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Title: Spatial Relationships of Vesicular-Arbuscular Mycorrhizae, Soil Fauna and Soil Nutrients in the Juniper-Sagebrush-Grass Communities of Central Oregon

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A Study conducted at The Island, Lake Billy Chinook, in Central Oregon, examined differences in the pattern of soil properties between a sagebrush-grass and a juniper-sagebrush-grass community. Juniper invasion is linked with the desertification process in which the sagebrush shrubs and perennial grasses decline. Patterns in soil nutrients and other properties can influence the distribution of vegetation and vice-versa. With an increase in heterogeneity of a soil resource, plants may fail to regenerate if the patch size of the resource is smaller than required.

The study tested the hypothesis that juniper invasion in a sagebrush-grass community changed the heterogeneity of soil properties at scales relating to the

vegetation. Soil nutrients, moisture, pH, vesicular-arbuscular mycorrhizal (VAM) infection and soil micro-arthropods were examined. Soil properties are frequently very variable such that the difference between the means of two communities may not be detectable by parametric statistical analyses alone. Spatial statistical methods adapted from geostatistics, including the semivariogram and correlogram, differentiated between the patterns of soil properties of the two communities. The semivariograms provided information on the range of autocorrelation and relative variance at increasing lags. Moran's I and Geary's C correlograms provided estimates of the average of patch and interpatch size and distribution.

Communities with junipers had lower summer soil moisture, fewer soil micro-arthropods and a higher rate of vesicular-arbuscular mycorrhizal infection. Soils under sagebrush contained more moisture and soil arthropods than bare ground. However, there was more bare ground and less sagebrush in the community with junipers than in the sagebrush-grass community.

Long range variation at lag distances greater than 18 m was found in both communities, indicating that pattern forming processes other than juniper were operating at these scales. Variation at scales related to sagebrush distribution occurred in soil moisture, the nitrogen fractions and soil fauna. Soil fauna also showed variation at scales relating to the grasses. VAM infection data showed no pattern structure at all scales measured, and a high nugget variance, indicating variation below scales of 0.5 m. Although the scale of the pattern (range and average patch size) did not differ between sagebrush-grass and juniper-sagebrush-grass, short range variation (<10 m) was higher than long range (>10 m) more

frequently in the plots with junipers. This implied more contrast in the data and a more abrupt edge between patch and interpatch areas in plots with juniper.

Spatial Relationships of Vesicular-Arbuscular Mycorrhizae, Soil Fauna and Soil Nutrients in the Juniper-Sagebrush-Grass Communities of Central Oregon.

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1. INTRODUCTION

Background

The big sagebrush-bluebunch wheatgrass communities of central Oregon have undergone an increase in the establishment of Juniperus occidentalis Hook since the turn of the century (Eddleman, 1989). This tree is regarded as a weed of rangelands by cattle ranchers because it outcompetes both the sagebrush Artemesia tridentata and the perennial grasses for moisture and other nutrients. However, the mechanisms of these competitive interactions are not entirely clear.

The junipers are evergreen, allowing growth and nutrient absorption whenever conditions are favourable. Water loss in junipers is reduced by limiting stomates to the protected inner surfaces of the scale-like leaves and by having a waxy cuticle on leaf surfaces (Miller 1989).

Sagebrush has two sets of leaves: ephemeral leaves which it sheds at the onset of drought to reduce water loss, and perennial leaves which allow it to photosynthesise early in the rainy season. This confers some drought tolerance and gives it a lead in carbohydrate fixation over the grasses. Both sagebrush and junipers have fine surface roots to take advantage of rain and deeper roots to obtain groundwater. However juniper has a much deeper tap root than sagebrush, and it

can therefore sustain active growth for a longer period as it is less water limited than the grasses or sagebrush. Juniper also has a more extensive surface root system than sagebrush (Flanagan et al, 1992). The extensive root system of junipers allows them to exploit soil resources several meters from the tree. Nutrients absorbed from the soils between junipers are recycled as litter beneath the canopy (Miller 1989). It is likely that this redistribution of resources effectively reduces the pool available for grasses and sagebrush in the soils between junipers. Cattle forage is thus reduced and there is an observable increase in the amount of bare ground in plots invaded by juniper.

Fire suppression and overgrazing have contributed to the spread of junipers, which are more susceptible to fire than the perennial grasses, which can resprout from underground rhizomes. Grazing cattle consume the vegetation that can sustain and carry a ground fire, setting a positive feedback system in operation which aids juniper establishment and reduces forage plants (Eddleman, 1989).

The mutualistic association of vesicular-arbuscular mycorrhizal (VAM) fungi with juniper, sagebrush and the common perennial grasses Agropyron spicatum, Poa secunda, and Festuca idahoensis increases the efficiency of the host plant to sequester soil nutrients (Trappe, 1981), particularly when there is nutrient stress. Thus VAM may increase the survival and establishment potential of desired perennial grasses. Because juniper, sagebrush and grass all form VAM associations, VAM may contribute to the development of patterns of soil nutrients at the scales of these three vegetation types.

Soil fauna play a part in the decomposition of organic matter in the soil and the release of nutrients to the soil (Whitford, 1986; Santos et al, 1981), and their abundance is related to litter quality and microclimate (Wallwork et al, 1984). The fungivorous micro-and macro-arthropods may also have an effect on the abundance, distribution and function of VAM fungi by consuming hyphae and spores external to the root (Rabatin and Stinner, 1985). Changes in soil fauna abundance and guild composition have the potential to change nutrient cycling patterns by the indirect effect of selective feeding on decomposer fungi or microbes (Rabatin and Skinner, 1985, Ingham et al, 1985).

Effective management of ecosystems requires a knowledge of the characteristics, processes, dynamics and response to change within the system of interest. Perry et al (1989), discuss the importance of the link between above and below ground processes, and how positive feedback mechanisms can serve to either regenerate or degenerate a system, depending on which way the balance is tipped.

One of the most important aspects of an ecosystem is interaction between vegetation and soil which shapes the distribution of plant resources in the soil. Soils analyses frequently concentrate on finding a mean value of a soil commodity such as moisture or nitrate in a parcel of land. However, the mean value in a plot is less important to a plant than the value of the nutrient in its root zone. Thus, if the spatial pattern of the resource changes it may result in patches of nutrient too small or conversely, large but too widely spaced to support the original vegetation cover.

As plants develop, soil nutrients accumulate (or are depleted) in the zone of influence of the plants, creating heterogeneity that corresponds to plant cover (Belsky et al, 1993). As vegetation complexity develops, different pattern scales interweave on the landscape. If there is competition for nutrients, this patterns may determine the pattern of establishment of new plants.

Pattern analysis of soil properties can reveal spatial relationships among different properties and between soils and the landscape features (e.g vegetation) which play a part in soil formation. Parametric statistics such as analysis of variance and comparison of means can distinguish between differing mean values of a soil property provided the variance is not too great. Similarly, regressions can detect relationships between soil properties provided the properties involved are not separated in time and their variance is not great. Most soils data do not lend themselves to parametric statistical analyses because point to point variation can be very high and can hide real differences

between means, and soils data typically are spatially autocorrelated. Autocorrelated data violate the requirement for independent data in parametric statistics. Robertson (1987), discussed the use of autocorrelation techniques in determining data independence in continuous media (lakes and soil).

Spatial statistical methods adapted from geostatistics, originally developed for use in the mining industry, have become increasingly useful in ecology. These methods measure patterns of natural variation, and in particular how these change as a function of distance. The tools of spatial statistics include the semivariogram, log-

log semivariogram, fractal dimension and correlogram. The semivariogram gives information on the distance over which a soil property is autocorrelated, the relative importance of the variation as a function of distance, the amount of variation at scales shorter than the minimum sampled, and the total variance within the area sampled.

The log-log semivariogram helps clarify autocorrelation ranges over the shorter distance classes which may be harder to see in the semivariogram, and can also be used to obtain the fractal dimension. The fractal dimension distills the essence of complex natural patterns into a single numerical value, assuming a self similar pattern. If a pattern, when magnified, is revealed as being constructed of smaller patterns appearing the same as the whole, then it is said to be self similar. Natural examples include a fern frond or a stream network. If the pattern is known at one scale, the fractal dimension can be used to predict the pattern at lesser or greater scales.

Correlograms can help identify the size and regularity of features on the landscape, supporting and adding detail to the information from the semivariograms. Correlograms also can be tested for statistical significance, unlike semivariograms.

Burrough, 1983(a and b), used semivariograms and fractals to describe the nested variation in soils as a result of soil forming processes acting at a number of different scales. He observed that more variation occurred at the shorter ranges associated with the effects of vegetation than at the longer ranges associated with parent material or climate.

Kotliar and Weins (1990) discussed the nesting of variation as it pertained to heterogeneity within a patch and between patches, and the detection of patch size and structure at different scales. We expected nested scales of variation in our Central Oregon study site because it has three major vegetation types (grasses, sagebrush and junipers).

Sokal and Oden (1978) and Rossi et al (1992), describe geostatistical analyses of ecological data. Robertson et al (1988) used semivariograms to investigate soil properties such as moisture, respiration and nitrogen processes. However, the evenly spaced single scale grid system they used for sampling meant that very general conclusions only could be drawn from the spatial patterns, and their ecological interpretations were minimal. Pierson and Wight (1991) used a similar grid but tailored the spacing of samples to optimise the data at the scale of sagebrush plants for a study of soil temperatures. Their semivariograms showed periodicity in the data relating to the scales of sagebrush, from which they were able to make some useful interpretations as to the mechanics of temperature mediation by the shrubs.

To maximise the ecological interpretations possible from a spatial study of the juniper-sagebrush-grasslands of central Oregon, we tailored a sampling design to obtain maximum information about the variation at three nested scales relating to the vegetation composition of those sites.

Objectives and hypotheses

This thesis used an observational study on The Island, Lake Billy Chinook, Palisades State Park, Central Oregon to test if the spatial partitioning of soil resources changed when the sagebrush-grassland was invaded by junipers.

The objectives of this study were to describe the spatial patterns and relationships between a set of soil properties in sagebrush-grass communities with and without juniper, using parametric statistics, semi-variograms and correlograms as tools. The properties investigated were the root infection levels of vesicular-arbuscular mycorrhizae (VAM), pH, moisture, plant available nitrogen and soil fauna. A further aim was to determine how closely these soil properties related spatially to each other and to the vegetation, in order to better understand the below ground dynamics of vegetation change.

This study addressed the hypothesis that juniper invasion would increase soil heterogeneity of sagebrush-grass communities by introducing variation at large scales relating to their spacing, and that this large scale variation would be absent from sagebrush-grass communities without juniper. An innovative sampling design was developed based on concentric nested subplots at three hierarchies of sampling intensity to determine whether soil patterns were related to the distribution of the three major vegetation species: juniper sagebrush and grass.

2. METHODS

APPROACH

This research addressed the following set of hypotheses that relate ecological processes to spatial patterns in juniper-sagebrush-grass systems of central Oregon:

1. If vegetation affects the distribution of soil properties then spatial structure in soil data will be related to the spatial distribution of junipers, sagebrush plants and grass clumps in the study site. Soils in the juniper-sagebrush-grass community will therefore have a higher coefficient of variation than sagebrush-grass soils due to the addition of juniper, and additional variation at long range scales (18 m or more) corresponding to the spacing of junipers, which are not found in the sagebrush-grass system.

2. Although the spacing of plants is similar in both communities, the sagebrush and grass clumps appear to be smaller and separated by more bare ground in the juniper-sagebrush-grass community than in the sagebrush-grass community. The difference between the relationship of patch (plant) to interpatch (bare) between the two communities will be detectable as a difference in the ratio of short to long range variation. The sparser vegetation in the community with juniper will thus produce greater short

range than long range variation, and a higher fractal dimension over the 0 - 30 m lags.

Site selection

To study the natural processes and patterns of soil nutrient partitioning, a site in as near natural condition as possible was selected with the aid of aerial photographs, advice from U.S.D.A. Forest Service personnel in the Bend office, and site visits. "The Island" on Lake Billy Chinook, in the Palisades State Park, Central Oregon provided a site with minimum disturbance due to its inaccessibility to vehicles and cattle, although in the 1920s a small number of sheep were grazed there (Driscoll, 1964a). Deer, rabbits and ground squirrels are now the main mammalian herbivores. The climate is xeric with warm dry summers and cool dry winters. Mean monthly temperatures range from -1.3°C in January to 19.2°C in July, but a minimum temperature of -42.8°C and a maximum of 44.4°C have been recorded. Rainfall at Madras, approximately 9 miles to the northeast of The Island, averages 236 mm per year, 88% of which falls as snow or rain between October and June. Frosts can occur during any month of the year, but are less likely during June, July and August (Driscoll 1964a).

The Island is a mesa rising more than 200 feet from the surface of Lake Billy Chinook. The lake was formed by the damming of the Deschutes and Snake rivers which flow north along the west and east sides of The Island and converge at its

its northern tip. The Island's geology consists of 10,000 to 15,000 year old basaltic flows interspersed with volcanic ash deposits. The soil parent material is composed of unconsolidated lake sediments laid down before the Deschutes and Crooked rivers cut the canyons that now surround the site (Driscoll, 1964a). The subsequent Mazama eruption 8,000 years ago and later Newberry crater eruptions may also have contributed ash deposits to the site. The soils are classified as Typic and Lithic Cryorthents and tend to be shallow with basaltic rocks at the surface.

The vegetation community consists of Juniperus occidentalis (western juniper), Artemesia tridentata (sagebrush), Agropyron spicatum (bluebunch wheatgrass), and Poa sandbergii (sandberg bluegrass) predominantly, with some Pershia tridentata (antelope bitterbrush), Festuca idahoensis (Idaho fescue) and Bromus tectorum (cheatgrass).

The study site examined in detail (Figures 2.1 and 2.2) was a level area of approximately 1 km^2 supporting a vegetation of predominantly sagebrush and perennial grasses, with junipers encroaching at the northern section.

SAMPLE DESIGN

Sample plot location

Paired plots were selected where sagebrush-grass and juniper-sagebrush-grass communities occurred adjacent to one another. Each sampled plot consisted of a circular sampling design with three concentric circular subplots (Figure 2.3).

Initially a design with randomly located points within each nested circle was chosen rather than a regular sampling grid, because the latter may fail to capture a regularly spaced landscape pattern or one occurring below the minimum distance between points. However, in pilot studies a purely random design yielded irregular numbers of pairs of points in each distance class and too few points at the maximum lag (i.e. the distance between any two sampling points within a plot). To improve the precision of the semi-variogram at the maximum lag three regular grids were superimposed on the concentric circular plots, and sampling points were randomly located in each grid cell. Grid sizes were 20 m for the 100 m, 2 m for the 10 m and 0.5 m for the 2 m diameter subplots. This design satisfied the requirements to have (1) pairs of points at as many lag distances as possible, (2) equal numbers of pairs of points at each lag distance, and (3) lag distances roughly coinciding with the scale of grasses, sages and junipers. Fifty-two points were sampled in each plot: 12 at the 2 m diameter scale, and 20 each at the 10 m and 100 m diameter scales. Each sample plot had a uniquely chosen set of randomly located points.

Sample collection

A total of ten plots were sampled in December 1991 and May 1992 (Figure 2.4). In December 1991, three complete plots and part of a fourth plot were sampled, two in the sagebrush/grass community and one in the adjacent juniper/sagebrush/grass community. To minimize variation due to moisture and temperature differences, all samples from the complete plots were collected on the same day. A fourth plot in the juniper-sagebrush-grass was sampled one week later. However due to snowfall only 22 of the 52 planned samples in this plot were collected, 12 from the 2 m diameter subplot and 10 from the 100 m subplot. In May of 1992, a complete set of six plots, three in each of the two community types, was sampled over the course of two days of settled weather.

Plot centres were randomly selected, separated by at least 100 m, within each community type. Plot centers could fall in four locations: under the canopies of juniper, sagebrush or grass or on bare ground. In the December sampling, the centre of the partially sampled plot fell at the edge of a juniper canopy. In the May sampling, one plot was centred approximately 1 m away from the edge of the juniper canopy. The eight other plot centres fell between the canopies of sagebrushes or junipers, on or close to a grass clump, such that the grass clump was within the inner 2 m diameter subplot. The type of plant cover was recorded at each sampling point within the plot. Surface litter was removed and a 10 cm diameter by 5 cm deep core was taken and transferred to a marked sealed polythene bag for

microarthropod extraction. From the area immediately surrounding the core, approximately 500 g of soil to a depth of 5 cm was removed to a second sealed polythene bag for chemical analysis.

Collection of other data

The average and nearest neighbour spacing of the sagebrush was determined by mapping the locations of all sagebrush plants within 15 m of a randomly selected central point in each of the juniper and non-juniper areas. Juniper locations were recorded in a 50 m radius plot. The spacing between grass clumps was determined by measuring the distances across the bare ground between each clump of grass and its nearest neighbour in three 3x3 m plots in each of the juniper and non-juniper areas. This method was adopted for the grasses as grass clumps were irregularly shaped unlike the discrete circular units of the junipers and sagebrush. These data were used to create a frequency distribution of nearest neighbour distances between plants. Mean minimum spacings were used to construct artificial landscapes, (discussed below), and in the interpretation of spatial structure in the data.

Vegetation composition was determined by the point-intersection method using the vegetation cover data from the 50 m radius subplot of each sampling plot. Soil morphology, including colour, structure and texture, was described from samples collected with a bucket auger at a set of 12 points in the juniper and non-juniper areas.

Sampling handling and storage

Samples were transported off the site in backpacks and transferred within one day to a cool room at 4°C, where they were stored at field moisture prior to analysis (Bartlett and James 1980). The samples for microarthropod extractions taken in May 1992 were very dry. These samples were humidified to break drought-induced dormancy in the soil fauna by adding approximately 3 ml of distilled water to each polythene bag with a plant mister prior to cool storage. Arthropod extractions were begun within three days of return from the field.

Soils were sieved through a 2 mm mesh prior to chemical analysis. Roots of diameter 0.5-1 mm remaining on the sieve were transferred to "Tissue Tek" capsules and stored in tap water at 4°C for up to 3 days prior to the staining procedure used to determine infection by vesicular-arbuscular mycorrhizal (VAM) fungi.

Variability introduced by storage of the samples was distributed throughout the samples by analyzing them in random order. This precaution was taken to reduce any bias in the subsequent spatial analyses. A composite sample was mixed and stored along with the other samples, then re-analyzed with each batch to measure the change in pH, moisture and nitrogen fractions due to storage over the three weeks required to analyze all the samples.

LABORATORY ANALYSES

Microarthropod extraction

Soil arthropods were extracted from the 10 cm diameter cores using a MacFayden high gradient extraction funnel (Freckman et al, 1986; Merchant and Crossley, 1970). The high gradient extractor collects active animals which move away from a hot, dry, brightly lit environment induced by a heat lamp, towards a dark, cool, moist environment at which there is a collecting vessel. The heat lamp was on for 4 hours on day 1 and an additional 2 hours on each subsequent day until it remained on continuously. On day 11 the first collecting vessel containing 2-3 ml of fungicide solution in water was removed and replaced with a dry vessel, which was left in place until the soil had dried completely. The complete extraction required approximately 14 days. The animals collected from wet and dry vessels were pooled for each sampling point and placed in 10% ethanol in a small glass bottle. One to 2 ml of clear mineral oil were added to the bottle, which was gently shaken for a few seconds and allowed to settle. This method differentiates between lipophilic and lipophobic cuticles on animals and renders them easier to see and identify (Moldenke, A. personal communication). Numbers of each species were noted for each sample. Species were grouped into guilds based on diet (A. Moldenke, personal communication.) Microcosm experiments to determine diet in

unknown cases were performed in the O.S.U. Entomology Department by Dr. A. Moldenke, who also supplied information on biomass of each species.

Soil chemical analyses

Chemical analyses were carried out on the < 2 mm fraction of soil at field moisture content. Results were expressed per gram of oven dry soil. Moisture was determined by weight difference between fresh and oven dried samples (24 hours at 100°C). Soil pH was measured using a pH meter with a glass electrode (Corning, model no. 215), on a 2:1 deionised, distilled water:soil ratio. The prepared mixture was left to stabilise overnight, then stirred one hour prior to reading.

Mineralizable N (NH4-N + NO3-N) was determined on split samples. Initial NH4-N and NO3-N were extracted immediately from one subsample with a 2N KCl solution using a 1:5 soil:KCl ratio. The second subsample was incubated aerobically at 25°C for 14 days before extraction for NH4-N and NO3-N. The extracts were assayed for nitrogen content on an auto-analyzer (Alpkem R.F.A. model no. 300) in the Forest Science Soil Laboratory, using an Indophenol assay for NH4 and a cadmium reduction assay for NO3 (Keeney and Nelson, 1982; EPA-600/4-79-020). Net N mineralized was determined as $N_{(incubated)} - N_{(initial)}$. December samples were incubated at field moisture. May samples were brought to December field moisture content (approximately 25%) by the addition of distilled water introduced with a

plant mister while gently shaking the soil to achieve crumb formation. This method helped retain an aerobic soil structure.

Vesicular-arbuscular mycorrhizal infection assessment.

Roots of 0.5 to 1 mm diameter collected from each soil sample into "Tissue Tek" capsules during soil seiving were cleared in hot 10% KOH solution for 0.5 to 1.5 hours in a steamer, or until most of the pigmentation was removed. After neutralizing in 1% HCl, they were stained with trypan blue (Phillips and Hayman, 1970), then de-stained and stored in lactoglycerin.

Infection was assessed under a dissecting scope using a grid intersection method (Giovannetti and Mosse, 1979) and expressed as a percentage of the total root-grid intersections. A random selection of 20 samples were checked by Christine Fischer, a mycologist familiar with the technique to assess the accuracy of the estimation. This check indicated that the technique had approximately a 10% error.

Replication of chemical analyses.

A set of 25 randomly selected samples from the December sampling period were split. Analyses of these samples were replicated once and the mean differences between replicates 1 and 2 of the 25 samples were used to estimate laboratory error.

DATA ANALYSIS

Parametric statistical analysis

Parametric statistical analyses assume independence of the data. To determine which data were independent and which were autocorrelated, non parametric statistical methods such as the semivariogram described below under "Spatial statistics", were used. Sampling points within 10-15 m of one another were autocorrelated. Only data from sampling points greater than 10-15 m apart were independent of one another, and these were used for the parametic analyses. In other words, sampling points in the outer subplot (separated on average by 20 m were independent, so these data were used in parametric analyses. The partially sampled plot taken in December contributed 10 independent data points from outside of the 10 m diameter subplot and one datum from within this subplot, this single point being an average of 12 autocorrelated data from within the 2 m diameter plot, all taken from beneath the same juniper tree. This average point increased the representation of data from under juniper (the least well represented of all plant cover) in parametric analyses while still maintaining independence.

Catagorical variables were created for the plant cover, season and community type. Plant cover had 4 categories: bare ground = 1, grass = 2, sagebrush = 3, juniper = 4. Season had 2 categories: December = 1, May = 2. Community type had 2 categories: sagebrush-grass = 1, juniper-sagebrush-grass = 2.

Each variable was examined for normality and a transformation was applied to normalize it as necessary. All normalizations were accomplished with a $\log_{10}$ transformation. Soil pH, all nitrogen fractions, soil fauna biomass and numbers were all log-normally distributed. VAM were normally distributed. Moisture could not be normalized because the large difference in values between the December and May sampling periods created a bimodal distribution, so the dataset was divided into the two separate seasons and normalized with a $\log_{10}$ transformation. Initial data examination included scatterplots and box and whisker plots by season and by plant cover.

A Spearman rank correlation analysis was performed on the untransformed data. A Pearson correlation analysis was performed on the log transformed data using a Bonferroni corrected significance test (Steel and Torrie, 1980). The Pearson correlation coefficient measures linear relationships between variables while the Spearman Rank correlation measures dependence between variables whether linear or not (Rossi et al, 1992.) The data from the partial plot, as described above, was included in these analyses.

A 2x2 factorial ANOVA was conducted for each of ten soil properties using the catagorical variables of season and community type as the treatment factors. Significance was determined using the least significant difference (lsd) comparison of means. This is a simple test for pre-planned comparisons of paired means. In this case the number of replicates in each category was not the same. Lsd was calculated following Steel and Torrie (1980):

$$lsd = t_{(\alpha=0.05,df)} S_{\bar{Y}i-\bar{Y}i'} = S^2(1/r_i + 1/r_{i'})$$

where t is Students t for the chosen significance level, in this case $\alpha = 0.05$, r_i and $r_{i'}$ are the numbers of observations in each group mean, and S^2 is the pooled error variance.

The partial winter plot data (plot B) was omitted from the ANOVA as its samples were collected under different weather conditions than the three complete December plots.

For each soil property, the means, standard deviation, maximum and minimum, and coefficient of variation were computed, by plot, for the transformed independent data, and back-transformed for examination using the following formulae:

Mean: $\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$ where X_i is the sample value and n is the number of samples.

Standard deviation: $s = \frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{(n-1)}$

$$C.V. = \frac{s}{\bar{X}}$$

All the statistical procedures mentioned above were performed using the "Systat" software package for Macintosh computors (Systat 1992).

Principal component analysis (Harris, 1975) was performed on the soil fauna data from December 1991, using all samples per plot. Three analyses were performed using just the species data to create ordination series for the axis. The three series pertained to guild structure, species composition and vegetation cover. Each ordination series generated using the Decorana program for the IBM (Hill, 1979) explained a portion of the variation in the data. The first and second axis (x and y) used in each analysis explained the largest and second largest portion of the variation respectively. An ordination plot of the samples from plots A and C (sagebrush-grass) and B and F (juniper-sagebrush-grass) was constructed using the first and second axes (Ludwig and Reynolds, 1988).

Spatial statistics

A range of spatial statistical procedures were used on untransformed real and synthetic data. Spatial statistics included semi-variograms, correlograms, and fractal dimensions.

Semivariograms

Semivariograms were constructed by plotting the semivariance, (equal to half the squared difference of the values of the soil property between pairs of sampling points) against the distance between the pair, known as the lag or lag distance.

Figure 2.6a illustrates a semivariogram, the interpretation of which is discussed below under "Interpretation of spatial autocorrelation and spatial pattern." The formula for calculating the semivariance, $\hat{y}(h)$, at lag h, is:

$$\hat{y}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_{(i+h)})]^2$$

where N(h) is the number of points separated by distance h; $z(x_i)$ and $z(x_i + h)$ are the values of the soil property at positions x_i and $x_{(i+h)}$ respectively (Rossi et al, 1992). In this study, h is measured in Euclidean distances over all directions in two dimensions (scalar). Each point on the semivariogram represents the mean semivariance for 30 pairs of data points, following Legendre and Fortin (1989), who note that fewer than this number of pairs is inadequate to produce significant results. Distance classes of less than 30 m (one third of the maximum sampling interval) form the most precise part of the semivariogram. As the lag distance increases, the 30 pairs of data points from which each semivariance is calculated have a larger range of distances separating them, thus blurring any spatial patterns.

