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Optimal selection of fertilisers by horticultural consultants

A thesis presented in partial fulfilment of
the requirements for the degree of
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Agricultural Systems and Management
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Abstract

Horticultural consultants recommending fertilisers must consider a large amount of information to determine an optimal fertiliser mix. Difficulty arises when matching the estimated levels of nutrient requirements with those available in fertiliser products, as it is unlikely a single, or combination, of fertilisers will match exactly the required nutrients. It is assumed that consultants are proficient at making fertiliser recommendations, but desire to improve the process of making, and accuracy of, the recommendations. The objectives of this study were to describe the process consultants go through when providing a fertiliser recommendation and then use this information to design a decision support system (DSS) as an aid to the fertiliser selection process.

Data was collected from three consultants to develop a conceptual model of how the fertiliser recommendation service consultants provide operates. With this information a DSS model consisting of client and fertiliser databases, an optimisation component and an user interface was developed. The optimisation component uses a compromise programming approach. The objective function minimises the deviations from the targets of a cost goal and nutrient requirement goals.

The DSS was run using samples provided by the consultants and the results were compared with what they had recommended. Even though the results from the DSS model did not match exactly what the consultant had recommended, most of the DSS solutions were cheaper and weighed less. The information generated provides a good starting point from which to make a fertiliser mix recommendation by combining other factors such as pH and solubility of each fertiliser, and other rules of thumb that consultants use.

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Chapter 1

Introduction

1.1. Nutrient use in horticulture

Many New Zealand soils have a low nutrient status in their natural state and are often deficient in one or more essential plant nutrients (McLaren & Cameron, 1986). Thus site selection of horticultural enterprises should be primarily based on soil versatility rather than on fertility as it is easier to enhance a soils nutrient status than to alter its physical characteristics required to improve versatility. After developing land for horticultural use fertiliser application can change the soils nutrient status considerably over time and if performed correctly can increase the soils suitability for growing plants. Fertilisers are, therefore, an important aspect of land management as they are involved in both improving and maintaining soil fertility.

The nutrients that plants require can become unavailable in ways such as the incorporation into plant products, leaching, adsorption by the soil, and volatilisation. Generally nutrients are lost from the soil environment because they have been transported to another area, for example, the harvesting of fruit or pruning removes the nutrients accumulated in these products. Free draining soils are prone to nutrient loss from leaching and of the macronutrients, phosphates leach the slowest and nitrates the fastest (Clark et al., 1986). Fertiliser nutrients are also rendered temporarily unavailable to plants if they are strongly adsorbed by soil particles or incorporated into the organic matter of the soils (Clark et al., 1986). The gaseous loss of nitrogen - volatilisation - can occur whenever there is free ammonia present in the soil surface, for example, following the application of urea or ammonium fertiliser (McLaren & Cameron, 1986). Each of these processes vary between soil types and differ according to climatic conditions. It is, therefore, important to have an understanding about the relationships between the soil and the processes that take place within it. This understanding of the soil system will aid with the estimation of replacement nutrient levels.

1.2. Estimating nutrient requirements

The number of nutrients included in tests when determining the nutrient requirements for a specific crop is generally greater for a horticultural enterprise than for a farm. The frequency of nutrient testing is also usually greater for horticulture than other forms of agriculture. For example, a market garden may test nutrient levels before planting each crop, an orchard may test once or twice a year, while a farm may only test nutrient levels every two to five years. In horticultural enterprises the number of tests conducted on a per unit area is also higher. This more intensive testing increases cost, although this is somewhat offset by the higher value of the crop, on a per unit area basis.

The availability of nutrients for plant uptake can influence both crop quality and quantity. The quality of the crop (e.g., whether there are blemishes on a piece of fruit) is an important factor in determining its value. Therefore, when determining nutrient recommendations the effect the nutrient may have in crop quality needs bearing in mind. Since different crops have different nutrient requirements different optimal levels will exist for each crop and due to changes in the environment the optimal level will also vary from year to year. For optimal growth nutrients availability needs maintaining within a preferred range. If nutrient levels fall outside of this range then crop yield will tend to decrease when nutrient levels are too low then, while if levels are too high then the plant may be damaged and also decrease yield.

There are several methods of assessing the nutrient availability and nutrient requirements of soil; these include, pot and field trials, soil analysis, plant analysis, and fertiliser models.

