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Research Article

Influence of Lime and Phosphorus Application Rates on Growth of Maize in an Acid Soil

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The interactive effects of lime and phosphorus on maize growth in an acid soil were investigated in a greenhouse experiment. A completely randomized design with 12 treatments consisting of four lime levels, 0, 2, 10, and 20 t ha^{-1}, in a factorial combination with three phosphorus rates, 0, 30, and 100 kg ha^{-1}, was used. Maize was grown in pots for six weeks and its heights and dry matter yield were determined and soils were analyzed for available P and exchangeable acidity. Liming significantly reduced the exchangeable acidity in the soils. The effect of lime on available P was not significant but available P increased with increasing P rates. There was a significant effect of lime, P, and P by lime interactions on plant heights and dry matter. Without lime application, dry matter increased with increasing P rates but, with lime, dry mattes increased from 0 to 30 kg P ha^{-1} but declined from 30 to 100 kg P ha^{-1}. The highest dry matter yield (13.8 g pot^{-1}) was obtained with a combined 2 t ha^{-1} of lime with 30 kg P ha^{-1} suggesting that lime application at low rates combined with moderate amounts of P would be appropriate in this soil.

1. Introduction

The problem of acid soil infertility in the tropics has been recognized for a long time [1, 2]. In acid soils with pH < 5.5, the solubility of aluminium increases to toxic levels that severely restrict root systems and reduce plant growth [3, 4]. In addition, phosphorus reacts with iron and aluminium in soil solution under acidic conditions to form insoluble phosphates hence reducing its availability to plants [5]. Phosphorus deficiency often, therefore, occurs simultaneously with aluminium toxicity in these soils [6]. Efforts to ameliorate the deleterious effects of soil acidity must therefore be accompanied by measures to increase available phosphorus in soils.

Addition of lime to agricultural acid soils has been widely adopted as an amelioration strategy for many years as a means of improving crop production [7, 8] but is rarely used in western Kenya. Failure to use lime, together with the increased use of acidifying fertilizers such as urea and diammonium phosphate, which are used to correct N and P deficiencies, has resulted in a marked increase in acidity of many of these soils [9]. Changes in soil pH brought about by liming may have profound effects on the availability of many elements absorbed by crops. Liming increases soil pH and therefore eliminates aluminium toxicity at pH > 5.5 by precipitating Al thus making it unavailable for plant uptake [10]. It also improves Ca supply and Mo availability and ensures optimal bacterial nitrogen fixation [11]. But its effect on availability of P is controversial [12].

Conflicting reports suggest that the prior liming of highly weathered acid soils can result in an increase, a decrease, or no change in the availability of applied phosphate. These effects appear to be dependent on the rates of lime and P fertilizer applied and their interactions [13]. For example, at high lime rates, the soil pH increases to >6 and the soluble P forms a complex with Ca, and consequently P availability is decreased [14] while low lime rates are insufficient to eliminate soluble Al and Fe which fix P at low pH. Appropriate combination of lime and P is therefore an important strategy for improving crop growth in acid soils [15]. There is however paucity of information on interactive effects of lime and phosphate fertilizers on crop performance in western Kenya and this limits the ability of farmers to make informed decisions on the appropriate rates of lime and P fertilizer to be combined. The objective of this study was therefore to investigate the interactive effects of lime and phosphate fertilizer on

Table 1: Initial soil physical and chemical characteristics (0–20 cm) at Maseno University.