Anisotropy is a change in local mean with direction (Rossi et al, 1991). When present anisotropy introduces variation at scales greater than those sampled and thus detracts from the power of the semivariogram to detect pattern. Anisotropy was assessed by examining the slope of the data plotted against the sample position along a North-South and an East-West axis. To correct for anisotropy the axes were reorientated with one along the line of steepest slope and a perpendicular one along the flattest slope, and a new set of cartesian coordinates was calculated for each

sample point plotted on the new axes. Spatial analyses were conducted on the residuals of the steep slopes. The anistotropy-corrected semivariograms calculated using these "corrected" values were visually compared to and the uncorrected semivariograms. However in this design forty of the fifty two sampled points were within 5 m of the centre, and therefore the slope of the regression correction was dictated by a few outermost points, so this correction factor did not account for gradients in the dataset as a whole. This is discussed further in the results section below.

Outliers are uncharacteristic data values which can influence the interpretation of the spatial structure of the data (Rossi et al, 1992). An outlier may cause a peak in the variance which masks finer structure in the data. Suspected outliers were removed from three datasets. All the data from one sampling point were removed from a December sagebrush-grass plot (plot "C") and from a December juniper-sagebrush-grass plot (plot "F"), as all soil properties at that point were uncharacteristic of the datasets for that plot, and a local phenomenon (probably recent animal urination on the sampled area prior to sampling) was suspected. First one, then a second suspected outlier was removed from the moisture dataset of a May juniper-sagebrush-grass plot (plot "I"). After removal of each outlier, the spatial analyses were rerun and the results compared with those conducted on the full dataset to identify differences in their interpretation.

Standardised semivariograms were prepared by dividing each semivariogram value by the plot variance following the methods in Rossi et al (1992). This

technique allows semivariograms with different ranges of variance to be directly compared.

Spatial autocorrelation coefficients.

Moran's I and Geary's C are spatial autocorrelation coefficients. Moran's I compares the values found at all pairs of points in a given distance class (Legendre and Fortin, 1989). Values of Moran's I usually range between -1 and +1, depending on the degree of similarity shown by the values at those pairs of points. A positive value of Moran's I corresponds to positive autocorrelation (similar values), a negative I to negative autocorrelation (different values). Moran's I for each distance class, from Sokal and Oden (1978) and Legendre and Fortin, (1989) is:

$$I(h) = [n \sum_{i=1}^{m} \sum_{j=1}^{n} w_{ij} (y_i - \bar{y})(y_j - \bar{y})]/[W \Sigma_i (y_i - \bar{y})^2]$$

where I(h) is the Moran's I at distance h, n is the number of data points, y_i and y_j are the values of the variables at i and j, $\bar{y}$ is the their mean of the variables at all locations, w_{ij} takes the value of 1 when the pair are at the distance class being computed, and 0 otherwise, and W is the number of pairs used for the distance class. In this case 30 pairs were used for each correlation point as in the semivariograms. Following Sokal and Oden (1978) a 95% confidence interval was constructed around each expected value of Moran's I. The expected value of Moran's I is:

$$\mu_1' = \frac{-1}{(n-1)}$$

The confidence interval was constructed from the variance of I, which is:

$$\mu_2 = \frac{n[(n^2 - 3n + 3)\, S_1 - nS_2 + 3W^2] - b_2[(n^2 - n)S_1 - 2nS_2 + 6W^2]}{(n-1)^{(3)}\, W^2} - \frac{1}{(n - 1)^2}$$

where n = number of observations in the total data set (ie. 52)

$$S_1 = 1/2 \sum_{i=1}^{m} \sum_{j=1}^{n} (w_{ij} + w_{ji})^2 \qquad \text{(group size = i.e. 30)}$$

$$S_2 = \sum_{i=1}^{m} (w_{i\cdot} + w_{\cdot i})^2 \qquad \text{(i.e. group size * 4)}$$

$$b_2 = \frac{n \sum_{i=1}^{n} (X_i - X)^4}{[\sum_{i=1}^{n} (X_i - X)^2]^2} \qquad \text{(heteroskedasticity)}$$

$$(n - 1)^{(3)} = (n - 1)(n - 2)(n - 3) \quad \text{(ie. 51 x 50 x 49, or 124950)}$$

The upper and lower bounds of the confidence interval are then

I_u = upper bound = $\mu_1' + 1.96\sqrt{\mu_2}$

I_l = lower bound = $\mu_1' - 1.96\sqrt{\mu_2}$

An example and interpretation of a Moran's I correlogram appears below under the heading "Interpretation of spatial autocorrelation and data."

Geary's c spatial autocorrelation coefficient has a numerator which sums the squared differences between values found at the pairs of points under consideration, and is thus related to the semivariance (Legendre and Fortin, 1989; Sokal and Oden, 1978). The formula for Geary's C therefore generates positive values, those between 0 and 1 being positively autocorrelated, and those above 1, negatively

autocorrelated. The shape of the graph resembles, but is not identical to, the semivariogram. Again, 30 pairs of data points were used in the calculation of each coefficient. Geary's c was calculated using the formula in Legendre and Fortin, (1989):

$$c(h) = [(n-1) \Sigma \Sigma w_{ij} (y_i - y_j)^2]/[2W \Sigma (y_i - \bar{y})^2]$$

The notation is the same as for the Moran's I formula.

The semivariograms, Moran's I, Geary's c and significance tests were calculated using a program written in C for the SUN workstations by J.A. Jones and B. Marks in the Department of Forest Science, Oregon State University (see Appendix A).

The Fractal dimension

The fractal dimension D, otherwise termed the Hausedorf-Besicovitch dimension, is a measure of the ratio of short range to long range variation in the data, ie. the relative amounts of roughness at a range of scales (Burrough, 1983a; Goodchild and Marks, 1987). In two-dimensional data such as in this study, D has an expected value between 2 and 3. A high D denotes a high short range variation compared to the long range variation at the scale sampled. An example would be a table surface (low D) compared to a crumpled tablecloth (high D). The fractal dimension over lag h D_h was calculated from the slope m of a linear regression fitted

to the log-log standardised semivariograms (Figure 2.6b) following Burrough (1981; 1983a,b.):

$$\text{Slope} = m = (4\text{-}2D_h)$$

In the absence of any structure in a semivariogram the short and long range variation are similar (equal "noise" at all scales), and the slope of the regression line fitted to the log-log semivariogram would be zero, giving a D value of 2. When short and long range variation are not equal (i.e. some structure is seen), the regression of the log-log semivariogram has a slope other than zero, for example, a high short to long range variation of slope -1 would have a D value of 2.5.

Fractal dimensions were calculated for the 0-2 m and the 2.1-10 m lags in each log-log semivariogram. Slopes were compared using a 95% confidence interval to determine any significant differences between plots.

Artificial landscapes

It was critical to demonstrate that the study sampling design and spatial statistical analyses used would be able to detect a spatial pattern if one existed. Therefore the sampling design was applied to simulated landscapes with two kinds of known a priori patterns: (1) no pattern (random) and (2) regular patterns. Data in the random plots were created by assigning random numbers within the same ranges as the real variables to each sampling point in place of the measured variables. For soil properties whose measured values were log-normally distributed, random

numbers were generated in the range of the logged real data and antilogged. Twelve random landscapes were generated, one for each measured property.

The regularly patterned artificial landscapes were constructed from on points representing plants arranged in a diagonal grid (Figure 2.5). The spacings between artificial "plants" in the artificial landscapes were set equal to the mean nearest neighbour distances calculated in the field for junipers and sagebrush plants. Each artificial juniper was represented by two concentric circles, a larger circle for the root crown and a smaller circle (with half the diameter) for the canopy. An artificial soil property value of 1 was assigned to the bare area, 2 to the root crown and 3 to the canopy area of junipers in artificial landscapes. Each artificial sagebrush plant was represented by a single circle, whose canopy area was given an artificial soil property value of 2, and the bare area was given a value of 1. Simulated landscape designs are shown in Table 2.1.

Design 1 was based on the smallest junipers observed (1 m canopy diameter, 2 root crown diameter). It tested whether the sampling design and spatial statistics could detect a regular pattern consisting of small patches (2 m) and a large bare area area (94%). Design 2 with 5 m canopy diameter junipers spaced at 18 m apart, simulated the size and spacing of the larger trees on the Island site. Designs 3 to 6 were based on juniper spacings observed at the pilot study site near Haystack Butte (10 m apart). Designs 5 and 6 had juniper root crowns which touched or overlapped, these designs tested whether very close spacing was detectable. In the case of design 6 the bare areas were eliminated by the overlapping root crowns.

Design 7 tested whether the sampling design and spatial statistics could detect a pattern consisting of regularly spaced 1 m diameter sagebrush with 2 m spacing. Design 8 tested whether a pattern of regularly spaced 10 m large junipers with 18 m spacing superimposed on regularly spaced 1 m diameter sagebrushes with 2 m spacing was detectable. Design 9 tested whether a pattern was detectable in a random numbers set within the range of values used for the simulated landscapes above.

Once the artificial landscapes had been produced, synthetic datasets were created by overlaying one of the ten random sampling designs on each of the nine regularly patterned artificial landscapes. To assess the effect of position relative to the pattern each artificial landscape was sampled with the plot centred in two places: on the canopy edge and in the intercanopy space. To simulate natural variation at scales below the scale of the junipers and sagebrushes, a random number between 0 and 0.02 was added to or subtracted from each value. Each of the twenty artificial datasets (12 random and 8 regular) was then evaluated using the same spatial statistical analyses as the field-measured data.

Interpretation of spatial autocorrelation and spatial pattern

Spatial structure in the data was interpreted from semivariograms, correlograms and fractal dimensions. Standardised semivariograms were interpreted based on the nugget variance, the range and the sill (Burgess and Webster, 1980).

The nugget variance is the semivariance at the y intercept. A zero nugget variance implies that adjacent points have identical values. A higher nugget semivariance indicates that some non-zero variance occurs at lags smaller than the shortest distance between samples, or that variation has been introduced during the sampling, handling or analyses techniques (Rossi et al, 1992).

The range is the point along the x axis at which the variance ceases to rise and levels off or declines (for example Figure 2.6a). Sampling points that are spaced at lags less than the range are autocorrelated (Burgess and Webster, 1980). A semivariogram with a slope rising in steps is indicative of several scales of autocorrelation, and the changes in slope indicate the breaks between scales (Burrough, 1983b). The sill, (Figure 2.6a), is the maximum semivariance observed within the semivariogram.

The following interpretations were made based on comparisons of semivariograms between plots and between soil properties:

1. An equal range for one soil property in all plots was interpreted as the scale over which a pattern-forming process was operating for that property throughout the two communities (landscape processes).
2. An equal range for all properties in one plot was interpreted as the scale at which a pattern forming-process affected all properties in that plot (local processes).

3. More than one range for a given property in a plot was interpreted as nested scales of pattern-forming processes such as may occur under plants of different sizes and distributions within a plot (process/property interactions).

4. When a given property had different ranges in two or more plots this was interpreted as pattern-forming processes occurring on different scales in each plot (plot/process interactions).

When more than one range was identified in a plot, the relative magnitude of the semivariance at each of these ranges was interpreted as a measure of their relative contribution to the total variability for that soil property in the plot. Thus semivariances at more than one range were used to differentiate between plots that were dominated by short range variability and those dominated by long range variability.

Correlograms were interpreted from positive and negative significant values of Moran's I. A positive value of Moran's I results when pairs of points at a given distance apart have similar values more frequently than they have different values. For example, pairs of like values such as A-B or C-D at approximately 1 m lag in the landscape in Figure 2.7b occur more frequently than pairs of dissimilar values like B-C. In this example, the significant positive Moran's I at 0.5 to 1 m could be interpreted as a measure of the minimum patch size (Legendre and Fortin 1989).

A negative value of Moran's I results when the frequency of dissimilar pairs of points exceeds that of similar pairs at a given lag distance. The negative correlations at 1.5 m to 2 m lags in Figure 2.7c can be interpreted as approximately

half the pattern wavelength or the distance between the patch centre and the centre (see for example pairs A-D, D-F, F-G versus C-E or E-G in Figure 2.7). The positive significant values of Moran's I at 3 and 6 m in Figure 2.7c can be interpreted as a full wavelength or the distance between successive patch centres (Legendre and Fortin 1989).

Information from correlograms based on Gearys' C was used to corroborate interpretations of the semivariograms and correlograms based on Morans' I.

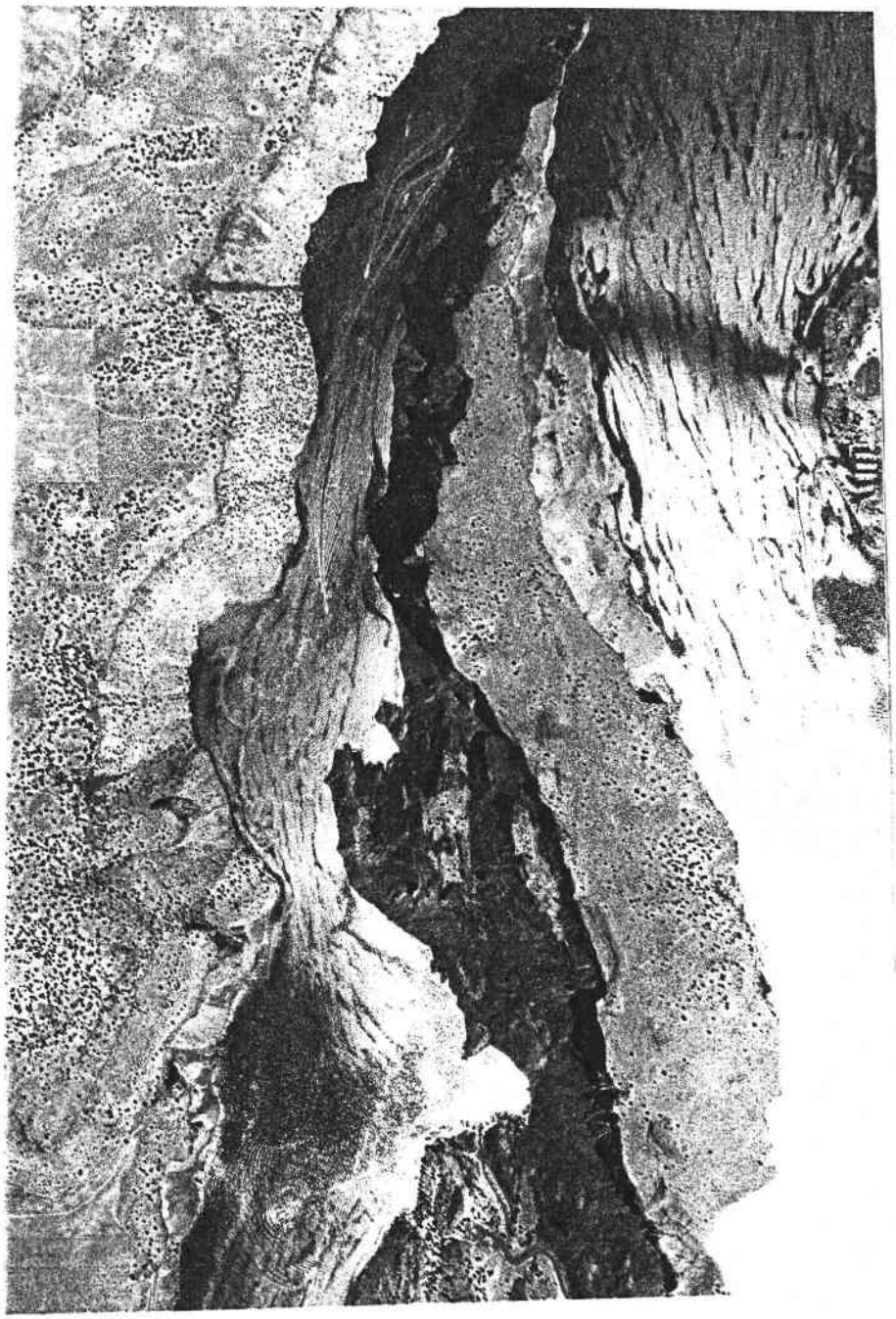


Figure 2.1. Aerial photograph of The Island. The difference between the natural vegetation on the Island and the managed vegetation on the mainland is apparent.

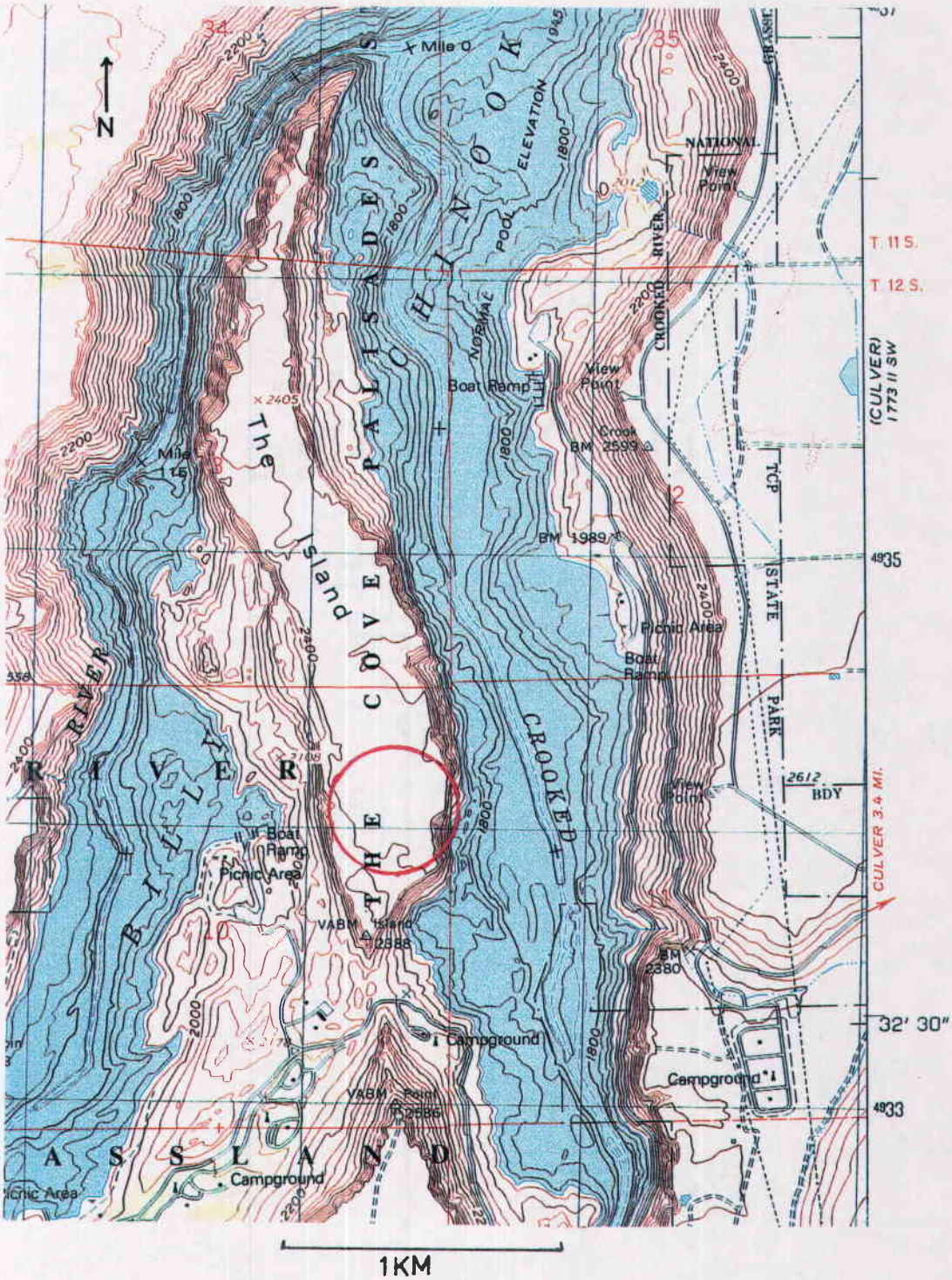


Figure 2.2. Map of The Island showing the study area circled in red.

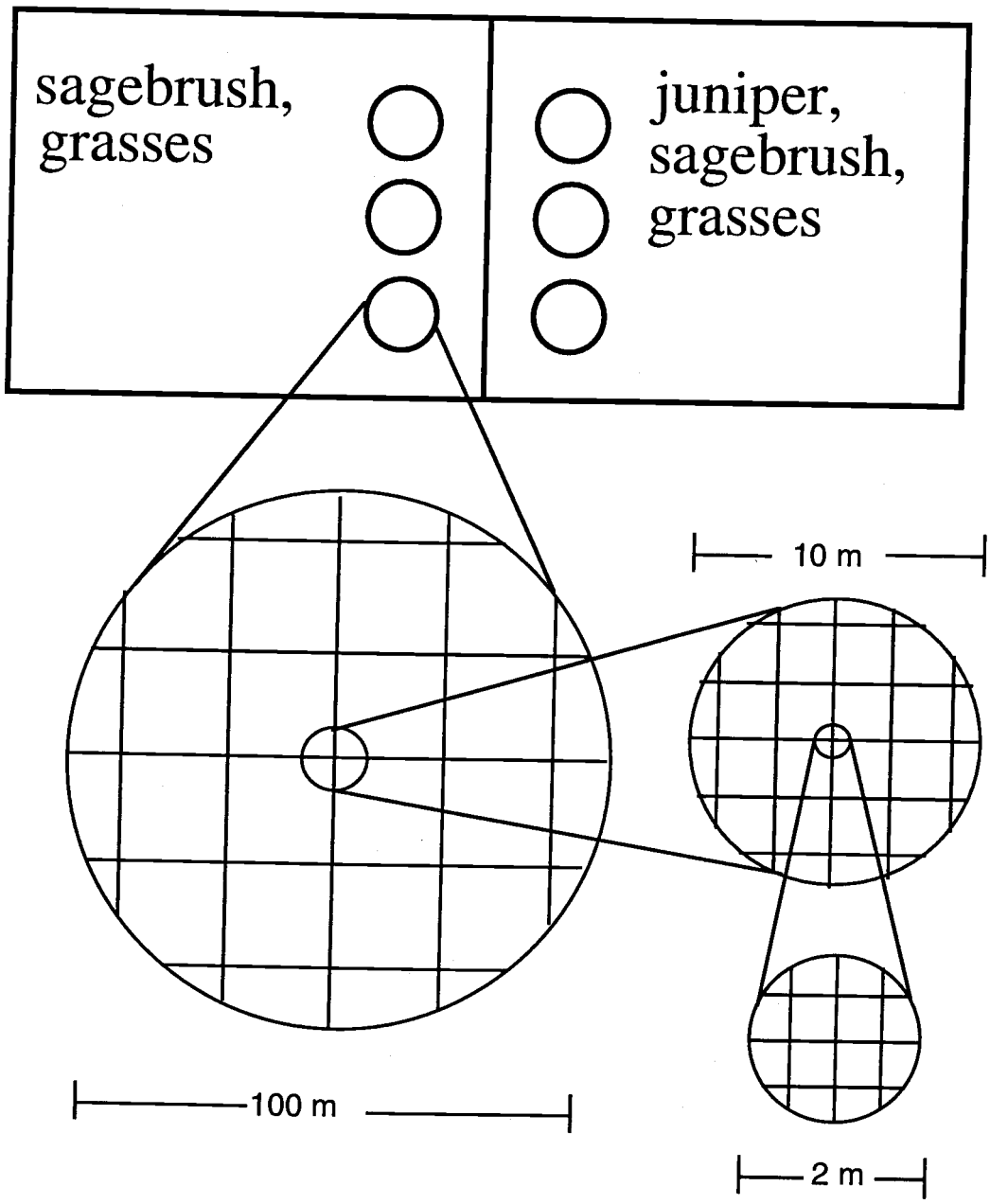


Figure 2.3. The sampling design used for the study of spatial patterns of soil biological and chemical properties under sagebrush-grass and juniper-sagebrush-grass communities in central Oregon. In each of three pairs of 50m radius plots, soils were sampled to capture variation at three scales using three nested randomised grids with cell sizes of 20, 2, and 0.5m.

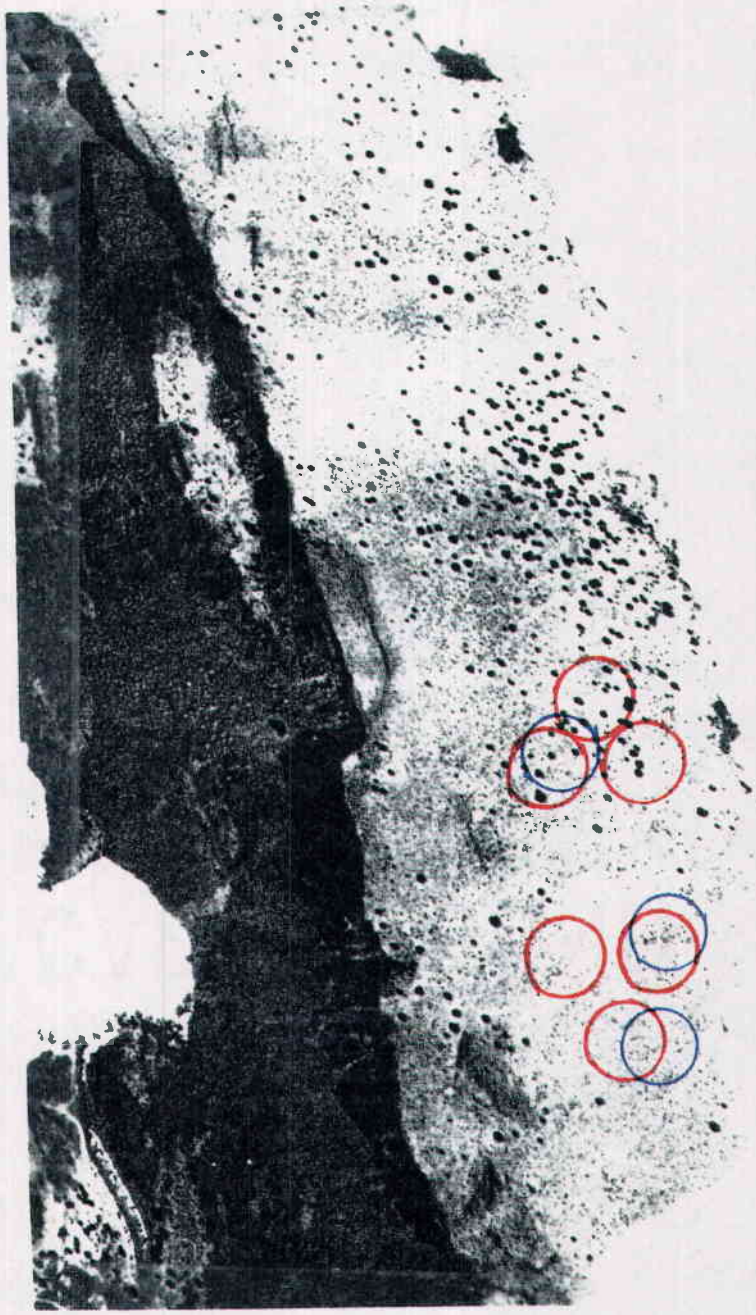


Figure 2.4. Locations of the plots sampled in December (outlined in blue) and May (outlined in red). The plots are grouped by community type with the juniper-sagebrush-grass community to the north and the sagebrush-grass community to the south.