Pot trials and field trials involve applying a range of fertiliser rates to individual pots or field trials and measuring the change in yield at each rate. Currently there is a lack of detailed information from fertiliser trials regarding the quantity of the fertiliser needed to maintain production for the range of crops, soil types and climates within New Zealand (Clark et al., 1986). Although pot and field trials are time consuming and expensive, they are essential for the development and calibration of soil tests and plant analysis (McLaren & Cameron, 1986).

Soil tests involve the collection of soil samples for analysis to determine their nutrient content. Along with nutrient levels soil test results also provide information such as

the soils cation exchange capacity, base saturation and bulk density. These measurements reflect the soil's texture and capacity for nutrient absorption (Yates, 1989). Soil tests need calibrating because the readily available nutrients that soil tests quantify represent only a small fraction of nutrients within the soil environment (McLaren and Cameron, 1986). Currently there lacks a suitable chemical extractant to enable the calculation of the bulk store of nutrients. Clark et al. (1986) state that there is little definitive information available on the optimum soil test values for most horticultural crops grown in New Zealand. Clark et al., therefore, suggest that in the absence of well defined target values for each nutrient, the presence of healthy high yielding plants should be a guide as to whether or not soil conditions are optimal for growth. They also suggest that annual soil tests provide a qualitative guide and should be carried out with the aim of monitoring and correcting trends in nutrient values rather than being in pursuit of attaining particular soil test values.

The effect of plant nutrition on plant yield forms the basis of plant analysis. Reducing a nutrient deficiency increases yield until the critical nutrient level is reached. At the critical nutrient level yield no longer increases, even though the amount of nutrient in the plant still increases (McLaren & Cameron, 1986). The advantage of plant analysis is that results reflect the nutrient availability of the plants full rooting depth, whereas the depths of soil tests are restricted (McLaren & Cameron, 1986).

Models are often used to combine data from a range of sources in an effort to estimate the nutrient requirements for a soil. These models are based on the inputs (e.g., fertiliser) and outputs (e.g., leaching and harvested crop) of nutrients. These models usually assume that the sizes of the nutrient cycling pools remain constant and therefore, fertilisers are only required to replace the nutrients that are permanently lost from the cycle (McLaren & Cameron, 1986). Example of a nutrient models used in New Zealand include the Kiwifruit Nutrition Management Service (KNMS) (Buwalda & Smith, 1988) provided by several Agriculture New Zealand consultants in conjunction with Hort Research and Outlook developed by the Soil Fertility Service of AgResearch (Barton, 1995).

Although the KNMS model is still in use today by some consultants much of its validity has been discredited. A review of the model was commissioned by the New Zealand Kiwifruit Marketing Board in 1991 with the aim of examining the validity of

the KNMS model (Bollard, 1991). The model was criticised for high levels of nutrients, namely nitrogen, which it suggested. Smith, Buwalda, Clark and Walton (1990) stated that the fruit production of mature vines is directly related to the size of the canopy, and therefore, the greater the size of the vine due to nitrogen inputs, the greater the fruit yield. However, as Sher and Yates (1992) point out, this ignores the undesirable interactions of vine growth driven by nitrogen upon inter-canopy shading, subsequent unfruitfulness, fruit size and quality.

The results that describe the nutrient requirements from the assessment methods described still only provide an estimate rather than an explicit list of the quantities of each nutrient required. In the past pot and field trials have been used as the basis of calculating optimum economic nutrient inputs (During, 1984). In calculating the optimum economic nutrient inputs nutrient requirements should aim to maximise the return to the grower rather than trying to attain maximum yield. Therefore, the optimal nutrient requirements will change with crop and fertiliser prices. Determining the effect that changing nutrient rates will have on crop returns requires knowledge of the relationships between plant nutrition and crop yield. This is especially important in horticulture where the quality and appropriate quantity of a crop is affected by crop nutrition (McLaren & Cameron 1986). However, data covering the range of crops and soil types in New Zealand does not exist.

1.3. The attributes affecting fertiliser selection

Following the estimation of the required nutrients, the fertilisers that can provide these nutrients need to be determined. In most situations the choice of fertiliser will depend, not on the need for a single nutrient, but on the need for two or more nutrients. When selecting a fertiliser, or group of fertilisers to meet the nutrient requirements, the literature suggests the following attributes must be considered: nutrient availability, effectiveness, rate of application, and cost, these points are now discussed.

The nutrient availability of a fertiliser refers to the proportion of nutrients within the fertilisers that are available to plants and the rate at which they become available (Clark et al., 1986). The proportions of nutrients within each fertiliser - the essential elements for plant life - are outlined by the manufacturer of the fertiliser, these are usually described as a percentage for macronutrients and by weight for micronutrients.

