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Field Evaluation of Dryland Wheat Cultivars for Aluminium Tolerance

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ABSTRACT: *In South Africa particularly Free State Province, most of the soils have a high concentration of Aluminum which adversely affect wheat growth and ultimately yield. This study was conducted to evaluate eighteen dryland wheat cultivars for Aluminum tolerance. Factorial design with four levels of lime regime (0, 1.6, 3.3 and 4.1 ton ha^{-1}) was employed in three localities of Bethlehem, Ficksburg and Betania situated in the Free State province. Analysis of Variance was performed with data generated from these localities. A highly significant difference ($P<0.05$) was obtained among wheat cultivars for yield, hectoliter mass, protein content and falling number. Different liming rates, localities and interaction of cultivar and localities showed a highly differences for yield, hectolitre mass, protein content and falling number. No significant difference was found in the interaction of cultivar and liming rate, and cultivar interaction with liming rate and localities. Gariep, Limpopo and Elands out-yielded other wheat cultivars in grain yield, hectolitre mass, protein content and falling number and can be selected to be grown under Al stressed environment. Ficksburg locality showed a good performance in all parameters studied, followed by Bethlehem and lastly Betania with very low performance.*

KEYWORDS: Aluminum tolerance, wheat cultivars, liming rates, South Africa.

INTRODUCTION

The importance of soil pH in wheat production cannot be over-emphasized as it adversely affect plant growth and ultimately yield. It exerts its influence on nutrients availability, root growth and development, rate of microbial activity and nitrogen transformation (Miles, 2013; Jensen, 2010; Delhaize and Ryan, 1995; Mengel and Kirby, 1978). The causes of soil acidity include inter alia; injudicious use of fertilizers, crop removal of cations in exchange for hydrogen ions, leaching of these cations being first replaced by hydrogen ions, and then Aluminum(Al), and decomposition of organic matter (Rout *et al*., 2001; Padra and John, 2000). Aluminum is always accompanied by high concentration of Iron and Manganese, and low concentration of Calcium (Mossor-Pietraszewska, 2001; Jarvis and Hatch, 1985). The occurrence of high concentration of Al become toxic to plant roots root tips and lateral roots become thickened and turn brown. This affects nutrients and water uptake by plants (Silva, 2012). Nonetheless, crops differ greatly on their tolerance to Al toxicity and even within a crop species, there are tolerant cultivars giving substantial yield. The reason for cultivar difference in response to Al relates to varying ability of a plant to modify pH of the soil root interface. Organic acids such as malate and citric acid are exuded by the roots. Some cultivars take up NO_3- at high rates in the presence of NH_{4+}, while others contain organic acids and polyphenol which detoxify Al by chelation (Panda *et al*., 2009).

South Africa is no exception to this problematic condition (Schroeder *et al*., 1994). Wheat farmers in the Free State, Kwa-Zulu Natal and Eastern Cape Provinces have raised a great concern about their farms that are giving low yield due to acidic soils, and some have been

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abandoned (Fertilizer Society of South Africa, 2007; Food and Agricultural Organization, 2005; Schroeder *et al*., 1994). They have appealed for assistance to overcome this problem. Furthermore, soil samples taken from different farms in the Free State province showed that most soils are acidic which necessitates research to be conducted to solve the problem (Visser *et al*., 2008). The cost of purchasing, transporting and applying lime is highly unaffordable to the farmers. It is therefore necessary to evaluate cultivars of wheat for their tolerance to Al toxicity as an alternative for wheat farmers. Extensive research on screening of cultivars for Al tolerance was started in 1988 and terminated in 2003 and it is now deemed necessary to continue the research since more new cultivars are being released and no evaluation is done. The ones that were screened had become obsolete. The objective of the study was to evaluate dryland wheat cultivars for Al tolerance at different localities and liming rate.

MATERIALS AND METHODS

Site description

An experiment was conducted in three localities in the Free State Province, name; Bethlehem, Betania and Ficksburg. The areas are situated between latitudes 26.6^{0}S and 30.7^0 S, longitudes 24.3^0 E and 29.8^{0}E, and altitude of 1800 m above sea-level. An average annual rainfall is 559 mm with minimum temperature of -4^{0}C in winter season and maximum of 27^{0}C. Snowfall is experienced between May and July. Soil type is Avolon characterized by grey/brown colour without structure, loamy sand to sandy loam top-soil on yellow/brown, without structure, loamy sand to sandy loam sub-soil on grey, mottled and soft plinthite. Soil depth is between 500 mm and 1200 mm.

