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Original Research

Phytometric Assessment of Fertility of Roadside Soils and Its Relationship with Major Nutrients

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Abstract

Roadside verges have obtained an important status in modern landscapes for conservation biodiversity, and their soils play a significant role in this regard. In designing more appropriate strategies for the integrated management of roadside habitats for nature conservation, the knowledge of physico-chemical characteristics of their associated soils is a prerequisite. The fertility of roadside soils in northern England was determined both by phytometric assessment using tomato plant and by chemical analyses of nitrogen, potassium, and phosphate levels. By comparing levels of these nutrients with their published normal levels, it was found that these soils have sub-optimum to optimum levels of fertility. The results of phytometric assessment revealed that the soils have low to medium levels of fertility. The fertility exhibited a pattern of zonation in the roadside soils with an increase with increasing distance from paved roads. Three nutrients were correlated with phytometirc assessments, and it was found that only nitrogen had a significant correlation with results of phytometric assessment.

Keywords: roadside verges, soil fertility, phytometric assessment, NPK analyses

Introduction

In the present landscape, road verges contribute significantly to the conservation of plants and are important in sustaining biodiversity and tourism of an area. Soil fertility is the predominant ecological factor affecting the distribution of individual species and composition of plant communities [1]. Assessment of soil fertility of roadside verges can serve as a basis for formulating conservation-based management and development strategies in these habitats.

The correct use of roadside verges for nature conservation requires precise knowledge of the physical, chemical, and biological characteristics of their habitat conditions, including those of roadside soils, with special emphasis on pollution and nutrient status. Nevertheless, most studies in roadside soils have only focused on automobile-induced pollution levels [2-6], while accurate knowledge of roadside nutrient dynamics and its role in management of vegetation conservation is poorly reported [9-12].

This study, which is a part of a broader research project on the ecology and conservation value of roadside vegetation in northern England, was designed and carried out to investigate the patterns of variation in levels of soil fertility in different zones of roadside verges. This objective was achieved by chemical analyses and phytometric studies of roadside soils. Since soil fertility has also been described as a major diversity-influencing factor [9-12], its implications for the achievement of floristically-rich and diverse roadside vegetation also are discussed.

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Material and Methods

Study Site and Sampling

The study area consisted of 35 roadside sites in north and west Yorkshire, England, along different A- and B-class roads. A few road verges in the Peak District also were sampled to survey the upland verges. During the survey of roadside verges, it was observed that in general, vegetation on the road verges could be divided into certain zones based on variation in the conditions and homogeneity of vegetation. In general, a road verge can be divided into these zones: border, verge, slope, and ditch [13]. The border zone is the narrow zone adjacent to the road and varies from 30 cm to 100 cm in width. In general, the verge is 1-3 m wide, slope is 1-3 m in height, and ditch is 1-1.5 m wide.

At each site, a 50 m tape was laid down parallel to the road in each arbitrary zone of the verge. From each 0.5×4 m quadrat, a soil sample was taken from two points with a stainless steel trowel. The soil was generally taken from the top 10-15 cm of the topsoil because much of the nutrient uptake by plants is within this depth [14]. The soil samples collected from 35 sites were analyzed for organic matter, exchangeable potassium, extractable phosphate and total nitrogen. In addition, soil fertility was determined by phytometric assessment method.

Chemical Analyses

Total nitrogen in the soil samples was estimated by semi-micro Kjeldahl method, which involved the digestion of soil samples with nitrogen-free sulphuric acid. Copper sulphate was added to raise the temperature and selenium tablets were used as a catalyst. On the completion of digestion, the sample was diluted and filtered. After filtration, ammonium nitrogen was estimated by distillation and titration [14].

For phosphate determinations, soil extractions were made with Olsen's reagent, which is recommended for the extraction of phosphate in neutral and calcareous soils [14]. Five grams of air-dried soil were shaken with 100 mls of Olsen's reagent (pH 8.5). Extractable inorganic phosphate-phosphorus was then determined by colorimetry using the ammonium molybdate reagent method on a Pye Unicam SP8-400 UV/VIS spectrophotometer [14].

