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VARIABILITY IN GROWTH AND NUTRIENT ACCUMULATION IN SORGHUM GROWN IN WATERLOGGED SOILS[1]

KEY WORDS: Mineral nutrition; Flooding tolerance; Rice-based cropping.

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ABSTRACT

Sorghum [*Sorghum bicolor* (L.) Moench] is a potential crop for use in lowland paddy soils following rice in the Philippines. Little is known about the variability in sorghum germplasm with respect to yield potential in these soils, or the alterations in mineral uptake which might occur if late season rains resulted in waterlogging. Eight sorghum cultivars including the most widely used Philippine cultivar were grown after rice under flooded or non-flooded

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conditions. Flooding was initiated 30 days after seeding and terminated when most cultivars were at or near the boot growth stage. Flooding markedly reduced dry matter production, and delayed bloom date on the average of 5.5 days. Grain yield was reduced about 57% over all cultivars. Early maturing cultivars were not reduced in days to bloom as much as the late maturing types, and there was a significant cultivar x treatment interaction for both bloom date and grain yield. Later maturing cultivars outyielded the other cultivars at physiological maturity in both flooded and non-flooded conditions. Concentrations of the major nutrients N, P, K, Ca, Mg, and S were decreased in foliage at the boot stage due to flooding. The only nutrient to fall below published "critical" levels in leaf tissue, however, was N, and plants growing in these conditions showed classical N deficiency symptoms. Iron and Mn concentrations were significantly higher in foliage at the boot stage with flooding, but not high enough to be considered toxic. Most differences observed at boot still existed at maturity, but of less magnitude. Marked variability existed in the response among cultivars to waterlogging. It would appear that flooding tolerant genotypes could be selected which would improve existing cultivar choices for use in these difficult soils.

INTRODUCTION

The need to increase production of cereal grain crops in certain areas of the world has led to more intensive land

utilization. Where paddy rice-based cropping systems are practiced, use of short-maturing upland crops such as sorghum [Sorghum bicolor (L.) Moench] grown in sequence with rice (Oriza sativa L.) may be practical to make more complete use of the growing season. Wetland rice production generally involves puddling of soils which greatly benefits this crop[3] but reduces pore space and water infiltration capacity. Subsequently, any crop grown in sequence immediately following paddy rice would be subject to temporary waterlogging following heavy rains.

Plant growth and grain yields of many crops are reduced markedly by cultivation in waterlogged soils[4,5,6]. Several physiological changes occur which could cause injury to plants grown under conditions of excessive moisture such as death of roots[7]. Among the changes is a reduction in uptake of nutrients such as nitrogen, phosphorus, and potassium[8]. Waterlogged plants usually have symptoms that resemble those of nitrogen deficiency, and can be partially overcome with addition of nitrogen to the surface of the waterlogged soil[9,10]. On the other hand, elements such as iron and manganese have been found to accumulate in tissue under these conditions[11]. The concentrations were not generally high enough, however, to cause toxicity[8]. Sodium, calcium, and magnesium concentrations were not modified in barley grown with low soil oxygen supply[12].

Species obviously differ in their response when grown in soils which are waterlogged[5]. Barley (*Hordeum vulgare* L.) and corn (*Zea mays* L.) have been shown to withstand flooding better than some other crops[6]. The production of adventitious roots having higher porosity appeared to be associated with tolerance to flooding[13]. Barley performed quite well in comparison to either cotton (*Gossypium hirsutum* L.) or sunflower (*Helianthus annuus* L.) when waterlogged[12]. Unpublished studies[4] on crops grown in sequence with rice in the Philippines indicated that cereals generally outperformed legumes when flooding occurred at different growth stages. Sorghum appeared to be the most tolerant in terms of grain yield of all the species tested. This was also confirmed elsewhere[15].

Little is known about specific varietal differences in sorghum response to flooded conditions. The objective of this study was to determine mineral element accumulation patterns of sorghum grown under flooded conditions and evaluate sorghum cultivar tolerance to differential flooding.

