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PHOSPHORUS REQUISITE FOR LEGUME-DOMINATED VEGETATION ON MINE WASTES

Paper Prepared Jointly

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INTRODUCTION

Two nutrients essential for sustaining plant life on mine waste are nitrogen and phosphorus. Whereas undisturbed soils generally have adequate nitrogen and phosphorus in forms used by plants to sustain life, this is not generally true for mine rock, tailings or, in some cases, overburden. In order for vegetation on mine waste to be self-sustaining and of sufficient quality and quantity to achieve revegetation objectives, nitrogen and phosphorus must be available to plants in quantities necessary to sustain growth and reproduction.

Rocks and minerals from which soils are formed, and which constitute the content of rock dumps and tailings ponds, contain very little nitrogen; so to satisfy plant requirements, nitrogen must be added; either in the form of:

a) fertilizer
b) by biological N Fixation or
c) as plant residues, with subsequent conversion of organic N to inorganic forms used by plants.

Phosphorus in soil comes largely from weathering of the mineral apatite which breaks down very slowly releasing phosphorus which subsequently forms a variety of compounds including the orthophosphate forms used by plants. Some plants develop a symbiotic association with certain soil micro-organisms which improve utilization of soil P; however, it has been our experience that the most effective method of providing phosphorus for vegetation on mine waste is by application of a phosphorus containing fertilizer.

Currently, fertilizers are the main source of N and P added during revegetation of mine waste. The usual approach is to apply fertilizer, generally containing N, P, and K at a somewhat arbitrarily selected amount prior to seeding in order to promote vegetation establishment; and, then, sustain growth by annual maintenance applications over a period of years. Once maintenance is discontinued, vegetation often deteriorates because the nutrient supplying capacity of the waste has not been increased to a level necessary to sustain growth. This is particularly true of vegetation dominated by grasses which are dependent upon maintenance applications of nitrogen to satisfy their requirements for growth and reproduction. In contrast, vegetation dominated by nitrogen-fixing legume species can sustain growth and produce substantial quantities of organic matter for several years after maintenance fertilizer has been discontinued; primarily, because of their ability to satisfy N requirements by utilizing atmospheric N. The advantages of establishing legume-dominated vegetation on mine waste are obvious; by eliminating the need for annual applications of nitrogen, maintenance costs can be reduced or even eliminated, and at the same time, substantial quantities of nitrogen can be added to the system in organic form for subsequent re-use by plants. However, phosphorus, which must be added to the system as fertilizer, must be available in sufficient quantity and in a form utilized by plants, if legume growth and N fixation are to be sustained at a level necessary to achieve revegetation objectives.

A study was initiated at Fording Coal in May 1977 to determine the phosphorus requirement of waste rock and overburden for establishing legume-dominated vegetation and for maximizing organic matter production and biological N fixation over an extended period of time, in this case a minimum of eight years. During this period, there would be no maintenance fertilizer applied. In other words, we are attempting to increase the phosphorus supplying capacity of the waste to a level necessary to sustain maximum legume growth over the long term. This would be achieved by applying the total phosphorus requirement in a single application prior to seeding and, at the same time, determine how much phosphorus fertilizer must be applied to achieve this objective. Since relatively large quantities of phosphorus fertilizer may be required, and since soluble fertilizer phosphorus reverts to less soluble forms following application, it was considered prudent to investigate various frequencies of application and the resultant effects on efficiency of phosphorus use. On adjacent areas, equivalent total amounts of phosphorus were applied in equal increments, either annually or biennially, throughout the study period.

EXPERIMENTAL DESIGN

The study is being conducted at Fording Coal, at an elevation of 1700 metres and on two types of growth media, waste rock and overburden. Waste rock is a mixture of sandstone and shale; overburden is a calcareous glacial till. Table 1 shows the chemical and physical characteristics of the waste rock and glacial till.

Phosphorus was applied at rates ranging from 0 to 1600 kilograms of P205 per hectare, and in the form of treble superphosphate. The fertilizer was broadcast prior to seeding and incorporated throughout the surface's 15 centimetres of waste using a rototiller.

Rambler Alfalfa and Boreal Creeping Red Fescue were seeded, as a mixture, at 30 kilograms per hectare. The legume comprised two-thirds of the mixture by weight and was appropriately inoculated. Nitrogen and potassium were applied at 50 kilograms per hectare each to promote seedling establishment and growth during the first growing season. We subsequently learned from another study that addition of potassium does not improve legume seedling establishment and growth on these two types of mine waste.

Two growing seasons have passed since the study was initiated. During the first growing season the effect of phosphorus on legume establishment was assessed by evaluating:

a) legume seedling populations
b) seedling height
c) seedling phosphorus content.

