EFFECTS OF APPLICATION OF WATER AND NITROGEN ON NUTRIENT USE FROM CORN AND SORGHUMS BY PIGS

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Summary

An experiment was conducted to determine the effects of growing conditions on nutrient yield and quality of corn and sorghum. Main effect treatments were: corn (C), bronze pericarp heterozygous-yellow endosperm sorghum (BS), and yellow pericarp homozygous-yellow endosperm sorghum (YS); optimal irrigation (I) and minimal irrigation (MI); 100 lb/acre of N fertilization (F) and no N fertilization (NF), in a 3 × 2 × 2 factorial arrangement. Grains were grown in 1988 (Year 1, with little rainfall) and 1989 (Year 2, with above average rainfall) in the semi-arid environment at Garden City, KS. In Year 1, sorghums yielded 15% more grain than C, and YS yielded 1.2% more grain than BS. Irrigation increased yield by 90%, and N application increased yield by 7%. In year 2, C yielded 11% more grain than the sorghums. In the pig metabolism study, C had greater nitrogen digestibility (ND) than sorghums in both years, greater biological value (BV) and nitrogen retention in Year 2, but lower BV in Year 1. Yellow sorghum had greater ND than BS in Year 1. Corn had increased cost per unit of utilizable nitrogen (CUN) and utilizable energy (CUE) and reduced utilizable nitrogen per inch of available water (UNW) and utilizable energy per inch of available water (UEW) for both years compared to BS and YS. In conclusion, optimally irrigated grains had higher nutritional value than minimally irrigated grains, and growing the grains under varying agronomic conditions did affect their nutritional quality.

(Key Words: Corn, Sorghum, Irrigation, Fertilization, Digestibility.)

Introduction

Research indicates great variation in nutritional value of sorghum, with feeding value ranging from < 90 to > 100% that of corn. Also, reports have been conflicting of the effects of seed coat color and endosperm type on nutrient digestibility in sorghums. Other research has demonstrated that irrigation and N fertilization will increase yield of grains, but the effects of these agronomic inputs on nutritional value are not well understood. It is known that irrigation increases yield, but irrigation also may reduce CP concentration of grain. Nitrogen application is needed to maximize yields and may correct the reduction in CP content of irrigated grains. Thus, agronomic inputs that increase yield of a grain may or may not benefit its nutritional value.

The need to understand the consequences of agronomic practices on corn and sorghum as food and feed led to the research discussed herein. The objective was to determine the nutritional value of corn and two sorghum varieties in response to irrigation and N application.

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Procedures

A commercial corn hybrid (C; Dekalb 656); a bronze pericarp, heterozygous-yellow endosperm sorghum (BS; Pioneer 8515); and a yellow pericarp, homozygous-yellow endosperm sorghum (YS; Dekalb 41Y) were grown on a Richfield silt loam soil at the Southwest Research and Extension Center, Garden City, KS, in 1988 and 1989. Preplanting irrigations of 5 and 6 in were applied to all treatments in 1988 and 1989, respectively (Table 1). The years were greatly different in rainfall, with 9.7 in for 1988 and 21.1 in for 1989. Additional water was applied to give treatments of optimal irrigation (I) and minimal irrigation (MI) for corn and the sorghums. These grains were grown with (F) or without (NF) 100 lb/acre N from ammonium nitrate granules. Thus, the overall treatment arrangement was a 3 × 2 × 2 factorial with main effects of grain type (C vs BS vs YS), amount of water application (I or MI), and N application (F or NF).