Experimental design

Factorial design consisting of four levels of liming regimes and eighteen dryland wheat cultivars was used. The main plot measured 108 m x 44 m with sub-plot having dimension of 6 m x 3 m. The number of rows in a plot was six with inter-row and intra-row spacing of 50cm and 7cm, respectively. There were three replications for each treatment resulting in 216 sub-plots. The aim was to have a variation of acid levels ranging from a pH(Kcl) of 3.9 (initial value) to 4.5, which is an acceptable value for wheat production. Soil analysis results before conducting experiment were; soil pH 3.9, Phosphorus (33.1 mg kg^{-1}), Potassium (71.5mg kg^{-1}), Calcium (114 mg kg^{-1}), Magnesium (28 mg kg^{-1}) and Sodium (3.3 mg kg^{-1}). Lime was incorporated into the soil using a mould-board plough, after which it was left for two months to allow lime to react with the soil. Before planting time, the following levels of soil acidity were recorded in the trial blocks:

Level 1: pH (Kcl) of 3.9 (no lime applied)

Level 2: pH (Kcl) of 4.2 (1.6 ton lime applied)

Level 3: pH (Kcl) of 4.4 (3.3 ton lime applied)

Level 4: pH (Kcl) of 4.6 (4.1ton lime applied)

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Establishment and maintenance of experiment

The land was prepared using mould-board plough, after which disc harrow was employed to level the seed-bed and break the soil lumps. Gasparo pneumatic planter was used to drill seed into the soil in rows. The seeding rate for all whet cultivars planted was 25 kg ha^{-1}. Seeds were treated with Gaucho and Vitavax for soil-borne fungal diseases. Compound fertilizer of 3:1:0(25) was applied at the rate of 225 kg ha^{-1} as basal dressing, after which limestone ammonium nitrate was broadcast at the rate of 100 kg ha-1 as top-dressing. Brush-off, Servian and Glean herbicides were applied at stem extension at the rate of 16ml/20 ml H_2O, 2g/16l H_2O and 16g/12l H_2O, respectively. Harvesting was performed using Wintersteiger plot harvester at 12% moisture content.

Data collection and analysis

Grain yield, hectolitre mass, falling number and grain protein content were determined in the laboratory. Analysis of variance was performed using Genstat generation 12. Mean separation was done by least significant difference.

RESULTS

There was a significant difference ($P<0.05$) among wheat cultivars for yield and hectolitre mass while protein content and falling number showed no significant differences (Table 1). The cultivar with the highest mean was Gariep, followed by Limpopo and Eland with 1.462 ton ha^{-1}, 1,442 ton ha^{-1} and 1.426 ton ha^{-1}, respectively. The lowest mean yield was found in PAN 3191, followed by PAN 3120 with 0.999 ton ha^{-1} and 1.045 ton ha^{-1} (Table 2). Highest hectolitre mass was obtained by PAN 3349 and Komati with 73.67 and 73.56 kg hl^{-1}, respectively. Caledon had a low hectolitre mass of 71.64 kg hl^{-1}, followed by Elands with 72.01 kg hl^{-1}. Liming rates exhibited highly significant difference ($P<0.01$) with 4.1 ton ha^{-1} application giving the highest yield of 1.338 ton ha^{-1} while 0 ton ha^{-1} (control) gave a yield of 1.139 ton ha^{-1}. The other two liming regimes, 1.6 and 3.3 tons resulted in the yield of 1.188 and 1.253 ton ha^{-1}. Significant difference ($P<0.01$) was revealed among three localities where the study was conducted. Ficksburg led with the yield of 1.758 kg ha^{-1}, followed by Bethlehem with 0.975 kg ha^{-1} and Betania 0.956 kg ha^{-1}. Interaction of cultivars and localities exhibited highly significant differences ($P<0.01$) with Komati obtaining highest yield of 2.336 ton ha^{-1} in Ficksburg while the lowest yield of 0.672 kg ha^{-1} was realized in Betania. No significant difference was obtained between the interaction of wheat cultivars and liming rates.