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TABLE 1

CHEMICAL AND PHYSICAL PROPERTIES OF FORDING COAL WASTE ROCK AND GLACIAL TILL OVERBURDEN

CHARACTERISTICS	WASTE ROCK	GLACIAL TILL
1. <u>CHEMICAL PROPERTIES</u>		
CaCO Equivalent (%)	5.3	26.0
C.E.C. (me/lOOg)	2.4	1.5
Exch. Cations (me/lOOg)		
Ca	20.2	42.8
Mg	2.6	2.0
K	0.5	0.4
Na	0.2	0.1
Fe	5.6	5.6
Total N (7»)	0.4	0.1
Total P (ppm)	850	1000
Extractable P (ppm)	1	1
Non-Exch. K (ppm)	800	1120
pH	8	8
ECe (mmhos/cm)	1.8	0.5
2. <u>PHYSICAL PROPERTIES</u>		
Clay (%)	11	16
Silt (%)	25	36
Sand (%)	64	48
Texture	si	1
Moisture Retention(%)		
1/3 atm	17	14
15 atm	4	4
A.W.S.C.	13	10

During the second growing season, the effect of phosphorus on legume growth and nitrogen fixation was assessed by evaluating:

a) legume content
b) biomass
c) nitrogen yield, and
d) phosphorus content.

Waste rock and overburden were sampled each growing season to determine extractable phosphorus levels.

RESULTS AND DISCUSSION

As indicated earlier, this study is planned to continue for a minimum of eight years. Results reported at this time will deal only with the effect of phosphorus applied over a wide range of rates on Alfalfa establishment during the first growing season, and Alfalfa and Creeping Red Fescue growth during the second growing season. The effects of varying application rates and frequency on phosphorus use efficiency will not be discussed at this time.

First Growing Season Results

Legume Seedling Populations. Phosphorus did not affect Alfalfa seedling populations on either type of waste (Figure 1). However, seedling populations were significantly higher on waste rock than on overburden. Overburden forms a hard surface crust on drying and this may account for reduced seedling emergence.

A minimum of 10 seedlings per 0.1 square metres has been suggested as necessary for optimum forage production in agriculture; our experience suggests 3 to 5 legume seedlings per 0.1 square metres will generally produce a satisfactory stand on mine waste. Although these numbers will vary with the plant species, it would appear that Alfalfa seedling