MATERIALS AND METHODS

The experiment was conducted in a lowland rice paddy soil (silty clay loam; typic Hapludoll) at the Institute of Plant Breeding, University of the Philippines at Los Banos. The soil had been puddled prior to seeding of rice and flooded during the rice growing season. The experiment was designed with four

replications as a split plot with flooding treatments as main plots and cultivars as subplots. Sorghum cultivars Cosor 5, CS 133, CS 295, CS 385, CS 160, CS 276, CS 402 and BTx 623 were sown into rice stubble immediately after rice harvest and before the soil became dry and cracked. Seeds were planted 3-4 per hill and thinned to one plant per hill 15 cm apart after emergence. Each plot consisted of one row, 2 m long in 0.5 m spacing. Approximately 30 days after seeding, water was applied to plots designated for the flooded treatment sufficient to saturate the soil and retain about 5 cm of water on the soil surface. Water was added as necessary to maintain this condition for 14 days at which time additions were terminated and the water allowed to dissipate through normal seepage and evaporation. The control treament (unflooded) did not receive irrigation throughout the growing cycle.

Above ground foliage was sampled at 14 days after treatments were initiated by harvesting the entire plant (2 plants combined per plot), drying and weighing. At this time, most cultivars were at or near the boot growth stage. Chemical analysis of N was made on finely ground material by the Kjeldahl method. Analysis of P, K, S, Mg, Ca, Mn, Fe, Cu, and Zn were made at the University of Nebraska using energy dispersive x-ray fluorescence spectrometry[16]. A second sampling of two plants per plot at physiological maturity was divided into stem plus sheath, leaf blade, and grain for similar

processing. Days to 50% bloom indicated the number of days past seeding for one-half of the plants in the plot to initiate flowering. The data were subjected to the appropriate analysis of variance and Duncan's multiple range test used if mean differences were detected for main effects.

RESULTS AND DISCUSSION

Flooding markedly reduced the growth of sorghum and delayed maturity (Table 1). Plants were visually stressed and showed yellowing of the foliage typical of nitrogen deficiency. Some cultivars also had leaf purpling which was an indication that other abnormalities in growth had occurred. We also observed that sorghum grown in the non-flooded treatments did not perform as well as would be expected in a well-drained medium textured upland soil. It was evident that the puddled rice soil has adverse effects on sorghum growth and is not well suited for growing upland crops without some preparation such as tillage.

Cultivars obviously differed in their response to the flooding treatment and there was a significant cultivar x treatment interaction for 14-day dry matter, days to bloom, maturity dry matter, and grain yield. Early growth reductions were dramatic in such cultivars as CS 133, CS 295, and CS 276, but not as noticeable for most of the others (Table 1). BTx 623 was not reduced in growth at all with flooding. Similarly, cultivars differed in response to flooding with respect to bloom

TABLE 1

Production of dry matter at 14 days after flooding and at physiological maturity, grain yield, and days to 50% bloom for eight sorghum cultivars grown after rice in a lowland paddy soil (F = flooded; C = non-flooded).

Cultivar	14-day Dry matter (g/2 plants)		50% Bloom (days)		Maturity Dry matter (g/2 plants)		Grain yield (g/2 plants)	
	F	C	F	C	F	C	F	C
Cosor	9.4 a*	12.8 b	52.3 cd	49.5 cd	75.1 bc	122.8 cd	20.8 bc	48.8 cd
CS 133	5.4 b	17.8 a	85.3 a	71.8 a	106.3 ab	201.8 b	35.2 ab	77.5 a
CS 295	5.1 b	10.5 c	54.3 c	52.8 bc	55.3 c	152.5 c	16.7 c	63.7 abc
CS 385	9.8 a	11.9 bc	50.0 d	50.3 bc	70.7 c	109.8 d	21.5 bc	37.0 d
CS 160	9.6 a	12.2 bc	49.0 d	46.3 d	55.8 c	98.3 d	17.2 c	39.6 d
CS 276	6.2 b	13.4 b	60.0 b	53.8 b	69.3 c	154.7 c	20.9 bc	59.1 bc
CS 402	11.4 a	12.8 b	55.8 c	50.5 bc	69.0 c	122.6 cd	19.9 bc	49.5 cd
BTx 623	7.0 a	6.5 d	84.3 a	71.3 a	135.5 a	257.0 a	40.8 a	69.6 ab
Mean	**8.0†**	**12.2**	**61.3†**	**55.8**	**79.6†**	**152.4**	**24.1†**	**55.6**