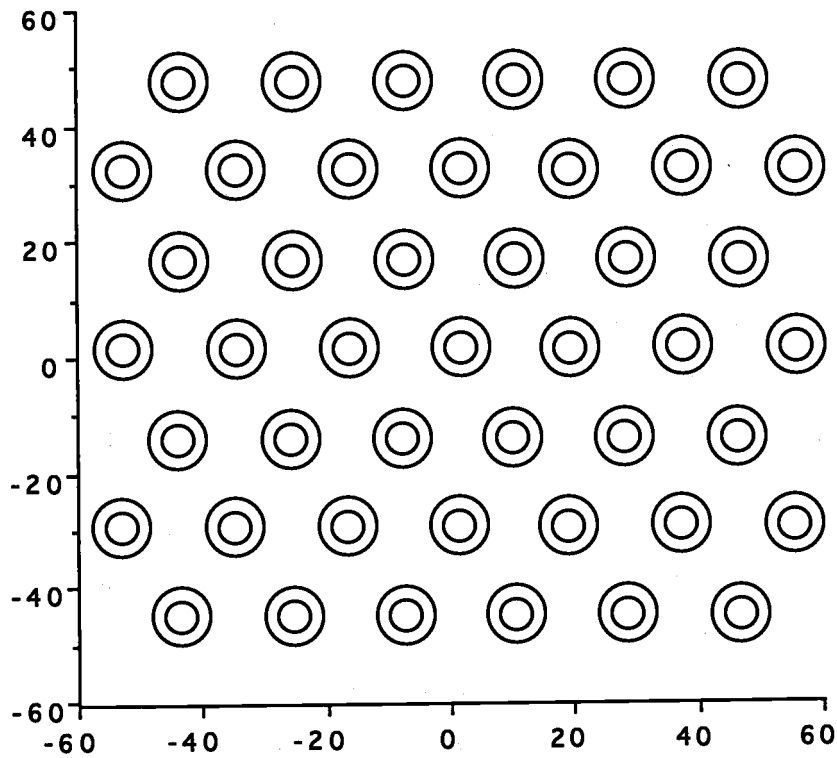


Figure 2.5. Example of the diagonal grid artificial landscape design. This shows junipers spaced at 18m apart. The central circles represent the canopy area, the outer circles represent the root crown and the space between the bare area. These areas were given the values 3, 2 and 1 respectively.

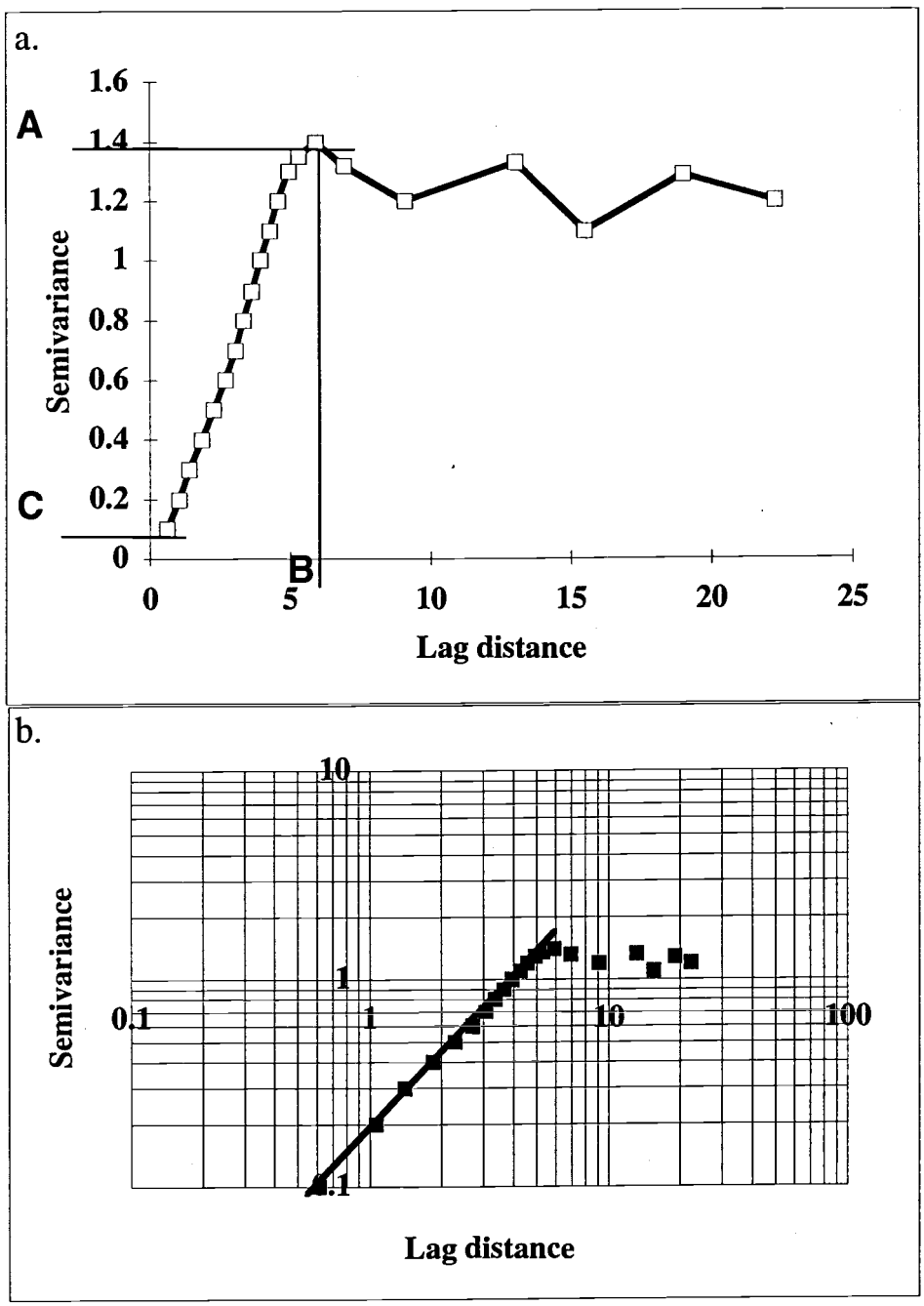
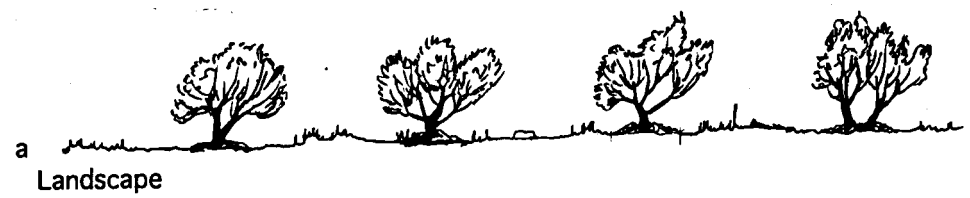
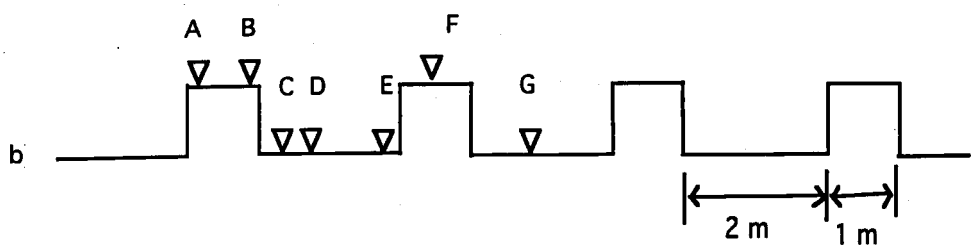


Figure 2.6a. Example of a semivariogram showing the sill (A), the range (B), and the nugget variance (C).

2.6b. The above semivariogram plotted on a log-log scale and a line fitted by least squares regression to the data within the range. The slope of this line is used to calculate the fractal dimension of the data over this range.





Soil property levels of landscape (simplified).

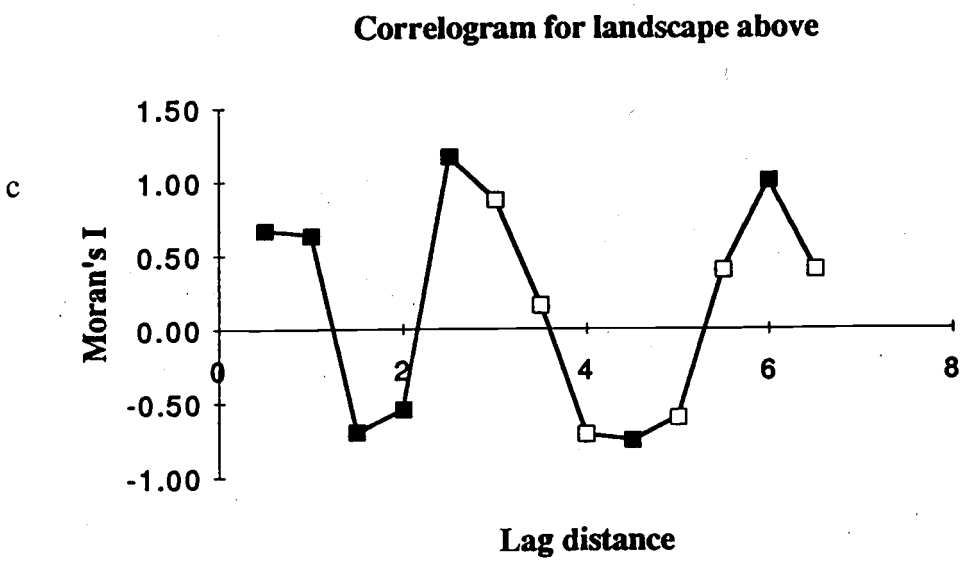


Figure 2.7. The landscape (2.7a) gives rise to varying levels of a soil property, shown in simplified version below the landscape (2.7b). The example Moran's I correlogram (2.7c), shows how the levels of the soil property are autocorrelated as a function of the distances between a pair of sampling points. Solid squares indicate significant values of I. See the text for full interpretation.

Table 2.1. Simulated landscape designs, spacing, canopy and root crown are in meters.

Design	Spacing	Canopy	Root crown	Spacing	Canopy
1	18	1	2	--	--
2	18	5	10	--	--
3	10	1	2	--	--
4	10	2.5	5	--	--
5	10	5	10	--	--
6	10	5	>10*	--	--
7	--	--	--	2	1
8	18	5	10	2	1
9	Random numbers from 0.98 to 3.02.				

3. RESULTS

Vegetation composition by community type.

Point intersection surveys of the vegetation indicated that one third of the area in the sagebrush-grass community was bare ground whereas almost one half was bare in the juniper-sagebrush-grass community (Table 3.1). Grass represented 39% of the cover in the sagebrush-grass community but only 30% in the juniper-sagebrush-grass community. Sagebrush covered 27% in the sagebrush-grass community but only 18% in the juniper-sagebrush-grass community. Juniper canopies covered 6% of the area in the juniper-sagebrush-grass community. Plant cover in the juniper-invaded community was 25% less for grass and 33% less for sagebrush than in the sagebrush-grass community.

Junipers were separated by nearest-neighbour distances of between 5 to 75 m with a mean of 19 m (Figure 3.1). Sagebrush plants in the juniper plot were separated by nearest-neighbour distances ranging between 0.5 and 14 m with a mean of 2.5 m (Figure 3.2). Nearest-neighbour distances between sagebrush plants in the sagebrush-grass community ranged from 0.5 to 7.5 m with a mean of 2 m (Figure 3.3). The sagebrush plants tended to be larger in the sagebrush-grass community than in the juniper-sagebrush-grass, although measurements of diameter were not taken. In the community with junipers, the nearest-neighbour distances between grass clumps ranged between 0.15 and 0.95 m with a mean of 0.42 m. In the

sagebrush-grass community, nearest-neighbour distances between grass clumps ranged from 0.1 to 1.3 m with a mean of 0.37 m. The mean diameter of grass clumps was 0.35 m in communities without junipers compared to 0.26 m in communities with junipers.

Laboratory replication errors.

The 25 randomly chosen soil samples from the December sampling period that were replicated to determine the error due to laboratory techniques showed mean differences and standard deviations that were less than 20% of measured values (Table 3.2.)

The accuracy between two estimations of percent V.A. infection in a root sample was within 5% for both personnel. The second person consistently estimated 10% more than the first. On comparison, the first person had counted as a positive reading those roots containing vesicles or arbuscles, whereas the second reader had included the fine hyphal structures found in the root hairs. This was a matter of personal technique and judgement. Since the study required a comparative rather than absolute measurement, this discrepancy between techniques was not a problem.

The changes in the standardized soil sample during three weeks of storage are illustrated in Figure 3.5. Moisture content remained the same and pH fell by 0.1 unit. Initial ammonium fell from 24 to 16 μg/gm oven dry soil but initial nitrate

rose by 2 μg/gm oven dry soil. Ammonium generated during incubation fell from 11 μg/gm oven dry soil in samples analyzed on the 5th January to 1 μg/gm in samples analysed on the 10th, where it stabilized for the remaining 15 days. Nitrate generated during incubation showed the reverse trend. Because the soils were analyzed in random order, effects of storage were spread throughout the plots, and therefore were unlikely to affect the structure of the data.

Correlations among soil properties.

Most measured soil N variables were strongly positively correlated in both December and May. However, net ammonification was negatively related to initial NO3 and NH4 in May (Tables 3.3 and 3.4). In other words, samples with high initial NO3 and NH4 also had higher rates of nitrification, ammonification and N mineralization. However in May, samples with initial high NO3 and NH4 tended to have lower ammonification rates.

All soil arthropod groups were strongly positively correlated (Tables 3.5, 3.6 and 3.7). Vegetation cover was strongly positively related to all soil arthropod groups in December, but only to totals and fungivores in May (Tables 3.8, 3.9). Numbers of soil arthropods per unit soil volume increased from bare ground to grass to sage to juniper (Table 3.15).

Moisture was strongly positively related to net nitrification and net mineralization in December, and weakly positively related to VAM and pH in May

(Table 3.8). Soil pH was strongly negatively related to initial ammonium, net nitrification and net mineralization, and positively related to net ammonification (Tables 3.8, 3.9). In other words, relatively wetter soil samples in December tended to have higher net nitrification and mineralization. In contrast, in May, when soil samples were equally wetted to field capacity, nitrification and mineralization were limited by a lower pH, and ammonification was relatively higher in more acid soil samples.

Soil Properties by plot and community type

Soil properties varied between plots (Tables 3.10 and 3.11). Most soil properties also varied by season (Table 3.13.) and between community types (Table 3.12). Mean soil moisture content was 16 to 20% in December but less than 3% in May, and soil arthropod numbers were 60 to 75 per sample in December but less than 5 in May (Tables 3.10, 3.11 and 3.13). Numbers of individuals in soil arthropod functional groups and arthropod biomass were an order of magnitude higher in December than May.

Soil pH varied from 6.3 to 6.7 in both seasons (Table 3.10). Initial nitrate varied from 0.4 to 1.8 μg/gm oven dry soil (ODS) and mean net nitrification by plot varied from 3 to 11 μg/gm ODS (Table 3.10). Initial nitrate and net nitrification were roughly three times higher in December than May (Table 3.13). Initial ammonium varied from 0.3 to 4.3 μg/gm ODS and net ammonification from 0.5 to -

3 μg/gm ODS (Table 3.10). Initial and net ammonification were approximately three times higher in May than December (Table 3.13). VAM infection varied from 29 to 43% (Table 3.10) but did not vary by season.

Soil moisture was weakly higher in sagebrush-grass plots than in juniper plots (Table 3.12). Juniper plots had significantly lower total soil arthropod numbers and biomass, and lower biomass of fungivores, micropredators and microfungivores (Table 3.12). Juniper plots had smaller differences in soil arthropod biomass between the two seasons than sagebrush-grass plots. Soil arthropod biomass in juniper varied seasonally by an order of magnitude, whereas it varied by almost two orders of magnitude in sagebrush-grass plots (Table 3.14).

In summary, soil samples collected in December were wetter, had higher rates of N mineralization, nitrification and ammonification, and much higher soil arthropod numbers and biomass than soils collected in May. V.A. mycorrhizal infection and soil pH varied little by season. Soils collected in the juniper-sagebrush-grass community had slightly higher rates of VAM infection, lower moisture in May and significantly lower arthropod biomass and numbers in both seasons than soils from the sagebrush-grass community.

Principal Component Analyses.

When analysed by guild composition, plots A and C from the sagebrush-grass community formed a cloud of points which overlapped each other slightly more completely than they overlapped F and B (juniper-sagebrush-grass), which also covered areas similar to each other (Figure 3.6). The analysis by species composition (Figure 3.7) showed more separation by community type, although there was still some overlap. The analysis by vegetation cover at each sampled point (Figure 3.8) showed the most distinct groupings, with clouds of points sampled on bare ground and under grass overlapping each other, and clouds of points sampled under sagebrush and juniper concentrated more towards the lower values of the first axis and only partially overlapping the bare and grass groupings. These analyses suggested that the relative proportions of functional groups of microarthropods were only slightly different (Figure 3.6), but the species composition making up those functional groups differed between the juniper and non-juniper communities (Figure 3.7). This was explained by the vegetation cover, because 13 of the 22 points in plot B, and 3 of the 52 points in plot F were sampled under juniper canopies, while all points in plots A and C fell under sagebrush, grass or on bare ground. Fewer samples were taken under sagebrush than in bare ground or under grasses, and even fewer were taken under juniper, which possibly influenced the tightness of the grouping by reducing the variation sampled.

Effects of outliers, non normality and anisotropy on the results of the spatial pattern analyses.

Removal of outliers

Removal of outliers affected the shapes of the semivariograms. The magnitude and graphical position of the effects and the shape and significance of the correlograms depended upon the degree of departure of the outlier from the range of the rest of the data and the position of the sampling point in the plot. In general, when a complete sampling point was removed from the data set it changed the overall interpretations and significances of semivariograms and correlograms only for those properties for which it was an outlier (Figures 3.9a and b and 3.10a and b).

No outliers were identified from the inner 2 m diameter subplots. Outliers removed from the 10 m and 100 m diameter subplots affected the long, mid and short range variation according to the degree to which they differed from the data. The greater the difference, the greater the range of lag distances affected. For example, a data point for initial nitrogen as ammonium in plot F was more than seven times higher than the next highest value. The removal of this outlier revealed spatial structures throughout the mid range of this semivariogram that had been suppressed by the large peak of variance due to the single outlying point (Figures 3.11a and b). In other cases, the removal of a datum approximately three times higher than the next highest value from the 5 m subplot affected variances and

correlations at the 24 m lag, while spatial structures at shorter lags remained virtually unchanged (Fig 3.12a and b, initial nitrogen as NH4). Removal of the same datum from a different property (nitrogen as ammonium after incubation) resulted in a change in the shape of the semivariogram and loss of significant Moran's I correlations only at short lags, (Figure 3.13a and b.) Thus removal of a single outlier could dramatically alter the shape of the semivariogram.

Plots of Geary's C tended to be similar in shape to the semivariograms, and removal of outliers produced similar changes in shape of the semivariograms and Geary's C correlograms. In most cases the Moran's I correlogram was more sensitive to the removal of outliers than the semivariogram. In plot F, values of Moran's I were significant at most lags for initial NH4 prior to the removal of the outliers (Figure 3.11a). After outlier removal, more detail was revealed particularly in the short range, and significant correlations were reduced to one in the short range and one in the longer range of around 27 m. (Figure 3.11b). When the removed observation was not an outlier, it had almost no effect on the shape and interpretation of the semivariograms and Geary's C, and little effect on the shape of the Moran's I correlogram, for example Moisture, plot L, observation 24 (Figure 3.14a and b). However, after its removal more short range and fewer long range correlations were significant

In this analysis, patterns were interpreted from semivariograms and correlograms with outliers removed. In most cases, removal of outliers resulted in fewer significant values of Moran's I, particularly when the data points removed had

a large influence on the shape of the semivariograms and correlograms (Figure 3.11a and b). Table 3.16 shows the percentage of cases where one or more significant Moran's I correlations were lost, gained or had some significant points unchanged by the process of removing outliers. The "In range" refers to those datasets where a the data removed (by the removal of a sampling point) were either within or close to the range of the rest of the data, and not therefore an outlier (20 cases). "Out of range" refers to the 31 cases where the removed data were outside of the range of the rest of the data. The proportion of Moran's I correlograms containing significant correlations robust to the data removal was the same whether the removed data was an outlier or not, indicating that about 65% of correlograms show real structure in the datasets. In 55% of the graphs a significant correlation was gained by the removal of a true outlier, an indication of the frequency of cases where spatial structures had been suppressed by the presence of the outlier.

The 95% confidence interval applied to the data should result in 5% of the correlations being significant due to chance. This was found to be true and is discussed in the section on simulated landscapes below. An average of 40% of the original significant Moran's I correlations remained following data removal for those properties where the removed data were within the range of the rest of the data, compared to 19% for those plots where the removed data were outside of that range. The sensitivity of individual correlograms to small changes in the data underscore the need for replication to increase the confidence in spatial structures identified in the correlograms. Removal of outliers had two main effects: it revealed structures

previously suppressed, and helped identify real structures robust to moderate data reduction.

Normalising datasets

Two datasets were normalized after outlier removal. Much of the data were difficult to normalize by a method that could be interpreted easily. For example, the 11th root was used to normalize NH4. The normalized datasets produced correlograms and semivariograms very similar to those from untransformed data (Figure 3.15c and d). There was a reduction in the number of significant Moran's I correlations in the shorter distance lags and an increase of one significant Moran's I in both the datasets normalized. Thus even when data were far from normally distributed, normalizing the data had little effect on the interpretation of the semivariances or the correlograms.

Correcting for anisotropy.

When the dataset with outliers removed was corrected for anisotropy the shape of the semivariograms and correlograms changed fundamentally (Figure 3.15c and e), as did the significance of the Moran's I correlations, which increased. The spatial pattern interpreted from such "anisotropy corrected" semivariograms and the correlograms differed from the original.

This sampling design produced a set of points that, when compressed along one axis, mostly fell in the centre of the axis. This formed a fulcrum around which the outlying points had a weighting effect disproportionate to their importance within the complete dataset. When the values of a soil property at these outer points differed from the mean, this could produce a non-zero slope in a simple curve fitted to the data (Figure 3.16). When the values for each plot and soil property were plotted against the North-South or the East-West axis, no plot property showed an r^2 of more than ± 0.14 and most were below 0.05. It was therefore not appropriate to correct these data for anisotropy as the variation attributed to it was minor compared to the variation within the plot, and was unlikely to suppress patterns found in the plot.

Normalizing then correcting the normalized dataset for anisotropy.

When both modifications were made to a dataset (Figure 3.15f), the shapes of the semivariograms and correlograms was predominantly influenced by the anisotropy correction.

Figure 3.15a - f shows the progression of shapes of semivariograms and correlograms, starting with the complete dataset, through the removal of outliers, normalizing the data, correcting for anisotropy to all the above manipulations. Graphs calculated with outliers removed and no other changes (e.g. Figure 3.15c) were used for the final interpretation.

Summary of the effect of data pretreatment on semivariograms and correlograms.

Removal of outliers seemed to be the most important manipulation of the data to identify, clarify, and reveal structure in these datasets. Normalizing the data had little additional effect other than identifying possible additional significant structures at longer lag distances, and increasing confidence in the significance of structures at the shorter lag distance. Correcting for anisotropy was unjustified given the sampling design, and merely confused the interpretation of the data.

The interpretations from simulated landscapes.

Random landscapes

The semivariograms and Geary's C from the 12 random landscapes showed no consistent spatial patterns (Figures 3.17 and 3.19 to 3.27). In all cases the nugget variance was 50% or more of the total semivariance. No range could be detected in 10 of the 11 semivariograms from random data. The log-log semivariograms showed slopes close to zero, indicating a similarity between short and long range variation. One exception was the random dataset for initial ammonium (Figure 3.18), whose semivariance descended from 2 at a lag of 0 down to 0.5 at a lag of 8 m, indicating a higher ratio of short to long range variation. Although this pattern was not detected in any of the other random datasets, it

suggests that spurious patterns can be found by chance, especially in strongly skewed data. Because of this possibility, patterns found in any of the datasets from the Island site need to be verified by comparison with other properties from the same plot.

The Moran's I correlograms calculated with random data did show significant autocorrelations at some lags, but the significant autocorrelations occurred at different lags for each soil property. Using a 95% confidence interval, 5% of the Moran's I values would be expected to be significant purely by chance. Thus, given 25 data points per correlogram, the expected frequency is 1.25 significant correlations by chance, or a total of 14 for the set of 11 random datasets. Of these, 10 (72%) should be within the 10 m lag distance, because 72% (18 out of the 25) autocorrelation coefficients are at lags less than or equal to 10 m. Five of the eleven correlograms created from random data showed one significant correlation each, and one correlogram showed two significant correlations. Six of these seven spurious significant correlations were at lags below 10 m. Thus the random data showed fewer than the number of significant correlations expected by chance.

The real data in many cases showed only one significant correlation per correlogram. The possibility that these occurred purely by chance cannot be ignored. To compensate for this possibility, patterns were interpreted only when correlograms showed significant autocorrelation at the same lag for more than two properties in a plot.

Simulated landscapes

The semivariograms for six out of the eight artificial (regularly patterned) landscapes produced semivariograms with a distinct shape compared to those from random landscapes (Figures 3.29-3.32 and 3.34-3.35). In these six cases the nugget variance was low compared to the overall variance, and the semivariance increased with lag distance up to an identifiable range, at which the semivariance dropped off or leveled out. The Geary's C correlograms were consistent with the semivariograms, with peaks of negative correlation corresponding to the high semivariance peaks. In the above six cases the log-log semivariogram showed a slope greater than zero, which also indicates structure in the data (see Methods section, page 26). Significant Moran's I correlations occurred four or more times in seven of the eight correlograms from artificial landscapes, much more than the 5% expected due to chance alone. These tests indicate that the sampling design used was able to distinguish between a random and a regularly patterned landscape.

