Field Crops Research 118 (2010) 259–263

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Critical precipitation period for dryland maize production

David C. Nielsen[a,*], Ardell D. Halvorson[b], Merle F. Vigil[a]

[a] USDA-ARS, Central Great Plains Research Station, 40335 County Road GG, Akron, CO 80720, United States
[b] USDA-ARS, 2150 Centre Ave, Building D, Ste. 100, Fort Collins, CO 80526-8119, United States

ARTICLE INFO

Article history:
Received 22 March 2010
Received in revised form 1 June 2010
Accepted 3 June 2010

Keywords:
Maize
Yield
Precipitation
Soil water

ABSTRACT

Grain yields for dryland maize (*Zea mays* L.) production in the semi-arid Great Plains of the United States can be unpredictable because of the erratic nature of growing season precipitation. Because of the high input costs for maize production, farmers need to have a tool that will help them assess the risk associated with dryland maize production. The objectives of this work were to determine the critical period for precipitation during the maize growing season and to develop a relationship between critical period precipitation and maize yield to use as a tool to quantify expected yield variability associated with dryland maize production in this region. Maize yield data were collected at Akron, CO from two dryland cropping systems experiments (1984–2009) in which maize was grown in a 3-year winter wheat (*Triticum aestivum* L.)–maize–fallow rotation. Yields were correlated with weekly precipitation amounts from planting to harvest in search of the period of time in which yield was most influenced by precipitation. Soil water contents at planting were measured either by gravimetric sampling or by neutron attenuation. Yields were found to be most closely correlated with precipitation occurring during the 6-week period between 16 July and 26 August. The data separated into two linear relationships defined by whether the sum of available soil water at planting and May precipitation was less than or greater than 250 mm. These two linear relationships between precipitation during this critical period and yield were used with long-term precipitation records to determine the probability of obtaining a maize yield of at least 2500 kg ha^{-1} (generally considered to be a break-even yield) at three locations across the central Great Plains precipitation gradient. This analysis quantified the production risk associated with the highly variable corn yields that result from erratic summer precipitation in this region.

Published by Elsevier B.V.

1. Introduction

Maize has been increasingly used as a component of winter wheat-based dryland cropping systems in the central Great Plains (Farahani et al., 1998; Anderson et al., 1999; Nielsen et al., 2005; Bowman et al., 1999; Peterson and Westfall, 2004; Norwood and Currie, 1998; Lyon et al., 2003). For example, in Colorado the fraction of dryland hectares planted to maize has risen from 0.6% in 1984 to about 12% in 2001, and thereafter remained relatively constant between 10 and 15% of planted dryland hectares (USDA-NASS Quick Stats-Crops, available at http://www.nass.usda.gov/QuickStats, verified 5/21/2010). The primary production system for dryland maize in Colorado is wheat–maize–fallow. But dryland maize yield can be greatly reduced by water stress that occurs during the reproductive stages of tasseling, silking, and pollination when the number of ovules that will be fertilized is being determined (Shaw, 1976; Robins and Domingo, 1953; Denmead and Shaw, 1960; Claassen and Shaw, 1970). Soil water depletion to the wilting point for 2 days during tasseling or pollination was reported by Robins and Domingo (1953) to decrease maize yield by 22%, while a 6–8-day period of such soil moisture stress could cause a yield reduction of 50%. Water stress at tasseling and silking reduces viability of maize pollen, delays silk emergence past pollen shed, and results in desiccation of silks, while subsequent water stress can induce embryo abortion or reduce the potential size of kernels (Waldren, 1983; Hall, 2001). Westgate (1994) provided a comprehensive review of literature describing the effects of water stress on the physiology of the maize plant in reproductive development that ultimately results in decreased seed yield.

In a more recent study, Nielsen et al. (2009) showed that maize yields in northeastern Colorado increased as soil water content at planting increased, but that the relationship between these two quantities was greatly influenced by the precipitation that fell from 15 July to 25 August (approximately 10 days prior to tasseling through the middle of grain filling). The yield response to available soil water at planting increased dramatically as the amount of precipitation during this critical phase of development increased.

---

* Corresponding author. Tel.: +1 970 345 0507; fax: +1 970 345 2088.
E-mail address: david.nielsen@ars.usda.gov (D.C. Nielsen).