DISCUSSION

Wheat cultivars reacted differently to liming regimes as some performed very well under low regime while others showed very poor performance in yield, hectolitre mass, protein content and falling number. Among these cultivars, there were some which performed consistently the same across the different liming regimes. The results emphasizes the difference in the genetic constitution of wheat cultivars that enables them to adapt faster to the environment in which they are grown and resist the negative effects of Al toxicity. This lies entirely on the ability of some wheat cultivars to exude organic acid from the roots such as malate and citrate acid as a mechanism to buffer high level of Al (Singh *et al*., 2011). The exudation of organic compounds

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capable of chelating Al into rhizosphere complex increases Al resistance. The organic acid release (Al inducible) by root apex of Al tolerant genotypes have been identified and have provided evidence for the existence of such a tolerant mechanism where the exuded organic acid chelates reduce the activities of toxic Al in the rhizosphere (Makau *et al*.,2011). Wheat cultivars can be ranked at various liming regimes according to their resistance and susceptibility to Al toxicity based on the parameter being studied. This variation among cultivars of wheat assist in selection of resistant ones that can be grown where Al toxicity level is high and still give a substantial yield. Gariep, Limpopo and Elands performed very well and can be selected to be grown under Al stressed environment. Wang *et al*., (2007) evaluated 45 wheat cultivars for acid tolerance under five regimes and found 22 cultivars being tolerant to Al toxicity and used them to select for breeding program. Similarly, Carver and Ownby (1995) screened 30 wheat cultivars for acid soil tolerance and found 12 of them being tolerant to Al toxicity.

The results also revealed the differences in the performance of different wheat cultivars grown in three localities. Similarly, there were some cultivars which performed well in all localities whereas others did not yield good results. At Fickburg, most wheat cultivars gave a high yield, followed by Bethlehem and lastly Betania with poor results. The difference in environmental conditions at three localities also affected wheat cultivars. It is well documented that temporal and spatial variation affects the gene expression for Al tolerance (Laferver, and Campbell, 1997; Foy,1988). Environmental conditions such as temperature, nutrients availability and soil type may have effects on the ability of the crop to express themselves and be tolerant to Al toxicity, hence similar results could not be found in all localities (Singh *et al*., 2011).

Interaction between localities and liming rates showed a highly significant difference because of the environmental conditions that existed within each which differ from the others. The environmental factors such as soil temperature may increase the rate of lime reaction in the soil if it is high. But where soil temperature is low, the rate of lime reaction with the soil is slow, The reaction of lime with the soil due to temperature had an impact on the increase in the soil pH. Soil moisture content in the localities differed resulting in the reaction of lime and soil being affected. High moisture content increased the rate of reaction between lime and soil, thereby increasing the soil pH. Similarly, the rate of reaction between lime and soil was very slow where soil moisture content was low. This is typical of Betania where there was less moisture due to the nature of the place. No significant difference was obtained with interaction of cultivars and liming rate, cultivar with localities and interaction of cultivar, liming rate and localities. The results obtained in this study was consistent with the findings of Aniol (1991) who did not get interaction among the liming rates, wheat cultivars and localities.

CONCLUSION

The experiment reveals clearly that there was a genetic variability that existed among wheat cultivars grown in different localities under differing liming regimes. This implies that some wheat cultivars can be selected and grown under Al stressed environments. The cultivars can be ranked according to their tolerance to Al and be incorporated in the breeding programme to produce even more superior ones. Localities with its environmental aspects may modify the expression of some cultivars to AL tolerance.

