RESEARCH SUB-PROGRAM

Variable Rate Technology For N Fertilizer Application

October 1997

COESA Report No.: RES/FARM-005/97

Prepared by: Dr. Gary Kachanoski and Peter von Bertoldi,
Dept. Land Resource Science, University of Guelph,
Guelph, Ontario N1G 2W1

On behalf of: Research Branch, Agriculture and Agri-Food Canada,
Pest Management Research Centre (London)
1391 Sandford St.
London, Ontario N5V 4T3

Disclaimer: *The views contained herein do not necessarily reflect the view of the Government of Canada, nor the Green Plan Research Sub-Program Management Committee*

FORWARD

This report is one of a series of **COESA** (Canada-Ontario Environmental Sustainability Accord) reports from the Research Sub-Program of the Canada-Ontario Green Plan. The **GREEN PLAN** agreement, signed Sept. 21, 1992, is an equally-shared Canada-Ontario program totalling $64.2 M, to be delivered over a five-year period starting April 1, 1992 and ending March 31, 1997. It is designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Federal component will be delivered by Agriculture and Agrifood Canada and the Ontario component will be delivered by the Ontario Ministry of Agriculture and Food and Rural Assistance.

From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. **Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes** through land application, with emphasis on water quality implications
    - **A.** Animal Manure Management (nutrients and bacteria)
    - **B.** Biodegradable organic urban waste application on agricultural lands (closed loop recycling) (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)

2. **On-Farm Research**: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)

3. **Development of an integrated monitoring capability** to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

The original level of funding for the research component was $9,700,000 through Mar. 31, 1997. Projects will be carried out by Agriculture and Agri-Food Canada, universities, colleges or private sector agencies including farm groups.

This Research Sub-Program is being managed by the Pest Management Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford St., London, ONT. N5V 4T3.

Dr. Bruce T. Bowman, Scientific Authority
E-Mail: bowmanb@em.agr.ca

Green Plan Web URL: http://res.agr.ca/lond/gp/gphompag.html

The following report, approved by the Research Management Team, is reproduced in its entirety as received from the contractor, designated on the previous page.

TABLE OF CONTENTS

Variable Rate Technology For N Fertilizer Application

Dr. Gary Kachanoski and Peter von Bertoldi, Dept. Land Resource Science
Univ. of Guelph, Guelph, Ont. N1G 2W1

1. Executive Summary

The goal of the study is to determine the feasibility of variable rate technology for N fertilizer application, to maximize economic crop response while minimizing environmental impacts on water quality. Specific objectives include (1) To assess different methods of obtaining the field map for variable application N of fertilizer, (2) Determine the economic benefits of variable application of N fertilizers, and (3) Determine the change in potential nitrate loading to the groundwater from variably applying N fertilizer. Two sites were established in the spring of 1993 in Huron Co. near Londesboro, Ontario on the farm of Bruce Shillinglaw. Each site consisted of 4 adjacent blocks of no-till planted corn. Each block consisted of 2 treatments; (1) Fertilizer added (F) at 160 kg N ha^{-1}, and (2) No fertilizer N added (NF). Each treatment was 8 rows of corn with 75 cm row spacing and a length of approximately 325 m. Spatial patterns of yield with fertilizer added and yield with no fertilizer were obtained from detailed hand harvesting (approx. 250 hand yield samples per field). Yield patterns were also obtained using a commercial on-the-go yield sensor attached to a combine. Soil cores were taken in a dense grid from each field to obtain the spatial pattern of the soil N test. Extensive soil sampling to a 90 cm depth was also carried out in the fall period to obtain the spatial patterns of residual mineral soil N, and the subsequent loss of N by leaching. All of the instrumentation and sampling was referenced to a detailed elevation map of the site obtained from a detailed survey of each site. The data from the year of results was used in the second year to construct two variable rate maps for fertilizer N application for each of the two field sites (S1, S2). The 2 variable rate maps were based on 1) the N soil test and 2) a differential yield map (fertilizer yield - check yield). Thus, in 1994 each of the two field sites had N fertilizer rate treatments consisting of: check (0 Kg N ha^{-1}), constant rate at 150 Kg N ha^{-1}, variable rate from soil test prediction, and variable rate from the differential yield map. In 1995 the site was planted to soybeans and hand sampled yields were taken in representative areas to examine any carry-forward influences from the variable N treatments. In 1996 the site was seeded to barley and fertilizer applied (67 kg N ha^{-1}) in the original blocks that had fertilizer in 1993. Hand sampled yields were taken in the same locations as in 1993. Throughout the study soil samples were taken to examine the influence of the fertilizer treatments on soil N storage and losses. Soil solution samplers were installed to measure the concentration of nitrate in drainage water. Major findings of the study are:

A yield map based on one fertilizer N application rate is not enough information to determine the spatial pattern of N application for site specific management.

A new yield index called the Delta yield) Y_F was developed to estimate the spatial pattern of N fertilizer response. It is based on the difference between yield with and without fertilizer N.

Yield measurements with an on-the-go combine monitor were significantly correlated to hand yield measurements, but the monitors may not be accurate enough to estimate) Y_F. Robust spatial interpolation methods are needed for yield monitor data.

Site specific application based on) Y_F used 40 \$ ha^{-1} less N fertilizer, but resulted in a decrease in crop yield valued at 36 \$ ha^{-1}. Application based on soil test used 63 \$ ha^{-1} less N fertilizer, but lost 92 \$ ha^{-1} from crop yield decline.

The soil N test map did not stay constant with time. The) Y_F pattern was quite constant and 1996) Y_F values for barley were similar to 1994) Y_F values for corn.

Variable N application significantly decreased subsequent soybean yields in areas with low or no fertilizer N. This cost must be incorporated into economic models of site specific management.

Constant fertilizer application resulted in nitrate in drainage water that exceeded the Ontario drinking water objectives. However, at one site the water standards were exceeded where no fertilizer N was applied. Drainage losses increased in sites with high spatial variability.

Fertilizer N applied using site specific methods was used more efficiently by the crop compared to constant fertilizer N application. Drainage N losses were reduced with site specific N application proportional to the decrease in average fertilizer N applied.

The) Y_F relationship with recommended N and the spatial patterns of) Y_F measured at the two study sites indicate it may be better to only vary N application for major changes in N requirements. A simple 3-rate (0 %, 50 %, 100 % of recommended) fertilizer N applicator was built.

Sommaire

L'étude avait pour but d'évaluer l'utilisation de la technologie d'épandage à taux variable d'engrais azotés afin de maximiser le rendement des cultures de grande importance économique tout en réduisant le plus possible les incidences sur la qualité de l'eau. Voici quels étaient les objectifs particuliers:

1 Évaluer différentes méthodes d'établissement de cartes de terrain pour l'épandage à taux variable d'engrais azotés.
2 Déterminer les avantages économiques de l'épandage à taux variable d'engrais azotés.
3 Déterminer l'effet sur la charge potentielle de nitrate dans les eaux souterraines de l'épandage à taux variable d'engrais azotés.

Deux sites d'étude ont été établis au printemps 1993 à la ferme de Bruce Shillinglaw, près de Londesboro, dans le comté de Huron.

On trouvait à chaque site quatre parcelles adjacentes de maïs planté sans travail du sol. Chaque parcelle a subi deux traitements: 1) l'épandage d'engrais au taux de 160 kg d'azote ha^{-1} (F) et 2) l'absence d'engrais (NF). Dans chaque cas, on étudiait huit rangs de maïs de 325 m de longueur espacés de 75 cm. On a déterminé la configuration spatiale du rendement des parcelles traitées à l'engrais et non traitées par une récolte manuelle minutieuse (environ 250 spécimens récoltés à la main par champ). On a également déterminé la configuration spatiale du rendement à l'aide d'un capteur vendu dans le commerce installé sur une ceuilleuse-batteuse. Pour déterminer la configuration spatiale de la teneur du sol en azote, on a prélevé des carottes à l'intérieur d'une grille à mailles serrées dans chaque champ. De plus, un échantillonnage approfondi du sol jusqu'à 90 cm de profondeur a été effectué en automne pour la détermination de la teneur en azote du sol minéral et la perte ultérieure d'azote par lessivage. Tous les instruments et les échantillonnages ont été mis en référence sur une carte en relief détaillée des sites résultant de levés détaillés.

Les données recueillies la première année ont servi, la deuxième année, à produire deux cartes de taux variable d'épandage d'engrais azotés pour chacun des deux sites (S1 et S2). Ces deux cartes étaient basées sur: 1) la teneur en azote des sols et 2) une carte du rendement différentiel (rendement après utilisation d'engrais - rendement sans engrais). Dès lors, en 1994, chacun des deux sites a fait l'objet des traitements suivants: absence d'engrais (0 kg/ha^{-1} d'azote), épandage d'engrais azoté à un taux constant de 150 kg/ha^{-1} d'azote, épandage à un taux variable établi selon la teneur en azote du sol prévue et épandage à un taux variable établi en fonction de la

carte du rendement différentiel. En 1995, on a planté du soja aux deux sites et mesuré les rendements au moyen d'échantillonnages manuels effectués dans des zones représentatives afin d'évaluer et de reporter les effets des traitements à des taux d'épandage d'azote variables. En 1996, on a planté de l'orge et épandu de l'engrais (à raison de 67 kg/ha^{-1} d'azote) dans les parcelles traitées à l'engrais en 1993. Les échantillonnages manuels servant à la mesure des rendements ont été effectués aux mêmes endroits qu'en 1993. On a prélevé des échantillons de sol tout au long de l'étude afin de déterminer l'influence des traitements à l'engrais sur la rétention et les pertes d'azote. Des échantillonneurs de solutions de sol ont été installés pour la mesure des concentrations de nitrate dans les eaux de drainage.

Points saillants:

- Une carte du rendement basée sur le taux d'épandage d'engrais azoté ne fournit pas assez d'information pour déterminer la configuration spatiale de la teneur en azote du sol pour une gestion propre à un site.
- On a établi un nouvel indice de rendement, appelé rendement delta ( ) YF), pour estimer la configuration spatiale de la réaction à l'engrais azoté. Cet indice est basé sur la différence entre le rendement après traitement à l'engrais azoté et le rendement sans engrais azoté.
- Il existait une corrélation significative entre les mesures du rendement à l'aide du capteur installé sur la cueilleuse-batteuse et les mesures à partir de la récolte manuelle, mais le capteur n'était pas assez précis pour permettre d'estimer le) YF. Des méthodes d'interpolation spatiale robustes sont nécessaires pour la surveillance du rendement.
- L'épandage adapté au site basé sur le) YF réduisait de 40\$ ha^{-1} le coût de l'engrais azoté utilisé, mais se traduisait par une perte de rendement des cultures évaluée à 36\$ ha^{-1}. L'épandage basé sur la teneur en azote du sol réduisait de 63\$ ha^{-1} le coût de l'engrais azoté utilisé, mais entraînait une perte de rendement de 92\$ ha^{-1}.
- La carte basée sur la teneur en azote des sols n'était pas constante dans le temps. En revanche, le) YF est demeuré très constant et les valeurs du rendement dYF en orge en 1996 étaient comparables aux valeurs du) YF en maïs en 1994.
- L'épandage d'engrais azoté à taux variable a réduit considérablement le rendement ultérieur en soja dans les zones où la teneur en azote provenant de l'engrais était faible ou nulle. Cet effet doit être pris en compte dans les modèles économiques de gestion adaptée au site.
- À la suite de traitements constants à l'engrais, la teneur en nitrate des eaux de drainage dépassait la limite correspondant aux objectifs de qualité de l'eau potable en Ontario. Toutefois, à un site, cela s'est produit même en l'absence d'azote provenant d'engrais. Les pertes d'azote dues au drainage augmentaient là où la variabilité spatiale était élevée.

- L'épandage d'engrais azoté par des méthodes adaptées au site assurait un meilleur rendement des cultures que l'épandage constant. Les pertes d'azote dues au drainage étaient réduites lorsque l'épandage d'engrais azoté adapté au site était proportionnel à la baisse de la quantité moyenne d'azote utilisée.
- Le rapport entre le) YF d'une part et la teneur en azote recommandée et la configuration spatiale du YF mesurée aux deux sites d'étude d'autre part montre qu'il serait peut-être préférable de faire varier le taux d'azote seulement lorsqu'il y a d'importants changements dans les besoins en azote. On a fabriqué un simple épandeur à trois taux d'épandage correspondant à 0, 50 et 100% de la quantité d'azote recommandée.

2. OBJECTIVES

The overall objective of the study is to determine the feasibility of using variable rate technology for N fertilizer application, and to maximize economic crop response while minimizing environmental impacts on water quality. The main objectives include:

1. To assess different methods of obtaining the field map for variable application N of fertilizer,
2. Determine the economic benefits of variable application of N fertilizers,
3. Determine the change in potential nitrate loading to the groundwater from variably applying N fertilizer within a field compared to constant application.

Additional objectives that are examined are,

4. Determine residual effects of variable rate N treatments on subsequent soil N tests the following spring,
5. Determine residual effects of variable rate N treatments on subsequent soybean yields,
6. Compare spatial variations of soybeans and barley yields to spatial patterns of corn yield,
7. Determine if a field map for spatially varying N fertilizer based on corn N response is valid for a different crop (with appropriate changes in absolute amounts), and
8. Evaluate the performance of a variable rate 28 % N applicator.

3. METHODOLOGY

3.1 Site Description

Two main sites (S1, S2) were established in the spring of 1993 in Huron Co. near Londesboro, Ontario on the farm of Bruce Shillinglaw .

The 2 sites were set-up in a similar manner. Each site in 1993 consisted of 4 adjacent blocks planted to corn (Figures 1, 2). Each block was 16 rows of corn wide (12 m) and consisted of 2 treatments; (1) Fertilizer added at 160 kg N ha^{-1}, and (2) No fertilizer N added. Each treatment was 8 rows of corn with 75 cm row spacing. Thus, the sites were each 6 m wide. The monitoring area of the S1 site was 340 m long. The monitoring area of the S2 site was 310 m long. Numbered stakes were placed every 10 m in a transect down the centre of each treatment. The transects were numbered from 1 to 8 from left to right. An electronic marking sond was buried at a 60 cm depth at the start of each transect. At each of the sites a detailed elevation survey was completed using a total station. Elevation measurements were taken on a 10 m x 10 m grid. The detailed elevation maps are referenced to buried marker sonds on the sites. The sonds were geopositioned using a survey grade differential Global Positioning System that is accurate to within 5 cm. A sample of site location and elevation data is given in Appendix 1., including schematics and surface relief maps.

In 1994, the sites were again seeded to corn. Each 1993 treatment (8 corn rows; fertilized, no fertilized) was split into 2 paired sub-treatments of 4 rows each. Each pair had one sub-treatment with a constant rate of fertilizer (150 Kg N ha^{-1}), and the second sub-treatment with one of two different variable rate treatments (see section 3.5).

In 1995, the sites were seeded to soybeans with no treatments other than the residual influences of the previous two years. In 1996, the sites were seeded to barley, and the 4 original blocks established in 1993 were delineated again, and again split into areas with fertilizer applied (67 Kg N ha^{-1}) and no fertilizer applied. The areas receiving fertilizer in 1993 (in corn) were the same areas that received fertilizer in 1996 (in barley). The no fertilizer applied areas were also the same in 1993 and 1996. A summary of the crop management information for the sites is given in Table 1. A composite plot diagram is given in Figures 3 and 4.

3.2 Crop Yield Measurement

Yield measurements were taken using both hand sampling and an on-the-go yield monitor mounted on the combine. Hand yields were taken by harvesting 5 m of the middle two rows of each treatment. In 1993, hand samples were taken every 10 m for each fertilized and unfertilized treatmment, in each of the 4 blocks at both sites. A total of approximately 280 and 256 hand yield samples were taken in 1993 at sites S1and S2, respectively. This provided an even intermeshing grid of fertilized and unfertilized yield values. In 1994, the yield sampling was carried out the same way except that each fertilized and unfertilized treatment had two sub-treatments which were sampled separately. Thus, in 1994 the hand yield sample numbers were double than those in 1993. In 1995, soybean hand yield samples were taken by harvesting 5 m x 2 rows and threshing on-site. In 1996, a plot combine harvester was used to collect barley yield measurements at the exact same locations as the 1993 corn hand yield samples. In 1995, selected treatments were sampled in late July to assess the impact of past fertilizer N treatment on soybean nodulation. Approximately 2-3 plants per location were dug-up by hand, and the roots washed in the laboratory. The nodules were removed, dried and weighed.

The hand harvested corn yields were determined by weighing all of the cobs with a field portable electronic balance, and a subset of 10 cobs were taken for determination of moisture content and shelling percentage. A subsample of the grain corn from each yield measurement was taken and analysed for total % N to calculate an N balance for the site. A sample of the hand harvested yield data (corn, soybeans) and % N, and the plot combine data (barley) along with a description of the data format are given in Appendix 2.

The on-the- go yield monitoring system was contracted with Beltane Agri-Services Ltd. (Bruce Shillinglaw). The system uses an Ag-Leader 2000 yield monitor (Ag-Leader Technologies, Ames, Iowa USA). Briefly, the system is comprised of an impact sensor that measures the mass flow rate of grain through the clean grain elevator. A grain moisture sensor is used to correct for the grain moisture content. These sensors are combined with a dead reckoning system connected to the drive shaft or to a Differential Global Positioning System (DGPS). All of the data (grain flow rate, grain moisture, location and speed) are stored every second in a laptop computer and used to calculate yield as a function of spatial location.

Beltane Agri-services supplied a calibrated, fully instrumented yield monitoring system for the project. In 1993, dead reckoning was used for each of the 8 treatment plots for both sites S1 and S2. Research technicians marked the start and end of each treatment transect. Thus, the data was largely used for testing the yield monitoring device and not the integrated GPS- yield monitoring system. In 1994 and 1995, the complete GPS- yield monitoring system was tested without dead reckoning. A summary of the on-the -go yield data and yield monitoring system used is given in Appendix 3.

3.3 Soil Sampling

In 1993, soil samples were taken to a depth of 30 cm at the time of planting at each site. The samples were taken at each of the numbered stakes (ie every 10 m) in the transects of the unfertilized treatments. This gave a total of 140 and 128 benchmark locations in S1 and S2 respectively. At each benchmark location, a composite soil sample (0-30 cm depth) was obtained from 4 cores taken within 0.25 m of each other, using a 0.5 cm diameter soil probe. The soil samples were analysed for nitrate-N (ie. The soil N test) and ammonium-N. The purpose was to give the spatial pattern of initial soil N requirements as predicted by the soil N test. A second sampling similar to the first was carried out in June 1993 to examine early season changes.

A third set of soil samples were obtained in the early fall (sept.) of 1993. A single soil core (0.5 cm diam.) was taken at most benchmarks (every 10 m) to a depth of 90 cm, in both the fertilized and unfertilized treatments. This totaled approximately 200 locations in each of S1 and S2. The 90 cm cores where sliced into 15 cm increments and again analysed for nitrate and ammonium N. This sample set gave the spatial distribution of the residual mineral N in the root zone, for both the fertilized and unfertilized treatments. Identical soil samplings were carried out in the spring (early May) of 1994. These samples were used to calculate the change in total mineral soil N in early fall and over the winter.

By the end of the 1994 growing season the number of treatments was too large to sample every benchmark in every treatment, particularily the variable rate fertilizer treatment. Thus, in the fall (Oct.) of 1994, selected benchmarks were sampled to a depth of 120 cm to compare residual soil N. A final sampling occurred in spring 1995 to again determine soil test levels. A sample of the soil sampling data is given in Appendix 4.

3.4 Water Quality Measurements

In addition to the sequential soil sampling to determine N leaching losses, additional measurements of the quality of leaching water were made. Porous ceramic solution samplers (2.5 cm diam., 5.0 cm long) were installed at 5 soil landscape positions (crest/shoulder, upper backslope, lower backslope, footslope, and depression) in the fertilized and unfertilized areas, in both S1 and S2 sites. Each landscape position had 6 solution samplers (3 in the row, 3 in the interrrow) at a depth of 80 cm, for a total 60 samplers per site. Soil water samples were taken by applying a vacuum of approximately 0.5 bar for 5 minutes. Samples were taken twice in the fall of 1993 and 7 times spaced throughout the spring and fall of 1994. A sample of the soil solution data and sampling times is summarized in Appendix 5. The locations are shown in Figures 3 and 4.

Average solute transport rates at the 5 landscape positions instrumented with solution samplers were also measured by tracking the movement of a chloride tracer applied in early September, 1993. At each landscape position, directly adjacent to the solution samplers, KCl was added (100 g m^{-2} of Cl) to a 3 m x 3 m plot. The tracer was added on Sept. 27 and Sept. 28, 1993, for the S1 and S2 sites respectively. The sites were sampled in early November and December, 1993 and again in the spring 1994. Each sampling consisted of 4 to 6 soil cores (3.2 cm diam.) taken to a depth of 80 cm. Each core was sliced into 5 cm increments and a composite sample for each increment analysed. A sample of the tracer data is also given in Appendix 5.

3.5 Site Specific N Application

The primary objective of the first year (1993/94) was to obtain the information necessary to predict how N fertilizer might be varied within the test sites in 1994. Two different methods of obtaining the spatial map of fertilizer N were compared. These were (1) a map predicted from the soil sampling (N Test) and (2) a map predicted from the difference in yield with fertilizer Y_F, and check yield Y_c, ie. the Delta Yield method. The procedure for the soil test was obtained from the N test calibration for corn in Ontario (Kachanoski and Beauchamp, 1992).

The 1993 yield maps with fertilizer were subtracted from the yield maps for the same sites without fertilizer. This gave a map of yield increase from applied fertilizer in 1993, $)Y_F = Y_F - Y_c$. This delta yield map was used to obtain an estimate of the map of the optimum fertilizer N requirements, N_R. The Delta yield procedure used a general relationship between $)Y_F$ and N_R (recommended rate) identified by analysis of over 250 plot-yrs of corn N response trials in Ontario. The relationship was approximated by: $N_R = 175 \; (1 - e^{-0.001 \;)YF})$ and is shown in Figure 5. For example, according to equation (1), $)Y_F = 1200$ kg ha^{-1} would give an average recommended fertilizer N rate of 120 kg N ha^{-1}. Note: see section 4.0.

Fertilizer N was applied using a commercially available on-the go variable 28 % N applicator supplied by Beltane Agri-Services. The minimum fertilizer management area was designated as 10 m x 3.2 m wide (4 rows) which is the sampling interval for the hand sampled yields. In 1994, each 10 m x 4 row block of the variable rate treatment areas received a recommended rate from the appropriate map.In the first year, the variable rate equipped 28% N applicator was not linked to a global positioning system. The rates were switched manually on each area because the range of possible rates was not great enough. Subsequent modification of the variable drive system allowed a greater range of N rates to be used. In addition, a very simple 3 rate variable N adapter kit was built in 1996.

4. DELTA YIELD THEORY DEVELOPMENT

The Delta Yield relationship approximated by $N_R = 175 \quad (1 - e^{-0.001\,\Delta YF})$ was used to estimate the 1994 variable N treatments. The relationship is a regression equation that fits an observed relationship between measured economic yield increase and maximum economic N rate. In this section, the theoretical reasons behind the relationship are given. These relationships were developed after the 1994 growing season and expand the application and accuracy of the Delta Yield approach to estimating variable N fertilizer maps. The theory is an unexpected outcome of the study and is the topic of a paper being prepared for publication. However, the theory is best given at this point in the report since it serves as a framework for discussing the results of the field data and the economic analysis. The Delta yield approach is considered important because yield monitors can collect the data necessary to describe the yield distribution in the field in detail. How to apply this data to create the management maps necessary for the application of nitrogen fertilizer remains a subject of debate in research. Of particular concern is that yield is often found to be poorly correlated to soil fertility because of variations among locations attributable to climate and soil. Yield distribution data collected on-the-go from combines will be of little utility to predict fertilizer application rates without a yield index that relates strongly to applied fertilizer.

Consequently, the objectives of this theory development were to examine the shape of the corn yield response curve and different yield indices as predictors of maximum economic rate of nitrogen (MERN), utilizing two large independent historical data sets of corn yield response to applied nitrogen fertilizer from Ontario, and to develop a predictive relationship for MERN based on the most useful of these indices. An examination of the shape of the corn yield response curve would give insight into the choice of yield indices for predicting MERN. To examine the shape of the curve, data from a wide geographical and historical basis should be used, the largest data set available. A 1962-1986 data set of 202 field trials and a 1986-1990 data set of 52 field trials from across Southern Ontario provide data from a wide geographical and historical basis for this purpose. An examination of the shape of the yield response curves from these data sets, and the relationship between various yield indices and MERN, should provide insight into a choice of yield indices for fertilizer nitrogen application from yield monitor collected data.

Data sets from 202 field N response trials conducted across southern Ontario from 1962 to 1986 were obtained from a comprehensive review of nitrogen requirements for corn done by Beauchamp et al. (1987). Beauchamp et al (1987) fit a quadratic polynomial equation to the data from each of the 202 field trials, of the form

$$Y = A + B \cdot N - C \cdot N^2 \qquad \textbf{(1)}$$

where Y= yield, N = rate of applied N fertilizer and A, B and C are coefficients of the quadratic polynomial equation.

The nitrogen rate for maximum yield (N_{max}) and the rate for the most economic yield were obtained by setting the first derivative of equation (1) equal to zero and the price ratio (R), respectively, and then solving for N. The price ratio was taken to be the estimated price of corn per kg divided by the estimated price of nitrogen per kg. In Beauchamp's (1987) review of the yield response data, a price ratio of 0.214 was used. The economic yield (Y_e), and maximum yield (Y_{MAX}) were obtained by setting N = MERN and Nmax, respectively, in equation (1). Economic yield increase over check yield ( ) Y_e) and maximum yield increase over check yield ( ) Y_{MAX}) were obtained by subtracting check yield from Y_e and Y_{MAX}, respectively.

In the present study, the correlation between MERN and the yield indices check yield (Y_c), Y_e, Y_{MAX},) Y_e,) Y_{MAX} was examined to determine the utility of the indices as predictors of MERN.

The data sets were grouped into three classes or regions of origin: Southwestern, Central, and Eastern Ontario. The data set classes were significantly different according to a t test (p = 0.05). In addition, the Southwestern Ontario data class was further subdivided into preplant N applications and sidedress N applications. The four classes of data will be used in this analysis.

Further research on corn yield response to applied N fertilizer was conducted in Ontario, a total of 52 plot years/sites across five years, 1986-1990, in soil ranging from sand to clay, from Eastern to Southwestern Ontario (Kachanoski and Beauchamp, 1990, personal communication).

Fertilizer response data were fit to a quadratic function of the form of equation (1). The MERN was found by taking the first derivative of equation (1) and setting it equal to the price ratio, R and then solving for the N rate at the MERN where

$$MERN \ ' \ \frac{B \ \& \ R}{2 \cdot C} \qquad \textbf{(2)}$$

Note that in this research R was defined as the price per kg of N fertilizer/ price per kg corn grain. This is the inverse of the definition of price ratio used by Beauchamp et al. (1987) in the analysis of the 1962-1986 trials. This definition is used in all further calculations in this paper.

The nitrogen rate for maximum yield (N_{max}) was obtained by setting the first derivative of equation (1) equal to zero and then solving for N. The economic yield (Y_e), and maximum yield (Y_{MAX}) were obtained by setting N = MERN and Nmax, respectively, in equation (1). Economic yield increase over check yield ( ) Y_e) and maximum yield increase over check yield ( ) Y_{MAX}) were obtained by subtracting check yield from Y_e and Y_{MAX}, respectively.

The correlation between MERN and the yield indices check yield (Y_c), Y_e, Y_{MAX},) Y_e,) Y_{MAX} was examined to determine the utility of the indices as predictors of MERN. In the analysis of this data the quadratic equation (1) was chosen because it adequately represented the data and tended to give the highest coefficient of determination (r^2) for the individual data sets (Beauchamp et al., 1987). Beauchamp et al. (1987) also fit a square root and a log model to the data. However, the MERN and Y_e values calculated by each model were highly correlated ($r > 0.9$), thus the trends in the data sets can be interpreted using equation (1).

Y_{MAX} (yield potential) explained only 7.4 %, 0.7 %, 2.2 % and 10.3 % of the variability of the MERN, for the four 1962-1986 data sets, respectively, and only 1.3 % of the variability for the 1986-1990 data set. Y_e was, as expected, related to Y_{MAX} with correlation greater than $r = 0.98$ in three of the 1962-1986 data sets and the 1986-1990 data set and $r = 0.94$ in the fourth 1962-1986 data set. Y_e was approximately 90 to 95 % of Y_{MAX} . However, the relationship between Y_{MAX} and Y_e did not increase the ability to predict the rate of fertilizer required to give the most economic yield. The correlations between Y_e and MERN are as poor as between Y_{MAX} and MERN. Y_e explained only 7.4 %, 0.1 %, 7.7 % and 15.0 % of the variability of the MERN, for the four 1962-1986 data sets, respectively, and 1.5 % of the variability for the 1986-1990 data set.

The poor correlation between the yield indices Y_{MAX} , Y_e and MERN suggests that recommended rates of N fertilizer would not be very well predicted by yield data in either form. However, the data indicated a very strong relationship between yield with no fertilizer, Y_c and MERN. Y_c explained 24.8 %, 56.4 %, 47.3 % and 19.6 % of the variation in the MERN in the 1962-1986 data sets and 51.1 % of the variability in the 1986-1990 data set. In all five data sets, Y_c explained more of the variation in the MERN than did Y_{MAX} or Y_e. This suggests that in Ontario, the nitrogen supplying capacity of the soil is so different from location to location or from one year to the next, that it significantly reduces the usefulness of the indices Y_{MAX} or Y_e as predictors of the MERN.

For other nutrients, actual yields often do not correlate well with soil test results because of variations among locations attributable to climate and soil. In these cases, yield increase over check yield ( ) Y) has been used and had the advantage that direct economic interpretations can be made.) Y_{MAX} explained 77.1 %, 69.8 %, 49.5 % and 56.6 % of the variation in the 1962-1986 data sets and 74.1 % of the variability in the 1986-1990 data set.) Y_e explained 74.7 %, 66.8 %, 49.5 % and 60.6 % of the variation in the 1962-1986 data sets and 73.0 % of the variation in the 1986-1990 data set.

The high correlation between) Y_e ,) Y_{MAX} and the MERN, and the lower correlation of Y_c with Y_{MAX} and Y_e illustrate the poor ability to predict the MERN from only Y_m and Y_e . However,) Y_e ,) Y_{MAX} appear to be reasonable predictive indices of the MERN and would be more useful in interpreting yield response data.

An examination of the overall relationship of yield and applied N fertilizer showed that the B and C coefficients of the quadratic response curves (eq. 1) of the 1962-1986 and 1986-1990 trials were also highly correlated ($r = 0.95$, Southwestern Ontario (sidressed), and $r = 0.92$, Southwestern

Ontario (preplant), Central and Eastern Ontario for the 1962-1986 data sets; r = 0.96, 1986-1990 data set). This is really quite remarkable as it derives from such a large number of trials and years and is consistent across two independent historical data sets.

As the coefficients are related, C can be described in terms of B, where, for the 1962-1986 data sets in Central Ontario,

$$C = 0.00315 \cdot B, \qquad r^2 = 0.85 \tag{3}$$

in Southwestern Ontario (sidedressed),

$$C = 0.00271 \cdot B, \qquad r^2 = 0.91 \tag{4}$$

in Southwestern Ontario (preplant),

$$C = 0.00247 \cdot B, \qquad r^2 = 0.85 \tag{5}$$

in Eastern Ontario,

$$C = 0.00311 \cdot B, \qquad r^2 = 0.85 \tag{6}$$

and for the 1986-1990 data set

$$C = 0.003051 \cdot B, \qquad r^2 = 0.92 \tag{7}$$

The fact that the coefficients B and C are related is a very useful relationship as it allows the modelling of MERN as a function of ΔY.

If

$$= \alpha \tag{8}$$

and from equation (1) we can say that

$$\Delta Y = B \cdot N - C \cdot N^2 \tag{9}$$

then utilizing the relationship between B and C (eq. 8) you can produce a single variable relationship where MERN is a function of ΔY_N, for a given R and application rate N.

From equations (8) and (9) it follows

$$B = \frac{\Delta Y}{\left(N - \alpha \cdot N^2 \right)} \tag{10}$$

$$C = \frac{\alpha \cdot \Delta Y}{\left(N - \alpha \cdot N^2\right)} \qquad \textbf{(11)}$$

Substituting equation (10) and equation (11) into

$$MERN = \frac{B - R}{2 \cdot C} \qquad \textbf{(12)}$$

$$MERN = \frac{1}{2 \cdot \alpha}\left[1 - \frac{R \cdot (N - \alpha \cdot N^2)}{\Delta Y_N}\right] \qquad \textbf{(13)}$$

Equation (13) indicates that MERN can be estimated from a measurement of the yield increase over check yield, ΔY_N, for any given rate of fertilizer, N. Setting N = MERN gives a unique relationship between MERN and maximum economic yield gain, that depends only on α.

Figure 6 shows the relationship ($r^2 = 0.91$) between C and B for the corn grain fertilizer response trials for side-dress application of N fertilizer (1962-1986) in south-western Ontario. The relationship suggests $\alpha = 0.00271$. A comparison of measured and predicted ΔY_N vs MERN using $\alpha = 0.00271$ and equation (13) is given in Figure 7. The procedure appears to also work for other crops. The relationship for ΔY_N vs MERN for barley in Ontario is given in Figure 8.

The theoretical analysis indicates that the spatial variability of yield from a single rate of applied fertilizer is not enough information to calculate the map for site specific application of N fertilizer. Furthermore, the non-linear shape of the ΔY_N versus MERN relationship indicates that equal levels of yield response variability do not translate into equal variations in N fertilizer recommendations. For example, all ΔY_N values greater than 2000 kg ha^{-1} for corn would have the same fertilizer recommendation.

5. RESULT AND DISCUSSION

5.1 Crop Yield (1993)

Average hand harvest grain yields and soil N test values are given in Table 2 and Table 3, for S1 and S2 respectively.

Average yield with fertilizer N applied was 6200 kg ha^{-1} in S1. The average yield without N fertilizer was 5000 kg ha^{-1}. Thus, the average increase in yield to applied N fertilizer was 1200 kg grain ha^{-1}. The yield gain from applied fertilizer) Y_F can be used to estimate the optimum fertilizer N required. The procedure uses the general relationship between) Y_F and N_R (recommended N rate) identified by Kachanoski (1987) from the analysis of over 250 plot-years of N fertilizer response in Ontario. This relationship is shown in Figure 5. According to equation (1),) Y_F = 1200 kg ha^{-1} for S1 gives an average recommended fertilizer N rate of 120 kg N ha^{-1}.

Average yield with fertilizer N applied was 5700 kg ha^{-1} in S2, which is lower than S1. However, even though the fertilized yield was lower in S2, the gain in yield due to adding fertilizer (ie) Y_F) was higher. The average value of) Y_F was 2200 kg ha^{-1} in S2 compared to 1200 kg ha^{-1} in S1. Thus, the predicted recommended fertilizer N rate from equation (1) is 155 kg N ha^{-1}. The lower yield potential, but higher fertilizer N requirement in S2 compared to S1 indicates the need to know both Y_e and Y_F (ie) Y_F) and not just Y_F values for a field.

Yield (fertilized and nonfertilized) varied considerable in both fields, but significantly more in S1 than in S2. The spatial patterns will be discussed in more detail in the next section. Check yields in S1 varied from essentially zero (100 kg ha^{-1}) to over 9000 kg ha^{-1}. Fertilized yields varied from 2000 to 8700 kg ha^{-1} in S1. Even block averages varied significantly (Tables 2 and 3).

The N soil test was on average 103 kg N ha^{-1} in S1 compared with 66 kg N ha^{-1} in S2. The higher average N test in S1 is consistent with a lower yield gain in S1 from applied fertilizer N. The lower average check yield (yield with zero fertilizer) in S2 is consistent with a lower N soil test and higher fertilizer N response. The soil N test ranged from 40 to 420 kg N ha^{-1}, with a spatial coefficient of variation, CV = 53% in S1. The N test ranged from 31 to 134 kg N ha^{-1} in S2 with a CV = 21%. The higher CV and range in soil N test in S1 is consistent with the higher variability in both check yields and yield gain from fertilizer in S1 compared to S2.

The recommended fertilizer rate from the average soil N test values are 20 kg N ha^{-1} for S1, and 100 kg N ha^{-1} for S2. However, Kachanoski and Fairchild (1996) have indicated that an average soil N test cannot give an accurate fertilizer N recommendation in fields which have considerable variability in N fertility. The calibration relationships between soil N test and N fertilizer recommendation were modified by Kachanoski and Fairchild (1996) to account for the variability. Their calibration relationships vary as a function of the spatial CV (%) of the soil N test. For a CV = 57 %, a soil N test of 100 gives a recommended fertilizer N rate of 100 kg N for S1, which is similar to the recommended rate (ie 120 kg N ha^{-1}) predicted from the measured yield gain) Y_F and equation (1). For S2, a soil N test of 66 and a CV = 20 % gives a recommended N fertilizer rate of 120 kg N ha^{-1} compared to the rate of 155 kg N ha^{-1} from the yield gain. However, the data in Table 2 indicates that the variability is not constant in different parts of the field. The CV of soil N test varied from 14 % to 75 % in the 4 blocks of S1 and from 10 % to 32 % in S2. This would pose problems in the application of a single correction for variability to a single composite sample.

The discussion on variability indicates the need to incorporate variable application into our current fertilizer management. Recommended rates of fertilizer N greather than 120 kg N ha^{-1} for the two sites (S1, S2) are justified based on average yield increases. However, these N rates cannot be predicted from average soil N test values, and the large range in yield response and check yields indicates there are significant areas within the field which do not need this much fertilizer.

The on-the-go yield sensor did a good job of mapping the yield patterns. A summary of the average yields for the sensor and hand yields are given in Table 4.

For the fertilized treatment, the on-the-go sensor measured yield was on average 17.7 % and 25 % lower than the hand yields, for S1 and S2 respectively. A minimum yield difference of 12 % was expected because of yield removal by the hand harvesting. The remaining yield difference between the sensor and hand sampling (5.7 % and 12.5 %) is reasonable considering the differences in shelling efficiencies (hand vs machine). The overall correlation of transect averaged yield by hand versus the on-the-go sensor was r = 0.925 (significant $P < 0.001$). The regression relationship is

$$\text{Hand Yield (kg ha}^{-1}\text{)} = 0.82 \quad \text{Sensor Yield} + 1825$$

The values are graphed in Figure 9. The intercept value of 1825 kg ha^{-1} in the relationship indicates that the sensor needed a minimum mass flow rate before it registered yield. This is seen in transect plots of yield from the sensor and the hand sampled yields (Figure 10, 11). When the hand sampled yields were 2000 kg ha^{-1}, the sensor registered 0 kg ha^{-1} yield. For yield greater than 2000 kg ha^{-1}, the sensor immediately responded and was highly correlated to measured hand yields. The patterns of yield measure by the sensor are very accurate. Of particular interest is the cyclical yield measurement of the on-the-go sensor at a frequency of 10 m. This is the spacing of hand sampling, and the sensor was sensitive and accurate enough to measure the yield decrease from the hand sampling. The overall performance of the yield sensor has to be judged as excellent, with some fine-tuning needed regarding lower limit sensitivity. The absolute accuracy is approximately plus or minus 250 kg ha^{-1}.

The field map of yield gain from applied fertilizer,) Y_F, can be used to estimate the optimum fertilizer N requirement map. The procedure for estimating fertilizer N requirement is best illustrated for a single transect from Block 1 in S1 (Figure 12). The check yield, Y_C increases dramatically from 2000 kg ha^{-1} to more than 7000 kg ha^{-1} at distance of 200 to 250 m. The large check yield coincides with the presence of a depression. The graph of) Y_F along the transect is given in Figure 13, along with the predicted recommended N fertilizer rate predicted using) Y_F .

The spatial distribution of the yield with fertilizer, without fertilizer,) Y_F , and predicted recommended fertilizer N rate with the surface relief map are given in Figures 14a, 15a, 16a, and 17a respectively for site S1. The same data for site S2 are given in Figures 14b, 15b, 16b, and 17b.

The yields were extrapolated to the whole field from the 140 hand yields taken in the 4 alternating blocks with fertilizer added. The extrapolation was carried out using a moving polynomial smoothing function and the Surfer^{TM} software package. The yield maps (Y_F, Y_C,) Y_F) can be used in a number of ways to determine variable application management. The Y_F map indicates there are significant areas within the fields where the yield was less than 3000 kg ha^{-1}. The economic return from <u>any</u> inputs (seed, herbicide, etc) into these areas needs to be assessed. The Y_C maps indicate areas within the field where the check yield was < 2000 kg ha^{-1} and other areas where the check yield exceeded 8000 kg ha^{-1}. The projection of the check yield contour intervals onto the elevation relief map (Figures 15a, 15b) indicates a close relationship between yield Y_C and topographic position. The highest Y_C yields were generally obtained in the lower slope areas as expected.