0378-4290/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.fcr.2010.06.004

Table 1
Weekly precipitation at Akron, CO during the maize growing season (1984–2008).

Year	Week ending																				
	5/13	5/20	5/27	6/3	6/10	6/17	6/24	7/1	7/8	7/15	7/22	7/29	8/5	8/12	8/19	8/26	9/2	9/9	9/16	9/23	9/30	Total
												(mm)										
1984	0	17	8	6	17	24	13	21	11	0	20	0	47	58	2	9	5	0	2	1	5	266
1985	45	22	1	5	17	1	3	8	1	1	64	3	59	1	11	0	28	8	3	13	9	303
1986	14	22	0	39	70	0	7	1	0	2	6	0	4	6	6	2	10	12	1	1	1	204
1987	6	23	26	1	16	3	29	10	37	11	17	0	54	15	4	28	0	10	12	9	0	311
1988	0	72	11	11	4	3	6	30	33	6	15	11	3	26	8	0	2	0	15	0	8	264
1989	10	11	0	20	67	0	12	14	0	36	0	0	11	56	5	5	17	10	13	2	0	289
1990	16	9	50	28	10	12	0	1	35	5	29	51	34	17	54	7	0	1	0	11	6	376
1991	0	31	24	58	9	5	1	3	7	24	21	24	6	4	1	0	15	0	3	0	0	236
1992	3	0	12	44	2	14	25	38	11	13	15	12	5	11	13	70	4	0	0	1	0	293
1993	0	0	12	7	25	2	17	0	15	10	45	30	4	11	15	6	1	1	9	14	0	224
1994	8	3	12	0	1	0	5	0	11	26	20	13	6	11	4	5	5	0	1	7	0	138
1995	77	6	36	53	49	0	28	7	3	18	17	0	1	13	0	0	7	24	1	20	16	376
1996	21	2	66	27	3	34	22	6	36	17	1	17	26	4	15	15	22	1	11	65	7	418
1997	0	6	38	21	19	10	2	38	1	2	7	21	15	17	7	5	18	22	0	3	0	252
1998	10	1	9	2	2	0	6	0	22	12	17	28	34	44	1	0	0	0	2	6	0	196
1999	0	15	0	40	19	23	4	15	0	5	29	6	75	30	0	27	41	0	0	11	28	368
2000	3	9	5	3	0	15	0	3	3	15	47	0	13	0	9	16	17	5	0	24	10	197
2001	0	5	0	45	13	13	0	2	2	27	0	37	37	6	14	1	0	25	18	1	0	246
2002	1	6	3	1	22	2	19	0	1	0	0	2	11	1	0	2	27	13	23	0	1	135
2003	77	7	2	16	19	64	13	5	11	6	0	6	2	22	4	1	0	20	1	1	1	278
2004	8	15	3	13	6	12	38	11	16	0	15	19	2	45	5	12	9	14	12	10	5	270
2005	17	1	16	26	36	7	21	12	23	49	0	8	8	23	4	49	0	9	0	0	2	311
2006	5	0	29	3	0	13	2	3	18	2	17	20	6	2	3	7	73	3	3	21	0	230
2007	5	8	16	23	0	32	3	0	0	4	2	42	0	17	47	26	0	2	2	1	11	241
2008	3	0	13	8	61	0	3	0	13	0	5	26	6	90	63	0	0	22	10	0	0	323
2009	7	0	24	32	13	48	13	13	40	4	6	40	4	8	3	4	10	7	1	0	0	277
Average	13	12	16	20	19	13	11	9	13	12	16	16	18	21	12	12	12	8	6	9	4	272

23.6 kg ha^{-1} for every additional mm of precipitation received during this 6-week period.

Inspection of the data points in Fig. 1A indicated two distinctly different responses to precipitation during this period. All but two of the 14 points that are above the regression line in Fig. 1A came from years when the sum of available soil water at planting and May precipitation (ASWP + MP) was greater than 250 mm (Table 3). Fig. 1B shows the data separated into the two categories defined by ASWP + MP greater than 250 mm (open circles) and ASWP + MP less than 250 mm (closed circles).

Table 2
Linear regression (yield [kg ha^{-1}] = $a + b \times$ precipitation [mm]) statistics for several relationships between precipitation during various periods and dryland maize yield at Akron, CO (1984–2009).

