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EFFECT OF SOIL pH ON THE GROWTH AND MINERAL CONTENTS OF OATS

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A glasshouse experiment was set up to study the growth of oats in the organic and eluival horizons of a podzol. A standard dressing of N, P and K fertilizers was applied and three lime treatments including an unlimed one were examined.

Leaf tip burn on older leaves appeared in oats in the unlimed soils. The younger leaves were normal green but were short and narrow. The roots of the plant were stunted, thick and spotted brown.

The growth of oats in unlimed soils was poorer than when lime was applied, although there was no clear difference between the growth of plants in limed soils. Growth of oats at each lime treatment was better in the organic soil than in the eluvial soil. This was possibly due to differences in soil physical condition affecting water relations.

The concentration of P and K in tops was reduced in unlimed soils compared with limed ones, whilst the contents of Fe, Mn, Zn and Cu were similar or greater than the contents in both limed treatments. The plant experiment indicates the key importance of Al in the productivity of unlimed Welsh hill soils.

INTRODUCTION

Crop failure on acid soils is a problem which has confronted research workers for a long period. One of the first lines of evidence bearing on the subject arose from nutrient solutions experiments, which showed that plant growth was restricted as the pH of the medium fell below 5.0 [2]. early studies on acid soils, it was found that soluble Al and Mn were the most common cause of failure of agricultural crops in acid soils [8, 9, 15, 19, 29].

The soils of Wales are generally acidic with low fertility status. Upland soils are generally deficient in Ca and P and they are devoid of earthworms. Under hill farming conditions adverse soil and climatic conditions limit productivity and make it unprofitable to grow arable crops. The structureless surface water gley podzols occur extensively on the hills of mid-Wales [13].

The poor growth of plants associated with acid soils is a complex functions of many contributing factors all of which may be modified by liming [28]. The application of liming materials to acid soils brings about many characteristic changes that generally results in better crop growth [17]. Lime is added to soils to neutralize acidity, supply Ca and Mg as nutrients for plant growth and to improve the physical conditions of soils [11].

The chemical forms and solubility of many plant nutrients depend largelly on pH. A soil pH of 6.5 is usually considered optimum for general farming and most lime recommendations are designed to raise the pH of the soil, approximately to this level [11]. It was considered worthwhile to study to beneficial effects of liming on the growth and mineral contents of oats growing in acid hill soils of mid-Wales. An excess lime treatment was also included to examine the possible ill-effects of overliming these soils.

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MATERIALS AND METHODS

Soil samples of organic and eluvial horizons were collected from a Placic Spodosol (soil series, Hiraethog) on a hill slope in mid-Wales. These were air-dried in a glasshouse and rubbed down by hand. Stones, gravel and roots were removed. The soils were collected from an area which as far as was known had not received any fertilizer or lime. Some general characteristics of the soils are given in Table 1.

The bulk samples (24 kg) of each of two soils were placed separately on plastic sheets and a basic plant nutrient dressing added at the rate of 1.517 g $NaNO_3$, 0.438 g KH_2PO_4 and 0.165 g K_2SO_4 per kg of soil. These amounts supplied in μg/g soil 250 N, 100 P and 200 K.

In order to bring the soils to pH values of 6.5 and 9.5, the amount of lime needed for both the soils was obtained by a lime requirement method [1] and the amounts calculated are shown in Table 2.

After mixing in the basic amount of fertilizers, each bulk samples of 24 kg soil was divided into three subsamples. The calculated amount of lime was then mixed with

Table 1. Some general characteristics of the soils used.

Soil horizons	Available (μg/g soil) P	K	Exchangeable (μg/g soil) Fe	Zn	Total exchangeable acidity (me/100 g soil)	Exch Al (%)	pH (1:1 H_2O)	O.M. (%)
	(μg/g soil)							
Eluvial	1.9	320	29.0	7.0	7.6	84	3.8	10.4
Organic	1.8	410	15.5	15.5	7.0	69	3.5	53.8

Table 2. Lime required for two soils.

Soil samples	Initial soil pH	Amount of $Ca(OH)_2$ added in g/kg of soil: Unlimed soil L0	pH 6.5 L1	pH 9.5 L2
Organic soil	3.5	0.0	7.45	16.31
Eluvial soil	3.8	0.0	5.48	13.01

two subsamples of each soil to give three lime treatments (L0, L1 and L2).

Germination of Seeds. Oats *(Avena sativa* L.) seeds of cv. 56183 were soaked overnight in tap water. The seeds were then spread over moistened filter paper in an enamel tray, which was placed in the dark for a few days. When the seeds germinated the tray was taken from darkness and placed under light in a glasshouse.