The importance of having information on both Y_F and Y_C, to calculate) Y_F and fertilizer requirement, is clearly demonstrated in this data set. For example, in site S1 the lower slope areas have the highest Y_F yields with most 6500 kg ha^{-1}. However, Y_C yields are also the highest in these areas. The net yield gain to adding fertilizer,) Y_F is usually less than 1000 kg grain ha^{-1} in the lower slope areas compared to the mid and upper slope) Y_F values of 3000 kg grain ha^{-1}. Some of the lower-slope areas had) $Y_F = 0$, indicating no fertilizer N requirement (Figure. 17a). These areas still had yields > 6500 kg ha^{-1}. These data clearly indicate that a map of yield from fields with a single rate of fertilizer added will not be enough information to determine variable fertilizer input. In fact, fertilizer inputs based on yield potential (ie. Y_F values) would give the opposite optimum fertilizer rate for many areas in this field. There are areas of no fertilizer N requirements that have very high yields and also very low yields. In addition, although considerable variability in yield exists at site S2 for Y_F, Y_C and) Y_F, the values of) Y_F are all high enough that the variability does not translate into spatial differences of predicted N fertilizer requirement (Figure 17b). Thus, the presence of variability does not always result in a management opportunity.

The spatial distribution of the fertilizer requirements as predicted from the soil N test are given in Figures 18a and 18b for sites S1 and S2, respectively. The relationship between fertilizer recommendations predicted from the soil test and the) Y_F are not very similar and are not statistically significant. The reason for the difference is not known, but is disconcerting given the high cost of obtaining gridded soil test data. The) Y_F predictions can be viewed as a bio-assay that any other method must approximate.

5.2 Crop Yield (1994)

For determining the variable rate N treatments for the 1994 growing season, it was decided that 4 rates would be used; 0, 50, 100, and 150 kg N ha^{-1}. The minimum fertilizer management area was designated as 10 m x 3.2 m wide (4 rows) which is the sampling interval for the hand sampled yields. Each of 10 m x 4 row block of the variable rate treatment areas received a recommended rate from the appropriate map. The fertilizer and treatment maps for site S1 and S2 are shown in Figures 19a and 19b, respectively. The fertilizer was applied using a variable rate equipped 28 % N applicator, but not linked to a global monitoring system. The rates were switched manually on each area because the purpose of this experiment was to test the influence of variable rate application on yield response and not if the variable applicator worked.

A comparison of the individual hand sampled yields obtained in the fertilized plots in 1993, and the same location in 1994 is given in Figures 20a and 20b for sites S1 and S2, respectively: If the pattern of yield was exactly the same in both years, then the points should scatter around the 1:1 line. The data indicate a correlation, but the slope of the line is not 1. The locations of the field with low yield in 1993 tended to have relatively higher yields in 1994. The areas with high yields (1993) tended to have the same yields in 1994.

The check yields (ie yields with no fertilizer N) from 1993 and 1994 are plotted against each other in Figures 21a and 21b for sites S1 and S2, respectively. The data indicates significant correlation, but the check yields are mostly lower in 1994. This was expected since the 1994 sites have had no fertilizer for 2 years compared to only 1 year for the 1993 check yields. The soil has an N pool that becomes available in the time scale of 1-3 yrs. Thus, check yields tend to be higher for the first year as the crop uses the N released in this pool. The pool decreases because no other rich source of N has been supplied (ie fertilizer N).

Examples of the spatial patterns of check yield, fertilized yield, and) Y_F for 1993 and 1994 are given in Figures 22 and 23 for site S1, block 1. Similar graphs are given in Figures 24a, 24b, and 24c for S1, block 3. In blocks 1 and 2 (site S1) the 1993 and 1994) Y_F values are significantly correlated ($r = 0.65$; $p < 0.01$). In blocks 3 and 4 (S1), the patterns are clearly similar, but slightly offset from each other. This resulted in no significant correlation between) Y_F in 1993 and 1994 on these blocks. Similar results were found with site S2. These graphs indicate that the spatial pattern of the yields remain reasonably similar, but that small differences can create major differences in the) Y_F pattern. It appears that slight offsets and differences in the method of interpolation may therefore result in considerable error in estimating the pattern of) Y_F. Robust mathematical interpolators are clearly needed.

A summary of the 1993 and 1994 yields broken down by block, N application rate, and method determining variable rate N requirements is given in Tables 5a and 5b for sites S1 and S2, respectively. The tables also give the total plant N (kg N ha^{-1}) measured for each treatment. Based on the experimental layout, blocks 1, 2 and 3 are valid comparisons for continuous versus variable rate f or) Y_F in S1 (because of the well area in the last treatment of block 4). All blocks can be used in S2.

In S1, the variable rate application of fertilizer N based on the) Y_F map resulted in 98 kg N ha^{-1} (average) being applied (ranging from 0 kg N ha^{-1} to 150 kg N ha^{-1}) compared to 150 kg N ha^{-1} in the continuous. The soil test map indicated only 68 kg N ha^{-1} were needed. Variable rate N using the) Y_F map resulted in 300 kg ha^{-1} less grain worth 36.00 \$ ha^{-1} (at 0.12 \$ kg^{-1}), but used 52 kg ha^{-1} less N fertilizer for an input savings cost of \$40.00 (at 0.77 \$ kg^{-1} N). As mentioned earlier, the S2 site did not have any predicted reduction in fertilizer requirements from the) Y_F measurements (ie no management opportunity). The results of variable rate using the N test were similar to site S1 in that, the yield reduction was higher than the economic benefit from reduced fertilizer N rates (Table 6). The soil test map lost a significant amount of yield that was not economic based on N fertilizer savings (Table 6).

A major benefit of the variable rate N application is illustrated in the simple N balance for the field (Table 6). Constant rate application resulted in 53 kg ha^{-1} more N applied as fertilizer than is taken off the field as N in the grain. Variable rate application based on) Y_F resulted in only 10 kg ha^{-1} more N applied as fertilizer than is taken off the field (as N in the grain).

5.3 Crop Yield (1995)

The soybean yields measured in 1995, summarized by treatment in the field in both 1993 and 1994 are given in Table 7a and 7b for sites S1 and S2, respectively. The purpose of planting the soybean crop was to determine any residual carry forward effects of variable N treatments on the preceding corn crops. In S1 and S2 the average soybean yield (neglecting the well area in block 4) for areas receiving continuous application of 150 kg N ha^{-1} (1993, 1994) was 3110 kg ha^{-1} (S1) and 3120 kg ha^{-1} (S2). The yields for areas with no fertilizer applied (either 1993 or 1994) were 3000 kg ha^{-1} and 2940 kg ha^{-1}, for sites S1 and S2 respectively. The decline in yield (avg = 5.7%) is significant ($p < 0.01$) for those areas which had no N fertilizer for 2 years. This is important because it suggests that there is a carry-forward cost to variable application. How much of the yield loss could have been avoided by a small application of 10 kg N ha^{-1} is not known. The nodulation measurements (Appendix 6) were not significantly different on a per unit area basis or on a per plant basis, for areas with and without fertilizer N.

The spatial distribution of the 1995 soybean yields were not very correlated to the corn yields (1993, 1994) at either site S1 or S2. For example, the highest yielding block for corn in 1994 had a lower soybean yield than the lowest yielding block for corn.

5.4 Crop Yield (1996)

The barley yields taken in 1996 are summarized by treatment (1993, 1994) and given with the 1993 and 1994 corn yields, in Table 5a and 5b for sites S1 and S2, respectively. Barley yield with fertilizer averaged 3128 kg ha^{-1} and 2500 kg ha^{-1} for sites S1 and S2, respectively. The check yields were 2898 kg ha^{-1} and 1155 kg ha^{-1} for sites S1 and S2, respectively. This gives a field averaged) Y_F for barley of 230 kg ha^{-1} for S1 and 1345 kg ha^{-1} for S2.

The similarity in Y_F, Y_C and) Y_F average values for barley (1996) and corn (1993) is remarkable and very consistent across the two sites. The) Y_F in 1993 and the soil N test (1993) predict that barley would need minimal N on S1 and a full rate on S2. This is exactly as was measured in 1996 (3 yrs later). A) Y_F = 230 kg ha^{-1} for barley (1996) translates into a recommended N rate for barley of approximately 30 kg N ha^{-1} for site S1 (Figure. 8). The predicted recommended rate for S2 is 90 kg N ha^{-1}. The predicted average recommended barley N rate (1996) based on the 1993) Y_F values for corn are 40 kg N ha^{-1} and 80 kg N ha^{-1} for S1 and S2, respectively. This is similar to predicted values of 30 and 90 kg N ha^{-1} from the measured) Y_F (1996) from barley. The measured) Y_F (1993) of corn of 1200 and 2200 kg ha^{-1}, for S1 and S2 respectively, give a predicted) Y_F (1996) of barley of 500 kg ha^{-1} and 1200 kg ha^{-1}, which is very similar to the measured values of 230 and 1345 kg ha^{-1}. The higher N requirement for barley (1996) in S2 compared with S1 is not reflected in a higher absolute yield. This is also similar to the corn yield data in 1993. Clearly, the requirement for N fertilizer for both barley and corn is related to the) Y_F and not the absolute yield.

A graph of the average 1996 barley yield with fertilizer vs. 1993 corn yield with fertilizer for the major blocks and fertilizer treatments (Tables 5a, 5b) is given in Figure 25. The same graph for unfertilized yields (corn, 1993 vs barley, 1996) is given in Figure 26. The relationships for fertilized yield is significant at $P < 0.01$ ($r = 0.81$). The relationship for unfertilized yield is different, but also significant at $p < 0.01$ ($r = 0.7$). Of significance is an outlier pair of points in the 3rd fertilized block of S1. In that block, 15/33 sites had an average yield of 4882 kg ha^{-1} in 1993, which was not different from adjacent check yields. Thus, these sites were scheduled for 0 fertilizer application in 1994. In 1994, with no fertilizer these sites yielded 4995 kg ha^{-1}, which was 100 kg ha^{-1} higher than the year before. This should have been an excellent example of the) Y_F approach. However, the yield on the matching 1994 fertilized area of these sites rose dramatically to over 6500 kg ha^{-1}.

This increase in yield, which was not predicted, was the main reason the 1994) Y_F treatment was 300 kg ha^{-1} lower on average than the continuous fertilizer treatment (Table 6). Yield loss in this area reduced the average yield in the) Y_F treatment by 230 kg ha^{-1}. The fact that the barley yield in 1996 also had excellent yield in this area, and that the barley yield vs corn yield pair are outliers on the general relationship (Figure 25), suggests the corn 1993 yields in this area were artificially low. The yield of corn relative to barley for this area falls almost directly on the predicted relationship for check yields (Figure 26). A possible explanation is that the fertilizer applicator plugged in these areas during application in 1993. However, this is only speculation.

5.5 Soil Nitrogen Sampling

The Ontario soil N test was originally calibrated against fertilizer response trials and is a 0 to 60 cm soil sample (ie a 2 foot sample). The test has been expanded to allow a 30 cm depth sample based on a correlation between 30 cm and 60 cm samples from a number of farm fields. The relationship for converting the 30 cm soil test into a 60 cm soil test (and thus into a fertilizer recommendation) is,

Soil test (60 cm) = 1.6   Soil test (30 cm)

Thus, on average it is assumed that the second 30 cm of soil sample has 60 % of the nitrate N in the first 30 cm of sample. This general relationship was obtained by comparing composite soil samples from different farm fields (Kachanoski and Beauchamp, 1992). Given the variability in leaching conditions within a field and the spatial variability, there is some question about this approximation for examining within field variability. This question is important for site specific farming because of the considerable increase in cost of soil grid sampling if a 60 cm sample, rather than 30 cm soil sample was required.

The predicted 60 cm soil test values based on the 30 cm sampling depth are graphed against the measured 60 cm soil test values in Figures 27a and 27b, for sites S1 and S2, respectively. The prediction using the 30 cm soil sample is significantly correlated to the measured 60 cm soil test values across the range of landscape positions found in both S1 and S2. The variability of the prediction increases with increasing soil test value.

The average soil test value increased by 42 % in S1 between the time of the first May 1993 sampling and the second sampling in early June 1993. This is similar to the 33 % average increase found by Kachanoski and Beauchamp (1992). The soil test values at S2, however, more than doubled in the same time period. A graph of the first sampling versus the second sampling for all sampling locations is given in Figures 28a and 28b, for sites S1 and S2 respectively. There was considerable variability in the change in soil test between the different locations.

The main problem with the soil N test predictions for 1994 is that the 1993 soil test values are quite a bit larger than, and not significantly correlated to the soil test values from the same locations in 1994 (not given). Thus, any fertilizer recommendation map produced in 1993 would not predict fertilizer requirements in 1994. The average soil test in S1 declined from 102 kg ha^{-1} in 1993 to 57 kg ha^{-1} in 1994. The spatial variability of the soil test also declined considerably. A similar relative decline was measured in S2 with a decline from 66 to 41 kg ha^{-1}. The lower soil test in 1994 corresponds to the higher yield response in 1994. However, given the time required for sampling and for map generation, a spring sampling of the same year is not feasible for site specific management. The time requirements and the cost to grid soil sample would be too large to be carried out each year.

The high soil test values in 1993 are attributed to manure application in 1992 (spring). Even though a crop was grown in 1992 , the residual effects of the manure were still present. This will create significant challenges to defining the expert map for site specific management. Interestingly, the most opportunity for varying N rates exists at higher soil fertility levels.

A comparison of the 1994) Y_F values versus the 1994 soil test values (not given) indicated the 2 indices were significantly correlated ($P < 0.05$). The same was not true for the 1993 soil test values. Thus, the one year of corn appears to have been enough to offset the effects of the manure application.

The influence of the fertilizer N application on the soil N levels is given in Table 8. At S1 in the fall of 1993, 217 kg N ha^{-1} of mineral N were stored in the top 90 cm. The following spring the value was 94 kg N ha^{-1}, for a loss of 123 kg N ha^{-1}. This high value reflects the low crop N uptake (85 kg N ha^{-1}) relative to 150 kg N ha^{-1} fertilizer applied (Table 6). The loss also reflects the high soil N from previous management. The check plots also lost over 75 kg N ha^{-1}, which was reflected in the decline in soil test values mentioned earlier. Thus, a significant portion of the 1993/94 loss is from past manure application.

The high soil N losses are reflected in soil solution data summarized in Table 9. In the fall of 1993, and through the 1994 growing season, nitrate N values in leaching water of S1 are quite high in the fertilized treatments and exceed the Ontario drinking water objective (10 mg L^{-1}). The nitrate values are proportionately lower in the S1 unfertilized treatments, and in S2 in general. The lower values in S2 correspond with the higher predicted and measured fertilizer N response in S2 compared with S1. The values for S2 are , however, still above the Ontario drinking water objective.

The problem of base-line N leaching is also illustrated in the soil solution data. The nitrate N leaching values are on average 9.4 mg L^{-1} in the unfertilized plot, which is almost equal to the drinking water objective. The unfertilized solution sample values in S2 are considerably smaller averaging 3.4 mg L^{-1}. The differences in the baseline values in the unfertilized plots reflect the influence of past management and the soil at each site. The data clearly indicate the need to manage site S1 much more carefully than site S2. This was predicted from the average soil test values and the measured) Y_F values regardless of the opportunity for site specific management. The soil N loss and the solution sampling data for S1 indicate it will be very difficult to keep the nitrate in the leaching water at concentrations less than the drinking water objective using constant fertilizer application.. Even in site S2, which didn't have a site specific management opportunity and responded very well to applied fertilizer, the average nitrate values were higher than 10 mg L^{-1}. The crop N uptake values reflect this (Table 6) with grain N uptake equalling only 85 kg N ha^{-1} in both S1 and S2. An excess of 65 kg N ha^{-1} fertilizer applied over grain N uptake, with 30 cm of drainage water, would easily result in leaching concentrations exceeding 10 mg N L^{-1}.

The site specific fertilizer management treatments resulted in considerable improvements in the N balance (Table 6). In 1994, the constant fertilizer application (S1) had 53 kg N ha^{-1} more applied fertilizer than grain N uptake. The) Y_F site specific treatment had only 10 kg N ha^{-1} more fertilizer applied than grain N uptake. In addition, although the constant treatment had an extra 52 kg ha^{-1} of fertilizer N compared to the) Y_F treatment, this resulted in only 10 kg ha^{-1} more N in the grain. The soil test site specific treatment had 8 kg N ha^{-1} *less* fertilizer applied than taken up by the grain.

The increased N efficiency in the site specific treatments was reflected in the amount of soil N available for leaching in the fall, 1994. The) Y_F treatment had 40 kg N ha^{-1} less fall mineral soil N storage to 90 cm than the constant fertilizer treatment, while the soil test site specific treatment had 82 kg N ha^{-1} less. The decreases in average fall soil N storage are similar to the decreases in the average amount of fertilizer applied (52 kg N ha^{-1} less fertilizer for the) Y_F treatment, 82 kg N ha^{-1} less fertilizer for the soil test treatment sites). Thus, the site specific fertilizer application has a clear environmental benefit.

6. SUMMARY AND CONCLUSIONS

This study examined the spatial distribution of crop response to fertilizer N application at two sites in southwestern Ontario. A theoretical basis for a new crop yield response index was developed and then tested. A comparison of the temporal changes in the fertilizer response pattern was carried out across 4 years and 3 different crops. The relationship between the predicted fertilizer response pattern based on gridded soil N test values and the measured fertilizer response was also examined. Finally, the impact of the different fertilizer management systems on soil N loss and quality of water draining from the site was assessed. The major findings of the study are listed below.

A yield map based on one fertilizer N application rate is not enough information to determine the spatial pattern of N application for site specific management.

A new yield response index called the Delta Yield,) $Y_{F,}$ was developed to estimate the spatial pattern of N fertilizer response. It is based on the difference between yield with and without fertilizer N.

Yield measurements with an on-the-go combine monitor were significantly correlated to hand yield measurements, but the monitors may not be accurate enough to estimate) Y_F . Robust spatial interpolation methods are needed for yield monitor data.

Site specific application based on) Y_F used 40.00 \$ ha^{-1} less N fertilizer, but resulted in a decrease in crop yield valued at 36.00 \$ ha^{-1}. Application based on soil test used 63 \$ ha^{-1} less N fertilizer, but lost 92.00 \$ ha^{-1} from crop yield decline.

The soil N test map did not stay constant with time. The) Y_F pattern was quite constant and 1996) Y_F values for barley were similar to 1994) Y_F values for corn.

Variable N application significantly decreased subsequent soybean yields in areas with low or no fertilizer N. This cost must be incorporated into economic models of site specific management.

Constant fertilizer application resulted in nitrate concentrations in drainage water that exceeded the Ontario drinking water objective. However, at one site the water standards were exceeded even if no fertilizer N was applied. Drainage N losses increased in the site with high spatial variability.

Fertilizer N applied using site specific methods was used more efficiently as measured by crop yield compared to constant fertilizer N application. Drainage N losses were reduced with site specific N application proportional to the decrease in average fertilizer N applied.

The)Y_F relationship with recommended N and the spatial patterns of)Y_F at the two study sites indicate it may be better to only vary N application for major changes in N requirements. A simple 3 rate (0 %, 50 %, 100 % of recommended) fertilizer N applicator was built.

7. NITROGEN APPLICATOR [1]

7.1 Nitrogen Fertilizer Application

The nitrogen in year 1 was applied in a single rate in the form of 28 % liquid nitrogen. The applicator had a 2300 L (500 gal) storage tank and a ground driven John Blue positive displacement metering pump. Narrow blades on a Rawson Coulter with Rawson spring injector nozzles delivered the liquid nitrogen below the soil surface. This system worked well with a single rate of nitrogen because an orifice type nozzle could be selected which delivered a uniform amount of liquid between each row based on ground speed and total volume of liquid required. It is important to have enough back pressure in the system so that all nozzles would be under equal pressure and therefore deliver similar volumes. However, in 1994 variable rates of nitrogen were applied and so a variable speed hydraulic drive system called *Accu Plant* manufactured by Rawson Control Systems, Inc. was installed in place of the ground drive system on the applicator. This system could change rpms on demand either by manually changing the desired rate or by connecting the controller to a notebook computer which used a variable rate value layer embedded in software as well as receiving a DGPS Signal from a Satloc DGPS receiver. Now both the position in the field as well as the desired rate could be determined and appropriate signals could be transmitted to the variable speed hydraulic drive unit. Ground speed would be accurately determined by a radar ground speed unit.

The required N rates at site S1 varied from 0 to 150 kg N ha^{-1}. This is a very large range, but probably a common scenario in Ontario. The zero application rate is quite simple to obtain by just shutting off the flow. The next highest rate needed was 50 kg N ha^{-1}. To get the desired application rates, which ranged from a low of 13 US gal per acre to a high of 50 US gal per acre, much larger nozzles had to be used. However, with the larger nozzles there wasn't enough pressure maintained in the system to get uniform lower rates. The solution was to purchase a special flow compensator distributor manufactured by the John Blue company. This unit accurately distributed uniform flow to 12 outlets at rates which ranged from 5 US gals to over 60 US gal per acre.

7.2 Simple three rate 28 % N Applicator

As mentioned earlier, the results of the study suggest that a simple manual 3 rate applicator may be the optimum choice for many fields. The cost is low and the rate change is done manually in response to visual clues in the field (for example topography). A schematic diagram of modifications to a 28 % N applicator are shown in Figure 32. The design allows the operator to

---

[1] This work was carried out in cooperation with J. Lauzon and I. O'Halloran, Dept Land Resource Science, Univ. Of Guelph.

select between three rates of application on the go (0 plus two additional rates). Additional rates could be added with the addition of more solenoid valves, but it may be difficult for the operator to keep tract of more than three application rates

The system design is quite simple. Two normally closed solenoid valves with accompanying gate valves and a bypass line are used to attain the three rates. The zero rate is attained when both solenoid valves are closed (all flow goes through the bypass line). The high rate of application is attained by opening the solenoid valve that does not have a gate valve attached and adjusting the flow rate using the pumps flow rate adjuster (in this case the stroke length of the variable stroke length piston pump was adjusted). The third rate is attained by opening the second solenoid valve. This solenoid valve was also connected to a gate valve which can be adjusted to get the desired rate. This gate valve could be removed and replaced with a flow limiting washer with an opening surface area of 50 % of the solenoid outlet surface area, if 50 % of the high rate setting is always desired.

A pressure relief valve is used on the bypass line instead of a gate valve because this valve adjusts with pressure. The valve will "open up" more when both solenoids are closed, thus preventing over pressuring of the pump. In the same way, the valve will partially close when only one of the solenoids are open, which will direct more flow to the injectors. The valve will close more with the high rate as a result of the lower back pressure when the larger of the two injector outlets is open.

Shown in Figure 32 is a separate line which can be used to bypass the solenoid valves if the operator chooses to use the applicators original rate selector.

The flow divider was the most expensive part of the system. This particular flow divider has a diaphragm in it which adjusts the opening diameter of its outlet lines with pressure to give a much greater range in output flow rates than a conventional fixed output sized flow divider. This unit will be required on any variable rate system to allow the range of flow rates that will be required.

Operating the system in the field is quite simple. The zero rate is attained with the toggle switch in the off position, and then you adjust the toggle either to tahe forward or backward position to get the other two rates.

The system was calibrated to give 0, 50 %, and a full rate. After calibration, several runs were made with buckets collecting the flow from the injector lines to evaluate reproducibility of rates. The system reproduced the rates quite well, moreover the pump output could be changed and the outputs would change in a relative way to continue giving a full rate and a 50 % full rate.

8. EFFICIENCY GAINS WITH DECREASING MANAGEMENT SIZE [2]

The purpose of this study is to examine the efficiency gains from nitrogen fertilizer on corn for alternative field fertility distributions associated with changing the size of the nutrient management unit. The management unit size varies from the whole field on which a single nitrogen rate is applied to the smallest area that can be identified and managed under present technology. The next section describes the methods for determining optimal fertility usage and corn yield for a given field under each management unit size. A computer simulation model was developed to generate fertility test values at each location within the field under the assumption that the test values follow a stochastic first order autoregressive process. Results of the efficiency gains for alternative fertility distributions are then described followed by conclusions.

8.1 Methods

The methods for calculating the efficiency gains for each possible management unit size and fertility distribution are as previously outlined in Figure 33. A hypothetical field is divided into a single strip of cells each 1.5 m in length which represents the area of the smallest possible management unit (MU) size. The model assumes there are 1000 cells and thus the field is 1500 m long. The width of the field is given by the width of the applicator and does not need to be specified at this time since it is assumed that the fertility level for any 1.5 m cell is constant across the width of the applicator. The length of 1.5 m is based upon how fast present fertilizer applicator systems can change rates of application (Ichthyic). The ability of the applicator to integrate ground speed, global positioning, and use of information determines how quickly rates can be adjusted. Other less costly VRT systems change rates at longer distances. This minimum MU size of 1.5 m also represents the distance between sampling locations.

Once the field is divided into cells, the next step is to assign soil nitrogen test values to each cell on the basis of a given spatial fertility distribution as summarized by the mean, coefficient of variation, and correlation coefficient. Soil test values generated from this distribution are spatially correlated and are assumed to follow a stochastic first order autoregressive AR(1) process. The relationships between the moments of a distribution and the parameters of an AR(1) process form the basis for generating the soil test values.

Three values are assumed for each of the mean, coefficient of variation and correlation coefficient in this study resulting in a total of 27 fertility distributions on which the optimal management unit size for fertility management is evaluated. The parameter values are 80, 55,

---

[2] This section was carried out by Sunil Thrikawala, Alfons Weersink and Gary Kachanoski, University of Guelph.

and 30 kg ha^{-1} for the mean fertility, 50 %, 25 % and 10 % for coefficient of variation and 0.6, 0.3, and 0.1 for the autocorrelation coefficient.

The next step is to determine gross revenues less nitrogen fertilizer costs for each management unit size. The assessment described below is conducted for each MU beginning with the minimum MU size which is the soil test cell size of 1.5 m. The process is then repeated by increasing the size of the MU by one cell at a time until the size of the MU is the whole field. A constant rate application method is used when there is only one MU and all 1000 cells are combined into that unit.

The initial step is to calculate the average fertility for a MU. For the minimum MU size, average fertility is simply the soil test value for the cell. For larger MU sizes, average fertility for a particular MU is the average of soil nitrogen of the cells within that unit. Once the average fertility for each area of a given MU size is assessed, the optimal rate of nitrogen fertilizer can be determined. The optimal rate based on average Ontario condition for the yield response of corn to nitrogen fertilizer and prices for both fertilizer and corn.

The gain in profits for a given MU of *s* cells (EG_s) in \$ ha^{-1} as compared to not applying any fertilizer is given by

$$EG_s = P \cdot \Delta Y_s - W \cdot N_s^* \qquad \textbf{(14)}$$

where P is the price of corn and W is the price of nitrogen. The profit gain for the whole field (*EG*) in \$ ha^{-1} is the sum of the weighted average of the profit gain of each MU.

$$EG = \sum_{i=1}^{n} \frac{EG_{s_i} \cdot s}{m} \qquad \textbf{(15)}$$

where EG_{S_i} is the efficiency gain in \$ ha^{-1} for MU i consisting of *s* cells, and m is the number of cells in the field ($m = \sum_{i=1} S_i$) and *n* is the number of MU ($n \leq m/s$) in the field. Note that if the MU consists of all the cells in the field ($s = m$), then $n = 1$.

The process of calculating the gross returns less fertilizer costs is repeated for each MU size starting from the minimum MU size (soil test value cell of 1.5 m) until the whole field becomes the MU. This procedure is repeated for alternative draws of the same field characteristic until the profit gain of the field for every MU size is stabilized (Figure 33). In other words the procedure continues for different draws until the mean of the draws for each MU size does not change with the addition of another draw. Soil test values in each cell are randomly drawn from the assumed distribution and the profitability of each MU size then assessed as just described.

8.2 Results and Discussion

8.2.1 *Mean Fertility*

8.2.1.1 Nitrogen Applied and Yield Gain

The higher the average fertility in the field, the lower the amount of fertilizer required to boost fertility to the desired level. This inverse relationship between mean fertility levels and nitrogen applied and thereby yield gain is not symmetric and is assumed to be bounded at either end. The yield gain function assumes that any soil nitrogen test lower than 30 kg ha^{-1} requires 167 kg of N ha^{-1} and produces a maximum yield gain of 10,000 kg ha^{-1} whereas any location in the field with a soil nitrogen test above 115 kg ha^{-1} requires no fertilizer and consequently generates no yield gain.

Variations in mean fertility levels for the generated soil test values have the expected negative effect on nitrogen applied (see Table 14). For example, decreases in the mean level from 80 to 55 to 30 kg ha^{-1} with a CV of 50 % and a correlation coefficient of 0.6 increases the amount of nitrogen applied from 68 to 118 to 164 kg ha^{-1} when there is a single MU. Yield gain also increases with the increase in average fertility from 1031 to 2967 to 7111 kg ha^{-1}. Thus, increases in mean fertility levels increase yield gain at a decreasing rate reflecting the diminishing rate of marginal productivity embodied in the yield gain response function.

Altering the size of the management unit for a given fertility distribution can have an impact on application levels and yield gain depending on the mean soil test values. Increasing the number of management units from 1 to 1000 (decreasing MU size from 1500 m to 1.5 m) increases the amount of nitrogen applied from 68.16 kg ha^{-1} to 78.88 kg ha^{-1} for the fertility distribution with a mean of 80 kg ha^{-1}, a CV of 50 %, and a correlation coefficient of 0.6. Decreasing MU size has a no effect on the average nitrogen rate applied when the mean of the above fertility distribution is reduced to 55 kg ha^{-1} and a negative effect when it is lowered to 30 kg ha^{-1} (164 kg N ha^{-1} to 154.3 kg N ha^{-1}). The result is due to the bounded nature of the yield response function. If the average fertility level is 55 kg ha^{-1}, very few cells in the hypothetical field will have test values above 115 kg ha^{-1} for which no nitrogen should be applied and below 29.6 kg ha^{-1} for which the maximum is applied. Thus, the average N rate for a large MU will not differ from that for a small MU. However, the rate will increase by decreasing MU size as fertility levels increase. To illustrate, assume the field consists of only two cells which have soil fertility test values of 100 and 140. The average fertility is 120 kg ha^{-1} and so no fertilizer should be applied if both cells are treated as a single unit. If the MU size was decreased so that each cell was treated differently, 29.92 kg ha^{-1} would be applied to the cell with an average fertility of 100 kg ha^{-1} and none to the other cell with the high average fertility. Thus, the average application rate has increased from zero to 15 kg ha^{-1} ((0 + 29.92)/2) by decreasing the MU size. The opposite occurs when the average fertility in the field is low. Decreasing the MU size allows regions in the field that do not require the maximum application rate to be identified. The effect of altering MU size on nitrogen applied is diminished with the alternative average fertility levels as the spatial variability is reduced. A lowering in the CV value means fewer cells have test values at the upper or lower bound as will be discussed further in the next section.

The changes in the nitrogen application rates for changes in MU size directly determine changes in yield gain. For fertility distributions with a CV of 50 % and a correlation coefficient of 0.6, going from the largest to the smallest MU size increases yield gain by 17 % (1032 kg ha^{-1} to 1241 kg ha^{-1}) when the average fertility is 80 kg ha^{-1}, a negligible effect when it is 55 kg ha^{-1} , and a slight negative effect when average fertility is lowered to 30 kg ha^{-1} (-1.7 %).

8.2.1.2 Efficiency Gains

The effect on yield gain from a change in mean fertility levels is reflected in gross profit for the alternative fertility distributions and MU sizes is given in Table 15. Decreases in average fertility significantly increase efficiency gains from fertilizer application. For example, with a MU size of 1500 m and a fertility distribution with a CV of 50 %, a decrease in the mean soil test value from 80 to 55 to 30 kg ha^{-1} increases the profit gain per hectare from approximately \$ 207 to \$ 710 to \$ 2190.

By definition, gross profits never decrease with a decrease in MU size. Application costs are not considered and so the only costs are those associated with fertilizer. Therefore, decreasing MU size will not lower efficiency but should improve it if the profit maximizing application ratio differs in the smaller MUs from the larger MUs. The increase in cost from applying more fertilizer with a decrease in MU size for a high average fertility field is less than the increased revenue from higher yields. Efficiency gains for a field with an average fertility of 80 kg ha^{-1} a CV of 50 % and a correlation coefficient of 0.6 increase from approximately 207 \$ ha^{-1} for the largest MU size to 253 \$ ha^{-1} for the smallest. At lower mean values, the decreased cost of applied nitrogen is greater than the reduction in revenue from lower yield gains. For example, for a field with the same CV and correlation coefficient as the previous scenario but an average fertility of 30 kg ha^{-1}, gross profits increase slightly by 0.31 % (1887 kg ha^{-1} -1893 kg ha^{-1}) by decreasing MU size.

The increase in gross profits with a decrease in MU size is more pronounced the greater the degree of spatial variability for any mean fertility level. However, the marginal change in profit going from CRT to VRT is reduced with a reduction in average fertility. At low mean soil test values (30 kg ha^{-1}), approximately 50 % of the cells will be below the minimum soil test value of 30 at which the maximum N rate is applied regardless of how low the soil test value is. Since a large portion of the field should be receiving the single maximum rate, decreasing the MU size will not significantly alter the average application rate as discussed earlier. Thus, profit gains are not significantly changed with MU size at this low mean level. In contrast, there are gains in breaking up the field into smaller management units at higher average fertility levels since the application rate is not as likely to be bounded. These gains would be reduced if the mean average fertility approached the lower bound of the yield response function.

8.2.2 *Coefficient of Variation*

8.2.2.1 Nitrogen Applied and Yield Gain

The greater the spatial variability in soil fertility as measured by the coefficient of variation (CV), the greater the benefits to breaking up a field into smaller management units. However, at a given MU size, there is no discernable effect of CV on nitrogen applied regardless of the mean and correlation coefficient. For example, with an average fertility of 80 kg ha^{-1} and a correlation coefficient of 0.6, the average application rate is approximately 69 kg ha^{-1} for the largest MU regardless of the CV level. The result is as expected since it is average fertility within a MU that determines the fertilizer rate. However, fertilizer application does increase with CV values as the size of the MU decreases for fields with high average fertility. For example, for a fertility distribution with the same mean and correlation coefficient as above, average fertilizer applied increases from 68.16 kg ha^{-1} with a 1500 m MU size (whole field) to 79 kg ha^{-1} for the smallest MU size of 1.5 m when the CV is 50 % but remains unchanged when the CV is 10 %. Since there is little spatial variation for the low CV scenario, the optimal fertilizer rate for the whole field will not be significantly different than for individual location in the field.

The relatively small effect of increases in spatial variability on the average application rate appears inconsistent with the study by Kachanoski and Fairchild (1996) who found that the average rate should increas with the degree of variation in soil fertility. The difference is due to the way in which the nitrogen rate for each MU was determined. It was calculated based on the average soil fertility test for the MU rather than from the average of the optimal rate for each cell within the MU. Thus, the application rate changes little with changes in the CV using local average soil tests whereas it might have had the local responses within the MU been known.

While increases in CV only affect the rate of nitrogen application at smaller MU sizes, changes in CV affect yield gain for a given mean and autocorrelation regardless of the MU size. For example, for the fertility distribution with a mean of 80 and correlation coefficient of 0.6, average application remains approximately constant at 69 kg ha^{-1} regardless of spatial variability but yield gain drops from 1032 kg ha^{-1} when the CV is 50 % to 465 kg ha^{-1} when the CV is 10 %. For that fertility distribution, there is a 22 % increase in yield gain moving from the largest to smallest MU size when the CV is 50 % (1032 vs 1241) but only a 1 % increase when the CV is 10 % (465 vs 471). The increased yield gain in response to the decreased MU size for a relatively constant nitrogen rate is due to the fact that yield gain was calculated for each cell within the MU from the nitrogen rate applied for the whole MU. This effect of the CV with decreasing MU size is significantly reduced and even reversed when the mean fertility is lowered since the yield gain is less likely to be bounded as was discussed in the previous section on mean fertility.

8.2.2.2 Efficiency Gains

Given that fertilizer levels are relatively unaffected and yields increase significantly as CV increases (at least at high average fertility levels), there are pronounced differences in returns less fertilizer costs for differences in spatial variability for a given mean and correlation coefficient. For example, for a field distribution with a mean of 80 kg ha^{-1} and correlation coefficient of 0.6, decreasing the degree of variability from 50 % to 25 % to 10 % for the largest MU size decreases the efficiency gain ($ ha^{-1}) from approximately 205 to 56 to 38. For a field with the same correlation coefficient but mean fertility of 30 kg ha^{-1}, the efficiency gains decrease from 2,190 $ ha^{-1} to 1890 $ ha^{-1} as the CV is reduced from 50 % to 10 % for the largest MU. The largest impact on efficiency gains from changes in the coefficient of variation are observed for fertility distributions with a mean of 55 kg ha^{-1}. With this mean fertility level, higher degrees of variability are less likely to generate soil test values over the upper bound (115 kg ha^{-1}) than for distributions with a mean fertility of 80 kg ha^{-1} and more likely to have values below the lower bounds that are associated with the maximum increases in yield gain.

There are few efficiency gains for given CV values as MU size decreases except at high average fertility levels. The efficiency gain curves are relatively flat for changes in MU size regardless of average fertility for CV values of 10 %. With such little relative variation in fertility, there are few gains from breaking the field up into smaller units.

8.2.3 ***Autocorrelation***

8.2.3.1. Nitrogen Applied and Yield Gain

Nitrogen applied and yield change little with changes in the correlation coefficient for soil fertility distributions with the same average fertility and degree of spatial variability. For example, with the whole field as the management unit and a distribution with a mean of 80 and a CV of 50 %, fertilizer applied is approximately 68 kg ha^{-1} and yield gain around 1030 kg ha^{-1} regardless of the correlation coefficient.

Decreasing MU size increases (decreases) the applied nitrogen and yield gain for higher (lower) mean fertility levels with all autocorrelation levels as discussed earlier. It is hypothesized that the rate of change in fertilizer applied and yield gain for a given average fertility level will decrease the higher the correlation coefficient. The higher this value is, the more similar the fertility level of the neighbouring cell will be. Thus, the benefits of treating the two cells as distinct units rather than one single unit will be less than if the cells had been significantly different. While such a trend can be noted for very small mus.., the effect of the correlation coefficient is minimized by the size of the correlation length scale in relation to the MU size considered. There is no effect of the correlation coefficient when the MU size is greater than the correlation length scale since by definition, neighbouring samples are independent. For a correlation coefficient of

0.6 and the assumed sampling distance of 1.5 m, the correlation length scale (L) is 8.8 m [3]. Thus, there is no relationship between sampled values for MU sizes larger than 8.8 metres and consequently the correlation coefficient has no effect on either average application rate or yield gain.

8.2.3.2 Efficiency Gains

When the soil test values of a fertility distribution are highly correlated, the marginal increase of profit should be increasing at an decreasing rate until eventually the profit gains plateau and decreasing MU size further would yield no extra benefits. On the other hand, efficiency gains will continue to increase the smaller the MU if the adjacent soil test values are unrelated. Increases in the level of correlation coefficient increases the curvature of the profit curves for decreases in MU size particularly in the situation with a high degree of spatial variability. The strict concavity of the efficiency gain function is only noted for MU sizes which are smaller than the correlation length scale which is approximately 9 m for a correlation coefficient of 0.6 and a sampling distance of 1.5 m. For MU sizes larger than 9 m, the efficiency gain function is linear. However, the correlation of 0.6 is not strong enough to make the efficiency gain curve plateau and hence profits are still increasing at the smallest MU size.

8.3 Summary and Conclusions

The efficiency gains of breaking a field into smaller management unit sizes have been assessed for simulated fields in which the fertility levels are lognormally distributed and the stochastic pattern follows an AR (1) process. Twenty seven alternative field fertility distributions were randomly generated by varying the mean, coefficient of variation, and correlation coefficient. The major conclusions from the analysis are:

Nitrogen application rate, yield gain, and efficiency gains (gross revenue - applied nitrogen cost) are inversely related to average fertility.

The average application rate and yield gain for the field increases with decreases in management unit size for high fertility fields as areas in the field requiring fertilizer can be identified. The opposite occurs in low average fertility fields. Rather than apply a high rate based on the low average for a larger region, less fertilizer can be applied to those more fertile areas in that region.

---

[3] Correlation length scale (L) is given by the following formula: $L = \log(1 - 0.95) / D_1$ where D_1 = autocorrelation at first lag.

Efficiency gains increase with decreases in management unit size.

At low average fertility levels, the efficiency gain from decrease in MU size are due to the cost savings from reduced total fertilizer applied being greater than the reduction in gross returns from lower average yields. The opposite occurs in high average fertility fields.

Increases in spatial variability do not affect average application rates which are based on average fertility levels within a management unit but do increase average yield gain which are calculated for each cell within the MU for the average fertility rate.

The efficiency gains from decreasing management unit size are enhanced with increases in spatial variability.

The rate of increase in efficiency gains found by decreasing management unit size decreases with the correlation coefficient. However, the effect is limited and bounded by the relatively small correlation length scale compared to the management unit sizes.