Patch sizes smaller than the shortest distance between sampled points cannot be detected in correlograms. Similarly, sparsely distributed patches of any size may not be detected. The two artificial landscapes whose semivariograms or correlograms did not show spatial structure were the "sagebrush at 2 m apart with canopy diameter of 1 m" (Figure 3.28) and the "juniper at 18 m apart with canopy diameter of 1 m" (Figure 3.33). In the landscape with sagebrush only (Figure 3.28), a nonsignificant negative correlation was produced at 1 m because pairs of points at

this lag distance were slightly more likely to span a patch to division than to span the patch or interpatch area alone. This finding suggests that Moran's I and Geary's C correlograms may fail to detect regular patterns whose spacing equals twice the patch size, when the patch size (1 m) is roughly twice the minimum sampling interval (0.5 m).

The semivariogram for the artificial landscape with widely spaced small junipers, (Figure 3.33), showed high semivariance at 0.5 m - 1 m, reflecting the fact that the greatest contrasts in the landscape occur immediately around the small (1 m) canopies. The low semivariance at longer lags, reflects the fact that the junipers were rarely sampled and the homogeneous "grass" background predominated. A second peak at 17 m appeared in the semivariogram and a significant negative correlation occurred at 22 m in the Geary's C and Moran's I correlograms. These features could be interpreted as indicating the maximum lag between unlike samples before encountering the pattern repeat at 18 m. The positive significant Moran's I correlations at 6 to 9 m appear to be spurious significant values produced by chance from the random grass landscape.

From the above two landscapes the limitations on the scales of patterns detectable by the sampling design become clear. A pattern of patch size 1 m or less could be detected by this sampling design only when the plot was centred sufficiently close to a patch to ensure that several sampling points fell within it. When the pattern is either widely distributed in comparison with the sampling points, as in the case of the small junipers at 18 m apart, or when the pattern is small scale compared

to the minimum spacing between sampling points, the semivariograms and correlograms detect spurious patterns from the random background. It becomes difficult to distinguish between the structured and random parts of the graph without prior knowledge of the true pattern analyzed. Also, the lags at which significant correlations occurred were not precise estimators of patch size or spacing particularly beyond the 10 m lags. The average distances (20 m) between sampling points in the outermost (50 m radius) subplot meant that pairs of points spanning a wide range of distances (e.g. 21 to 30 m) were used to calculate a single semivariance or autocorrelation coefficient.

Semivariograms and correlograms also correctly detected regular patterns of junipers of small, medium and large size (1, 2.5 and 5 m diameter) spaced at 10 m intervals with a correspondingly decreasing interpatch size (Figures 3.29 to 3.32). The semivariances showed a range in the region of 5 to 7 m for the small and medium size junipers, slightly less at 4 to 7 m for the larger junipers, with maximum Geary's C at lags of 5, 5 and 4 m respectively. Moran's I showed positive significant correlations up to 3.2 m for the small junipers, 2.3 m for the medium, and 2 for the large, indicating that the correlations could relate to either the patch or the interpatch area, and thus may be closer to an average size of the two areas. The significant negative Moran's I correlations at around 5 m for the small and medium junipers, and 3.6 m to 5 m for the large, could be interpreted as the distances between contrasting areas.

Semivariograms and correlograms detected the average between the patch and interpatch sizes of regular patterns of 5 m diameter junipers with 18 m spacings, but not that of the 1 m diameter junipers with 18 m spacings (Figures 3.33 and 3.34). Maximum variation was within the first 1 m for the 1 m junipers and at around 9 m for the 5 m diameter junipers, indicating a difference in pattern between the two. Figures 3.29 and 3.33 have a similar interpatch distance despite the differences in the juniper size and distribution, and the semivariance and Geary's C both indicated maximum variance at around 5 m. The analyses did not clearly distinguish between the 10 m and 18 m spacings, except that the 10 m distributions showed more significant Moran's I correlations in the 0 to 10 m lags than the 18 m distributions. The log-log semivariograms of the 10 m distributions had slightly steeper slopes than those of the 18 m distributions.

Semivariograms and correlograms also detected some aspects of artificial landscapes consisting of two regularly spaced patterns at two different scales. Figure 3.35 shows the analyses of a two-scale pattern similar to the distribution of vegetation on the Island site. The semivariogram had ranges at approximately 1.5 and 9 m, indicative of the averages between patch and interpatch sizes of the sagebrush and the juniper patterns. The presence of the sagebrush in the interpatch areas of the junipers effectively reduced the contrast in values between the junipers and the interpatch. This depressed the short to long range variation ratio when compared to that of the junipers alone (Figure 3.34). Moran's I detected the small

patch size with a significant positive correlation at 1 m, and the half wavelength at 7 to 11 m.

Summary of simulated landscape tests

Results of simulated landscape analyses suggest that this sampling design can discriminate regular patterns when the minimum patch size is equal to or greater than the size of the smallest nested subplot, but only when the contrasting zones created by regular patterns are not sparse, i.e. they cover at least 7% of the area (estimated from Figure 3.29, the 1 m junipers at 10 m apart). A further limitation is that statistically significant values of Moran's I may not accurately estimate patch size, but rather measure the average size of patches and interpatch areas when these are not equal. In short, this sampling and statistical design can reliably distinguish random from regular patterns, and distinguish regular patterns dominated by short range variation from regular patterns dominated by long range variation.

The analyses of simulated random and regular landscape patterns indicate that to determine non-randomness in the datasets from the Island, the analyses needed to be grouped by plot and again by property for each community type and interpreted first of all as a group. Structure in the semivariograms and significance of correlations is unlikely to be due to chance when several analyses show similar shapes. More detailed interpretations can then be made of individual analyses using the observations of the analyses of simulated regular landscapes. The steepness of

the slope of the semivariogram and the corresponding slope of the log-log semivariograms give an indication of the degree of contrast of the pattern. A more widely spread pattern returns a lesser slope than a tighter one, but it should be noted that there is little distinction between patches and interpatch areas, so large patches which leave small widely spaced interpatch areas return an analysis similar to a sparse, small pattern at the same scale. Geary's C shows correlation peaks which support the estimate of range from the semivariograms. Moran's I gives rough estimates of average patch size, distance between areas of high contrasting values, which may be detected at one or more half wavelengths of the pattern, and the presence of variation at more than one scale. The relative importance of the different scales of variation is depicted by the log-log semivariogram.

Interpretations of the semivariograms, Geary's C and Moran's I correlograms, and the log-log semivariograms of the data from The Island.

Determination of non-random structure

For the nine plots sampled, the spatial pattern analyses of the following nine soil properties were examined for non-random structures in the data; VAM infection, moisture, pH, initial nitrate and net nitrification, initial ammonium and net ammonification, total numbers of arthropods and biomass of micro-arthropods. Net

nitrogen mineralized was included in the range determinations and interpretations below.

Structure which more closely resembled the simulated regular landscapes than the random landscapes was found in more than two thirds of all the soil properties analysed for each plot except plot J. The structures observed were a relatively low nugget variance, a positive slope to the semivariograms and log-log semivariograms over the first few metres of lag, and a higher frequency of significant Moran's I autocorrelation coefficients than in random landscape analyses. The analyses from plot J, taken in May 1992 from the sagebrush-grass community, had a negative slope with high nugget variance in all but two soil property datasets and one or zero significant Moran's I autocorrelation coefficients (i.e. a random pattern) in VAM infection and the five nitrogen fractions. The spatial analyses for VAM infection resembled the random landscapes more closely than the regular simulated landscapes in all plots except plot L (sagebrush-grass community). These were all subjective judgements and were difficult to distinguish between non-random and random structures in a few analyses. These were assumed to be random until further observations suggested otherwise.

In summary, eight of the nine plots displayed non-random spatial structure for moisture, pH, initial, mineralized and net nitrogen fractions, soil arthropod numbers and biomass. The spatial structure of VAM infection was not distinguishable from random at the scales sampled.

Soil properties at plot J may have a truly random spatial structure, or they may have structures on a scale not detectable by the sampling design used. The analyses of artificial landscapes indicated that small or widely dispersed regular patterns, particularly the 1 m sagebrush spaced at 2 m and the 1 m junipers at 18 m spacing, produced semivariograms and correlograms similar to those from random landscapes. In the case of plot J, if the structure were truly random, the shape of the semivariograms would differ between soil properties, as in the simulated random landscapes above. There was however a similarity between the semivariograms in plot J. All but pH had a high nugget variance and a negative slope over the shorter lags up to about 5-7 m suggesting a structure smaller than the 0.5 m shortest lag distance, and which appeared increasingly homogenous at scales up to about 7 m.

Interpretation of structures

The juniper-sagebrush-grass and the sagebrush-grass communities had similar maximum standardized and unstandardized semivariances (Table 3.17). Juniper plots had slightly higher coefficients of variation than sagebrush-grass plots for initial and net ammonification, net nitrification, net nitrogen mineralized, and microarthropod numbers and biomass, but not for initial nitrate, VAM infection and pH (Tables 3.10 and 3.11). These results indicate that junipers may introduce more variation in the landscape, but their effect is partially obscured by other sources of variation in both community types.

The semivariograms showed more than one range for each plot for most soil properties (Table 3.18). All plots in both seasons had a short range peak in variation at between 1 and 5 m. This varied slightly between plots and properties with some plots having observed ranges of 2-3 m for three or more soil properties, and others with ranges in the 3-4 m lags. These small differences were not consistent with season or community type. This short range variation appears to reflect the distribution of grass clumps, individual sagebrush plants and groups of sagebrush plants (Figures 3.2 and 3.3). Moran's I supported these observations with significant negative correlations relating to the ranges from 3 to 9 m.

A second peak in variation was apparent in five of the plots at between 10 and 17 m, (plots A,H,J,and L in the sagebrush-grass community, and plot G in the juniper-sagebrush-grass). Again, individual plots differed as to the lags over which this range was apparent. Three plots (C,J, F and I) showed a range at 6 to 9 m, intermediate between the former two ranges. Variation at this scale in the sagebrush-grass system might be related to the spacing between sagebrush clumps (Figures 3.2 and 3.3).

Three or more soil properties in one sagebrush-grass plot (plot C) and two juniper-sagebrush-grass plots (plots F and K), showed a third peak of variation at the 23-30 m lags. Moran's I values supported these observations with significant negative correlations at these lags in these plots. Negative correlations also occurred at 23-30 m lags in plots J and L (sagebrush-grass) and K (juniper-sagebrush-grass). The occurrence in both community types of peaks of variation at long ranges

corresponding to the spacing of junipers suggests that some factor other than junipers is operating to produce variation in the plots. The relief and drainage patterns of the underlying basaltic bedrock, small scale burn sites or other disturbances could be sources of such variation in the soils. The soil cores revealed variation in soil depth from 8 inches to more than 24 inches, with varying degrees of profile development. No attempt was made to test the spatial scale of soil depth but it is likely to be a factor regulating vegetation distribution.

From Tables 3.18 to 3.21, it appears that all soil properties within a given plot with the exception of VAM infection have similar spatial structures at lags up to 18 m each plot, and that the shorter ranges show more similarity between plots and between soil properties than the longer ones. This suggests that the processes regulating spatial distribution of soil properties operate at the same scalesin all plots, and that these spatial scales are similar to the spacings of the grasses and sagebrush plants.

Moisture and net nitrogen mineralized showed fewer Moran's I correlations in the 0-2 m range than other soil properties (Table 3.19), but a similar frequency to other properties in the 2-10 m and 10-30 m ranges (Tables 3.20 and 3.21). This suggests that these two properties are distributed on scales relating more to sagebrush plants (and possibly junipers) than to grass clumps.

The microfauna show fewer ranges and correlations at lags greater than 18 m in the juniper-sagebrush-grass community than in the sagebrush-grass community (Tables 3.18 and 3.21). This suggests that soil fauna associate more closely with the

sagebrush plants and grasses than with the junipers (spaced at approximately 19 m apart), and may also point to a difference in the source of variation at lags greater than 18 m between the sagebrush-grass and the juniper-sagebrush-grass communities.

Examination of the standardized semivariograms and log-log semivariograms (Appendix B) shows that the long range semivariance (at lags over 10 m) was greater than the short range semivariance (at lags less than 10 m) in 30 of the 50 semivariograms for the sagebrush-grass community (60%), but only 16 of 40 semivariograms for the juniper-sagebrush-grass community (40%). Of the remainder, 4 of the 50 (sagebrush-grass) and 8 of the 40 (juniper) showed equal short and long range variation. In plots with junipers present short range variation was equal to long range variation in (20%) of cases, or more than long range variation in (40%) of cases.

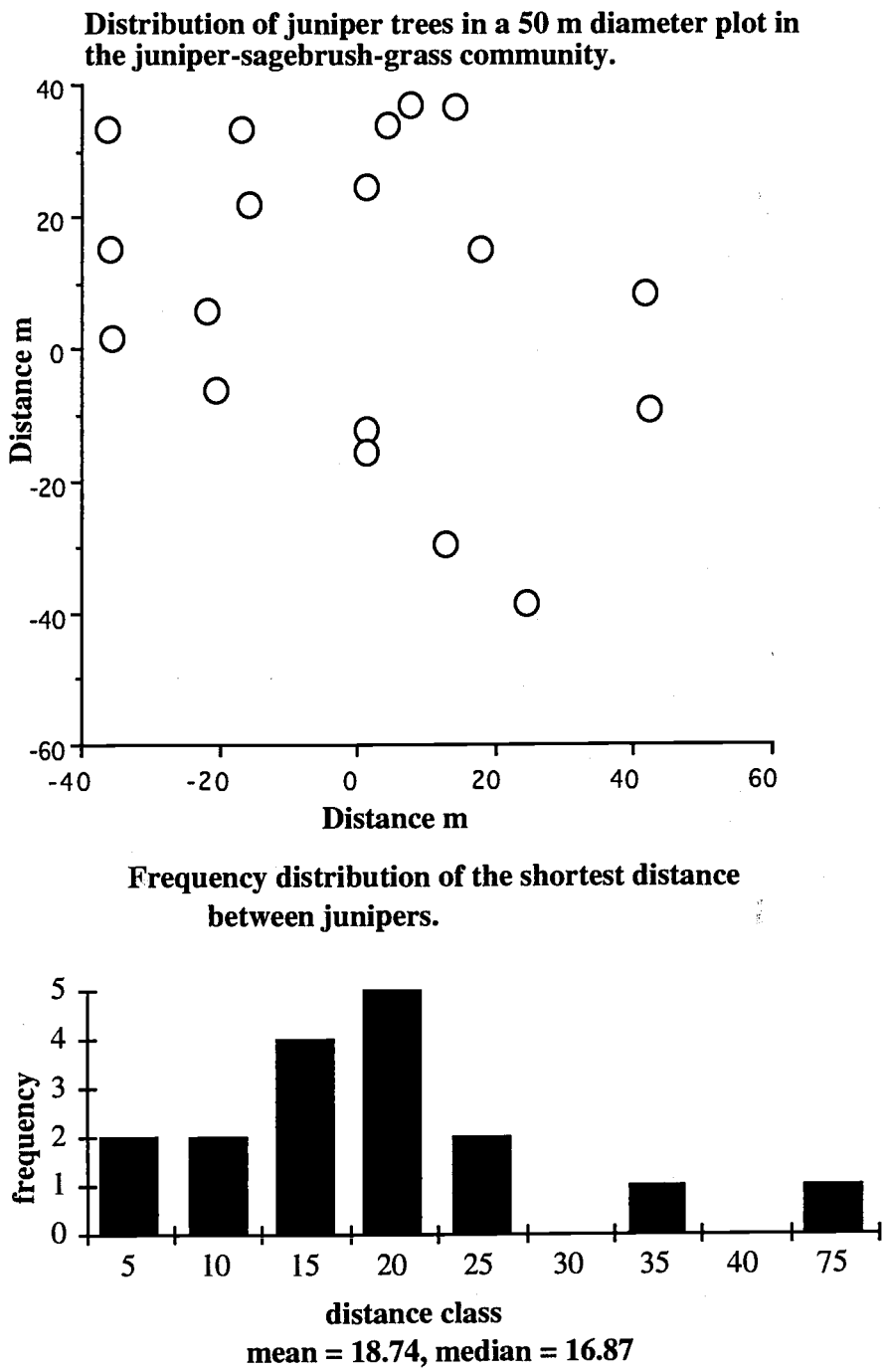


Figure 3.1. Layout of juniper trees in a 50 m diameter circle and the frequency distribution of the shortest distances between them.

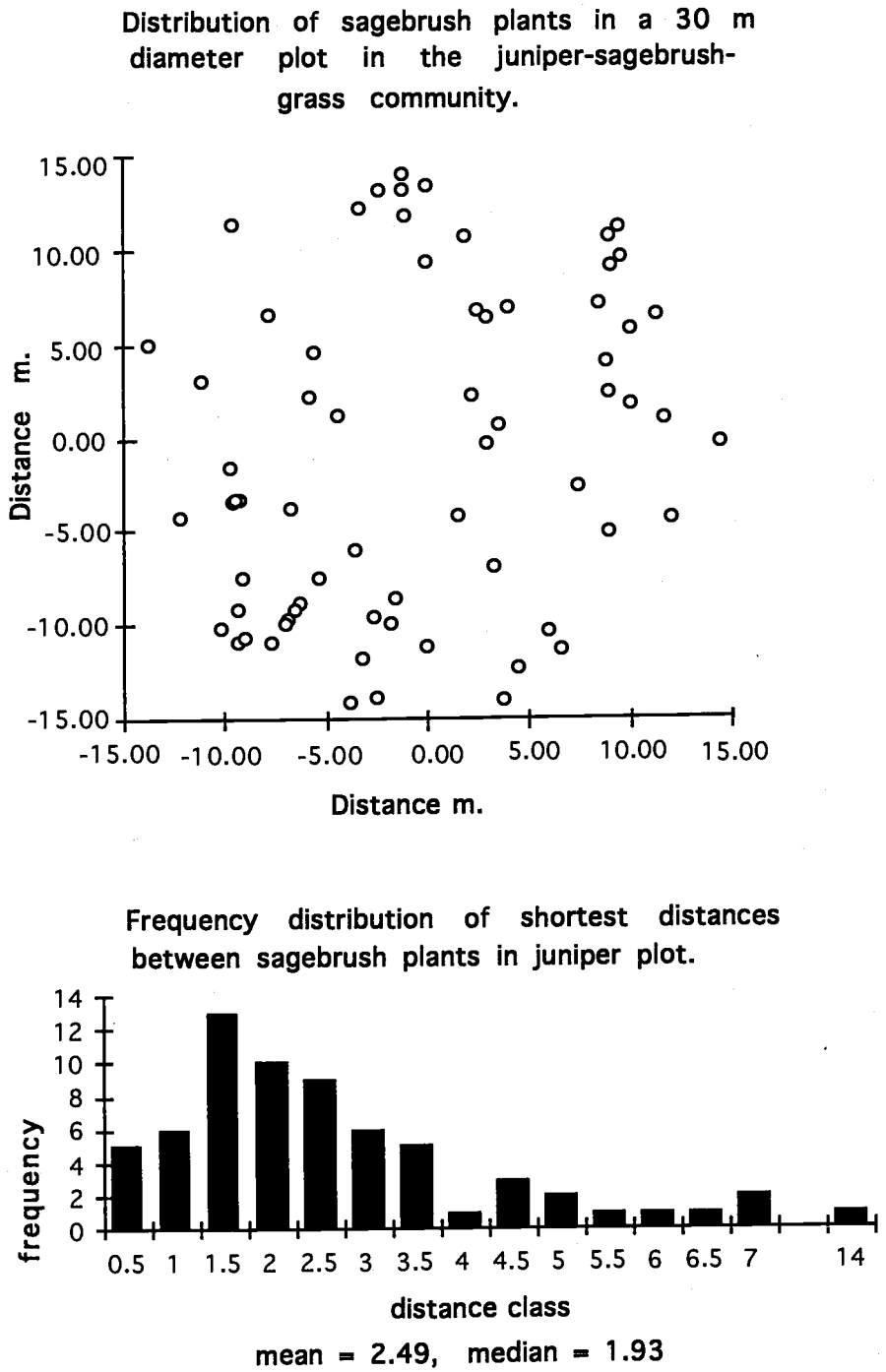


Figure 3.2. Layout of sagebrush plants in a 30 m diameter circle in the juniper-sagebrush-grass community and the frequency distribution of the shortest distances between them.

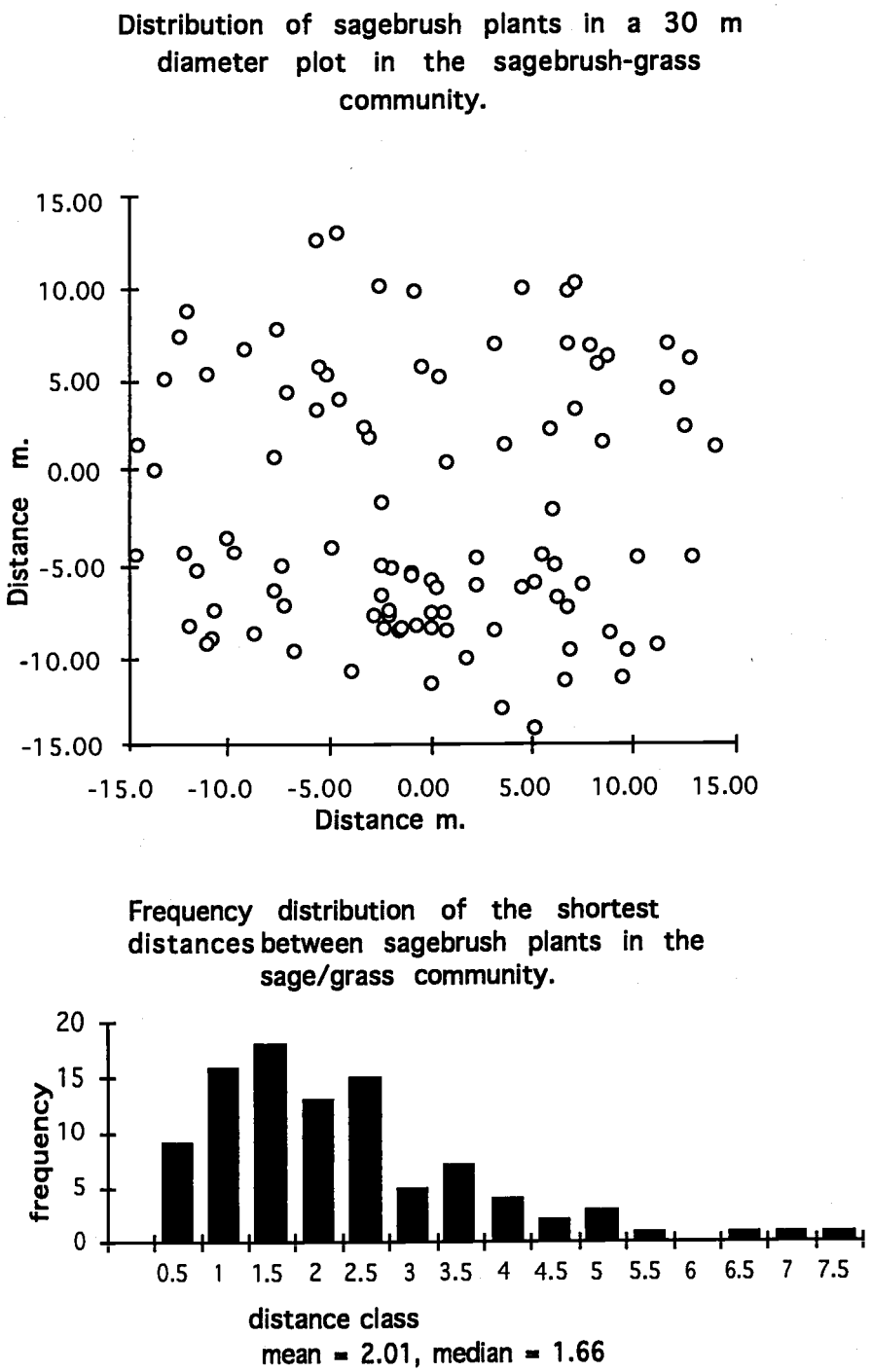
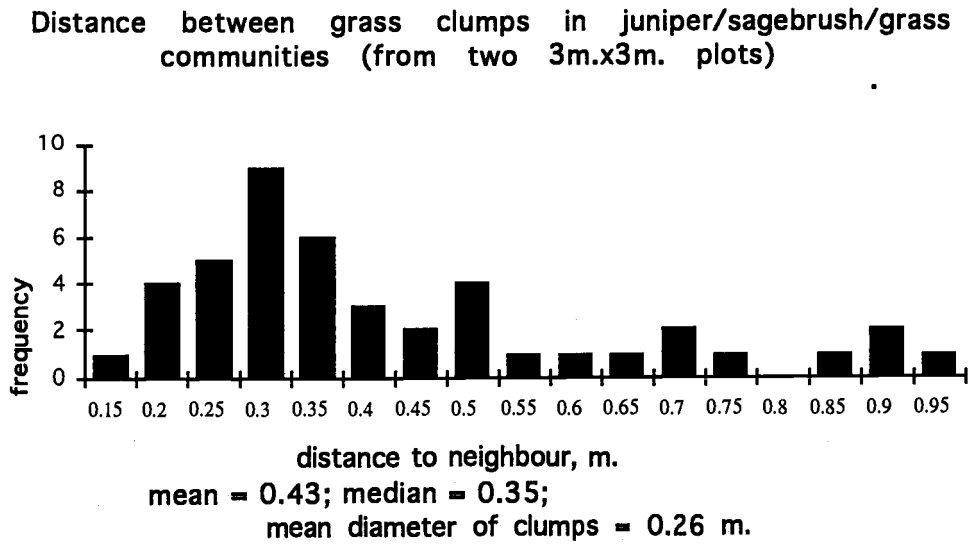


Figure 3.3. Layout of sagebrush plants in a 30 m diameter circle and the frequency distribution of the shortest distances between them.



