Hindawi Publishing Corporation
International Journal of Agronomy
Volume 2012, Article ID 925408, 10 pages
doi:10.1155/2012/925408

Research Article

Corn Hybrid Response to Water Management Practices on Claypan Soil

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Received 19 January 2012; Revised 17 February 2012; Accepted 4 March 2012

Academic Editor: Bernd Lennartz

A study evaluated corn (*Zea mays* L.) hybrids (Asgrow785, DKC61-73, DKC63-42, LG2642, and Kruger2114) and water management systems (nondrained, nonirrigated (NDNI); drained, nonirrigated (DNI) with subsurface drain tiles 6.1 and 12.2 m apart; drained plus subirrigated (DSI) with tiles 6.1 and 12.2 m apart; nondrained, overhead irrigated (NDOHI)) on yields, plant population, and grain quality from 2008 to 2010. Precipitation during this study was 36 to 283 mm above the past decade. Planting date was delayed 18 d in the nondrained control in 2009, and additional delayed planting controls were included this year. Grain yields were similar in the 6.1- and 12.2 m-spaced DNI and DSI systems in 2008 and 2010, but plant population increased 74% and yields were 3.1 Mg ha^{-1} greater with DSI at a 6.1 m spacing compared to 12.2 m in 2009. At a 6.1 m spacing, DNI or DSI increased yield 1.1 to 6.6 Mg ha^{-1} (10 to over 50%) compared to NDNI or NDOHI soil. High yielding hybrids achieved similar yields with DNI, while NDNI DKC63-42 had 1.2 Mg ha^{-1} greater yields compared to DKC61-73. A 6.1 m spacing for DNI claypan soils is recommended for high yielding corn production.

1. Introduction

Within-season climate variability is a primary factor affecting corn yields in Missouri [1]. Although Midwestern farmers have been planting up to two weeks earlier than in the 1980s [2], recommendations for initiating planting continue to be based on field conditions and soil temperature [3]. Soils that are cool and wet can delay planting. Adequate soil drainage helps soils dry and warm quickly. The distribution of rainfall in upstate Missouri generally peaks in mid-April to mid-May, with periods of drought and little water available to plants in late June, July, and early August [4–7]. Drought conditions during July and August are usually yield limiting in claypan soils, due to their low water-holding capacity [1, 4, 8]. However, these soils' poor drainage may contribute to excessive yield loss, due to stand loss, fertilizer loss, and poor root development [4, 6, 8–10].

Several studies have evaluated corn response to drainage water management systems [11–14], interactions between drainage and nitrogen management [15–17], and the impacts of drainage on water quality [18–21]. Other studies have evaluated the effects of drainage and overhead irrigation on yield response of corn in a claypan soil in Southern Illinois [22–24]. Corn yields synergistically increased 4.8 Mg ha^{-1} with overhead irrigation and subsurface drainage [24]. In dry years, drainage plus subirrigation increased 3-year average yields 23% over drainage only in dry years [25] and conserved water compared to overhead irrigation systems [6]. In wet years, these conditions produced limited yield increases [6, 25]. Soybean cultivar yield response to drainage plus subirrigation systems has been reported in Ohio [26] and Missouri [27]. But no known research has evaluated the interaction between corn hybrids and drainage water management systems at different drain tile spacings. Subsurface drains in claypan soils at 15-m spacings were reported to remove from 41 to 47% of the excess rainfall [23]. Simulations in a claypan soil indicated the need for 6-m drain tile lateral spacing for subirrigation, though the

