Proceedings of the New Zealand Grassland Association 53: 191-196 (1991)

Fertiliser history is a useful predictor of soil fertility status

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Abstract

A Fertiliser index is described which consists of summing total superphosphate applied to a site after using an annual discount to past applications. This index is related to relative pasture yield for 3 major New Zealand super-phosphate withholding trials using a Mitscherlich function. A discount factor of 0.15 was chosen. Accuracy of relative pasture yield prediction was at least as good as for an Olsen P predictor and better where sulphur responses were implicated in the response to super-phosphate (r^2;0.77 to 0.93). The effect on relative pasture yield predictions of measurement errors in Olsen P and Fertiliser index were similar using the Whatawhata site for comparison. A 20% error in predictor resulted in a 3 unit error in relative pasture yield estimation. Measurement errors in the Fertiliser index are minimal if the last 10 years' fertiliser history are known. Where this knowledge is not available, 5 years of known fertiliser history and use of national average fertiliser statistics beyond that may give acceptable estimates of relative yield. The advantage of the model for on-farm use is that intended fertiliser use directly affects the index and hence prediction of relative pasture yield. This facilitates economic analysis of options. An analysis using the model to investigate production consequences of fertiliser use at the industrylevelshowscontinuationofcurrentfertiliser levels on hill country farms will result in a drop in farm output of 13% in the next 10 years.

Keywords super-phosphate, discount, Olsen P, policy, regional production, pasture yield, fertiliser strategy

Introduction

The subject of appropriate level of phosphate fertiliser for New Zealand farms has received widespread attention in recent years (e.g. Gillingham *et al.* 1984; Quin & Scobie 1988; Clark *et al.* 1990). Of particular interest is the consequence of withholding fertiliser on developed farms in years of low product prices. Economic evaluation of these actions requires knowledge of pasture yield responses to various fertiliser application strategies, including withholding and re-applying fertiliser.

A number of useful New Zealand data now exist which describe annual pasture yield responses to long term fertiliser strategy (Gillingham *et al.* 1990; O'Conner *et al.* 1990; Lambert *et al.* 1990; Nguyen *et* al. 1989). These data provide a valuable resource to study means of predicting pasture yield for giving fertiliser advice to farmers.

The standard means of assessing soil phosphate (P) status in New Zealand is the Olsen P test. A simple alternative could be to construct an index of past fertiliser (superphosphate) application rates. Related ideas of describing soil Pstatus such as the accumulation of applied P, allowing for annual losses, have been used in Australia (Helyar & Godden 1977) and were promoted by Scobie & St Pierre (1986).

The purpose of this paper is firstly; to determine if a Fertiliser index can be constructed to predict relative pasture yield (yield/non-P limited yield) for 3 major New Zealand fertiliser withholding trials, and secondly, to compare the accuracy of the Fertiliser index approach with Olsen P in practical situations.

The fertiliser index model

The Fertiliser index consists of summing total superphosphate applied to a site (kg/ha) after applying an annual discount to past applications. This discount allows for soil and animal losses from the soil inorganic phosphate pool. Index values were calculated for each year of availabledata from long term trials at Whatawhata (Gillingham *et* al. 1990). Ballantrae (Lambert *et al.* 1990) and Winchmore (Rickard & McBride 1987; Nguyenetal. 1989). Pasture yield wascalculatedrelative to yield on the highest fertiliser treatment each year. Known fertiliser history extended from 1973 to 1987 for both the Whatawhata and Ballantrae sites and from 1949 to 1986 for the Winchmore site. Fertiliser index and relative yield data for 1984 to 1987 and 1979 to 1987 were used from the Whatawhata and Ballantrae trials, respectively. These corresponded to the immediate pre-withhholding and withholding periods of these trials. Data for 1957 to 1986 were used from Winchmore. This included periods of withholding and re-application of fertiliser.