This chapter has examined the differences in gross returns less cost of fertilizer applied from breaking the simulated fields into smaller management units. The ultimate feasibility of the technologies that permit application of varying rates across the field must also consider the information and application costs. The next chapter outlines three application methods and their costs and combines it with the efficiency gains calculated here to determine the economic viability of the approaches.

9, ECONOMIC FEASIBILITY OF SITE SPECIFIC APPLICATION [4]

The purpose of this study is to assess the economic feasibility of variable rate technology in the application of nitrogen fertilizer to corn in Ontario.

9.1 Methods

The three fertilizer application scenarios evaluated in this study involve the broadcast application of nitrogen fertilizer to corn fields with a tractor-pulled 4-tonne spreader. The fertilizer application scenarios can be broadly divided into two main categories; constant rate technology (CRT) and variable rate technology (VR). CRT is the application of single constant rate over the entire field based on average fertility for that field. In contrast, VRT is the application of variable rates depending on the fertility at different locations. The VRT scenario is further divided into two application methods. First, is the application of just three rates using a simple manually operated 3 way switch. Location in the field is subjectively assessed by the operator of the fertilizer applicator while driving the tractor with the aid of a fertility map developed through either grid soil sampling or yield monitoring. It is assumed that the operator will switch the rate of application at a minimum distance of 100 metres on average. The second VRT applies more than three rates and requires the fertilizer spreader to be coupled with GPS (global positioning systems) in order to pinpoint the exact location in the field. When coupled with a VRT module on the spreader and a differential real time correction source, these navigation systems are capable of changing fertilizer rates at a rate of 2 times per second. If a tractor on which the fertilizer spreader is pulled travels at a speed of 10 km hr^{-1}, the machine is thus capable of changing fertilizer rates every 1.5 m based on the average fertility in the 1.5 m cell.

The benefit of breaking a field into smaller management units is positively related to spatial variability in field fertility. Thus, the revenues for each of the three application methods will vary depending upon the fertility distribution. This aspect is incorporated into the model by calculating gross revenue per hectare for a field in which the fertility values are generated from a given distribution. The profit maximizing application rate is calculated for each management unit associated with each application method. The length of the management unit will increase from 1.5 m for the multiple rate VRT to 100 m for the 3-rate VRT to the whole field for the constant rate application method. The approach for calculating revenue gains for each possible management unit size (application method) and fertility distribution is outlined in Figure 33 and described further below.

---

[4] This part of the study was carried out by Sunil Thrikawala, Alfons Weersink, and Glenn Fox from the Dept. Agric. Econ. And Business, Univ. of Guelph in cooperation with Gary Kachanoski and with partial funding from this project

9.1.1 *Soil Fertility Distributions*

A hypothetical field is divided into a single strip of cells each 1.5 m in length which represents the area of the smallest possible management unit (MU) size associated with the multiple rate VRT. The model assumes there are 1000 cells and thus the field is 1500 m long. The width of the field is given by the width of the applicator and does not need to be specified at this time since it is assumed that the fertility level for any 1.5 m cell is constant across the width of the applicator. This minimum MU size of 1.5 m also represents the distance between sampling locations.

Once the field is divided into cells, the next step is to assign soil nitrogen test values to each cell on the basis of a given spatial fertility distribution as summarized by mean, coefficient of variation, and correlation length scale. Soil test values generated from this distribution are spatially correlated and are assumed to follow a stochastic first order autoregressive AR (1) process. The relationships between the moments of distribution and the parameters of an AR (1) process from the basis for generating the soil test values. Three values are assumed for each of the three parameters summarizing the fertility distributions (mean, coefficient of variation, and correlation coefficient) in this study resulting in 27 fertility distributions on which the optimal management unit size for fertility management is evaluated. The parameter values are 80, 55, and 30 kg ha^{-1} for the mean fertility, 50 %, 25 %, and 10 % for coefficient of variation and 0.6, 0.3, and 0.1 for the autocorrelation coefficient.

9.1.2 *Optimal Nitrogen Rate*

The optimal fertilizer rate depends on the soil fertility level, the yield response of corn to nitrogen fertilizer and prices for both fertilizer and corn. For the minimum management unit size, average fertility is the soil test value for a cell. At the other extreme, average fertility for the whole field (CRT) is the simple average of fertility across the 100 cells comprising the field. For 3-rate VRT with a management unit length of 100 m, average fertility is the average of soil nitrogen cells within that unit. A quadratic yield gain function estimated for Ontario conditions and prices (Kachanoski and Fairchild, 1996) was then used to determine the optimal nitrogen rate based on the average fertility. The yield gain function assumed that any soil test value less than 30 kg ha^{-1} requires 167 kg of nitrogen per hectare and produces a maximum yield gain of 10,000 kg ha^{-1} whereas any location with a soil test above 115 kg ha^{-1} requires no fertilizer.

9.2 Costs of Application Method

Three types of costs are associated with each application scenario; a) fertilizer cost; b) information costs; c) application costs. The fertilizer cost is the amount of nitrogen multiplied by the price. The total amount of fertilizer used for each application scenario is the profit maximizing level as calculated with the process described above. Information costs are the costs associated with soil sampling, chemical analysis, and map making whereas fertilizer application costs consist of the equipment costs of placing the fertilizer in the field at constant rate or varying rates. The size of information and application costs are inversely (directly) related to the management unit size (the degree of VRT technology). In order to standardize the comparison, the costs are based on the assumption that the producer does all the sampling and purchases all the equipment rather than having the work completed by a custom operator. Thus, the costs likely represent a maximum for most producers. Custom rental rates are also provided to serve as a comparison.

9.3 Results and discussion

9.3.1 *Revenue*

Revenue gains for the three fertilizer application methods under alternative fertility distributions are given in Table 11. Increased revenue generated from fertilizer application increases significantly with decrease in average fertility and increases in spatial variability. For example, with the constant rate application method (CRT), revenue gains in field with a CV of 50 % and a correlation coefficient of 0.6 are approximately 309 \$ ha^{-1} when the mean fertility is 80 kg ha^{-1} and increases to 890 \$ ha^{-1} when mean fertility is 55 kg ha^{-1} reflecting the benefits of enhancing soil fertility with nitrogen fertilizer.

The relationship between the increased revenue from fertilizer application and average fertility is not linear reflecting the diminishing marginal productivity for fertilizer embedded in the production function. In the case when average field fertility is 80 kg ha^{-1}, decreasing the coefficient of variation from 50 % to 25 % drops the revenue gains associated with CRT from 309 \$ ha^{-1} to 159 \$ ha^{-1}. The increase is due to the greater potential for yield increases across location in the field with increases in the variability of fertility among those locations where average fertility is medium to high. Decreasing spatial variability decreases the revenue gain when average fertility is low due to the bounded nature of the yield response function. The increase in CV at low fertility means more areas that receive the maximum nitrogen rate and generate the maximum possible yield gain.

The advancement of the technology significantly increases the revenue gains of fields with high average fertility and spatial variability. For example, revenue gains increase from 309 \$ ha^{-1} for CRT to 324 \$ ha^{-1} for 3-rate VRT to 375 \$ ha^{-1} for multiple rate VRT under a fertility distribution with 0.6 correlation coefficient, 50 % CV, and 80 kg ha^{-1} mean. This is due to the greater potential for yield increases across location in the field with increase in spatial variability among those locations where average fertility is high as discussed above. The correlation coefficient has no discernable effect on revenue gain for alternative application methods.

9.3.2 *Fertilizer Cost*

Table 11 also gives the cost of fertilizer nitrogen for the 3 different application methods for each fertility distribution. The cost of nitrogen is inversely related with soil fertility. However, changes in the coefficient of variation or correlation coefficient do not have a consistent impact on the cost of applied nitrogen. At higher (lower) average fertility levels, decreases in MU size slightly increases (decreases) fertilizer costs. Advancing the fertilizer application technology also increases the fertilizer cost at higher average fertility.

9.3.3 *Information Costs*

Information costs of applying fertilizer are the soil sampling and chemical analysis costs which are summarized for a 50 ha field in Table 12 for each application method. The generation of the information on fertility is assumed to be done every 3 years and so the costs are annualized over that time frame. CRT requires less intensive sampling and no mapping so information costs are relatively low. One sample per 10 hectare should be tested for nitrogen and each sample should be a composition of 20 sub-samples (OMAFRA, 1995). With labour costs of collecting at 10 \$ hr^{-1} and approximately 15 minutes needed for a complete sample to be taken and packed (Lowenberg-DeBoer and Swinton, 1995), the cost of sampling for a 50 ha field with CRT is \$12.50 [0.25 * (10 \$ hr^{-1}) * (5 samples)]. The cost of lab analysis is 12 \$/sample for the total of 5 samples.

In contrast to CRT which applies a single rate based on an average fertility rate, VRT methods require differentiating the fertility levels in the field. Intensive sampling and/or a high level of technology is necessary to obtain such a fertility map. In the case of 3-rate VRT system, it is assumed that the operator will switch rates at most every 100 m which means the grid size of the fertility map will be 1 ha (100 m X 100 m). It is assumed that 2 sub-samples are taken to form one complete sample to form one complete sample for every hectare. Since the same number of sub-samples are collected per hectare as in the CRT scenario, collection costs are the same. However, rather than analysing a single average sample for every 10 ha and averaging the one composite sample, every hectare must be analysed at a cost of 12 \$/sample. Thus, the analysis costs for a 50 ha field are \$600 (50 samples * 12 \$/sample). This fertility information at each 1 ha grid must then be translated into a fertility map using a procedure such as kriging with map making software that can be purchased for \$ 425 (Lowenberg-DeBoer and Swinton, 1995). The approximate 21 \$ ha^{-1} cost of an individual producer sampling, analysing, and the making fertility map is slightly less than 25 \$ ha^{-1} charged by the private companies for this complete service.

The level of detail required for soil fertility map increases with the possible number of application rates. Information on soil fertility can be obtained directly by grid soil sampling as used in the 3-way VRT method but these costs increase with decreases in grid-size. For example, the cost of chemical analysis alone with 1.5 sq. m grid sampling on a 50 ha field is approximately $ 453,000. A less expensive method applicable in the case of nitrogen is to monitor actual yield at harvest and compare it to neighbouring locations on which no nitrogen was applied. The delta yield (actual yield - check yield) generates nitrogen recommendations by location based on this yield gain. The opportunity cost of the check strip necessary to obtain the fertility map is 21 $ ha^{-1}.

The no-nitrogen yield is compared to actual yield as obtained from a yield monitor on the combine. The equipment required to continuously record yield in every area of the field represents a fixed information cost. The yield monitors with GPS is assumed to cost $ 13,600 (Ichthyic). To sample at 1.5 m intervals requires a differential correction source which costs an additional $ 3000 (Bruce Shillinglaw, personal communication).

9.3.4 *Application Costs*

The variable application costs are the fuel and labour costs based on tractor operation which are common for the three methods of application. In general a tractor burns 5 gallons of fuel (2.38 $/gallon) per hour to spread fertilizer on an area of 12 ha (OMAFRA, 1989). The labour charge of fertilizer spreading is 10 $ hr^{-1} [5]. The variable rate equipment involves switching the track speed within the spreader from a wheel-driven one that can be changed only when stopped to one that can be adjusted through hydraulics while driving. The cost of doing so for a 3-way system is approximately $ 1500 (Kachanoski, personal communication). The custom rate of applying nitrogen fertilizer using 3-rate method is 11 $ ha^{-1} (Bruce Shillinglaw, personal communication). The multiple rate VRT method requires a GPS-linked control system that can be purchased for approximately $ 4500 (Green Lea Agri Centre, 1996). In addition, other necessary options include a variable rate option costing $ 950 and the options costing $ 2200 that integrate yield monitoring, mapping, and variable rate application, such as survey option, light-bar and map stick (see Table 12). The complete cost of application plus the GPS system for 50 ha field is 133 $ ha^{-1} which is greater than the custom rate $ 25 per hectare (Cargill, Princeton Ont.). However, only two units are presently available in Ontario and costs approximately $ 500,000. Both variable rate control systems are assumed to last for 5 years.

9.3.5 *Annualized Costs*

The fertilizer costs calculated were on an annual value. Therefore, to obtain the net gain or loss of fertilizer application for the different technologies, all costs must be annualized. Since the general practice is to sample once in every 3 years for fertilizer recommendations (OMAFRA,

---

[5] Labour costs however, will be slightly larger for 3-way VRT since the operator has to figure out where he is in the field.

1995), all information costs associated with sampling and analysis are annualized over 3 year period. The GPS, yield monitor, map making software, and variable rate control systems are annualized assuming a lifetime of 5 years. The spreader used in all scenarios is assumed to have a useful life of 10 years.

9.3.6 *Net Benefits*

The net gain or loss for each of the three fertilizer application methods is the revenue gains minus the cost of application. The fertilizer costs in Table 11 and annualized costs in Table 12 are subtracted from the revenue gains (Table 11) to obtain the net returns under cost scenarios for the three application methods (Table 13). The fertility distributions associated with a mean 30 kg ha^{-1} and a CV of 10 % are not included here since there was little change in gross profits per hectare with variation in MU size.

Net returns are positive for CRT and 3-way VRT for all fertility distributions and assumptions on cost determinants. Multiple rate VRT suffers net losses only on smaller fields with high average fertility and low variability. Although revenue gains are positive, are insufficient to cover application costs when the returns to any application are smaller and particularly for VRT since such fields are relatively more homogeneous. The extent of the losses for multiple VRT are reduced and even reversed as the discount rate is reduced and years of life for the equipment or area of use is increased.

Not only are net returns positive for CRT, they are generally greater than that for either of the VRT systems for the distributions with low average fertility. When the average fertility is 55 kg ha^{-1}, the CV is 50% and the correlation coefficient is 0.6, net returns for CRT (689 \$ ha^{-1}) are 30 \$ ha^{-1} greater than 3-way VRT (659 \$ ha^{-1}) and 105 \$ ha^{-1} greater than the multiple rate VRT system (584 \$ ha^{-1}) for a 50 ha application area. The absolute level of returns for all three systems increases as field area covered increases since fixed costs are spread over more hectares. For 200 ha application area under the above fertility conditions, net returns are still highest for CRT but the difference as compared to the VRT system is much smaller. The relative benefits of multiple rate VRT in particular increase with area since a larger portion of the costs with this system are associated with fixed equipment costs. CRT is also more profitable for areas with a fertility CV of 25 % regardless of average fertility. Without the variation within the field, the benefits of breaking up the field into smaller management units does not exceed the costs except when spread over a large area. Only for large application areas is the multiple rate VRT system preferred. While the relative net returns rankings indicating a preference for CRT over VRT were expected for more homogeneous fields, the unexpected high relative net returns with CRT for the variable fields with low average fertility is due to the large gains from applying even the average amount of fertilizer on such fields.

9.4 Summary

This paper calculated net returns for three different application methods for nitrogen fertilizer on corn; constant rate, 3-rate VRT, and multiple rate VRT. Net returns are positive under each cost scenario for the constant rate and 3-way application systems. The multiple rate VRT system also generated positive net returns at application areas much smaller than most commercial farms. However, CRT was generally more profitable than either VRT systems for fields with low average fertility and/or low spatial variability. Net returns for multiple rate VRT eventually became larger than those for CRT as the application area over which the fixed costs could be spread became larger. The application area at which the relative profitability between the two systems changed was largely determined by the characteristics of the fertility distribution rather than assumptions made in calculating costs such as the level of the discount rate.

10. REFERENCES

ASHTECH Ag-Navigator Price List 1996. F.O.B. Sunnyvale, California, USA.

Beauchamp, E. B. , P. G. Newdick, and R. W. Sheard. 1987. Nitrogen requirements for corn in southern Ontario. (120 p.). Department of Land Resource Science, University of Guelph, Guelph, Ontario. CANADA. N1G 2W1

Kachanoski, R.G. and G.L. Fairchild (1996). Field Scale Fertilizer Recommendations: The Spatial Scaling Problem. Can. J. Soil Sc.

Kachanoski, R. G. and E.G. Beauchamp. 1992. A Soil N test for corn in Ontario. Dept. Land Resource Science, Univ. Of Guelph, Guelph, Ontario.

Lowenberg-DeBoer, J. L. and S. M. Swinton (1995). Economics of Site-Specific Management in Agronomic Crops. Staff Paper. Department of Agricultural Economics, Michigan State University, East Lancing, Michigan.

Ontario Ministry of Agriculture, Food and Rural Affairs (1995). 1995-1996 Field Crop Recommendations. Publication 296.

Ontario Ministry of Agriculture and Food (1989). Grain and Forage Crops: Estimated Production Costs for Ontario. Publication 89-05.

Statistics Canada (1994). Farm Input Price Index and Prices.

Tables

Table 1 . Crop management and agronomic data.

Year/Management	Site	
	S1	**S2**
1992 Crop	Winter Wheat	Soybeans
1993		
Crop	Corn, Great Lakes GL3V6 @ 29,900 pl/ac	Corn, Great Lakes GL200 @ 29,900 pl/ac
Tillage/planting	shallow cult, 2 coulter no-till planter	no pre-tillage
Planting date	May 11/93	May 22/93
Fertilizer	150 kg/ha 6-26-26-60 kg N/ha (28%) banded sidedress (June 15) to total of 150 kg N/ha	150 kg/ha 6-26-26-60 kg N/ha (28%) banded sidedress (June 15) to total of 150 kg N/ha
1994	Same Management as 1994 except variable rate treatments as described in methodology.	
1995		
Crop	Soybeans, M. Donavan. @ 160,000/ac in 20" rows	Soybeans, PS 42. @ 160,000/ac in 20" rows
Tillage/planting	3 coulter no-till	3 coulter no-till
Planting date	May 18/95	May 24/95
Fertilizer	None	None
1996		
Crop	Barley OAC, Stephen. @ 100 #/ac in 7.5" rows	Barley OAC, Stephen. @ 100 #/ac in 7.5" rows
Tillage/planting	1 coulter, no-till drill	1 coulter, no-till drill
Planting date	May 5/96	May 5/96
Fertilizer	Broadcast 125 #6-26-30 + 28% N to 67 kg N/ha	Broadcast 125 #6-26-30 + 28% N to 67 kg N/ha

Table 2 . Average measured yield values for Variable Rate Nitrogen application for Site S1

Block	Treatment	Hand Harvested Yield [ton ha^{-1}]				Soil N Test [kg N ha^{-1}]			
		Average	**Min**	**Max**	**Std Dev**	**Average**	**Min**	**Max**	**Std Dev**
1	**Fert**	6.7	3.3	8.7	1.1				
	Non Fert	4.7	1.9	8	1.8	98	40	267	49
2	**Fert**	6	2.2	7.8	1.5				
	Non Fert	4.6	1.8	8.6	1.8	95	53	179	31
3	**Fert**	5.8	3	8.6	1.5				
	Non Fert	5.7	1.5	8.4	1.8	98	60	170	31
4	**Fert**	6.2	2.1	8.3	1.5				
	Non Fert	5	0.1	9.1	1.9	122	57	420	80
	Avg. Fert	6.2	2.1	8.7	1.4				
	Avg. Non Fert	5	0.1	9.1	1.8	103	40	420	53
	Avg.Yield Gain	1.2							

Table 3 . Average measured yield values for Variable Rate Nitrogen application at Site S2.

Block	Treatment	Hand Harvested Yield [ton ha^{-1}]				Soil N Test [kg N ha^{-1}]			
		Average	**Min**	**Max**	**Std Dev**	**Average**	**Min**	**Max**	**Std Dev**
1	**Fert**	5.7	5.1	6.5	0.4				
	Non Fert	3.4	1.8	5.2	0.6	65	41	104	14
2	**Fert**	5.8	5.3	6.5	0.4				
	Non Fert	4.3	2.8	6.1	0.7	79	31	134	28
3	**Fert**	5.5	4.4	6.7	0.5				
	Non Fert	2.7	1	5.1	1.1	58	34	128	15
4	**Fert**	5.6	4.3	6.8	0.6				
	Non Fert	3.5	2.1	5.2	0.7	60	31	127	18
	Avg. Fert	5.7	4.3	6.8	0.5				
	Avg. Non Fert	3.5	1	6.1	1	66	31	134	21
	Avg. Yield Gain	2.2							

Table 4 . Comparison of average hand yield and the on-the-go yield sensor measurements, 1993.

Block	Treatment	Site S1 Measured Yield [ton ha^{-1}] Hand Yield	Site S1 Measured Yield [ton ha^{-1}] Yield Sensor	Site S2 Measured Yield [ton ha^{-1}] Hand Yield	Site S2 Measured Yield [ton ha^{-1}] Yield Sensor
1	**Fert**	6.7	5.1	5.7	5.4
	Non Fert	4.7	2.9	3.4	2.3
2	**Fert**	6	4.6	5.8	5.3
	Non Fert	4.6	3.1	4.3	3
3	**Fert**	5.8	5.2	5.5	4.9
	Non Fert	5.7	3.9	2.7	1.9
4	**Fert**	6.2	5.6	5.6	4.9
	Non Fert	5	3.8	3.5	2.1
	Avg. Fert	6.2	5.1	5.7	4.3
	Avg. Non Fert	5	3.4	3.5	1
	Avg. Yield Gain	1.2	1.7	2.2	3.3

Table 5a. 1993-94 Yield and Grain Total N for all Blocks, Treatm. and Fertilizer Rates for site S1.

1993					1994						1993			1994			1996			
BLK Nr	Fert. Rate kgN/ha	Corn Yield			BLK Nr	Trm	Fert. Rate kgN/ha	Corn Yield			Corn Grain N			Corn Grain N			Fert Rate kgN/ha	Barley Yield		
		Mean	SD	n				Mean	SD	n	Mean	SD	n	Mean	SD	n		Mean	SD	n
		kg grain/ha						kg grain/ha			kgN/ha			kgN/ha				kg grain/ha		
1	150	6705	1172	33	1	C	150	6995	742	33	92	16	33	103	12	33	67	3673	916	33
1		7098	112	3	2	DY	0	6770	1258	3	99	1	3	92	25	3		4302	540	3
1		7026	483	2	2	DY	50	7555	448	2	98	9	2	100	16	2		3547	54	2
1		6689	1764	7	2	DY	100	7338	1005	7	92	20	7	101	16	7		4103	988	7
1		6624	1100	21	2	DY	150	6698	597	21	90	17	21	96	11	20		3452	918	21
AVG	150	6705	1172	33	AVG	DY	120	6892	784	33	92	16	33	97	13	32	67	3673	916	33
2	0	4634	1817	33	3	O	0	3715	1471	33	52	22	33	43	19	33	0	3151	867	33
2		4776	1698	6	4	ST	0	4224	889	6	54	14	6	51	14	6		3346	486	6
2		4941	1529	10	4	ST	50	6287	702	10	54	20	10	89	11	10		3074	837	10
2		4443	2125	16	4	ST	100	5949	1171	16	51	27	16	86	19	16		3153	1037	16
2		3760	0	1	4	ST	150	6409	0	1	42	0	1	94	0	1		2733	0	1
AVG	0	4634	1817	33	AVG	ST	68	5752	1210	33	52	22	33	81	21	33	0	3151	867	33
3	150	5902	1503	33	5	C	150	6210	949	33	83	21	33	95	17	33	67	2432	797	33
3		5871	1270	5	6	ST	0	3744	1311	5	79	18	5	46	17	5		1984	367	5
3		6432	1334	17	6	ST	50	6001	1206	17	91	18	17	82	22	17		2579	741	17
3		5097	1594	11	6	ST	100	6174	1241	11	74	22	11	88	23	11		2410	981	11
AVG	150	5902	1503	33	AVG	ST	59	5717	1465	33	83	21	33	79	25	33	67	2432	797	33
4	0	4536	1748	33	7	O	0	3029	1564	33	46	21	33	35	20	33	0	2481	880	33
4		6580	2490	6	8	DY	0	5510	2264	6	77	28	6	68	30	6		2988	1469	6
4		3037	1223	2	8	DY	50	4277	316	2	32	14	2	49	9	2		1473	412	2
4		4699	1539	4	8	DY	100	6115	1346	4	46	13	4	88	22	4		1972	589	4
4		4064	1092	21	8	DY	150	6633	817	21	39	10	21	95	14	21		2530	637	21
AVG	0	4536	1748	33	AVG	DY	111	6224	1355	33	46	21	33	87	23	33	0	2481	880	33
5	150	5745	1489	33	9	C	150	6688	1169	33	79	21	33	92	18	33	67	3208	813	33
5		4882	1616	15	10	DY	0	4995	2152	15	68	21	15	60	32	15		3150	1028	15
5		6600	433	11	10	DY	100	6410	664	11	90	6	11	87	14	11		3095	522	11
5		6250	1381	7	10	DY	150	6971	603	7	83	24	7	97	10	7		3511	685	7
AVG	150	5745	1489	33	AVG	DY	65	5886	1719	33	79	21	33	77	28	33	67	3208	813	33
6	0	5629	1847	33	11	O	0	3621	1891	33	60	23	33	40	26	33	0	3353	749	33
6		5562	1761	6	12	ST	0	3162	965	6	62	20	6	31	9	6		2710	813	6
6		6330	959	14	12	ST	50	6597	1312	14	67	15	14	81	21	14		3760	464	14
6		6363	617	3	12	ST	100	7030	814	3	70	17	3	93	12	3		3805	484	3
6		4467	2557	10	12	ST	150	5933	1371	10	48	30	10	77	19	10		3035	740	10
AVG	0	5629	1847	33	AVG	ST	76	5811	1773	33	60	23	33	72	26	33	0	3353	749	33
7	150	6209	1558	33	13	C	150	7219	889	33	87	20	33	101	16	33	67	3200	779	33
7		6378	1627	20	14	ST	50	6101	1345	20	89	20	20	78	23	20		3179	926	20
7		5949	1470	13	14	ST	100	6928	949	13	83	21	13	96	18	13		3232	509	13
AVG	150	6209	1558	33	AVG	ST	70	6427	1257	33	87	20	33	85	23	33	67	3200	779	33
8	0	5019	1937	33	15	O	0	5138	1693	31	56	24	33	66	25	31	0	2605	757	33
8		4943	2426	13	16	DY	0	5387	1918	10	58	29	13	67	28	10		2758	834	13
8		7686	2002	2	16	DY	50	6659	170	2	81	25	2	94	14	2		3130	370	2
8		5452	1509	7	16	DY	100	6227	930	7	63	20	7	82	15	7		2575	881	7
8		4349	1058	11	16	DY	150	6359	816	11	46	14	11	92	13	11		2347	602	11

Table 5b. 1993-94 Yield and Grain Total N for all Blocks, Treatm. and Fertilizer Rates for site S2.

1993					1994						1993			1994			1996			
BLK Nr	Fert Rate kg N/ha	Corn Yield			BLK Nr	Trm	Fert Rate kg N/ha	CornYield			Corn Grain N			Corn Grain N			Fert Rate	Barley Yield		
		Mean	SD	n				Mean	SD	n	Mean	SD	n	Mean	SD	n		Mean	SD	n
		kg grain/ha						kg grain/ha			kg N/ha			kg N/ha				kg grain/ha		
1	0	3303	549	17	1	O	0	2737	663	17	34	7	17	27	7	17	0	1229	427	17
2	150	5710	408	17	2	C	150	6754	546	17	89	8	17	95	6	17	67	3077	428	17
3	0	4447	795	19	3	O	0	4396	839	19	51	13	19	48	10	19	0	1265	465	19
3		4663	732	14	4	ST	100	6452	586	14	54	14	14	85	10	14		1433	384	14
3		3843	697	5	4	ST	150	7103	592	5	43	9	5	103	9	5		1054	270	5
3	0	4447	795	19	4	ST	113	6623	642	19	51	13	19	90	12	19	0	1333	390	19
4	150	5688	315	19	5	C	150	6786	581	19	88	5	19	95	8	19	67	2349	704	19
4		5379	180	2	6	DY	100	6611	308	2	83	2	2	85	3	2		2210	521	2
4		5725	310	17	6	DY	150	6527	1048	17	89	5	17	91	14	17		2645	683	17
4	150	5688	315	19	6	DY	145	6536	991	19	88	5	19	90	14	19	67	2599	669	19
5	0	2973	1154	19	7	O	0	2718	920	19	31	13	19	29	11	19	0	1069	314	19
5		4563	0	1	8	DY	100	7027	0	1	48	0	1	97	0	1		2112	0	1
5		2884	1120	18	8	DY	150	6608	651	18	30	13	18	95	9	18		1041	400	18
5	0	2973	1154	19	8	DY	147	6630	640	19	31	13	19	95	9	19	0	1097	459	19
6	150	5536	492	32	9	C	150	6432	612	32	83	7	32	89	10	32	67	2151	449	32
6		5490	421	14	10	ST	50	4218	490	14	82	6	14	45	7	14		2604	398	14
6		5572	550	18	10	ST	100	6097	672	18	84	8	18	74	9	18		2337	549	18
6	150	5536	492	32	10	ST	79	5275	1116	32	83	7	32	61	16	32	67	2454	500	32
7	0	3542	787	19	11	O	0	2415	806	19	37	12	19	25	10	19	0	1055	338	19
7		3742	873	5	12	ST	0	2779	407	5	41	13	5	29	4	5		1864	430	5
7		3406	890	10	12	ST	50	4954	1392	10	36	13	10	57	18	10		2171	357	10
7		3633	428	4	12	ST	100	6899	639	4	36	7	4	89	12	4		2248	538	4
7	0	3542	787	19	12	ST	47	4791	1789	19	37	12	19	56	25	19	0	2106	420	19
8	150	5576	540	18	13	C	150	6207	949	18	82	7	18	84	13	18	67	2425	617	18
8		4285	0	1	14	DY	100	6672	0	1	68	0	1	88	0	1		3411	0	1
8		5619	456	18	14	DY	150	6884	546	18	82	7	18	97	7	17		3118	699	18
8	150	5549	538	19	14	DY	147	6873	533	19	81	7	19	97	7	18	67	3133	683	19

Table 6. Comparison of variable versus constant rate fertilizer application.

Treatment Pair	Fertilizer Applied	Average Yield	Crop N Uptake	N Balance
	kg ha^{-1}			
Site S1				
1. Continuous	150	6630	978710	53
) Y_F	98	6330		+10
Difference	52	300		43
Value \$ ha^{-1}	\$ 40	\$ 36		
2. Continuous	150	7610	967620	54
NTest	68	5930		-8
Difference	82	770		62
Value \$ ha^{-1}	\$ 63	\$ 92		
Site S2				
Continuous	150	6545	916922	+59
N test	79	5563		10
Difference	71	982		49
Value \$ ha^{-1}	\$ 55	\$ 117		

Table 7a. Yearly Yields for Treatment and Fertilizer Rates on Paired Locations for Site S1.

Measured Crop Yield on Paired Locations (kg/ha)													
Treatment	**Fertilizer Rate** kg N/ha	**Corn,1993**			**Corn,1994**			**Soybeans,1995**			**Barley,1996**		
		Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
C	150	6287	1444	62	6748	945	62	3113	440	62	3183	952	62
DY	0	5292	2090	18	5117	2164	17	3242	789	18	3148	1147	18
DY	50	5916	2492	6	6163	1537	6	3144	367	6	2716	1012	6
DY	100	6082	1724	14	6416	988	14	3220	697	14	3058	1133	14
DY	150	5193	1791	33	6664	824	33	3355	510	33	2919	872	33
O	0	4917	1912	84	3588	1754	83	2975	619	84	2934	895	84
ST	0	4855	1609	10	3470	1116	10	2943	363	10	2473	723	10
ST	50	5995	1471	30	6120	1262	30	2988	581	30	3247	750	30
ST	100	5634	1869	25	6432	1213	25	2800	726	25	3240	908	25
ST	150	4495	2351	8	6379	1066	8	2819	420	8	3072	737	8
SD= standard deviation, n=sample #													

Measured Crop Yield on Paired Locations (kg/ha)														
Block Number	**Treatment**	**Fertilizer Rate** kg N/ha	**Corn,1993**			**Corn,1994**			**Soybeans,1995**			**Barley,1996**		
			Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
1	C	150	6984	1371	17	7023	786	17	3146	388	17	3916	858	17
2	DY	0	7098	112	3	6770	1258	3	4228	244	3	4302	540	3
2	DY	50	7026	483	2	7555	448	2	3487	291	2	3547	54	2
2	DY	100	6777	2485	4	6811	1004	4	3430	1119	4	3997	1380	4
2	DY	150	7035	1256	8	6864	753	8	3496	690	8	3823	816	8
3	O	0	4760	1961	23	3936	1583	23	3156	502	23	3293	831	23
4	ST	0	3750	1823	3	3725	1102	3	3207	419	3	3075	408	3
4	ST	50	5167	1600	7	6288	620	7	3089	739	7	3347	568	7
4	ST	100	4859	2281	12	6225	1146	12	3038	656	12	3362	1062	12
4	ST	150	3760	0	1	6409	0	1	3225	0	1	2733	0	1
5	C	150	6061	1073	16	6269	877	16	3175	520	16	2489	769	16
6	ST	0	5880	538	3	4162	1136	3	2929	271	3	1925	272	3
6	ST	50	6293	1376	6	5760	1367	6	3070	672	6	2410	689	6
6	ST	100	5940	1056	7	6576	1418	7	2614	704	7	2799	884	7
7	O	0	4316	1630	26	2809	1399	26	3009	670	26	2388	859	26
8	DY	0	6899	2239	3	5346	2555	3	3631	446	3	3230	1741	3
8	DY	50	3037	1223	2	4277	316	2	2960	482	2	1473	412	2
8	DY	100	4699	1539	4	6115	1346	4	3293	781	4	1972	589	4
8	DY	150	4043	1040	17	6588	812	17	3427	436	17	2487	621	17
9	C	150	5597	1444	17	6543	1048	17	3086	466	17	3143	783	17
10	DY	0	4551	1109	8	4596	2076	8	2964	803	8	2897	990	8
10	DY	100	6319	413	5	6163	731	5	3068	258	5	3271	552	5
10	DY	150	6788	1535	4	7367	262	4	2996	339	4	3474	491	4
11	O	0	5509	1737	24	3407	1776	24	2837	645	24	3303	744	24
12	ST	0	4915	1755	4	2761	925	4	2756	335	4	2432	861	4
12	ST	50	6214	904	10	6196	1193	10	2965	514	10	3696	359	10
12	ST	100	6462	839	2	6649	673	2	3013	279	2	3750	672	2
12	ST	150	4600	2519	7	6375	1151	7	2761	418	7	3120	782	7
13	C	150	6575	1606	12	7287	756	12	3019	389	12	3128	847	12
14	ST	50	6254	2011	7	6152	1857	7	2851	519	7	3225	870	7
14	ST	100	7008	890	4	6695	1563	4	2307	978	4	3387	169	4
15	O	0	5372	2498	11	5065	1798	11	2522	1036	11	2664	727	11
16	DY	0	4216	3113	4	4038	2671	4	2197	1502	4	2723	1101	4
16	DY	50	7686	2002	2	6659	170	2	2986	76	2	3130	370	2
16	DY	100	7647	0	1	7312	0	1	2843	0	1	2578	0	1

Table 7b. Yearly Yields for Treatment and Fertilizer Rates on Paired locations for Site S2.

Measured Crop Yield on Paired Locations (kg/ ha)													
Treatment	**Fertilizer Rate** kg N/ha	**Corn,1993**			**Corn,1994**			**Soybeans,1995**			**Barley,1996**		
		Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
C	150	5514	438	39	6521	684	39	3129	545	39	2160	942	39
DY	100	4700	498	3	6697	318	3	2598	1229	3	969	440	3
DY	150	4038	1670	25	6840	564	25	3170	477	25	1791	853	25
O	0	3073	989	32	2508	813	32	2896	587	32	1656	797	32
ST	0	2986	0	1	2346	0	1	3080	0	1	950	0	1
ST	50	4484	1298	20	4614	1092	20	2872	450	20	2032	1050	20
ST	100	4971	846	17	6120	714	17	2809	561	17	2086	801	17
ST	150	3221	654	2	7663	64	2	3396	202	2	1057	69	2
SD= standard deviation, n=sample #													

Measured Crop Yield on Paired Locations (kg/ ha)														
Block Number	**Treatment**	**Fertilizer Rate** kg N/ha	**Corn,1993**			**Corn,1994**			**Soybeans,1995**			**Barley,1996**		
			Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n
1	O	0	2788	665	4	2816	739	4	2114	698	4	1492	689	4
2	C	150	5750	457	4	6720	623	4	3087	330	4	2767	232	4
4	ST	100	4482	317	3	6518	569	3	2856	490	3	1634	132	3
4	ST	150	3221	654	2	7663	64	2	3396	202	2	1057	69	2
5	C	150	5612	396	6	6738	410	6	2837	427	6	1247	342	6
6	DY	100	5252	0	1	6393	0	1	1881	0	1	775	0	1
6	DY	150	5725	445	4	6997	690	4	2430	172	4	1429	234	4
7	O	0	2810	1180	14	2490	810	14	3133	282	14	2331	660	14
8	DY	100	4563	0	1	7027	0	1	1896	0	1	1473	0	1
8	DY	150	2675	1110	13	6770	494	13	3247	256	13	2397	637	13
9	C	150	5518	401	21	6503	603	21	3198	583	21	2751	563	21
10	ST	50	5562	430	10	4275	569	10	2807	274	10	3002	441	10
10	ST	100	5478	390	11	5838	627	11	2724	647	11	2523	581	11
11	O	0	3417	782	14	2437	871	14	2883	619	14	1027	214	14
12	ST	0	2986	0	1	2346	0	1	3080	0	1	950	0	1
12	ST	50	3406	890	10	4954	1392	10	2938	586	10	1062	207	10
12	ST	100	3599	518	3	6760	705	3	3077	188	3	937	291	3
13	C	150	5313	542	8	6306	1047	8	3189	611	8	991	524	8
14	DY	100	4285	0	1	6672	0	1	4018	0	1	659	0	1
14	DY	150	5409	377	8	6876	667	8	3416	512	8	986	528	8

Table 8.Soil profile mineral N to 90 cm depth for Site S1.

Total Soil Mineral Nitrogen (kg N ha^{-1})											
BLOCK	**Treatment CODE**	**Fertilizer Rate KgN ha^{-1}**	**Fall,1993**			**Spring,1994**			**Diff**		
			Mean	**SDev**	**n**	**Mean**	**SDev**	**n**	**Mean**	**SDev**	**n**
1	**C**	150	225	76	21	93	36	23	132	69	21
3	**C**	150	198	86	22	86	40	22	111	75	22
5	**C**	150	194	78	22	95	39	22	99	51	22
7	**C**	150	258	88	18	103	38	18	155	80	18
Average		150	**217**	**86**	**83**	**94**	**39**	**85**	**123**	**72**	**83**
2	**O**	0	157	59	22	89	39	22	68	55	22
4	**O**	0	126	43	22	80	29	22	46	39	22
6	**O**	0	186	80	23	87	26	23	99	69	23
8	**O**	0	193	101	7	74	23	7	119	79	7
Average		0	**160**	72	74	**84**	31	74	**76**	64	74

Table 9. Measured soil solution sampler Nitrate N values.

Slope Position	**Site S1 : Solution Sampler Nitrate N** (mg/L)					
	Fall 1993		Spring 1994		Fall 1994	
	Unfertilized	Fertilized	Unfertilized	Fertilized	Unfertilized	Fertilized
Crest	6.2	37.6	12.1	12	24.7	25.4
Shoulder	4.5	35.1	9.8	10.8	5.6	16
Upper Back	5.5	50.1	6.7	13.4	22.2	42.4
Lower Back	7	13.2	10.1	14.1	13.4	18.4
Depression	2	10.8	9.5	32.2	3.1	18.3
Average	**5**	**29.4**	**9.6**	**16.5**	**13.8**	**24.1**
	Site S2 : Solution Sampler Nitrate N (mg/L)					
Crest	3	3.2	0.8	5.6	0.4	0.2
Shoulder	0.3	5.5	5.9	4.4	6.3	16
Upper Back	0.8	3.1	3.3	25.6	3.8	30.9
Lower Back	2.4	5.5	3.4	8.2	1.7	5.2
Depression	6.7	13	7.1	7.1	5.2	24.5
Average	**2.6**	**6.1**	**4.1**	**10.2**	**3.5**	**15.4**

Table 10. 28 % N applicator modification and budget.

Part name	Approximate Cost	Supplier and Notes
T Fittings	$4 each (2 req.)	Any spray equipment supplier
Solenoid valves	$190 each (2 req.)	Any spray equipment supplier
Relief valve	$32 each	Any spray equipment supplier
Gate valve	$12 each	Any spray equipment supplier
Flow divider	$800	John Blue
toggle switch	$10	Any 12 volt electrical supplier
hose bibs	$0.50 each (12 req.)	Any spray equipment supplier
	Total cost: $1250 Approx	

Table 11.Revenue Gains from and Cost of Applied Nitrogen for Alternative Fertility Distributions and Different Fertilizer Application Methods.