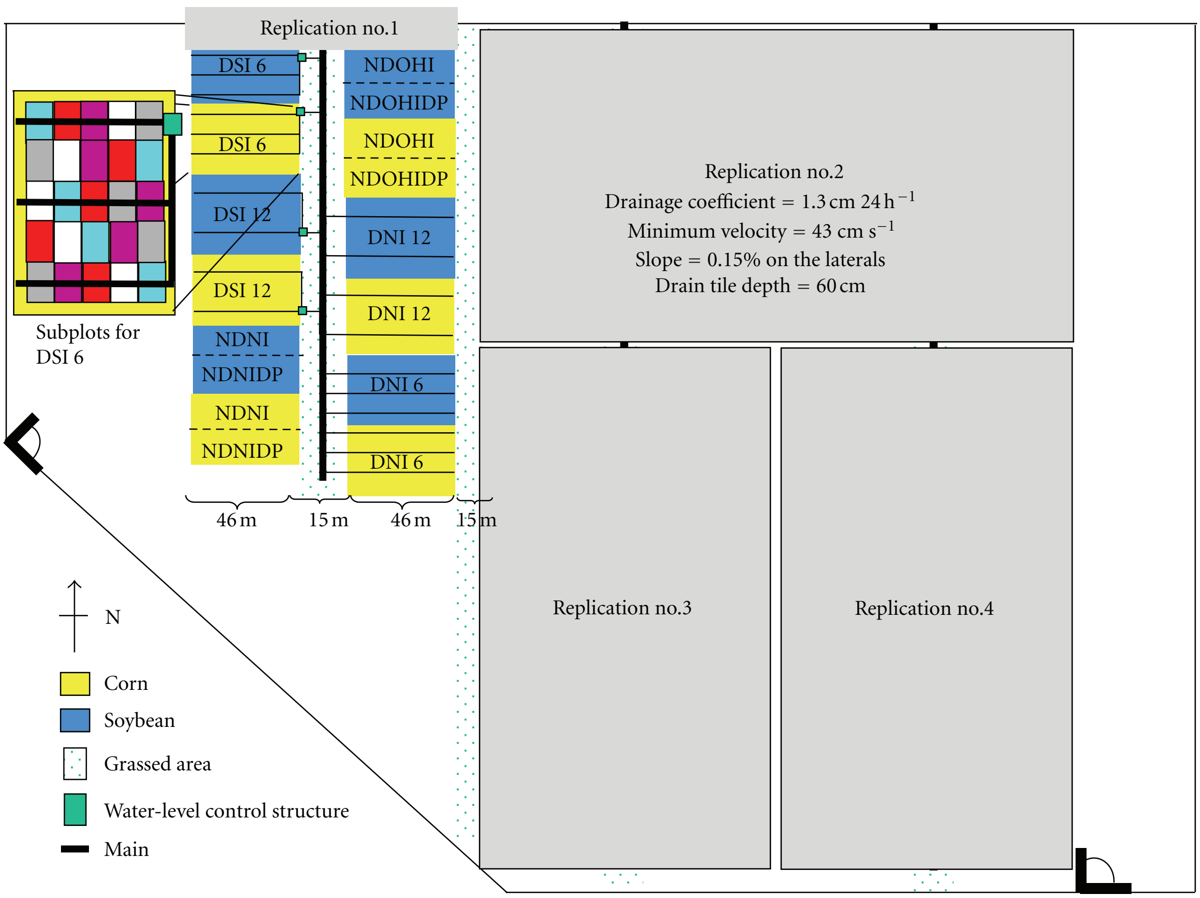


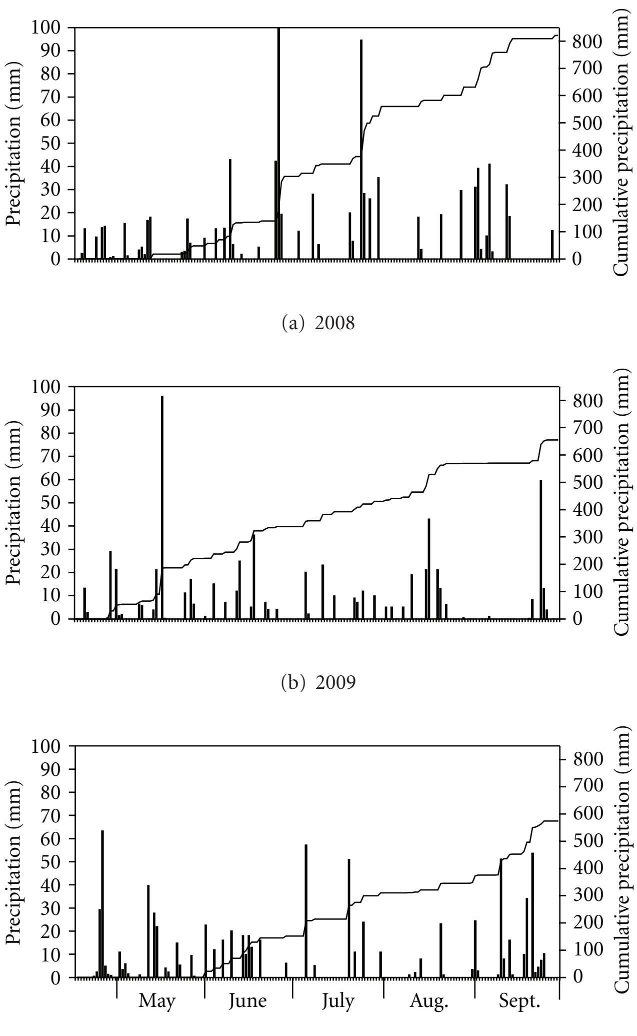
Figure 1: Split-plot design at the MUDS site. A representative subplot randomization above and between tile lines was represented by the insert for drainage plus subirrigation (DSI 6) at a 6.1 m spacing. The boxes with different colors represent five different hybrids randomly planted in 3 by 9.1 m plots above and between the tile lines. In 2009, the nondrained, nonirrigated (NDNI) and nondrained, overhead irrigated (NDOHI) controls were split to include a delayed planting (DP) treatment to avoid confounding planting dates between systems. Corn plots in 2008 and 2010 were rotated to soybean, and soybean plots were rotated into corn in 2009.

system's drainage component limited the lateral spacing [28]. However, little verification research has been conducted in corn [6], especially during extremely wet years. This research evaluated corn yield, plant population, and grain quality response to drainage only or drainage plus subirrigation at 6.1 and 12.2 m spacings and high yielding hybrids.

