Effects of P, K, and liming on soil pH, Al, Mn, K, and forage barley dry matter yield and quality for a newly-cleared Cryorthod

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Abstract
Forage barley dry matter yield and quality, as well as soil pH, Al, and Mn were monitored in response to P, K, and lime application on a newly cleared Typic Cryorthod (Orthid Podzol). The overall yearly yield level was affected by precipitation. Without liming soil acidification occurred after three years of production. The liming rate of 2.2 Mg.ha$^{-1}$ was found optimal for maintaining initial pH levels (5.66) and increasing forage barley yields. It was also found optimum for K and P utilization for these first years of production. Soil pH dropped an average of 0.33 units over the three years on unlimed P plots and 0.46 units over 4 years on K plots. Phosphorus and K fertilization increased N utilization and resulted in decreased soil acidification.

Phosphorus availability was greater in the first year of cropping than in subsequent years, this was likely due to the effects of higher available moisture, liming release of native P, and effects of initial fertilization. There was a 148% increase in total dry matter yield and an 85% increase in protein yield of forage barley with P application. Liming increased total forage barley yields an average of 69% and total protein yields 48%. Reduced barley yields in unlimed plots were due to low soil pH. After two years of cultivation, unlimed plots contained exchangeable Al and soluble Mn levels reported toxic for other soils. The higher liming rates of 4.4 and 6.6 Mg.ha$^{-1}$ reduced soluble Mn to near critically low levels. Soil Al and Mn were highly correlated to pH. Soil exchangeable Al, Mn, and soluble Mn along with tissue Al were inversely correlated to percentage yield.

The average yield response to three levels of applied K, increased from zero initially to 67% by the fourth year. Total dry-matter production increased 32% and total protein yield increased an average of 32% and total protein yield increased an average of 15% with K fertilization over four years. About 60% of the yield response occurred between the 0 and 22 kg K.ha$^{-1}$ rates. Initial soil exchangeable K levels were not maintained even at the highest 66 kg K.ha$^{-1}$ treatment. Soil exchangeable Al and soluble Mn were elevated with dropping pH. Soil K reserves and resupply of exchangeable K in these soils over the long term will be an important factor in crop production.

Introduction

Cryorthods of Alaska and Podzols of Canada are being taken out of forests and put into cultivation (Hoyt et al., 1966). Research on cultivated Canadian Podzols has identified several specific soil fertility problems which can generally be associated with these acidic soils. Toxic effects of soluble Al and Mn were found to be of primary importance in limiting crop production on the Canadian Podzols (Hoyt et al., Hoyt and Webber, 1974). Soil pH has been found to be inversely related to soluble Al and Mn in these soils. Yield levels of barley, rapeseed, and buckwheat on the Podzols were found to have a high negative correlation to the soluble Al and Mn. Another soil fertility consideration for
Spodosols is the availability of $P$ and $P$-fertilizer response character with various levels of liming. Cryorthods are known to have relatively high $P$-sorption characteristics (Ping and Michaelson, 1986), but little is known of the $P$ and lime requirements of Alaska Cryorthods. In cooler regions where acidic Spodosols are in production, low temperature and often relatively low base saturation present particularly interesting conditions with respect to $K$ fertilization, soil acidification, and lime requirements. Studies of Podzols in the Peace River region of Canada have shown relatively high rates of soil acidification due to $N$ fertilization (Hoyt and Henning, 1982). In addition, ammonia sources of $N$ fertilizers have been shown to cause decreased $K$ release from soils (Acquaye and MacLean, 1965). Alaska Spodosols, which are just now coming into cultivation, have cryic soil temperature regimes (Rieger, 1983) and little is known of their $K$-supplying potential.

The Typic Cryorthods of southcentral Alaska are moderately to strongly acidic with low base saturation ($2-4\%$) and have a high lime requirement. The clay-fraction is relatively low in layered silicates and high in amorphous materials, about which relatively little is known of cation exchange reactions as compared with other soil minerals (Schalscha et al., 1975). Additions of $K$ have been found to increase perennial grass production for several years (Laughlin et al., 1981). Liming of Alaska Cryorthods has resulted in increased barley production (Laughlin, 1974) and with high rates of $K$ application increased lettuce yields.

Although it is known that the Spodosols in southcentral Alaska have high $P$-fixing capacity and often require $K$ additions as they are cropped, little is known about their ability to supply $P$ and $K$ under forage production and liming. This study was initiated in 1982 on a newly-cleared Cryorthod. The objectives of this study was to investigate the response of forage barley to $P$, $K$, and lime applications in the first years of cultivation.

 Materials and methods

Field plot design

The test plots were located in southcentral Alaska (Lat. 61°23'N, Long. 150°02'W, elev. 53 m). The soil is formed in volcanic ash, about 20 to 50 cm thick, overlying glacial outwash. This well-drained soil is mapped as a Kashwitna series and classified as medial over sandy or sandy-skeletal, mixed Typic Cryorthod in the USDA system (Orthic podzol in FAO system). The soil-water $pH$ (1:1) was 5.66, organic carbon 5.4% (wet oxidation), total $N$ 0.24% (Kjeldahl digestion), Bray 1 extractable-$P$ 3 mg.kg$^{-1}$, cation exchange capacity 29 meq.100 g$^{-1}$, Ca 1.54 meq.100 g$^{-1}$, Mg 0.22 meq.100 g$^{-1}$ and K 0.03 meq.100 g$^{-1}$ (each by neutral $1\ N$ ammonium acetate extraction and atomic absorption spectroscopy), clay 13% and silt 70% (hydrometer method). The native forest was cleared from the field plot site in 1980 and the site was undisturbed until the experiment was initiated in the spring of 1982.

The experimental design was a randomized complete block (3 blocks) design with $P \times$ lime treatments consisting of all combinations of $P$ at 0, 15, 30, and 45 kg.ha$^{-1}$ with calcium carbonate lime at 0, 2.2, 4.4, and 6.6 Mg.ha$^{-1}$. In a separate set of $K \times$ lime plots of the same design, treatments consisted of all combinations of $K$ at 0, 22, 44, and 66 kg.ha$^{-1}$ with the same lime rates as above. The lime rates were applied only in the spring of the first year while the $P$ and $K$ rates were reapplied just before planting each year. Uniform $N$ rates were applied each year at 135 kg.ha$^{-1}$. Uniform $P$ rates of 45 kg.ha and $K$ rates of 56 kg.ha$^{-1}$ were applied each year to $K \times$ lime and $P \times$ lime plots, respectively. Sources of $N$, $P$, and $K$ fertilizers are urea, triple superphosphate and potassium sulfate, respectively. Fertilizer and lime were rototilled into the surface 15 cm of soil. Individual plots ($0.9 \times 3$m) were planted to awnless barley ($Hordeum vulgare$ L. var. 'Weal'). The center three rows ($7.3$m) were harvested each year at the early milk stage and dried at 65°C for yield determination. Soil samples from 0—15 cm were taken from each plot prior to fertilization.

Chemical analysis

Dried barley tissue samples were ground in a Wiley mill to pass a 20-mesh screen and acid digested (Isaac and Johnson, 1976). Tissue digests were analyzed for $N$ on a Technicon autoanalyzer II using ammonia-salicylate colorimetric procedure. Protein was calculated from tissue $N$ (%) multi-