DIFFERENTIAL REACTION OF WHEAT AND TRITICALE TO PHYSICAL AND CHEMICAL PROPERTIES OF SOILS IN MUGAMBA, BURUNDI

J.J. Schalbroeck, L. Opdecamp, and R. Baragengana

ISABU-Gisozi
B.P. 75
Bujumbura, Burundi

Abstract

In a series of 55 on-farm trials conducted in 1985, the effect of Mugamba soil properties on the yields of wheat (Triticum aestivum L. cv. Romany) and triticale (X Triticosecale Wittmack, cv. Mizar) was investigated. No mineral fertilizers were applied to the trial plots. In northern Mugamba, the soils are moderately to weakly acid and are predominantly hygrokaolisols with a few kaolintic brown soils. The mean yields of wheat and triticale on these soils were similar (1.6 t/ha). However, in southern Mugamba where the soils are dominated by humiferous kaolisols, which are strongly acid and which often have high levels of exchangeable aluminum, the mean yields of wheat and triticale were 1.2 and 1.7 t/ha, respectively. The differential response of wheat and triticale, in respect to the soil types, is discussed in relation to the topsoil chemical characteristics (the different levels of acidity, base saturation, exchangeable aluminum and available phosphate).

Introduction

In Burundi, wheat (*Triticum aestivum* L.) is cultivated mainly in regions above 1900 m elevation in the Zaire-Nil ridge and, for the most part, during the second crop cycle (March-August). In 1984 area sown to wheat in the Mugamba region totalled about 7700 ha, of which 6600 were planted during the second season (2). The use of varieties like Romany, which are well adapted to the not very fertile soils of the region, would result in mean yields of 1.3 t/ha with weed control and no manure application (18).

Introduced in Burundi in 1975, triticale (X. *Triticosecale* Wittmack) quickly appeared to be the cereal of the future on very acid soils. In multilocational varietal trials in 1980, mean yields of the best triticales were 3.9 t/ha, 20% better than those of wheat variety Romany. Triticale's superiority over wheat, however, varied from site to site. On very unsaturated and acid soils (pH 4.9) where Romany produced only 0.9 t/ha, the best triticales outyielded it by 70-140% (20).

A study of the differential reaction of these two cereals to physical and chemical soil properties was begun in 1984 and continued in 1985. Its objective was to identify the most adequate soils for each of these crops, as well as potential yield levels, in order to make the best recommendation to farmers concerning the allocation of their natural resources.

Articles on this subject have already been published, based on the 1984 results (16, 21, 24) where soils were classified using the INEAC scale (26). A more detailed analysis has also been presented (17) that takes into account the results of two years of testing and uses the prototype classification established for tropical, nonvolcanic, humid regions (15).

This report is based essentially on the 1985 results and uses the INEAC soil classification scale adopted at the beginning of the study. It complements the paper presented at the preceding Regional Wheat Workshop at Njoro (21).

Materials and Methods

In 1985 wheat variety Romany (origin: Colotana x Yaktana) and triticale variety Mizar (origin: Maya II x Arm.), bred in Kenya (8) and Italy (29), respectively, were compared in 55 trials conducted on farmers' fields in Mugamba. These trials, situated at 1900-2200 m, were distributed over six subregions (Figure 1).

The trials were planted in three randomized complete blocks and basic 8 m^2 plots, using a seeding density of 140 kg grain per hectare, with 20 cm between rows, after maize (*Zea mays* L.) intercropped with beans (*Phaseolus vulgaris* L.). All trials were conducted with no mineral or organic fertilization and were weeded manually. They were planted on 21-29 March north of the Bugarama-Muramvya axis, and 28 March-9 April south of the axis (Figure 1).

The chemical analysis of the topsoil (0-20 cm) in each plot was done on a composite of 40-samples taken before or just after planting. Soils were classified using the INEAC scale (26).

Results and Discussion

Climatic conditions--Based on climatic data for Nyakararo and Munanira (Figure 1), total rainfall and its distribution over the growth cycle were similar for all the research area (Table 1). Since April is the rainiest month in Burundi, there was ample water for wheat and triticale from seeding through the beginning of stem elongation. Heading and grain-filling, on the other hand, took place during the dry season beginning the last 10 days of March.

Mean temperatures, characteristic of a highland equatorial regime, showed little variation throughout the cycle, although at Nyakararo they were slightly lower during the dry season. Mean temperatures were slightly higher in northern Mugamba, causing a shortening of the vegetative cycle (Table 1).