2. Materials and Methods

This study used drainage and irrigation plots at MU's Drainage and Subirrigation (MUDS) site located near the University of Missouri Lee Greenley Jr. Memorial Research Center on the Ross Jones farm (39°56′N, 92°3′W) near Bethel, MO, from 2008 to 2010. The site has been previously described [6, 27, 29, 30]. The soil was a Putnam silt loam (fine, smectitic, mesic Vertic Albaqaulfs) with poor drainage, slope of less than 1%, and a Bt horizon with a claypan at a depth of approximately 51 cm. The drainage and drainage-plus-subirrigation systems were installed in 2001. Drain tiles (7.6 cm diameter) were installed 60 cm deep at 0.15% slope with a minimum flow velocity of 43 cm sec^{-1} and a drainage coefficient of 1.3 cm 24 h^{-1}.

The experiment was arranged in a split-plot design with four replications (Figure 1). The main plot was water management system (nondrained, nonirrigated (NDNI); nondrained, overhead irrigated (NDOHI); drained, nonirrigated at 6.1 m drain spacing (DNI 6); drained, nonirrigated at 12.2 m drain spacing (DNI 12); drained, subirrigated at 6.1 m drain spacing (DSI 6); drained, subirrigated at 12.2 m drain spacing (DSI 12)), and subplots were hybrids (Asgrow785, DKC61-73, DKC63-42, LG2642, and Kruger2114). Subplots were randomized above and between the drain tiles in 3 by 9.1 m plots. The total number of plots was 30 in 2008 and 2010. Soil conditions in 2009 were favorable for planting in the DNI and DSI treatments on 24 Apr. Soil conditions were poor for tillage and planting in the nondrained control, but half of the plot area was planted to avoid confounding results due to a delayed planting date. The delayed planting control treatments were denoted as nondrained, nonirrigated, and delayed planting (NDNIDP) and overhead irrigated, nondrained, and delayed planting (NDOHIDP), which increased the total number of plots to 40. Rainfall following planting was intense and extensive (Figure 2(b)). As a result, planting of the NDNIDP



(a) 2008

(b) 2009

(c) 2010

Figure 2: Daily (bars) and cumulative (line) precipitation for nonirrigated treatments in (a) 2008, (b) 2009, and (c) 2010. The solid line starts at the time when corn was planted.

and NDOHIDP treatments was delayed 18 days. The corn hybrids were selected from among the region's high yielding hybrids [31]. In the subsurface-drained and subirrigated treatments, three subsurface drain tile laterals were spaced 6.1 m apart, and two subsurface drain tile laterals were spaced 12.2 m apart (Figure 1). They were operated as DNI or DSI. The subirrigation system's water level control devices (AgriDrain, Adair, IA) managed water depth and limited water flow during the winter months as a best management practice to reduce NO_3-N loss [13].

The site was in a corn-soybean [*Glycine max* (L.) Merr.] rotation, with corn and soybean present each year (Figure 1). Corn production utilized conventional or reduced tillage in the fall or spring before planting (Table 1), while the soybean crop was no-till planted. Corn was planted (John Deere 7000, Moline, IL) in 75-cm-wide rows at 79,000 seeds ha^{-1} in 2008 and 81,500 seeds ha^{-1} in 2009 and 2010. In 2009, half of the nondrained control was planted on 24 Apr. 2009 and the other half was planted on 12 May due to extremely wet soil conditions in the nondrained control (Figure 1) and nearly complete stand loss in the early planting date. This prevented confounding results due to planting date this year. All plots received broadcast applications of N-P_2O_5-K_2O (Table 1) based on University of Missouri soil test recommendations in 2008, but no P and K fertilizer was applied for the 2009 and 2010 growing seasons due to wet soil conditions. Soil test P and K was high [32] in 2009 and 2010 (data not presented). Corn management practices are summarized in Table 1.

Overhead irrigation application times and amounts were based on the Woodruff scheduling chart [33]. Drainage water management, irrigation dates and amounts are summarized in Table 2. Total cumulative rainfall was 821 mm in 2008, 655 mm in 2009, and 574 mm in 2010 (Figure 2). This exceeded the region's May–September precipitation average of 538 mm during the past decade [7]. High yielding corn from 1895 to 1998 typically had rainfall of approximately 633 mm [1]. In this research, supplemental irrigation totaled 108 mm in 2008, 92 mm in 2009, and 0 mm in 2010 (Table 2). Irrigation scheduling was difficult during this "wet" study because overapplication of water could risk fertilizer loss generally as denitrification and root damage on poorly drained claypan soils [6, 8, 34]. That situation may require rescue N applications [35]. However, anhydrous ammonia was used at a rate that averted the possibility of N being limiting (Table 1).