*Means followed by the same letter within the same column are not significantly different at P = 0.05

†Overall mean of the flooded treatment is significantly different from the non-flooded treatment.

date although growing in waterlogged conditions tended to delay bloom date on the average of 5.5 days over all cultivars (Table 1). Some cultivars were delayed little or none (CS 385) while others such as CS 133 or BTx 623 were delayed nearly 2 weeks.

Growth was retarded by flooding throughout the season even though the treatment was terminated at or near the boot growth stage for most cultivars. The average total dry weight for the flooded sorghums was only 52% that of the non-flooded cultivars at physiological maturity (Table 1). Similarly, grain yield was reduced about 57%. All cultivars were subject to marked reductions in both total dry matter production and grain yield at maturity. There was, however, a high degree of variability in response which indicated certain cultivars would be better suited for growing in waterlogged conditions than others. Interestingly, the most tolerant cultivar at physiological maturity, CS 385, when judged by dry matter reduction was also affected little by flooding when judged in terms of delay in bloom date. This cultivar, however, is an early maturing type and had the lowest potential grain yield of the cultivars tested when grown in non-flooded conditions in these difficult soils. The highest potential grain yielders, CS 133 and BTx 623, were the longest maturing types yet also appeared to be relatively tolerant to flooding in terms of grain yield stability. These suffered the most in terms of delayed bloom date, however.

Several desirable characteristics of upland crops used in paddy conditions following rice have been listed and discussed[17]. These included drought tolerance, tolerance for waterlogging, early maturity, and photoperiod insensitivity. Our study tested cultivar tolerance for waterlogging the most critically, and showed that differences exist which could provide a basis for cultivar improvement. We could not confirm under the conditions of this study that an early maturing sorghum cultivar was better than a late maturing one. The local variety, Cosor 5, commonly used in upland sole cropping in the Philippines, appeared to have early flooding tolerance but relatively little grain yield potential under the conditions of this experiment.

Flooding reduced uptake of many major elements in sorghum at or near the boot stage (Table 2) which is not different from research in other crops[8]. Of the major elements studied, only Ca was not affected during early growth. Concentrations of mineral elements such as N, P, Mg and S were reduced by half or more in many of the cultivars when grown in the waterlogged situation. Potassium concentration was reduced by approximately one-third. Concentrations of N, P, Ca, and Mg dropped to such low levels in flooded plants that differences which existed among the cultivars in non-flooded conditions (controls) were no longer evident. When judging by nutrient sufficiency values previously published[18] for sorghum, we concluded that N

TABLE 2

Concentration (%) of N, P, K, Ca, Mg, and S in above-ground foliage at boot growth stage of eight sorghum cultivars subjected to flooded (F) or non-flooded (C) conditions in a lowland paddy soil.