The Mitscherlich functional form was chosen to represent the relationship between Fertiliser index and relative pasture yield because of its historical use in soil fertility models (Middleton 1984).

The form of the Mitscherlich model is:

$$RY = a - br^{I} \quad (1)$$

where RY is relative pasture yield, a is the maximum relative yield (1.0) and I is the Fertiliser index.

Relative yield at a site in the absence of fertiliser (RY_o) is given by:

$$RY_o = a - b \quad (2)$$

In calculating the Fertiliser index the discount (d) to previous years fertiliser applications (P) was commenced one year after application, at time (t-l).

The Fertiliser index is described by:

$$I_t = P_t + (1-d)P_{t-1} + (1-d)^2P_{t-2} \ldots + (1-d)^nP_{t-n} \quad (3)$$

Model parameters

The Mitscherlich model was fitted separately to data from each site using non-linear least squares procedures on Genstat. The choice of discount factor (0.15) for the Fertiliser index equation (3) was made by comparing r^2 values for the relative yield predictions over a range of discount factors (Table 1). The goodness of fit was not particularly sensitive to choice of discount factor. Low discount factors made relative yield predictions more sensitive to the influence of past fertiliser applications because past applications are given greater weighting in the index. This presupposes lower P losses. A discount factor of 0.15 was used for all sites.

Parameter values and summary statistics are given for the models fitted to each site in Table 2. Degree of model fit is shown in Figure 1. Values greater than 1 .O were obtained for maximum relative yield (a) from unconstrained fitting of the model. Relative yields of up to 1.04 in the raw data (Ballantrae) reflected variation between experimental replicates in the highest fertiliser treatment. In subsequent use of the Fertiliser index model, maximum relative yield was assumed to occur at the fitted maximum by scaling as in equation 4. That is:

$$RY = (a - br^{I})/a \quad (4)$$

This assumes we accept the Mitscherlich model as correct and implies the highest fertiliser treatments were 96% of maximum at Whatawhata and Winchmore and 84% of maximum at Ballantrae.

Table 1 The effect of discount value on percent variance (2) accounted for in relative pasture yield predictions.

Discount parametre	0.100	0.125	0.150	0.175	0.200	0.225
Site						
Ballantrae	64.4	85.2	05.3	64.6	63.5	61.6
Winchmore	91.0	92.2	92.6	92.5	92.3	91.9
Whatawhata	75.6	76.3	77.0	77.5	77.9	70.2