Plant height was measured 42 d after planting in 2009 but not in 2008 and 2010 because treatments showed no differences by visual observation. Plant population was determined before harvest each year by counting a plot length of one harvested row. A plot combine (Kincaid Equipment, Haven, KS in 2008 and Wintersteiger Delta, Salt Lake City, UT in 2009 and 2010) was used to harvest grain and determine its moisture. Grain yield moisture was adjusted to 150 g kg^{-1} before analysis. Grain samples were collected and ten subsamples were analyzed for oil, protein, starch, and extractable starch with a Foss 1241 (Eden Prairie, MN) near infrared spectrometer similar to other research [5, 36] using previously established calibrations [37–39]. Grain samples with symptoms of diplodia (*Stenocarpella maydis*) [40], confirmed with the University of Missouri Plant Diagnostic Clinic, were quantified as the number of grains in the harvested sample of 100 seeds and converted to a percentage of seeds with the disease [36].

The effect of water management system and hybrid was subjected to an ANOVA using PROC GLM [41]. Since planting date was delayed in 2009 and plant populations were reduced over 70% in the NDNI control compared to DNI or DSI at a 6.1 m spacing, data for this year were presented separately (Tables 3 and 4). Data from 2008 and 2010 were combined because there was no delay in planting date among treatments and only minimal interactions between years (Tables 5 and 6). Interactions were presented when significant. Main effects were presented in the absence of a significant ($P = 0.1$ or 0.05) drainage water management system × hybrid interaction. Means were separated using Fisher's Protected LSD at $P = 0.1$ or 0.05.

Table 1: Soil organic matter and pH from 0 to 15 cm and corn management practices in 2008, 2009, and 2010.

Soil and site management practices†	2008	2009	2010
Soil test values			
Soil organic matter (g kg^{-1})	18 ± 1‡	21 ± 1	22 ± 1
pH (0.01M $CaCl_2$)	6.6 ± 0.05	6.9 ± 0.1	6.7 ± 0.3
Fertilizer (N-P_2O_5-K_2O kg ha^{-1})			
34-90-180	26 Nov. 2007	NA	NA
200-0-0 as anhydrous ammonia	1 May	8 Apr.	27 May
Tillage (date)	Chisel plow (25 Nov. 2007) Tilloll§ (2 May)	Tilloll (23 Apr.)	Tilloll (19 and 20 May)
Planting date	5 May	24 Apr.	28 May
Nondrained, nonirrigated delayed planting		12 May	
Weed control¶			
Timing, date	EPOST, 29 May	EPOST, 21 May	PRE, 30 May
Herbicide (rate)	Glyphosate (0.84 kg ae ha^{-1}) + DAS (20 g L^{-1}) + premixture of atrazine + S-metolachlor + mesotrione (3.3 kg ai ha^{-1})	glyphosate (0.84 kg ae ha^{-1}) + premixture of atrazine + dimethenamid-P (3.5 kg ai ha^{-1})	Saflufenacil (0.025 kg ai ha^{-1}) + glyphosate (0.84 kg ae ha^{-1})
Timing, date		POST, 25 June	POST, 22 June
Herbicide (rate)		Glyphosate (1.2 kg ae ha^{-1}) + DAS (20 g L^{-1})	Premixture of acetochlor + atrazine (5 kg ai ha^{-1})
Timing, date			LPOST, 29 June
Herbicide (rate)			Glyphosate (0.84 kg ae ha^{-1}) + DAS (20 g L^{-1})

† Abbreviations: EPOST: early postemergence; DAS: diammonium sulfate; LPOST: late postemergence; NA: none applied; PRE: preemergence.
‡ Standard deviation.
§ Tilloll 875, Marysville, KS.
¶ Herbicide chemical names: acetochlor: (2-chloro-2′-methyl-6′-ethyl-N-ethoxymethylacetanilide); atrazine: (6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-2,4-diamine); dimethenamid-P: (2-chloro-N-[(1-methyl-2-methoxy)ethyl]-N-(2,4-dimethyl-thien-3-yl)-acetamide); glyphosate: (N-(phosphonomethyl)glycine); mesotrione: (2-[4-(methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione); S-metolachlor: (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide); saflufenacil: (N′-[2-chloro-4-fluoro-5-(3-methyl-2,6-dioxo-4-(trifluoromethyl)-3,6-dihydro-1(2H)-pyrimidinyl)benzoyl]-N-isopropyl-N-methylsulfamide).

Table 2: Drainage and irrigation water management schedule by year.