	N		P		K		Ca		Mg		S	
Cultivar	F	C	F	C	F	C	F	C	F	C	F	C
Cosor 5	0.79 a*	1.96 bc	0.08 a	0.36 ab	2.14 cd	3.27 c	0.35 a	0.34 ab	0.19 a	0.30 ab	0.09 b	0.18 c
CS 133	0.78 a	2.14 b	0.11 a	0.34 b	2.51 a	3.56 ab	0.37 a	0.40 a	0.19 a	0.33 ab	0.09 b	0.18 c
CS 295	0.69 a	2.17 b	0.10 a	0.36 ab	2.43 ab	3.20 c	0.37 a	0.38 a	0.22 a	0.32 ab	0.11 a	0.22 ab
CS 385	0.69 a	2.02 bc	0.08 a	0.39 ab	2.13 d	3.23 c	0.28 b	0.31 b	0.20 a	0.29 ab	0.08 b	0.17 cd
CS 160	0.68 a	1.75 c	0.08 a	0.28 c	2.15 cd	3.07 c	0.35 a	0.35 ab	0.20 a	0.28 b	0.08 b	0.15 d
CS 276	0.86 a	1.98 bc	0.09 a	0.36 ab	2.43 ab	3.30 bc	0.37 a	0.32 b	0.22 a	0.30 ab	0.12 a	0.21 b
CS 402	0.69 a	1.78 c	0.07 a	0.36 ab	1.93 d	3.27 c	0.36 a	0.35 ab	0.21 a	0.30 ab	0.08 b	0.18 c
BTx 623	0.75 a	2.63 a	0.08 a	0.40 a	2.43 ab	3.80 a	0.32 ab	0.35 ab	0.21 a	0.35 a	0.09 b	0.23 a
Mean	0.74†	2.05	0.09†	0.36	2.27†	3.34	0.34	0.35	0.21†	0.31	0.09†	0.19

*Means followed by the same letter within the same column are not significantly different at P = 0.05.

†Overall mean of the flooded treatment is significantly different from the non-flooded treatment.

concentrations in the flooded plants dropped below a "critical" level of 1% for all cultivars, and P concentrations below a "critical" level of 0.1% for all cultivars except CS 133 and CS 295. This was most likely a contributing factor to the marked early growth reductions we observed due to flooding. Waterlogging symptoms in barley shoots were overcome by additions of calcium nitrate[9]. Apparently, absorption of the element was occurring via the newer superficial roots produced near the surface since absorption of water and nutrients in an anaerobic condition rapidly ceases[8]. On the other hand, non-flooded plants in this experiment did not grow particularly well even with leaf nutrient concentrations well above that necessary for normal growth. Apparently other unknown difficulties contribute significantly to growth reductions in these soils even when not flooded.

Concentrations of minor elements were also altered at the boot stage by flooding (Table 3). Similar to most of the major elements, Cu and Zn concentrations were significantly reduced. According to published results for sorghum[17] however, Zn concentration did not fall below the "critical" level for growth, and information on critical Cu levels is not available. Concentrations of both Fe and Mn were higher in the flooded treatment for all cultivars except Fe in Cosor 5. The Fe level in tissue of unflooded plants seemed abnormally high, however,

Concentration (μg/g) of Cu, Fe, Mn, and Zn in above-ground foliage at boot growth stage of eight sorghum cultivars subjected to flooded (F) or non-flooded (C) conditions in a lowland paddy soil.

	Cu		Fe		Mn		Zn	
Cultivar	F	C	F	C	F	C	F	C
Cosor 5	6.3 a*	12.9 a	449 a	499 a	127 abc	46 a	18.7 a	44.0 b
CS 133	8.0 a	11.8 ab	568 a	283 ab	135 ab	49 a	16.1 a	44.2 b
CS 295	6.8 a	12.7 ab	529 a	184 b	146 a	46 a	17.3 a	41.7 b
CS 385	6.0 a	11.8 ab	350 a	193 b	109 c	45 a	16.1 a	43.5 b
CS 160	6.2 a	12.5 ab	458 a	173 b	121 bc	57 a	17.3 a	44.3 b
CS 276	8.0 a	13.9 a	465 a	185 b	118 bc	41 a	15.8 a	51.7 b
CS 402	6.0 a	10.4 b	474 a	168 b	128 abc	51 a	17.4 a	61.4 a
BTx 623	6.6 a	14.2 a	383 a	224 b	115 bc	39 a	15.3 a	50.2 b
Mean	6.7+	12.5	460+	239	125+	47	16.5+	47.6

*Means followed by the same letter within the same column are not significantly different at P = 0.05.