All trials were planted during the best seeding period. Parallel testing done in 1985 showed that planting dates from 20 March to 3 April in northern Mugamba and from 27 March to 10 April in southern Mugamba did not affect wheat yields (22). It can therefore be assumed that yields produced by Romany and Mizar in each trial adequately reflect their response to natural soil fertility at each site.

Distribution and physical and chemical properties of soils in Mugamba--According to Opdecamp et al. (17), the Mugamba region is made up of two main landform and pedological areas situated on either side of the axis that joins Bugarama to Muramvya (Figure 1).

Northern Mugamba, a hilly to mountainous area, is composed mainly of hygrokaolisols, while southern Mugamba, cut by valleys, is composed mainly of humiferous kaolisols. Although brown kaolinitic soils are occasionally found in northern Mugamba, hygrokaolisols and humiferous kaoliosols are more or less equally distributed in the wheat-producing area of Mugamba.

A correlation between terms of the classification scale that was used and those of the American scale (28) cannot be attempted unless certain approximations are accepted. Hygrokaolisols are classified preferably in the agrudalf, paleudult and palehumult subgroups, humiferous kaolisols in the palehumult, haplohumox and sombrihumox subgroups, and brown soils in the agrudalf and palehumult subgroups.

Of the 55 trials, 25 were planted in humiferous kaolisols, 26 in hygrokaolisols and 4 in brown kaolinitic soils. Trials planted in humiferous kaolisols were situated south of Bugarama, while those planted in hygrokaolisols were situated north of it. Trials planted in brown soils were situated in the Munanira subregion (Figure 1).

Topsoil chemical properties of the 55 sites, classified according to soil type, are summarized in Table 2.

Humiferous kaolisols are characterized by an accumulation of humus, which can sometimes be 1 m deep in this locality. Because of the high organic content, generally between 8 and 13% in the topsoil, they have a high cation exchange capacity (T = 23-30 meq/100 g). These soils range from heavy to very heavy (65-85% clay), if derived from basic schist (60% of the soils), or have a lighter (45-60 % clay) texture if they are composed of acid micaceous rock (30% of the soils). In spite of their high clay content, they are very permeable.

Hygrokaolisols and brown soils generally contain 3-5% organic matter and have a cation exchange capacity of 11-18 meq/100 g. Dry soils, 90% of which are derived from basic schist, have a heavy to very heavy texture (65-85% clay).

According to criteria mentioned by Boyer (3), the soils of the 55 sites should have good levels of exchangeable potassium; their potassium content is higher than deficiency thresholds set at 0.1 meq/100 g or 2% of the sum of exchangeable cations. Moreover, the Mg/K and Ca + Mg/K ratios are below the threshold of 25, and 40-50 above ratios at which unbalanced potassium nutrition is normally observed.

Calcium and magnesium levels are generally good in absolute terms. However, if one refers to Boyer's criteria (3), certain soils, especially humiferous kaolisols, could present calcium and magnesium deficiencies caused by an imbalance between these elements and potassium, when the Mg/K and Ca + Mg/K ratios are lower than the thresholds by 3-4 and 12-18, respectively.

Humiferous kaolisols are, on average, more acid (pH 4.9-5.5) than hygrokaolisols and brown soils (pH 5.6-6.4). In humiferous kaolisols, plants would have difficulty assimilating phosphorus. Indeed, it is assumed that at levels below pH 5.5, a high proportion of this element is in the form of ferric compounds that are not very soluble (3). On-farm trials with phosphate fertilizer and using only wheat variety Romany indicate that it responds better to available phosphorus on humiferous kaolisols than on hygrokaolisols and brown soils (23).

Humiferous kaolisols have high levels of exchangeable aluminum. For the 25 trials planted in this type of soil, the level of exchangeable aluminum in the topsoil is an average of 2.0 meq/100 g or, at most, 3.9 meq/100 g. Kamprath's m index, which conditions the effect of exchangeable aluminum on plants, shows a 0-62 variation. Many authors (12, 14) cited by Boyer estimate that on Brazil's acid soils it is no longer possible to grow most crops above m = 45-50, and that there is practically no risk of aluminum toxicity below m = 5-10.

Soil-plant interactions--Mean yields of triticale variety Mizar are similar in northern and southern Mugamba, while wheat variety Romany mean yields are 36% better in the north (Table 3). The highest yields for both cereals were produced on brown soils rich in bases (Tables 2 and 4). Thus these results confirm the 1984 results (21).