Water management schedule	2008	2009	2010
Drainage mode	15 Mar.	15 Mar.	15 Mar.
Controlled drainage date	17 July	25 June	6 July
Subirrigation date	17 July–25 July, 4 Aug.–15 Sep.	25 June–16 Sep.	2 Aug.–10 Sep.
Drainage mode	25 July–4 Aug., 15 Sep.	16 Sep.	10 Sep.–29 Oct.
Controlled drainage	15 Nov.	22 Nov.	29 Oct.
Overhead irrigation dates and amounts	18 July, 13 mm 8 Aug., 43 mm 19 Aug., 32 mm 28 Aug., 20 mm	1 July, 34 mm 20 July, 21 mm 30 July, 25 mm 6 Aug., 12 mm	None applied

Table 3: ANOVA table of water management (WM) and corn hybrid treatments for height, plant population, grain moisture, yield, and diplodia in 2009.

Source		Height		Population		Moisture		Yield		Diplodia	
	df	*F*-value	Pr > *F*	*F*-value	Pr > *F*	*F*-value	Pr > *F*	*F*-value	Pr > *F*	*F*-value	Pr > *F*
Rep	3	2.9	0.035	0.5	0.687	1.7	0.162	0.6	0.646	24.0	<0.0001
WM	7	13.1	<0.0001	27.4	<0.0001	3.1	0.016	12.0	<0.0001	4.0	0.004
Rep × WM	21	2.9	<0.0001	3.1	<0.0001	1.8	0.025	1.4	0.138	5.5	<0.0001
Hybrid	4	0.6	0.669	0.6	0.644	0.3	0.909	1.3	0.275	13.3	<0.0001
WM × hybrid	28	1.7	0.012	1.0	0.454	1.6	0.028	1.2	0.205	0.9	0.650

Table 4: ANOVA table of water management (WM) and corn hybrid treatments for grain oil, protein, starch, and extractable starch concentration in 2009.

Source		Oil		Protein		Starch		Extractable starch	
	df	*F*-value	Pr > *F*	*F*-value	Pr > *F*	*F*-value	Pr > *F*	*F*-value	Pr > *F*
Rep	3	4.3	0.006	7.2	0.0001	0.5	0.678	14.6	<0.0001
WM	7	5.6	0.0004	14.6	<0.0001	1.4	0.238	6.6	0.0001
Rep × WM	21	2.3	0.001	6.9	<0.0001	0.7	0.850	3.8	<0.0001
Hybrid	4	6.9	<0.0001	13.0	<0.0001	0.2	0.938	22.6	<0.0001
WM × hybrid	28	1.0	0.533	1.0	0.457	0.6	0.962	1.3	0.183

Table 5: ANOVA table of water management (WM) and corn hybrid treatments for plant population, grain moisture, yield, and diplodia in 2008 and 2010.

Source		Population		Moisture		Yield		Diplodia	
	df	*F*-value	Pr > *F*	*F*-value	Pr > *F*	*F*-value	Pr > *F*	*F*-value	Pr > *F*
Year	1	94.4	<0.0001	578.4	<0.0001	0.8	0.38	151.1	<0.0001
Year × rep	6	1.0	0.449	0.5	0.801	2.6	0.049	0.8	0.544
WM	5	0.8	0.571	3.9	0.008	1.9	0.116	1.0	0.463
Year × WM	5	5.3	<0.0001	15.7	<0.0001	15.8	<0.0001	6.9	<0.0001
Year × rep × WM	30	6.7	<0.0001	4.1	<0.0001	8.1	<0.0001	7.2	<0.0001
Hybrid	4	3.8	0.005	205.4	<0.0001	11.8	<0.0001	15.2	<0.0001
Year × hybrid	4	4.0	0.003	7.3	<0.0001	2.1	0.081	13.0	<0.0001
WM × hybrid	20	1.3	0.159	1.5	0.094	2.2	0.001	1.2	0.277
Year × WM × hybrid	20	0.8	0.668	0.5	0.965	1.1	0.382	1.1	0.304

Table 6: ANOVA table of water management (WM) and corn hybrid treatments for grain oil, protein, starch, and extractable starch concentration in 2008 and 2010.

Source		Oil		Protein		Starch		Extractable starch	
	df	*F*-value	Pr > *F*	*F*-value	Pr > *F*	*F*-value	Pr > *F*	*F*-value	Pr > *F*
Year	1	17.3	0.0002	0.1	0.776	76.1	<0.0001	14.5	0.0006
Year × rep	6	0.55	0.737	1.5	0.235	1.3	0.310	0.7	0.631
WM	5	0.83	0.540	2.0	0.111	2.2	0.079	1.8	0.144
Year × WM	5	1.2	0.307	11.5	<0.0001	7.9	<0.0001	8.8	<0.0001
Year × rep × WM	30	1.5	0.058	5.8	<0.0001	3.6	<0.0001	4.9	<0.0001
Hybrid	4	142.2	<0.0001	32.3	<0.0001	21.8	<0.0001	62.6	<0.0001
Year × hybrid	4	18.6	<0.0001	1.4	0.226	9.6	<0.0001	10.2	<0.0001
WM × hybrid	20	1.9	0.011	1.1	0.306	1.5	0.089	1.1	0.382
Year × WM × hybrid	20	0.7	0.791	0.8	0.774	1.0	0.422	0.5	0.951

Table 7: Effects of water management and hybrid interaction on plant heights 42 d after 24 April planting date in 2009.