+Overall mean of the flooded treatment is significantly different from the non-flooded treatment.

and may have been contaminated in the process of sampling or overseas transit and processing.

Concentrations of Mn and Fe increased markedly in alfalfa (Medicago sativa L.) after 72 h of flooding[11]. This crop is known to be sensitive to Mn toxicity and its poor response in poorly aerated soils has been associated with this specific element sensitivity. The poor response of waterlogged barley could not be attributed to Mn toxicity, however, even though levels in the foliage were increased[4]. It apparently takes anywhere from 140 - 405 ug/g Mn in plant material before toxicity becomes evident[8]. None of the sorghum cultivars in the current experiment reached this level at or near the boot stage, and there were essentially no cultivar differences for any of the minor elements within either of the treatments.

Many differences in mineral element concentrations observed at the boot growth stage due to flooding were largely negated in the plants at maturity (Table 4). Leaf blades had significantly lower values for N, K, S, Cu and Zn, but the magnitude of these differences were small in comparison to that observed at boot. Concentrations of P and Mg were the same for both treatments. The increase for Mn in leaves of flooded plants was not significant although it was in the stalk. Increases in Fe concentration on the other hand, were significant for the non-flooded treatment in leaf blades, and significantly lower in the stalk. There were little or no differences in the means of

TABLE 4

Means of concentrations of mineral elements in leaf, stalk, and seed of sorghum cultivars grown in flooded (F) or non-flooded (C) conditions in a lowland paddy soil.

Plant Part	Treatment	N	P	K	Ca	Mg	S
		%					
Leaf	F	1.27*	0.25	0.84*	0.28	0.11*	0.55*
	C	1.48	0.23	0.98	0.27	0.14	0.48
Stalk	F	0.26	0.30	1.71	0.24	0.12*	0.18*
	C	0.33	0.24	1.91	0.22	0.14	0.13
Seed	F	1.38	0.35	0.48	0.11	0.11	0.13
	C	1.39	0.35	0.50	0.10	0.11	0.14

		Cu	Fe	Mn	Zn
		μg/g			
Leaf	F	244	392*	7.3*	39.2*
	C	212	524	8.8	48.4
Stalk	F	78*	116*	10.6	67.0*
	C	33	90	11.6	74.5
Seed	F	18	55	4.8	19.7*
	C	21	53	4.5	21.8

*Significantly different from flooded treatment at 0.05 probability.

mineral element concentrations of the seed between flooded and non-flooded treatments.

Flooding reduced total mineral accumulation in the stover at maturity for all elements but Mn (Tables 5 and 6). As expected, cultivar differences in mineral accumulation ranked similar to their dry matter accumulation for the major elements (Table 5). These values are the product of DW and concentration with the latter changing little among cultivars (data not shown). Cultivars BTx 623 and CS 133 which had the highest dry matter at maturity generally ranked highest for major nutrient accumulations in either treatment (Table 5). However, if one were to judge flooding tolerance as ability of a cultivar to maintain important nutrients at a high percent of control plants, then a cultivar such as CS 160 would rank high since its N level was reduced only 38% (compared to 65% for BTx 623) and its P level not at all by flooding.

Cultivar BTx 623 also ranked highest for total minor element accumulation (Table 6). Higher tissue concentrations of Mn in flooded plants however, did not result in higher total Mn contents for all cultivars as the reductions in dry matter production were too great to offset.

We concluded from this experiment that sorghum is severely limited in yield potential when grown in lowland rice paddy soils under short term waterlogged conditions. These soils appeared to be ill suited for producing satisfactory sorghum

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TABLE 5

Total mineral element content (mg) of N, P, K, Ca, Mg, and S in the stover at maturity of eight sorghum cultivars subjected to flooded (F) or non-flooded (C) conditions in a lowland paddy soil.