Precipitation period	Weeks	a	b	R^2	P
2 July–8 July	1	2829	32.8	0.06	0.27
9 July–15 July	1	3528	−26.3	0.05	0.32
16 July–22 July	1	3119	5.6	0.00	0.78
23 July–29 July	1	2517	45.3	0.18	0.04
30 July–5 August	1	2550	38.2	0.26	0.01
6 August–12 August	1	2680	24.7	0.13	0.09
13 August–19 August	1	2634	47.0	0.28	<0.01
20 August–26 August	1	3268	4.1	0.00	0.82
27 August–2 September	1	3492	22.7	0.06	0.24
23 July–5 August	2	1844	41.9	0.45	<0.01
23 July–12 August	3	1462	32.2	0.52	<0.01
23 July–19 August	4	1478	26.0	0.58	<0.01
16 July–19 August	5	1275	23.2	0.53	<0.01
16 July–26 August	6	1100	23.6	0.67	<0.01
16 July–2 September	7	921	21.4	0.48	<0.01
9 July–26 August	7	716	23.4	0.54	<0.01
9 July–2 September	8	655	21.5	0.44	<0.01
2 July–26 August	8	611	22.0	0.55	<0.01
2 July–2 September	9	501	20.8	0.46	<0.01
25 June–26 August	9	496	21.5	0.57	<0.01
25 June–2 September	10	375	20.5	0.49	<0.01

Yield increased at a rate of 20.5 kg ha^{-1} per mm of precipitation when ASWP + MP was greater than 250 mm (open circles, top line in Fig. 1B). This regression relationship explained 87% of the yield variation occurring in these 12 years. But under drier early season conditions (ASWP + MP less than 250 mm, filled circles, lower line in Fig. 1B) maize yields were distinctly lower for the same amount of precipitation between 16 July and 26 August. Under these drier conditions yield increased at a rate of 32.2 kg ha^{-1} per

Table 3
Available soil water at maize planting (ASWP) and May precipitation (MP) at Akron, CO.

Year	ASWP (mm)	MP (mm)	ASWP + MP (mm)
1984	165	59	224
1985	201	85	286
1986	276	56	332
1987	249	113	362
1988	160	136	296
1989	127	24	151
1990	197	104	301
1991	212	104	316
1992	234	28	262
1993	151	27	178
1994	156	29	185
1995	316	145	461
1996	173	116	289
1997	170	53	223
1998	132	25	157
1999	79	80	159
2000	243	20	263
2001	320	107	427
2002	162	13	175
2003	197	92	289
2004	142	38	180
2005	106	68	174
2006	162	37	199
2007	192	57	249
2008	268	53	311
2009	215	39	254

critical period precipitation was found to be linear, with the slope of the response being dependent on the sum of available soil water at planting and May precipitation. When that sum was greater than 250 mm, maize yield increased 20.5 kg ha^{-1} per mm of precipitation falling between 16 July and 26 August. The slope of the response was 32.2 kg ha^{-1} per mm of precipitation under drier early season conditions when the sum of available soil water at planting and May precipitation was less than 250 mm.

The two well defined linear relationships between maize yield and critical period precipitation were used with long-term precipitation records from three Central Great Plains locations to construct yield probability distributions. Those probability distributions indicated that the probability of achieving at least a break-even yield of 2500 kg ha^{-1} ranged from 20% (Fort Morgan) to 52% (McCook) when the sum of available soil water at planting was less than 250 mm, but that the probabilities increased to 93% (Fort Morgan) to 97% (McCook) when early season water availability was greater. These results confirm the conclusion of Nielsen et al. (2009) that profitable dryland maize production in the central Great Plains remains a highly risky enterprise, but the risk is significantly lower when available soil water at planting is near field capacity and/or if May precipitation is much above average resulting in significant early season precipitation storage. This suggests that farmers could use measurements of available soil water at planting and long-term precipitation records to quantify the risk associated with dryland maize production and to make a decision about whether or not to plant maize.

Acknowledgement

The authors express their appreciation to Tawney Bleak for assistance with data analysis.

References

Anderson, R.L., Bowman, R.A., Nielsen, D.C., Vigil, M.F., Aiken, R.M., Benjamin, J.G., 1999. Alternative crop rotations for the central Great Plains. J. Prod. Agric. 12, 95–99.