Water management system	DKC63-42	LG2642	Asgrow785	Kruger2114	DKC61-73
			cm		
Nondrained, nonirrigated (NDNI)	28	36	28	67	53
Nondrained, nonirrigated, delayed planting (NDNIDP)	41	53	46	53	50
Drained, nonirrigated (DNI) at 6.1 m	82	77	73	73	86
Drained, nonirrigated (DNI) at 12.2 m	59	65	61	54	66
Drained plus subirrigated (DSI) at 6.1 m	77	76	60	72	78
Drained plus subirrigated (DSI) at 12.2 m	53	60	49	58	40
Overhead irrigated, nondrained (NDOHI)	49	24	45	28	34
Overhead irrigated, nondrained, delayed planting (NDOHIDP)	43	49	50	46	49
LSD ($P = 0.05$)			30		

Table 8: Water management main effects for plant population before harvest and grain yield, moisture, diplodia, oil, protein, starch, and extractable starch in 2009.

Water management system	Plant population	Yield	Moisture	Diplodia	Oil	Protein	Starch	Extractable starch
	No. ha^{-1}	Mg ha^{-1}	g kg^{-1}	%	g kg^{-1}	g kg^{-1}	g kg^{-1}	g kg^{-1}
Nondrained, nonirrigated (NDNI)	13,600	4.5	14.5	21	41.3	95.2	711	657
Nondrained, nonirrigated, delayed planting (NDNIDP)	55,600	14.4	19.3	8	43.2	89.4	709	662
Drained, nonirrigated (DNI) at 6.1 m	47,400	9.2	17.1	23	39.8	94.4	714	660
Drained, nonirrigated (DNI) at 12.2 m	33,800	7.6	15.3	21	39.8	95.0	702	659
Drained plus subirrigated (DSI) at 6.1 m	45,200	9.8	17.6	18	39.8	92.9	713	661
Drained plus subirrigated (DSI) at 12.2 m	25,900	6.7	14.6	20	40.0	95.9	712	657
Overhead irrigated, nondrained (NDOHI)	6,700	2.6	13.5	15	41.9	85.2	716	673
Overhead irrigated, nondrained, delayed planting (NDOHIDP)	54,300	12.8	19.4	9	40.6	86.4	714	673
LSD ($P = 0.05$)	17,800	3.0	3.9	9	2.2	7.7	NS	11

Table 9: Hybrid main effects for grain diplodia, oil, protein, and extractable starch in 2009.

Hybrid	Diplodia	Oil	Protein	Extractable starch
	%	g kg^{-1}	g kg^{-1}	g kg^{-1}
DKC63-42	23	40.9	94.3	660
LG2642	8	41.7	89.6	668
Asgrow785	15	39.6	90.7	669
Kruger2114	33	39.3	98.4	645
DKC61-73	17	39.7	95.3	661
LSD ($P = 0.05$)	5	0.9	1.8	3

3. Results and Discussion

3.1. Delayed Planting (2009). Corn plant height 42 d after planting was affected ($P = 0.012$) by drainage water management and hybrid selection (Table 7). In general, the tallest plants were in the DNI and DSI at 6.1 m spacing. However, corn height for drainage or DSI 6 was similar to DSI 12, except for Asgrow785 planted into DSI 12. Although the NDNIDP was planted 18 d later, heights were similar to the early planted nondrained corn. These data indicated better growing conditions for plants in the DNI and DSI treatments compared to their NDNI and NDOHI counterparts. This was evident in final plant population at harvest (Table 8). Nearly all plants in the NDNI or NDOHI controls were eliminated by early wet conditions. DSI 6 had 74% greater plant population than DSI 12, due to the closer spacing's more efficient drainage. Typically, a delay in planting date results in a lower yield, but in a wet year it was beneficial to wait until the seedbed dried adequately to establish plants well.

Grain yield was ranked NDNIDP = NDOHIDP > DSI 6 = DNI 6 = DNI 12 ≥ DSI 12 ≥ NDNI = NDOHI. Differences in drain tile spacing were probably due to lateral flow limitations caused by the claypan [23]. DNI 6, DSI 6, and DNI 12 increased yield from 4.7 to 7.2 Mg ha^{-1} compared to the nondrained (NDNI and NDOHI) controls. Subsurface drain tiles in a claypan soil in central Missouri at a 15.3 m spacing removed from 41% to 47% of excess precipitation [23]. Overhead irrigation or subirrigation appeared to decrease yield, though it was not significantly different than appropriate nonirrigated controls in 2009 with its high rainfall that made scheduling difficult. This scenario has been common in other water management research on claypan soils [6, 8, 23]. Sustained rainfall throughout the summer months allowed the DNIDP and NDOHIDP controls to produce high yields (>12 Mg ha^{-1}), which is atypical for these soils. In general, grain moisture was higher and diplodia was lower with late-planted NDNIDP and NDOHIDP corn.