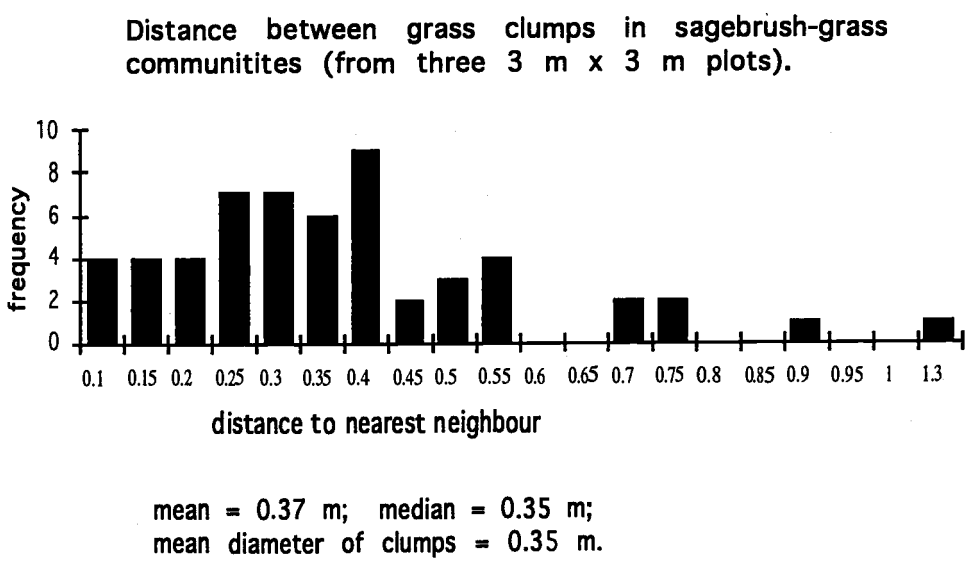


Figure 3.4. Frequency distributions of distance to nearest neighbour of perennial grass clumps in juniper-sagebrush-grass and sagebrush-grass communities.

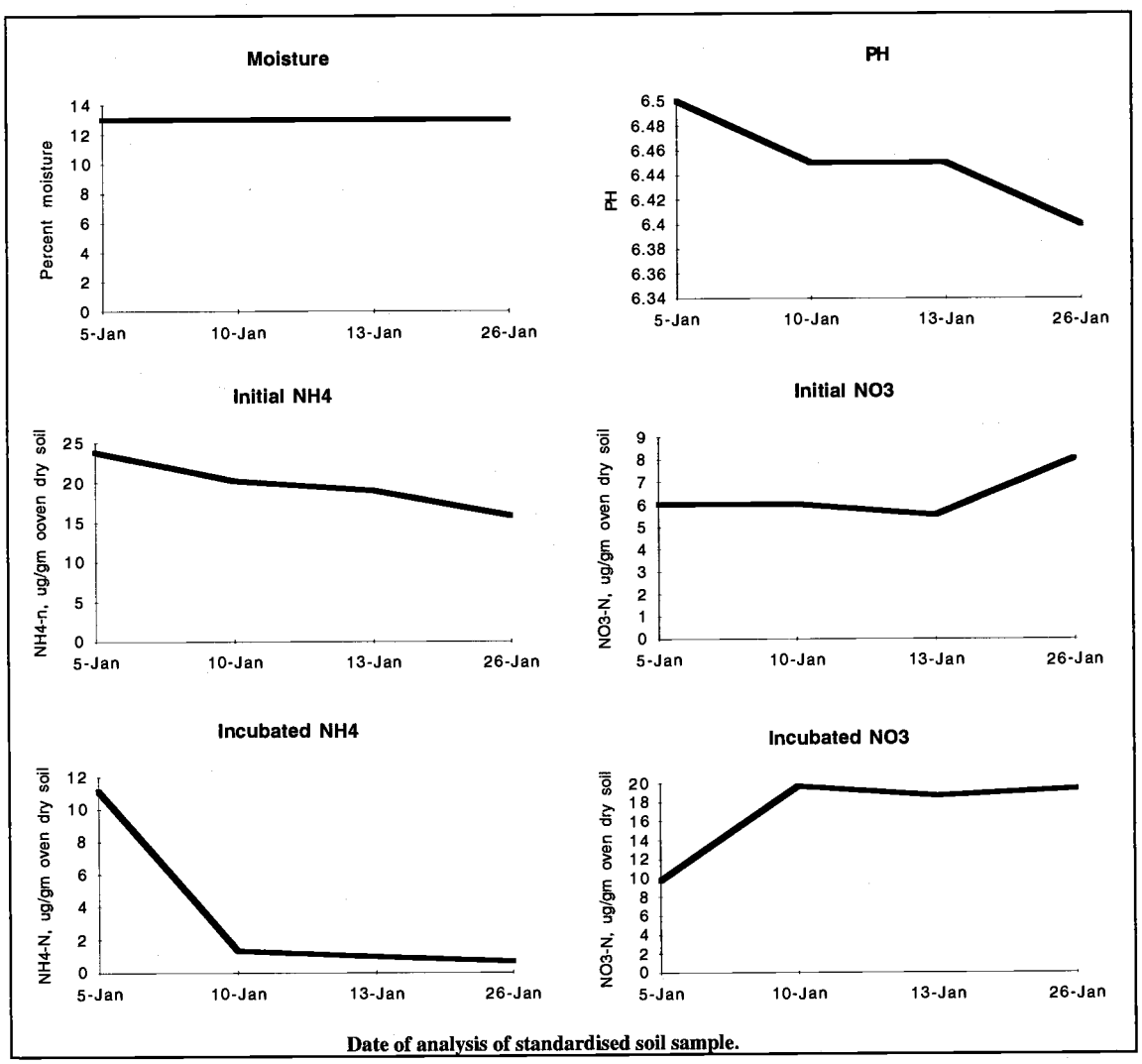


Figure 3.5. Changes during storage in a standardized soil sample.

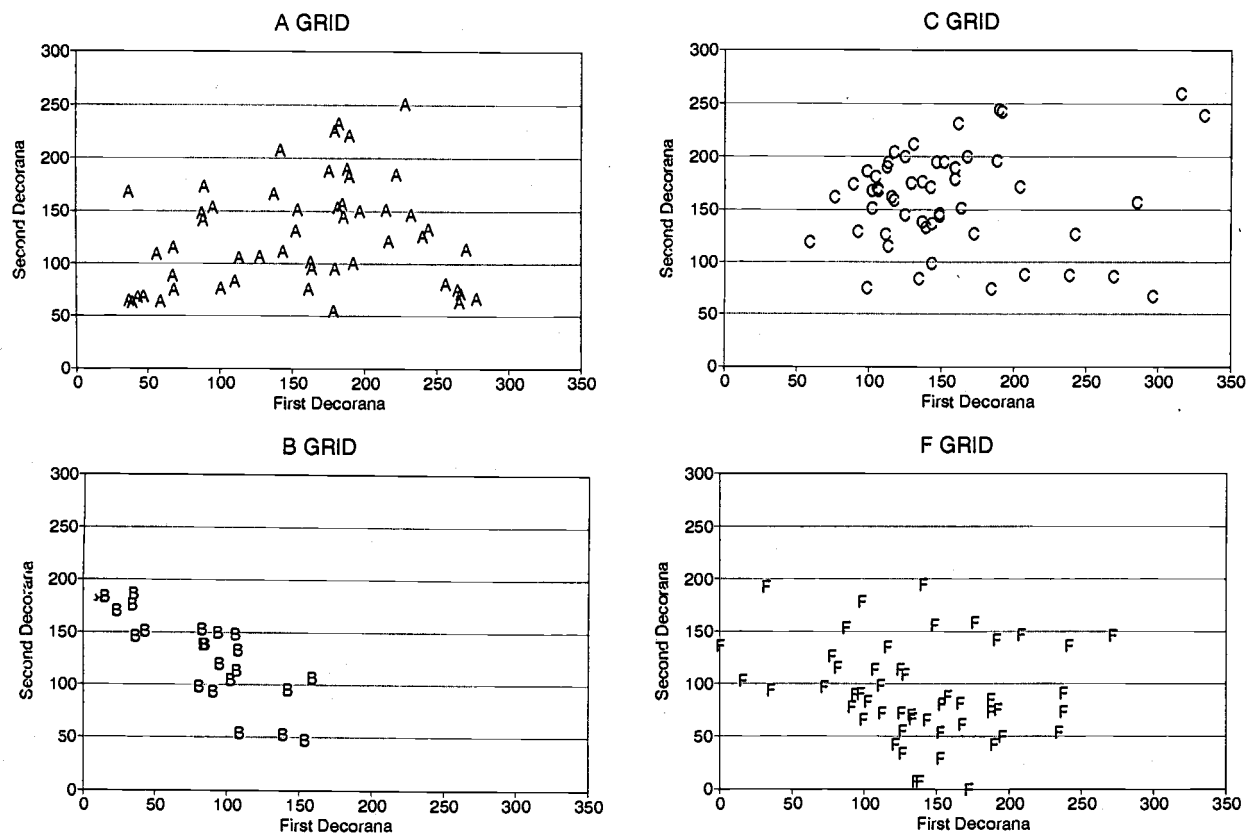


Figure 3.6. Principal component analyses of soil fauna data by guild for plots A and C from the sagebrush-grass community, and B and F from the juniper-sagebrush-grass community.

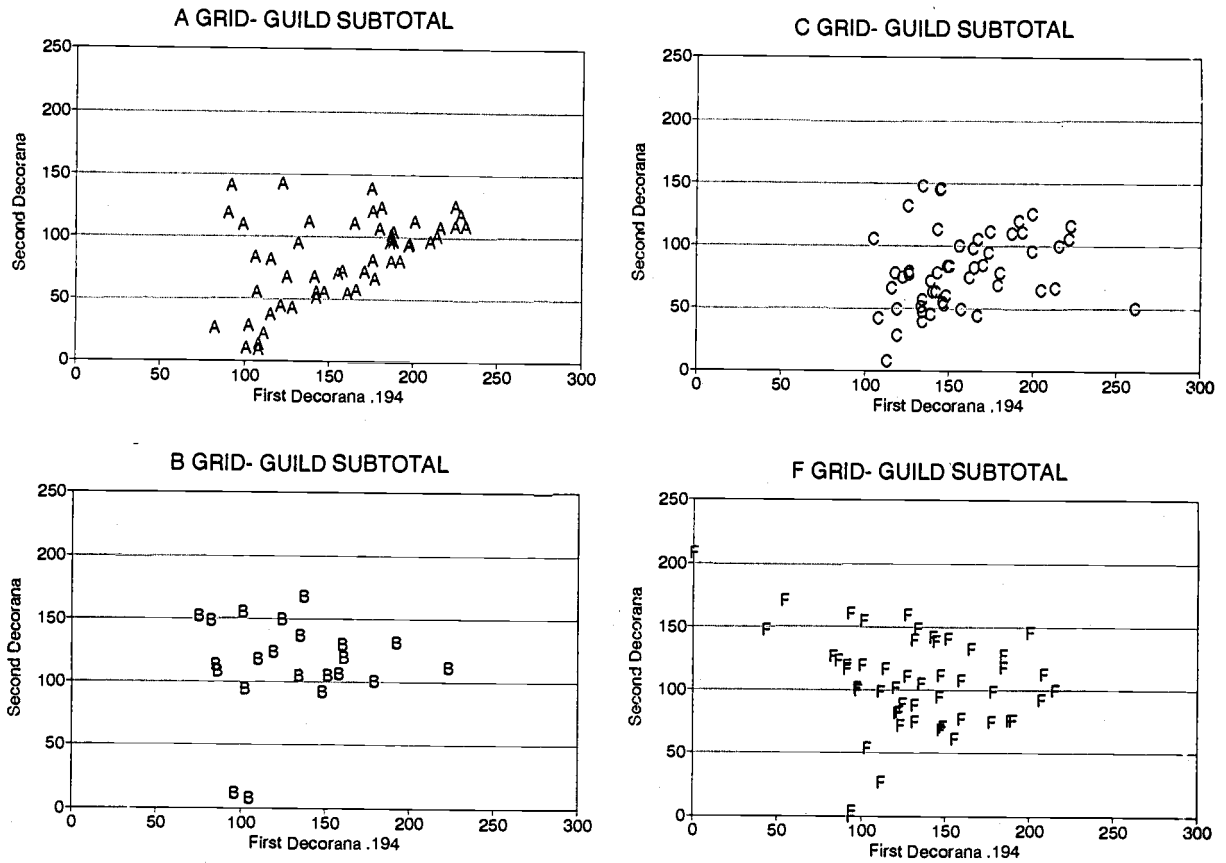


Figure 3.7. Principal component analyses of soil fauna data by species composition for plots A,B,C and F collected December 1991.

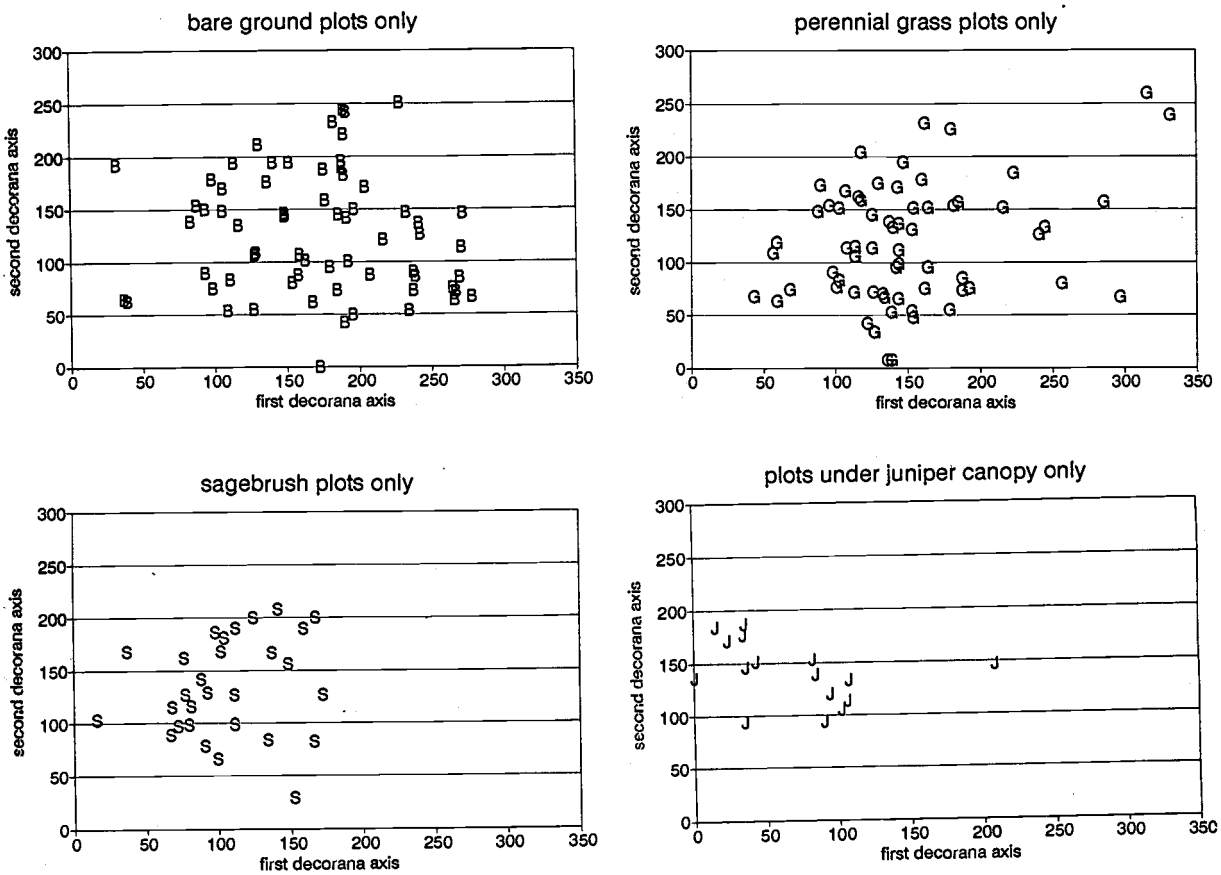
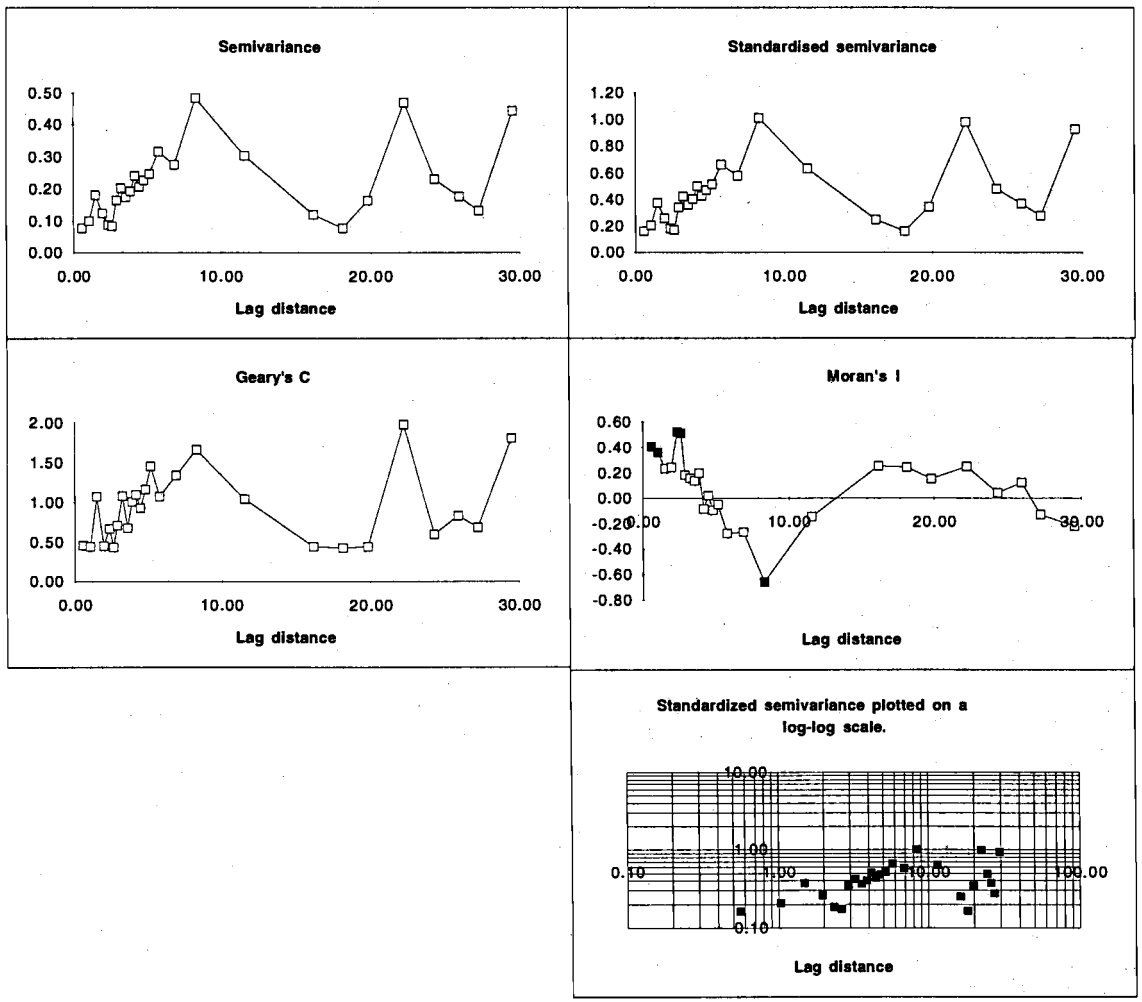
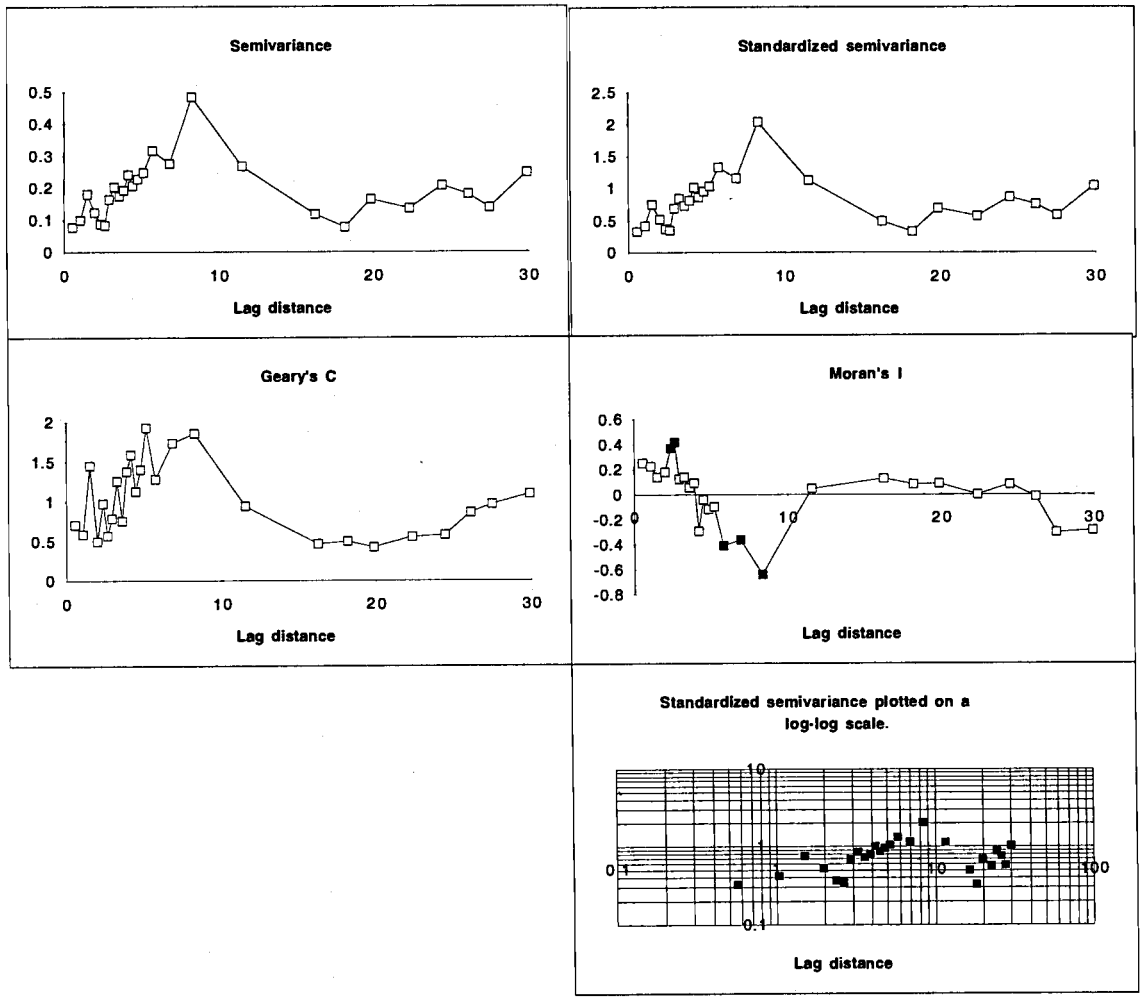


Figure 3.8. Principal component analyses of soil fauna data by vegetation cover for plots A,B,C and F collected December 1991, B = bare ground; G = perennial grasses; S = sagebrush; J = juniper.



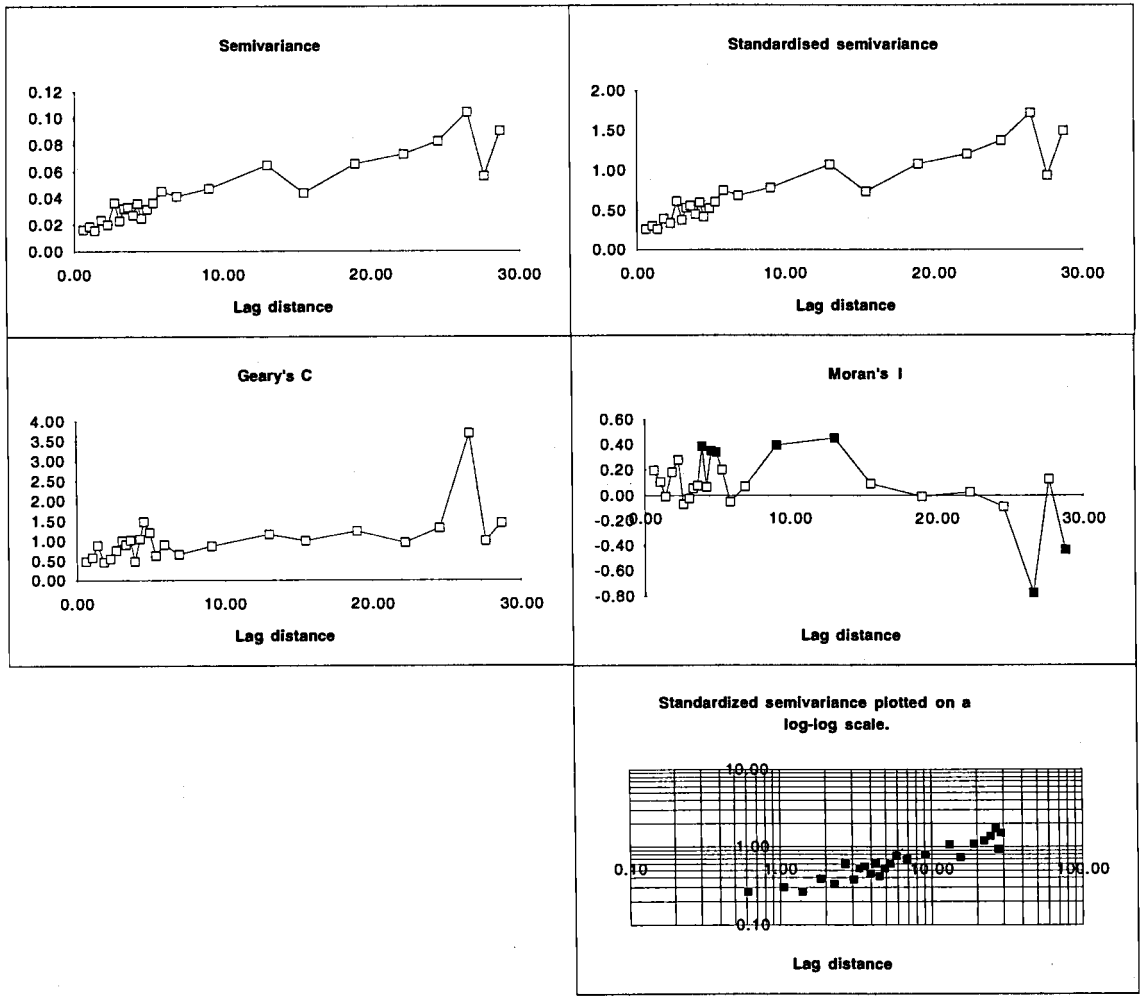
a. Moisture, plot I, May1992, juniper-sagebrush-grass community.