Fertility Distribution			Revenue Gains ($ ha^{-1})			Cost of Applied Nitrogen ($ ha^{-1})		
			Fertilizer Application Method			Fertilizer Application Method		
Corr-coeff.	CV (%)	Mean (kg ha^{-1})	CRT (MU size = 1500m)	3-Rate VRT (MU size = 100m)	Multiple Rate VRT (MU size = 1.5m)	CRT (Musize = 1500m)	3-Rate VRT (MU size = 1500m)	Multiple Rate VRT (MU size = 1500m)
0.6	50	8	309.46	324.28	372.38	102.24	113.75	118.32
		55	890.24	851.18	904.24	177.84	160.85	177.62
		30	2133.45	2131.75	2124.74	246.08	246.56	231.45
	25	80	159.02	186.69	173.4	103.41	130.01	105.47
		55	473.7	415.02	485.38	175.56	139.76	175.52
		30	2244.65	2244.97	2239.01	249.3	250.5	241.47
	10	80	139.62	166.88	141.33	103.22	132.63	103.22
		55	371.42	308.16	373.02	176.58	132.63	176.58
		30	2438.33	2438.63	2435.69	249.74	250.5	246.68
0.3	50	80	305.69	329.08	368.1	102.68	119.97	118.37
		55	890.64	833.31	905.38	177.11	146.94	177.17
		30	2123.06	2121.7	2114.16	246.06	246.45	231
	25	80	158.13	189.19	172.67	103.05	132.63	105.21
		55	470.02	404.28	481.71	175.53	134.33	175.5
		30	2241.59	2241.85	2235.88	249.5	250.5	241.47
	10	80	140.36	167.33	142.1	103.59	132.63	103.59
		55	359.99	306.3	361.57	174.5	132.63	174.5
		30	2423.8	2424.18	2421.14	249.54	250.5	246.53
0.1	50	80	311.2	347.2	375.27	102.87	127.83	118.95
		55	877.95	817.69	893.26	175.58	140.12	175.88
		30	2161.52	2161.82	2151.59	248.75	250.5	233.28
	25	80	152.9	186.39	167.95	100.58	132.63	102.93
		55	472.33	404.25	483.71	176.04	133.02	176
		30	2256.95	2257.12	2251.28	249.81	250.5	241.67
	10	80	140	167.17	141.78	103.37	132.63	103.37
		55	360.15	306.43	361.75	174.5	132.63	174.5
		30	2427.25	2427.59	2424.56	249.63	250.5	246.54

* Price of corn = $1.5

Table 12. Information and Application Costs Associated with Different Fertilizer Application Methods for a 50 ha Field.

Source	Fertilizer Application Method					
	CRT		3-way VRT		Continuous VRT	
INFORMATION COSTS						
Variable Costs						
Core Sampling	12.5		12.5			
Lab Analysis ($12/sample)	60		600			
Map Making			425			
Opportunity Cost of Check Strips					21.49	
Per Hectare Cost	1.05		20.75			
Annualized Cost (3 years)		0.39		7.62		7.89
Fixed Costs						
Ag Navigator (Yield Monitoring)					13600	
Differential Correction Source					3000	
Per Hectare Cost					332	
Annualized Cost (5 years)						76.7
APPLICATION COSTS						
Variable Costs						
Nitrogen Application -Fuel	1		1		1	
-Labor	0.83		0.83		0.83	
Per Hectare Annual Cost		1.83	1.83	1.83		1.83
Fixed Costs						
Fertilizer Spreader	8000		8000		8000	
Per Hectare Cost	160		160		160	
Annualized Cost (10 years)		20.72		20.72		20.7
Fertilizer Rate Controler			1500		4500	
VRT Option					950	
Other Options					2260	
Per Hectare Cost			30		154.2	
Annualized Cost (5 years)				6.93		35.6
Total Per Hectare Annualized Cost		22.94		37.1		143

Table 13. Net Returns ($ ha^{-1}/year) for Different Application Scenarios and Fertility Distributions for a Discount rate of 5% and 5 Years of Life for Variable Rate Equipment.

Fertility Distribution			**Net Returns for 50 ha Area**			**Net Returns for 200 ha Area**			**Net Returns for 500 ha Area**		
Mean (kg ha^{-1})	CV (%)	Correlation Coefficient	CRT	3-rate VRT	Continuous VRT	CRT	3-rate VRT	Continuous VRT	CRT	3-rate VRT	Continuous VRT
80	50	0.6	184.28	184.27	111.36	200.11	210.72	217.01	203.28	216.01	238.14
		0.3	180.08	181.25	107.04	195.91	207.7	212.69	199.08	212.99	233.82
		0.1	185.39	188.01	113.61	201.22	214.46	219.26	204.39	219.75	240.39
	25	0.6	32.67	18.55	-74.76	48.5	45	30.89	51.67	50.29	52.02
		0.3	32.14	17.9	-75.24	47.97	44.35	30.41	51.14	49.64	51.54
		0.1	29.39	14.92	-77.65	45.22	41.37	28	48.39	46.66	49.13
55	50	0.6	689.46	658.99	583.93	705.29	685.44	689.58	708.46	690.73	710.71
		0.3	690.59	660.29	585.52	706.42	686.74	691.17	709.59	692.03	712.3
		0.1	679.44	651.29	574.68	695.27	677.74	680.33	698.44	683.03	701.46
	25	0.6	275.21	247.38	167.16	291.04	273.83	272.81	294.21	279.12	293.94
		0.3	271.55	243.79	163.51	287.38	270.24	269.16	290.55	275.53	290.29
		0.1	273.35	245.39	165.02	289.18	271.84	270.67	292.35	277.13	291.8

Table 14. Applied Nitrogen and Yield Gain* (kg ha^{-1}) for Alternative Fertility Distributions and Management Unit Size in meters (Number of Management Units).

Fertility Distribution			Management Unit Size (Number of Management Units)										
Mean	Corr-Coeff	CV (%)	1500 -1	750 -2	500 -3	300 -5	150 -10	60 -25	30 -50	15 -100	6 -250	3 -500	1.5 -1000
80	0.6	50	68.16	68.16	68.16	68.16	68.16	68.28	68.74	70.67	74.01	76.63	78.88
			1031.53	**1032.12**	**1032.35**	**1034.24**	**1037.66**	**1046.71**	**1066.39**	**1104.07**	**1165.66**	**1207.4**	**1241.27**
		25	68.94	68.94	68.94	68.94	68.94	68.94	68.94	68.97	69.32	69.77	70.31
			530.05	**530.23**	**530.31**	**530.58**	**531.45**	**533.85**	**538.03**	**545.1**	**558.27**	**568.38**	**578**
		10	68.81	68.81	68.81	68.81	68.81	68.81	68.81	68.81	68.81	68.81	68.81
			465.4	**465.41**	**465.45**	**465.5**	**465.62**	**465.94**	**466.34**	**467.2**	**468.77**	**469.95**	**471.1**
	0.3	50	68.45	68.45	68.45	68.45	68.45	68.45	68.56	69.09	71.44	74.77	78.91
			1018.97	**1019.46**	**1019.59**	**1020.53**	**1021.97**	**1026.63**	**1034.82**	**1053.1**	**1102.8**	**1159.04**	**1227.01**
		25	68.7	68.7	68.7	68.7	68.7	68.7	68.7	68.71	68.83	69.25	70.14
			527.09	**527.16**	**527.25**	**527.42**	**527.97**	**529.27**	**531.4**	**535.54**	**545.06**	**558.28**	**575.57**
		10	69.06	69.06	69.06	69.06	69.06	69.06	69.06	69.06	69.06	69.06	69.06
			467.88	**467.89**	**467.91**	**467.94**	**467.99**	**468.17**	**468.46**	**468.96**	**470.22**	**471.74**	**473.68**
	0.1	50	68.58	68.58	68.58	68.58	68.58	68.58	68.59	68.72	70.44	73.88	79.3
			1037.34	**1037.66**	**1037.68**	**1038.45**	**1039.64**	**1042.65**	**1047.79**	**1056.86**	**1095.51**	**1157.77**	**1250.89**
		25	67.05	67.05	67.05	67.05	67.05	67.05	67.05	67.05	67.08	67.37	68.62
			509.67	**509.75**	**509.83**	**509.94**	**510.23**	**511.09**	**512.37**	**514.98**	**522.71**	**535.59**	**559.84**
		10	68.91	68.91	68.91	68.91	68.91	68.91	68.91	68.91	68.91	68.91	68.91
			466.67	**466.67**	**466.68**	**466.7**	**466.72**	**466.82**	**466.98**	**467.33**	**468.39**	**469.97**	**472.61**
55	0.6	50	118.56	118.56	118.56	118.56	118.56	118.56	118.55	118.44	118.27	118.36	118.41
			2967.47	**2967.47**	**2967.41**	**2967.1**	**2966.84**	**2964.99**	**2963.96**	**2965.89**	**2979.03**	**2996.35**	**3014.14**
		25	117.04	117.04	117.04	117.04	117.04	117.04	117.04	117.04	117.03	117.03	117.01
			1579.01	**1579.15**	**1579.48**	**1579.82**	**1580.64**	**1583.17**	**1587.53**	**1593.22**	**1603.72**	**1611.11**	**1617.93**
		10	117.72	117.72	117.72	117.72	117.72	117.72	117.72	117.72	117.72	117.72	117.72
			1238.07	**1238.09**	**1238.12**	**1238.16**	**1238.3**	**1238.57**	**1239.07**	**1239.89**	**1241.29**	**1242.39**	**1243.41**
	0.3	50	118.07	118.07	118.07	118.07	118.07	118.07	118.07	118.07	117.96	117.94	118.11
			2968.8	**2968.79**	**2968.65**	**2968.79**	**2968.15**	**2966.93**	**2965.57**	**2964.78**	**2968.24**	**2984.38**	**3017.95**
		25	117.02	117.02	117.02	117.02	117.02	117.02	117.02	117.02	117.02	117.02	117
			1566.73	**1566.85**	**1566.98**	**1567.1**	**1567.46**	**1568.66**	**1570.59**	**1573.96**	**1582.54**	**1592.86**	**1605.71**

Bolded Figures Represent Yield Gain

Table 15 Gross profits ($ ha^{-1}) for Alternative Fertility Distributions and Management Unit Size.

Fertility Distribution			**Management Unit Size** (Number of MUs= meters)										
Corr. Coeff	Mean	CV (%)	1500 -1	750 -2	500 -3	300 -5	150 -10	60 -25	30 -50	15 -100	6 -250	3 -500	1.5 -1000
0.6	80	50	207.22	207.4	207.47	208.03	209.06	211.59	216.8	225.21	238.68	247.28	254.06
		25	55.61	55.66	55.69	55.77	56.03	56.75	58	60.07	63.5	65.86	67.94
		10	36.4	36.4	36.41	36.43	36.47	36.56	36.68	36.94	37.41	37.76	38.11
	55	50	712.4	712.41	712.39	712.29	712.22	711.66	711.36	712.11	716.3	721.37	726.63
		25	298.15	298.19	298.29	298.39	298.64	299.4	300.71	302.41	305.57	307.79	309.86
		10	194.84	194.85	194.85	194.87	194.91	194.99	195.14	195.39	195.81	196.14	196.44
	30	50	1887.4	1887.7	1888	1888.4	1889	1889.8	1890.6	1890.9	1891.1	1891.8	1893.3
		25	1995.4	1995.5	1995.6	1995.7	1996	1996.5	1996.8	1997	1997.1	1997.2	1997.55
		10	2188.6	2188.6	2188.7	2188.7	2188.7	2188.8	2188.9	2189	2189	2189	2189.02
0.3	80	50	203.02	203.17	203.21	203.49	203.92	205.32	207.61	212.3	223.68	235.56	249.74
		25	55.08	55.1	55.13	55.18	55.35	55.73	56.37	57.6	60.27	63.61	67.46
		10	36.77	36.78	36.78	36.79	36.81	36.86	36.95	37.1	37.48	37.93	38.51
	55	50	713.53	713.53	713.49	713.53	713.34	712.97	712.56	712.33	713.53	718.4	728.22
		25	294.49	294.52	294.56	294.6	294.71	295.07	295.64	296.66	299.23	302.33	306.21
		10	185.49	185.5	185.5	185.5	185.52	185.57	185.63	185.76	186.11	186.53	187.07
	30	50	1877	1877.2	1877.4	1877.7	1878.2	1878.9	1879.6	1880.3	1880.9	1881.5	1883.16
		25	1992.1	1992.2	1992.3	1992.4	1992.6	1993	1993.3	1993.6	1993.9	1994	1994.41
		10	2174.3	2174.3	2174.3	2174.3	2174.3	2174.4	2174.5	2174.6	2174.6	2174.6	2174.62
0.1	80	50	208.33	208.43	208.44	208.67	209.02	209.93	211.46	213.98	222.99	236.52	256.31
		25	52.33	52.36	52.38	52.41	52.5	52.76	53.14	53.92	56.19	59.62	65.02
		10	36.64	36.64	36.64	36.65	36.66	36.68	36.73	36.84	37.16	37.63	38.42
	55	50	702.38	702.33	702.3	702.23	702.19	702.01	701.53	701.1	701.44	704.8	717.38
		25	296.29	296.3	296.32	296.36	296.43	296.71	297.11	297.8	299.86	302.79	307.72
		10	185.65	185.65	185.65	185.66	185.66	185.69	185.73	185.83	186.11	186.55	187.25
	30	50	1912.8	1912.9	1913	1913.2	1913.5	1914.3	1914.9	1915.7	1916.6	1916.9	1918.31
		25	2007.1	2007.2	2007.3	2007.4	2007.6	2007.9	2008.2	2008.6	2009.1	2009.3	2009.62
		10	2177.6	2177.6	2177.6	2177.6	2177.7	2177.7	2177.8	2177.9	2178	2178	2178.03

Figures

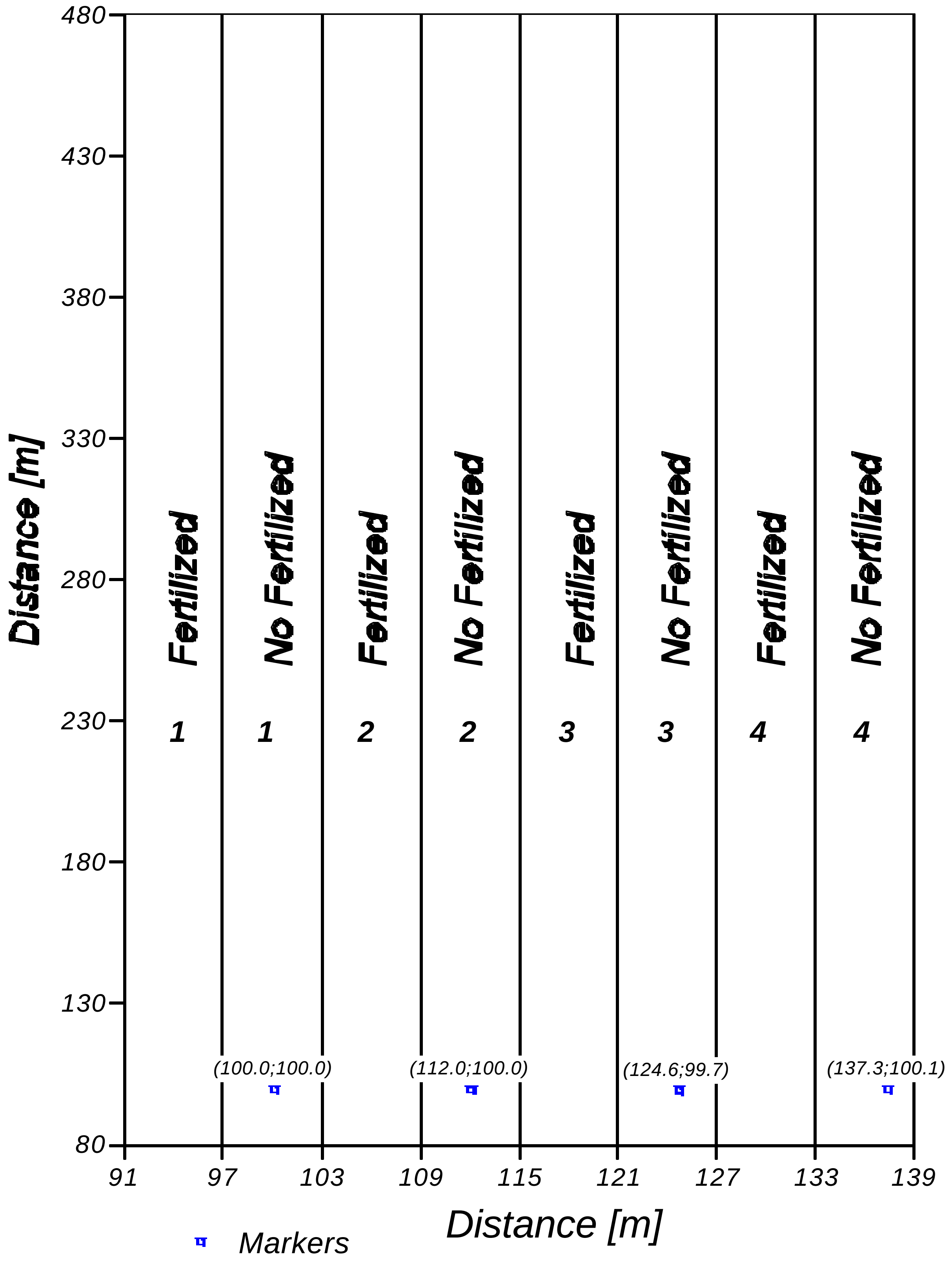


Figure 1. Schematic plot diagram for site S1, 1993.

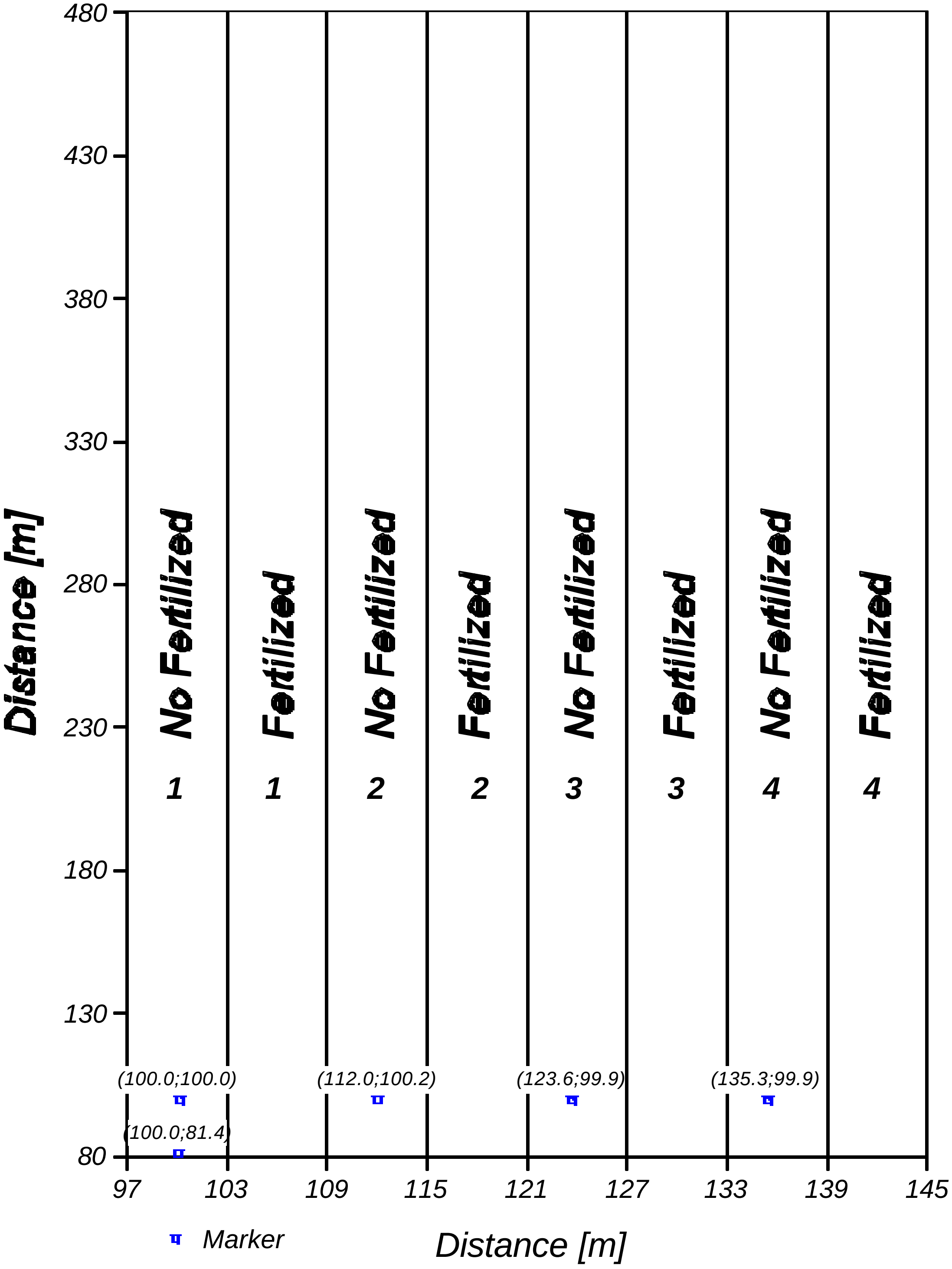


Figure 2. Schematic plot diagram for site S2, 1993.

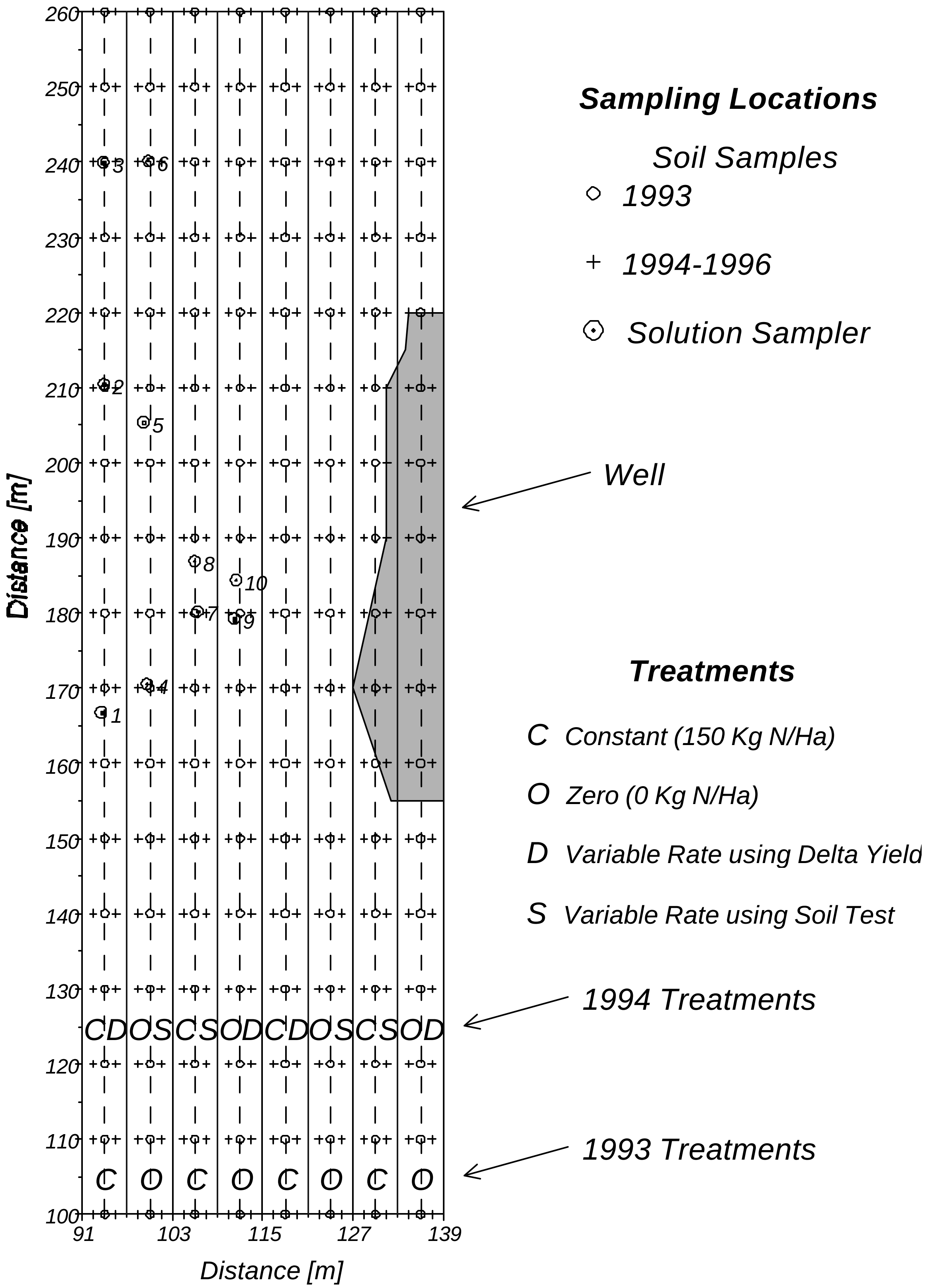


Figure 3. Schematic plot diagram for all years for Site S1.

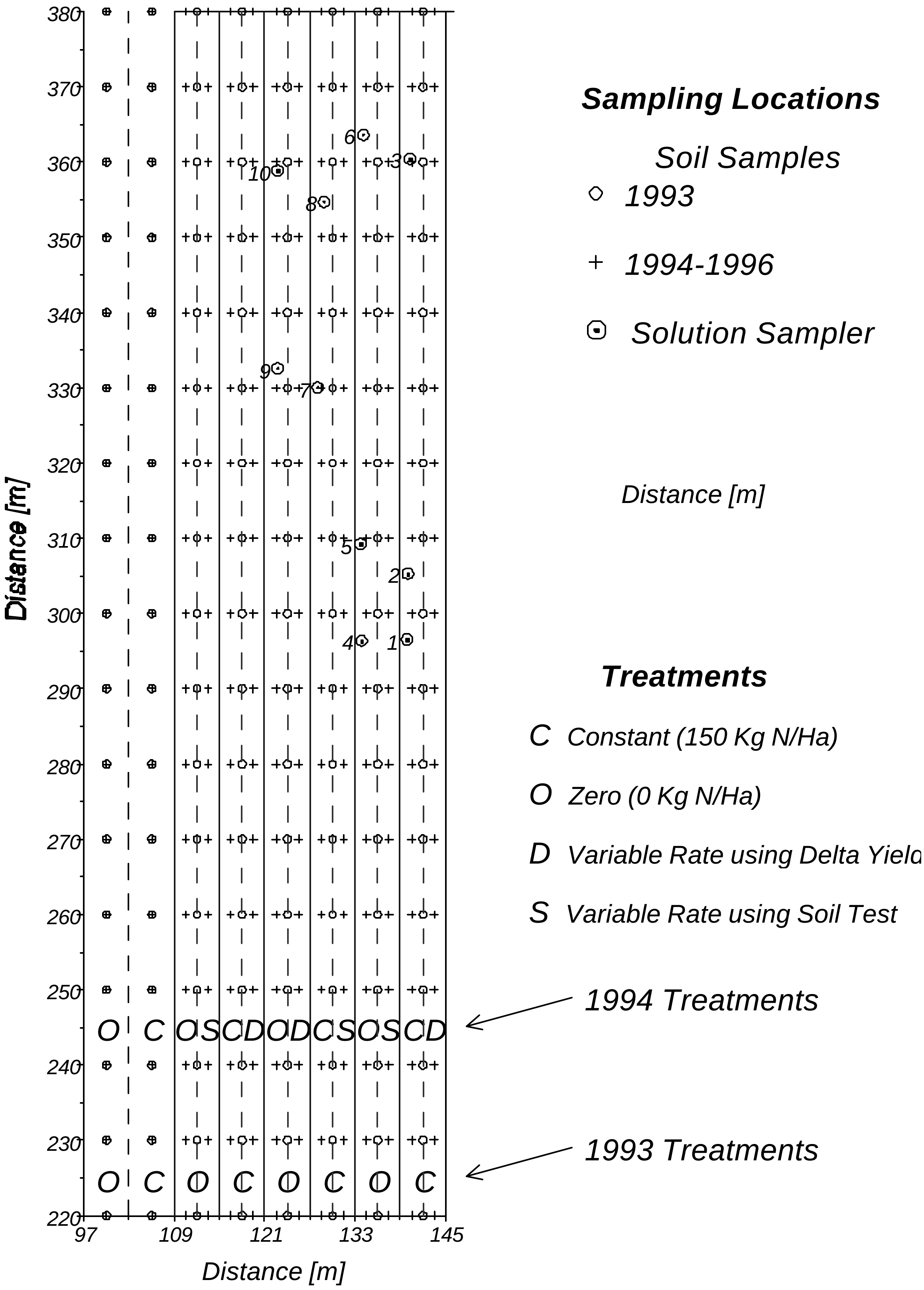


Figure 4. Schematic plot diagram for all years for Site S2.

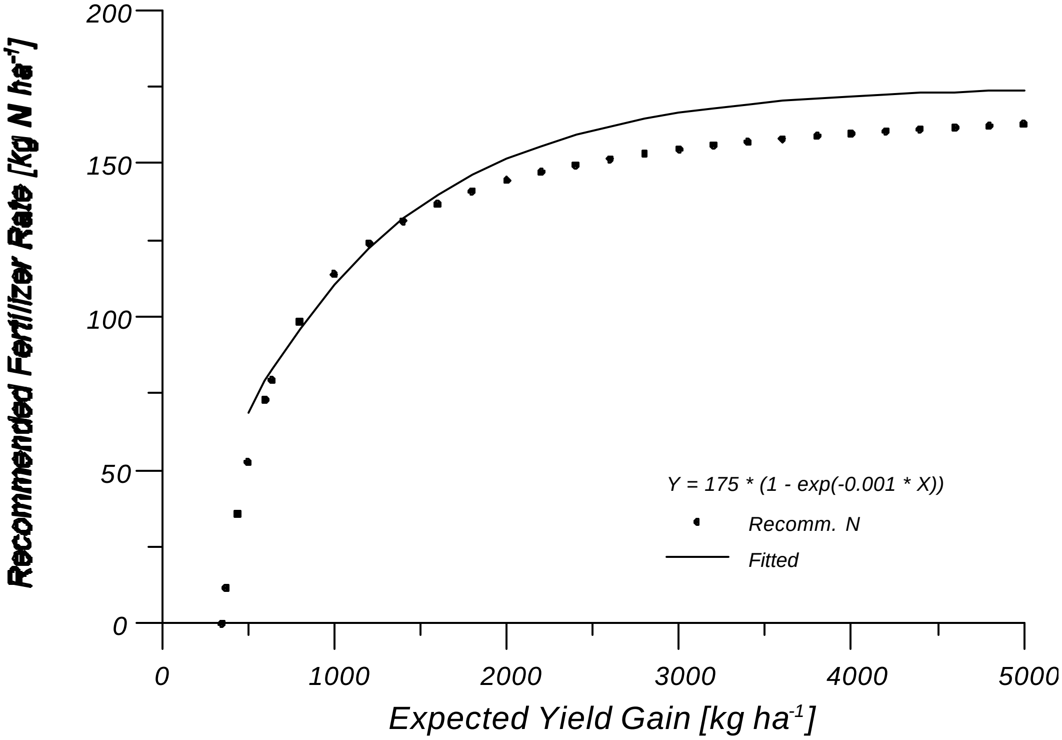


Figure 5. Average relationship between expected yield gain from adding N fertilizer and Recommended N Fertilizer rate.

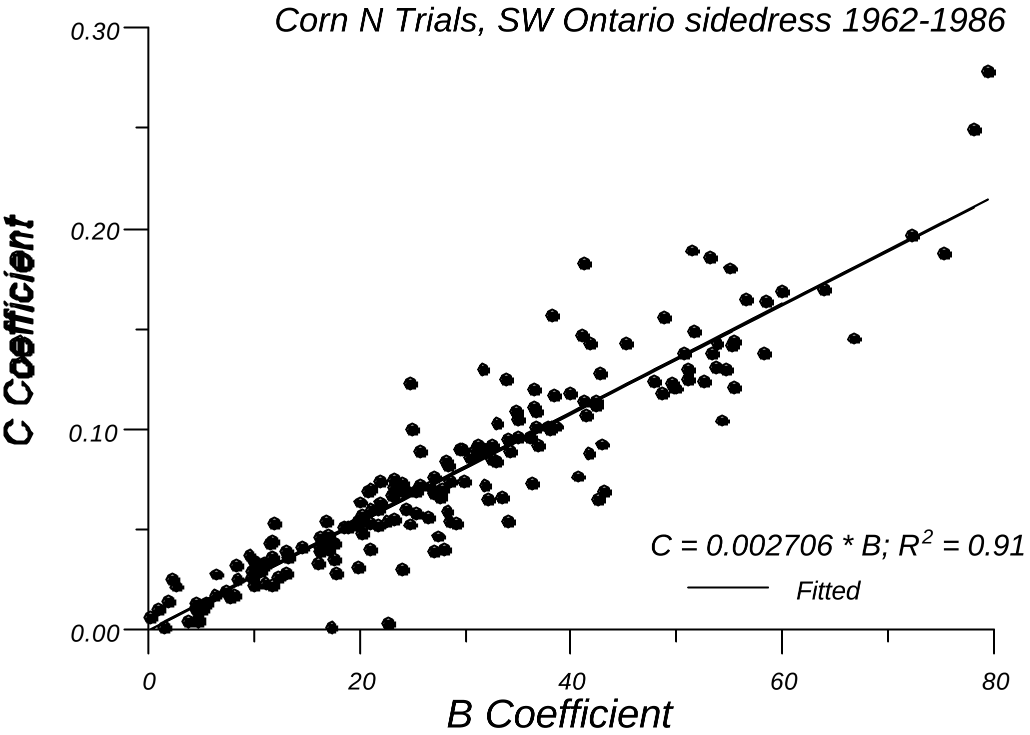


Figure 6. Relationship between the yield response coefficients B and C for Southwestern Ontario side dress N application.

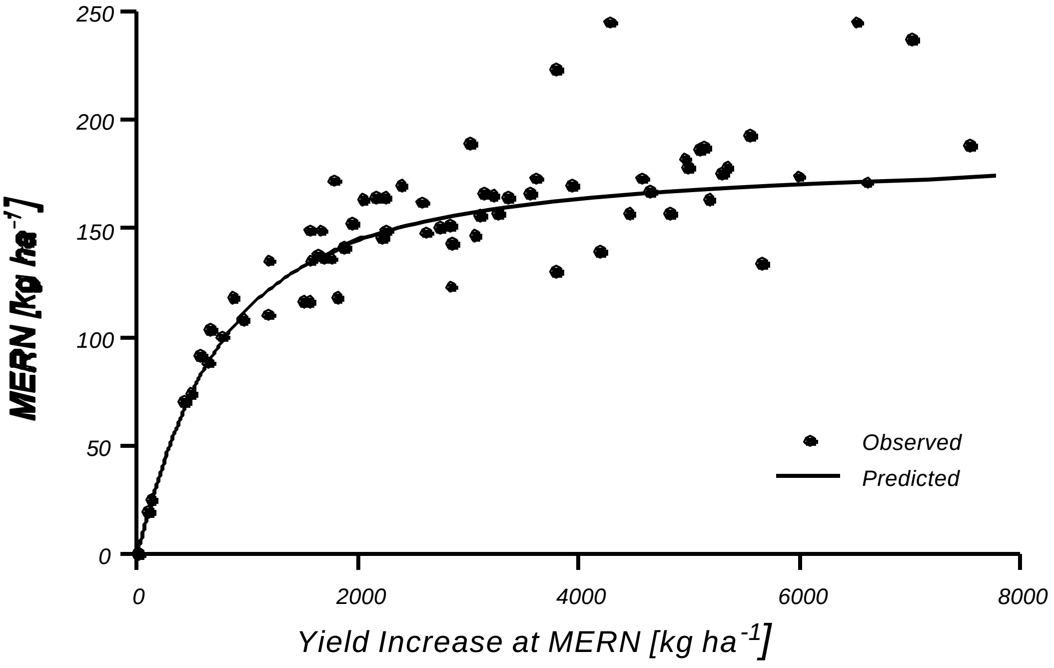


Figure 7. The predicted and measured relationship between Corn Delta Yield and Recommended N Rate for Southwestern Ontario side dress N application.

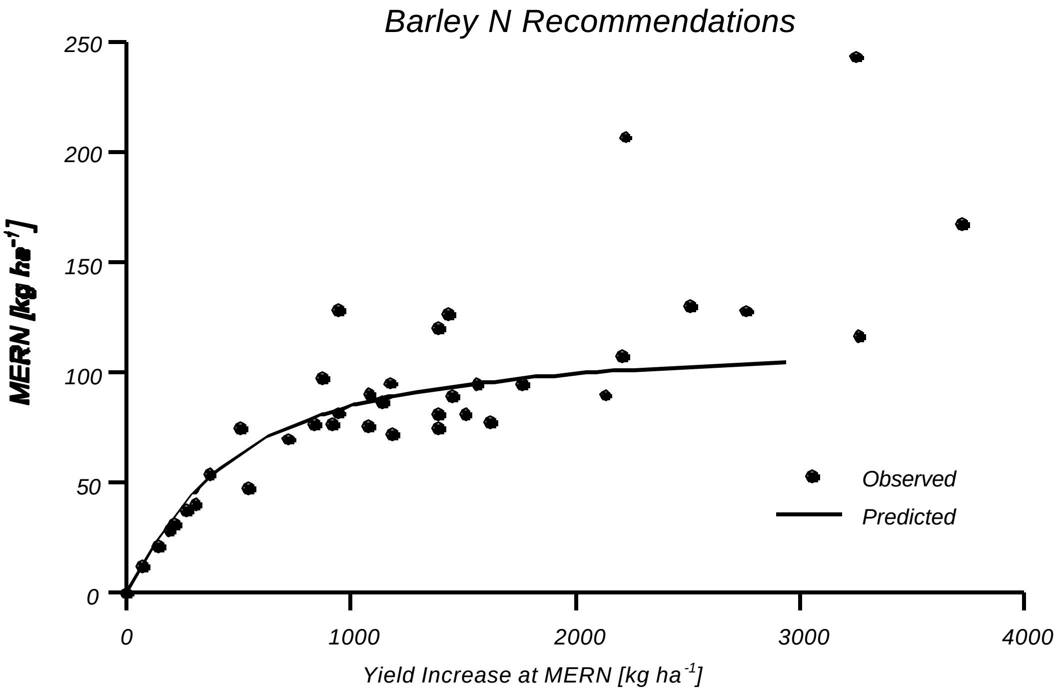


Figure 8. The predicted and measured relationship between Barley Delta Yield and Recommended N Rate for Ontario.

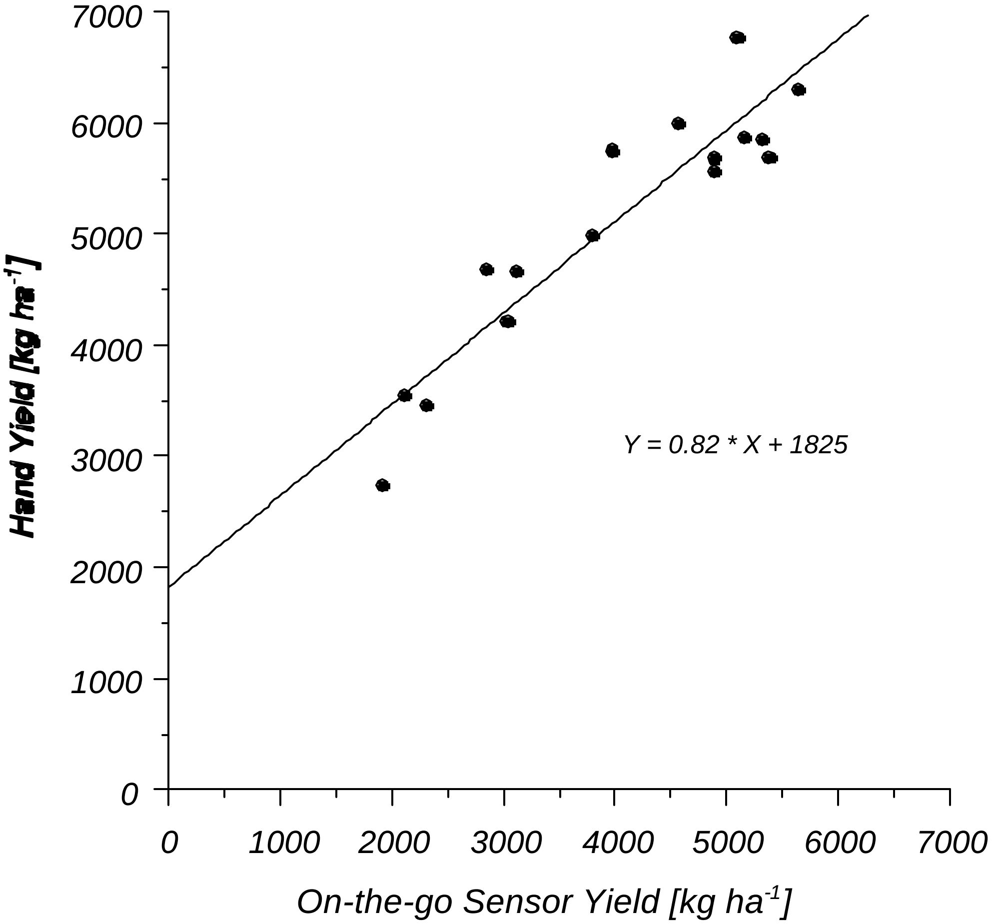


Figure 9. Comparison of average hand measured yields and on-the -go combine yield monitor measurements for major treatments blocks.