Oil and protein concentrations usually are inversely related [39]. The NDNIDP had the highest oil (43.2 g kg^{-1}) concentration, and delayed planting controls had the lowest protein (85.2 to 86.4 g kg^{-1}) concentration (Table 8). Water management did not affect starch concentration, but extractable starch was highest (673 g kg^{-1}) in the overhead-irrigated controls. The effect of water management on grain quality was due primarily to planting date and differences in population at harvest. In a year with consistent summer rainfall, stand establishment was essential for high yielding corn.

Since no interaction between drainage water management and high yielding hybrid was detected in 2009 (Tables 3 and 4), main effects for hybrid are presented in Table 9.

Table 10: Corn grain yield, moisture, oil, and protein response to water management systems and hybrid in 2008 and 2010. Data were combined over years.

Water management system[†]	Hybrid	Yield $Mg\,ha^{-1}$	Moisture $g\,kg^{-1}$	Oil $g\,kg^{-1}$	Starch $g\,kg^{-1}$
NDNI	DKC63-42	11.1	167	41.3	725
	LG2642	10.8	179	43.8	721
	Asgrow785	10.5	158	39.5	727
	Kruger2114	10.3	175	41.6	733
	DKC61-73	9.9	155	39.0	725
DNI 6	DKC63-42	12.2	160	41.7	724
	LG2642	11.7	178	43.4	720
	Asgrow785	12.1	155	37.7	729
	Kruger2114	11.2	174	41.9	723
	DKC61-73	12.1	151	39.3	722
DNI 12	DKC63-42	11.7	164	42.0	725
	LG2642	11.8	181	43.8	720
	Asgrow785	11.6	154	38.7	727
	Kruger2114	11.2	179	41.6	723
	DKC61-73	11.2	152	38.3	725
DSI 6	DKC63-42	11.6	166	41.9	724
	LG2642	11.1	175	43.2	722
	Asgrow785	11.0	157	40.2	726
	Kruger2114	10.5	174	40.8	728
	DKC61-73	10.8	149	38.2	727
DSI 12	DKC63-42	12.1	168	41.5	726
	LG2642	11.1	177	43.5	722
	Asgrow785	10.7	153	38.3	730
	Kruger2114	11.1	177	41.6	726
	DKC61-73	10.4	151	37.9	727
NDOHI	DKC63-42	10.7	163	42.7	724
	LG2642	11.4	175	43.5	723
	Asgrow785	11.0	156	38.3	729
	Kruger2114	10.6	172	42.7	724
	DKC61-73	10.2	153	37.3	728
LSD		1.1[‡]	8[§]	2.1[‡]	5[§]

[†] Abbreviations: DNI 6: drained, nonirrigated (6.1 m drain spacing); DNI 12: drained, nonirrigated (12.2 m drain spacing); DSI 6: drained, subirrigated (6.1 m drain spacing); DSI 12: drained, subirrigated (12.2 m drain spacing), NDNI: nondrained, nonirrigated; NDOHI: nondrained, overhead irrigated.
[‡] $P = 0.05$.
[§] $P = 0.10$.

Plant populations were low (<38,000 plants ha^{-1}), but no differences were found in plant population, moisture, yield, and starch concentration among hybrids (Tables 3 and 4). Grain with diplodia, which was due to hybrid differences, ranged from 8% for LG2642 to 33% for Kruger2114. Oil concentration was greatest with LG2642 (41.7 $g\,kg^{-1}$) and DKC63-42 (40.9 $g\,kg^{-1}$). Protein concentration 98.4 $g\,kg^{-1}$ with Kruger2114 and 89.6 $g\,kg^{-1}$ with LG2642.

3.2. No Delayed Planting (2008 and 2010). Data were pooled over 2008 and 2010 since no significant three-way interactions (year × water management × hybrid) were detected for dependent variables (Tables 5 and 6). In 2008 and 2010, grain yield was 9.9 to 11.1 $Mg\,ha^{-1}$ in the NDNI control with DKC63-42 yielding 1.2 $Mg\,ha^{-1}$ greater than DKC61-73 (Table 10). When compared to the NDNI control, DNI at 6.1 m increased yield of all hybrids from 1.1 to 2.2 $Mg\,ha^{-1}$. At a 12.2 m spacing, grain yield increased with Asgrow785 and DKC61-73 1.1 and 1.3 $Mg\,ha^{-1}$, respectively. This indicates either that DKC61-73 was more susceptible to water stress or that with appropriate drainage it could reach its production potential more so than other hybrids. None of the DSI treatments affected yield compared to the NDNI except DKC61-73 at 6.1 m, indicating that the subirrigation should have remained in drainage mode throughout the season for optimal crop production. Similarly, overhead irrigation had no effect on yield in extremely wet years similar to 2009.