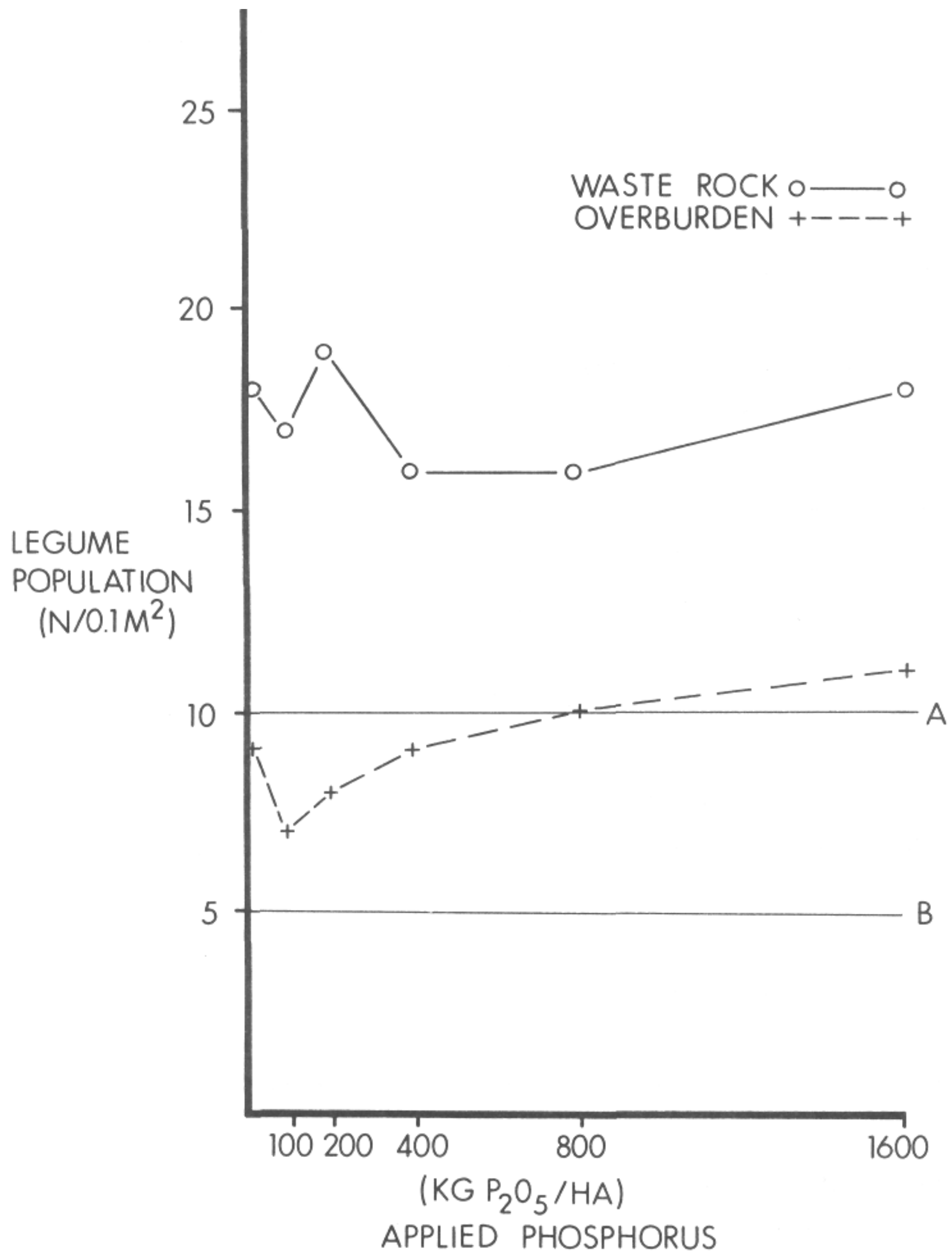

Figure 1: Effect of Phosphorus on Legume Seedling Population

populations were adequate on both types of mine waste without addition of phosphorus.

Legume Seedling Growth. The effect of phosphorus is more evident when related to Alfalfa seedling growth (Figure 2). Seedling height was increased significantly by addition of phosphorus. On waste rock, near maximum height was produced by 400 kilograms of P_2O_5 per hectare. At the lower phosphorus rates, seedlings were significantly taller on waste rock than on overburden.

In regions of severe climate, seedling height has been correlated with winter survival and seed production during the second growing season.

Legume Seedling Phosphorus Content. The phosphorus content of Alfalfa seedlings was increased significantly by phosphorus fertilizer, and was significantly higher in seedlings grown on waste rock than on overburden (Figure 3). One hundred kilograms of P 0 per hectare added to waste rock, increased phosphorus content of seedlings to within the "critical P range" for Alfalfa (1) ; while 400 kilograms of P^ per hectare increased phosphorus content to 0.26%, a level reported necessary for maximum Alfalfa yield. On overburden, however, 800 kilograms of P_2O_5 hectare was required to increase seedling phosphorus content to within the critical range. The term critical level is referred to as the plant composition below which growth may be expected to be limited by a low supply of a nutrient (1).

Second Growing Season Results

Legume Content. Legume content describes the percentage of the total vegetative cover of a grass-legume stand which was due to the legume