Bowman, R.A., Vigil, M.F., Nielsen, D.C., Anderson, R.L., 1999. Soil organic matter changes in intensively cropped dryland systems. Soil Sci. Soc. Am. J. 63, 186–191.

Claassen, M.M., Shaw, R.H., 1970. Water deficit effects on corn. II. Grain components. Agron. J. 62, 652–655.

Denmead, O.T., Shaw, R.H., 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J. 52, 272–274.

Farahani, H.J., Peterson, G.A., Westfall, D.G., 1998. Dryland cropping intensification: a fundamental solution to efficient use of precipitation. Adv. Agron. 64, 197–223.

Hall, A.E., 2001. Crop Responses to Environment. CRC Press, New York.

Halvorson, A.D., Nielsen, D.C., Reule, C.A., 2004. Nitrogen fertilization and rotation effects on no-till dryland wheat production. Agron. J. 96, 1196–1201.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M., Smith, C.J., 2003. An overview of APSIM, a model designed for farming systems simulation. Eur. J. Agron. 18, 267–288.

Lyon, D., Boa, J.F., Arkebauer, T.J., 1995. Water-yield relations of several spring-planted dryland crops following winter wheat. J. Prod. Agric. 8, 281–286.

Lyon, D.J., Hammer, G.L., McLean, G.B., Blumenthal, J.M., 2003. Simulation supplements field studies to determine no-till dryland corn population recommendations for semiarid western Nebraska. Agron. J. 95, 884–891.

Martin, D., 2007. Impact of advances in irrigation engineering and management. In: 2007 Water Law, Policy and Science Conference, The Future of Water Use in Agriculture, University of Nebraksa, Lincoln, NE, 26–27 March 2007 (available at http://watercenter.unl.edu/WaterConference/2007WLPS/PPTs/Martin.pdf, verified 3/23/2010).

Nielsen, D.C., Unger, P.W., Miller, P.R., 2005. Efficient water use in dryland cropping systems in the Great Plains. Agron. J. 97, 364–372.

Nielsen, D.C., Vigil, M.F., Benjamin, J.G., 2009. The variable response of dryland corn grain yield to soil water content at planting. Agric. Water Manage. 96, 330–336.

Norwood, C.A., Currie, R.S., 1998. An agronomic and economic comparison of the wheat–corn–fallow and wheat–sorghum–fallow rotations. J. Prod. Agric. 11, 67–73.

Peterson, G.A., Westfall, D.G., 2004. Managing precipitation use in sustainable dryland agroecosystems. Ann. Appl. Biol. 144, 127–138.

Peterson, G.A., Westfall, D.G., Peairs, F.B., Sherrod, L., Gangloff, W., Larson, K., Thompson, D.L., Ahuja, L.R., Koch, M.D., Walker, C.B., 1999. Sustainable dryland agroecosystem management. Tech. Bull. TB99-1. Colorado State University Agricultural Experiment Station, Fort Collins (available at http://www.colostate.edu/Depts/AES/Pubs/pdf/tb99-1.pdf, verified 3/23/2010).

Ratliff, L.F., Ritchie, J.T., Cassel, D.K., 1983. A survey of field-measured limits of soil water availability and related laboratory-measured properties. Soil Sci. Soc. Am. J. 47, 770–775.

Ritchie, J.T., 1981. Soil water availability. Plant Soil 58, 327–338.

Robins, J.S., Domingo, C.E., 1953. Some effects of severe soil moisture deficits at specific growth stages in corn. Agron. J. 45, 618–621.

Schlegel, A., Thompson, C., Dumler, T., 2007. Large-scale dryland cropping systems. Kansas State University (available on-line at http://www.wkarc.org/DesktopDefault.aspx?tabid=81, verified 3/23/2010).

Shaw, R.H., 1976. Climatic requirement. In: Sprague, G.F. (Ed.), Corn and Corn Improvement. Agronomy 18, 591–623.

Waldren, R.P., 1983. Corn. In: Teare, I.D., Peet, M.M. (Eds.), Crop–Water Relations. John Wiley and Sons, Inc., New York, pp. 187–211.

Westgate, M.E., 1994. Seed formation in maize during drought. In: Boote, K.J., Bennett, J.M., Sinclair, T.R., Paulsen, G.M. (Eds.), Physiology and determination of crop yield. ASA-CSSA-SSSA, Madison, WI, pp. 361–364.