A soil will be able to support continued plant growth only if the nutrients removed from the soil solution by the plant are rapidly replaced (McLaren & Cameron 1986) from the bulk store of nutrients previously adsorbed by the soil. If a nutrient is held very strongly in the soil it may not replenish in the soil solution quickly enough (Archer, 1988) or alternatively the total amount of the nutrient in the soil may be inadequate. If the nutrients within the fertiliser are water soluble then they are immediately available to plants. However, they are also immediately available to react with and become adsorbed by soil particles or be leached out of the rootzone (Clark et al. 1986). For example, under high levels of rainfall or irrigation sulphate and nitrate may suffer substantial leaching losses (McLaren & Cameron 1986), whereas some insoluble nutrients such as nitrogen in organic fertiliser needs releasing through microbial action before it becomes available to plants. The choice of fertiliser may, therefore, depend on the time frame within which the nutrients are required by the plant.

A choice between different fertilisers will often depend on their relative abilities to increase or maintain yields, (i.e. the agronomic effectiveness of the fertiliser). Agronomic effectiveness is usually determined in field experiments by measuring fertiliser response in relation to a standard fertiliser material of known high effectiveness. McLaren and Cameron (1986) state that the agronomic effectiveness of a fertiliser will be determined by its properties (e.g., its solubility and forms of nutrient), and by the soil and climatic conditions in which it is used. A fertiliser that may perform well in one set of conditions may be relatively ineffective in another. Reactive phosphate rock, for example, which may be as good as superphosphate in acid soils, gives very poor responses on well-limed soils.

Comparing the cost of fertiliser is based on the cost per kilogram of nutrient within the fertiliser, rather than on the cost per tonne or kilogram of fertiliser. In addition to the basic cost of the fertiliser the costs of transport and spreading needs considering. The higher the concentration of the nutrient in the fertiliser, the less the weight of the fertiliser required to give the desired application rate, which, therefore, lowers the cost of transport and spreading (McLaren & Cameron, 1986). The application rate, the quantity of fertiliser to apply on an area basis, is derived from the estimate of the nutrient requirement and the percentage of plant available nutrient in the fertiliser.

1.4. Problem Statement

Although fertiliser expenditure is only a small expense within the budget (e.g., approximately 3% for a kiwifruit orchard (Oliver & Burt, 1995)), fertiliser use can have far reaching effects on yield quantity and quality and, therefore, returns to the grower. The effective use of fertiliser will improve the soil's suitability for growing crops. However, ineffective fertiliser use leads to an inappropriate application of nutrients, which can both damage the environment and reduce returns to the grower. A lack of the required nutrients can lead to a reduction in crop quantity. The use of fertilisers containing nutrients that are not required can cause an excessive build-up of a nutrient, which may damage the plant and is likely to leach from the soil into the waterways. Incorrect timing of the fertiliser application and uneven spreading can be detrimental to the crop and the environment. The budget for the enterprise will reflect the cost associated with incorrect fertiliser usage through reduced crop returns, higher than required fertiliser costs, or payments for fixing damage to the environment.

Fertiliser recommendations typically begin with the testing of soil and, or leaf samples. The samples are analysed and the results provide an estimate of the nutrient status of the sample. The grower's consultant then makes an estimate of the nutrient requirements and the fertilisers to use to replenish the nutrient loss.

The literature suggests that when selecting fertilisers to meet a set of nutrient requirements the attributes that describe the fertiliser need considering. The proportions of each nutrient in the fertilisers and their availability to plants provide a basis for calculating the application rate and comparative costs of each nutrient in the fertilisers. Solubility of the fertilisers gives an indication of how soon after application the plants will be able to utilise the nutrients. If there are any constraints such as handling and spreading requirements of particular fertilisers a grower must ensure that they have the means to overcome the constraints if they wish to use the particular fertilisers.

There is a monetary cost associated with inappropriate fertiliser selection. A fertiliser used within the wrong soil or climatic conditions may be ineffective, for example, in dry conditions sulphate is likely to be more effective than elemental sulphur, while in wet conditions the reverse may be true (McLaren & Cameron, 1986). Where fertilisers are very soluble an excessive application could lead to leaching, damage to

the environment and the need to apply further fertiliser to still meet the nutrient requirements. If the nutrient availability is too slow to meet the nutrient requirements then the plant yield or quality may be reduced, leading to a lower return to the grower.