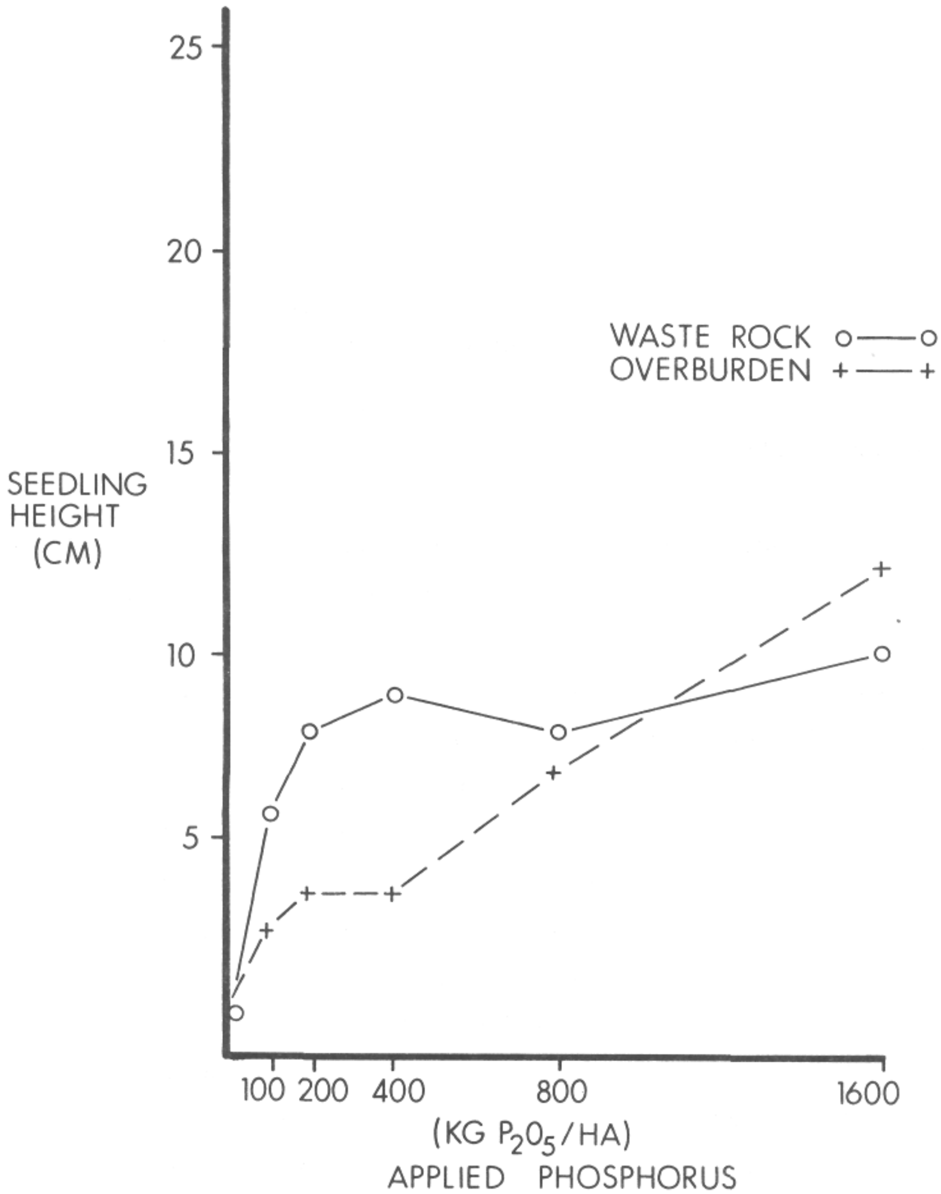

Figure 2: Effect of Phosphorus on Legume Seedling Growth

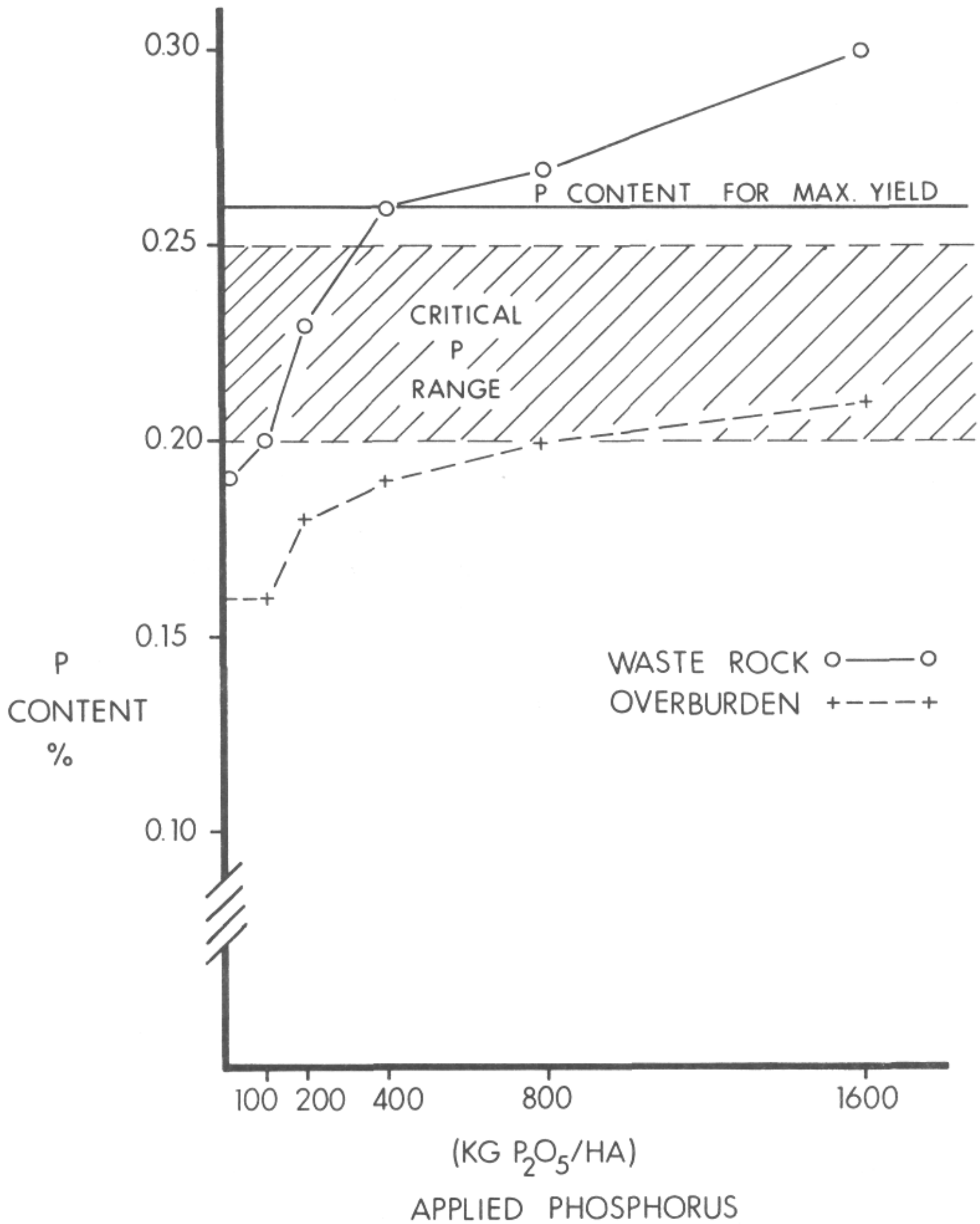

Figure 3: Effect of Phosphorus on P Content of Legume Seedlings

species present. To have a legume-dominated stand, the legume content should exceed 50%.

Phosphorus was essential for establishment of legume-dominated vegetation on both waste rock and overburden (Figure 4). However, substantially more phosphorus was required to achieve legume dominance on overburden than on waste rock.