Soil parameter	Value
pH (H_2O)	5.3
Exchangeable acidity	0.4 cmol kg^{-1}
Total N	2.0 g kg^{-1}
Organic C	16.8 g kg^{-1}
Bicarbonate extractable P	3.5 mg kg^{-1}
Exchangeable K	0.3 cmol kg^{-1}
Exchangeable Ca	4.2 cmol kg^{-1}
Exchangeable Mg	1.4 cmol kg^{-1}
Clay	36.5%
Sand	42.2%
Silt	21.3%

Table 2

Treatment number	Treatment combinations
1.	0 t ha^{-1} lime, 0 P kg ha^{-1}
2.	0 t ha^{-1} lime, 30 kg P ha^{-1}
3.	0 t ha^{-1} lime, 100 kg P ha^{-1}
4.	2 t ha^{-1} lime, 0 kg P ha^{-1}
5.	2 t ha^{-1} lime, 30 kg P ha^{-1}
6.	2 t ha^{-1} lime, 100 kg P ha^{-1}
7.	10 t ha^{-1} lime, 0 kg P ha^{-1}
8.	10 t ha^{-1} lime, 30 kg P ha^{-1}
9.	10 t ha^{-1} lime, 100 kg P ha^{-1}
10.	20 t ha^{-1} lime, 0 P kg P ha^{-1}
11.	20 t ha^{-1} lime, 30 P kg P ha^{-1}
12.	20 t ha^{-1} lime, 100 kg P ha^{-1}

exchangeable acidity, P availability, and maize growth in an acid soil of western Kenya.

2. Materials and Methods

2.1. Experimental Site and Soil. A greenhouse pot experiment was conducted from March to April 2016 at Maseno University (0°00′17.36″S and 34°36′01.62″E) in western Kenya. The soil used in the study was a Ferralsol whose initial properties were determined before the establishment of the experiment and are presented in Table 1. The soil was generally well drained clay loam, acidic and low in available P.

2.2. Experimental Design and Management. The soil (0–20 cm) used in the study was collected randomly from various spots at the Maseno University farm and bulked. It was air-dried, sieved through a 4 mm mesh, and applied in all the pots at a rate 4 kg of soil pot^{-1}. These pots consisted of the experimental units. There were twelve treatments consisting of four levels of lime (0, 2, 10, and 20 tons/ha) in a factorial combination with three rate of P (0, 30, and 100 kg P ha^{-1}) (Table 2) replicated thrice in a completely randomized design.

A burnt lime material with 92.5% calcium carbonate ($CaCO_3$) equivalent and ground to pass through a 0.25 mm sieve was used in this study. Triple superphosphate (46% P_2O_5) was used to supply P. Calcium ammonium nitrate and muriate of potash were applied to all the treatments at the rate of 60 kg ha^{-1} to supply N and K which are often limiting in these soils. All the fertilizers and lime were incorporated and thoroughly mixed with the soil at the time of planting. Two maize seeds were planted per pot and later thinned to one at one week after emergence. Soil moisture content was maintained at around field capacity by regular watering.

2.3. Data Collection. Soil was sampled six weeks after planting (WAP) from each treatment and analyzed for exchangeable acidity and available phosphorus using standard procedures as described by [16]. Exchangeable acidity was extracted using unbuffered 1 M KCl. In brief, 25 ml of 1 M KCl was added to 10 g of air-dry soil and shaken for 10 minutes on a reciprocal shaker and then allowed to stand for 30 minutes. The contents were filtered and the soil leached with 5 successive 25 ml aliquots of 1 M KCl. The filtrate was titrated with 0.1 M NaOH to determine the exchangeable acidity (H^+ and Al^{3+}) in the extract [16]. The available P was determined by the Olsen method [17] which has been reported to correlate well with maize yields in similar soils in western Kenya [18]. The method consisted of extracting soil P with 0.5 M $NaHCO_3$ (pH 8.5) using a soil extractant ratio of 1 : 20. The samples were shaken on a reciprocal shaker for 30 minutes and filtered through a Whatman number 5 filter paper and the P in the filtrate was determined colorimetrically at 880 nm. Plant heights were determined at 4 and 6 WAP while the dry weight was determined after harvesting at 6 WAP by oven drying at 70° Celsius to a constant weight.

2.4. Statistical Analysis. All the generated data were subjected to analysis of variance (ANOVA) using Genstat statistical program and the least significant difference between means (LSD) used to separate the treatment means at statistical significance level of $p \leq 0.05$.