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APPENDIX

Table 1. ANOVA for yield, hectolitre mass, protein content and falling number

Source of variation		Mean square			
	df	Yield (ton ha^{-1})	Hectolitre mass (kg hl^{-1})	Protein (%)	Falling number (sec)
Replication	2	352076**	35.434*	2.675	25194
Cultivars	17	610725	14.351	1.056	2428
Liming rate	3	1205461	1.418	2.585	13430
Localities	2	45259037*	1147.39988	194.103	511533**
Cultivar x Liming rate	51	223067	7.940	1.244	3386
Cultivar x Localities	34	447289	7.299	0.986	1492
Liming rate x Localities	6	125138	11.302	2.899	12404
Cultivar x Liming rate x Localities	102	146921	7.423	0.666	2103
Error	398	198773	8.688	1.456	2771
Total	615				

Table 2. Means of yield, hectolitre mass, protein content and falling number

Cultivars	Yield (ton ha^{-1})	Hectolitre mass (kg hl^{-1})	Protein content (%)	Falling number (sec)
Betta-Dn	1222	72.75	14.8	253.5
Caledon	1331	71.64	15.0	260.9
Elands	1426	72.01	14.4	270.7
Gariep	1462	72.08	14.9	271.2
Komati	1316	73.56	14.8	242.5
Limpopo	1442	73.00	14.8	264.2
Matlabas	1293	72.23	14.7	257.8
PAN 3118	1150	72.05	14.8	273.0
PAN 3120	1045	72.09	15.1	257.4
PAN 3122	1239	73.27	15.0	268.6
PAN 3144	1189	72.20	14.6	274.1
PAN 3191	999	72.53	14.7	265.0
PAN 3349	1178	73.67	14.8	273.2
PAN 3355	1127	72.07	14.6	273.2
SST 322	1243	72.23	14.8	268.5
SST 334	1155	73.44	14.9	265.7
SST 399	1113	73.24	15.0	266.8
SST 966	1200	72.96	15.1	261.0
Mean	1229	72.61	14.8	264.8
CV	10.3	4.1	8.6	4.1
LSD (5%)	357.8	1.366	0.5591	24.39

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Table 3. Performance of different wheat cultivars, quality parameters and localities.

Cultivars	Yield (ton ha^{-1})			Hectolitre mass (kg hl^{-1})			Protein content (%)			Falling number (seconds)		
	Betania	Bethlehem	Ficksburg	Betania	Bethlehem	Ficksburg	Betania	Bethlehem	Ficksburg	Betania	Bethlehem	Ficksburg
Betta-DN	1018	1173	1475	70.32	72.56	75.36	15.36	15.30	13.60	294.7	187.3	278.5
Caledon	1171	1034	1787	67.90	72.05	74.97	15.63	15.45	13.80	296.4	206.4	279.9
Elands	1002	999	2277	69.91	73.11	73.01	14.73	15.16	13.23	305.2	208.9	298.0
Gariep	1073	976	2336	70.27	71.92	74.06	15.35	15.44	13.76	320.8	215.7	277.2
Komati	908	1048	1992	71.20	73.41	76.08	15.90	14.93	13.67	270.2	192.8	264.4
Limpopo	1094	1082	2152	70.64	72.78	75.58	15.67	15.17	13.60	303.1	207.4	282.2
Matlabas	931	1016	1933	70.04	71.29	75.37	15.13	15.33	13.76	296.7	199.2	277.7
PAN 3118	927	964	1561	69.38	72.13	74.66	15.02	15.51	13.76	330.8	212.0	276.2
PAN 3120	838	966	1331	69.13	71.96	75.19	16.27	15.26	13.65	278.2	215.6	278.3
PAN 3122	1096	1048	1574	71.60	72.24	75.98	15.45	15.36	14.12	308.4	210.6	286.7
PAN 3144	972	893	1701	69.32	72.24	75.04	15.13	15.17	13,97	314.4	219.5	288.2
PAN 3191	954	923	1120	70.91	73.07	73.62	15.24	15.17	13.71	307.5	208.1	279.3
PAN 3349	707	795	2031	70.90	73.84	76.28	15.08	15.81	13.61	317.9	207.9	293.7
PAN 3355	672	946	1762	69.44	71.88	74.89	15.28	15.19	13.35	326.2	221.4	269.2
SST 322	1121	990	1619	70.70	72.03	73.96	15.10	15.68	13.71	319.9	224.7	261.0
SST 334	791	745	1736	71.90	74.00	74.43	15.28	15.52	13.82	296.0	218.1	283.2
SST 399	791	1002	1545	71.31	72.56	75.85	15.47	15.38	14.07	290.9	217.8	291.0
SST 966	944	947	1710	71.62	72.20	75.07	16.15	15.28	13.94	302.2	215.2	265.5

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