For exchangeable potassium determination, five grams of soil were extracted with 125 ml of 1M ammonium acetate (pH 7), and potassium was determined in the extract by a flame emission spectrophotometer [14]. The pH was measured by pH meter in a mixture of one part soil with one part deionized water.

The organic matter was determined gravimetrically by using the loss on ignition method. Air dried soil samples were dried in an oven at 105ºC for 24 hours. Pre-weighed and oven dried soil samples were placed in an electric furnace and heated at 460ºC for 24 hours. The loss of weight on ignition was expressed as a percentage of the dry soil [15].

Phytometric Assessment

Fertility of the roadside soils was determined using the net above-ground biomass production of tomato (*Lycopersicum esculentum* Mill. var. Alicante) as being indicative of soil fertility. For phytometric analysis, each soil sample was placed into a 3" pot, with 4 replicates per sample. Due to the large number of samples, these were randomly divided into three groups and each group was placed in a separate ventilated green house at the Department of Environmental Science. The tomato seeds were germinated in distilled water on filter paper and grown onto the two-leaf stage. The seedlings were then transplanted into each soil sample (1 seedling per pot). The tomato plants were grown for six weeks in the green houses and were irrigated with distilled water from the base to avoid leaching. Weeds were removed regularly from the pots. After growth for six weeks following transplantation, each plant was harvested and the above-ground biomass was dried at 80ºC for 24 hours. Net above-ground production was estimated by noting the dry weight increment of biomass over a period of six weeks. For comparison, the tomato plants were also grown on John Innes compost No. 3 as a control along with each group of soil samples. This compost contains a wide spectrum of nutrients needed for balanced plant growth, including N, P, K, and trace elements [16]. The soil fertility of each soil sample in a group was expressed as a percentage of the dry weight of the control for that group.

Data Analyses

One-way ANOVA (Analyses of Variance) was used to determine the effect of different zones of road verges on three major nutrient contents (N, P, and K) in soil. The relationship between shoot dry weight percentages and nutrient contents was calculated by Pearson's coefficient of correlation. All statistic tests were calculated on the significance level 0.05.

Results and Discussion

Determination of Chemical Nutrient Status

Soil fertility is generally considered to be related to three major nutrients: nitrogen, phosphorus, and potassium [17, 18]. Though needs of different plant species for these elements vary, they are all needed by plants in substantial quantities. Table 1 presents the mean values of these nutrients and their ranges in the roadside and normal soils. In soils, however, the concentrations of these elements show a lot of variation, and these values should be considered as a rough guide to their concentrations in roadside soils.

In the present study, the exchangeable potassium concentrations of the roadside soils showed a low mean level of 150 $\mu g \cdot g^{-1}$ compared to Allen's figures [14] (Table 1). Mean total nitrogen percentages in the roadside soils of 0.4% shows a fairly high nitrogen content in the roadside soils.

Table 1. Mean levels of major nutrients in roadside soils and their range in roadside and normal soils.

Factor	Roadside soil			Normal soil according to Allen [13]	
	Mean±SD	Low	High	Low	High
Total nitrogen (%)	0.40±0.01	0.10	0.40	0.10	0.50
Extractable phosphate (μg·g^{-1})	21±1	4	73	3	80
Extractable potassium (μg·g^{-1})	150±5	25	385	50	500

Mean phosphate levels in the roadside soils (21.1 μg·g^{-1}) are also toward the bottom end of Allen's range (Table 1). It shows that the roadside soils have sub-optimum to optimum concentrations of potassium and phosphorus, while nitrogen, in general, is present in high amounts. The availability of phosphate ions in a soil might be affected by pH of the soil. At very low pH (4-5) or high pH (7-8), phosphate ions may be 'tied up' in such a manner that they are less available to plants [19]. Since these roadside soils have a mean pH of 7.4, it might be thought that phosphate availability might have been adversely affected, particularly in border and verge zones. By comparing these values of nutrients with Allen's data (Table 1), it can be stated that the nutrient status of the roadside soils is sub-optimum to optimum.

Table 2. Mean values of some edaphic variables in different roadside zones.