3. Results and Discussion

3.1. Exchangeable Acidity. There was no significant interaction between lime and phosphorus application rates on exchangeable acidity (Table 3). The effect of phosphorus was also not significant. This is inconsistent with other studies that have reported that P can reduce exchangeable acidity by precipitating the Al in solution [19]. The rates of P used in such studies were however much higher than in the present study where the rates of P used are likely to have been too low to achieve this effect. Application of lime, irrespective of the rate used, significantly reduced the exchangeable acidity compared to the control. This is to be expected because lime is known to increase the soil pH, hence precipitating Al as $Al(OH)_3$ [20, 21]. This has the effect of reducing exchangeable acidity which comprises Al^{3+} and H^+. However, exchangeable acidity among the lime treatments did not differ significantly. It is likely that all the Al was precipitated with application of lime, even at the lowest rate, and the exchangeable acidity that

Table 3: Exchangeable acidity ($Cmolkg^{-1}$).

Lime rate t ha^{-1}	Phosphorus rates kg ha^{-1} 0	30	100	Means
0	0.42	0.38	0.43	0.41
2	0.15	0.16	0.13	0.14
10	0.14	0.12	0.12	0.13
20	0.15	0.12	0.13	0.13
Means	0.20	0.20	0.20	0.20
F probabilities for ANOVA for phosphorus and lime rates				
Lime			<0.001	
Phosphorus			0.873	
Lime × phosphorus			0.996	
LSD				
Lime			0.0924	
Phosphorus			0.0800	
Lime × phosphorus			0.1600	

Table 4: Available phosphorus (mg kg^{-1}).

Lime rate t ha^{-1}	Phosphorus rates kg ha^{-1} 0	30	100	Means
0	3.70	4.11	8.78	5.53
2	7.92	8.18	9.42	8.51
10	3.36	6.49	13.77	7.87
20	4.97	6.83	12.62	8.14
Means	4.99	6.40	11.15	7.51
F probabilities for ANOVA for phosphorus and lime rates				
Lime			0.239	
Phosphorus			<0.001	
Lime × phosphorus			0.389	
LSD				
Lime			3.210	
Phosphorus			2.780	
Lime × phosphorus			5.561	

Table 5: Plant height (cm) at four weeks after planting.

Lime rate t ha^{-1}	Phosphorus rates kg ha^{-1} 0	30	100	Means
0	50.1	72.7	82.6	68.5
2	79.3	92.1	51.9	74.4
10	88.9	64.5	73.3	75.6
20	61.0	68.3	67.9	65.7
Means	68.5	74.4	68.9	
F probabilities for ANOVA for phosphorus and lime rates				
Lime			0.032	
Phosphorus			0.188	
Lime × phosphorus			<0.001	
LSD				
Lime			7.39	
Phosphorus			6.40	
Lime × phosphorus			12.80	

Table 6: Plant height (cm) at six weeks after planting.

Lime rate t ha^{-1}	Phosphorus rates kg ha^{-1} 0	30	100	Means
0	63.3	95.6	103.1	87.4
2	99.3	114.4	64.3	92.7
10	110.1	83.6	95.6	96.4
20	80.7	87.6	88.7	85.7
Means	88.4	95.3	88.0	90.5
F probabilities for ANOVA for phosphorus and lime rates				
Lime			0.040	
Phosphorus			0.068	
Lime × phosphorus			<0.001	
LSD				
Lime			8.00	
Phosphorus			6.93	
Lime × phosphorus			13.85	

was measured was therefore due to only H^+. Hence there may be no need to apply lime at rates higher than 2 t ha^{-1} in this soil.

3.2. Available Phosphorus. The available P ranged from 3.70 (control with no P and lime input) to 13.77 mg kg^{-1}(10 t ha^{-1} of lime combined with 100 kg P ha^{-1}) (Table 4). There was no significant interaction between lime and phosphorus application rates on available P. The effect of lime was also not significant but available P increased with increasing P rates for a given lime rate. Generally, the available P levels were low even after application of fertilizers and lime, therefore confirming that P was deficient in this soil and that some of the applied P could also have been fixed since most of the soils in western Kenya are known to have high P fixation capacities [22, 23]. It was only at high rates of P application (100 kg ha^{-1}) with high lime rates of 10 or 20 t ha^{-1} that the available P exceeded the critical value of 10 mg kg^{-1} that has been reported to be adequate for maize production [24].

