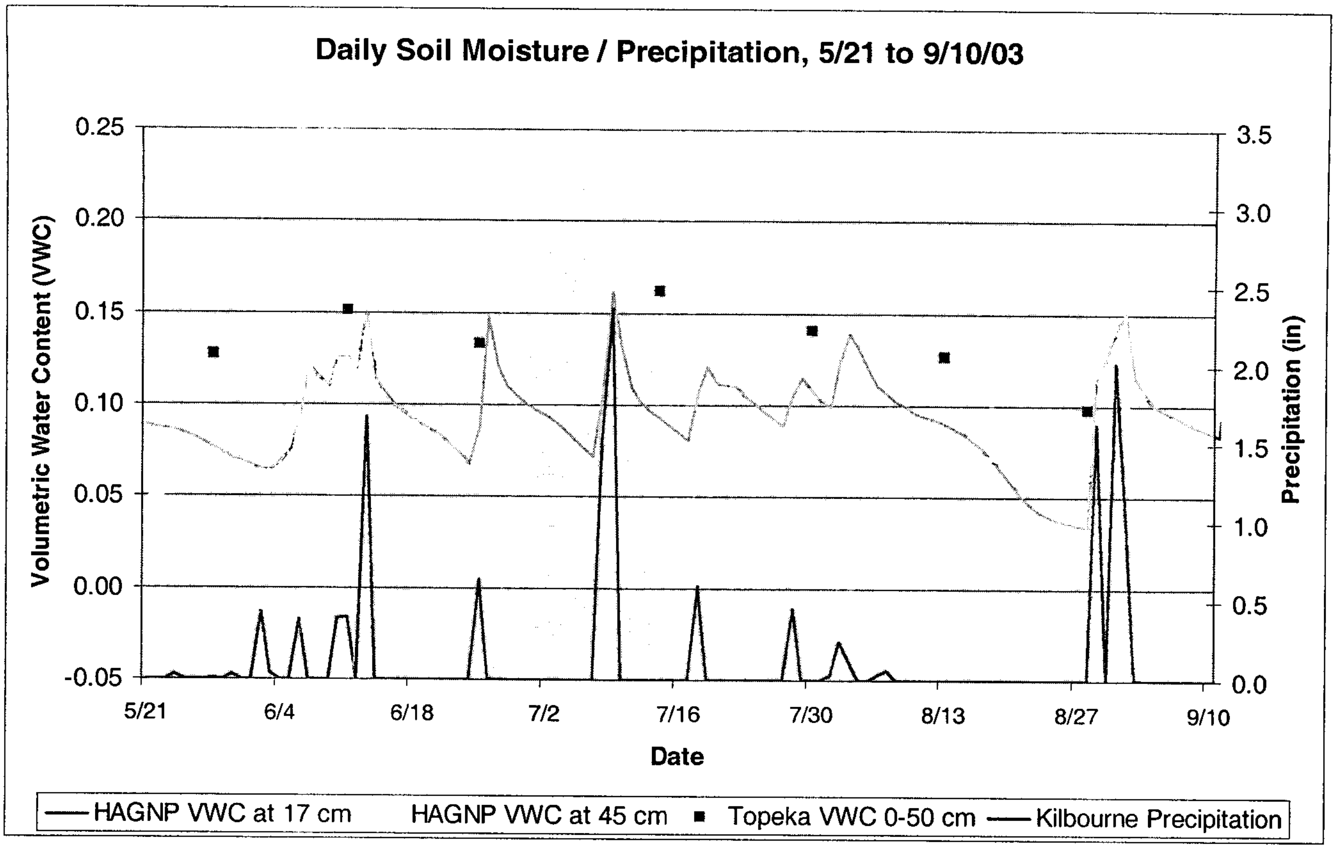
30
25
20
15
10
5
0
3/19
4/8
4/28
5/18
6/7
6/27
7/17
8/6
8/26
9/15
10/5
10/25
date
HAGNP 17 cm
HAGNP 45 cm
Kilbourne Air
Kilbourne 10-cm Soil
Kilbourne 20-cm Soil


Daily Soil Moisture / Precipitation, 5/21 to 9/10/03
Volumetric Water Content (VWC)
Precipitation (in)
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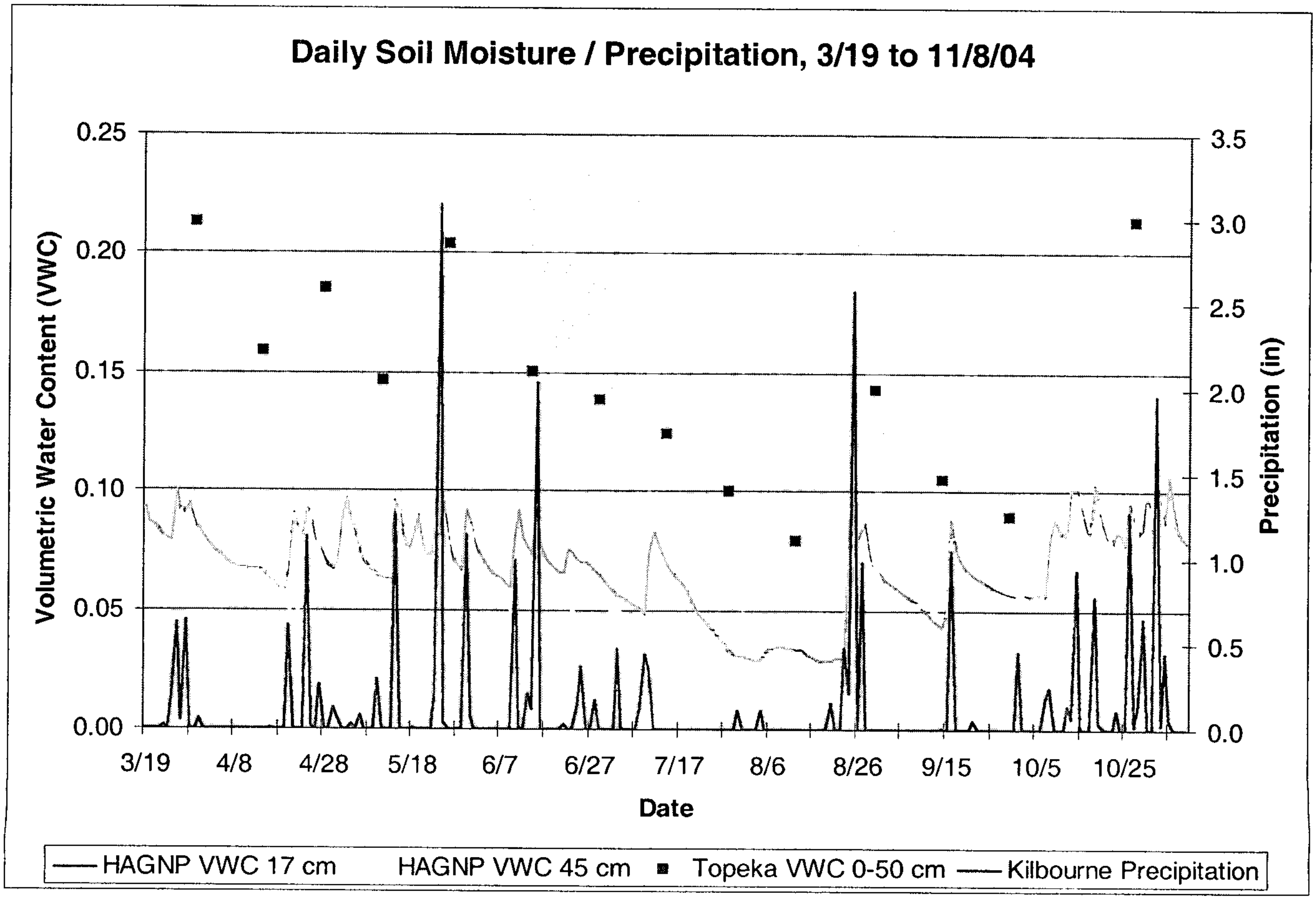
0.20
0.15
0.10
0.05
0.00
-0.05
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5/21
6/4
6/18
7/2
7/16
7/30
8/13
8/27
9/10
Date
HAGNP VWC at 17 cm
HAGNP VWC at 45 cm
Topeka VWC 0-50 cm
Kilbourne Precipitation


Daily Soil Moisture / Precipitation, 3/19 to 11/8/04
Volumetric Water Content (VWC)
Precipitation (in)
0.25
0.20
0.15
0.10
0.05
0.00
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3/19
4/8
4/28
5/18
6/7
6/27
7/17
8/6
8/26
9/15
10/5
10/25
Date
HAGNP VWC 17 cm
HAGNP VWC 45 cm
Topeka VWC 0-50 cm
Kilbourne Precipitation