Figure 3.9



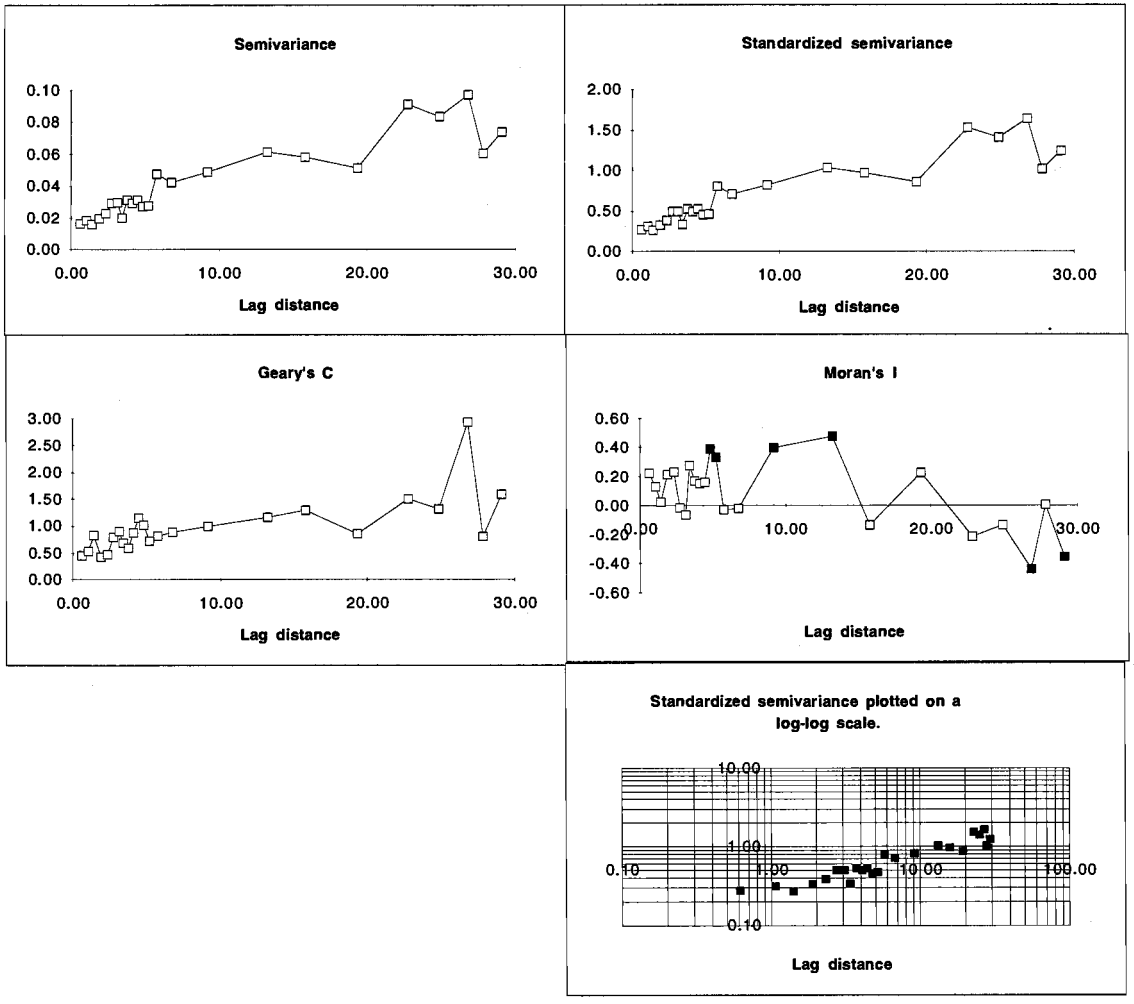
b. Moisture, plot I, observations 36 and 52 removed as outliers.

Figure 3.9 continued



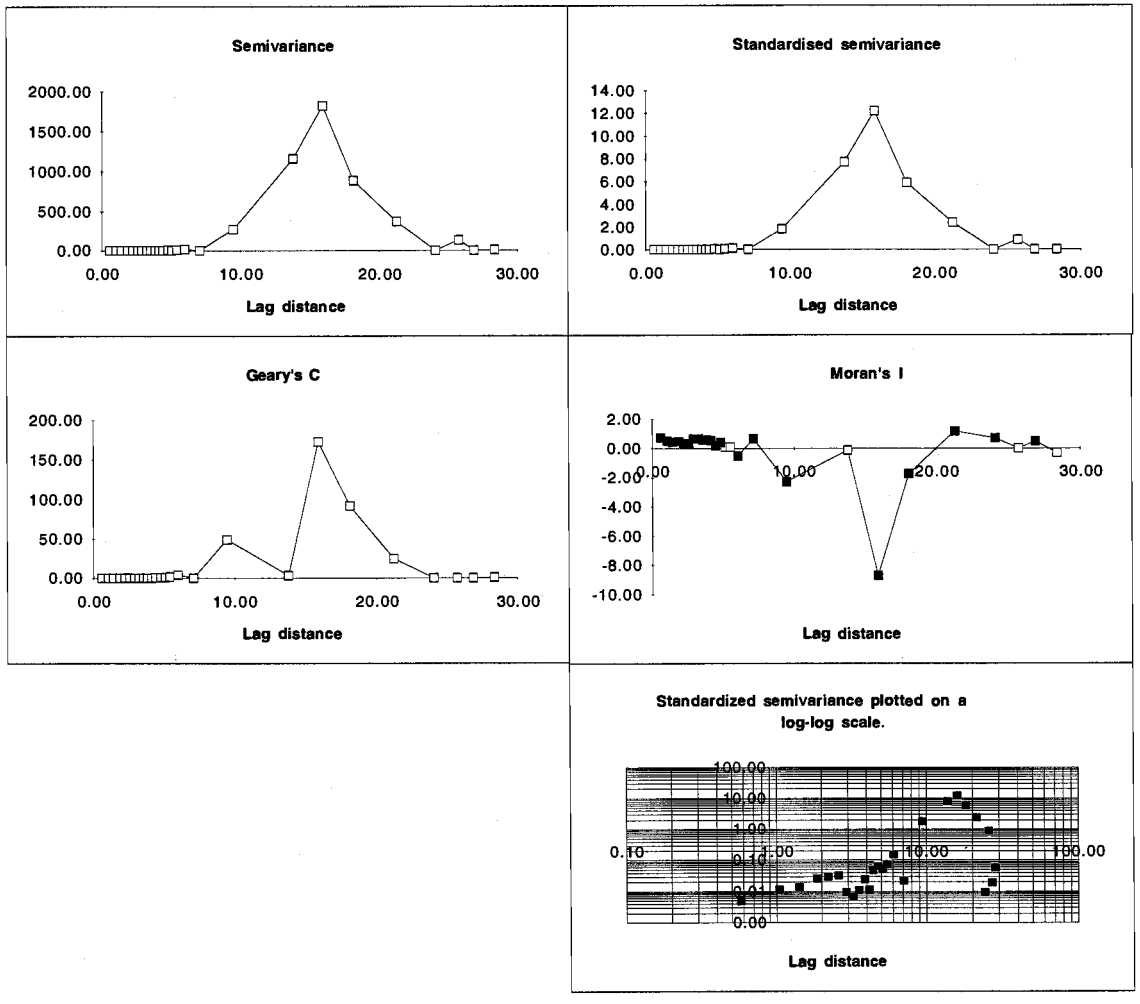
a. PH, plot C, December 1991, sagebrush-grass community.

Figure 3.10



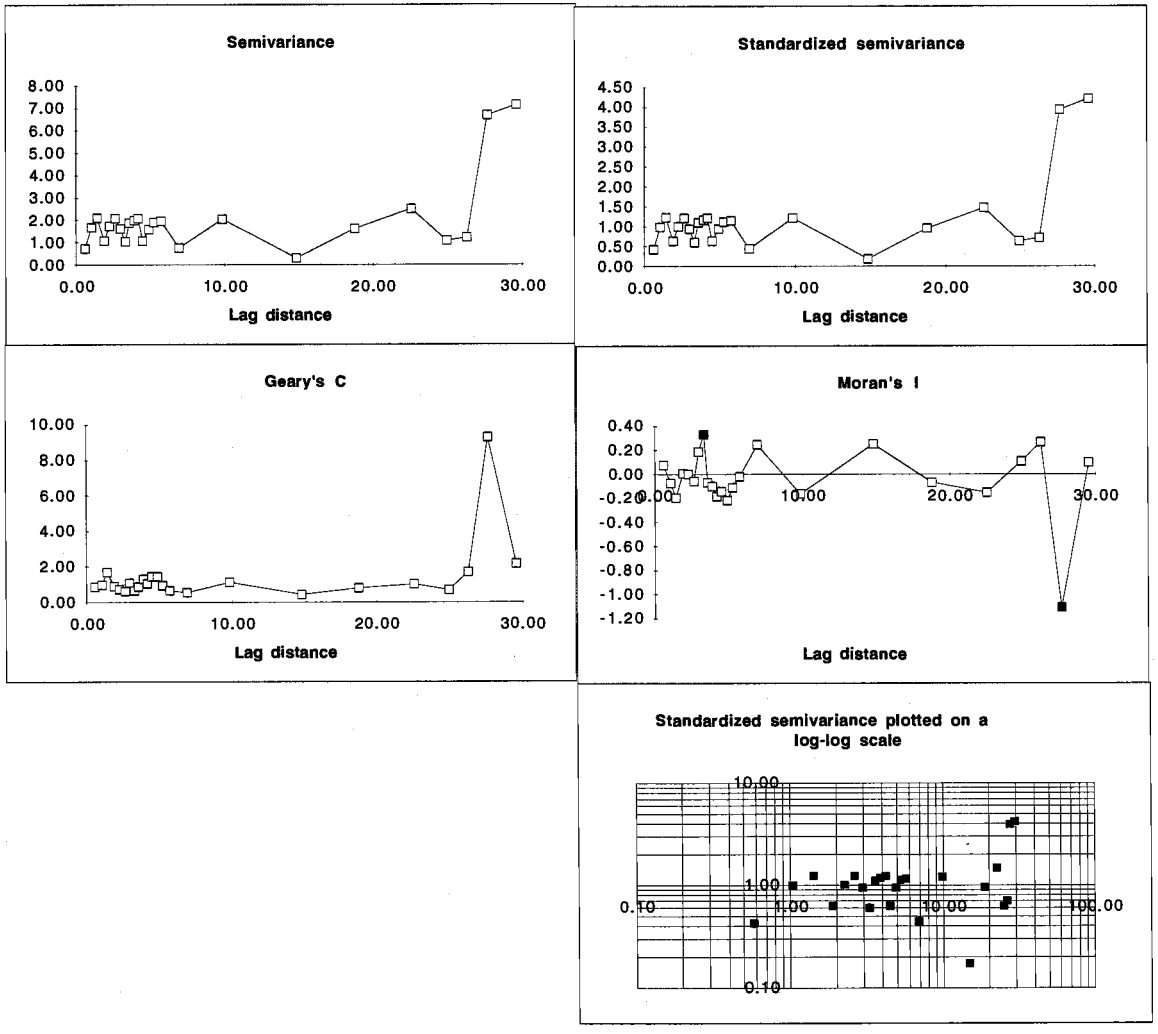
b. PH, plot C, observation 17 removed as an outlier.

Figure 3.10 continued



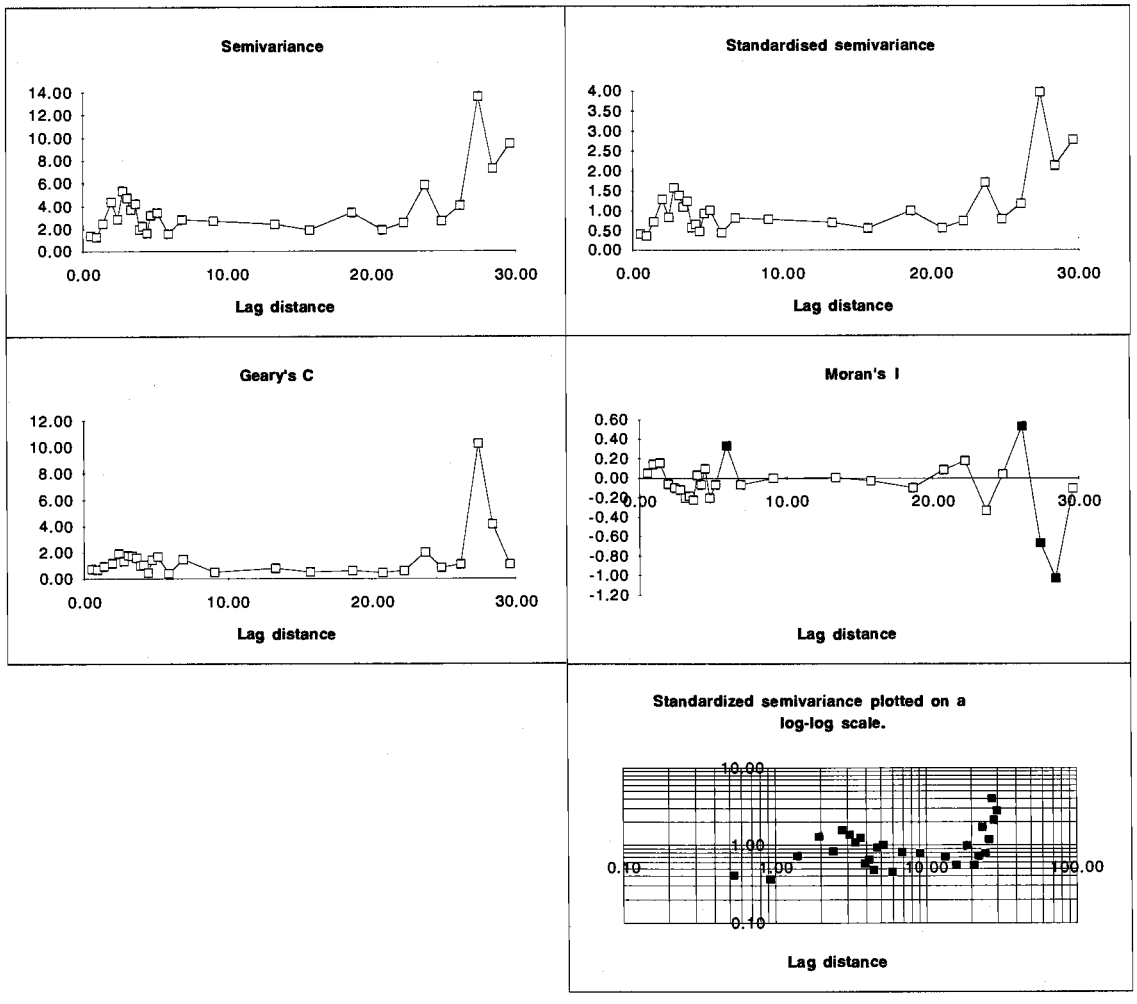
a. Initial Nitrogen as NH4, plot F, December 1991, juniper-sagebrush-grass community.

Figure 3.11



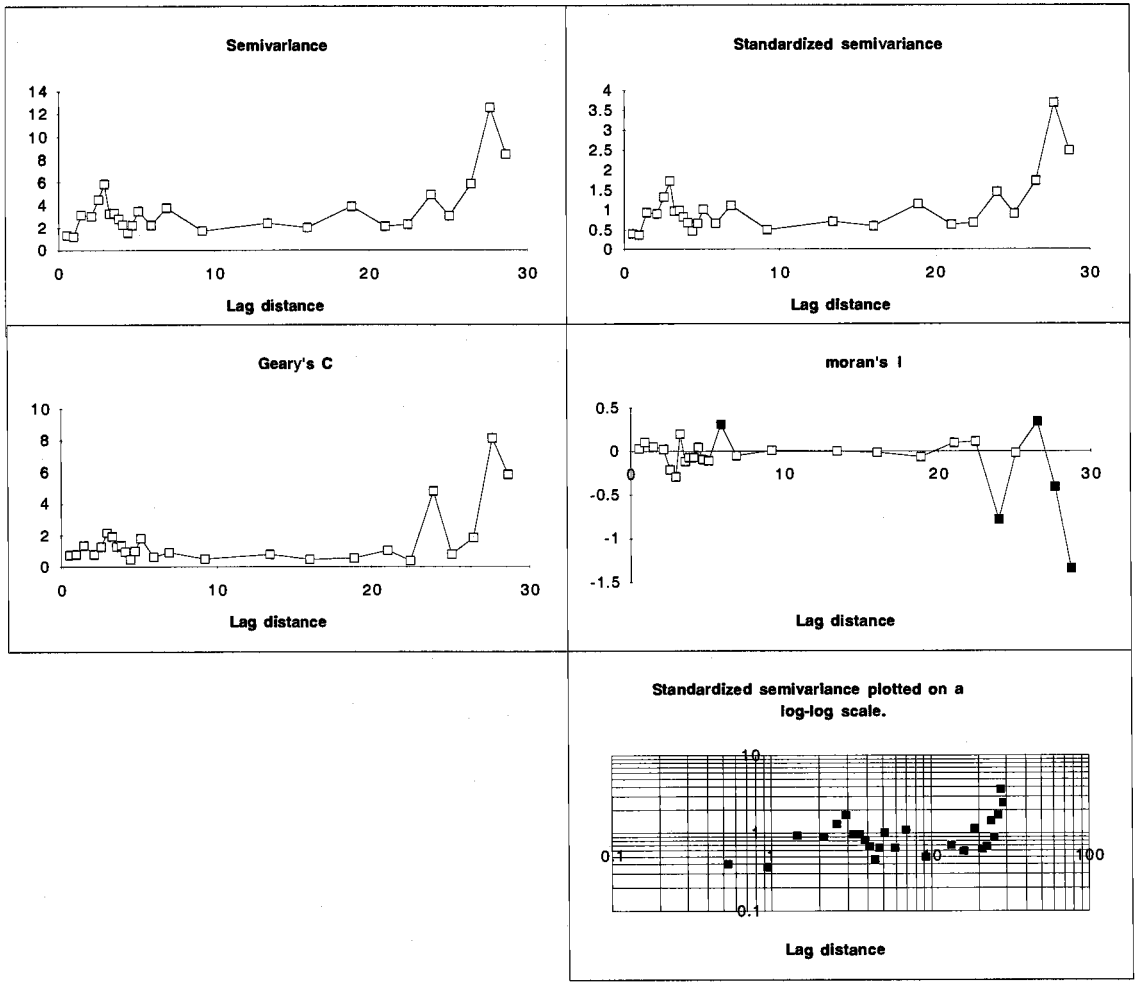
b. Initial nitrogen as NH4, plot f, observations 40,46 and 50 removed as outliers.

Figure 3.11 continued



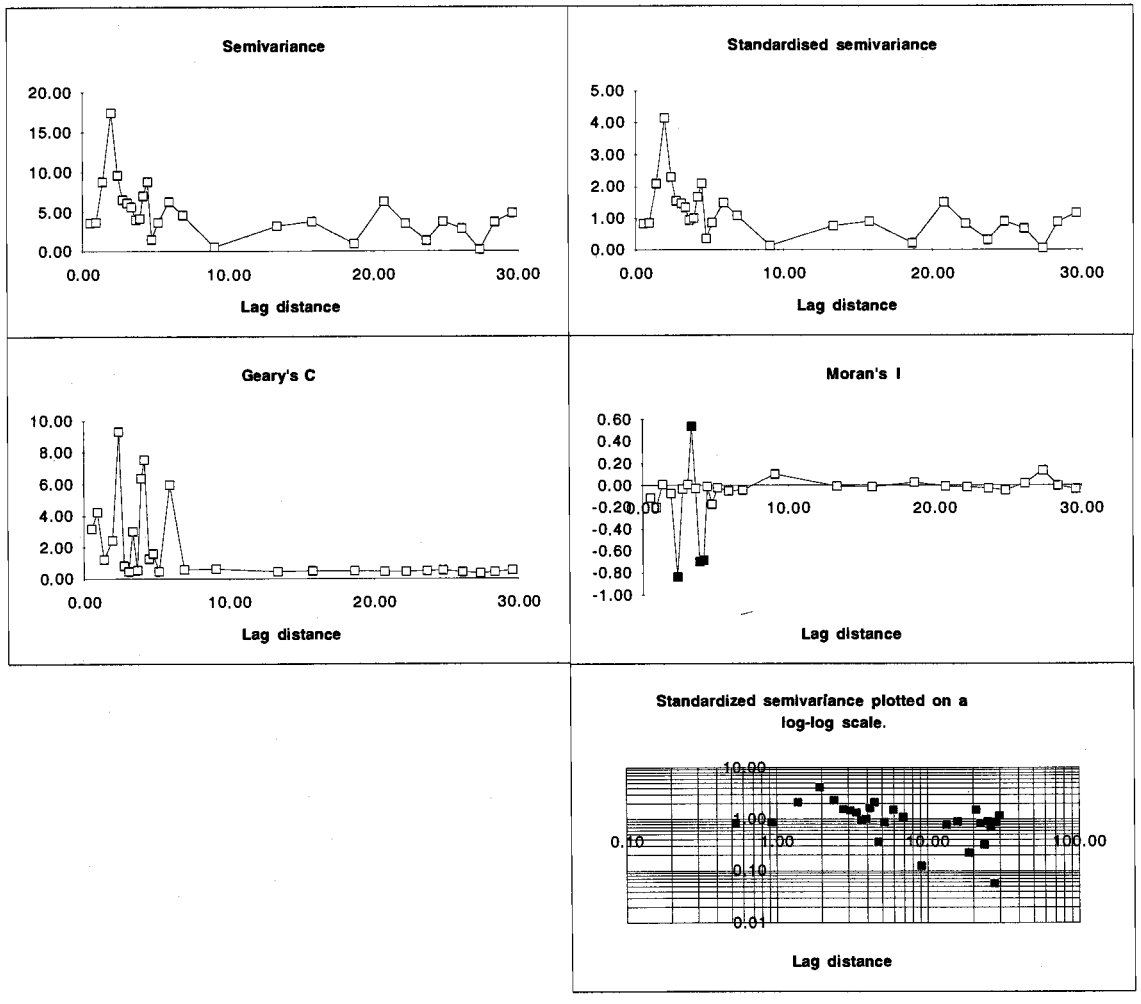
a. Initial Nitrogen as NH4, plot K, May 1992, juniper-sagebrush-grass community.

Figure 3.12



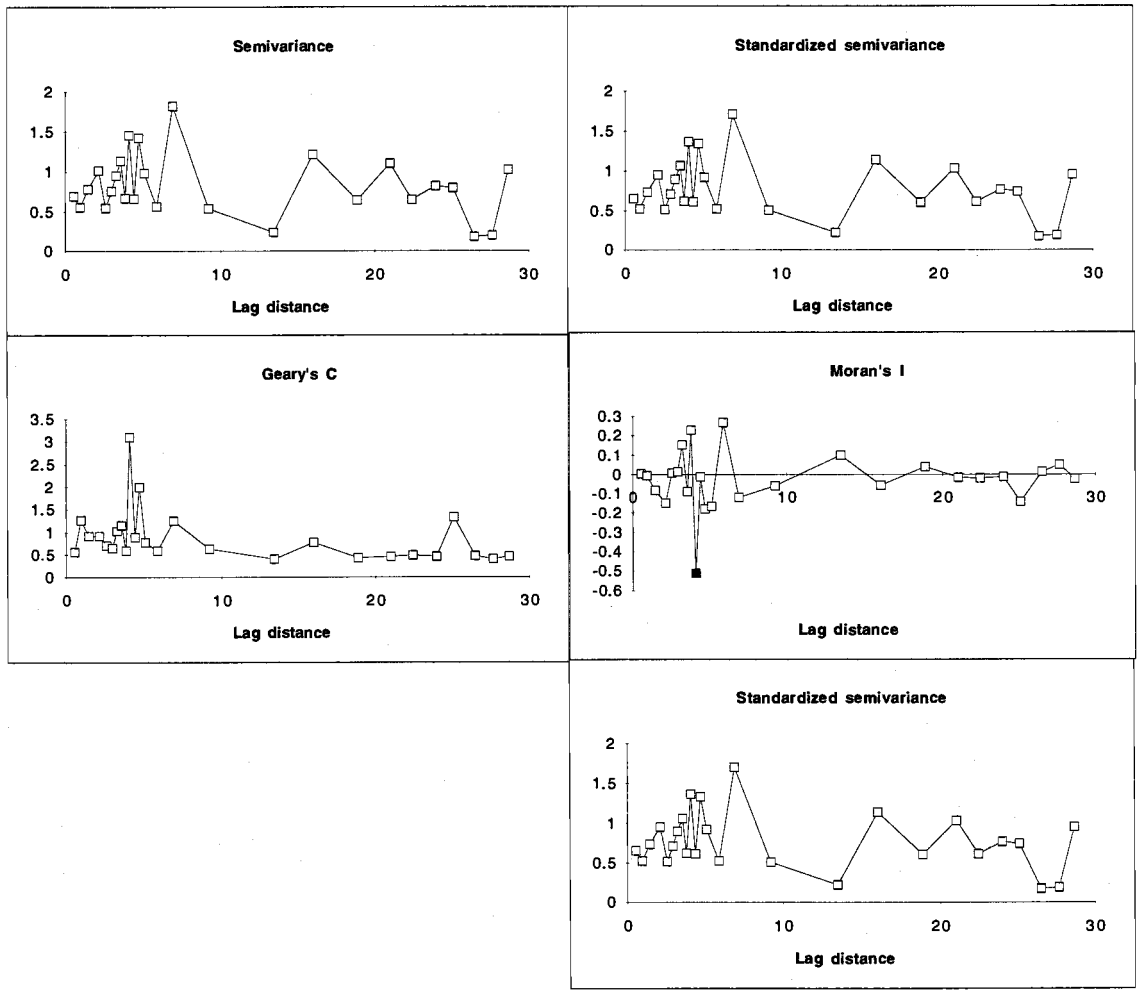
b. Initial Nitrogen as NH4, plot k, observation 23 removed as an outlier.