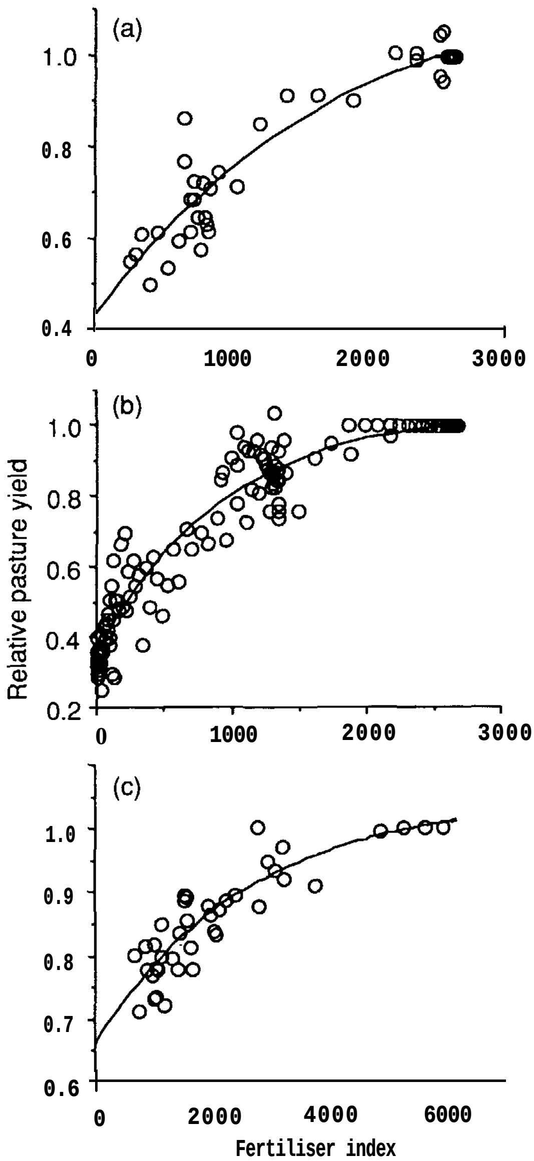

Figure 1 Feniliser index relative pasture yield relationships for a) Ballantrae, b) Winchmore and c) Whatawhata sites.

Accuracy of the model for on-farm use

The usefulness of the Fertiliser index approach for fertiliser advice was assessed by comparing it with the Olsen P approach of measuring soil fertility. The key to predictions using either system is the accuracy of the calibration between predictor (Olsen P or Fertiliser index) and relative yield. A relationship between Olsen P and relative yield was developed for the Whatawhata site using equation 1 and replacing Fertiliser index (I) by Olsen P. A linear ramp function gave a better fit to the data for the other sites (Figure 2). Olsen P values appeared to drop quite suddenly from 1981 in the Winchmore data. The reason for this is not entirely clear (McBride pers. comm.) so data from 1981-86 were omitted from the Winchmore, Olsen P regression. The problem with the ramp function is that it asymptoted at the highest Olsen P levels measured in the trials. This means Olsen P asymptoted at 84% of maximum yield at Ballantrae if we accept equation 4. and points to a problem in determining maximum yields which needs further investigation.

Using the r^2 criterion Fertiliser index gave equally good (Whatawhata, Ballantrae) or better (Winchmore) predictions of relative yield than Olsen P recorded at the end of the year (Table 2). Olsen P levels at the end of a measurement year (post) gave a better prediction of relative yield than Olsen P at the start of a year (pre) (Table 2). The Olsen P level at the end of a year includes the influence of fertiliser applied in that year which has also influenced pasture yield.

The data sets used in this analysis are from superphosphate rather than solely P trials. Responses to sulphur (S) will influence the calibration of predictor

Table 3 Fitted equations for fertiliser index and Olsen P relationships with relative pasture yield. (All coefficients significant p.<0.01.)

Site	Fertiliser index (I)	
Ballantrae (n = 40)	RY = 1.197 - 0.7635 * 0.99946^I, (0.1420) (0.0990) (0.000227)	r^2 = 0.69
Whatawhata (n = 40)	RY = 1.044 - 0.3646 * 0.99961^I, (0.0510) (0.0358) (0.000139)	r^2 = 0.77
Winchmore (n = 140)	RY = 1.044 - 0.6920 * 0.99692% (0.0224) (0.0220) (0.000096)	r^2 = 0.93
Site	**Olsen P (P)**	
Whatawhata (pre)	RY = 1.0325 - 0.3996 * 0.941 10^P, (0.0610) (0.0455) (0.02020)	r^2 = 0.66
Whatawhata (post)	RY = 1.010 - 0.4466 * 0.92230^P, (0.0274) (0.0565) (0.0207)	r^2 = 0.79
Ballantrae	RY = 0.22 + 0.0685 * P, (0.039) (0.00494)	r^2 = 0.89
Winchmore	RY = -0.26 + 0.0876 * P, (0.072) (0.00716)	r^2 = 0.63