Grain moisture with Asgrow 785 and DKC61-73 was generally drier than the other hybrids regardless of the drainage

Table 11: Hybrid main effects for plant population before harvest, diplodia, protein, and extractable starch in 2008 and 2010. Data were combined over years in the absence of an interaction.

Hybrid	Plant population 2008	Plant population 2010	Diplodia 2008	Diplodia 2010	Protein	Extractable starch
	no. ha^{-1}		%		$g\,kg^{-1}$	$g\,kg^{-1}$
DKC63-42	71,600	63,000	15	3	78.0	686
LG2642	71,900	60,300	13	1	74.8	686
Asgrow785	71,100	60,500	12	3	75.1	693
Kruger2114	71,900	58,000	14	1	78.7	673
DKC61-73	70,900	59,500	19	3	81.4	686
LSD ($P = 0.05$)	NS	2,200	2	1	1.2	2

system (Table 10). DSI 12 increased grain moisture by $8\,g\,kg^{-1}$ compared to DNI 6. The greatest disparity in grain moisture among hybrids was between DNI 6 and DNI 12 compared to the other water management systems. Although a significant interaction emerged between drainage water management and hybrid for oil and starch concentration (Table 6), there were no consistent effects of drainage water management on oil and starch concentrations (Table 10). This was consistent with research evaluating soybean grain quality response to drainage water management [27, 29], while Wiersma et al. [42] showed a $6\,g\,kg^{-1}$ increase in protein concentration as the drainage coefficient increased to $2\,cm\,day^{-1}$. There was no effect of drainage water management on harvested plant population (from 63,000 to 67,700 plants ha^{-1}), diplodia (8–10%), protein (76.1–80.2 $g\,kg^{-1}$), or extractable starch (682–687 $g\,kg^{-1}$) concentration, although differences between years were detected (Table 6).

Plant population at harvest was similar among hybrids in 2008. However, DKC63-42 had 2,500–5,000 plants ha^{-1} greater than the other hybrids (Table 11), which could have contributed toward higher overall yields in the NDNI, DNI 6, DSI 6, and DSI 12 treatments compared to the other hybrids (Table 10). Grain with diplodia symptoms was inconsistent between hybrids in 2008 and 2010 (Table 11). Diplodia was greatest in both years with DKC63-42 and DKC61-73 and lowest in both years with LG2642 and Kruger2114. Protein concentration in those years was from 74.8 to 81.4 $g\,kg^{-1}$, which was from 13.9 to 19.7 $g\,kg^{-1}$ less than 2009. Extractable starch was greatest with Asgrow785 and lowest with Kruger2114. Similarly, differences in soybean oil concentration depended more on the soybean cultivar than on water management [27].

4. Conclusion

In three wet years, DNI 6 increased yield from 1.1 to 6.6 $Mg\,ha^{-1}$ compared to the nondrained (NDNI or NDOHI) controls. In 2009, the NDNIDP control yields were from 4.6 to 5.2 $Mg\,ha^{-1}$ greater than DNI or DSI, due to an even distribution of summer rains. Grain yields were similar in the 6.1- and 12.2 m-spaced DNI and DSI systems in 2008 and 2010, but plant population increased 74% and yields were 3.1 $Mg\,ha^{-1}$ greater with DSI 6 compared to DSI 12 in 2009. In this study, drainage helped hybrids increase yields from 10% to over 50% in years with high rainfall. Differences among hybrids may be due to their tolerance of saturated conditions. Corn hybrids achieved their yield potential when adequate drainage was provided, and some hybrids had greater wetness tolerance compared to others. Some high yielding hybrids tested in this study reached a higher yield potential using drainage water management systems versus nondrained soil. Drainage is an important component of high yielding corn production systems.

Nomenclature

Corn: *Zea mays* L. "Asgrow785," "DKC61-73," "DKC63-42," "LG2642," "Kruger2114".

Abbreviations

DNI 6: Drained, nonirrigated (6.1 m drain spacing)
DNI 12: Drained, nonirrigated (12.2 m drain spacing)
DSI 6: Drained, subirrigated (6.1 m drain spacing)
DSI 12: Drained, subirrigated (12.2 m drain spacing)
NDNI: Nondrained, nonirrigated
NDNIDP: Nondrained, nonirrigated, delayed planting
NDOHI: Nondrained, overhead irrigated
NDOHIDP: Overhead irrigated, nondrained, delayed planting.

Acknowledgments

The authors would like to thank Katherine Ausmus, Kolton Bevill, Brett Craigmyle, Chris Dudenhoeffer, Miranda Glasgow, Hayden Hunziker, Clinton Meinhardt, and John Shetley for their technical assistance.

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