	N		P		K		Ca		Mg		S	
Cultivar	F	C	F	C	F	C	F	C	F	C	F	C
Cosor 5	256.9 b*	412.1 c	148.8 c	186.5 cd	752.3 c	1069.5 cd	127.7 cd	124.2 d	117.5 c	162.0 c	60.4 b	101.3 c
CS 133	358.5 a	801.7 b	227.2 b	329.5 b	1058.4 b	2421.7 b	168.7 ab	293.7 b	167.7 b	392.6 b	60.9 b	149.4 b
CS 295	175.5 b	445.5 c	93.1 c	192.6 cd	646.7 c	1790.6 bc	114.4 cd	189.4 c	104.1 c	195.9 c	47.6 b	102.5 c
CS 385	255.7 b	411.4 c	129.2 c	155.8 cd	705.0 c	1343.8 cd	116.9 cd	137.5 d	130.8 c	133.0 c	65.6 b	121.8 bc
CS 160	184.0 b	298.0 c	110.3 c	106.3 d	566.9 c	976.3 d	108.6 d	117.1 d	95.5 c	118.2 c	57.6 b	91.2 c
CS 276	210.2 b	467.5 c	147.7 c	245.1 bc	718.0 c	1546.9 cd	119.0 cd	152.7 cd	118.2 c	186.5 c	61.2 b	129.6 bc
CS 402	214.1 b	368.0 c	131.6 c	156.8 cd	641.4 c	1084.4 cd	145.0 bc	143.3 cd	119.4 c	146.5 c	55.3 b	95.0 c
BTx 623	378.6 a	1069.7 a	363.8 a	452.1 a	1783.4 a	3506.6 a	181.3 a	346.6 a	243.8 a	500.2 a	104.9 a	237.0 a
Mean	254.2+	534.3	168.9+	228.1	859.0+	1717.5	135.2+	188.1	137.1+	229.4	64.2+	128.5

*Means followed by the same letter within the same column are not significantly different at P = 0.05.

+Overall mean of the flooded treatment is significantly different from the non-flooded treatment.

TABLE 6

Total mineral element content (mg) of Cu, Fe, Mn, and Zn in the stover at maturity of eight sorghum cultivars subjected to flooded (F) or non-flooded (C) conditions in a lowland paddy soil.

	Cu		Fe		Mn		Zn	
Cultivar	F	C	F	C	F	C	F	C
Cosor 5	0.48 b*	0.71 b	11.4 ab	10.6 b	6.7 ab	5.4 cd	3.4 b	5.4 cd
CS 133	0.57 b	1.09 b	13.1 a	27.7 a	6.8 ab	8.8 b	4.4 a	8.8 b
CS 295	0.43 b	1.00 b	7.6 ab	15.0 b	4.7 c	6.3 bc	2.4 c	6.3 bc
CS 385	0.39 b	0.82 b	7.3 ab	10.7 b	5.0 bc	4.6 cd	2.6 bc	4.6 cd
CS 160	0.55 b	0.84 b	5.9 b	9.0 b	4.7 c	3.5 d	2.5 bc	3.5 d
CS 276	0.51 b	0.92 b	8.4 ab	16.9 b	5.8 abc	7.1 bc	2.9 bc	7.1 bc
CS 402	0.40 b	0.80 b	7.9 ab	10.9 b	6.1 abc	5.6 cd	3.2 bc	5.6 cd
BTx 623	0.88 a	2.42 a	10.6 ab	34.7 a	7.1 a	12.7 a	5.3 a	12.7 a
Mean	0.53†	1.08	9.0†	16.9	5.9	6.2	3.3†	6.8†

*Means followed by the same letter within the same column are not significantly different at P = 0.05.

†Overall mean of the flooded treatment is significantly different from the non-flooded treatment.

with the cultivars used in this test even when grown without waterlogging. Cultivars responded differently, however, which implies that selection pressure in a breeding program could result in improved sorghum genotypes capable of outperforming those being used most commonly. Restrictions in growth due to flooding may be related in part to nitrogen levels being reduced in leaves below that level "critical" for normal growth. Visually, nitrogen deficiency symptoms were evident most predominately. Although alterations occurred in other element

levels, there was no reason to suspect that they influenced growth as much as nitrogen.

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