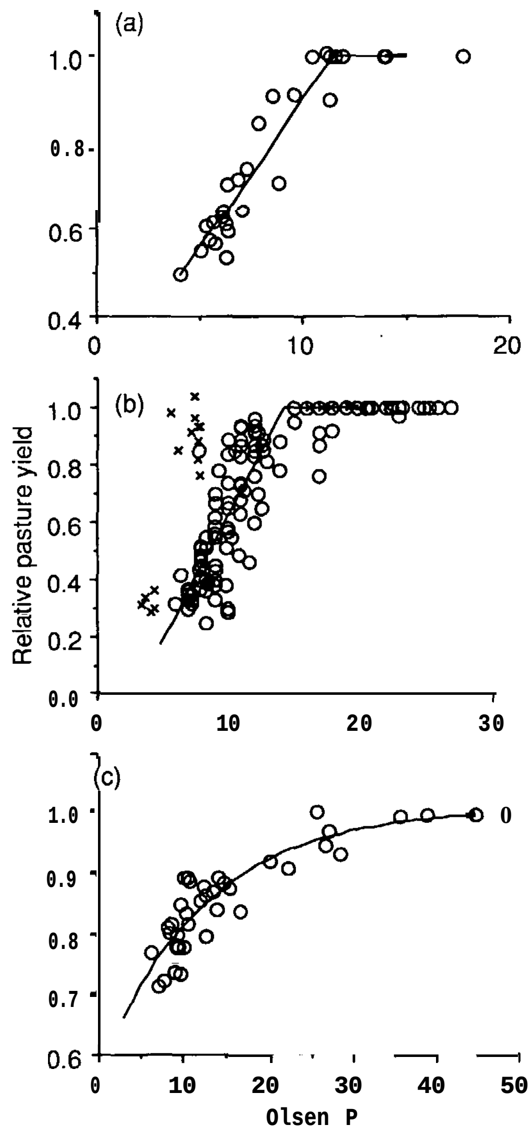

Figure 2 Olsen P - relative pasture yield relationships for a) Ballantrae. b) Winchmore and c) Whatawhata sites. X denotes data omitted from the regression.

with relative yield. The Ballantrae and Winchmore sites are responsive to S, at least in the presence of adequate P (Mackay *et* al. 1988; Nguyen & Rickard 1988). In contrast the Whatawhata site showed very small responses to added sulphur (I. Power pers. comm.)

The relatively good calibration against Olsen P at the S responsive sites indicates that P is still the most limiting factor at these sites. The size of response to superphosphate at any given Olsen P value will be increased where S is also deficient. Using Olsen P alone as a predictor of relative yield will be most appropriate at the Whatawhata site. This point needs to be considered in interpretating the sensitivity of the two approaches.

Comparing Olsen P and Fertiliser index as predictors of relative yield has three components. The first is the goodness of fit between relative yield and the predictor. In this analysis the r^2 values for both predictors were similar at the Whatawhata and Ballantrae sites and favoured the Fertiliser index at Winchmore (Table 1).

Secondly, the sensitivity of relative yield predictions to measurement error in the predictor value is important. The error in predicted relative yield caused by an error of 20% in the true value of Olsen P or Fertiliser index was calculated for relative yield in the range of 70 to 80%. A 20% error in predictor value gave a 3 unit error in estimated relative yield (i.e. 70 to 73%) using either Fertiliser index or Olsen Pas predictor at the Whatawhata site. Equivalent estimates for the other sites were a 4 unit error using the Fertiliser index and an 8 (Winchmore) and 5 (Ballantrae) unit error with Olsen P as predictor.

The final element in this analysis of the accuracy of prediction is the likelihood of errors occurring in the predictor value. Estimated Olsen P level has been shown to vary by up to 30% due to field sampling variability and time of year (White & Gregg 1990; Wheeler *et* al. 1991). Errors in calculating Fertiliser index will be due to unknown or erroneous fertiliser history. In order to assess the impact of errors in fertiliser history the impact of false fertiliser history was analysed.

The Fertiliser index model uses the last 15 years of fertiliser history as kg/ha of superphosphate as its inputs. Using a 'true' fertiliser history of 125 kg/ha (1975-1989) gives a relative yield of 59% for Ballantrae. The impact of unknown history on predicted relative yield is shown in Table 3.