Factor	Border	Verge	Slope	Ditch
pH	8.1±0.2	7.5±0.1	7.1±0.2	7.2±0.1
Organic matter (%)	8.7±1.4	10.5±0.4	10.7±0.5	12.3±0.8
Total nitrogen (%)	0.35±0.1	0.41±0.3	0.39±0.2	0.55±0.2
Extractable Phosphate (μg·g^{-1})	22.8±1.7	20.3±1.2	19.2±1.4	21.2±1.8
Extractable potassium (μg·g^{-1})	150±4.2	147.4±3.5	144.7±2.8	158.2±4.9

Phytometric Assessment of Soil Fertility

The dry weights of shoots of tomato plants were compared with the control plants and expressed as percentages of the dry weight of control to indicate soil fertility. The concentrations of total nitrogen, phosphate, and potassium in John Innes compost number 3 used as control were 0.3%, 170 μg·g^{-1} and 300 μg·g^{-1}, respectively (per. comm. W. S. Hort. Ltd). These results exhibited a considerable variation in percentage mean shoot dry weights of tomato plants between different soil samples. A majority of the soils (75%) showed a low level (< 50% of dry weight of control) of fertility. Soil fertility also exhibited a pattern of zonation in variation, with a gradual increase from the border zone to the ditch zone (Fig. 1). The mean shoot dry weight percentages of the border zone samples were found to be significantly lower than those of the other three zones. Among the other zones, the ditch zone showed the highest mean percentage of shoot dry weights. The frequent presence of *Urtica dioica* L. and *Rubus fruticosus* agg. in the ditch zone, species which are considered as common in fertile, nitrogen rich soils, also supports the view that ditch zone soils are more fertile.

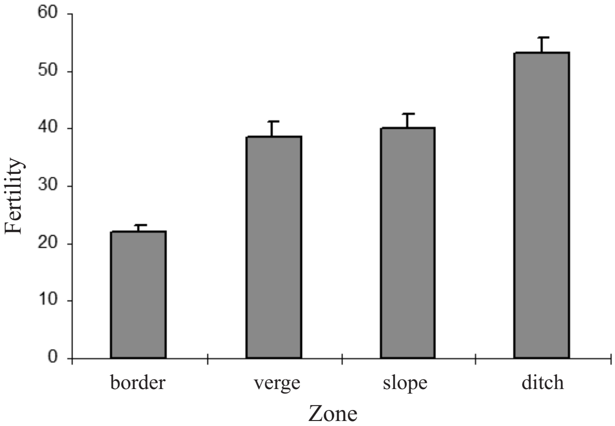

Fig. 1. Mean soil fertility values (percentage of control) of different zones of road verges, together with standard error bars. Differences between means are significant ($p<0.001$), based on ANOVA calculations.

In order to find the relationship between shoot dry weight percentages and three major nutrients (N, P, and K), Pearson's coefficient of correlation was calculated. No significant correlation was found between shoot-dry weight percentages and phosphorus and potassium contents of roadside soils. However, a low but significant (r=0.28***) positive correlation was found between shoot dry weight percentages and total nitrogen percentage of roadside soils. One reason for this non-significant relationship may be the fact that neither of these nutrients showed significant variation between the verge zones (Table 2). Roadside soils are usually characterized by high salinity and pH [20]. It has been reported that increases in the amounts of chloride and sodium in the tree leaves growing along roads does not have any influence on the content of N, P, and K [21].

There are different reports in the literature about the relationships of these nutrients (N, P and K) with soil fertility. Al-Farraj [22] evaluated the fertility of waterlogged, rich-fen peats by using *Epilobium hirsutum* L. as an indicator of fertility. They found no significant relationship between concentrations of major nutrients (N, P and K) in peat samples and growth of *E. hirsutum*. However, they reported that nitrogen-rich peats mostly sustained vigorous seedling growth. Gough and Marrs [1] compared the fertility of soils under semi-natural grassland, scrub, woodland, arable fields, and improved grasslands by chemical analyses and plant bio-assay techniques. They found available phosphorus to be a limiting factor to plant growth and reported no significant relationship between extractable potassium and total nitrogen and plant growth. Wheeler [23] assessed the fertility of undrained, rich-fen soils by measuring the growth of *E. hirsutum*. The correlation of phytometric response with concentrations of major cations (potassium, nitrogen and phosphorus) in soil extracts revealed that potassium and phosphorus showed a weak but significant relationship while nitrogen content showed an insignificant relationship.

