CHAPTER 1

INTRODUCTION

Plant nutrient management plays a vital role in the success or failure of modern lucerne (*Medicago sativa* L.) production. In South Africa, lucerne is produced under a wide range of climatic conditions, under dryland and irrigation. In the warmer regions, lucerne is produced throughout the year, which means that there is a continuous demand for nutrients under a wide range of environmental conditions. According to Fick, Holt and Lugg (1988), the lucerne crop usually shows a response to wide variety of environmental conditions, which also depends on factors such as the age, growth stage, prior condition and genotype of the crop.

There are several factors affecting the nutrient requirements of lucerne of which yield, cutting schedule, climate and management are the most important (Lanyon & Griffith, 1988). Studies show that there is a substantial increase in yield in response to nutrient applications and therefore nutrient requirement increase with increased yields.

Rhykerd and Overdahl (1972), found that the production of high-yielding lucerne removes much larger amounts of nutrients from the soil than grain crops such as maize or wheat. Thus, to obtain high yield levels, soil fertility status and plant nutrient concentrations must be monitored and adjusted to assure adequate nutrient availability. Lucerne has a high requirement for nutrient elements such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S). Essential micronutrient elements are, *inter alia* boron (B) and molybdenum (Mo). Of these elements N is obtained by symbiosis with certain N fixing bacteria, if conditions are ideal, and do not have to be supplemented.

The second factor that influence nutrient uptake is the cutting schedule. A close relationship exists between lucerne maturity and nutrient concentration. Lucerne is harvested at vegetative to early reproductive growth stages in high-yielding systems. When lucerne is harvested at a less mature growth stage, such as full bud rather than 10% blossom, the leaf-stem ratio is higher with a consistent increase in the concentration of P, K, Ca and Mg in the dry material.

A third factor that influences the nutrient uptake of lucerne is climate. Temperature, light intensity, rainfall patterns and day-length change within and among the harvest intervals of the production year. The variation in environmental conditions will influence nutrient concentrations in forage, because of changes in rate of dry matter production, ion movement in the soil, root activity and the uptake of nutrients by the plant.

The fourth factor that influences the nutrient uptake of lucerne is the management practices. Successful lucerne stands are obtained on deep, well-drained soils with $pH(H_2O) = 6.2 - 7.8$, P(Bray 1) ≥ 25 $mg.kg^{-1}$, K ≥ 80 $mg.kg^{-1}$, Ca ≥ 600 $mg.kg^{-1}$ and Mg ≥ 600 $mg.kg^{-1}$ (Fertilizer Society of South Africa, 1991).

Fertilizer recommendations will therefore depend on factors such as yield, cutting schedule and the soil nutrient status. The precision of statements that can be made about soil properties at any location depends largely on the amount of variation within the area sampled. Spatial and temporal variation of soil properties causes uncertainty in agricultural decision-making, but this variation is manageable if it is significant, controllable and predictable (Cook & Bramley, 2000). Traditionally, spatial variation is managed by grouping properties together in seemingly homogeneous units and assuming variability within the units to be purely random or uncorrelated. It also assumes that the sample mean is the best estimate of a soil property at any location within the sampling areas. The precision of these properties is characterized by parameters such as variance, standard error and confidence limits. The classical approach, however, takes no account of spatial correlation and the relative positions of sampling points. This results in the field being managed uniformly for activities such as sowing and fertilizer application, ignoring the soil spatial variability and hence the site-specific crop requirement (McBratney & Pringle, 1997). Site-specific management, unfortunately, requires a large investment in collecting the data required to make informed decisions at this scale, and prohibits the adoption of such an intensive management programme. Today, however, the spatial variation within a field can be managed with the use of geostatistical techniques. Soil scientists are restricted to limited observations, necessitating interpolation to estimate values at unsampled locations. The precision of such interpolations is strongly influenced by the variability of soil both within sampling units and between locations (Trangmar, Yost & Uehara, 1985).