To get within 3 units of the true value (i.e. 56-62) requires that the previous 10 years' history are known if earlier years are assumed to be zero. An alternative is to set unknown fertiliser history equal to average fertiliser use on Class 4 hill country from the Meat and Wool Board Economic Service Surveys (MWBES) (Figure 3). Using these data, knowing the last 7 years' history gets the predicted relative yield within 3 units of the true value in this example, despite MWBES data being 60% higher than the true values. These analyses emphasise the weighting which the more recent applications of fertiliser carry in the index. Fortunately, these are the values which are most likely to be known accurately.

One final complication, particularlyon hill country, is that parts of a farm will have different fertiliser histories. If these differences are known they can easily be included in the Fertiliser index and the model will be able to select those blocks most responsive to fertiliseruse. If the differences areunknown averaging the years' fertiliser history over the whole farm will give rise to some errors.

Table 3 The effect of number of years known fertiliser history on relative pasture yield predictions.

Number of years with known fertiliser history	Estimate of relative yield assuming: Unknown years set to zero	Unknown years set to MWBES data
15	59	59
10	56	60
5	51	62
3	46	63

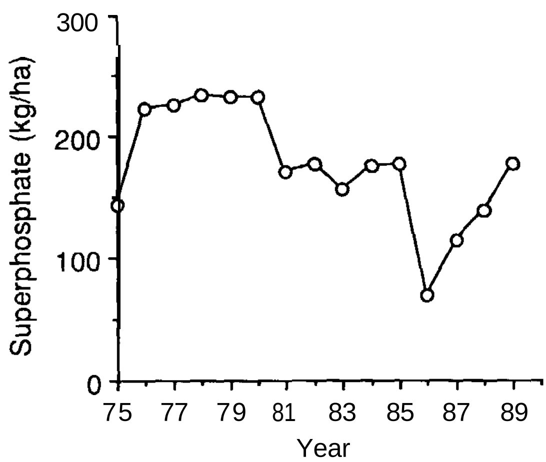

Figure 3 Average phosphate we on surveyed class 4 farms from NZMWBES (measured as superphosphate equivalents).

Evaluating **fertiliser strategies**

The on-farm usefulness of any index of soil fertility lies in its ability to predict changes in pasture yield in response to intended fertiliser strategy. The current MAF Soil Fertility Service models calculate the amount of fertiliser to maintain soil P status using a balance sheet approach. The Olsen P test is used to predict soil P status and relative yield in the past season. Modifying factors and potential carrying capacity are used to estimate fertiliser requirements for different stocking rates and pasture utilisation.

The Fertiliser index approach differs in that the consequences of a planned fertiliser strategy affect the Fertiliser index directly and are in turn reflected in relative pasture yield responses. Predicted changes in relative yield can be incorporated into an analysis of the economics of fertiliser use given fertiliser history, current stocking rate, returns per stockunit and fertiliser cost. For example, if a farm has an initial Fertiliser Index of 1400 then predicted pasture yield is currently 70% ofmaximum. Tomaintain this yield wouldrequire annual inputs of 210 kg super/ha, that is 15% of 1400. Ceasing topdressing for five years would give a reduction in Fertiliser Index to 620 and pasture yield to 54% of maximum. The short term saving in fertiliser can becompared with thelossinproduction toestimate the economics of this strategy. The cost of recovering would be the cost of maintaining yield at 54% of maximum (93 kg super/ha) plus a capital dressing of 780 kg super/ha.

The model can also be used to predict long run economic optimumpasture yields though there may be reasons for farmers to select a lower production level.

The direct and dynamic link in the Fertiliser index approach between soil P status, intended fertiliser use and relative pasture yield is an advantage in the application of this model to aid decision making. This type of link could be built into existing Olsen Pdriven models.