In the swine metabolism experiment, 24 pigs (averaging 114 lb body wt) were used to determine apparent digestibilities of dry matter (DM), nitrogen (N), and gross energy (GE) for the experimental grains. The basal diet was formulated to 14% CP, .66% Ca, and .55% P using the grain with the lowest CP concentration (Table 2). Other grains were substituted on an equal weight basis for the grain in the first diet. The daily feed allowance was $.05 \times BW^{.9}$, offered as equal feedings at 7 a.m. and 5 p.m. For Year 1 grain, the pigs were randomly assigned to the 12 grain treatments for a 6-d adjustment period and 4-d total collection of urine, feces, and orts. The pigs were reassigned for another adjustment and collection period with the restriction that no pig could be given the same treatment twice. This procedure was replicated five times. The same protocol was used for Year 2 grain, with the exception that the adjustment period was only 4 d. Urine samples were collected once daily and acidified with 120 ml of 10% HCl; a 5% subsample was frozen. Feces and orts were collected once daily and frozen. Apparent DM and N digestibilities, biological value (BV), N retention, DE, and ME were calculated.

Results and Discussion

In Year 1, the sorghums yielded 15% more grain than C, and YS yielded 1.2% more grain than BS (Table 3). Irrigation increased yield by 90%, and N application increased yield by 7%. Irrigation increased yield of YS more than C and BS (114, 89, and 70%, respectively). In year 2, C yielded 11% more grain than the sorghums. This was likely because of greater rainfall making growing conditions more favorable for production of C in Year 2 compared to Year 1. Yellow sorghum yielded 2% more grain than BS. Irrigation increased grain yield by 18%, and N fertilizer increased yield by 10%. Yellow sorghum responded most to I with a 38% increase in yield, C was intermediate (12% increase), and BS had the least response, (8% increase). Bronze sorghum responded most to F with a 24% increase in yield, and C and YS had moderate increases of 6 and 2%, respectively.

Irrigation has been shown by other researchers to increase grain yield, but increased available water tends to decrease grain CP concentration. In contrast with irrigation, N application increases both grain yield and grain CP concentration. However, the increased protein content is primarily because of greater synthesis of zein, which is practically devoid of lysine and of poor nutritional value. Similar responses to I (i.e., increased grain yield and decreased CP concentration) were observed in the experiments reported herein. Fertilization with N gave a slight and consistent increase in grain yield. However, F did not give consistent increases in percentage CP of the grains in Year 1. This may have been caused by the low water availability and its limiting effect on plant growth and response to F.

With the improved growing conditions of Year 2, yield of the grains were more similar among treatments. However, yield still was increased with I and F, and I decreased CP percentage of the grains. Nitrogen fertilization increased grain CP concentration, with more effect on I than MI grain.

In the pig metabolism experiment, no differences occurred among treatments for DM digestibility in Year 1 or 2 (Tables 4 and 5). Corn had greater ($P<.001$) N digestibility in both Year 1 and 2 compared to BS and YS. Corn had reduced ($P<.03$) biological value (BV) when grains were grown under dry conditions (Year 1) compared to BS and YS, but had greater BV ($P<.02$) and N retention ($P<.001$) under the more ideal growing conditions of Year 2. The YS had greater N digestibility ($P<.02$) than BS for Year 1, but they were not different in N retention ($P>.10$).

Irrigation of the grains increased BV ($P<.07$) and N retention ($P<.06$) for both years, with a greater response in Year 2. Fertilizer application decreased BV ($P<.01$) and N retention ($P<.003$) for the sorghums, but increased BV and N retention for the C when the grains were grown under the more ideal conditions of Year 2. This would indicate that the sorghums had excess N fertilizer and were using it to increase prolamin synthesis in the grains, but corn was below its maximum growth potential and was using the N fertilizer for synthesis of high quality proteins (e.g., albumins or globulins). Irrigation caused a slight decrease in DE ($P<.04$) and ME ($P<.05$) for Year 2 but had no effect in Year 1. This is opposite of what was expected; more available water should have increased energy concentrations of the grains because of increased starch filling.

The calculation of utilizable energy per acre (UE = ME × grain yield) indicated many interactions among main effects due more to grain yield responses than differences in nutritional effects. Sorghums had greater UE ($P<.001$) under dry growing conditions (Year 1), and C had greater UE ($P<.001$) under the more ideal growing conditions of Year 2. Irrigation ($P<.001$) and F ($P<.001$) applications increased UE in both years.