Conceptually, geostatistics offers an alternative approach in that spatial correlations are quantified, and estimates for a property at an unsampled location principally determined by measurements made close by, rather that assuming a class or plot average (Warrick, Myers & Nielsen, 1986; Di, Trangmar & Kemp, 1989) and thus, managing the spatial variation within a field to ensure cost effective management practices and the optimal use of resources. Based on the premise that the spatial variability of crop yield is influenced by spatial variability in soil factors at a similar scale, researchers have begun to examine the patterns observed in crop yield maps to identify potential management zones within a field as well as to improve sampling scheme designs (Stafford, Ambler, Lark & Catt, 1996; Venter, Beukes, Claassens & Van Meirvenne, 2003a; Frogbrook, Oliver, Salahi & Ellis, 2002). According to Boydell and McBratney (2002), stable yield zone patterns can be identified by using multi-seasonal yield maps.

Historically, the methodology for geostatistics began in mining engineering for assessment of ore bodies in South Africa by D. G. Krige, after whom "kriging" is named. The earlier development of techniques was for the application of very practical problems, for example to optimize the selection of blocks of ore to be processed on a sliding economic scale according to market price of the end product. Some of the terminology that is still in use originated from the South African gold mining industry like sill, range and nugget. The latter refers to the analogy where a pure gold nugget exists and at any finite distance away a much lower concentration is found. Dimensionally, applications of geostatistics could be for distances of a few molecules or kilometers.

A review of applications of geostatistics in soil science has been given by Warrick *et al*. (1986) and covers a number of soil properties like soil pH, organic C, electrical conductivity, sand content, water retention and soil temperature. Another application of geostatistics is in precision agriculture where the aim is to match "resource application and agronomic practices with soil attributes and crop requirements as they vary across a site". In their paper, McBratney & Pringle

(1997) discuss geostatistical methods to assess spatial variation of soil with reference to the implications for precision agriculture.

Some work has been done to evaluate the use of geostatistics in the design of agricultural field experiments (Dulaney *et al.,* 1994; Van Es *et al.,* 1989; Fagroud & Van Meirvenne, 2002). Dulaney *et al.* (1994), stated that geostatistical techniques have the potential to provide better field characterization, improve plot layout, increase the power of the consequential statistical techniques and can be used to select an optimal sampling strategy for characterization of soil spatial variability at the experimental field site. This is relevant because the costs associated with conducting long-term agricultural experiments make it imperative to obtain at least some level of assurance that the data used to establish field trials are precise enough for its intended purpose.

Agricultural researchers have long understood that the effect of locality, which is often caused by natural soil variability, or previous land-use practices, can significantly reduce the ability to detect experimental treatment differences (Dulaney, Lengnick & Hart, 1994). Present-day agronomic research has reached a point where the treatment effects being tested are small and the degree of accuracy required in such studies cannot easily be obtained with conventional experimental designs (Van Es, Van Es & Cassel, 1989). It is therefore imperative to establish a high level of experimental precision.

The adverse effects stemming from soil heterogeneity can be addressed by (1) conducting the study on uniform land, or (2) controlling the effects of soil variability through experimental design and improved statistical analysis in order to better account for the effect of field variability on experimental results (Van Es *et al.*, 1989). The latter measure includes replication, blocking, randomization, row-and-column designs and methods such as nearest neighbour and trend analysis. In general, such methods improve the detection of treatment effects, although improper block layout may actually adversely affect the analysis of experiments (Van Es & Van Es, 1993). In the presence of a significant spatial correlation over small distances, the assumption of independence between plots is violated and the researcher may be faced with contradictory results. The latter can result in clear differences in crop yields between experimental plots but no significant treatment effect (Fagroud & Van Meirvenne, 2002).

The objectives of this study were to:

- Examine the effects of spatial variation of certain soil properties on the winter yield of a lucerne stand.
- Explore the spatial relations between nutrient uptake of lucerne and soil properties.
- Investigate the temporal and spatial relations of nutrient uptake and yield of lucerne.
- Examine the spatial variation of soil and plant properties and its effects on the statistical design of a field experiment.