Industry predictions

The Fertiliser index model has potential uses beyond the farm gate estimating output consequences of industry fertiliser use. Given figures for average fertiliser history of a group of farms we can estimate current relative pasture yield. This provides the basis for estimating pasture production responses to future fertiliser inputs. Predicted changes inrelativepasture yield can in turn be used to indicate changes in livestock output.

MWBES figures for fertiliser use on Class 4 hill country indicate a current relative pasture yield of 63%, using the Fertiliser index for Ballantrae. This supports 20 million stock units (MWBES 1990). At constant annual inputs of 100 kg/ha of super-phosphate the model predicts that relative pasture yield will drop to 55% inside 10 years. If stock numbers drop in proportion, then there will be a decrease of 2.5 million stock units.

The model indicates that current production levels are still being influenced by thehigherrates of fertiliser applied in the 1976-85 period (200 kg/ha/yr). As the effect of these applications diminishes, production levels will fall into line with the level of more recent fertiliser use (125 kg/ha/yr of superphosphate equivalent in 1986-1989).

Discussion

The current Fertiliser index is based on superphosphate use. Different sites give different calibration curves. A limitation of the approach is that extrapolation beyond empirically fitted data points is dangerous. Part of the reason for differences in the estimate of RY_o between Whatawhata and other sites could be due to a lack of data for very low fertiliser indices at Whatawhata. Some of the differences between site calibrations may, however, be related to soil type influencing sulphurresponsiveness or the effect of climate on sulphur status or legume content. Interestingly, the discount factor which represents the rate at which P is lost from the system can be considered to be relatively constant between sites despite differences in soil parent material from volcanic ash (Whatawhata) to sedimentary (Ballantrae and Win&more).

The index has accounted for situations where superphosphate has been both withheld and re-applied after long periods of withholding (Winchmore). The caveat that must be stated, however, is that in the re-application treatment at Winchmore, pasture composition was upgraded by overdrilling at the time of re-application. Where pasture composition deteriorates under withholding, responses to re-application may not be as rapid as suggested by the index if some form of reseeding is not practised. This needs further experimental verification.

The nutrient index approach appears to offer encouragement as a means ofpredicting relative pasture production. The concept of discounting may be usefully applied to sulphur or potassium fertilisers or to other phosphate fertilisers. Obtaining calibration curves between nutrient index and relative pasture yield will require data from a comprehensive series of trials, where preferably both non-limiting and zero fertiliser treatments exist. Data from New Zealand trials are currently being collated in a common database (Edmeadespers. comm.) which we hope will besuitable for exploring these possibilities.

Conclusions

The Fertiliser index approach shows promise as a means of predicting relative pasture yield from fertiliser history under New Zealand conditions. It gaveabetterprediction of relative yield than Olsen P at sites where S responses were implicated in the response to superphosphate and was of similar accuracy to Whatawhata where a S response has not occurred.

The usefulness of the two methods of predicting relative pasture yield also depends on measurement errors of the predictor. In the case of Olsen P these arise due to sampling variation. In the case of the Fertiliser index imperfect knowledge of fertiliser history may lead to errors. While there is little difference in sensitivity to input errors between predictors, there may be more scope to reduce measurement errors in the calculation of Fertiliser index than inmeasurement of Olsen P.

The major feature of the Fertiliser index approach is the way in which it facilitates economic analysis of alternate fertiliser strategies. Fertiliser decisions are reflected directly in the index and in relative pasture yield predictions. The approach also has applicability in analysing farm production trends at the regional level.

Finally we speculate that the discount procedure in the Fertiliser index may be usefully applied to other nutrients. However further work is required to calibrate the index model to a wider range of data sets on varying soil types.

ACKNOWLEDGEMENTS

To Bay of Plenty Fertiliser Co., for financial assistance. To Tim Johnston and Steve McBride for technical discussion; Tony Pleasants and Barbara Dow for assistance in model fitting.

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