In a review of the economic analyses for producing grains under these varying agronomic conditions (Table 6), sorghums proved more economical under the dry conditions of Year 1, and on the average for both years, were the most profitable crops. The cost of additional irrigation to corn in this environment resulted in decreased profitability. Bronze sorghum-MI under both F treatments proved the most stable economically, with YS-I under either F treatment being a close second.

In an attempt to determine the cost per unit of nutrient and evaluate water utilization efficiencies of the grains under these different growing conditions, cost per utilizable nitrogen (CUN), cost per utilizable energy (CUE), utilizable nitrogen per inch of available water (UNW), and utilizable energy per inch of available water (UEW) were calculated from the pig digestibility trial (Table 7). Corn had increased cost per unit of utilizable N and energy ($P<.001$) and reduced utilizable N and energy per inch of available water ($P<.001$) for both years compared to BS and YS. This relates to the more efficient use of water and N associated with the sorghum plant compared to corn. Irrigation decreased CUN ($P<.001$) and CUE ($P<.001$) and increased UNW ($P<.001$) and UEW ($P<.001$) in pigs for Year 1, but increased CUN ($P<.001$) and CUE ($P<.001$) and decreased UNW ($P<.001$) and UEW ($P<.001$) in Year 2 when growing conditions were more ideal and irrigation had less effect on crop production. Fertilizer application decreased CUE ($P<.001$) and increased UEW ($P<.001$) for both years. The UNW ($P<.001$) for Year 2 in swine was increased by F.

Considering the holistic view of grain production and animal use of these grains, the most important factor is grain yield.

Grains should be grown that have high stability for their growing environment. This was evident because in Year 1 (extremely dry), the sorghums yielded more nutrients per acre than C, but in Year 2 (a wet year), C yielded more nutrients per acre than BS and YS. Considering both years, BS gave more consistent yield of nutrients and appeared to be a more stable crop for this semi-arid region of Kansas.

This research indicated that C had increased digestibility compared to the sorghums. Yellow sorghum, with homozygous-yellow endosperm, had increased nutrient digestibility and N retention compared to BS with heterozygous-yellow endosperm. Irrigated grains were of greater nutritional value, as well as having greater yields. Given these results, for irrigating grain in a semi-arid region and feeding it to monogastric livestock, YS would be the crop of choice. For growing grain in areas with greater rainfall, the increased yield of digestible nutrients by C would make it the crop of choice. In uncertain dryland production systems, the stability of nutrient yield by the BS would make it the grain of choice. Lastly, BS-MI was the most profitable across the variable environment of both years.

Table 1. Moisture Supplied to the Grain Crops, inches[a]

Item	C-I	C-MI	S-I	S-MI
Year 1				
Preplant irrigation	5.0	5.0	5.0	5.0
Irrigation	21.0	6.0	9.0	0
Rainfall	9.7	9.7	9.7	9.7
Total	35.7	20.7	23.7	14.7
Year 2				
Preplant irrigation	6.0	6.0	6.0	6.0
Irrigation	12.0	8.0	12.0	0
Rainfall	21.1	21.1	21.1	21.1
Total	39.1	35.1	39.1	27.1

[a]C = corn, S = sorghum, I = optimal irrigation, and MI = minimal irrigation.

Table 2. Diet Composition for the Pig Metabolism Experiment, %[a]

Item	Year 1	Year 2
Grain source	82.70	80.24
Soybean meal	14.50	16.96
Monocalcium phosphate	1.08	1.08
Limestone	1.02	1.02
Salt	.30	.30
Selenium premix[b]	.05	.05
Trace mineral premix[b]	.10	.10
Vitamin premix[b]	.25	.25
Total	100	100

[a]All diets were formulated to 14% CP, .66% Ca, and .55% P.
[b]Old KSU selenium, vitamin, and mineral premixes.