Mean yields of wheat and triticale do not differ significantly on hygrokaolisols and brown soils. In contrast, on humiferous kaolisols triticale's mean yields were higher by 30-40% than those of wheat, depending on the year (Table 4). Triticale's good performance on humiferous kaolisols was also observed in 1985 by the Highland Village Cultivation Project (CVHA, Projet Cultures Villageoises en Haute Altitude) (18). On 252 demonstration plots without mineral fertilizers, Mizar's mean yield, 1.60 t/ha, was 32% better than Romany's. However, triticale's superior yields on humiferous kaolisols vary from site to site. In 1985 trials, the standard deviation associated with production gains indicates that they fluctuate between -10% and +120% (Table 2).

A separate analysis of results obtained on humiferous kaolisols and on hygrokaolisols shows that wheat and triticale yields increase in a highly significant fashion depending on the sum of exchangeable cations and that they decrease as acid and aluminum levels rise (Table 5 and Figure 2).

Significant correlations between yields and the level of exchangeable aluminum observed on hygrokaolisols have only limited impact since 24 of 26 sites have a Kamprath m index of 6 or lower. The analysis of results of these 24 sites, where there should be no aluminum toxicity, indicates that on hygrokaolisols wheat and triticale yields are closely related to calcium and magnesium levels (Table 5). Nevertheless, it is impossible to determine whether the effect of either of these elements is dominant over the other, since they are closely correlated (r = 0.75).

Regression lines linking wheat yields on humiferous kaolisols to acid and base levels in the soil continue lines observed on hygrokaolisols (Figure 2). Poor wheat yields on humiferous kaolisols thus seem to be linked to high acid levels, though it is not possible to determine their main effect (calcium and/or magnesium deficiency, low availability of assimilatable phosphorus below pH 5.5, unfavorable effect of high aluminum content). Potassium deficiency in humiferous kaolisols is not evident despite a highly significant correlation between phosphorus content in the soil and yields (Table 5). Humiferous kaolisols are richer in exchangeable potassium than hygrokaolisols (Table 2) and mineral fertilizer trials on humiferous kaolisols have shown that potassium input has no significant effect on wheat yields when, without manure, they reach at least 0.9 t/ha (23). The significant yield/potassium correlation would be due to a close link between potassium content and calcium and magnesium levels ($r = 0.49$ and 0.62, respectively).

Upon examining correlation coefficients estimated for the 51 trials planted in humiferous kaolisols and hygrokaolisols, it is apparent that the relative value of triticale production gains, compared to wheat, increases with acid and exchangeable aluminum levels, whether expressed in absolute value or by Kamprath's m index (Table 5). These results go hand in hand with the lack of significant correlations between triticale yields and acid and exchangeable aluminum levels; in contrast, wheat yields are significantly correlated to these two soil characteristics.

Mizar also seems less susceptible to aluminum toxicity than Romany. Even when triticale yields on humiferous kaolisols decrease because of exchangeable aluminum levels, they are on average 40% higher than wheat yields (Figure 2). On humiferous kaolisols, however, triticale production gains compared to wheat are not linked to aluminum content (Table 4). Musa (13) thinks triticale's improved aluminum tolerance probably explains why it is superior to wheat on soils with 25-50% aluminum saturation in the subsoil. Many authors have nevertheless shown that triticale's aluminum tolerance is not generalized and that certain varieties are susceptible to aluminum (6, 11, 13). Mugwira et al. (10) suggest two mechanisms in certain triticale varieties which may explain their aluminum tolerance: aluminum precipitation in the root area caused by raising the pH level, as in certain aluminum-tolerant wheat varieties, or the ability to fix high aluminum concentrations in the roots without transferring the element towards the upper part of the plant, as rye has (*Secale cereale* L.).

Correlation coefficients estimated for the 51 trials planted in humiferous kaolisols and hygrokaolisols also show that triticale yields and the relative value of production gains, compared to wheat, are significantly linked to phosphorus content in the soil. A similar tendency is observed on humiferous kaolisols (Table 5). It can thus be hypothesized that triticale's good performance on humiferous kaolisols is caused by its ability to assimilate phosphorus more easily than wheat in very acid soils when aluminum is present. Triticale production gains compared to wheat would thus be even higher on acid soils with high aluminum content because they are rich in phosphorus. Andrew and Vanden Berg (1) have demonstrated with different forage leguminous plants grown in nutrient solution that in an aluminum-tolerant species, versus a susceptible one, phosphorus absorption and transference will take place when there are high aluminum levels in the solution. According to Fleming et al. (7), the response to phosphorus of an aluminum-tolerant plant (*Eragrostis curvula* (Schrad.) Nees) is not affected by high levels of aluminum in the solution. On the other hand, an aluminum-sensitive plant (*Festuca arundinacea* Schref.) shows a feeble response to phosphorus, which is noticeable especially in its poorly developed root system.