The results of the present study support the previous views that the proper assessment of soil fertility is difficult and all the available methods have their own drawbacks [24]. For instance, in a phytometric assessment of soil fertility, the results are comparative and give no absolute index of fertility. These results are also dependent on the species used for phytometric assessment as different species show different responses to variations in nutrient availability. The results of such studies, therefore, demand careful evaluation, and it is difficult to derive generalizations from these studies. This aspect is more pronounced in the case of disturbed soils such as roadside soils that receive inputs of different chemicals and undergo different levels of disturbance. The ordination analysis of roadside plant communities and environmental variables in another study in this project showed that roadside vegetation is influenced by many geographic, physico-chemical, and anthropogenic factors [25].

Soil fertility also is an important factor affecting the floristic composition of grasslands [1, 24, 25]. There is a general consensus that high soil fertility increases dominance of competitive and productive species, which leads to a decline in species diversity. In general, low nutrient levels are considered to give rise to higher species richness [26-29].

On newly built roads, vegetation composition is determined by re-vegetation techniques, type of construction activities, and the seed mixture used for turf development. With the passage of time, however, other factors such as road age and sequence of colonization of species become important [30]. For the establishment of floristically rich grasslands, high soil fertility would be a problem. Though topsoil is often considered to be nutrient poor, the addition of fertilizers and the subsequent addition of organic matter from the dead grasses increases its fertility. In addition, input of nitrogenous pollutants from automobile exhausts may increase fertility of roadside soils. If management of roadside verges is aimed at changing roadside plant communities to species-rich grasslands, the reduction of soil fertility would be an important part of management. For this purpose, instead of topsoil, use of sub soil is suggested and that after establishment of grass sward on verges, roadside grasses should be cut at least once a year and the cuttings should be removed [31, 32].

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References

1. GOUGH M.W., MARRS R.H. A comparison of soil fertility between semi-natural and agricultural plant communities: implications for the creation of species rich grassland on abandoned land. Biol. Conserv., **5**, 83, **1990**.
2. DESKA J., BOMBIK A., MARCINIUK-KLUSKA A., RYMUZA K. Trends in Lead and Cadmium Content in Soils Adjacent to European Highway E30. Pol. J. Environ. Stud., **20**, 317, **2011**.
3. GRIGALAVICIENE I., RUTKOVIENE V., MAROZAS V. The accumulation of heavy metals Pb, Cu and Cd at roadside forest soil. Pol. J. Environ. Stud., **14**, 109, **2005**.
4. AKBAR K.F., MAQBOOL,S., ASHRAF I., ANSARI TM., AHMAD SS. Some preliminary studies on plants and pollutants along Pindi Bhattian-Faislabad Motrway (M-3) Pakistan. Pakistan J. Bot., **43**, 2347, **2011**.
5. AKBAR K.F., HALE W.H.G., HEADLEY A.D., ATHAR M. Heavy metal contamination of roadside soils of northern England. Soil and Water Research, **4**, 158, **2006**.
6. WROBEL M., TOMASZEWICZ T., CHUDECKA J. Floristic diversity and spatial distribution of roadside halophytes along forest and field roads in Szczecin lowland (West Poland). Polish Journal of Ecology, **54**, 303, **2006**.
7. TRUSCOTT A.M., PALMER S.C., MCGOWAN G.M., CAPE J.N., SMART S. Vegetation composition of roadside verges in Scotland: the effects of nitrogen deposition, disturbance and management. Environ. Pollut., **136**, (1), 109, **2005**.
8. DE DEYN G.B., QUIRK H., YI Z., OAKLEY S., OSTLE N. J., BARDGETT R. D. Vegetation composition promotes carbon and nitrogen storage in model grassland communities of contrasting soil fertility. J. Ecol., **97**, 864, **2009**.
9. HASHIM N.R. Soil Fertility and Plant Diversity in Sabal Forest Reserve, Borneo. The IUP Journal of Soil and Water Sciences, **2**, 19, **2009**.
10. EILTS J.A, MITTELBACH G.G., REYNOLDS H.L., GROSS K.L. Resource heterogeneity, soil fertility, and species diversity: Effects of clonal species on plant communities. The American Naturalist, **177**, 574, **2011**.
11. LURCHENKO V., MYKHAILOVA L. Impact of highway on soil ecosystems of the roadside area. Transbaltica 2011. 236, **2011**.
12. EVANLYO G., BOOZE-DANIELS J.N., DANIELS L.W., HAERING K. Soil amendments for roadside vegetation in Virginia. Proceedings of the 2000 conference. Y2K Composting in the Southeast. Charlottesville Virginia, 89, **2000**.
13. DOWDESWELL W.H. Hedgerows and Verges. Allen and Unwin, London, **1987**.
14. ALLEN S.E. Chemical Analysis of Ecological Materials. 2nd ed. Blackwell Scientific Publications, Oxford, **1989**.
15. ROWELL D.L. Soil Science: Methods and Applications. Longman Scientific and Technical, Harlow, **1994**.
16. JOHN INNES MANUFACTURING ASSOCAIATION, BERKSHIRE, UK. Technical Data Sheet. 4, **2010**.
17. RAYACHAUDHURI S.P. Land and Soil. National Book Trust. Delhi, **1966**.