As you will recall from our discussion of first growing season results, Alfalfa seedlings growing on overburden fertilized with 400 kilograms of P_2O_5 per hectare and less, were small relative to those growing on waste rock, and contained less than the critical level of phosphorus for Alfalfa. Alfalfa seedlings on overburden may have suffered a higher mortality during the first winter than did the larger, more vigorous seedlings growing on waste rock.

<u>Organic Matter Production.</u> As indicated earlier, one objective of re-vegetation was to produce organic matter. A significant correlation was observed between biomass, expressed as tonnes per hectare, and phosphorus applied on both waste rock and overburden (Figure 5). Biomass ranged from 0.2 tonnes per hectare with no phosphorus, to between 4 and 5 tonnes per hectare with 800 kilograms of P_2O_5 per hectare.

The difference in biomass between waste rock and overburden was less than might be anticipated if the much wider differences in legume content are considered, particularly at phosphorus rates of 800 kilograms per hectare and less. The growth response to phosphorus by Creeping Red Fescue, which dominated vegetation on overburden fertilized with less than 800 kilograms of P_2O_5 per hectare, accounted for the relatively high production of organic matter on overburden.

<u>Biological Nitrogen Fixation.</u> Nitrogen yield was used as an indicator of biological nitrogen fixation (Figure 6). Nitrogen yield, expressed as kilograms of N per hectare, is the product of biomass times the nitrogen content of the vegetation. Significant correlations were observed between