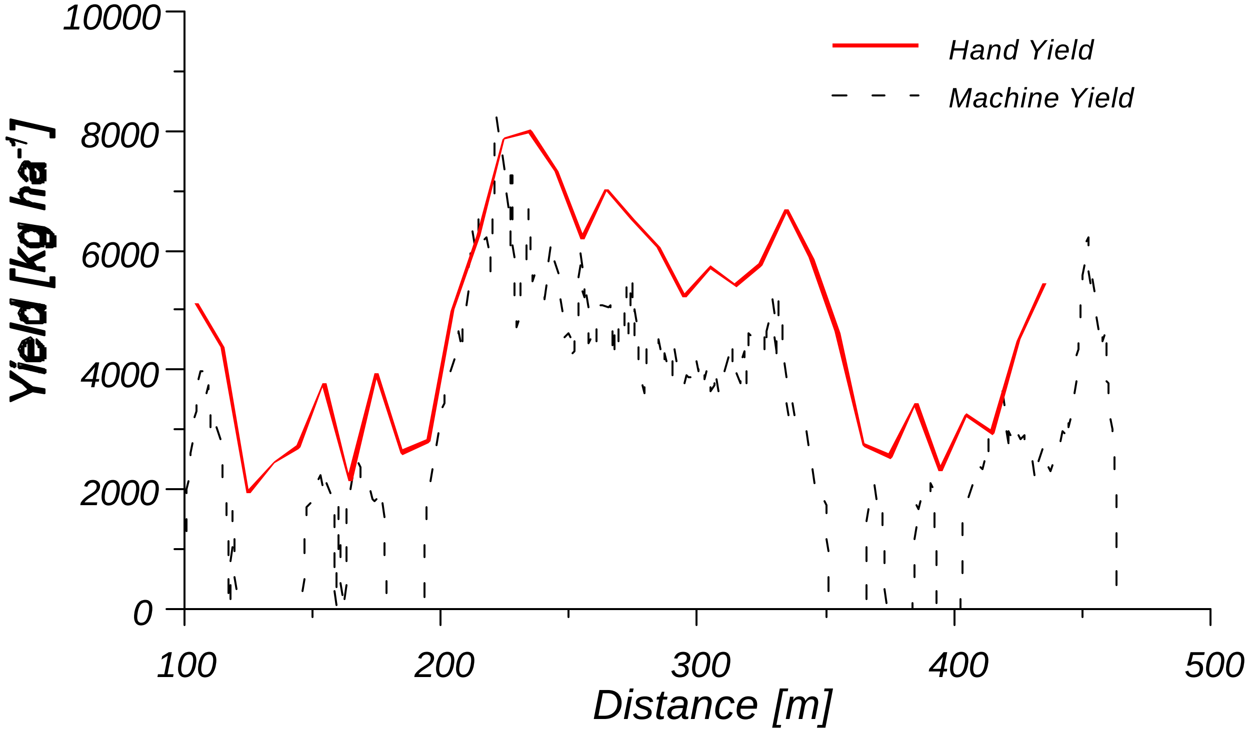


Figure 10. A comparison of the pattern of yield obtained from the combine monitor and from hand sampling for Site S1, Block 1.

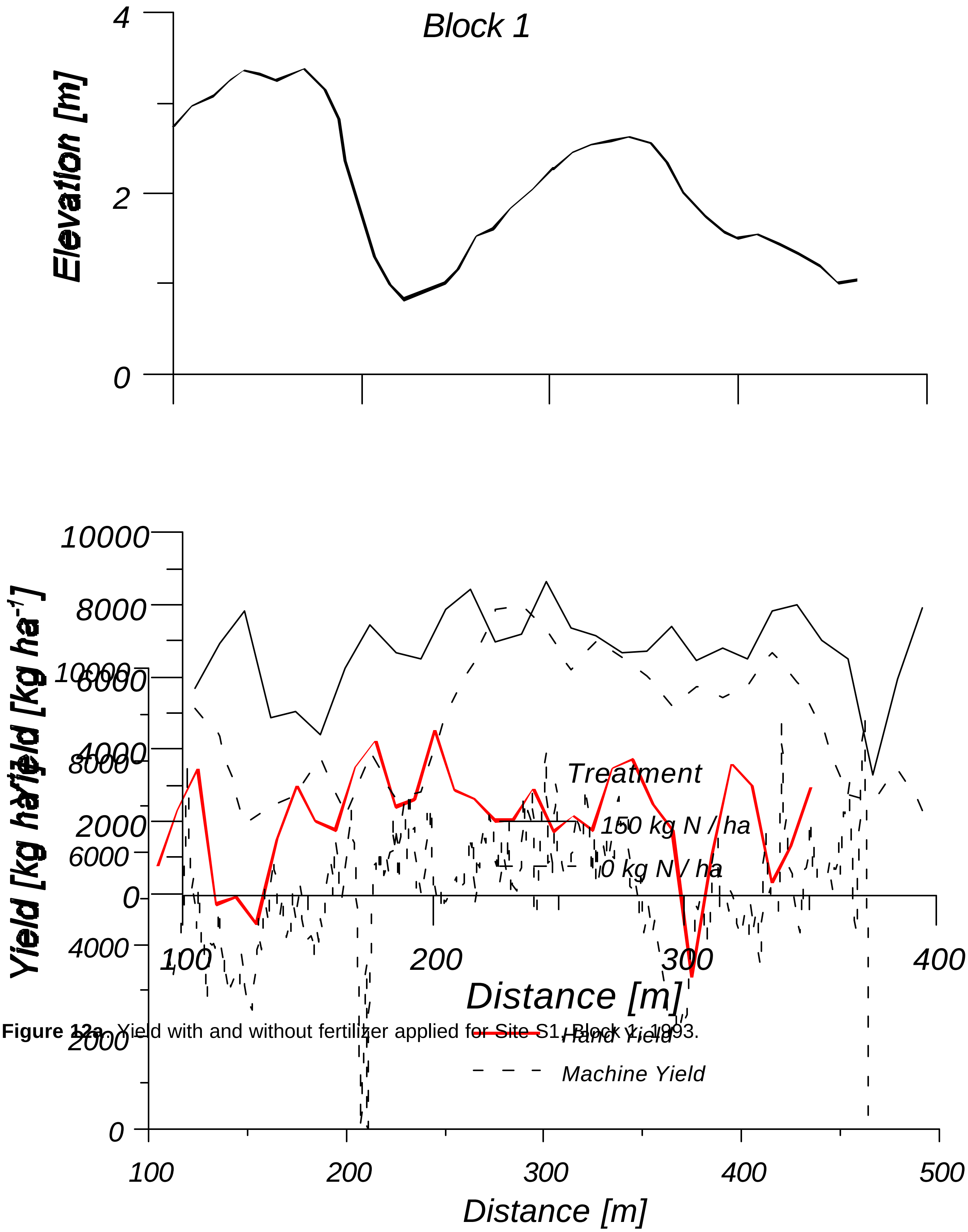


Figure 12a. Yield with and without fertilizer applied for Site S1, Block 1, 1993.

Figure 11. A comparison of the pattern of yield obtained from the combine monitor and from hand sampling for Site S1, Block 2.

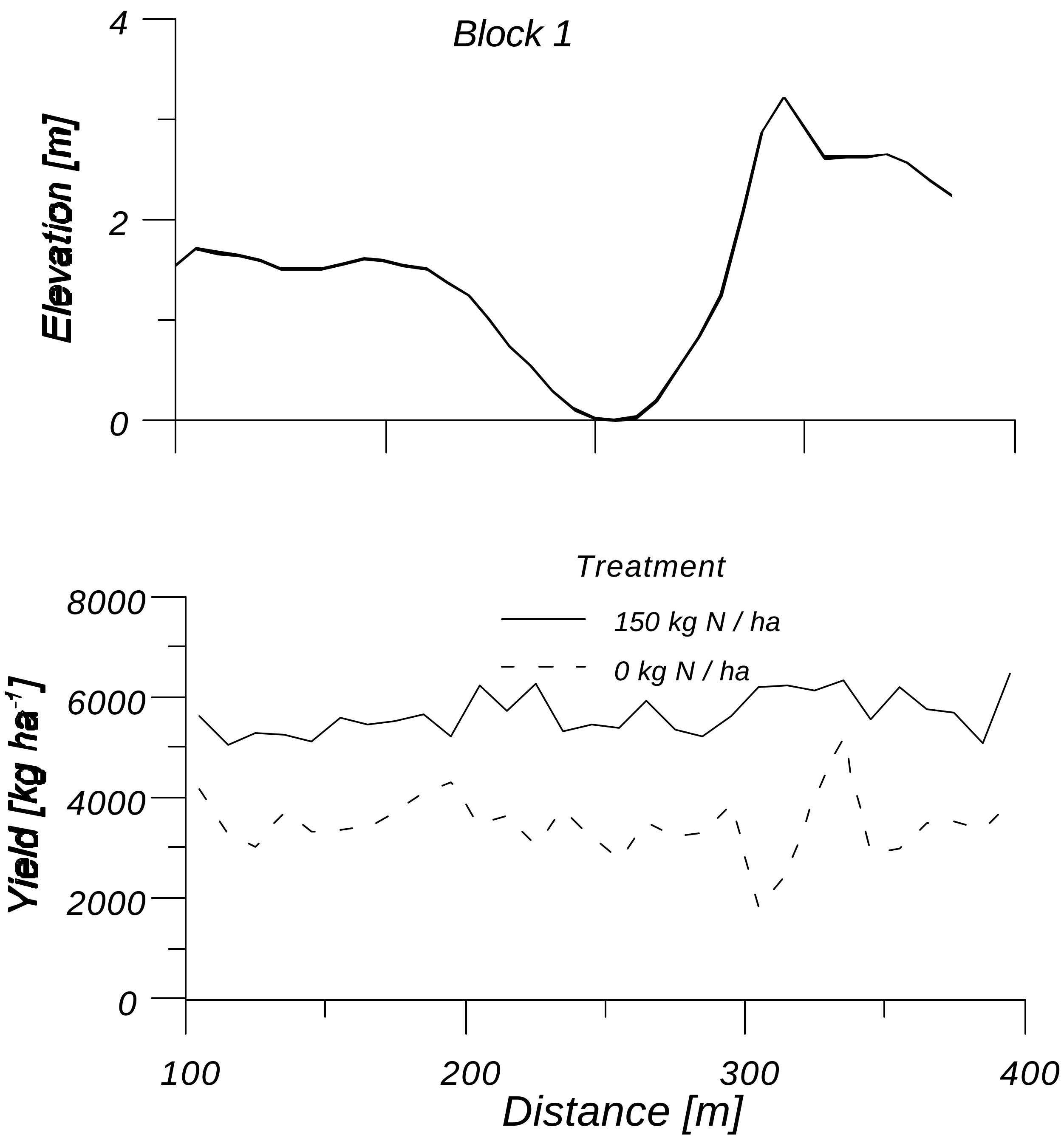


Figure 12 b. Yield with and without fertilizer applied for Site S2, Block 1, 1993.

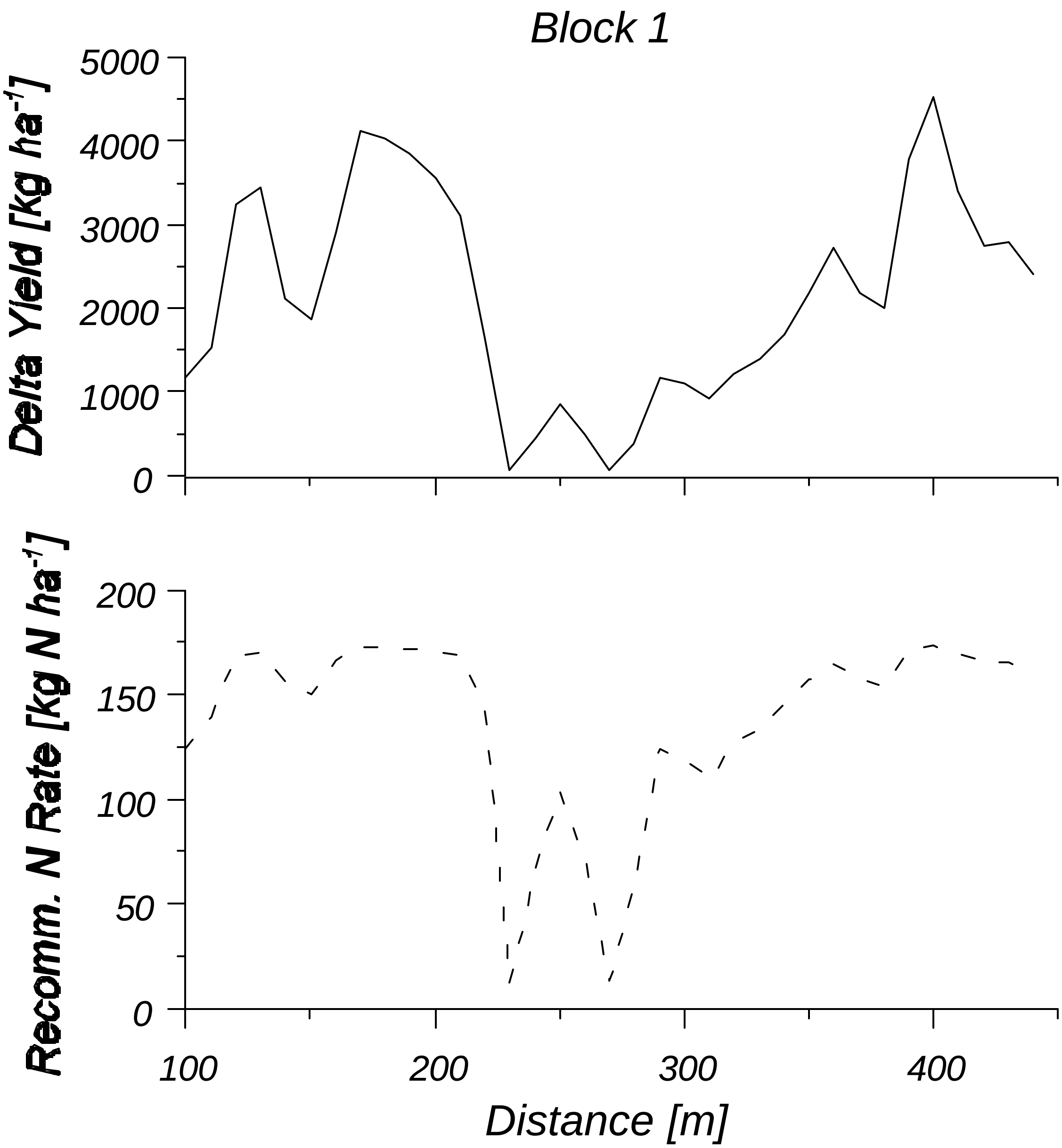


Figure 13a. Measured Delta Yield and corresponding Fertilizer Recommendation Rate for S1, Block 1, 1993.

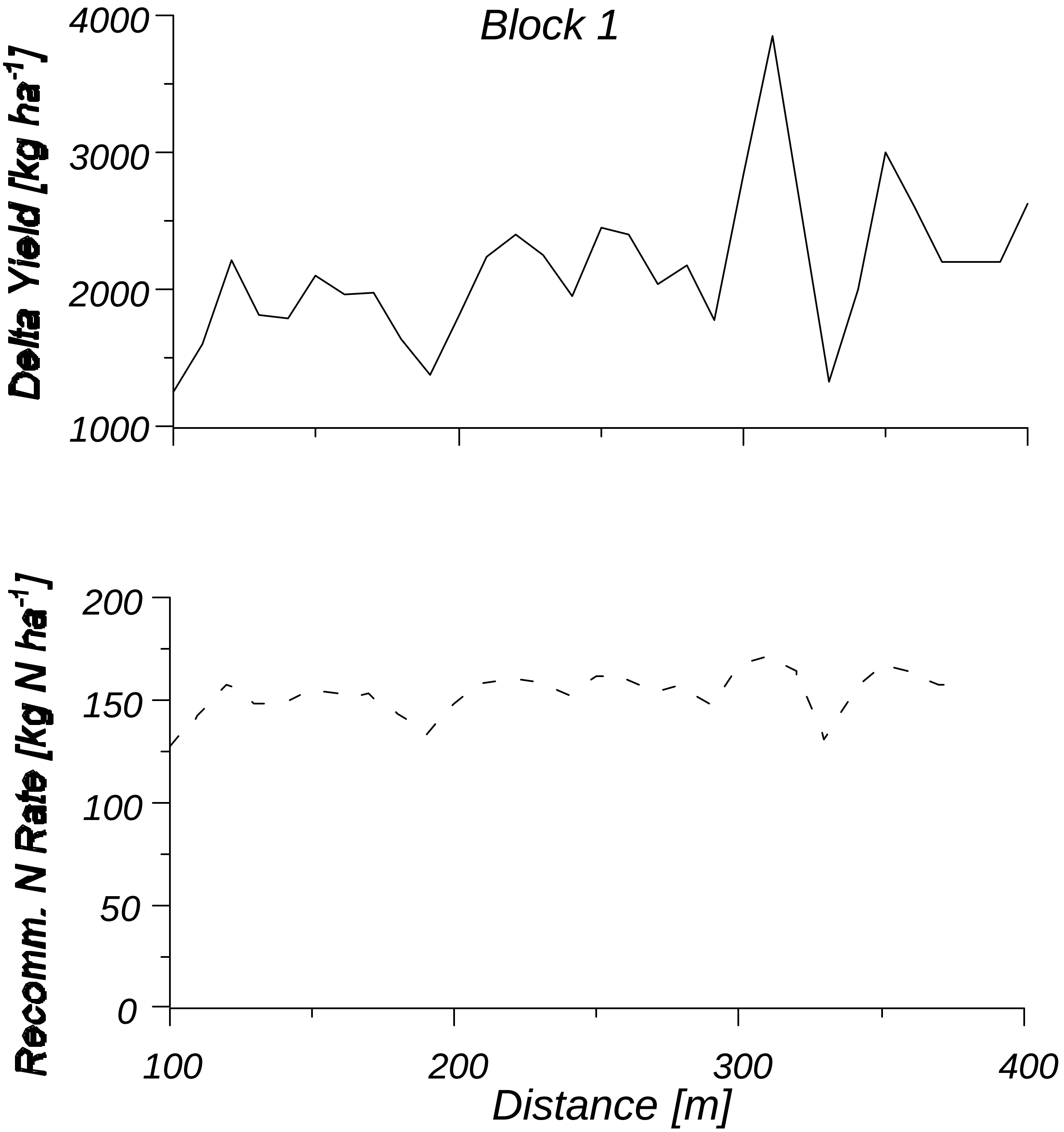


Figure 13b. Measured Delta Yield and corresponding Fertilizer Recommendation Rate for S2, Block 1, 1993.

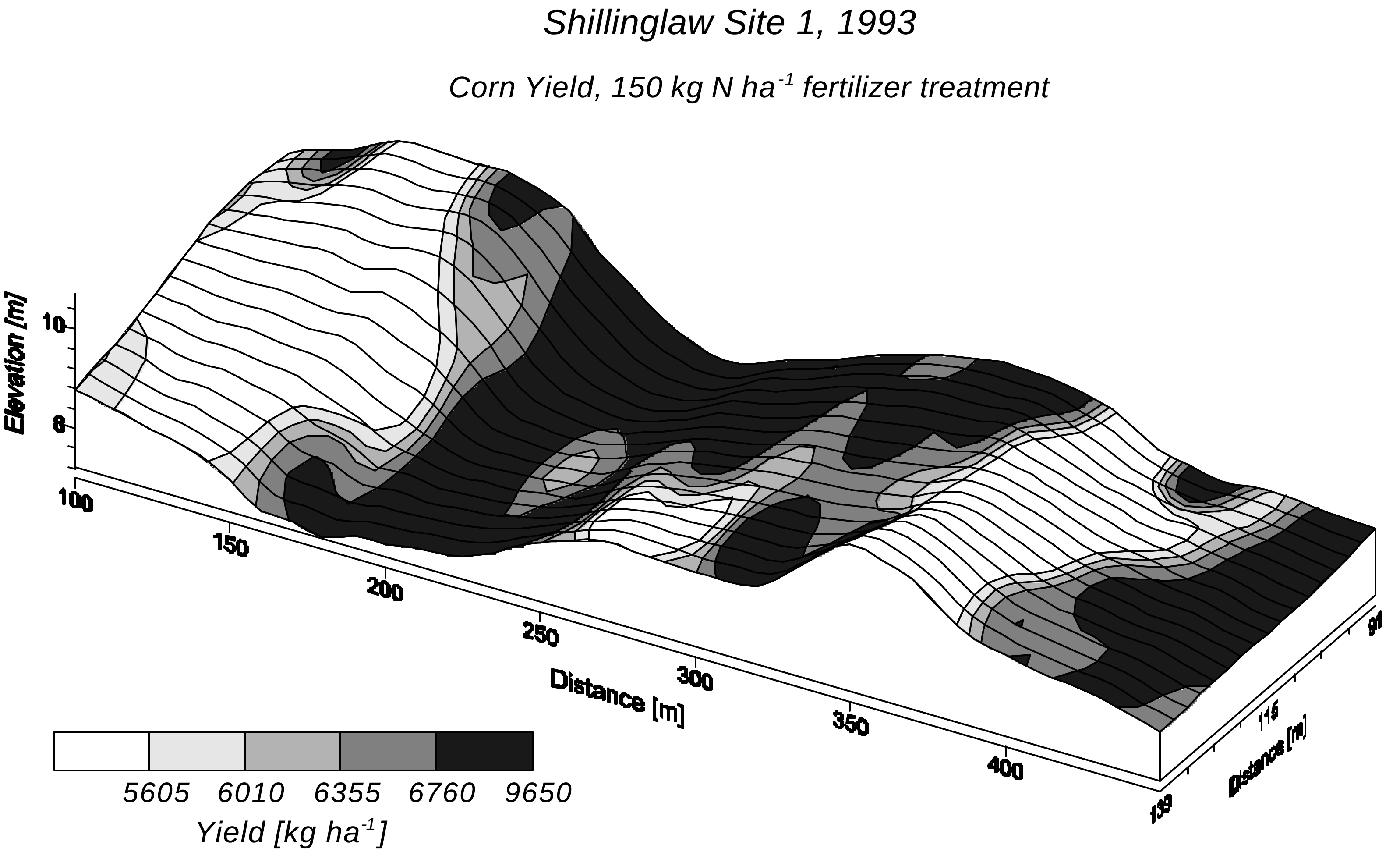


Figure 14a. Spatial distribution of fertilized yield for Site S1, 1993.

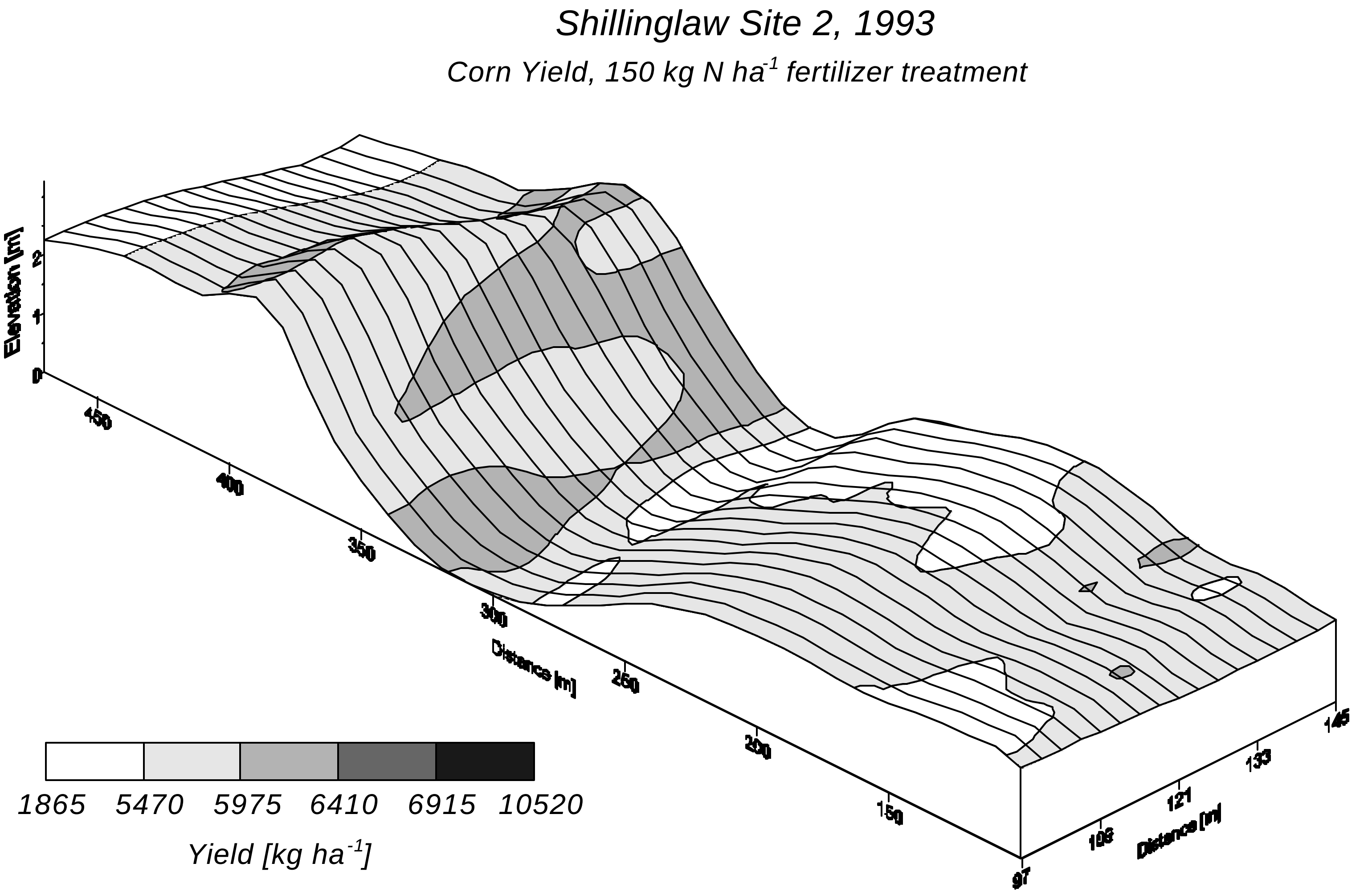
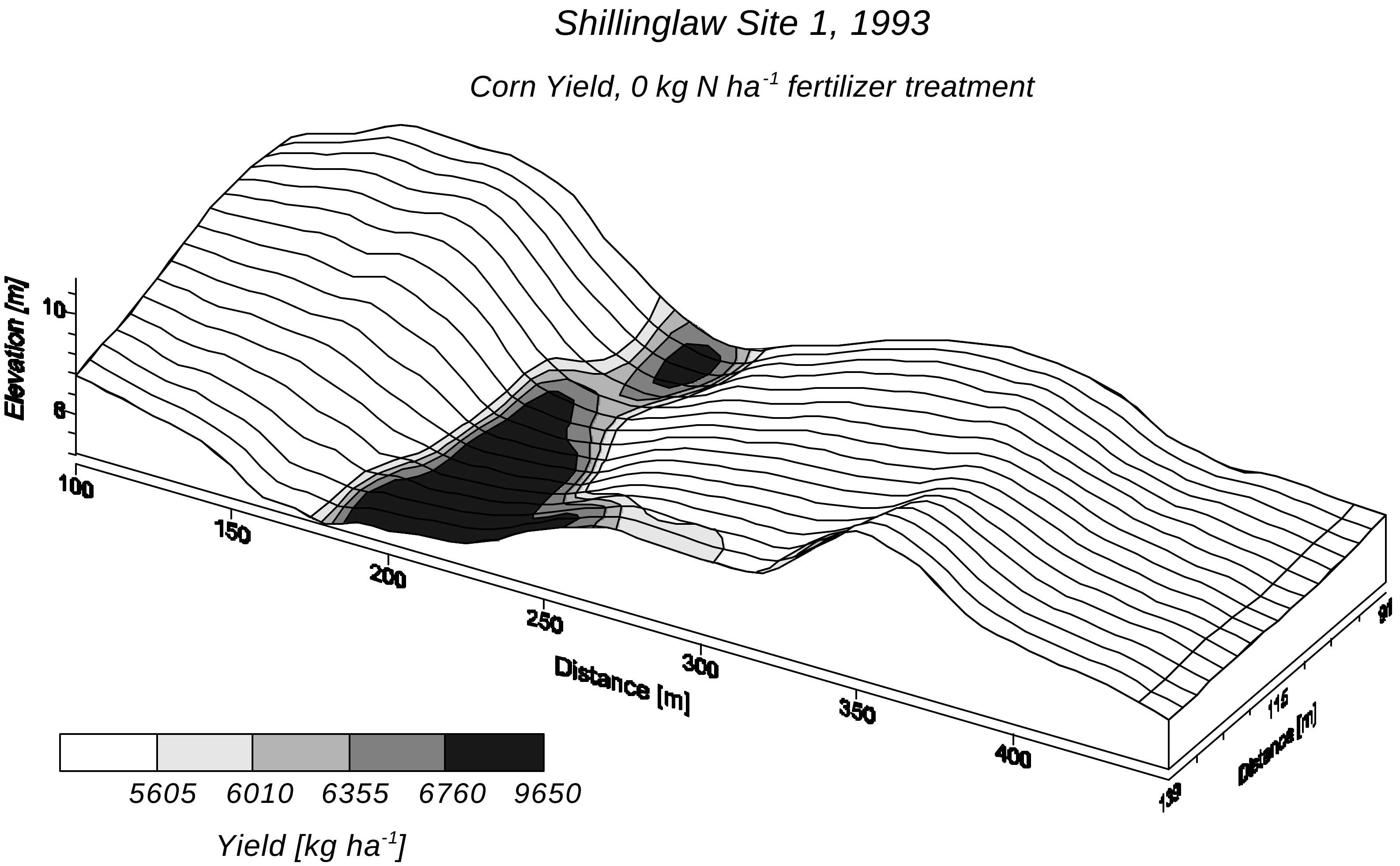


Figure 14b. Spatial distribution of fertilized yield for Site S2, 1993.



Shillinglaw Site 1, 1993

Corn Yield, 0 kg N ha^{-1} fertilizer treatment

Figure 15a. Spatial distribution of unfertilized yield for Site S1, 1993.

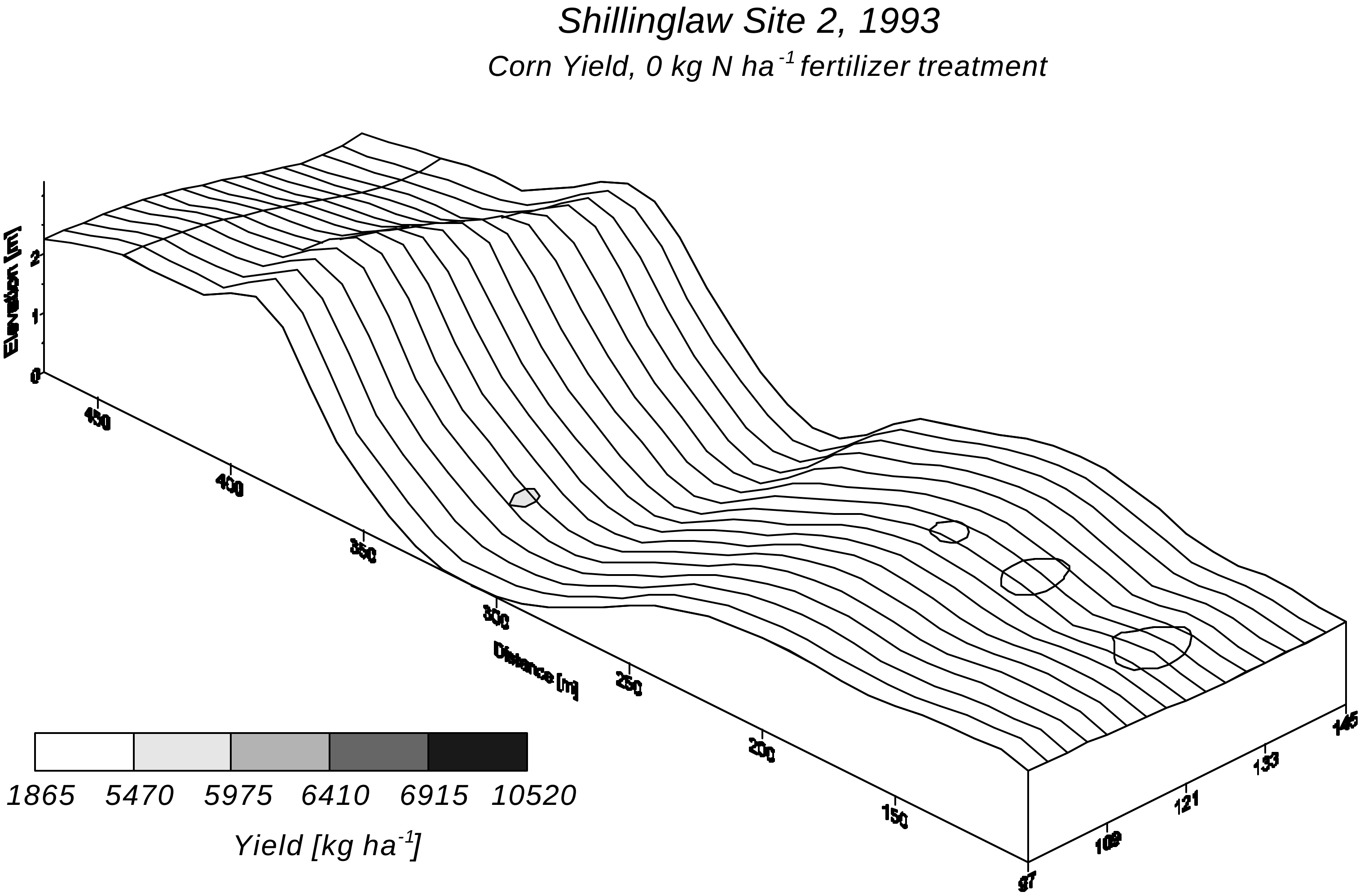


Figure 15b. Spatial distribution of unfertilized yield for Site S2, 1993.

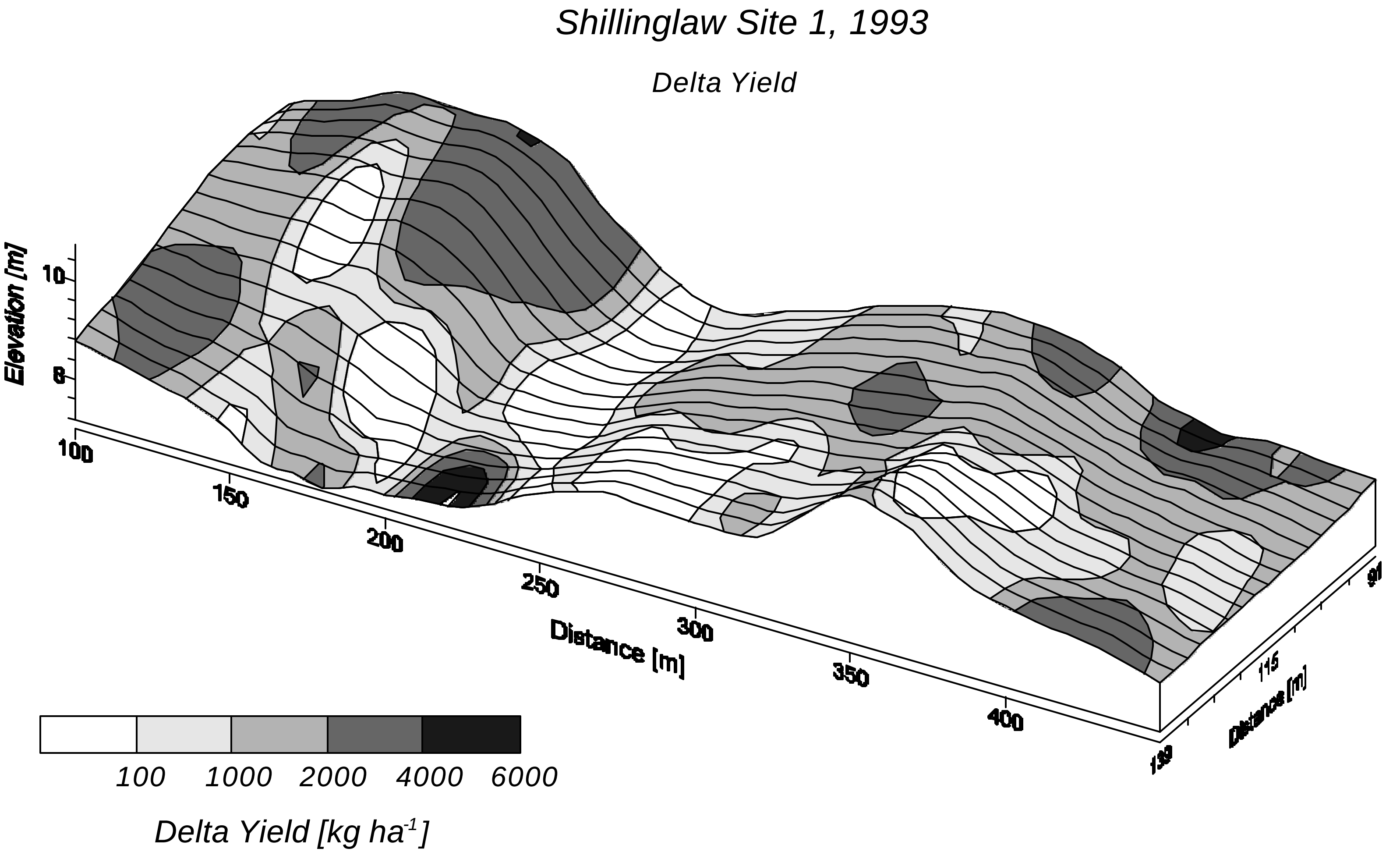


Figure 16a. Spatial distribution of Delta Yield for Site S1, 1993.