18. MARRS R.H. Soil fertility and nature conservation in Europe: theoretical considerations and practical management solutions. Adv. Ecol. Res., **24**, 242, **1993**.
19. ANDREW O.N., JACKOBS J.A. Roadside soil fertility. Public Works, pp. 90-91, **1966**.
20. RORISON I.H. Ecological inferences from laboratory experiments on mineral nutrition. In: RORISON I.H. (Ed.), Ecological Aspects of Mineral Nutrition of Plants, Blackwell Scientific, Oxford, pp. 155-176, **1969**.
21. DMUCHOWSKI W., BROGOWSKI Z., BACZEWSKA A.H. Evaluation of vigour and health of 'street' trees using foliar ionic status. Pol. J. Environ. Stud., **20**, 489, **2011**.
22. AL-FARRAJ M.M., GILLER K.E., WHEELER B.D. Phytometric estimation of fertility of waterlogged rich-fen peats using *Epilobium hirsutum* L. Plant Soil, **81**, 283, **1984**.
23. WHEELER B.D., SHAW S.C., COOK R.E.D. Phytometric assessment of the fertility of undrained rich-fen soils. J. Appl. Ecol., **29**, 466, **1992**.
24. THOMPSON J.R. Roadside: a resource and a challenge. In: Bradshaw A.D., Goode D.A., Thorpe E.H.P. Eds. Ecology and Design in Landscape, Blackwell Scientific, Oxford, pp. 325-340, **1983**.
25. AKBAR K.F., HALE W.H.G., HEADLEY A.D. Floristic composition and environmental determinants of roadside vegetation in north England. Polish Journal of Ecology, **57**, 73, **2009**.
26. GOLDBERG D.E., MILLER T.E. Effects of different resource additions on species diversity in an annual plant community. Ecology, **71**, 213, **1990**.
27. TILMAN D., DODD M.E., SILVERTOWN J., POULTON P.R., JOHNSTON A.E., CRAWLEY M.J. The park grass experiment: insights from the most long-term ecological study. In: Leigh R.A., Johnston A.E. Ed. Long-term experiments in agricultural and ecological sciences, CAB International, Wallingford, pp. 287-303, **1994**.
28. WEDIN D.A., TILMAN D. Influence of nitrogen loading and species composition on the carbon balance of grasslands. Science, **274**, 1720, **1996**.
29. LEPŠ J. Nutrient status, disturbance and competition: an experimental test of relationships in a wet meadow copy. J. Veg. Sci., **10**, 219, **1999**.
30. RENTCH J.S., FORTNEY R.H., STEPHENSON S.L., ADAMS H.S., GRAFTON W.N., ANDERSON J.T. Vegetation-site relationships of roadside plant communities in West Virginia, USA. J. Appl. Ecol., **42**, 129, **2005**.
31. ARONSON E. A phytometric assessment of the effects of the soil quality and drainage of the Sardinilla biodiversity project. Report No. ENVR 451, Smithsonian Tropical Research Institute, **2004**.
32. RAMSAY D. Roads and Nature Conservation. English Nature, Peterborough, **1993**.