3.3. Plant Heights and Dry Weight. Plant heights at 4 WAP ranged from 50.1 cm (no lime, no P) to 92.1 cm when 2 t ha^{-1} of lime was applied with 30 kg P ha^{-1} (Table 5). There was a significant interaction between lime and P. When no lime was applied, plant heights increased with increasing P rates but when lime was applied, plant heights increased from 0 to 30 kg P ha^{-1} but declined from 30 to 100 kg ha^{-1} P. A similar trend in plant heights was observed at 6 WAP (Table 6).

The results of the effects of treatments on dry weight of maize plants are presented in Table 7. The effect of lime, P, and P by lime interactions on dry weight was significant. Averaged

Table 7: Dry weight (grams pot^{-1}).

Lime rate t ha^{-1}	Phosphorus rates kg ha^{-1}			Means
	0	30	100	
0	2.03	8.50	10.57	7.03
2	9.73	13.17	3.87	8.92
10	11.30	7.37	8.20	8.96
20	3.64	7.73	7.13	6.17
Means	6.68	9.19	7.44	7.77
F probabilities for ANOVA for phosphorus and lime rates				
Lime			0.001	
Phosphorus			0.002	
Lime × phosphorus			<0.001	
LSD				
Lime			1.455	
Phosphorus			1.260	
Lime × phosphorus			2.521	

across all lime rates, the highest dry matter yield was obtained with 30 kg P ha^{-1} while averaged across all P rates the highest dry matter yield was obtained with 2 t ha^{-1} of lime. The trend in dry matter yield was similar to that of plant heights at 6 WAP whereby when no lime was applied dry matter increased with increasing P rates but when lime was applied dry matter increased from 0 to 30 kg P ha^{-1} but declined from 30 to 100 kg ha^{-1} P. Application of lime at 10 and 20 t ha^{-1} could have resulted in overliming which has been reported to reduce crop yields due to lime induced P and micronutrient deficiencies [15, 25]. In the present study, however, high rates of lime did not decrease the available P compared to control with no lime input and hence the likely cause of the low yields at high lime rates was micronutrient deficiencies. This is likely to have been exacerbated at high rates of P which have also been reported to aggravate Zn deficiencies in maize [26]. The observed increase in dry matter yield with increasing P rate, in treatments with no lime application, confirmed that P was limiting factor to maize growth in this soil. Similar responses to application of P fertilizers on P-deficient soils in western Kenya have been reported by other researchers [27–29] thus making the region ideal for P replenishment [22]. Aluminium toxicity is however not likely to have been a major problem because the exchangeable acidity of the soil was below the 1.00 cmolkg^{-1} critical level for soils to have acidity problem according to [30]. The observed positive effect of lime on maize growth was therefore likely due to its effect in increasing the pH and therefore increasing availability of most nutrients to maize rather than its ability to ameliorate aluminium toxicity.

4. Conclusions and Recommendations

The exchangeable acidity levels in the soil were low and Al toxicity is therefore unlikely to be a major factor limiting maize growth in this soil. However, liming is likely to have increased the pH to levels conducive for availability of most nutrients and hence its positive effect on maize growth. The available P was also low and was likely a limiting factor for maize growth in this soil. The effect of lime, P, and P by lime interactions on dry weight was significant. The highest dry matter yield was obtained with 2 t ha^{-1} of lime applied with 30 kg P ha^{-1}. The trend in dry matter yield was similar to that of plant heights whereby, when no lime was applied, dry matter increased with increasing P rates but, when lime was applied, dry matter increased from 0 to 30 kg P ha^{-1} but declined from 30 to 100 kg ha^{-1} P. Lime application at low rates combined with moderate amounts of P is therefore recommended for soils in the study area.