Conclusions

The Mugamba region presents landform and pedological contrasts along a north-south axis. In the hilly region of northern Mugamba hygrokaolisols predominate, though there are some brown kaolinitic soils. On these soils, with pH 5.6-6.4 and good base availability (an average of 8.7 meq/100 g), Romany and Mizar have similar yields, an average 1.6 t/ha, without mineral fertilizers. In the valleys of southern Mugamba, humiferous kaolisols predominate. They have high organic content and pH 4.9-5.5, are moderately rich in exchangeable bases (5.7 meq/100 g, on average) and are characterized by an aluminum saturation rate of the exchange complex that ranges between 0 and 62%. On humiferous kaolisols, Romany's mean yield without mineral fertilization is 1.2 t/ha. On the other hand, Mizar is as productive on humiferous kaolisols as on hygrokaolisols and brown soils, so that on humiferous kaolisols, its mean yield is 35% higher than Romany's. The study thus confirms triticale's good adaptation to acid soils, which was observed in Kenya (27), Madagascar (19), Uganda (30), Zambia (25), Rio Grande do Sul in Brazil and the State of Michoacan in Mexico (5, 29).

In the differential reaction of wheat and triticale to soil type, it is difficult to disassociate the effect of exchangeable aluminum from the other properties of acid soils, such as calcium and magnesium deficiencies and low phosphorus availability. Knowledge of the genetic and physiological basis for the differential reaction of these two cereals could lead to more efficient crop improvement technologies both for wheat and triticale.

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Résumé

L'incidence des propriétés des sols du Mugamba sur les rendements du blé (Triticum aestivum L. var. Romany) et du triticale (X Triticosecale Wittmack; var. Mizar) a été étudiée en 1985 dans une série de 55 éssais réalisés en milieu rural sans fertilisation minérale. Dans le nord du Mugamba, constitué principalement d'hygrokaolisols et occasionnellement de sols bruns kaolinitiques, moyennement à faiblement acides, les rendements moyens des deux céréales furent similaires (1,6 t/ha). Dans le sud du Mugamba où dominent les kaolisols humifères fortement acides et souvent à fortes teneurs en aluminium échangeable, les rendements moyens du blé et du triticale furent respectivement de 1,2 t/ha et 1,7 t/ha. Le comportement différentiel du blé et du triticale selon le type de sol est discuté en fonction des caractéristiques de l'horizon de surface (acidité, teneurs en bases et en aluminium échangeables, teneur phosphore assimilable).

Table 1. Total rainfall (P) and average daytime temperatures (T) recorded during the main development stages of Romany (R) and Mizar (M).

Southern Mugamba[a] (Southern Bugarama, Ijenda and Tora)				Northern Mugamba[b] (Munanira, Remera and Teza)			
Duration (days)		P	T	Duration (days)		P	T
R	M	(mm)	(°C)	R	M	(mm)	(°C)
Sowing–stem elongation							
40	40	336	16.0	34	34	434	16.8
Stem elongation–heading							
34	35	42	15.1	31	32	63	17.4
Heading–maturity							
63	70	5	14.2	59	65	10	17.3

[a] Mean planting date: 3 April, 1985

[b] Mean planting date: 26 March, 1985

Data from Nyakararo and Munanira weather stations.

Table 2. Topsoil (0–20 cm) characteristics and yields of Mizar (M) and Romany (R) in different soil types. Mean values (X) and standard deviation (S). 1985 trials