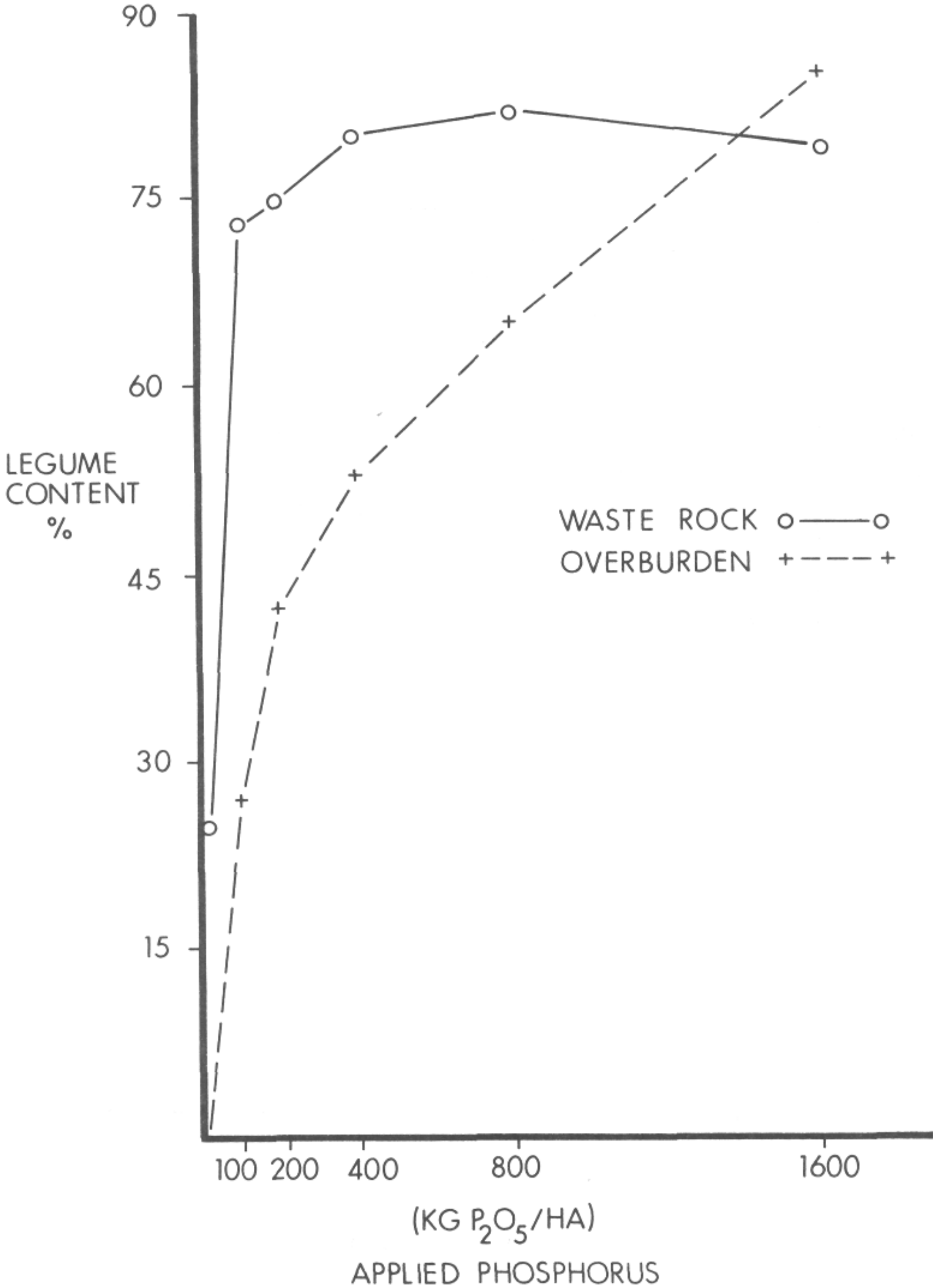

Figure 4: Effect of Phosphorus on Legume Content

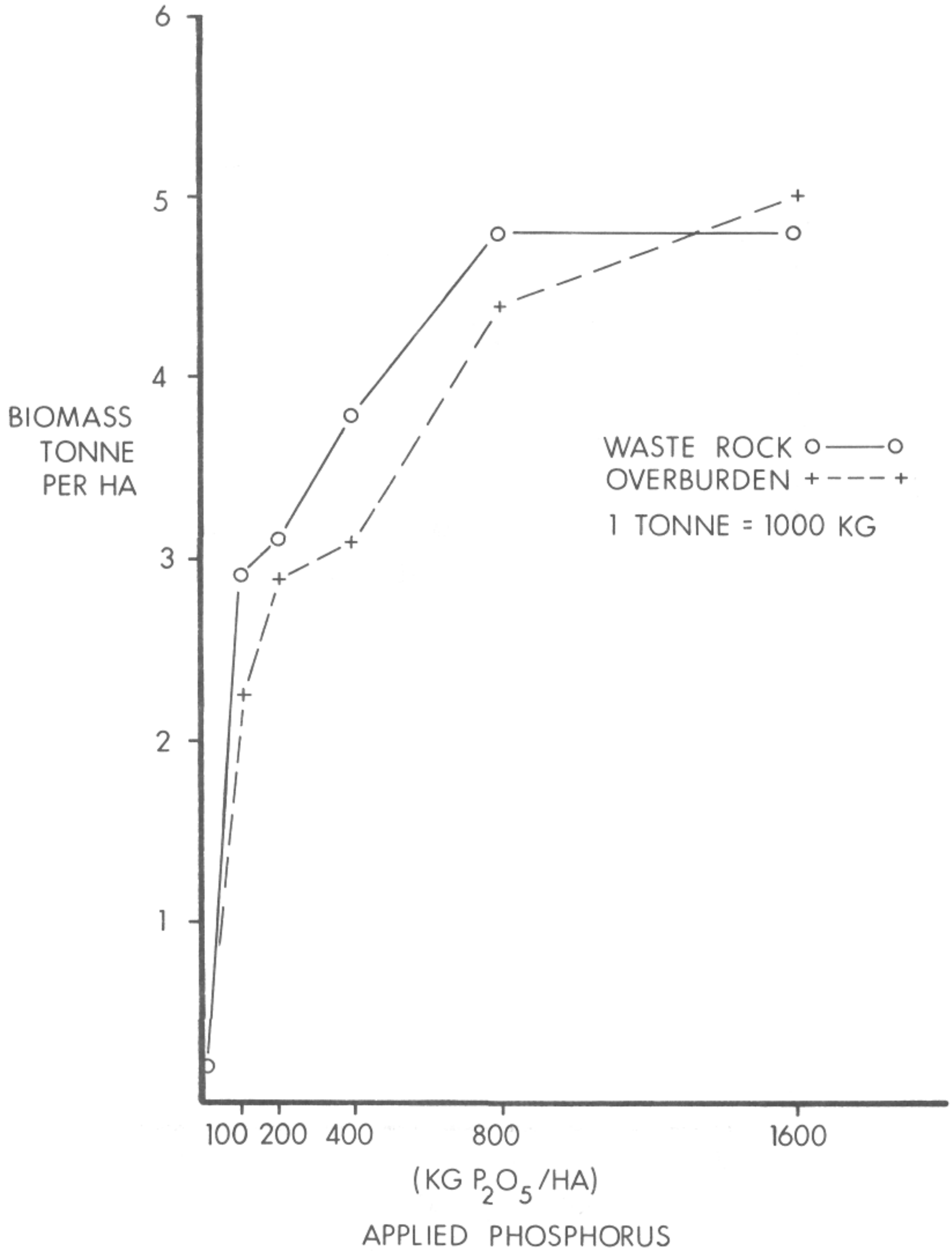

Figure 5: Effect of Phosphorus on Organic Matter Production

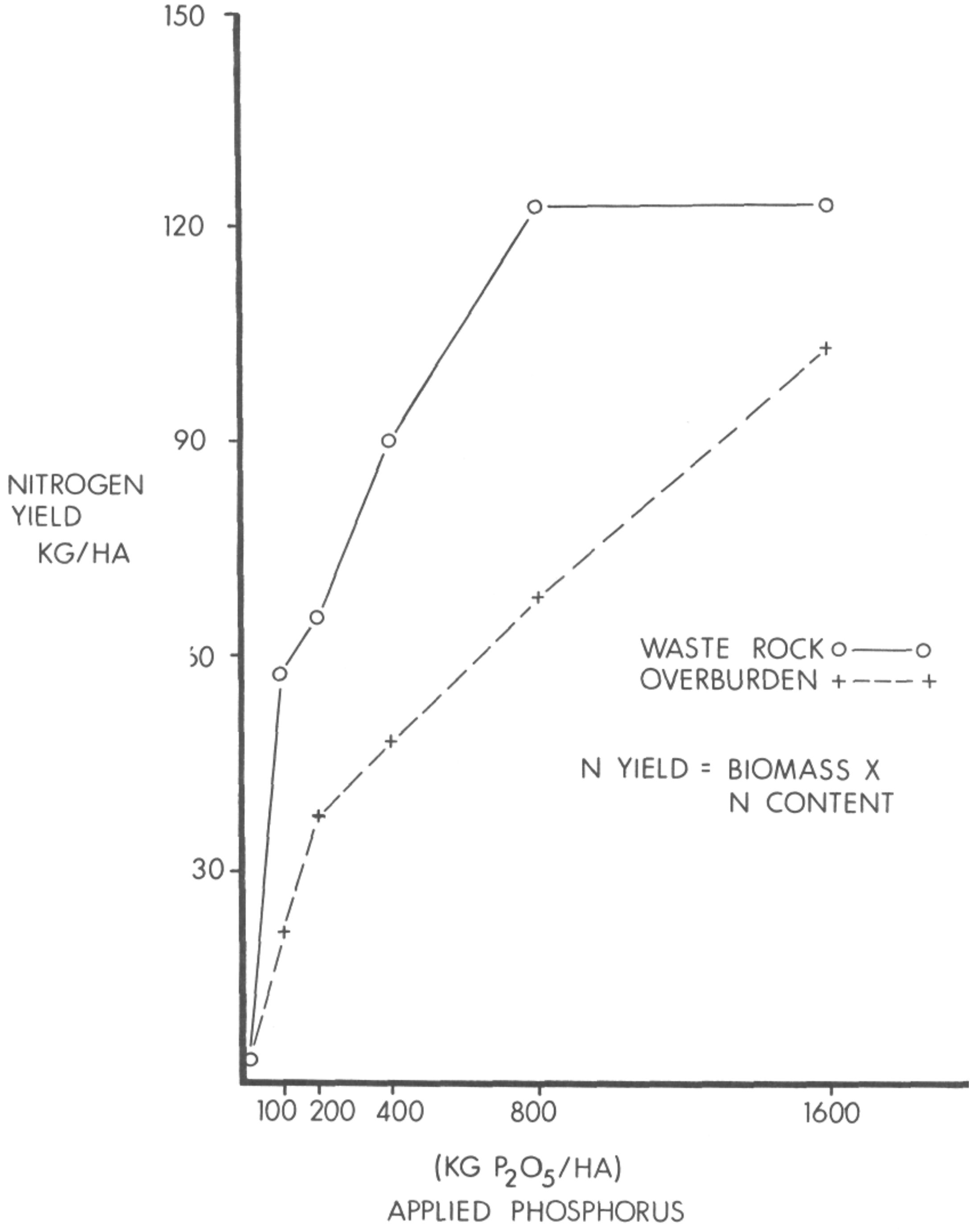

Figure 6: Effect of Phosphorus on Biological Nitrogen Fixation

N yield and applied phosphorus for both types of mine waste. Biological N fixation was significantly higher on waste rock than on overburden and is a reflection of both a higher legume content and higher organic matter production.

On waste rock N yield ranged from 3 kilograms of N per hectare with no phosphorus, to 123 kilograms of N per hectare with 800 kilograms of P_2O_5 per hectare, a difference of 120 kilograms per hectare of nitrogen. Current retail price for nitrogen fertilizer is in the order of 41 cents per kilogram of N; therefore, the value of nitrogen fixed during one growing season ranged from 23 dollars per hectare (9 dollars per acre) at the 100 kilograms per hectare phosphorus rate, to 49 dollars per hectare (20 dollars per acre) at the 800 kilograms per hectare phosphorus rate. I might add that transportation and application costs were not included in the above. Depending on how remote a mine is relative to a fertilizer dealer, transportation costs can be significant, as much as 24 cents per kilogram of N, which would increase the value of biologically fixed nitrogen by another 60%.

Phosphorus Content of Vegetation. As suggested earlier the critical phosphorus content for Alfalfa is in the range of 0.2% to 0.25%, and at levels below 0.2% Alfalfa growth and reproduction would be limited because of an insufficient supply of phosphorus. In addition to optimizing growth and reproduction, the phosphorus content of plant residues is considered an important factor in determining whether net mineralization or immobilization of phosphorus occurs during decomposition of residues by micro-organisms. The critical level above which mineralization or the release of organic P in a form which can be utilized by plants takes place is above 0.2% (2). On waste rock, these critical P levels in vegetation were not achieved until 800 kilograms of P_2O_5 per hectare was applied (Figure 7). On overburden, 1600 kilograms of P_2O_5 per hectare was required to produce vegetation with 0.2% phosphorus.