Table 3. Effects of Irrigation and Nitrogen Fertilizer on Grain Yield and Chemical Composition[a]

	Year 1			Year 2		
Item	Yield, lb/acre	CP, %	GE, kcal/lb	Yield, lb/acre	CP, %	GE, kcal/lb
C-I-F[b]	6,057	9.9	1,764	7,514	7.8	1,991
C-I-NF	5,754	8.9	1,799	7,228	7.7	2,025
C-MI-F	3,300	9.3	1,769	6,852	8.5	1,987
C-MI-NF	2,958	9.6	1,778	6,320	8.9	2,001
BS-I-F	6,657	10.1	1,760	7,514	10.6	1,983
BS-I-NF	6,382	10.1	1,765	5,396	8.4	1,984
BS-MI-F	4,051	9.8	1,766	6,286	11.3	1,991
BS-MI-NF	3,631	9.8	1,790	5,704	11.0	2,010
YS-I-F	7,480	8.8	1,754	7,565	9.1	1,974
YS-I-NF	6,813	8.8	1,775	7,116	8.3	1,996
YS-MI-F	3,413	9.0	1,745	5,205	10.2	1,966
YS-MI-NF	3,266	8.9	1,734	5,419	10.4	1,951

[a]All values on an as is basis. Yield=grain yield.
[b]C = corn, BS = bronze sorghum, YS = yellow sorghum, I = optimal irrigation, MI = minimal irrigation, F = N fertilized, and NF = no N fertilizer.

Table 4. Effect of Irrigation and Nitrogen Fertilizer on Nutrient Utilization in Pigs (Year 1)[a]

Item[b]	DMD, %[c]	ND, %[c]	BV, %[c]	NR, %[c]	DE, kcal/lb[c]	ME, kcal/lb[c]	UE, Gcal/acre[c]
C-I-F	89.1	84.1	52.2	44.0	1,560	1,521	9.2
C-I-NF	89.1	83.9	53.8	45.3	1,540	1,503	8.7
C-MI-F	89.7	82.8	47.5	39.4	1,593	1,559	5.2
C-MI-NF	88.1	82.2	41.5	34.3	1,512	1,467	4.3
BS-I-F	88.8	79.8	49.8	39.6	1,543	1,500	10.0
BS-I-NF	88.4	77.5	51.8	40.2	1,543	1,509	9.6
BS-MI-F	89.3	78.6	49.9	39.5	1,557	1,532	6.2
BS-MI-NF	88.7	77.2	56.0	43.3	1,557	1,527	5.5
YS-I-F	90.7	83.0	53.4	44.2	1,579	1,523	11.4
YS-I-NF	89.2	79.0	57.3	45.1	1,544	1,514	10.3
YS-MI-F	89.1	80.0	51.9	41.2	1,551	1,516	5.2
YS-MI-NF	89.5	81.6	52.3	42.7	1,546	1,519	5.0
Contrasts and Probabilities							
C vs S	—[d]	.001	.03	—	—	—	.001
BS vs YS	—	.02	—	—	—	—	.06
I	—	—	.07	.06	—	—	.001
C vs S × I	—	—	.03	.03	—	—	.001
BS vs YS × I	—	—	—	—	—	—	.001
F	—	—	—	—	.03	—	.001
C vs S × F	—	—	—	—	.08	.03	—
BS vs YS × F	—	—	—	—	—	—	—
I × F	—	—	—	—	—	—	—
C vs S × I × F	—	—	—	—	—	—	.04
BS vs YS × I × F	—	—	—	—	—	—	.001
SE	.8	1.5	3.0	2.6	17	18	.1

[a]Five pigs/treatment.
[b]C = corn, BS = bronze sorghum, YS = yellow sorghum, S = sorghums (BS+YS), I = optimal irrigation, MI = minimal irrigation, F = N fertilized, and NF = no N fertilizer.
[c]DMD = DM digestibility, ND = N digestibility, BV = biological value, NR = N retention, DE = digestible energy, ME = metabolizable energy, and UE = utilizable energy (ME × grain yield).
[d]Dashes indicate P>.10.