Ten-day old oat seedlings were transplanted in plastic pots (15-cm dia × 15-cm deep), containing 650 g soil, at the rate of 4 seedlings per pot. There were four replicates of each treatment. The pots were randomized and placed under light in glasshouse. The supplementary light provided a 14-hr photoperiod. The seedlings were allowed to grow with occasional addition of distilled water.

Visual observations on the growth of plants were recorded throughout the growth period. Symptoms of disorders were noticed in the unlimed L0, treatment of both soils. All the plants were harvested after 5 weeks of growth period, the fresh weight of shoot was recorded. The roots were separated from the soils and their length and visual appearance recorded and finally the soil samples from each pot was collected for chemical analysis. The plant material was dried at 80° for 24 hr and analyzed for P, K, Fe, Mn, Zn, Cu and Al.

Samples of plant material were digested in a mixture of concd HNO_3, H_2SO_4 and $HClO_4$ and the resulting solution diluted to a standard volume. Total phosphorus was determined colorimetrically [10]. Total aluminium was estimated using aluminon reagent [4]. Potassium was determined by flame photometer and total Fe, Mn, Zn and Cu were determined by atomic absorption spectrophotometry.

From the soil samples total exchangeable acidity and Al were determined by titration using 1*N* KCl as extractant [16]. Exchangeable Zn and Fe were extracted with 1*N* KCl and determined by atomic absorption spectrophotometer. Available P and K were extracted with 0.5*M* NH_4Ac/HAc. Extracted-P was determined by the method of Jackson [10] and available-K by flame photomtery.

RESULTS AND DISCUSSION

In the unlimed L0, treatment of both soils there was an early sign of leaf tip burn on the older leaves (Table 3). The younger leaves were generally normal green, but were short and narrow. During the later stages of growth the leaf tip burn on older leaves in the L0 treatment changed to yellowish brown and died-back progressed until harvest. The early leaf tip burn in oats could not be identified as being due to any particular nutritional abnormality.. In the unlimed soils, the roots were short, thick and spotted brown with little or no branching in contrast to the white and generally healthy and fibrous roots of the other treatments. The poor growth of roots was possibly due to a toxic effect of aluminium.It has been reported earlier that Al in soluble or ionic form restricts the root development of many agronomic plants, thereby reducing the yields [5, 7, 18, 23, 26, 27] and that aluminium toxicity is an important growth limiting factor for plants in many acid soils of the world [21, 22].

The data in Table 4 indicate that the dry matter yield of oats was found to be lower in the unlimed, L0 treatment of both soils than in L1 and L2 treatments, despite the adequate applications of basic dressing of N, P and K fertilizers. This indicates the overriding importance of soil pH in plant nutrition. The highest yield was recorded at the maximum lime treatment. The difference in yield between the treatment L0 and either the limed L1 or L2 was significant (organic soil), but not in eluvial soil. The differences in dry matter yield between the three treatments was quite small for both soils. This indicates a tolerance by oats of

Table 3. Visual observations on oats grown in eluvial and organic soils.

Treat-ments	Leaves (day) 10	Leaves (day) 20	Leaves (day) At harvest	Stems (day) 10	Stems (day) 20	Stems (day) At harvest	Roots At harvest
Eluvial Soil							
L0	Leaf tips burn on older leaves	Slight yellow -ing of older leaves	Older leaves die back	Thin	Thin	Thin	Short, yellowish white with a little branching
L1	Normal green	Normal green	Slightly yellowish green leaves	Thick	Thick and healthy	Thick and healthy	Healthy fibrous well branched
L2	Normal green	Normal green	Normal green and healthy	Thick	Thick and healthy	Thick and healthy	Healthy, fibrous, well branched
Organic Soil							
L0	Leaf tips burn on older leaves	Slight yellowing of older leaves	Older leaves die back	Thin	Thin	Thin	Short, yellowish white with a little branching
L1	Normal green	Normal green	Slightly yellowish green leaves	Thick	Thick and healthy	Thick and healthy	Healthy, well-branched, white, fibrous roots
L2	Normal green	Normal green	Normal green and healthy	Thick	Thick and healthy	Thick and healthy	Healthy, well branched, white, fibrous roots.

Table 4. Plant analysis of oats grown in eluvial and organic soils.