Figure 3.12 continued



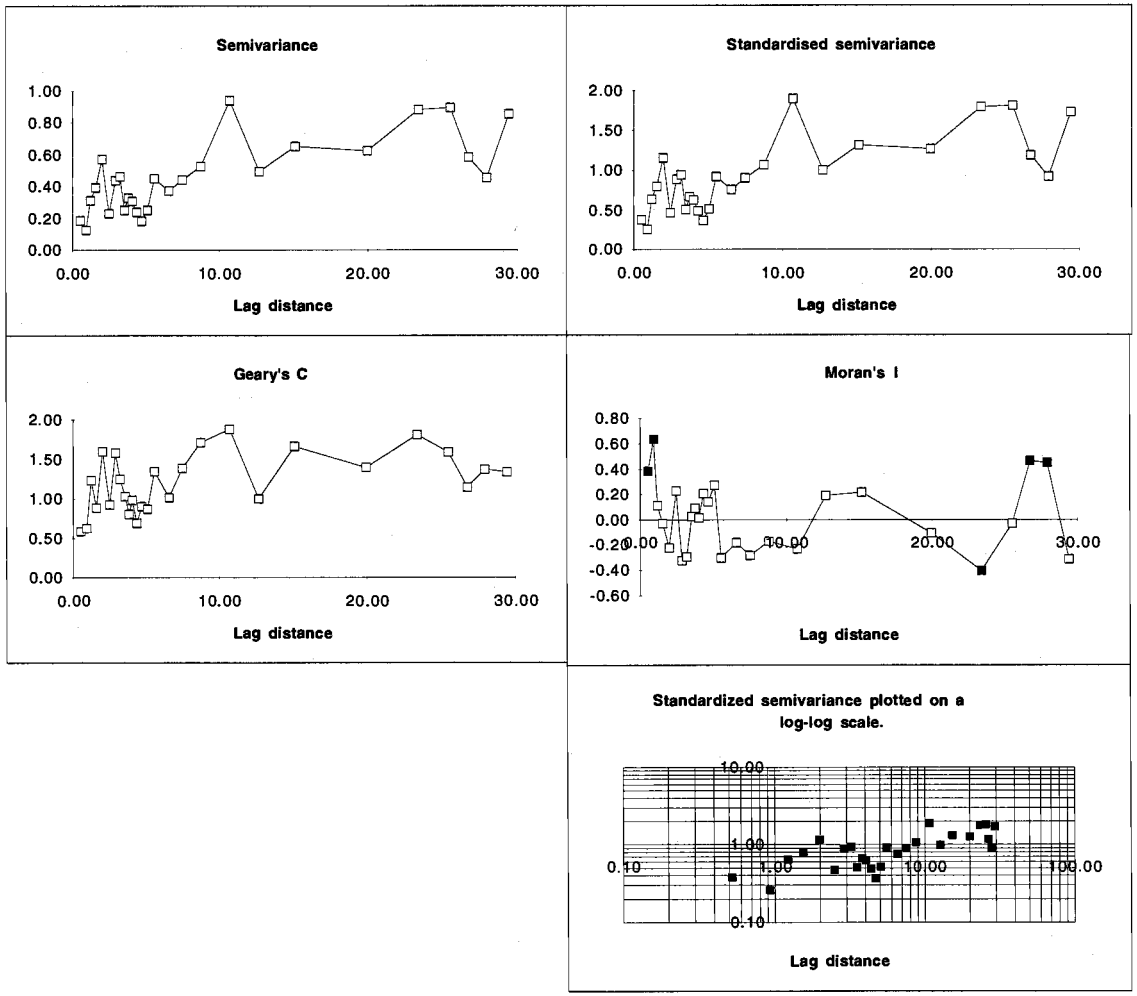
a. Nitrogen as NH4 after incubation, plot K, May 1992, juniper-sagebrush-grass community.

Figure 3.13



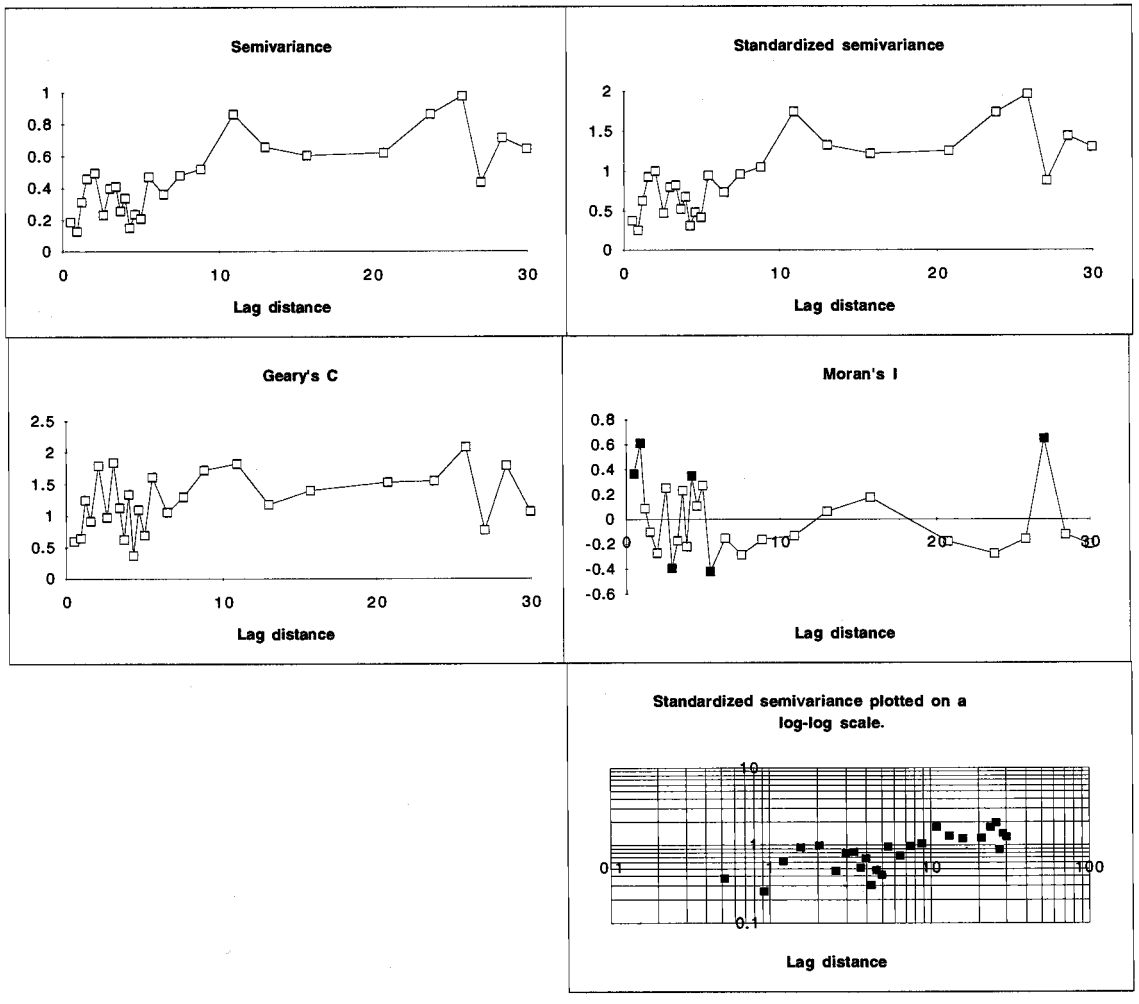
b. Nitrogen as NH4 after incubation, plot k, observation 23 removed as an outlier.

Figure 3.13 continued



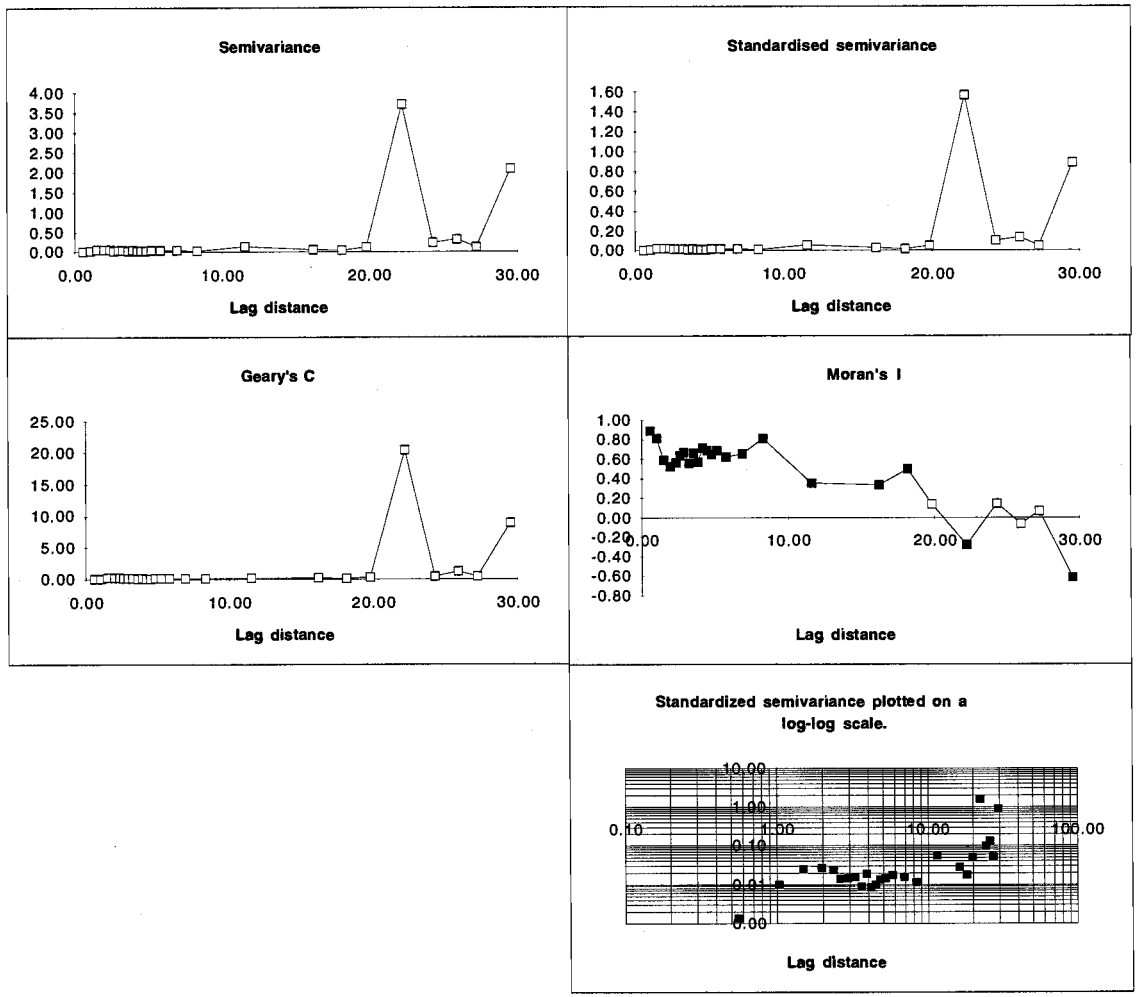
a. Moisture, plot L, May1992, sagebrush-grass community.

Figure 3.14



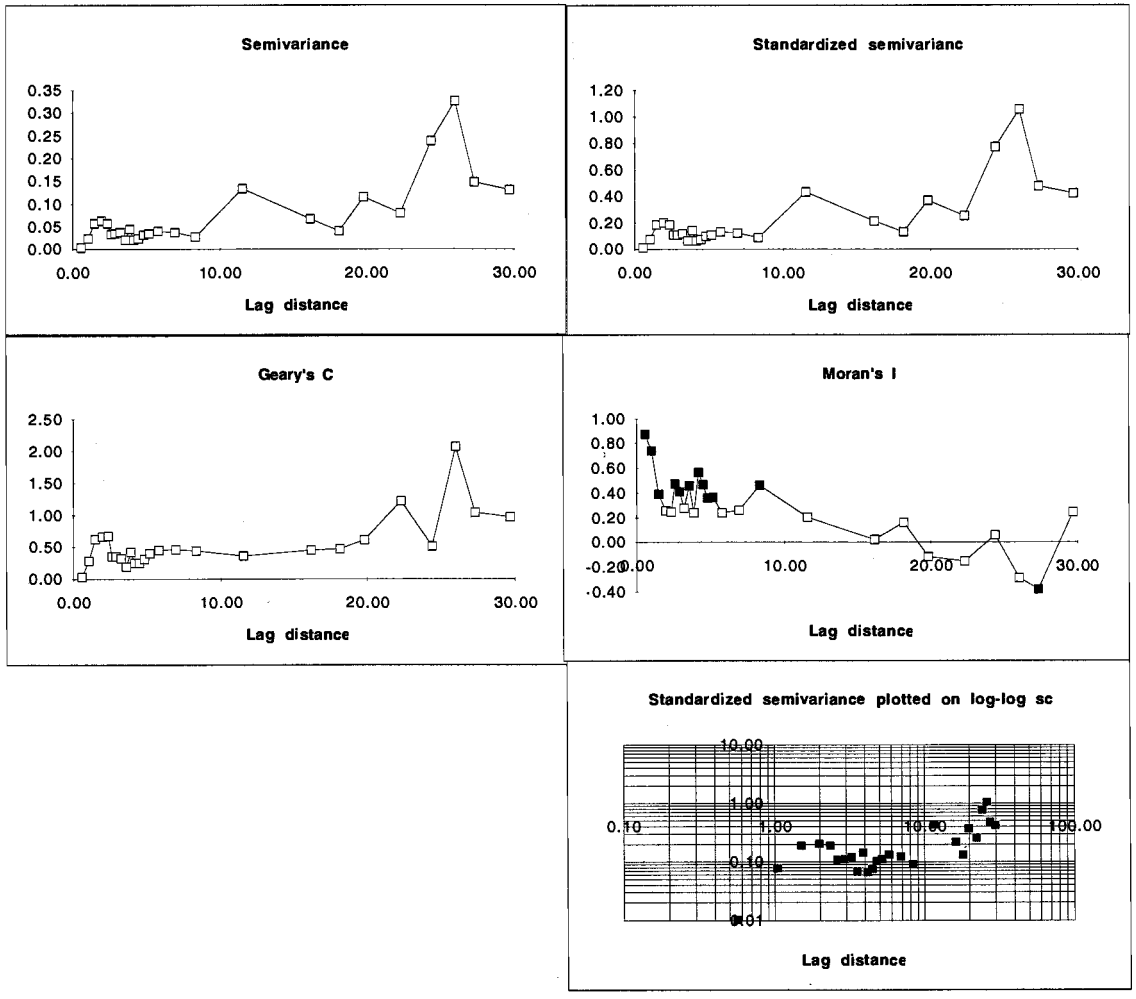
b. Moisture, plot L, observation 24 removed as an outlier.

Figure 3.14 continued



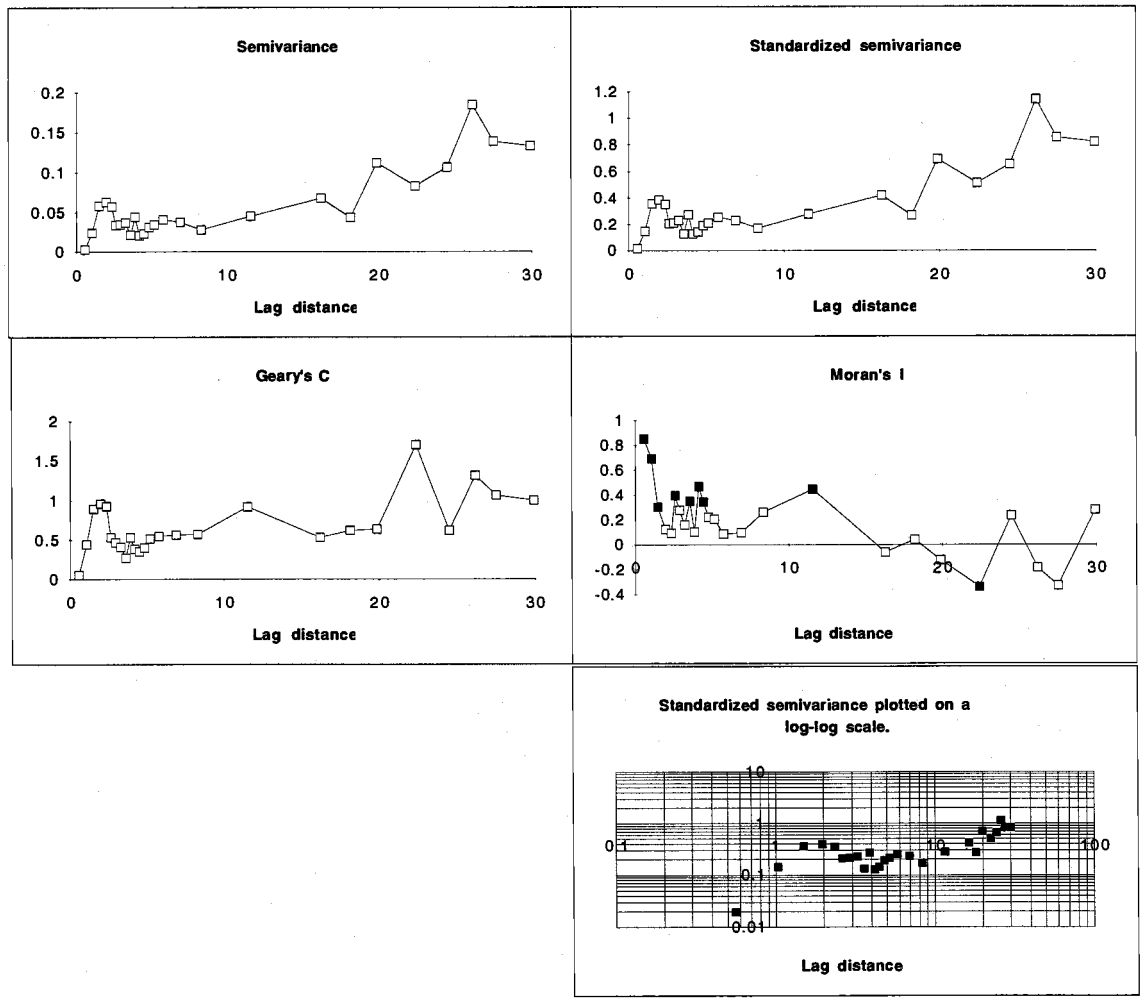
a. Initial Nitrogen as NO3, plot I, May 1992, juniper-sagebrush-grass community.

Figure 3.15



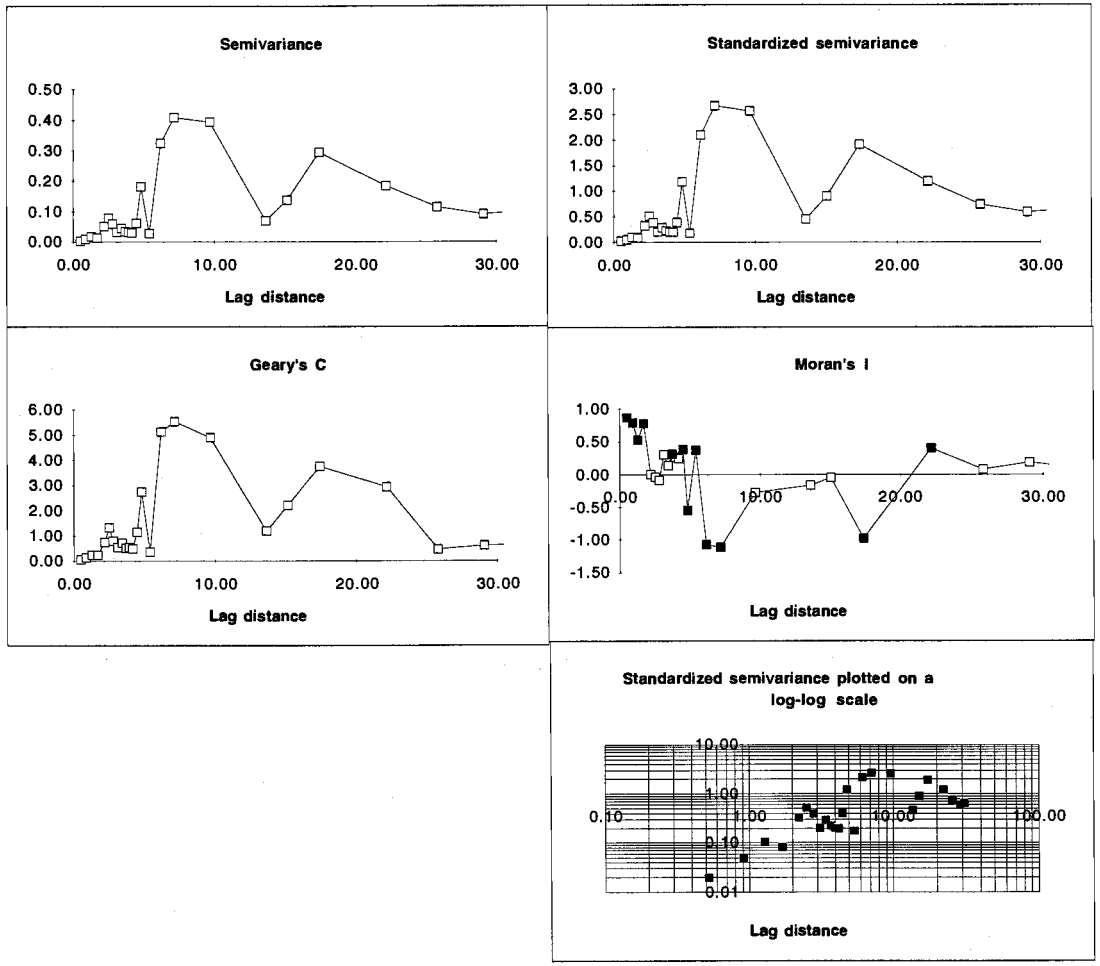
b. Initial Nitrogen as NO3, plot I, observation 52 removed as an outlier.

Figure 3.15 continued



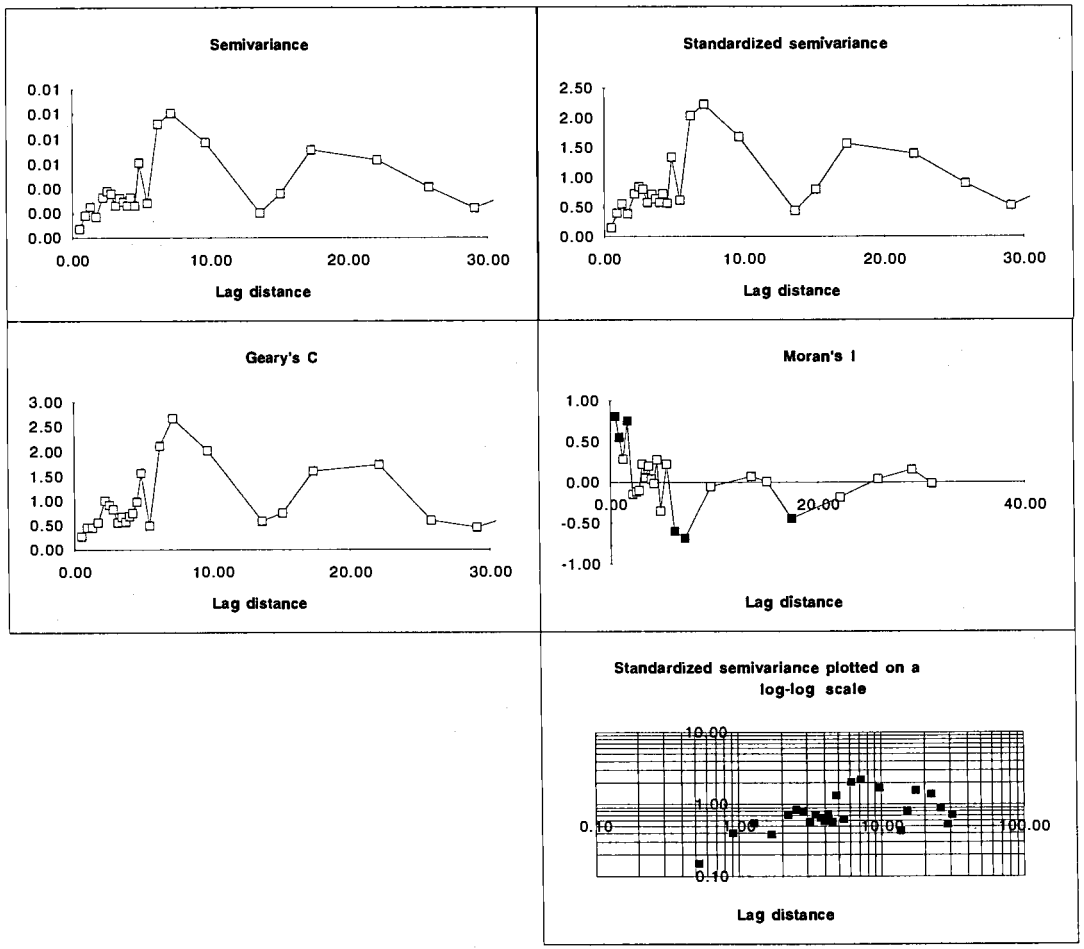
c. Initial Nitrogen as NO3, plot I, observations 36 and 52 removed as outliers.