Table 5. Effect of Irrigation and Nitrogen Fertilizer on Nutrient Utilization in Pigs (Year 2)[a]

Item[b]	DMD, %[c]	ND, %[c]	BV, %[c]	NR, %[c]	DE, kcal/lb[c]	ME, kcal/lb[c]	UE, Gcal/acre[c]
C-I-F	89.0	85.0	61.4	52.1	1,554	1,505	11.3
C-I-NF	88.1	83.6	57.3	47.8	1,555	1,513	10.9
C-MI-F	88.1	83.2	51.7	43.0	1,537	1,519	10.4
C-MI-NF	88.5	83.8	46.5	39.0	1,554	1,512	9.6
BS-I-F	86.9	77.7	52.3	40.6	1,578	1,547	11.6
BS-I-NF	87.9	78.7	54.2	42.5	1,588	1,548	8.4
BS-MI-F	88.6	77.4	41.9	32.2	1,600	1,556	9.8
BS-MI-NF	88.6	78.7	47.3	37.0	1,616	1,578	9.0
YS-I-F	85.7	73.7	45.6	32.6	1,541	1,509	11.4
YS-I-NF	88.5	81.7	52.7	43.1	1,588	1,550	11.0
YS-MI-F	88.6	82.3	50.3	41.5	1,615	1,579	8.2
YS-MI-NF	87.4	79.9	53.7	42.9	1,594	1,549	8.4
Contrasts and Probabilities							
C vs S	—[d]	.001	.02	.001	.001	.001	.001
BS vs YS	—	—	—	—	—	—	—
I	—	—	.003	.007	.04	.05	.001
C vs S × I	—	—	.04	.01	.03	—	.001
BS vs YS × I	—	.07	.01	.002	—	—	.001
F	—	—	—	—	—	—	.001
C vs S × F	—	—	.01	.003	—	—	.003
BS vs YS × F	—	—	—	—	—	—	.001
I × F	—	.10	—	—	—	—	.001
C vs S × I × F	.05	.04	—	—	—	—	.001
BS vs YS × I × F	—	.007	—	.08	.09	.07	.001
SE	.8	1.4	2.9	2.3	15	17	.10

[a]Five pigs/treatment.
[b]C = corn, BS = bronze sorghum, YS = yellow sorghum, S = sorghums (BS+YS), I = optimal irrigation, MI = minimal irrigation, F = N fertilized, and NF = no N fertilizer.
[c]DMD = DM digestibility, ND = N digestibility, BV = biological value, NR = N retention, DE = digestible energy, ME = metabolizable energy, and UE = utilizable energy (ME × grain yield).
[d]Dashes indicate P>.10.

Table 6. Cost of Grain Production

	Corn[a]				Bronze sorghum				Yellow sorghum			
	I		MI		I		MI		I		MI	
Item	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
Year 1, variable costs/acre, $												
Labor	31.1	31.1	15.5	15.5	20.7	20.7	5.2	5.2	20.7	20.7	5.2	5.2
Seed	21.2	21.2	14.9	14.9	5.2	5.2	2.3	2.3	5.2	5.2	2.3	2.3
Irrigation	128.7	128.7	54.4	54.4	69.5	69.5	24.8	24.8	69.5	69.5	24.8	24.8
Fertilizer	11.0	0	11.0	0	11.0	0	11.0	0	11.0	0	11.0	0
Herbicide, planting, and cultivation[b]	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
Harvesting and hauling	22.7	22.2	17.7	17.1	23.8	23.3	19.1	18.3	25.3	24.1	17.9	17.7
Interest on 1/2 of variable costs	15.1	14.4	9.0	8.3	10.0	9.4	6.0	5.3	10.1	9.4	5.9	5.2
Fixed costs/acre, $[c]	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1
Total costs/acre, $	338.9	326.7	231.6	219.3	249.3	237.2	177.5	165.0	250.9	238.0	176.2	164.3
Year 2, variable costs/acre, $												
Labor	20.7	20.7	15.5	15.5	20.7	20.7	5.2	5.2	20.7	20.7	5.2	5.2
Seed	21.2	21.2	14.9	14.9	5.2	5.2	2.3	2.3	5.2	5.2	2.3	2.3
Irrigation	89.1	89.1	69.1	69.1	89.1	89.1	29.6	29.6	89.1	89.1	29.6	29.6
Fertilizer	11.0	0	11.0	0	11.0	0	11.0	0	11.0	0	11.0	0
Herbicide, planting, and cultivation[b]	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
Harvesting and hauling	25.4	24.9	24.2	23.2	25.4	21.5	23.2	22.1	25.5	24.7	21.2	21.6
Interest on 1/2 of variable costs	12.3	11.6	10.3	9.6	11.3	10.4	6.5	5.8	11.3	10.6	6.4	5.7
Fixed costs/acre, $[c]	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1	72.1
Total costs/acre, $	288.8	276.6	254.1	241.4	271.8	256.0	186.9	174.1	271.9	259.4	184.8	173.5