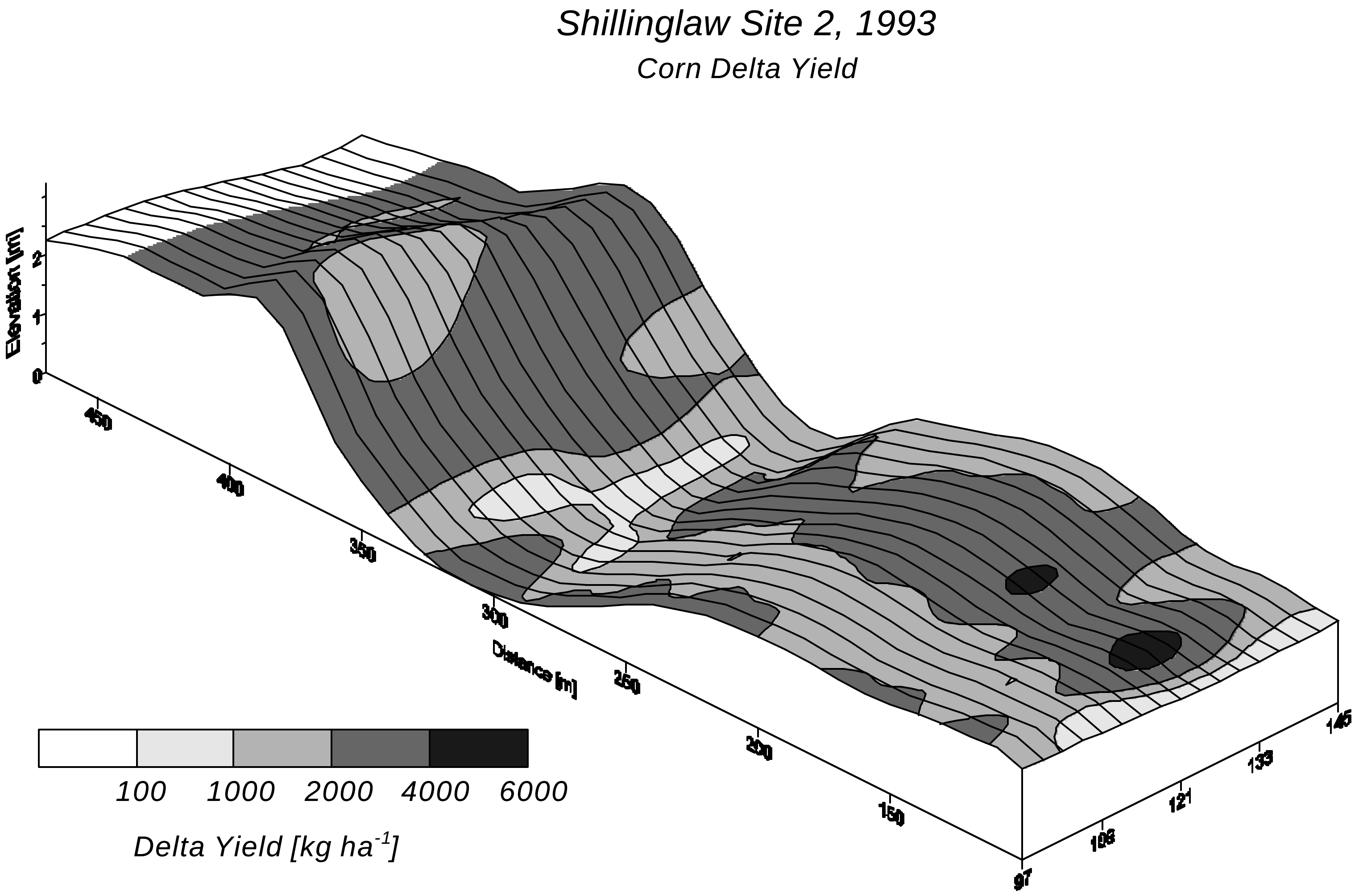
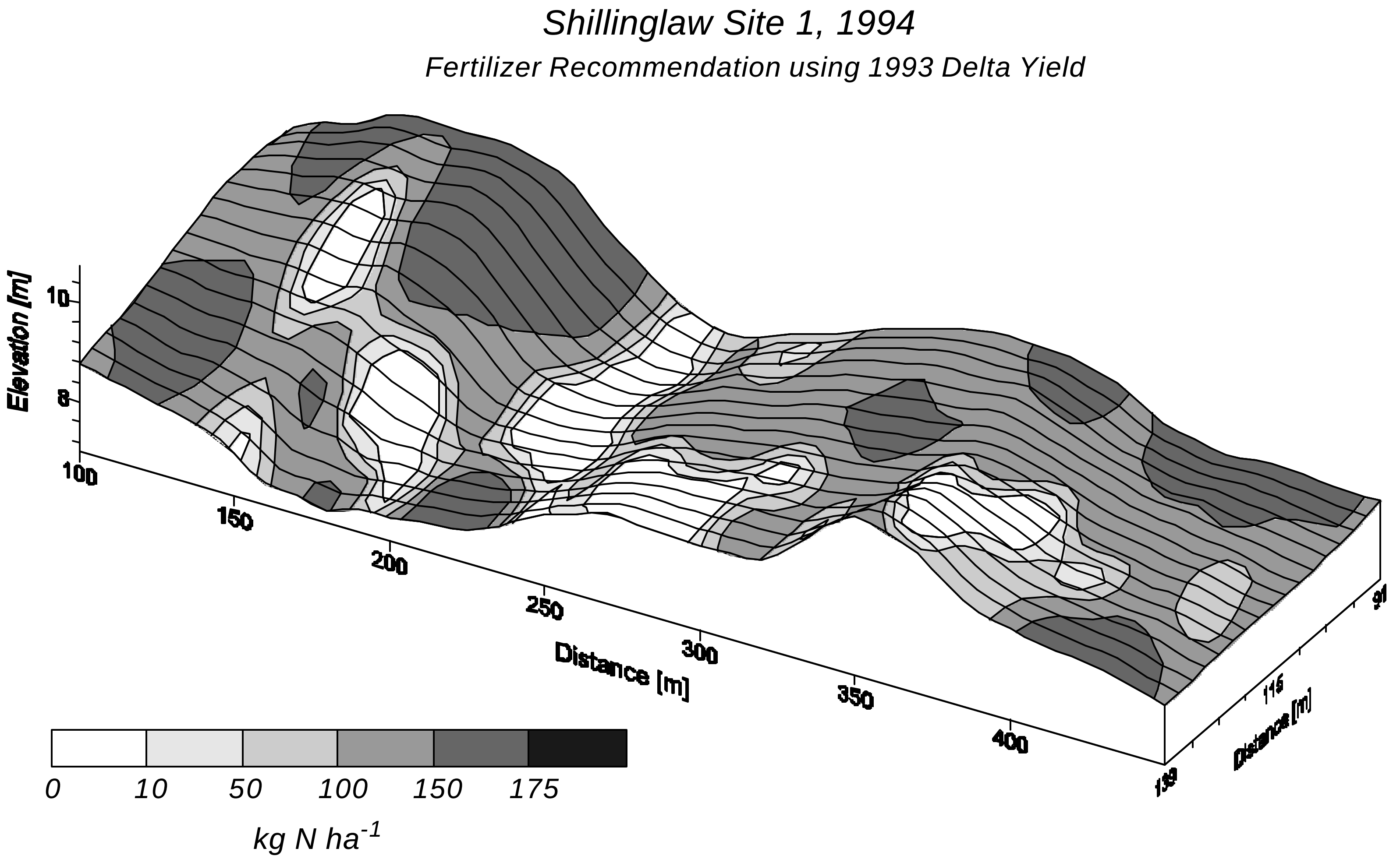


Figure 16b. Spatial distribution of Delta Yield for Site S2, 1993.



Shillinglaw Site 1, 1994

Fertilizer Recommendation using 1993 Delta Yield

Figure 17a. Spatial distribution of fertilizer recommendations predicted from Delta Yield measurements for Site S1.

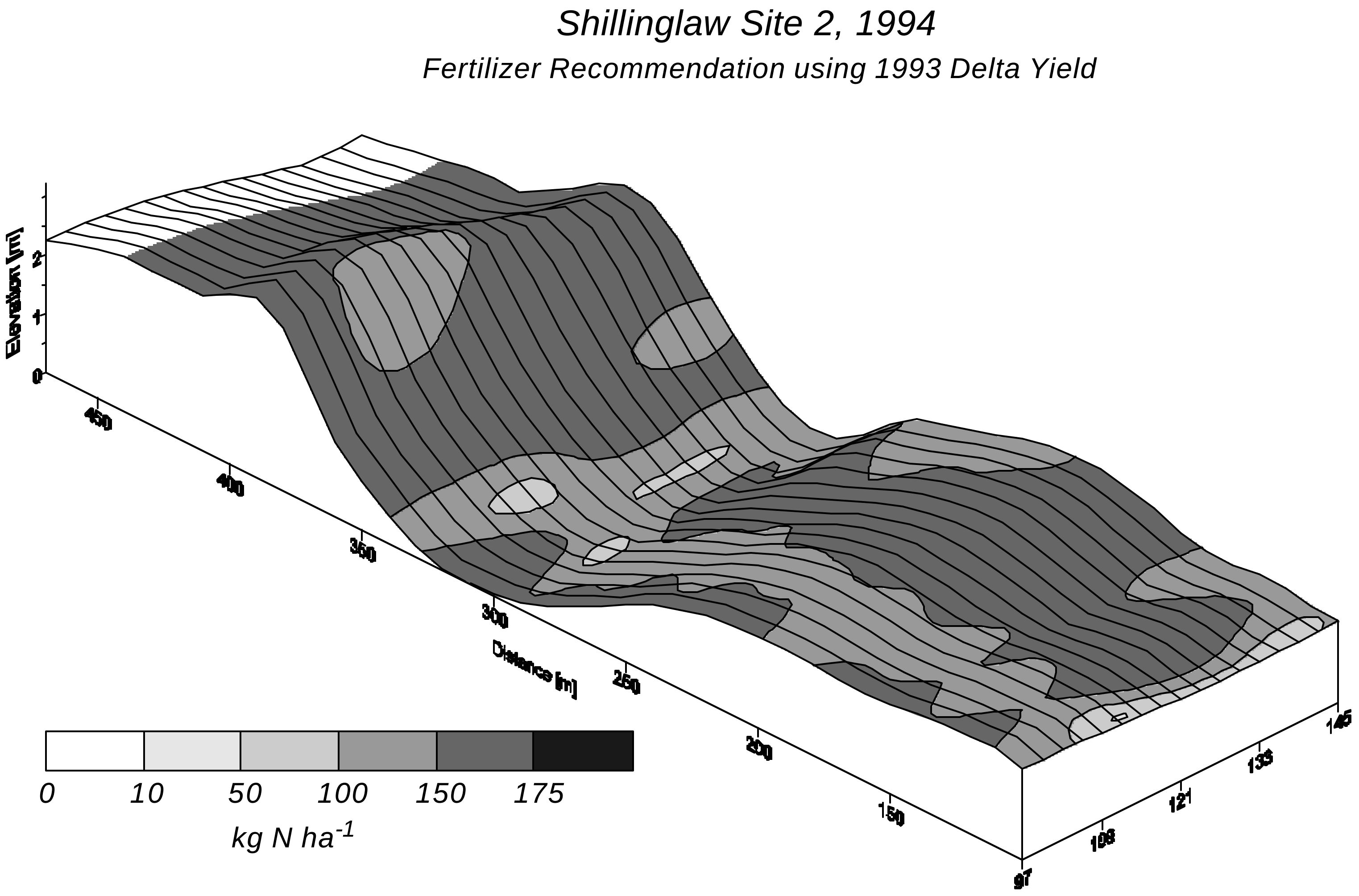
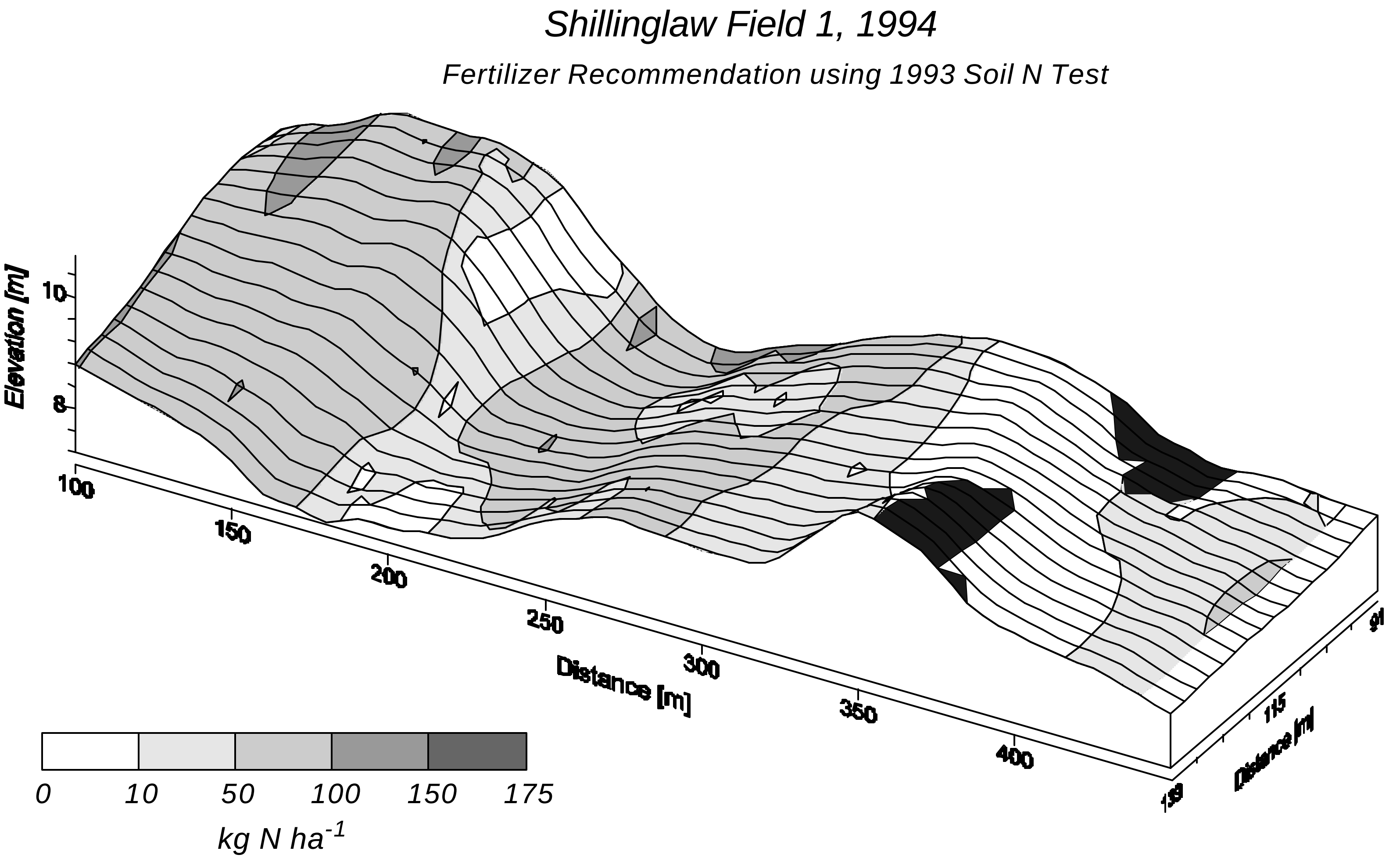


Figure 17b. Spatial distribution of fertilizer recommendations predicted from Delta Yield measurements for Site S2.



Shillinglaw Field 1, 1994

Fertilizer Recommendation using 1993 Soil N Test

Figure 18a. Spatial distribution of fertilizer recommendations predicted from Soil N Test measurements for Site S1.

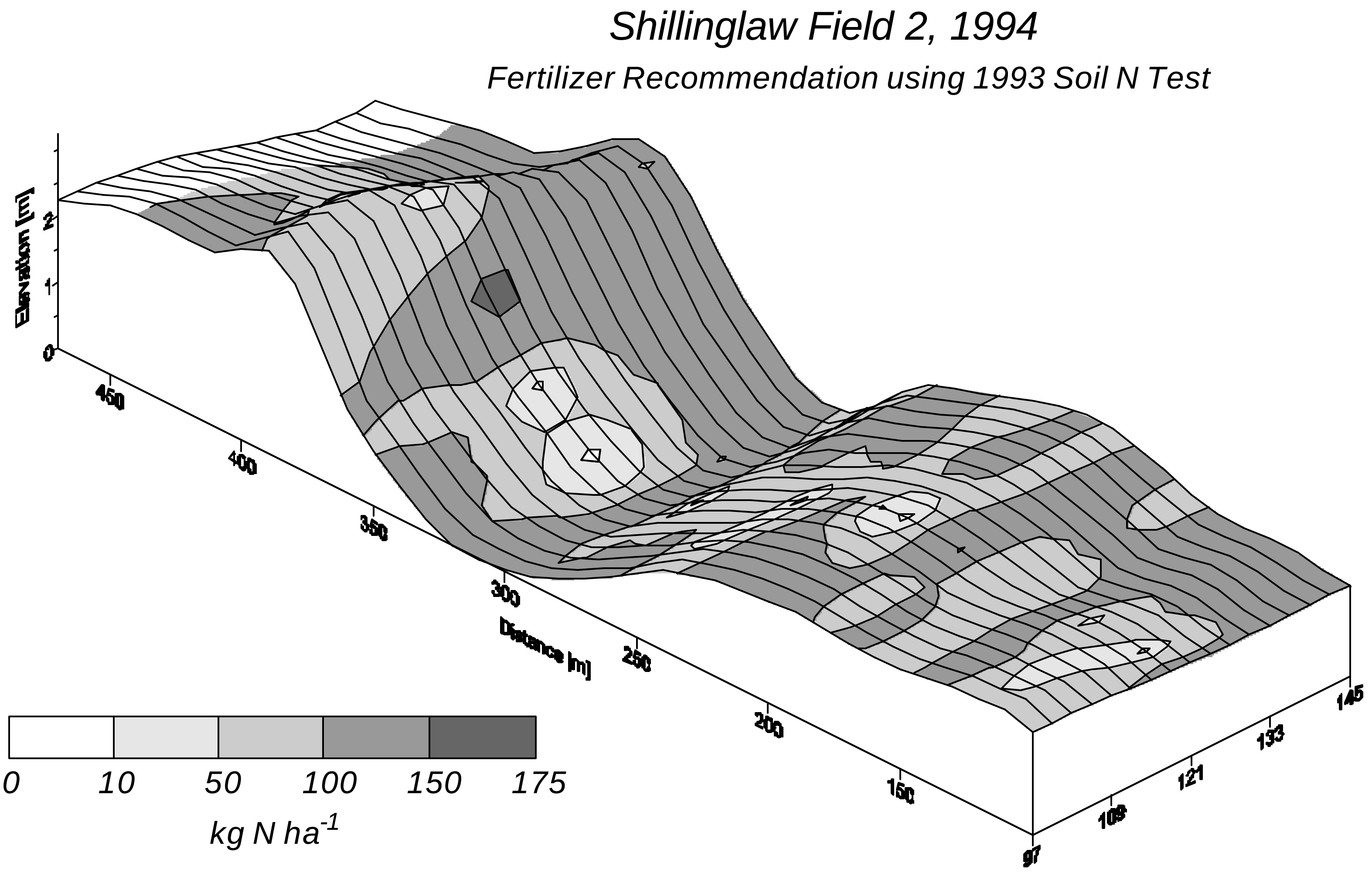


Figure 18b. Spatial distribution of fertilizer recommendations predicted from Soil N Test measurements for Site S2.

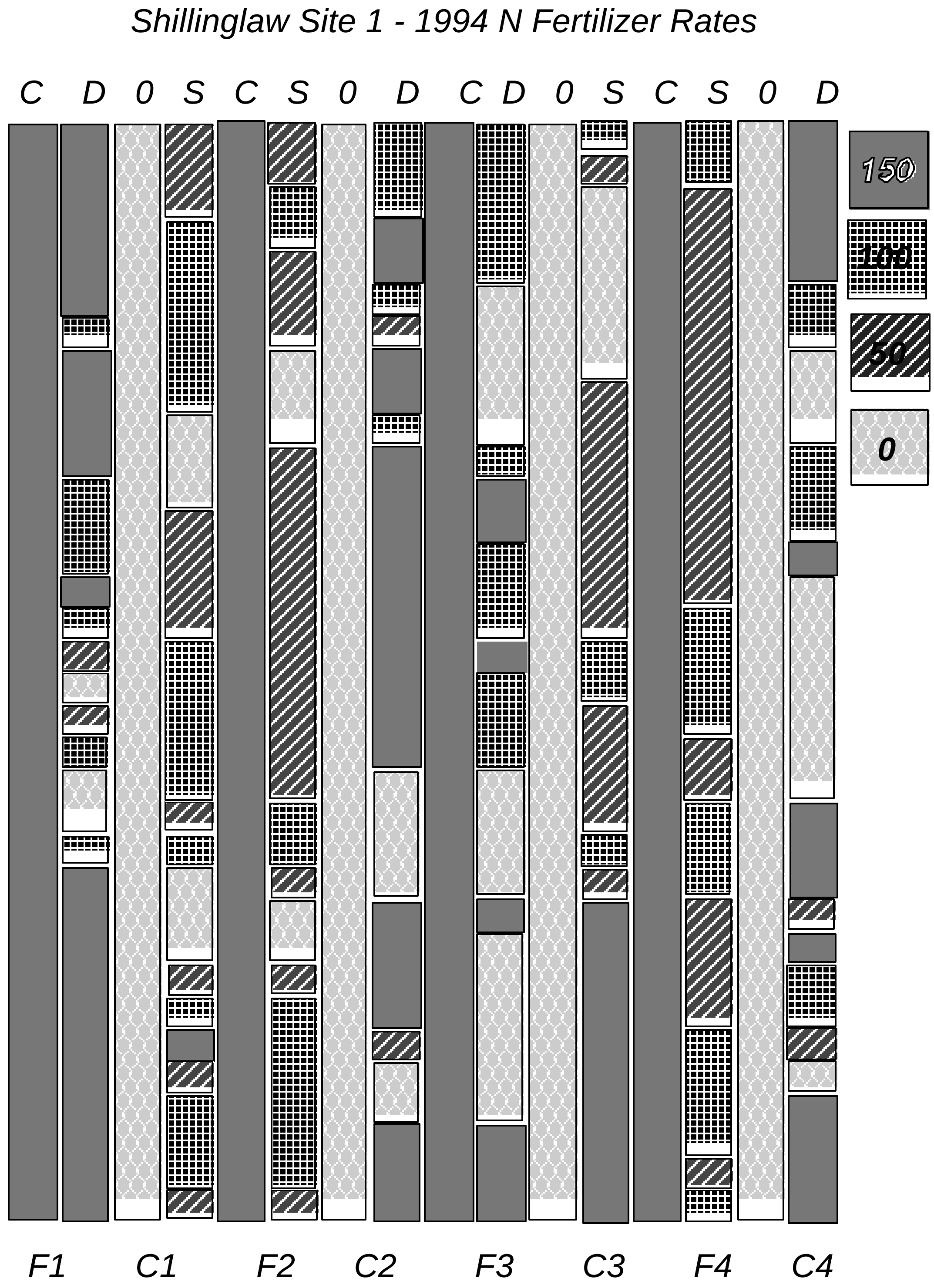


Figure 19a. Spatial distribution of fertilizer treatments used in 1994 for Site S1.

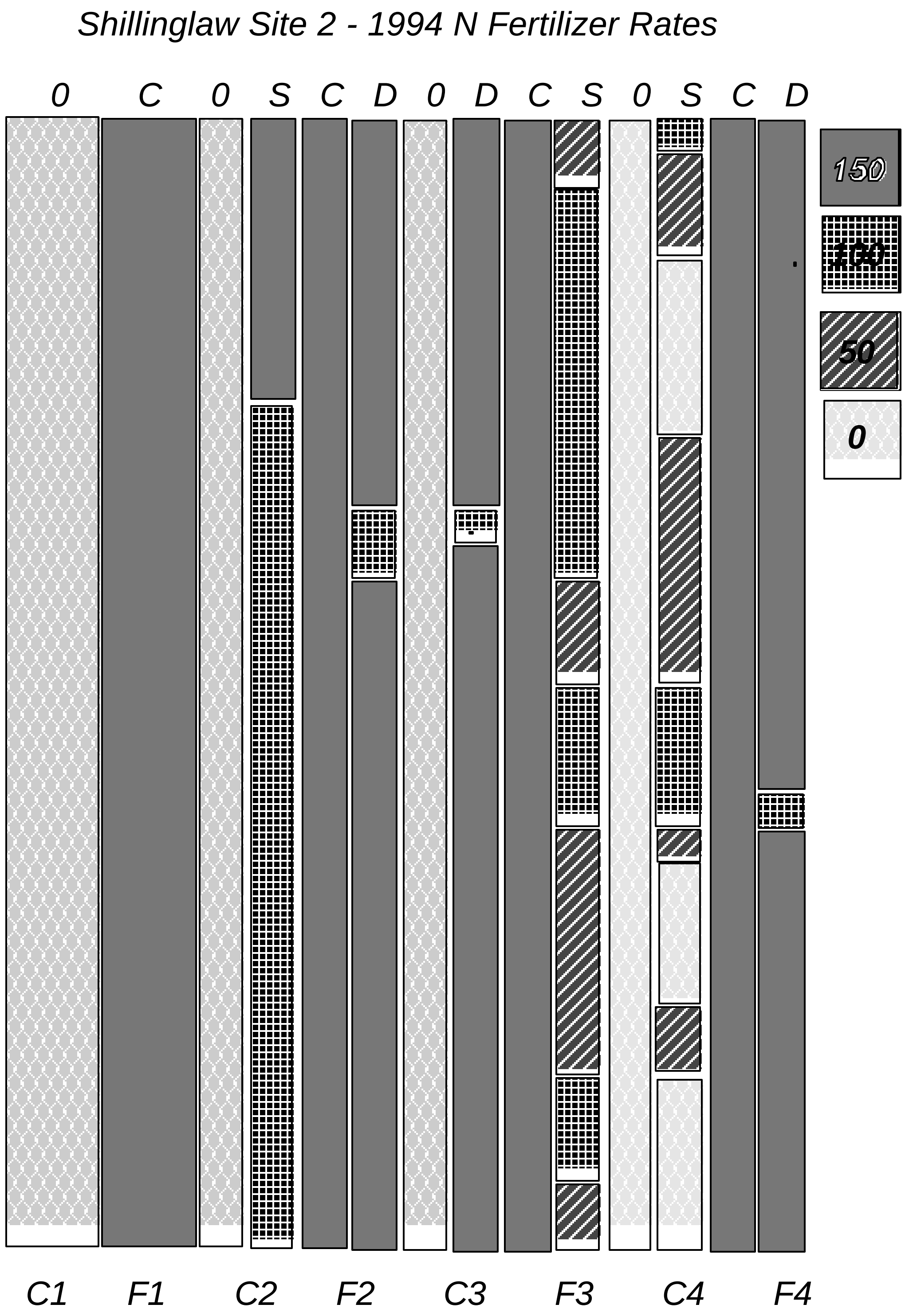


Figure 19b. Spatial distribution of fertilizer treatments used in 1994 for Site S2.

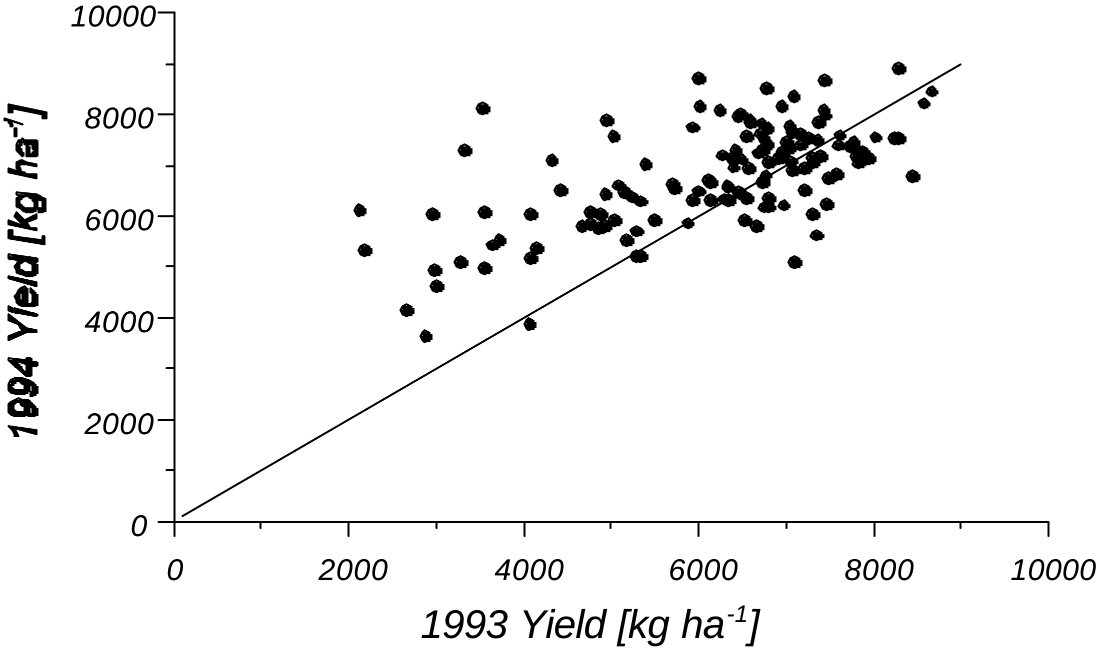


Figure 20a. Comparison of Fertilized Yield in 1993 and 1994 for Site S1.

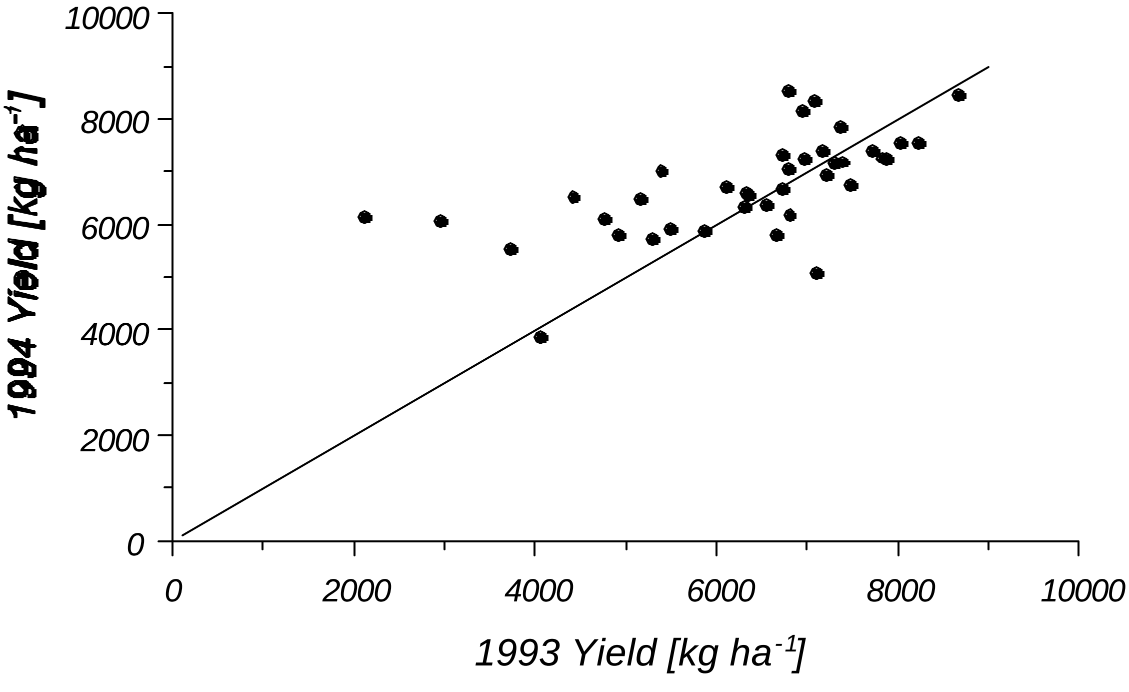


Figure 20b. Comparison of Fertilized Yield in 1993 and 1994 for Site S2.

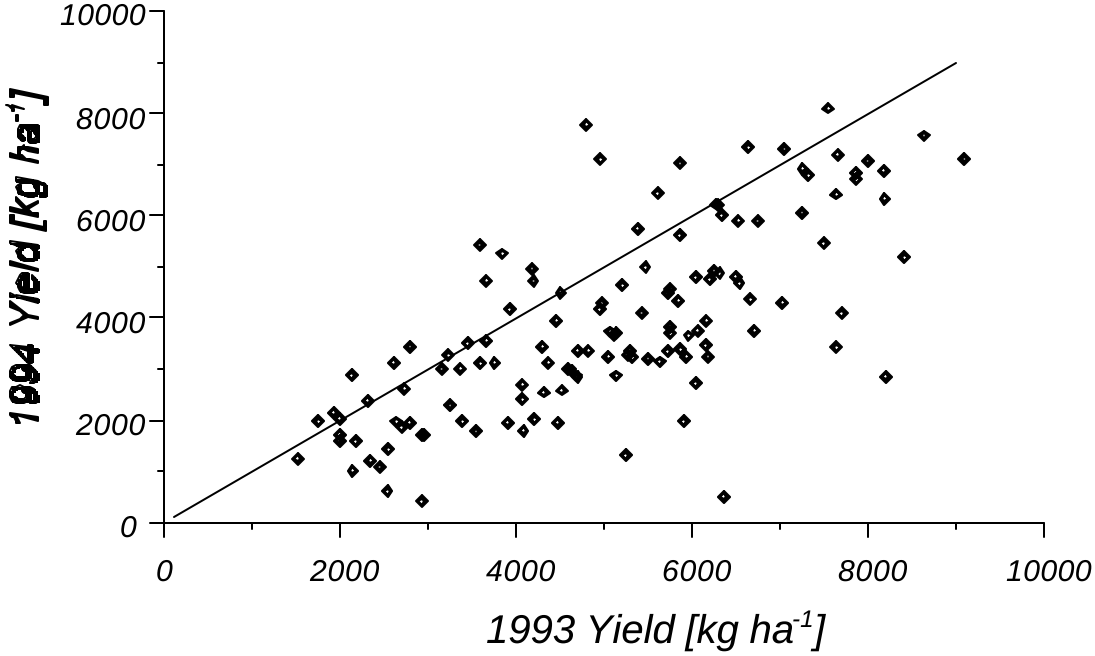


Figure 21a. Comparison of Unfertilized Yield in 1993 and 1994 for Site S1.

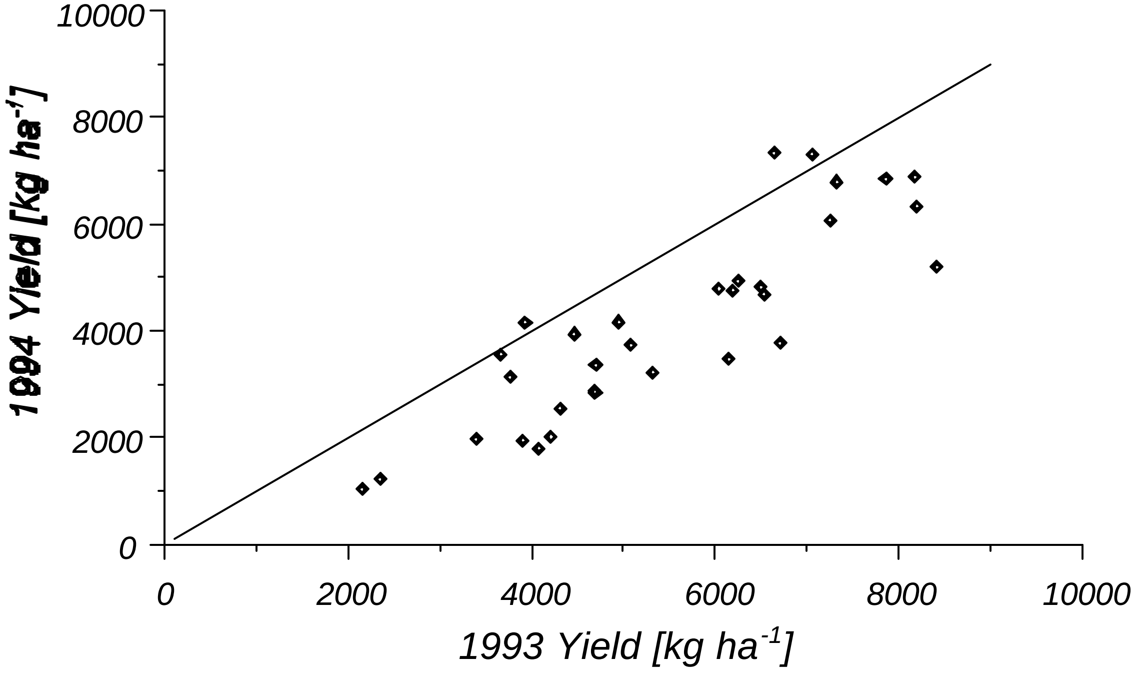


Figure 21b. Comparison of Unfertilized Yield in 1993 and 1994 for Site S2.

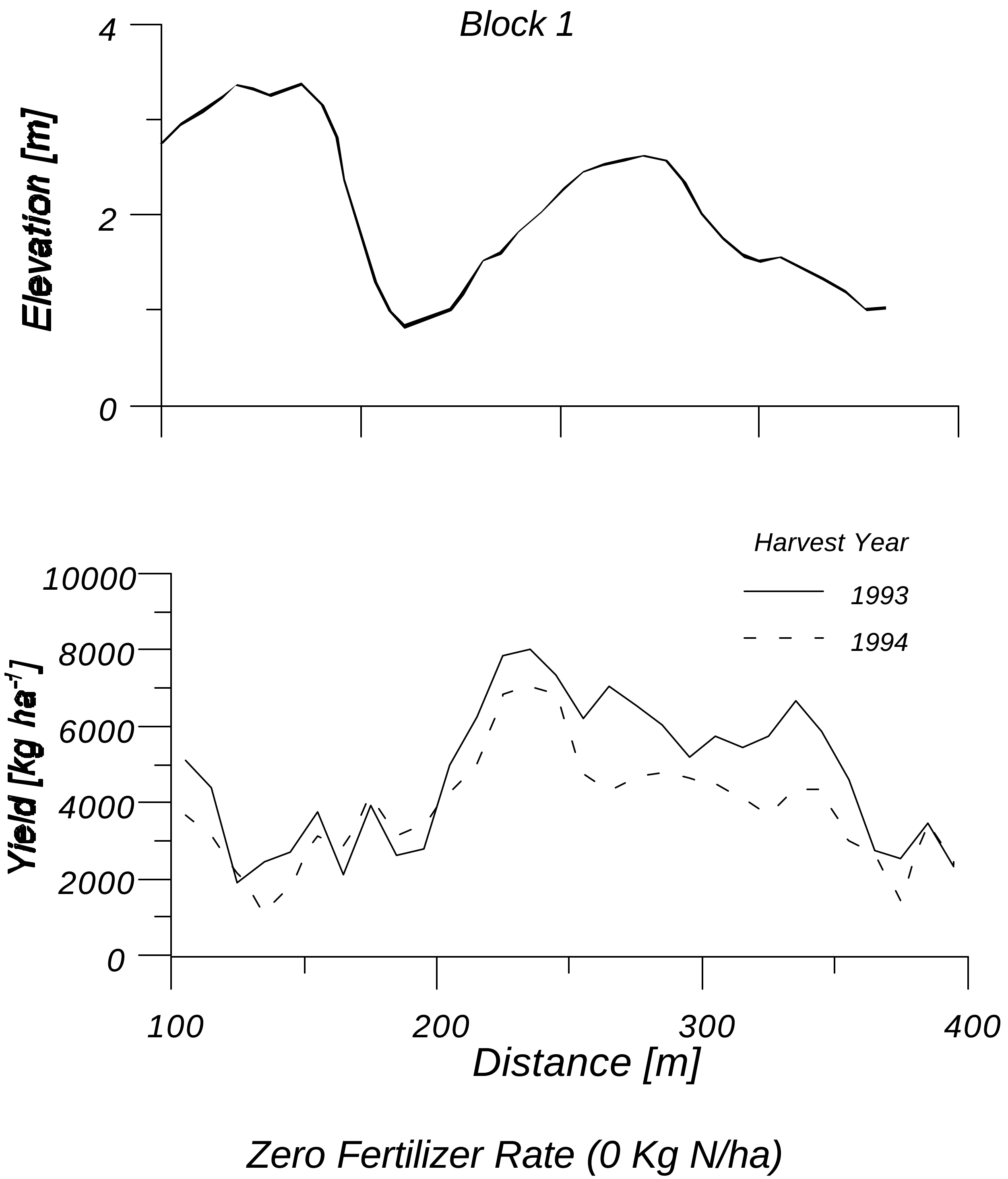
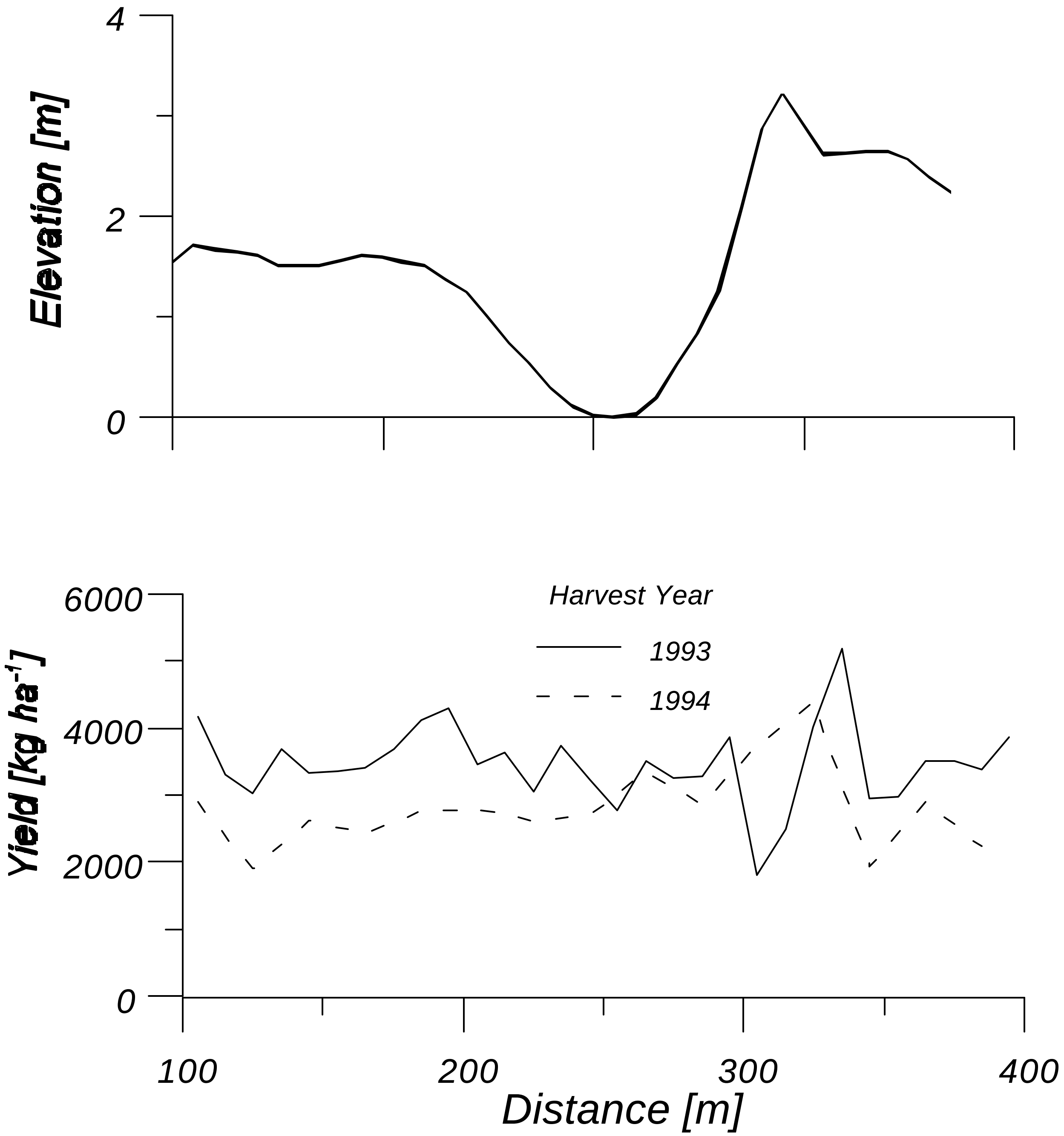


Figure 22a. Comparison of the spatial pattern of measured Yield for 1993 and 1994 for Site S1, Block 1.