Treat-ments	Fresh wt (g/pot)	Dry wt (g/pot)	Root length (cm)	P content (% in dry wt)	K content (% in dry wt)	Nutrient uptake μg/g dry wt Fe	Mn	Zn	Cu	Al
Eluvial Soil										
L0	1.27	0.19	10.4	0.30	3.80	540	118	81	26.5	62
L1	3.04	0.35	25.5	0.44	5.03	425	113	80	22.1	49
L2	3.47	0.44	16.8	0.37	5.20	383	94	64	18.3	47
LSD 5 %	NS	NS	3.6	0.06	0.55	67	21	14	NS	NS
Organic Soil										
L0	2.04	0.36	7.0	0.33	3.85	355	60	64	14.0	27
L1	8.07	0.89	18.3	0.50	5.19	239	70	78	13.7	18
L2	12.6	1.42	21.0	0.33	4.43	398	96	103	18.0	13
LSD 5 %	3.24	0.37	4.5	0.07	0.92	113	31	28	NS	NS

the acidic conditions in the unlimed soils. It was also found that dry-matter yields recorded for all treatments in the organic soil were larger than for the eluvial soil. This may have been due to the physical condition of the soil. The structureless eluvial horizon was retentive of moisture and this condition was harmful to oats. This was more pronounced in the unlimed L0 treatment. The organic soil had a better physical condition particularly when limed and was probably a better supplier of nitrogen through mineralization from organic matter. The difference in yield between the L0 treatment of the two soils suggests that soil physical condition was the more important.

The shoots of the plants were analyzed for phosphorus and it was found that P-content in shoots of unlimed L0 treatment was lower than in both L1 and L2 treatments of both soils. The treatments differed significantly (Table 4). The lower content of P in oats grown in unlimed soils can be explained by the established fact that toxic Al interferes with the uptake utilization of P [6, 14, 20, 24]. When the soils were analyzed for available P at the end of the experiment it was found that the levels of P in the unlimed L0 treatment was similar to L1 and L2 of both soils

Table 5. Chemical analysis of soil after growing oats in eluvial and organic soils.

Treatments	Soil pH: Before growing oats	Soil pH: After growing oats.	Total exch. acidity (me/100g soil)*	Exch. Al in TEA%*	Total exch. acidity (me/100g soil)†	Exch. Al in TEA(%)†	Nutrient in soil (μg/g soil): Available P	Available K	Exchangable Fe	Exchangable Zn
Eluvial Soil										
L0	3.8	4.1	6.4	63.3	6.5	76	42	290	60	7.3
L1	6.3	5.9	0.72	–	0.39	–	28	300	60	7.1
L2	7.9	7.5	0.50	–	0.24	–	48	350	57	6.2
LSD 5%	–	–	1.06	–	–	–	NS	NS	NS	NS
Organic Soil										
L0	3.5	4.2	4.5	71.3	3.5	60	40	285	64	11.9
L1	6.1	6.0	0.57	–	0.55	–	48	349	52	7.5
L2	7.7	7.5	0.42	–	0.28	–	49	250	49	5.8
LSD 5%	–	–	0.24	–	–	–	NS	48	NS	3.2

*Pretreatment, overnight soaking
†2 hr leaching

(Table 5). This suggests that soluble and exchangeable Al in the L0 treatments did not immobilise available P to any great extent. Nevertheless, the amount of exchangable Al in the L0 soils was lower at the end of the experiment.

The K content in tops of oats was least in the unlimed treatments of both soils. There was a significant difference between the treatment L0 and either the L1 and L2 in both soils. The available K in unlimed soils was similar or only slightly lower than in the limed ones (L1 and L2).

The contents of Fe, Mn, Zn and Cu in oats followed a similar pattern. For all these elements the concentrations in plants from unlimed soils were similar or greater than the concentrations in L1 and L2 treatments.

The Al concentrations in the plant tops from the unlimed soil was greater than that in the plants from the L1 and L2 treatments. Thus Al was taken up and translocated to the tops. This ability to translocate Al in oats may be a factor in Al tolerance. Plants adapted to acid soils typically have a lower calcium demand than those adapted to neutral soils [3].

It was also found that the exchangeable Al was very much higher in the unlimed soils, while it was virtually zero in the limed ones (Table 5). The reason for zero aluminium in limed L1 and L2 soils was probably due to the rapid precipitation of Al as Al $(OH)_3$ [12] and the % exchangeable Al was similar in both unlimed soils and accounted for about 3/4th of the total exchangeable acidity. This status of Al supports the contention that symptoms which appeared on roots in the L0 treatment were due to aluminium toxicity. Available evidences indicate that Al brings about toxicity in acid soils mainly via its effect on roots and that its effect includes the precipitation of phosphorus on thier cell wall [5, 20, 24].

A consistent characteristics of plants grown in acid soils in our experiment was reduction in yield and a reduction in the concentration in the shoots of several essential elements. A high Al ion concentration is the most common cause of failure of agricultural crops in acid soils [25]. Symptoms on roots suggested that Al toxicity was a major factor in reducing yields of oats in these unlimed soils from the hills of mid-Wales.

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