[a]I = optimal irrigation, MI = minimal irrigation, F = N fertilized, and NF = no N fertilizer.

[b]Herbicide costs = $15/acre, seedbed preparation and planting cost=$17/acre, and cultivation cost=$5/acre.

[c]Real estate taxes @ 1%=$6.80/acre, interest on land @ 12%=$40.50/acre, depreciation of irrigation equipment=$15.50/acre, and interest on irrigation equipment @ 2%=$9.30/acre.

Table 7. Effect of Irrigation and Nitrogen Fertilizer on Cost of Utilizable Nutrient per Acre in Pigs

	Year 1				Year 2			
	CUN,	CUE,	UNW,	UEW,	CUN,	CUE,	UNW,	UEW,
Item[a]	$/lb[b]	$/Gcal[b]	lb/in[b]	Gcal/in[b]	$/lb[b]	$/Gcal[b]	lb/in[b]	Gcal/in[b]
C-I-F	1.32	36.79	1.51	.257	.96	25.53	1.60	.289
C-I-NF	1.46	37.82	1.33	.243	1.05	25.30	1.40	.280
C-MI-F	1.93	45.10	1.20	.249	1.02	24.44	1.47	.297
C-MI-NF	2.29	50.60	.97	.210	1.12	25.29	1.28	.272
BS-I-F	.94	24.98	2.31	.421	.85	23.41	1.70	.297
BS-I-NF	.93	24.63	2.23	.406	1.34	30.64	1.02	.214
BS-MI-F	1.18	28.64	2.18	.421	.83	19.10	1.73	.361
BS-MI-NF	1.10	29.72	2.15	.376	.76	19.33	1.77	.332
YS-I-F	.87	22.04	2.51	.480	1.21	23.86	1.18	.292
YS-I-NF	.89	23.07	2.32	.435	1.03	23.55	1.34	.282
YS-MI-F	1.41	34.10	1.77	.351	.86	22.49	1.66	.303
YS-MI-NF	1.35	33.14	1.73	.337	.73	20.71	1.83	.310
Contrasts and Probabilities								
C vs S	.001	.001	.001	.001	.01	.001	.09	.001
BS vs YS	—[c]	.002	—	—	—	.01	—	.08
I	.001	.001	.001	.001	.001	.001	.001	.001
C vs S × I	.001	.001	—	.001	.001	.001	.001	.001
BS vs YS × I	.02	.001	.002	.001	—	.001	—	.001
F	—	.001	.07	.001	—	.001	.02	.001
C vs S × F	.01	.001	—	—	—	.002	—	.005
BS vs YS × F	—	—	—	—	.001	.001	.001	.001
I × F	—	.02	—	—	.01	.001	.02	.001
C vs S × I × F	—	.001	—	.04	.05	.001	—	.001
BS vs YS × I × F	—	.008	—	.001	.001	.001	.006	.001
SE	.09	.42	.72	.004	.05	.22	.51	.003

[a]C = corn, BS = bronze sorghum, YS = yellow sorghum, S = sorghums (BS+YS), I = optimal irrigation, MI = minimal irrigation, F = N fertilized, and NF = no N fertilizer.
[b]CUN = cost per lb of utilizable nitrogen, CUE = cost per Gcal of utilizable energy, UNW = utilizable nitrogen per in of available water, and UEW = utilizable energy per in of available water.
[c]Dashes indicate P>.10.