Competing Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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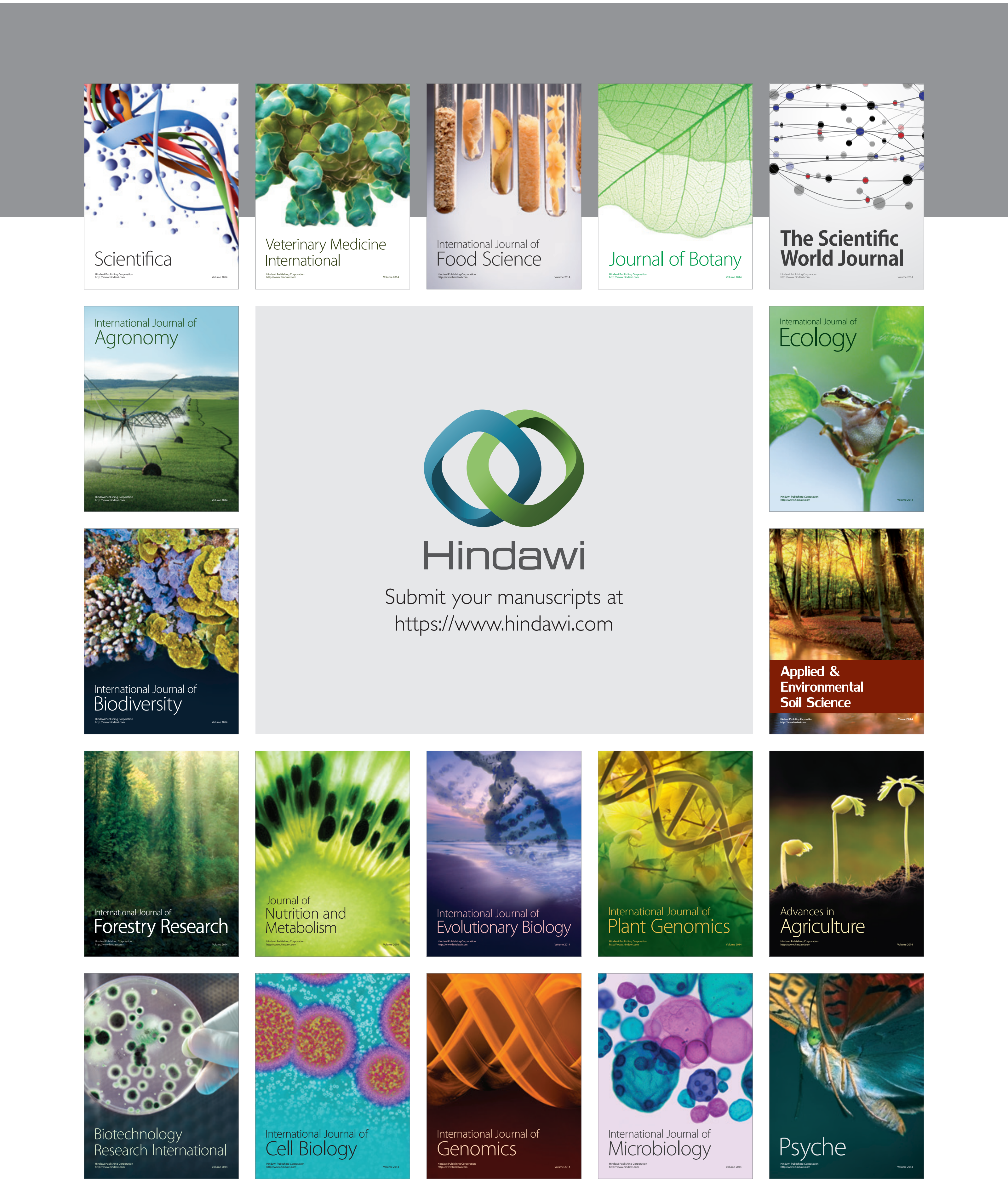
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