Consultants recommending fertilisers must consider a large amount of information to make an optimal selection. However, difficulty arises when matching the required nutrient levels with those available in fertiliser products, as it is unlikely that a single product or a combination of fertilisers will exactly match the ratios of nutrients required. It seems that fertiliser consultants currently make decisions regarding fertiliser using an estimate of the required nutrients in conjunction with their personal knowledge such as previous fertiliser application, crop performance, and fertiliser attributes. This is unlikely to result in the optimal fertiliser selection either in terms of nutrient needs or cost.

1.5. Objectives

The first objective of this study is to describe the process consultants go through when providing a fertiliser recommendation. The second objective involves using the data gathered from the first objective and incorporating this into the design of a decision support system that has the ability to aid the consultant in the fertiliser selection process. The objectives are as follows:

To model the process a consultant uses to make fertiliser recommendations.

To design a decision support system that a consultant could use as an aid in the fertiliser selection process by providing an optimal combination of fertilisers.

The people involved in making many of the recommendations as to which nutrients and fertilisers to apply are consultants acting on behalf of growers. It is assumed that consultants are proficient at making fertiliser recommendations, but that they desire to improve the process for making, and the accuracy of, recommendations. Consultants in the horticultural sector are the focus of this study, and they are likely to be the primary benefactors of this research.

An understanding of the current methods consultants use to make their fertiliser selection recommendations is essential for finding ways to improve the process.

Although the literature studied in this chapter suggests how to select fertiliser this may not reflect how consultants actually perform this task. Qualitative research methods are employed for gathering and analysing the data that describes the fertiliser selection process from the consultants. This technique is used in this study because the data is informal, unstructured and subjective.

The decision support system designed in this study aims to improve the selection of fertilisers by matching nutrient requirements with a combination of fertilisers.

Describing the consultant's fertiliser selection process provides a starting point for creating the decision support system. Interviews with the consultants will also allow them to identify areas that they consider need improvement, then these concepts can be implemented within the decision support system.

1.6. Organisation of the chapters

An introduction to fertiliser use in horticulture, estimating nutrient requirements, and the attributes affecting fertiliser have been discussed in this chapter. The role of consultants and how this study aims to improve the current fertiliser selection process was described and the objectives of the study were presented.

In Chapter Two the fertiliser selection process of three consultants is studied. The benefits of studying the process are described. Qualitative research methods are used for studying the consultants. The literature about qualitative data collection and analysis is discussed and the method for this study described. The results are discussed and the fertiliser selection process is presented.

Chapter Three consists of a description of a decision support system that represents the part of the consultant's fertiliser selection process that will be developed as a computer program. The part of the process that the conceptual model focuses on is that of converting nutrient requirements into fertiliser mix combinations. Each of the model components of the are described.

In Chapter Four optimisation techniques (such as linear programming, goal programming and compromise programming) are discussed with regard to optimisation theory and examples of it's application from the mathematical programming and multiple criteria decision making literature. The equations and the optimisation method this study uses are then presented and discussed.

The need for a database in the computer model is explored in Chapter Five. The structure of the database for the model is presented as an entity-relationship model and then its components are discussed.

The purpose of Chapter Six is to describe the implementation and evaluation of the prototype decision support system. The results from an evaluation of the optimisation routine are presented and then discussed.

Conclusions and recommendations are presented in Chapter Seven.

1.7. References

Archer, A. (1988). Crop nutrition and fertiliser use (2nd ed.). Suffolk: Farming

Barton, D. (1995). New fertiliser software a first. Evening Standard, February 21, pp 14.

Bollard, E. G. (1991). A review of some aspects of the nutrition of kiwifruit. NZKMB special report.

Buwalda, J. G. & Smith, G. S. (1988). A mathematical model for predicting annual fertiliser requirements for kiwifruit vines. Scintica Horticulturae, 37(1/2), 71-86.

Clark, C. J., Smith, G. S., Prasad, M., & Cornforth, I. S. (Eds.). (1986). Fertiliser recommendations for horticultural crops. Wellington: New Zealand Ministry of Agriculture and Fisheries.

During, C. (1984). Fertilisers and soils in New Zealand farming. Wellington: Government Printer.

McLaren, R. G. & Cameron, K. C. (1986). Soil science: an introduction to the properties and management of New Zealand soils. Auckland: Oxford.

Oliver, J. R. & Burt, E. S. (Eds.) (1995). Financial budget manual 1995. Canterbury: Lincoln University.

Yates, P. (1989). Kiwifruit: Computers and controversy. Horticulture News, September, pp 12-14.