Zero Fertilizer Rate (0 Kg N/ha)

Figure 22b. Comparison of the spatial pattern of measured Yield for 1993 and 1994 for Site S2, Block 1.

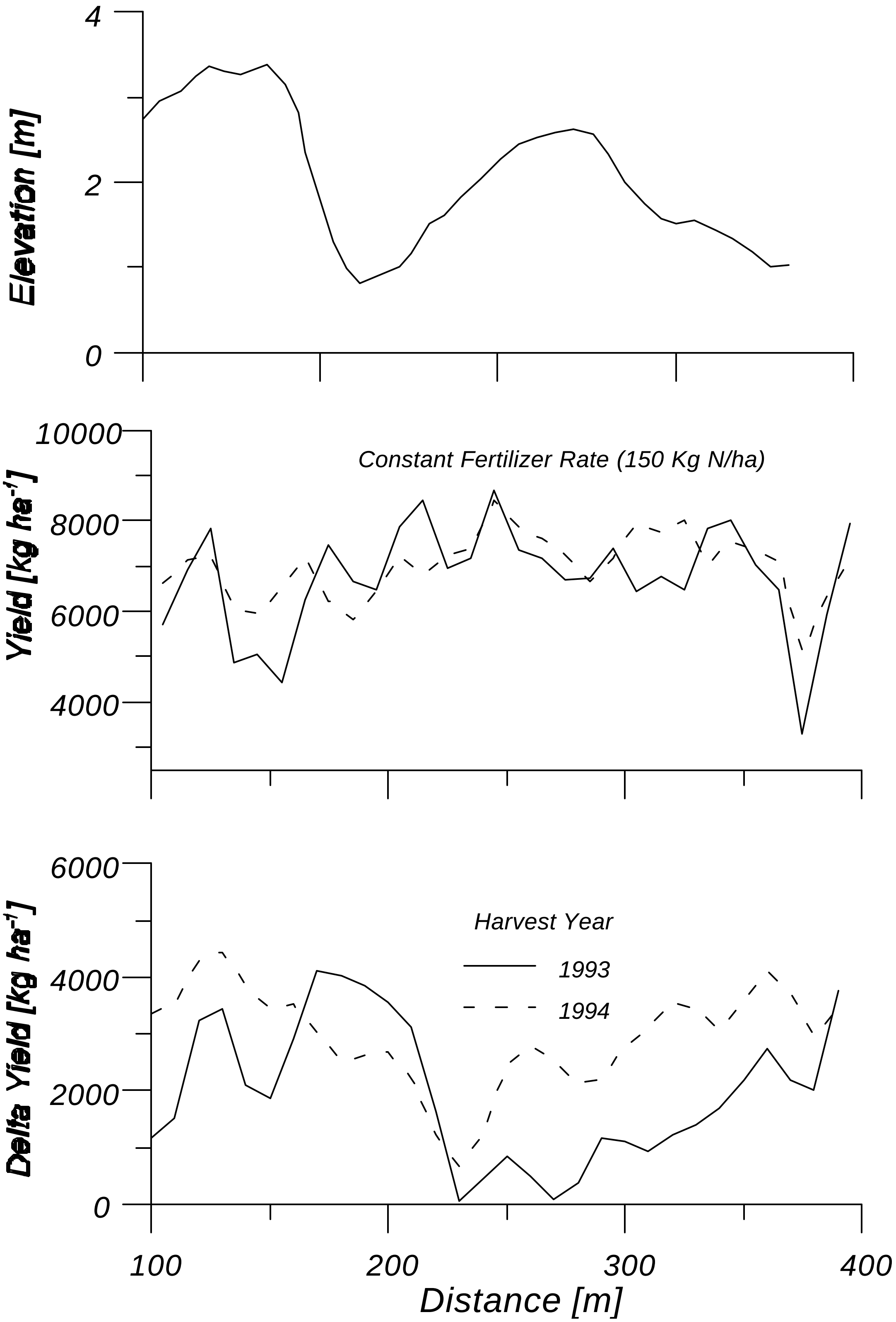


Figure 23a. Comparison of the spatial pattern of calculated Delta Yield for 1993 and 1994 for Site S1, Block 1.

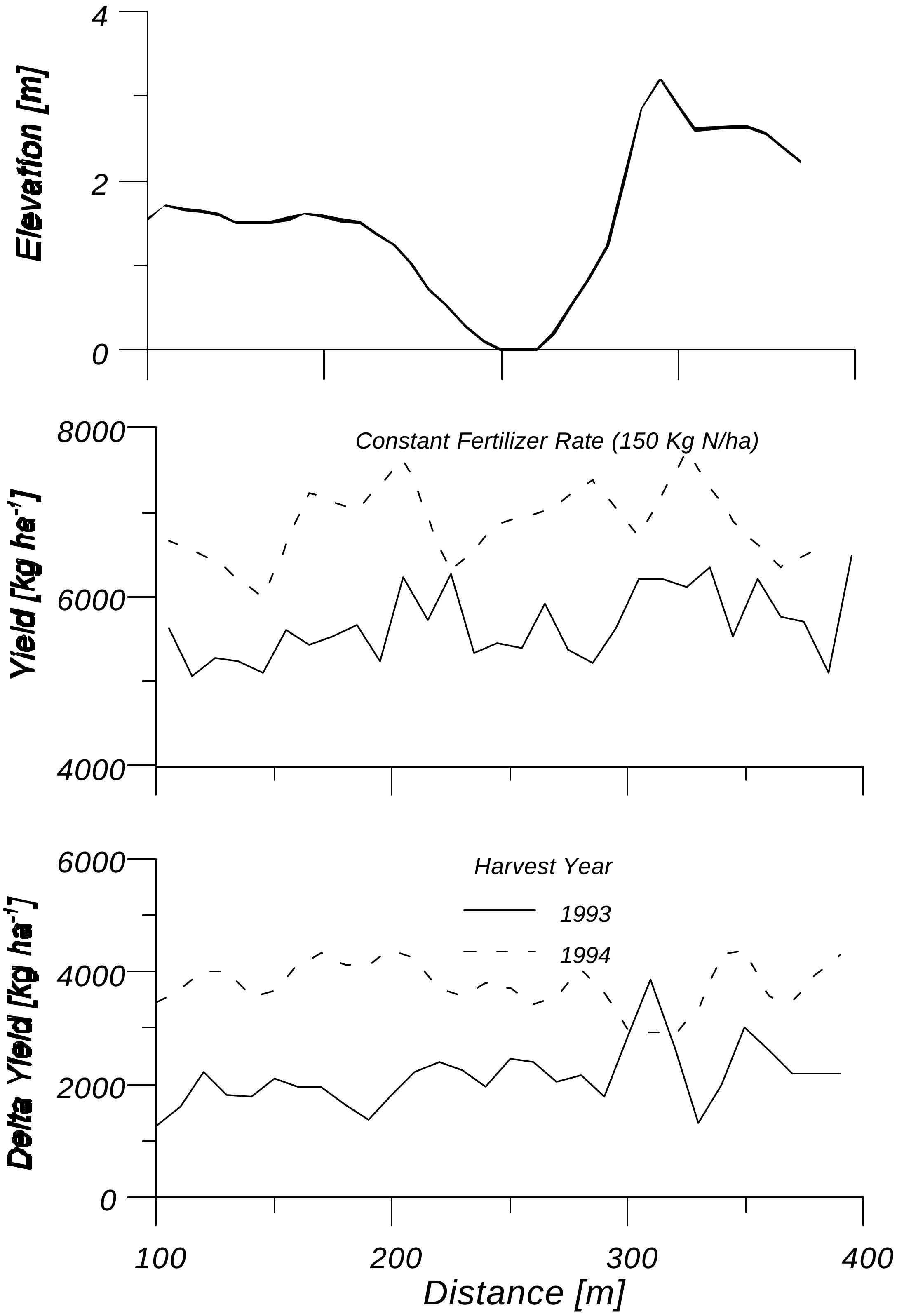


Figure 23b.Comparison of the spatial pattern of calculated Delta Yield for 1993 and 1994 for Site S1, Block 1.

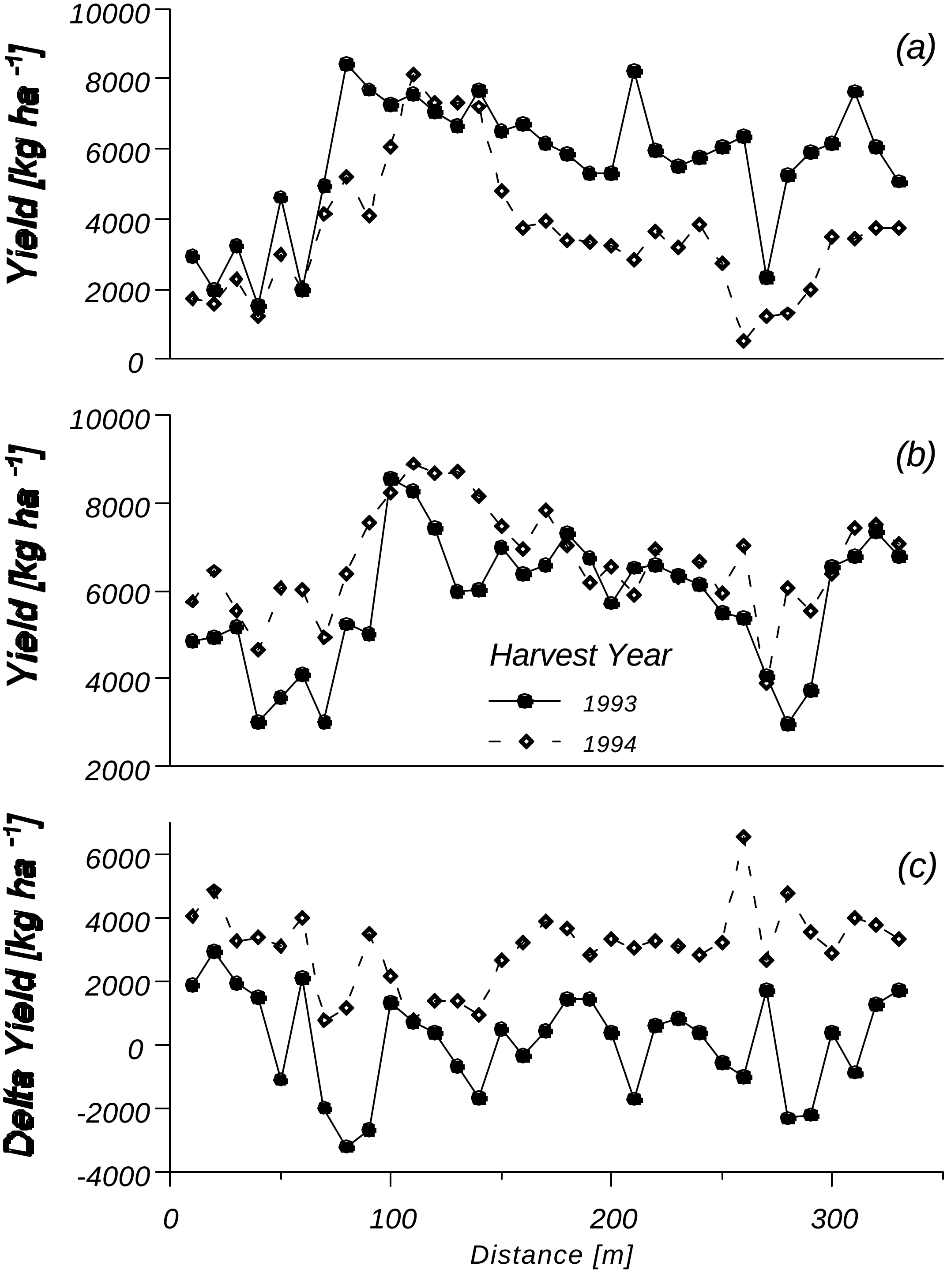


Figure 24. Comparison of the spatial pattern for Block 3 at Site S1 for 1993 and 1994 of (a) Check Yield, (b) Fertilized Yield and (c) Delta Yield.

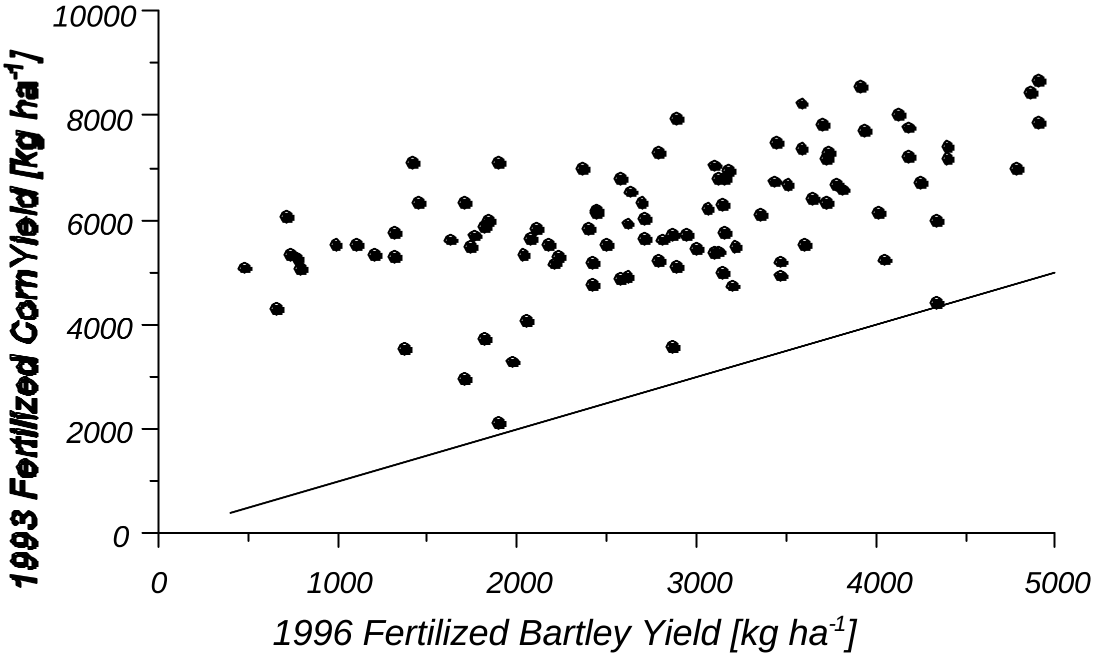


Figure 25. Comparison of the Fertilized Yield of Corn, 1993 and the Fertilized Yield of Barley, 1996, for major treatments blocks from both Sites.

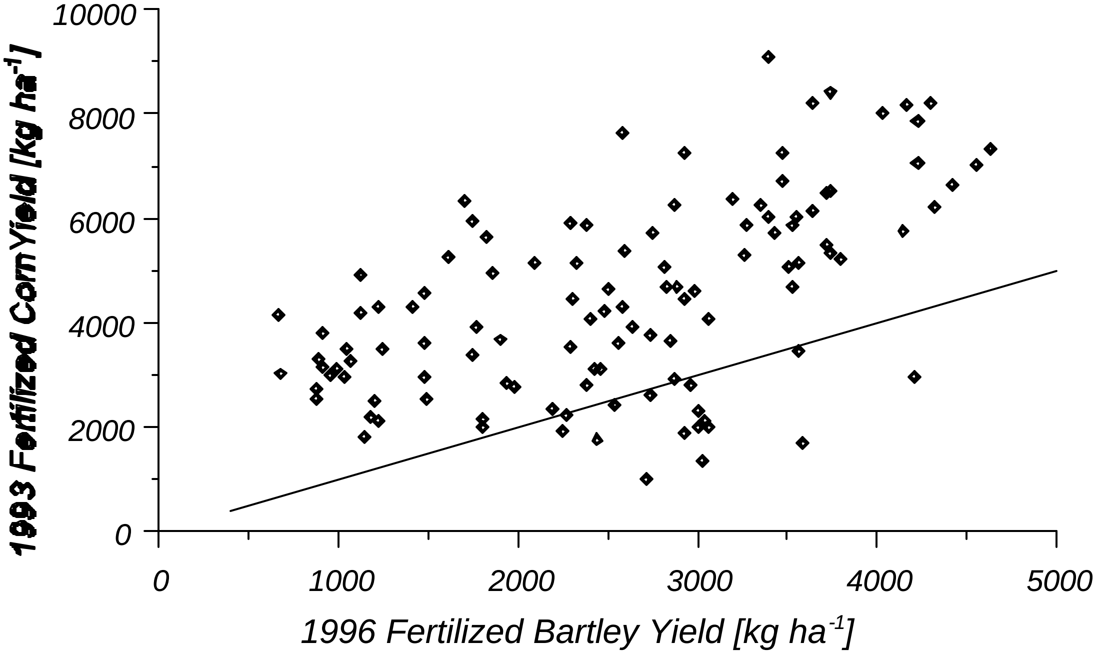


Figure 26. Comparison of the Unfertilized Yield of Corn, 1993 and the Fertilized Yield of Barley, 1996, for major treatments blocks from both Sites.

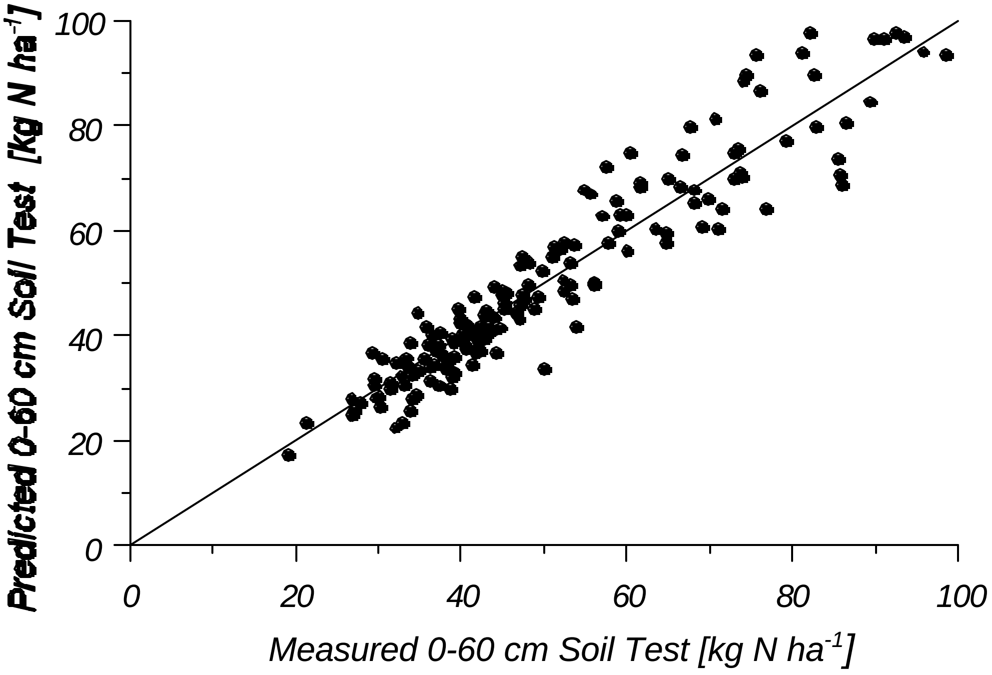


Figure 27a. Predicted 0-60 cm Soil Test values calculated from 30 cm Soil Test versus measured 0-60 cm Soil Test for Site S1, 1994.

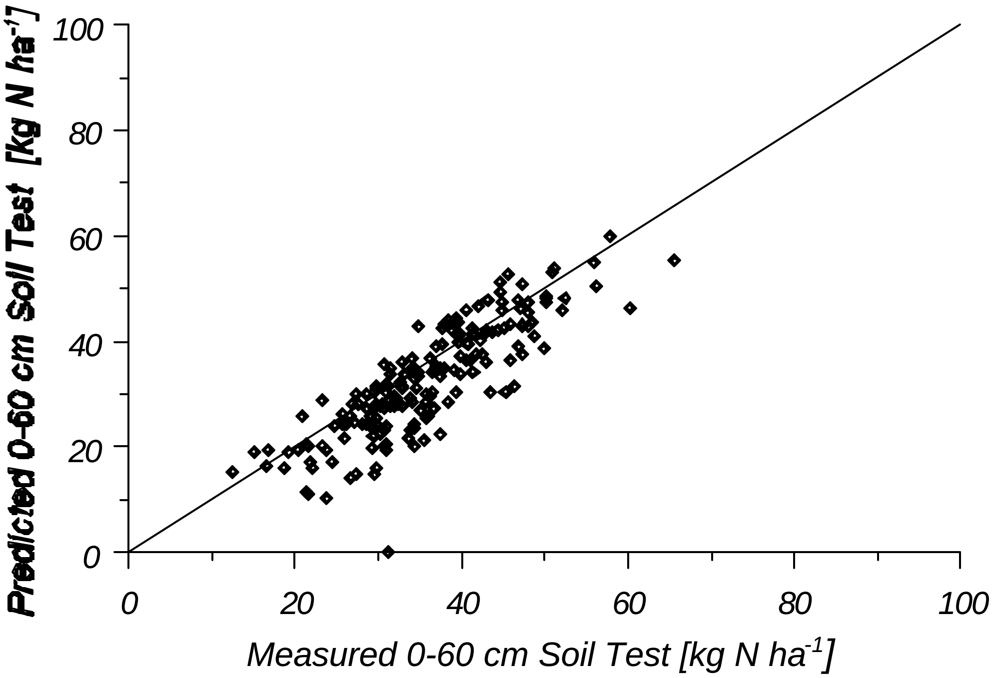


Figure 27b. Predicted 0-60 cm Soil Test values calculated from 30 cm Soil Test versus measured 0-60 cm Soil Test for Site S2, 1994.

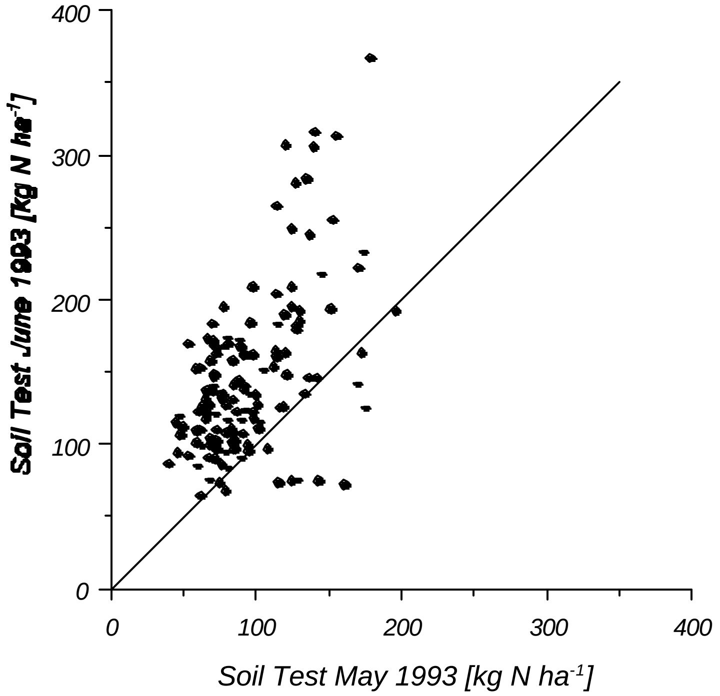


Figure 28a. Comparison of Soil N Test values taken in early May and early June, 1993, for Site S1.

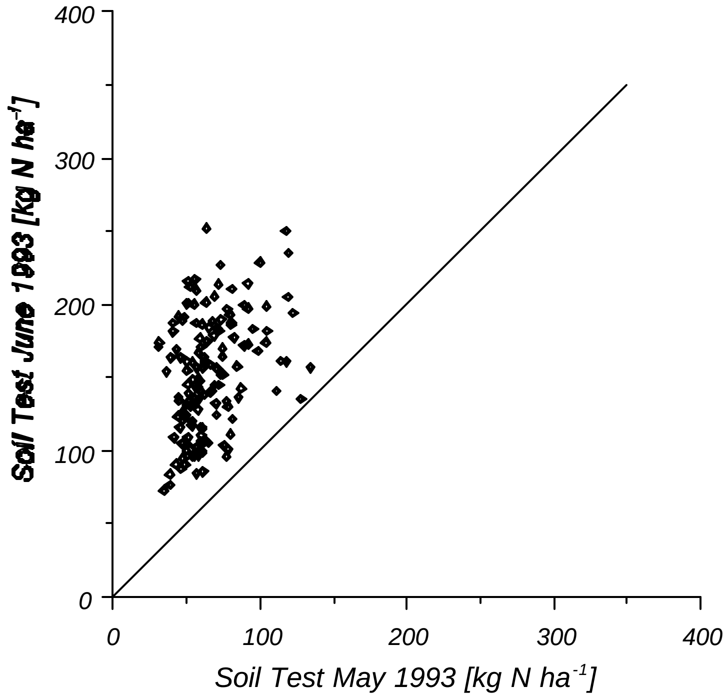


Figure 28b. Comparison of Soil N Test values taken in early May and early June, 1993, for Site S2.

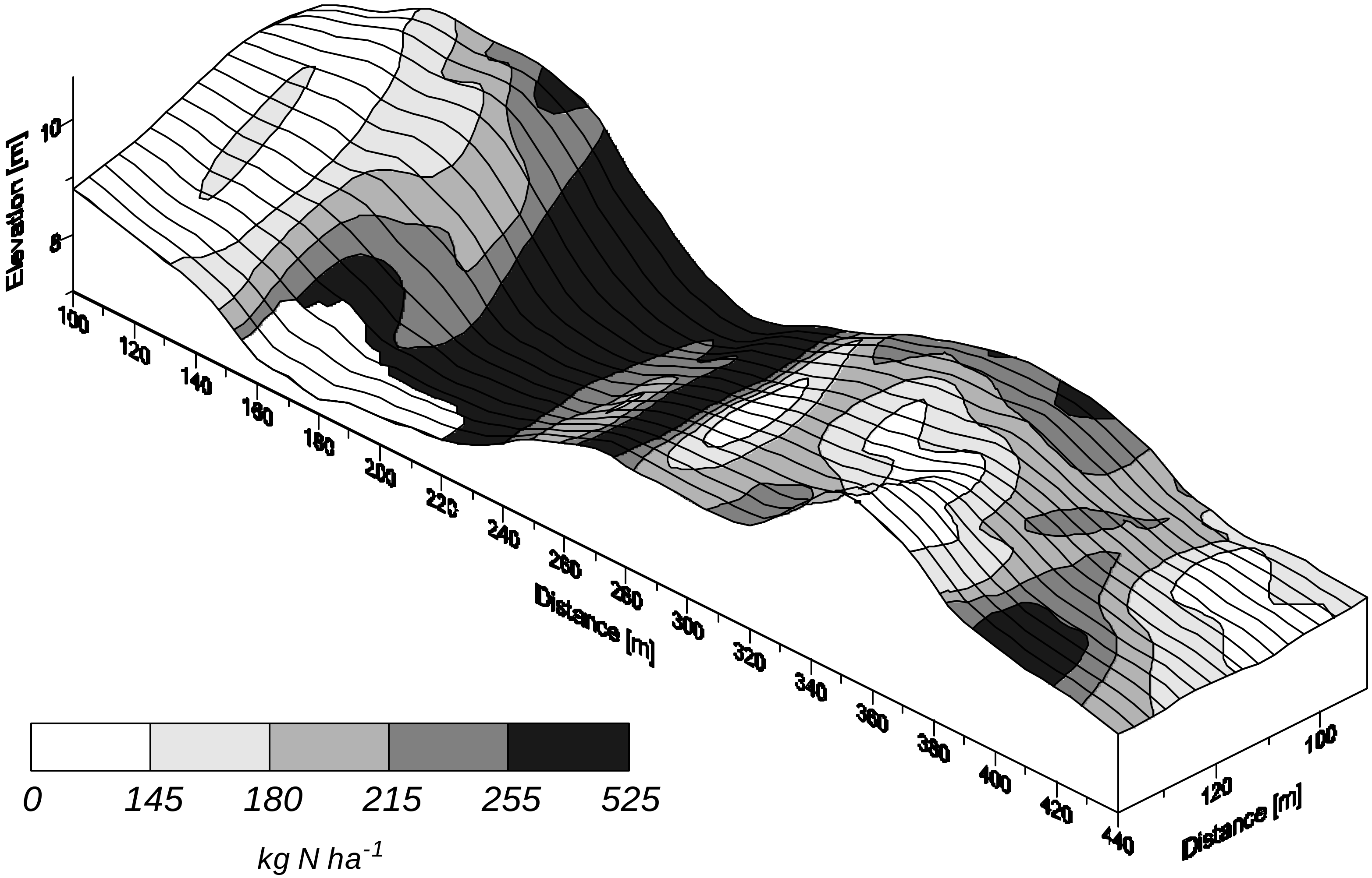


Figure 29. Spatial distribution of soil N in Fall 1993 (0-90 cm, kg N/ha) for fertilizer applied on Site S1.

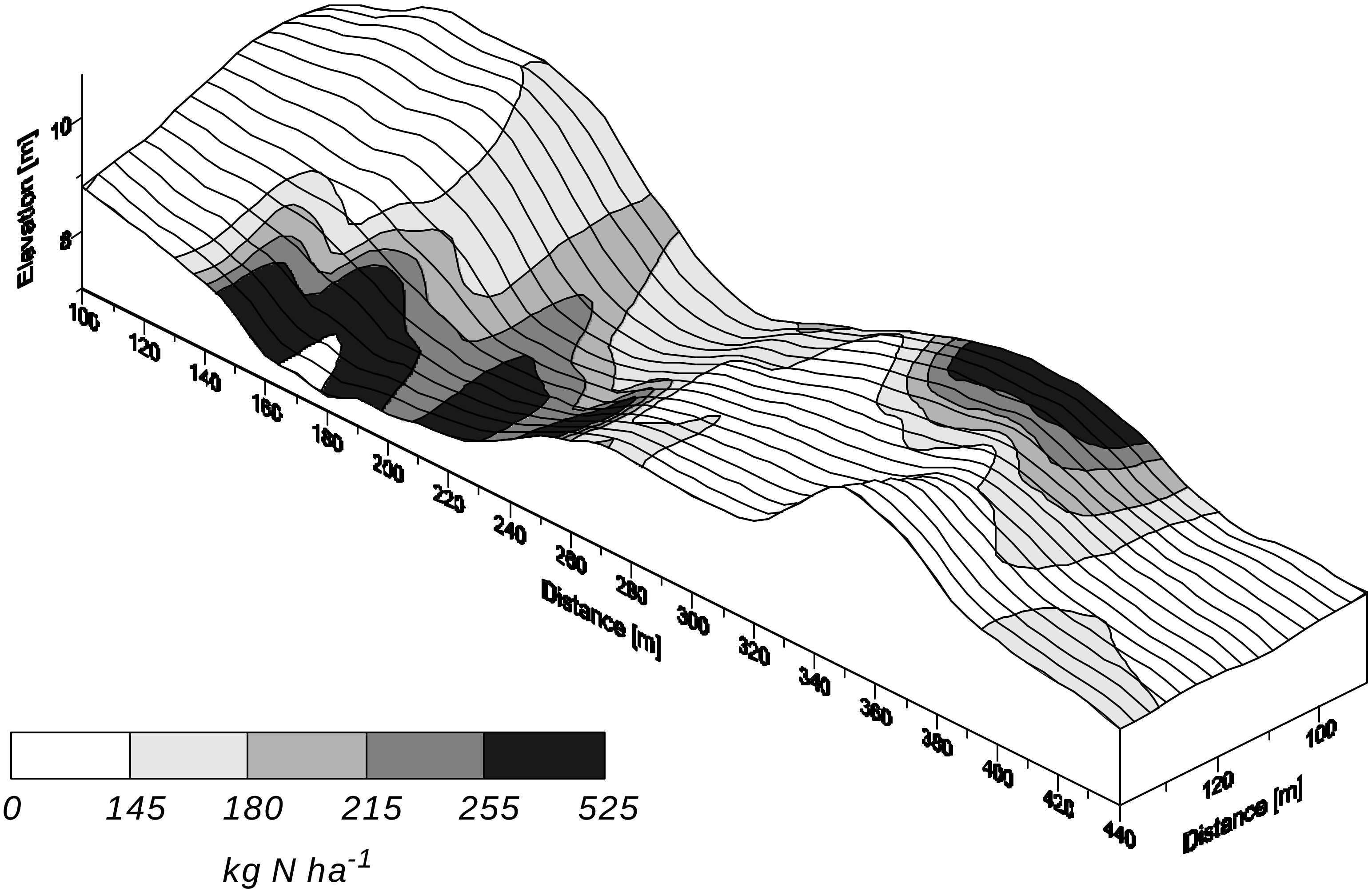


Figure 30. Spatial distribution of soil N in Fall 1993 (0-90cm, kg N/ha) for no fertilizer applied on Site S1.

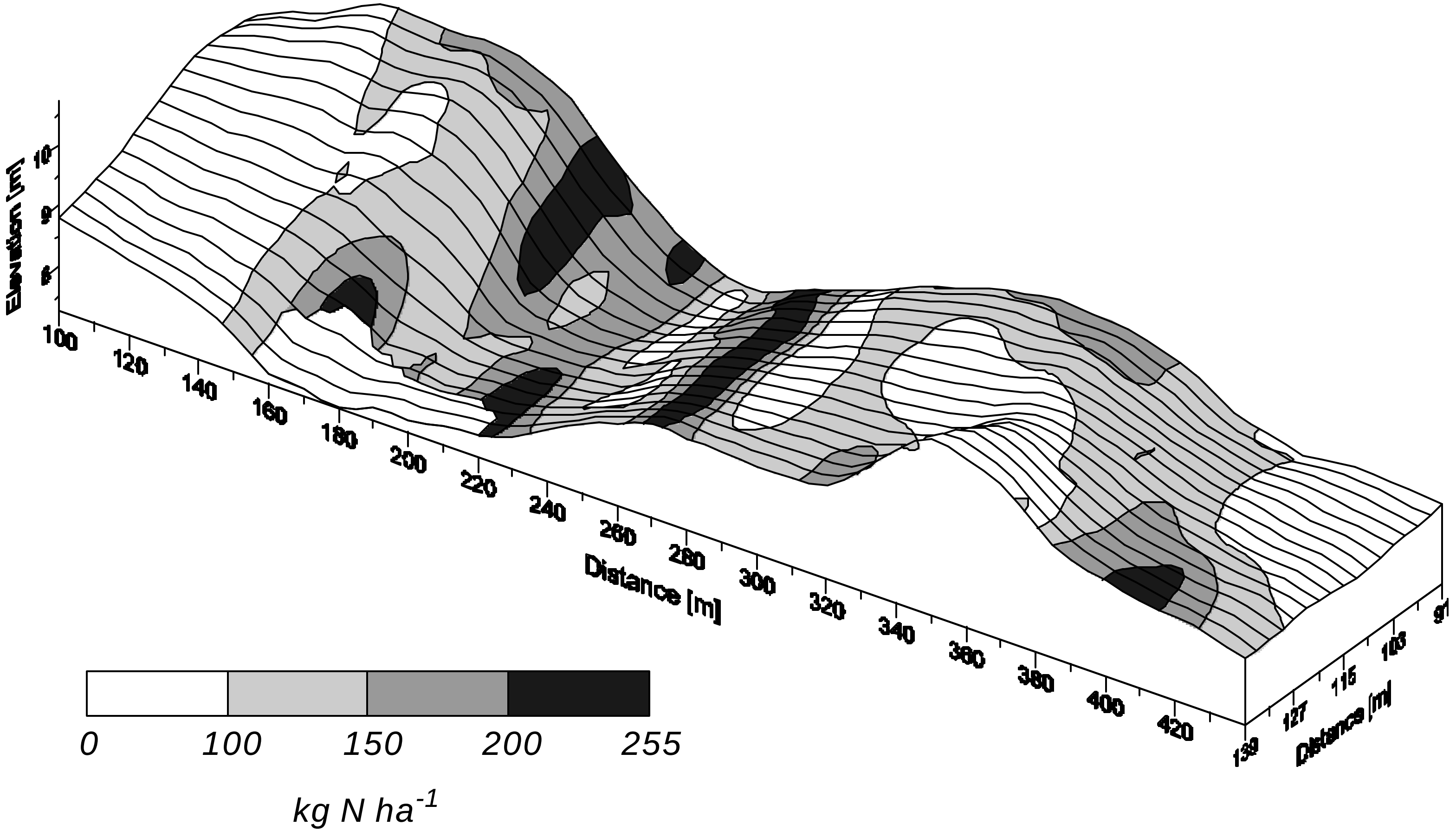


Figure 31. Spatial distribution of the difference between fertilizer and no fertilizer soil N (0-90 cm, kg N/ha] in the Fall 1993 on Site S1.

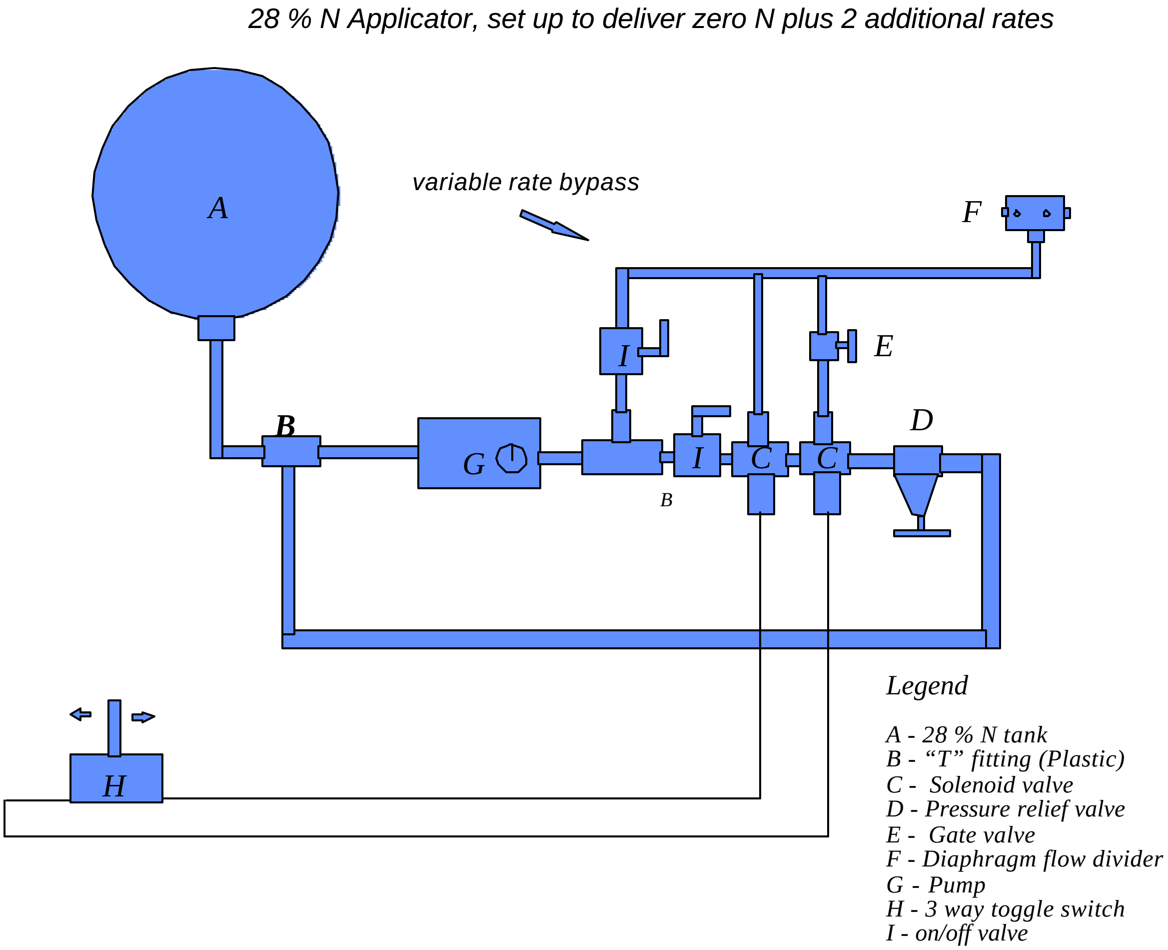


Figure 32. Schematic diagram of the manual three rates 28 % N applicator modifications.