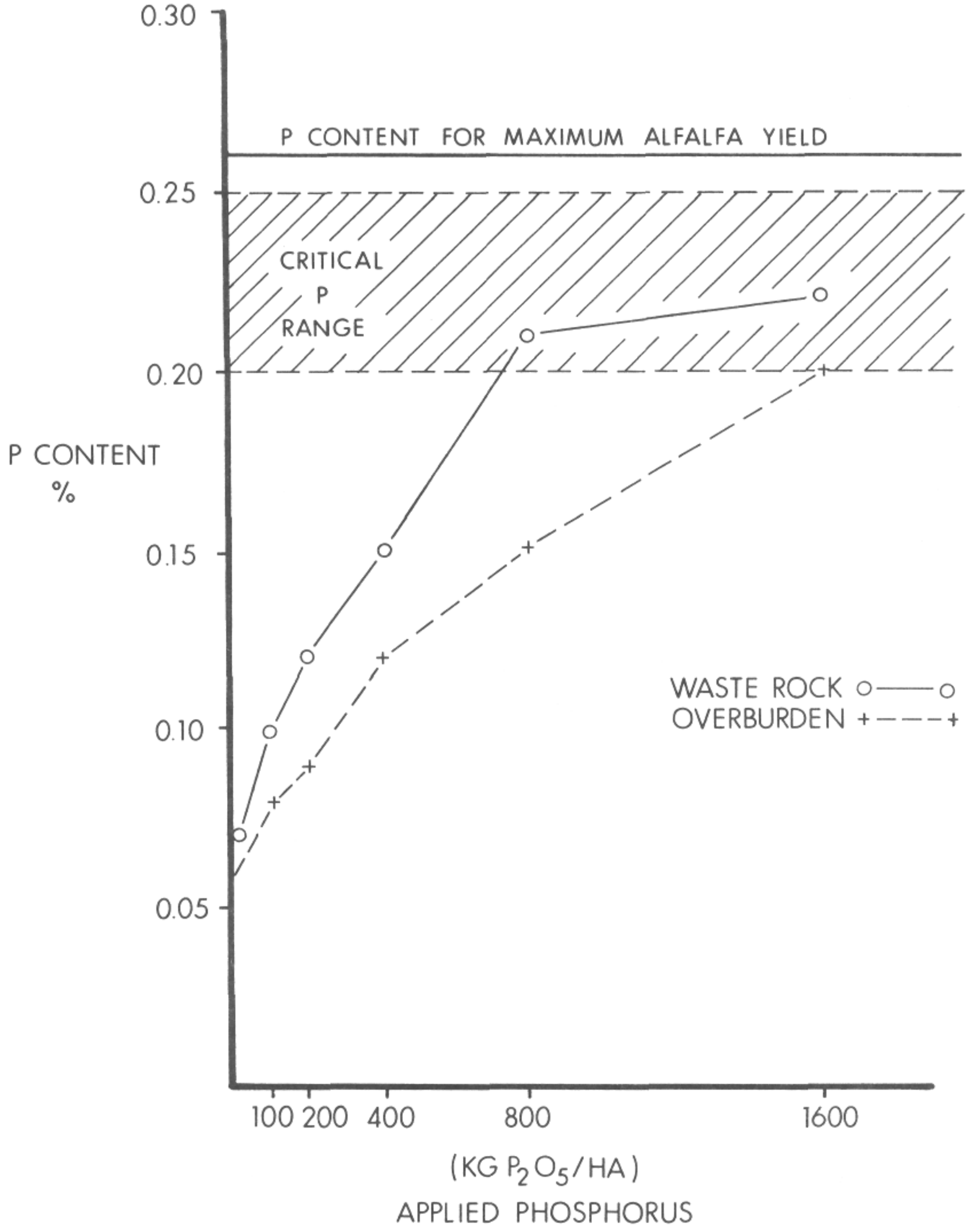

Figure 7: Effect of Phosphorus on P Content of Vegetation

SUMMARY AND CONCLUSIONS

The principle objective of this study was to determine if a maintenance-free plant community can be established on mine waste. Experimentation included using legume species to add nitrogen to the system, and increasing the phosphorus supplying capacity of the waste to a level capable of sustaining growth and reproduction over the long term, by applying the total phosphorus requirement as fertilizer prior to seeding. Other important objectives include determining the phosphorus requirement of two types of mine waste at Fording Coal and the most efficient method for applying phosphorus to these mine wastes.

The study will be monitored for a minimum of eight growing seasons during which period no maintenance fertilizer will be applied. Preliminary results after two growing seasons were reported.

Phosphorus has been confirmed as the only nutrient which limits the growth of nitrogen-fixing legume species on mine rock and overburden at Fording Coal. By supplying adequate phosphorus, legume-dominated vegetation produced large quantitities of plant residues, in the order of 4 to 5 tonnes per hectare, and fixed significant amounts of nitrogen, up to 125 kilograms of N per hectare per year.

To achieve the above levels of organic matter and nitrogen production, large quantities of phosphorus were required, in the order of 800 kilograms of P_2O_5 per hectare for waste rock and 1600 kilograms of P_2O_5 per hectare for glacial till overburden.

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