Soil chemical properties and yields	Humiferous kaolisols n=25[a] X and S	Hygro- kaolisols n = 26 X and S	Brown soils (kaolinitic) n = 4 X and S
C (%)	6.14+ 1.65	2.22+ 0.40	2.52+ 0.35
N (%)	0.50+ 0.12	0.20+ 0.04	0.24+ 0.02
C/N	12.1 + 1.2	10.9 + 1.1	10.5 + 1.1
P (ppm)[b]	92+40	64+36	68+47
pH H_2O	5.2 + 0.3	5.9 + 0.4	6.2 + 0.5
T (meq/100 g)[c]	26.8 + 3.6	14.2 + 3.1	16.6 + 2.6
S (meq/100 g)[d]	5.7 + 3.2	8.5 + 2.7	10.0 + 2.9
Ca(meq/100 g)	3.7 + 2.3	5.8 + 2.1	6.4 + 1.7
Mg(meq/100 g)	1.2 + 0.8	2.1 + 0.7	2.3 + 0.3
K (meq/100 g)	0.8 + 0.4	0.6 + 0.3	0.5 + 0.4
Mg/K	1.5 + 0.7	4.5 + 2.4	9.1 + 7.9
Ca + Mg/K	6.2 + 3.2	17.1 +10.1	35.5 +31.9
Al (meq/100 g)[e]	2.0 + 1.1	0.1 + 0.3	0.1 + 0.1
m[f]	29+18	2+4	1+1
Mizar (t/ha)	1.70+ 0.58	1.46+ 0.59	2.62+ 0.48
Romany (t/ha)	1.21+ 0.47	1.50+ 0.59	2.58+ 0.37
M/R (%)	154+66	100+21	102+10

[a] n = number of soils

[b] (2) Olsen method modified by Dabin

[c] T = cation exchange capacity measured using ammonium acetate N at pH 7

[d] S = sum of exchangeable bases (Ca + Mg + K = Na)

[e] K Cl 1 N extraction

[f] m = 100 Al/Al + S

Table 3. Mean yields of Romany and Mizar observed in southern and northern Mugamba. 1984 and 1985 trials

	Southern Mugamba	Northern Mugamba	N-M/S-M
1984			
Romany	1.15 a	1.56 b	136
Mizar	1.49 a	1.58 a	106
Number of trials	34	43	
1985			
Romany	1.21 a	1.64 b	136
Mizar	1.70 a	1.62 a	95
Number of trials	25	30	

a-b: yields of the same line followed by the same letter do not differ at the 5% probability level. The other yields differ at the 1% probability level (P.P.D.S.). Source of 1984 data: Schalbroeck (21).

Table 4. Mean yields of Romany and Mizar in Mugamba in different soil types. 1984 and 1985 trials

Soils and years	Number of trials	Romany t/ha	Mizar t/ha	Mizar % Romany
		Southern Mugamba		
Humiferous kaolisols				
1984	34	1.15 a	1.49 b	130
1985	25	1.21 a	1.70 b	140
		Northern Mugamba		
Hygrokaolisols				
1984	36	1.50 a	1.46 a	97
1985	26	1.50 a	1.46 a	97
Brown soils				
1984	7	1.86 a	2.18 a	117
1985	4	2.58 a	2.63 a	102

a-b: yields of the same line followed by the same letter do not differ at the 5% probability level. Yields on humiferous kaolisols differ at the 1 and 0.1% probability levels for 1984 and 1985, respectively (P.P.D.S.). Source of 1984 data: Schalbroeck (21).

Table 5. Linear correlation coefficients between the topsoil (0–20 cm) chemical properties of humiferous kaolisols and hygrokaolisols and Mizar (M) and Romany (R) yields. 1985 trials

	M	R	M/R	M	R	M/R
	All soils (n = 51)			Humiferous kaolisols (n = 25)		
pH	0.18	0.52***	-0.40**	0.44*	0.39	-0.04
S	0.48***	0.65***	-0.26	0.62***	0.54**	-0.03
Ca	0.44**	0.64***	-0.26	0.56**	0.52**	-0.04
Mg	0.36**	0.60***	-0.36**	0.60**	0.52**	-0.09
K	0.48***	0.15	0.22	0.72***	0.52**	0.05
Al	-0.09	-0.42**	0.43**	-0.44*	-0.43*	0.10
m	-0.13	-0.44**	0.41**	-0.50*	-0.47*	0.07
P	0.32*	0.06	0.31*	0.30	0.09	0.23
	Hygrokaolisols (n = 26)			Hygrokaolisols with m < 6 (n =24)		
pH	0.50**	0.54**	-0.21	0.38	0.40	-0.14
S	0.66***	0.70***	-0.19	0.62**	0.65***	-0.12
Ca	0.66***	0.69***	-0.16	0.60**	0.66***	-0.09
Mg	0.53**	0.61***	-0.28	0.43*	0.51*	-0.25
K	0.14	0.07	0.03	0.07	-0.04	0.09
Al	-0.43*	-0.47*	0.11	--	--	--
m	-0.44*	-0.48*	0.16	--	--	--
P	0.23	0.26	0.02	0.19	0.19	0.08

*, **, *** Significant at the 5, 1, and 0.1% probability levels, respectively.