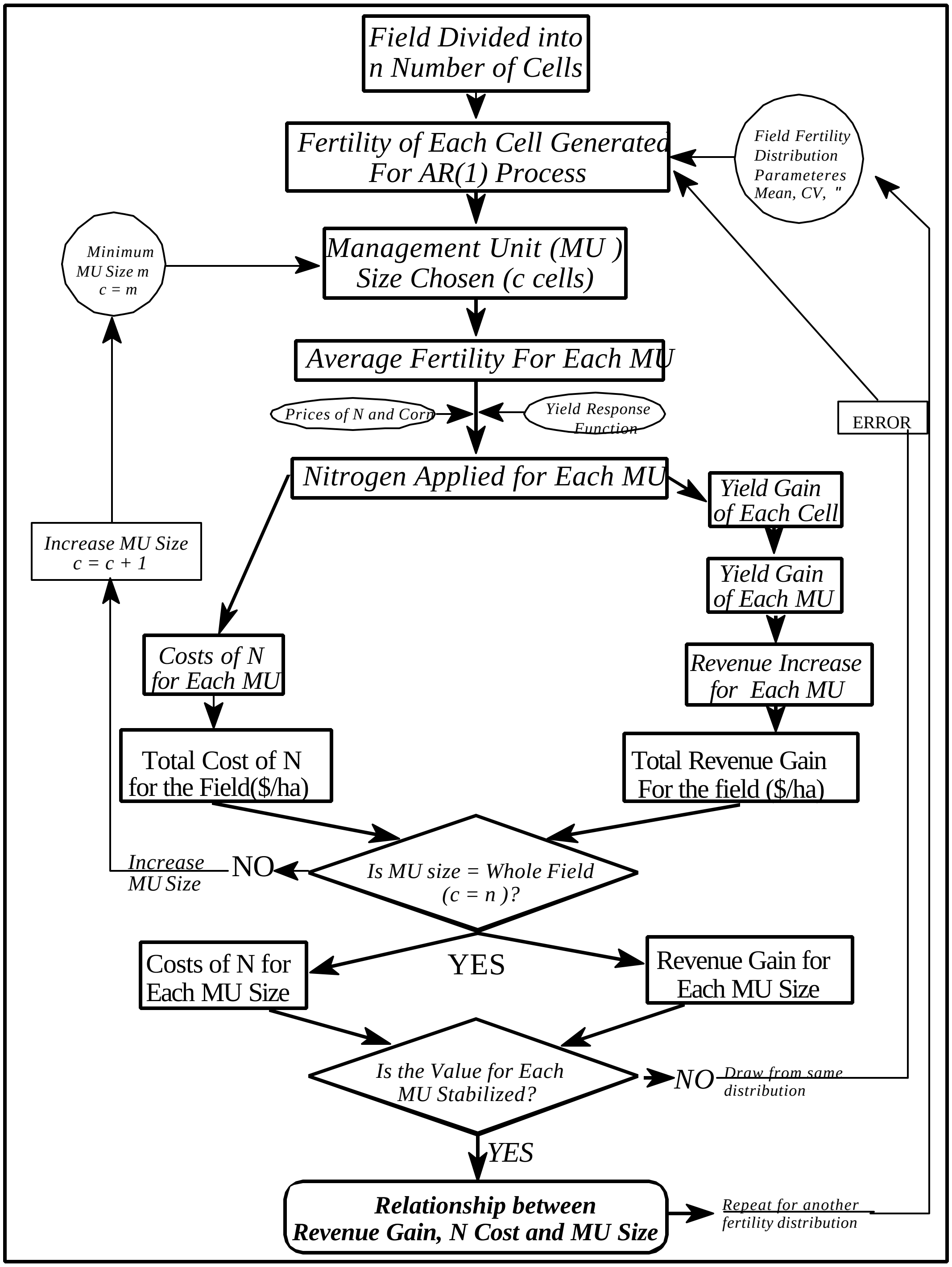


Figure 33. Flow-chart for generating the economic data for modelling.

Appendices

Appendix 1.
GEOGRAPHIC LOCATION - SURFACE RELIEF MAPS

A summary of site location and elevation data is given in Appendix 1., including schematics and surface relief maps.

Both sites were surveyed and the control treatment for each block was permanently marked with a telephone marker. The position is given as COGO coordinates, with the marker position corresponding to the Control Treatment C1, having coordinates 100, 100 and the long axis corresponding to the Y direction. At a later date those markers were geopositioned (Table 16) with a DGPS. The position was calculated using WGS 1984 reference ellipsoid and projected in UTM Zone 17.

Table 16. Geopositioned Telephone Marker Location.

Easting [m]	**Northing [m]**	**ID**
Site 1		
462999.5	4837340	2*
462987.6	4837319	4*
463221.6	4837217	11
463230.1	4837228	13
463207.7	4837191	15
Site 2		
468876.1	4835068	1*
468882.4	4835078	2*
468895.8	4835098	4*
468648.1	4835231	100*
468891.7	4835058	0*

* Buried Telephone Marker

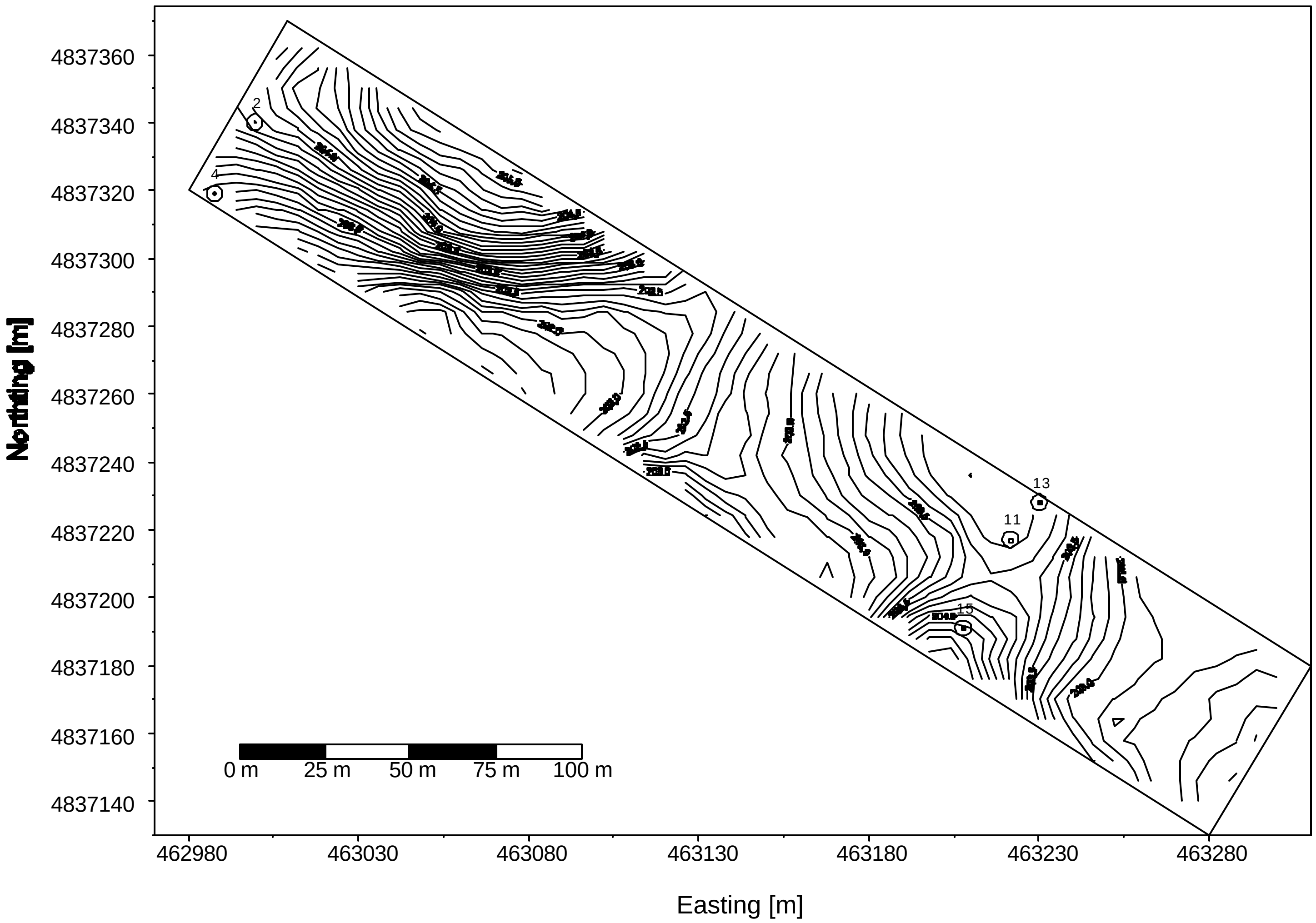


Figure 34a. Elevation contour plot and telephone marker location for Site 1.

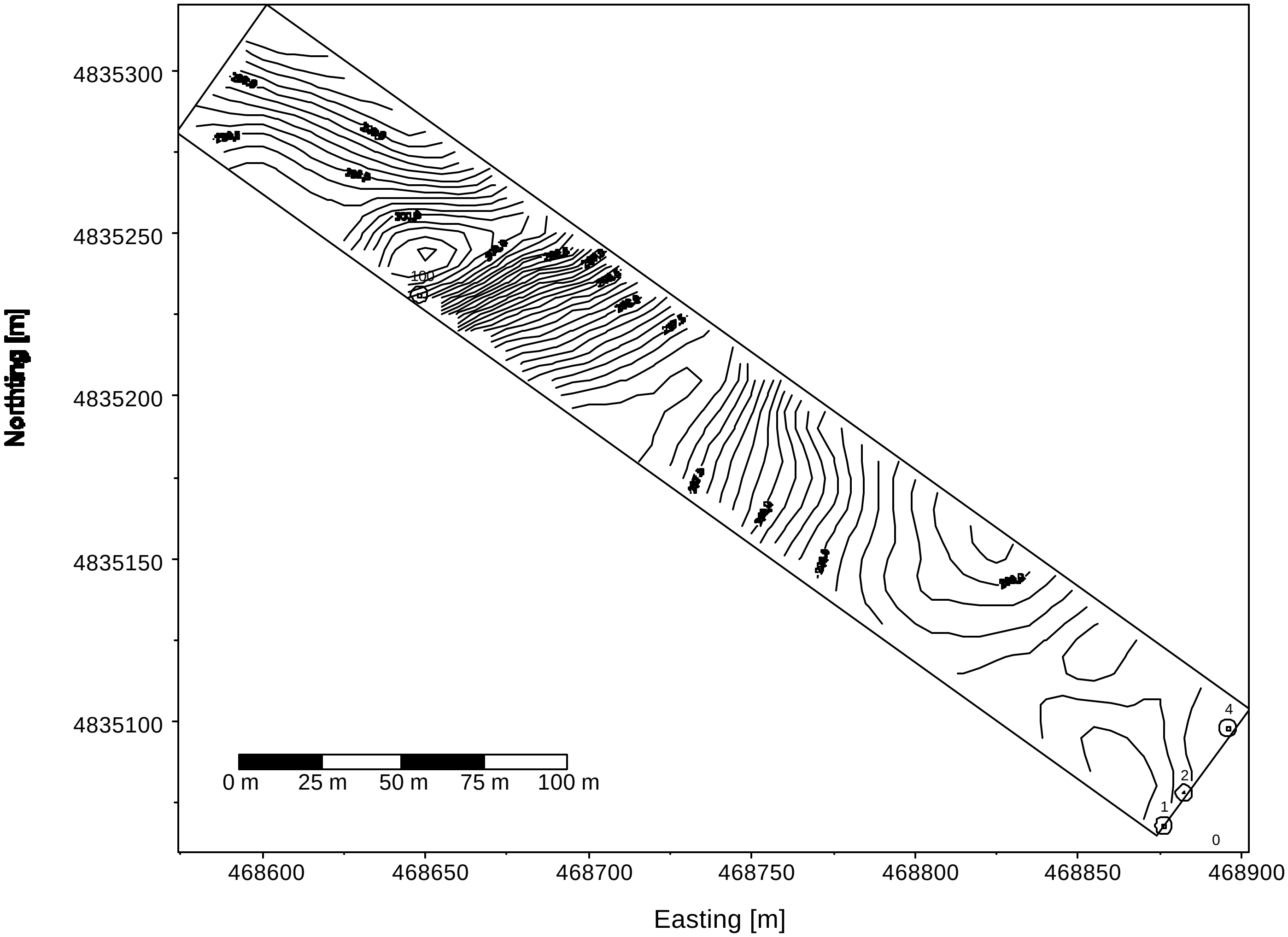


Figure 34b. Elevation contour plot and telephone marker location for Site 2.

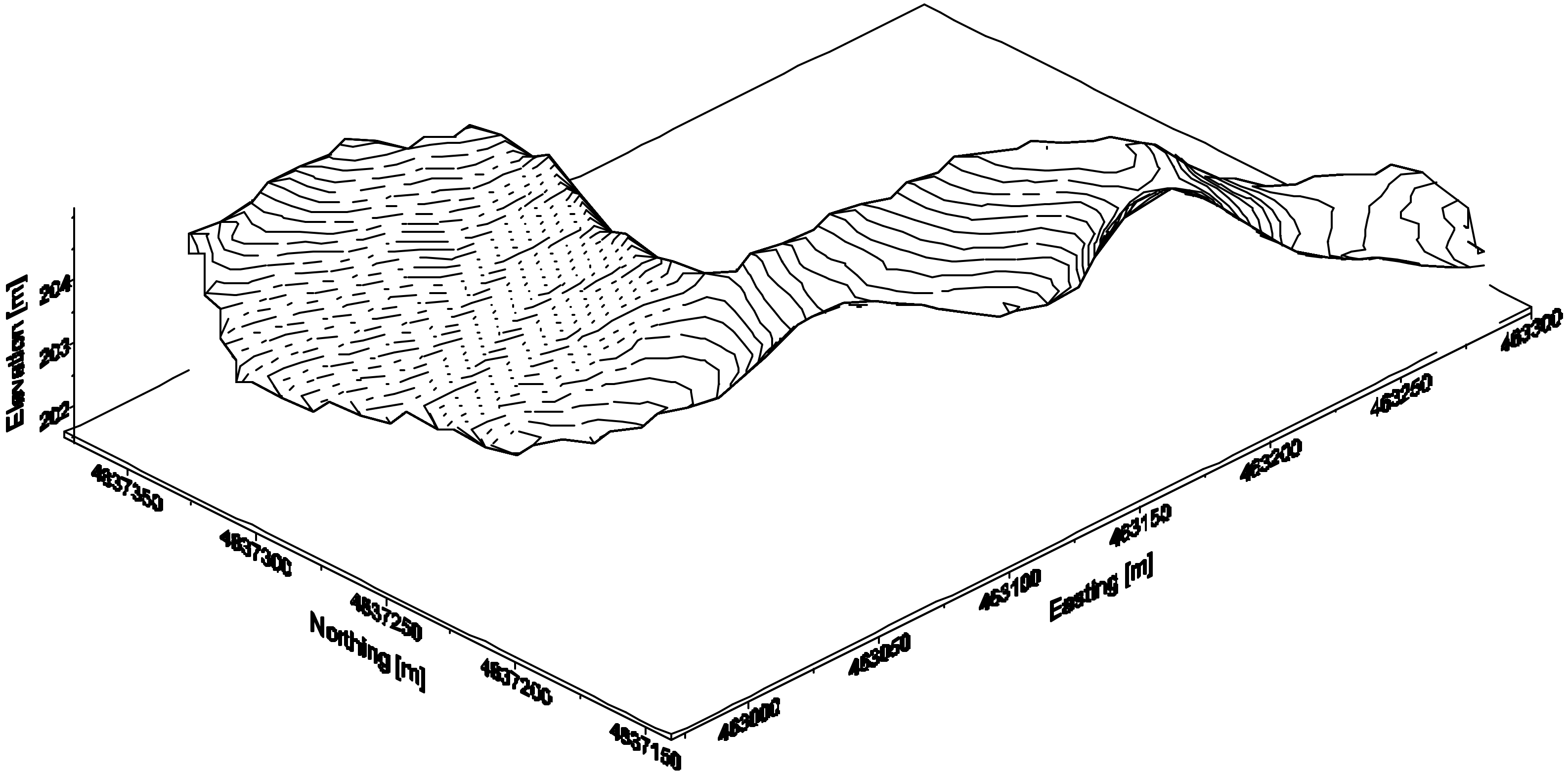


Figure 35a. Elevation 3D-surface plot of Site 1.

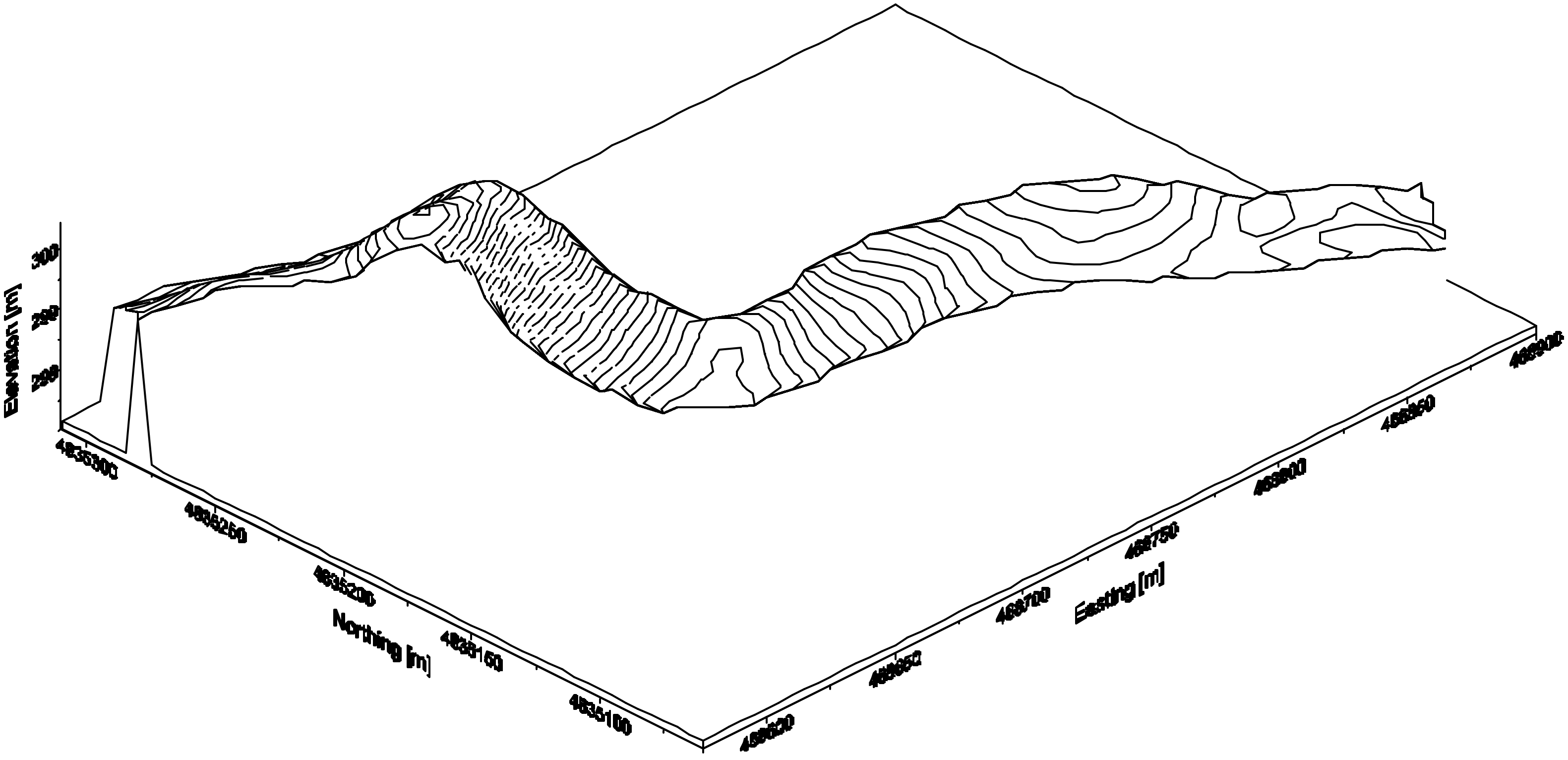


Figure 35b. Elevation 3D-surface plot of Site 2.

APPENDIX 2.
DATABASE DESCRIPTION

All the data collected is organized in DBF format when possible. The format of the DBF file is such that the first column has an ID constructed as follows:

ID Setup

The ID is made of 7 digits as follows:

```
FYSBBNN
1234567
```

F	Field	1, 2
Y	Year	3 - 6 (last digit of year = 93-96)
S	Sample type	see below
B	Block Nr	1 - 16
N	sample Nr	1 - <99

Sample Type

1	corn
2	soybeans
3	barley
4	Nodulation
5	Bulk Density
6	CI
7	EM
8	Soln-Sampler
9	Soil N

Each record has this ID, the sampling date (Julian day) and the sample(d) attribute(s), which can be linked to the corresponding file with positional data, which has the same ID and the x and y position, block and point number.

DESCRIPTION OF YIELD DATA (HAND and PLOT COMBINE HARVESTED)

DBF File Name	ID	Julian Day	Attrb 1	Attrb 2	Attrb 3	Attrb 4	Position		Block	PNr
							X	Y		
HY3_S1xy	ID						X	Y	Block	PNr
	1310101						94	105	1	1
	1310102						94	115	1	2
	1310103						94	125	1	3
HY3_S2xy	ID						X	Y	Block	PNr
	2310101						100	105	1	1
	2310102						100	115	1	2
	2310103						100 .00	125 .00	1	3
		(kg/ha)	(%)	kg/ha						
HY3_S1	ID	HYield	TotalNpc	TotalN						
	1310101	5703.9	1.071	61.09						
	1310102	6919.9	1.107	76.6						
	1310103	7836.7	1.271	99.6						
		(kg/ha)	(%)	kg/ha						
HY3_S2	ID	HYield	TotalNpc	TotalN						
	2310101	4164	1.25	52.05						
	2310102	3295.4	0.972	32.03						
	2310103	3021.5	1.032	31.18						
			(%)							
HY4_S1	ID	HYield	TotalNpc	TotalN						
	1410101	6626.1	1.468	97.27						
	1410102	7129.7	1.481	105.59						
	1410103	7260.7	1.465	106.37						
		(kg/ha)	(%)	kg/ha						
HY4_S2	ID	HYield	TotalNpc	TotalN						
	2410101	2900	0.939	27.23						
	2410103	1899.4	1.036	19.68						
	2410105	2626.4	0.887	23.3						
HY5_S1	ID	HYield	TotalNpc	TotalN						
	1520103	3261.9	6.14	200.28						
	1520106	2793.5	6.299	175.96						

DBF File Name	ID	Julian Day	Attrb 1	Attrb 2	Attrb 3	Attrb 4	Position		Block	PNr
							X	Y		
	1520109	2657.5	6.366	169.17						
HY5_S2	ID	HYield	TotalNpc	TotalN						
	2520102	3108.4	6.369	197.98						
	2520104	3353								
	2520106	3045.7	6.572	200.16						
		(kg/ha)	(%)	kg/ha						
HY6_S1	ID	HYield	TotalNpc	TotalN						
	1630101	997.65								
	1630102	3579.8								
	1630103	3736.3								
		(kg/ha)	(%)	kg/ha						
HY6_S2	ID	HYield	TotalNpc	TotalN						
	2630101	1666.7								
	2630102	1472.9								
	2630103	1337.2								

HARVEST DATES

File	ID	Date	Day	JDay
HY93_S1	1310101	1	05-Oct-93	278
HY93_S2	2310101	1	13-Oct-93	286
HY94_S1	1410101	1	04-Oct-94	277
HY94_S2	2410101	1	06-Oct-94	279
HY95_S1	1520103	1	03-Sep-94	246
HY95_S2	2520102	1	04-Sep-94	247
HY96_S1	1630101	1	14-Aug-96	227
HY96_S2	2630101	1	16-Aug-96	229

APPENDIX 3

ON-THE-GO YIELD MONITORING SYSTEM AND COMBINE YIELD DATA [6] [7]

1993 Ag Leader Yield Monitor 2000 Installed on a Gleaner R6 Combine 1986

The first year data was recorded on a notebook computer by using Dead Reckoning which meant that data was recorded by distance traveled and recorded by position. A special program called Mapsight captured the data and had features which the operator could indicate turns and the direction of the turn. The software would move the combine pass over the width of the combine header as recorded in the Monitor setup procedure, then proceed to record data in the correct direction. The dead reckoning system was used because the GPS Position Data which could be received in 1993 was not available with differential correction. Without DGPS, data recorded with a GPS position screen or by a printed coloured map in a second program called Yieldlink/Cropsight written by Ted Macey of Application Mapping.

Years 1994, 1995, 1996 the same yield monitor was used in conjunction with a Satloc Terrastar DGPS system which corrected for Selective Availability (error induced by US Military for security reasons) by accessing a differential signal broadcast from a communication satellite. The accuracy in positioning the yield data with differentially corrected GPS coordinates was much improved with accuracy now < 3 meters. Usually in the range of + or - 1 meter. The data was stored on an SRAM memory card at 1 second intervals and read from the storage card by a utility program supplied by AgLeader called AL2000 which archived the data and converted it to an ASCII file format. The data could then be viewed by any number of mapping programs or in spreadsheets.

Pricing

	Cdn $
AgLeader Yield Monitor 2000	$ 4700.00
Satlock TerraStar DGPS	$ 7000.00
(Note; Coast Guard Beacon Receivers DGPS now available)	$ 3400.00
Rawson Hydraulic Drive System	$6000.00
John Blue Pump	$ 1250.00
Flow Distributor Head (12 outlets)	$ 840.00
Software	
Mapsight Variable Rate controlling software for field use	$ 1500.00

---

[6] Note; all of this information is "as supplied" from the sub-contractor Beltane Agric-Services (Bruce Shillinglaw), R.R. #1, Londesboro, Ont., N0M 2H0.

[7] No product endorsement is meant by inclusion of this material

Mapping software (basic maps to full featured)	$400.00 - $ 980.00

Yield Monitor 2000 by Ag Leader

Yield Monitor 2000 designed and built by Al Meyers of Ag Leader Technologies, Ames, Iowa, uses a load cell connected to a small impact plate to calculate yield data from grain mass that is discharged against it by the clean grain elevator.

The sensing unit is technically called a mass flow rate sensor and is installed in an area where the grain is discharged by the clean grain elevator paddles. To maintain a constant angle of discharge, the top shaft of the elevator is adjusted to its upper limit. The chain adjustment is then made at the bottom of the elevator after minor modification and installation of supplied parts. The unit comes with a complete wiring harness designed to fit individual models of combines and uses clean grain elevator speed; ground speed; and distance travelled in its calculations. A sensor on the combine header determines when the combine is harvesting crop; accurate measurement of harvested area is then calculated.

Installation will take 2 people about 5 hours and all parts fit without any modification. To begin using the unit after installation, the following setup steps are needed:

1. Ground speed calibration
2. Input number of elevator sprocket teeth
3. Calibration numbers for individual crops (supplied with installation instructions)
4. Header working width
5. Crop type to be harvested

If the optional moisture meter is used, the standard dry grain moisture % needs to be inputed to calculate dry weight harvested.

The received unit stores total yield data by field and individual loads within the field; harvested data and time for each load as well as field totals.

In addition to selecting crop, header, width, field, load, the monitor can also display constant moisture readings, instant yield, harvesting rate in acres per hour, bushels per hour flow and distance travelled.

The installation instructions which come with the monitor are complete and easy to follow. After installing, everything worked but the header sensor switch which we had installed upside caused the unit to calculate acreage when the header was up.

Summary of Components

Yield Monitor 2000

- visually displays
  - Instant yield
  - Moisture of grain
  - Ground speed
  - Acres harvested per hour

- Fields with total acres
- Loads in field with harvested acres
- Average yield for each field
- Average moisture for each field
- Total wet and dry weight per field
- Dates and times for field data

Stored data
- All field data - acres, et wt., dry wt. moisture
- With GPS input Kriging Yield Maps for each field (Requires SRAM cards to store information. Maps printed by separate computer and software).

GPS Receiver
- Receives global location data and sends data to monitor or notebook computer

GPS Base
- Needed to calculate differential correction
- Differential may be transmitted from satellites late 1994

Notebook Computer
- Needed to store detail field yield data or to made additional notes in the field about crop and store in a site specific location

Mapsight
- In field data capturing software
  - used to store detail yield data
  - used to soil samples a field based on a grid layout

CropSight
- GIS mapping software
- Handles multiple layers of data eg. yield, soil tests, soil type, etc.
- Print colour yield maps, soil test data, etc. calculate acres, distances.

Grid enhancement add in for CropSight

YieldLink
- Yield map processing software used to correct problem data

Dynamic Yield Monitroing

Data Capture

Operationally, the yield monitor by itself will record and retain information for all of your fields, and even individual loads. It will always display a rolling average instantaneous yield estimate, but the current configuration of the monitor will only retain the accumulated weight at the load level.

While you can visually note yield variation within the field by watching the monitor, maintaining a permanent record of the variability at a site-specific level requires capturing the data from the monitor to another data storage device.

Applications Mapping has chosen to add a data capture capability to its popular MapSight real-time field positioning software. By using MapSight, you are actually recording the instantaneous yield each and every second for further analysis. In reality, we are recording yield, moisture, speed, cutting width, and position.

Your position can be determined by GPS or dead-reckoning techniques. MapSight is capable of either mode of operation. While dead-reckoning may work well for rectangular fields and a systematic parallel harvesting pattern, you will probably find GPS to work better for irregularly shaped fields or harvesting patterns where you are frequently breaking through, taking different header widths, etc.

MapSight runs on a standard IBM compatible computer with EGA/VGA graphics capabilities. A 286 class machine is sufficient, but we find a 25 Mhz386SX notebook computer to be a good platform for this type of activity. Using MapSight for capturing data from the yield monitor and positioning from the GPS receiver simultaneously requires 2 serial ports. Many notebooks don't have two serial ports. If the computer that you obtain for this application doesn't have two ports, we can supply a port concatenator that combines multiple serial devices into one port. This does require a pollable GPS receiver, though.

MapSight can be used for many things beyond yield monitoring data capture. For instance, it can be used to record field notes and weed problems observed during cultivation and spraying operations, as well as during harvesting. MapSight can also be used as a guide to manually control variable rate applications while the ag-controller industry is sorting out how an automated controller will be delivered to the farm marketplace.

APPENDIX 4.
DESCRIPTION OF SOIL SAMPLING AND SOIL ANALYSIS DATA

DBF File Name	**ID**	**Julian Day**	**Attrb 1**	**Attrb 2**	**Attrb 3**	**Attrb 4**	**Position**		**Block**	**PNr**
							X	**Y**		
			g/cm3							
BD3_S1	ID	Depth	Density	Tmnt						
	1350101	5	1.23	C						
	1350101	10	2.34	C						
	1350101	15	1.51	C						
							[m]	[m]		
BD3_S1xy	ID						X	Y	Block	PNr
	1350101						93.54	166.8	1	1
	1350102						93.89	210.4	1	2
			g/cm3							
BD3_S2	ID	Depth	Density	Tmnt						
	2350801	5	0.6	C						
	2350801	10	1.38	C						
	2350801	15	1.6	C						
							[m]	[m]		
BD3_S2xy	ID						X	Y	Block	PNr
	2350801						145.9	296.6	8	1
	2350802						146	305.3	8	2
SN3_S1	ID	JDay	Depth	NH4	NO3					
	1390101	138	30	2.79	33.06					
	1390102	138	30		10.97					
	1390103	138	30	0.98	7.13					
SN3_S2	ID	JDay	Depth	NH4	NO3					
	2390201	138	30		11.66					
	2390202	138	30		12.59					
	2390203	138	30		16.2					
SN3_S1xy	ID						X	Y	Block	PNr
	1390101						94	100	1	1
SN3_S2xy	ID						X	Y	Block	PNr
	2390201						106	100	2	1

DBF File Name	ID	Julian Day	Attrb 1	Attrb 2	Attrb 3	Attrb 4	Position		Block	PNr
							X	Y		
			mg/Kg	mg/Kg	mg/Kg					
SN3_S1	ID	JDay	NH4	NO3	TotalN					
	1390101	166		25.6	25.6					
	1390102	166	0.39	21.27	21.66					
	1390103	166	1.06	14.69	15.75					
SN3_S2	ID	JDay	NH4	NO3	TotalN					
	2390201	166	0.94	23.77	24.71					
	2390202	166	1.61	32.88	34.49					
	2390203	166	3.09	27.18	30.26					
			cm	mg/Kg	mg/Kg					
SN3_S1	ID	JDay	Depth	NH4	NO3					
	1390101	266	15		3.48					
	1390101	266	30		8.62					
	1390101	266	45		7.56					
			cm	mg/Kg	mg/Kg					
SN3_S2	ID	JDay	Depth	NH4	NO3					
	2390101	266	15	0.76	11.01					
	2390101	266	30	0.71	7.28					
	2390101	266	45	0.4	8.78					
SN3_S1xy	FRate						X	Y	Block	PNr
	150						94	100	1	1
SN3_S2xy	FRate						X	Y	Block	PNr
	150						106	100	2	1
				mg/Kg	mg/Kg					
SN4_S1	ID	JDay	Depth	NH4	NO3					
	1490101	122	15	1.4	6.26					
	1490101	122	30	0.63	3.85					
	1490101	122	45	0.6	2.95					
SN4_S1	ID	JDay	Depth	NH4	NO3					
	1490103	274	15							
	1490103	274	30	7.65	47.86					
	1490103	274	45	5.64	26.23					
SN4_S2	ID	JDay	Depth	NH4	NO3					

DBF File Name	ID	Julian Day	Attrb 1	Attrb 2	Attrb 3	Attrb 4	Position		Block	PNr
							X	Y		
	2490101	133	15	0.45	6.7					
	2490101	133	30	0.71	4.8					
	2490101	133	45	0.3	2.81					
SN4_S2	ID	JDay	Depth	NH4	NO3					
	2490201	274	15	4.41	64.94					
	2490201	274	30	6.97	12.94					
	2490201	274	45	3.69	5.76					
SN5_S1	ID	JDay	Depth	NH4	NO3					
	1590103	213	30	5.13	21.78					
	1590103	213	60	7.5	5.73					
	1590103	213	90		7.73					
SN5_S2	ID	JDay	Depth	NH4	NO3					
	2590118	213	30	12.76	25.36					
	2590118	213	60	5.88	2.96					
	2590118	213	90	1.59	2.72					

SOIL SAMPLING DATES

File	ID	Date	Day	JDay
BD93_S1	1350101	1	34311	342
BD93_S2	2350307	1	08-Dec-93	342
SN931_SX				
S1	1390101	1	18-May-93	138
S2	2390201	1	18-May-93	138
SN932_SX				
S1	1390101	2	15-Jun-93	166
S2	2390201	2	15-Jun-93	166
SN933_S1	1390101	3	23-Sep-93	266
SN933_S2	2390101	3	23-Sep-93	266
SN94_SX				
S1_D1	1490101	1	02-May-94	122
S1_D2	1490103	2	01-Oct-94	274
S2_D1	2490101	1	13-May-94	133
S2_D2	2490201	2	01-Oct-94	274
SN95_SX				
S1	1590103	1	01-May-95	121
S2	2590118	1	08-May-95	128
SN96_SX	none			

Appendix 5.

DESCRIPTION OF SOLUTION SAMPLER DATA

DBF File Name	ID	Julian Day	Attrb 1	Attrb 2	Attrb 3	Attrb 4	Position		Block	PNr
							X	Y		
				ppm						
CL3_S2	ID	JDay	Depth	Cl	Tmnt					
	1360101	316	5	67.83	C					
	1360101	316	10	58.19	C					
	1360101	316	15	122.84	C					
	…	…	…	…	…					
	1360410	342	70	134.74	O					
	1360410	342	75	114.85	O					
							[m]	[m]		
CL3_S1xy	ID						X	Y	Block	PNr
	1360101						93.54	166.8	1	1
	1360102						93.89	210.4	1	2
				ppm						
CL3_S2	ID	JDay	Depth	Cl	Tmnt					
	2360101	316	5	37.35	C					
	2360101	316	10	36.8	C					
	2360101	316	15	60.94	C					
	…	…	…	…	…					
	2360410	342	65	49.98	O					
	2360410	342	70	50.44	O					
	2360410	342	75	83.25	O					
							[m]	[m]		
CL3_S2xy	ID						X	Y	Block	PNr
	2360801						145.9	296.6	8	1
	2360802						146	305.3	8	2
				Row	mg/Kg	mg/Kg				
SS3_S1	ID	JDay	Sampler	Position	NH4	NO3				
	1380101	258	1	r	10.91	21.39				
	1380101	258	2	r	2.13	37.71				
	1380101	258	3	r		7.25				
SS3_S1xy	ID	Topo	FRate				X	Y	Block	PNr
	1380101	LH	C				93.54	166.8	1	1
	1380102	SH	C				93.89	210.4	1	2

DBF File Name	**ID**	**Julian Day**	**Attrb 1**	**Attrb 2**	**Attrb 3**	**Attrb 4**	**Position**		**Block**	**PNr**
							X	**Y**		
	1380103	LL	C				93.77	240	1	3
				Row	mg/Kg	mg/Kg				
SS3_S2	ID	JDay	Sampler	Position	NH4	NO3				
	2380801	259	1	r						
	2380801	259	2	r						
	2380801	259	3	r	0.46	5.22				
SS3_S2xy	ID	Topo	FRate				X	Y	Block	PNr
	2380801	LL	C				145.9	296.6	8	1
	2380802	FS	C				146	305.3	8	2
	2380803	LH	C				144.2	360.5	8	3
				Row	mg/Kg	mg/Kg				
SS4_S1	ID	JDay	Sampler	Position	NH4	NO3				
	1480101	104	1	i	2.46	19.94				
	1480101	104	2	i	0.23	6.13				
	1480101	104	3	i	0.16	16.81				
	…	…	…	…	…	…				
	1480410	206	58	r	0.86	8.5				
	1480410	206	59	r						
	1480410	206	60	r	3.02	7.83				
SS4_S1xy	ID	Topo	FRate				X	Y	Block	PNr
	1480101	LH	C				93.54	166.8	1	1
	1480102	SH	C				93.89	210.4	1	2
	1480103	LL	C				93.77	240	1	3
				Row	mg/Kg	mg/Kg				
SS4_S2	ID	JDay	Sampler	Position	NH4	NO3				
	2480801	1	1	i	1.22	1.89				
	2480801	1	2	i	1.34	16.9				
	2480801	1	3	i	1.08	10.66				
	…	…	…	…	…	…				
	2480510	7	58	r						
	2480510	7	59	r	1.14	9.21				
	2480510	7	60	r	0.54	2.83				
SS4_S2xy	ID	Topo	FRate				X	Y	Block	PNr
	2480801	LL	C				145.9	296.6	8	1
	2480802	FS	C				146	305.3	8	2
	2480803	LH	C				144.2	360.5	8	3

SOIL Cl AND SOLUTION SAMPLERS SAMPLING DATES

File	ID	Date	Day	JDay
CL93_S1	1360101	1	12-Nov-93	316
		2	08-Dec-93	342
CL93_S2	2360101	1	12-Nov-93	316
		2	08-Dec-93	342
SS93_S1	1380101	1	15-Sep-93	258
		2	14-Oct-93	287
SS93_S2	2380801	1	16-Sep-93	259
		2	14-Oct-93	287
SS94_S1	1480101	1	14-Apr-94	104
		2	26-Apr-94	116
		3	30-May-94	150
		4	13-Jun-94	164
		5	27-Jun-94	178
		6	11-Jul-94	192
		7	25-Jul-94	206
SS94_S2	2480801	1	14-Apr-94	104
		2	26-Apr-94	116
		3	30-May-94	150
		4	13-Jun-94	164
		5	27-Jun-94	178
		6	11-Jul-94	192
		7	25-Jul-94	206

Appendix 6.

DESCRIPTION OF SOYBEANS NODULATION DATA

DBF File Name	ID	Julian Day	Attrb 1	Attrb 2	Attrb 3	Attrb 4	Position		Block	PNr
							X	Y		
	ID	JDay	TCode	FRate	Nodule					
NO5_S1	1540107	1	C		2.41					
	1540111	1	C		3.38					
	1540114	1	C		9.15					
	ID	JDay	TCode	FRate	Nodule					
NO5_S2	2540111	1	O		7.51					
	2540117	1	O		17.94					
	2540123	1	O		2.14					

NODULATION SAMPLIG DATES

File	ID	Date	Day	JDay
NO95_SX				
S1	1540107	1	01-Aug-95	213
S2	2540111	1	01-Aug-95	213