Correlation coefficients estimated for mean yields of each trial.

n = number of trials.

Figure 1. Location of Mugamba and Nyakararo and Munanira weather stations and distribution of trials within the six experimental subregions (A, B, C, D, E, F).

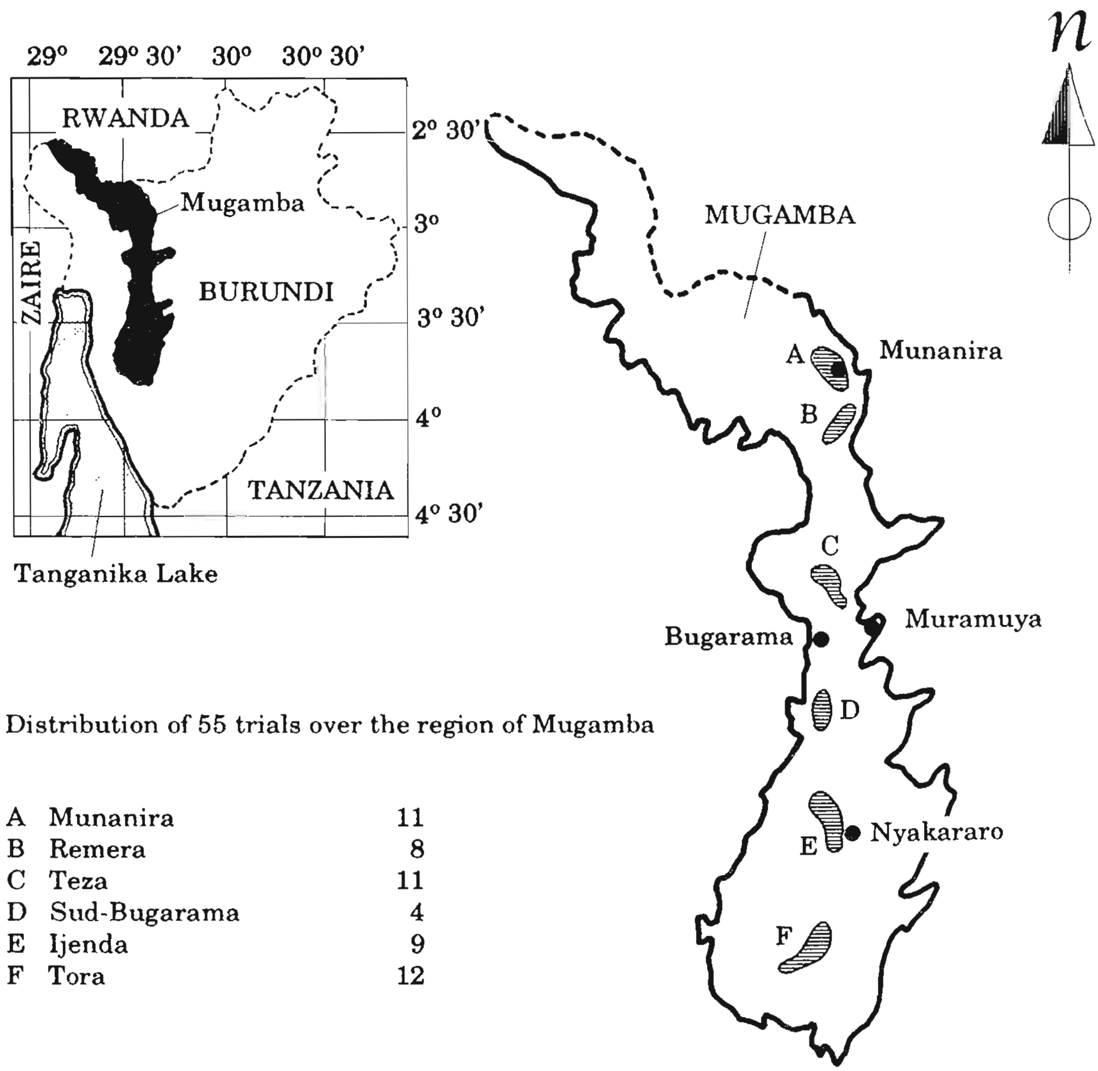

Figure 2. Yields of wheat variety Romany (R) and of triticale variety Mizar (M) according to levels of base saturation, aluminum saturation and topsoil acidity (0-20 cm) of humiferous kaolisols and of hygrokaolisols.