Figure 3.15 continued



e. Initial Nitrogen as NO3, plot I, observations 36 and 52 removed as outliers, then data corrected for anisotropy prior to calculating the semivariance, standardized semivariance, Geary's C and Moran's I

Figure 3.15 continued



f. Initial Nitrogen as NO3, plot I, observations 36 and 52 removed as outliers, then data normalized and corrected for anisotropy prior to calculating the semivariance, standardized semivariance, Geary's C and Moran's

Figure 3.15 continued

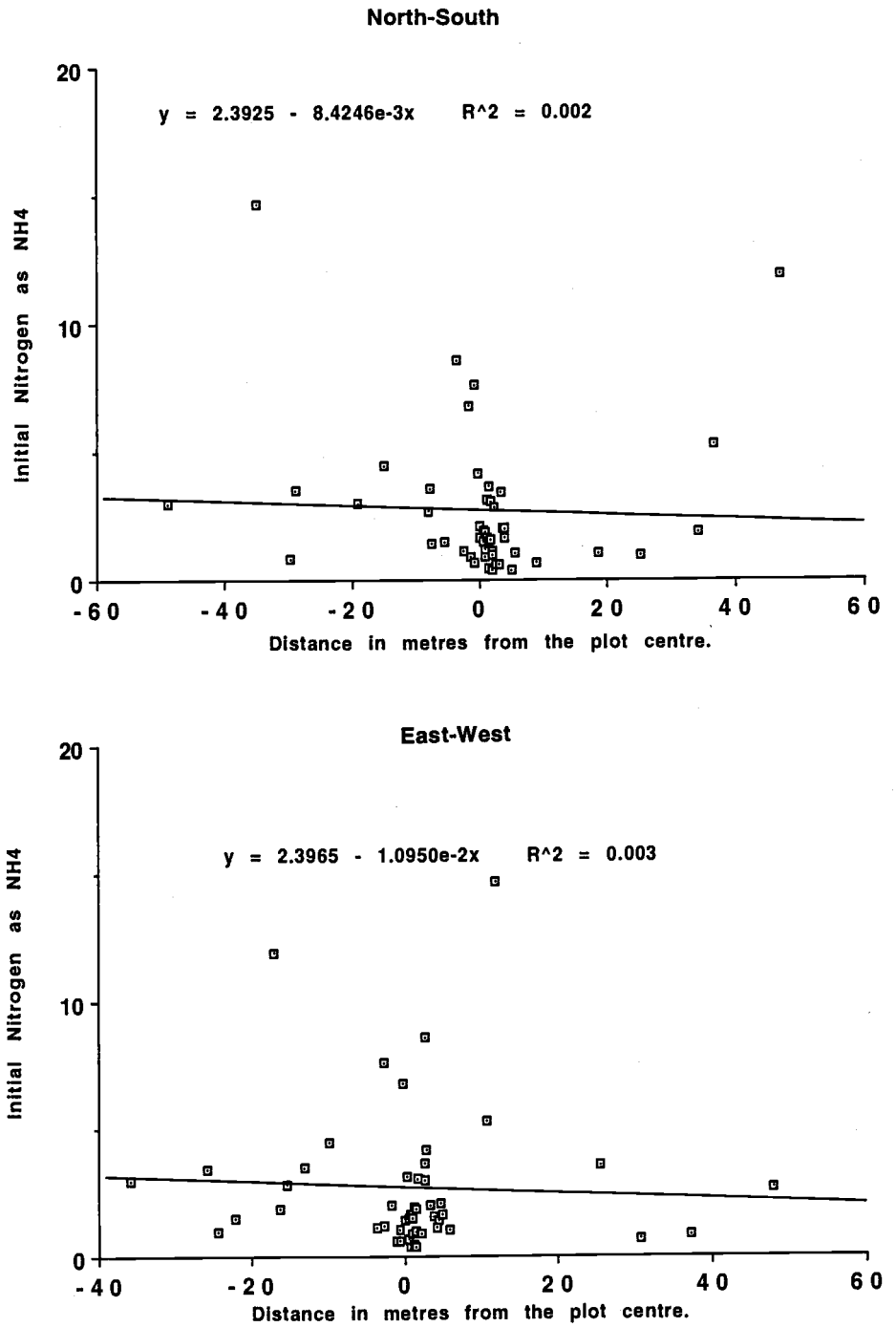


Figure 3.16. Plot I, distribution of values of sampled points along a North-South and an East-West axis

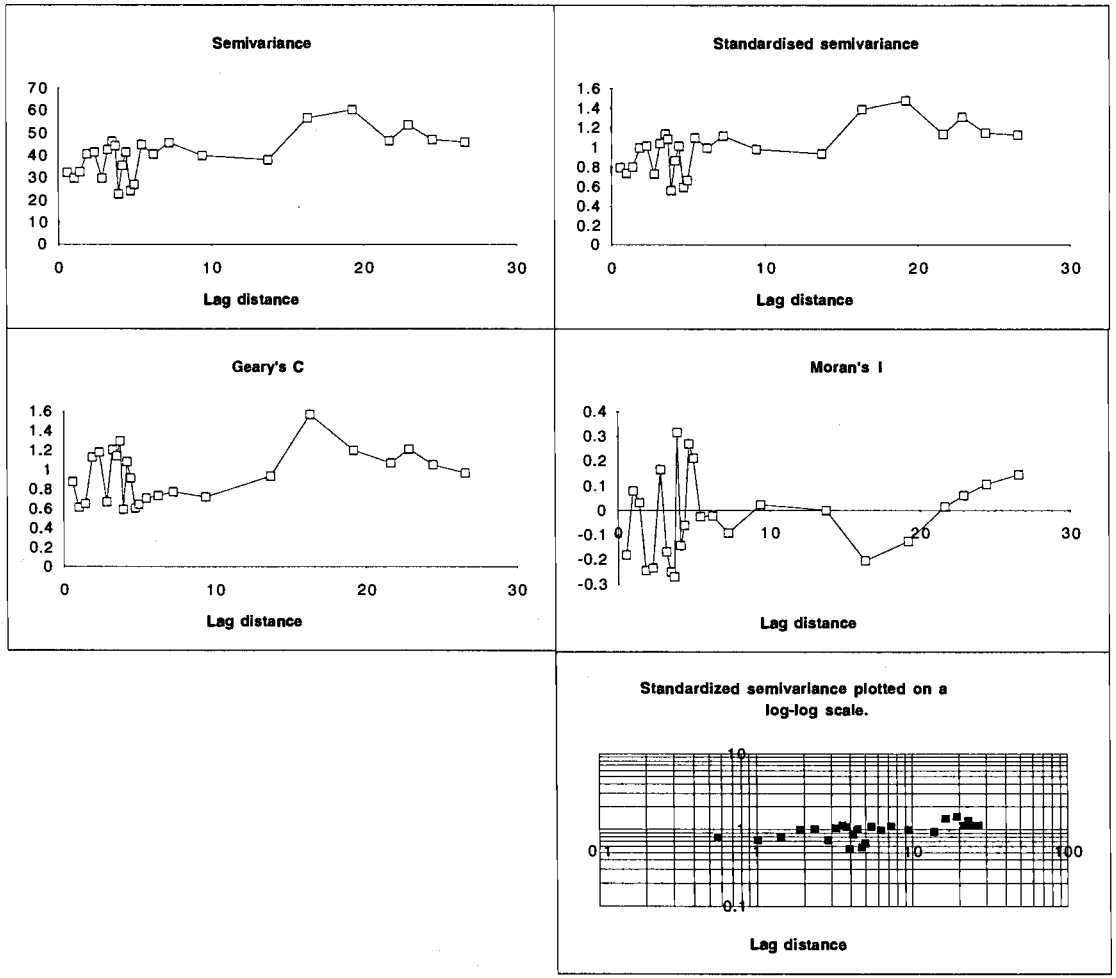


Figure 3.17. Random plot using log-normally distributed random numbers, antilogged to give a synthetic dataset in the range of moisture.

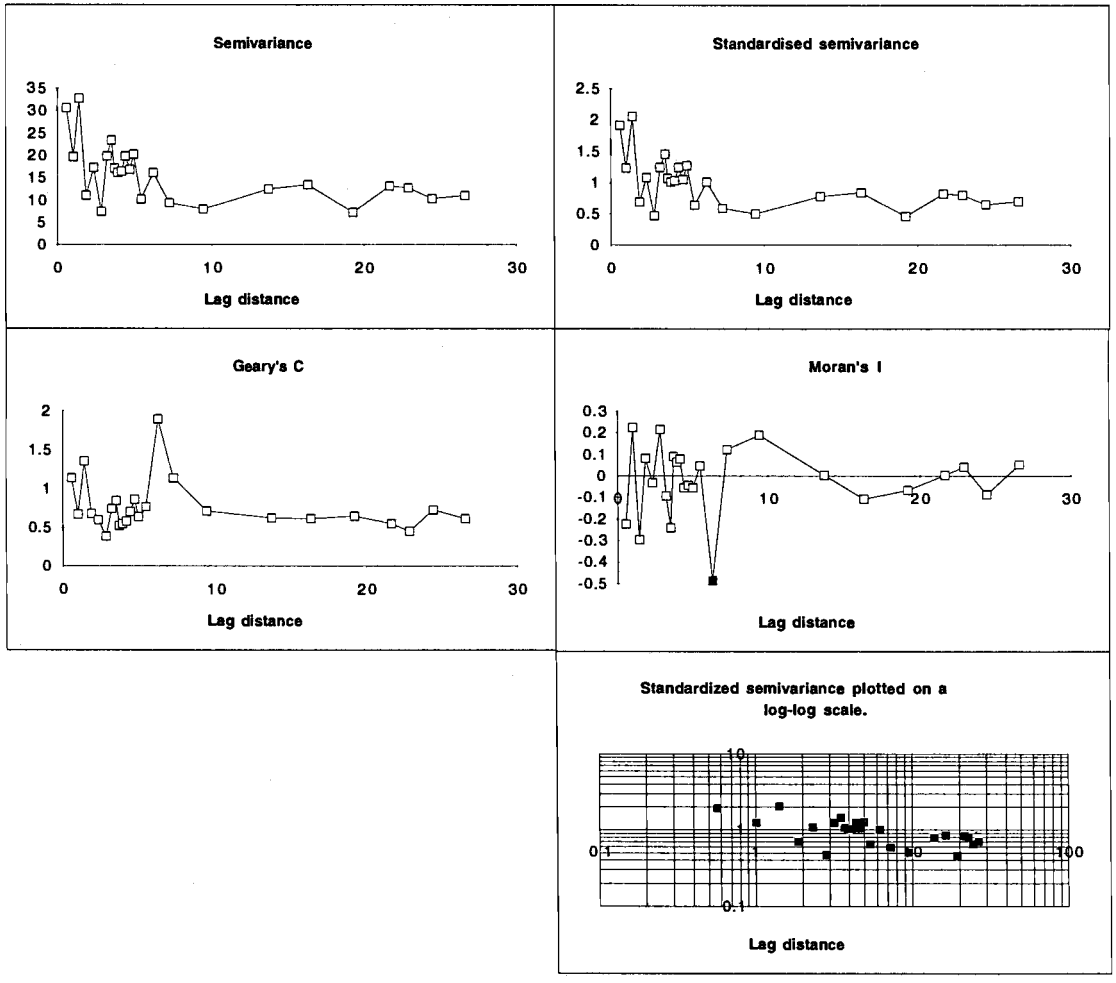


Figure 3.18. Random plot using log-normally distributed random numbers, antilogged to give a synthetic dataset in the range of initial nitrogen as NH4.

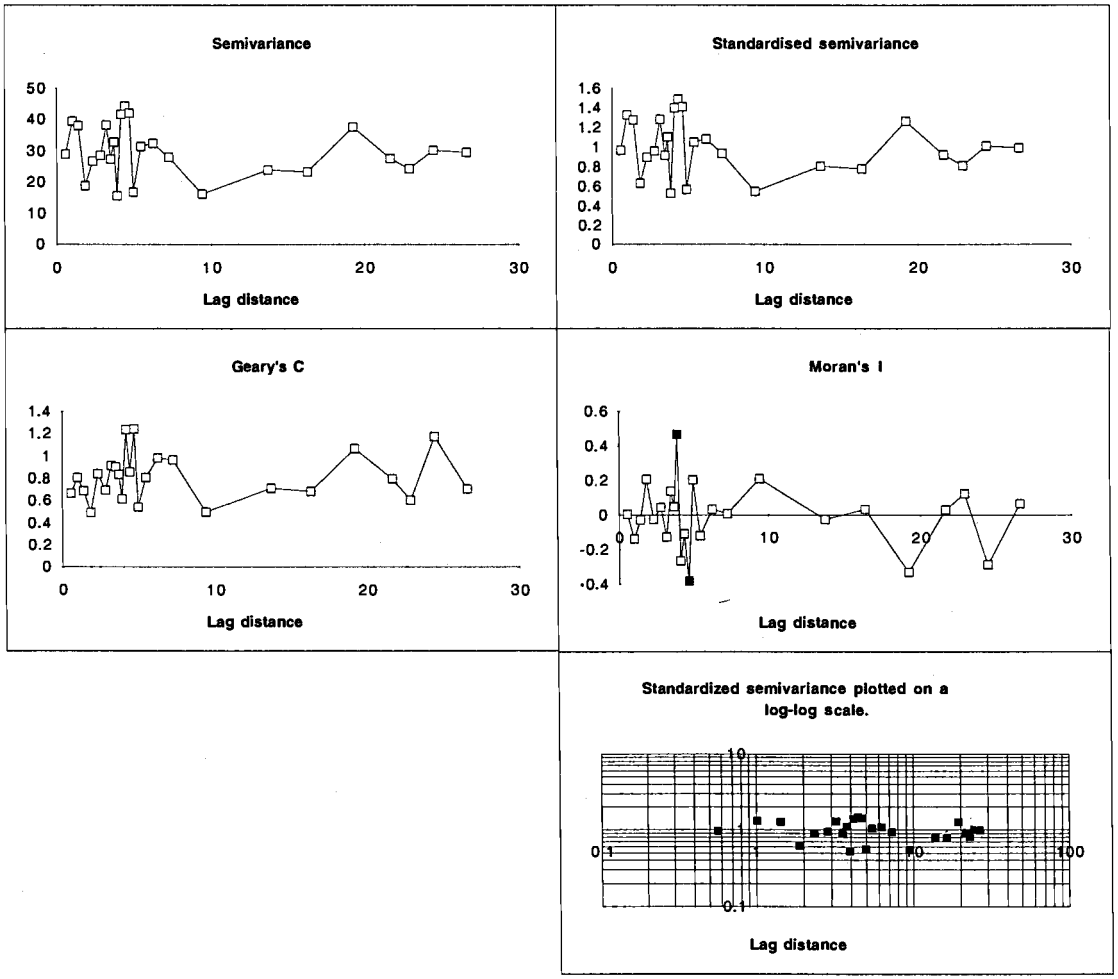


Figure 3.19. Random plot using log-normally distributed random numbers, antilogged to give a synthetic dataset in the range of initial nitrogen as NO3.

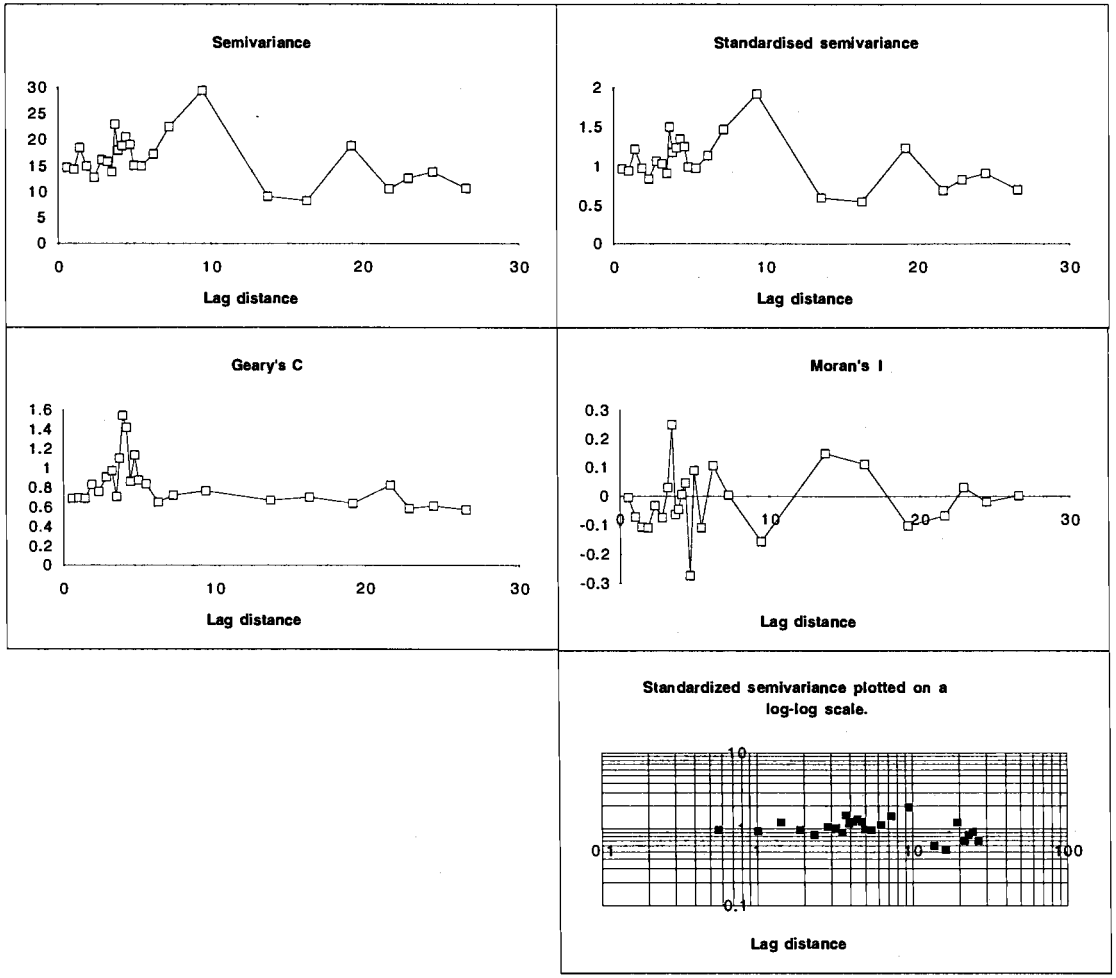


Figure 3.20. Random plot using log-normally distributed random numbers, antilogged to give a synthetic dataset in the range of nitrogen as NH4 after incubation.

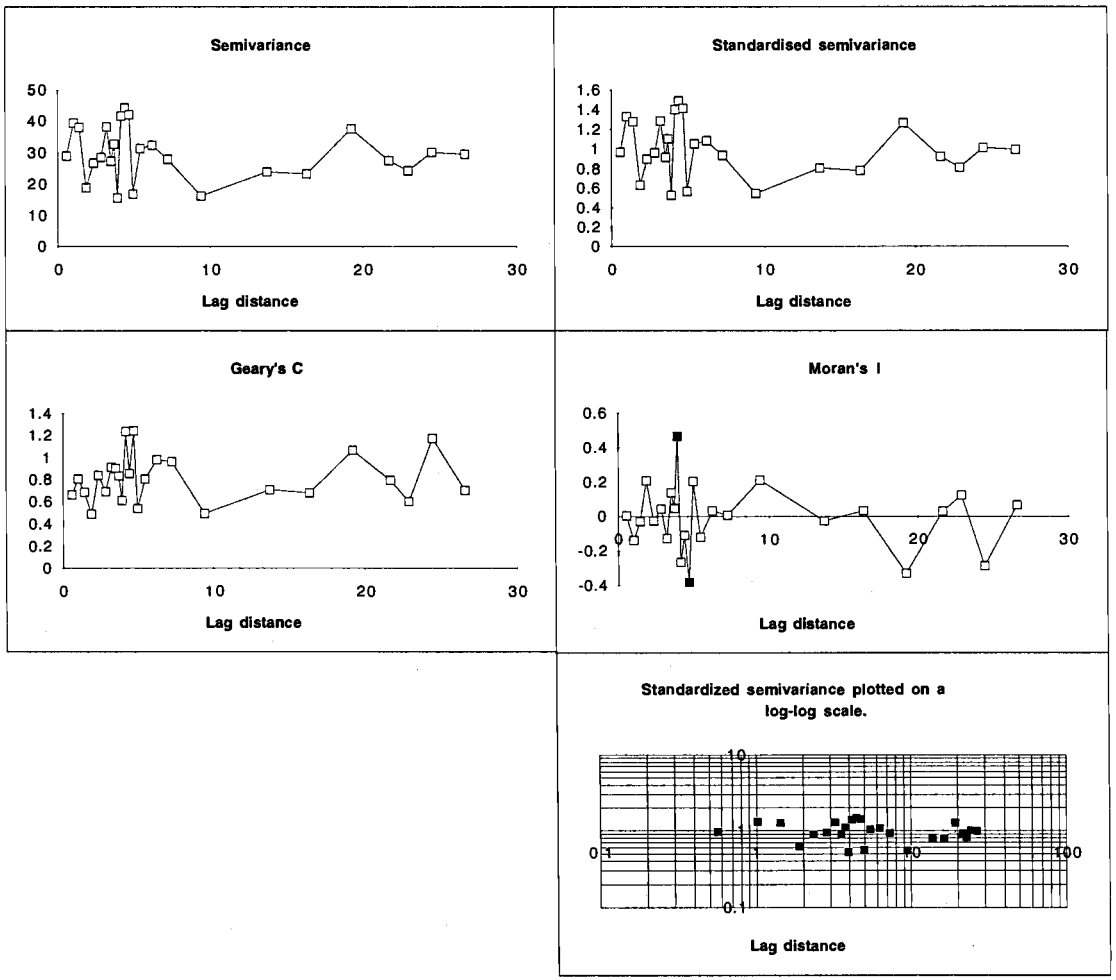


Figure 3.21. Random plot using log-normally distributed random numbers, antilogged to give a synthetic dataset in the range of nitrogen mineralized as NH4.

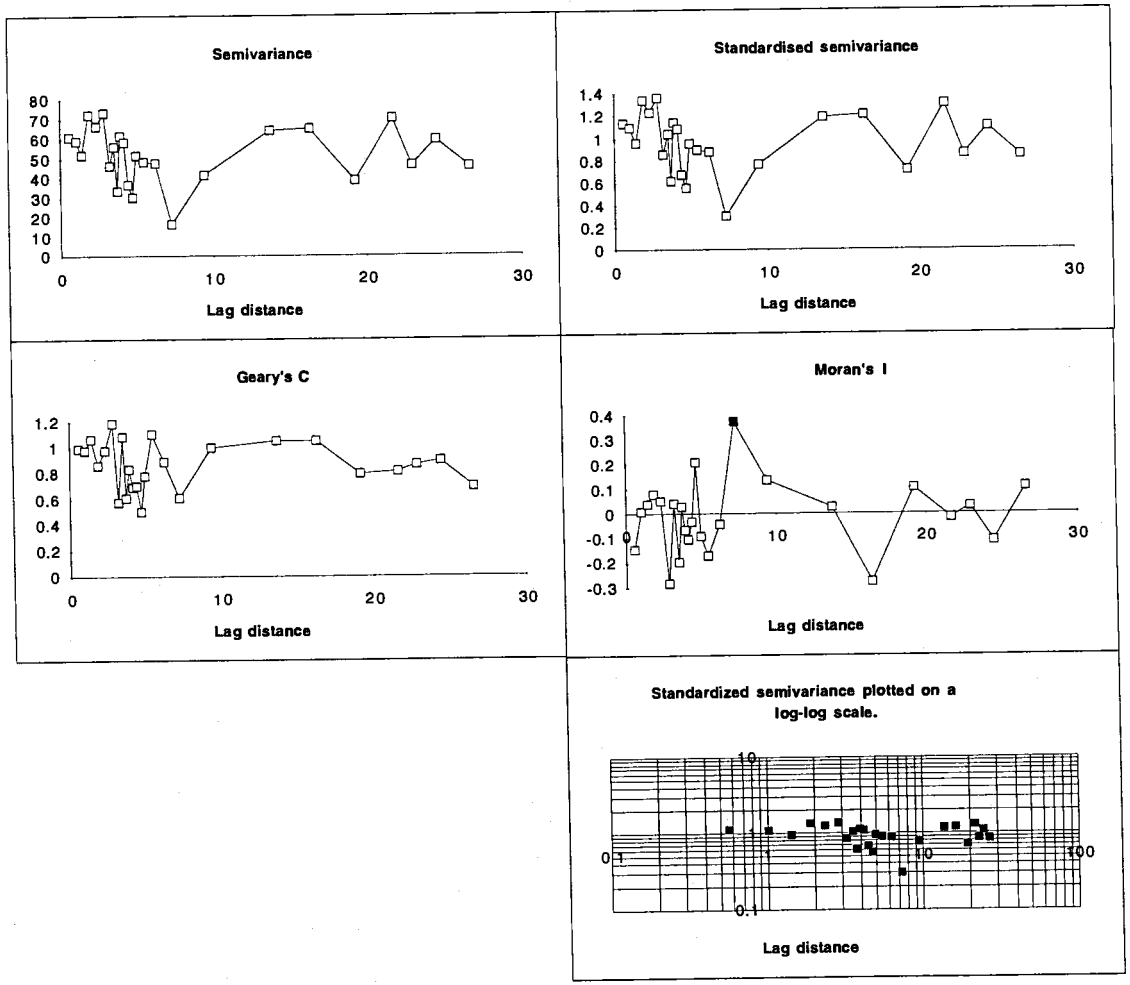


Figure 3.22. Random plot using log-normally distributed random numbers, antilogged to give a synthetic dataset in the range of nitrogen as NO3 after incubation.

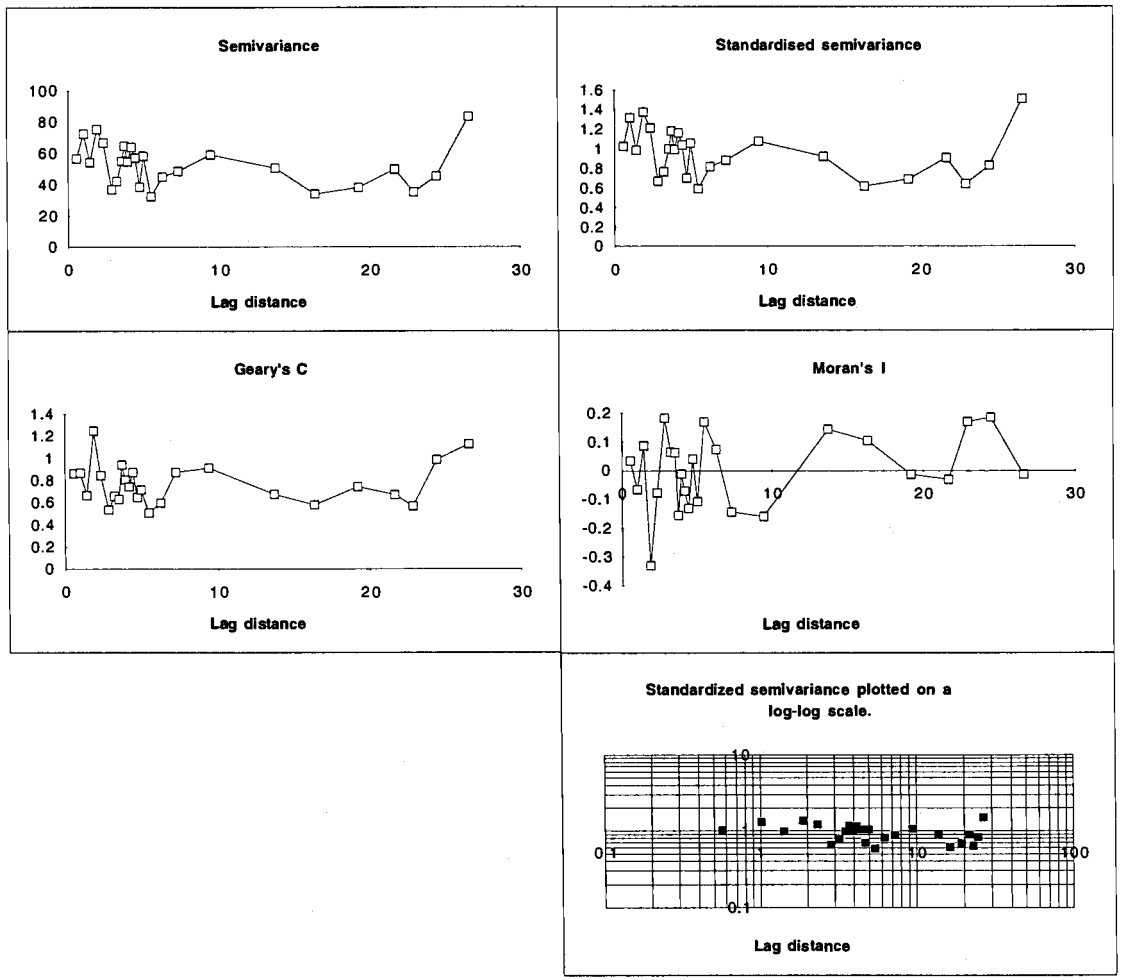


Figure 3.23. Random plot using log-normally distributed random numbers, antilogged to give a synthetic dataset in the range of nitrogen mineralized as NO3.

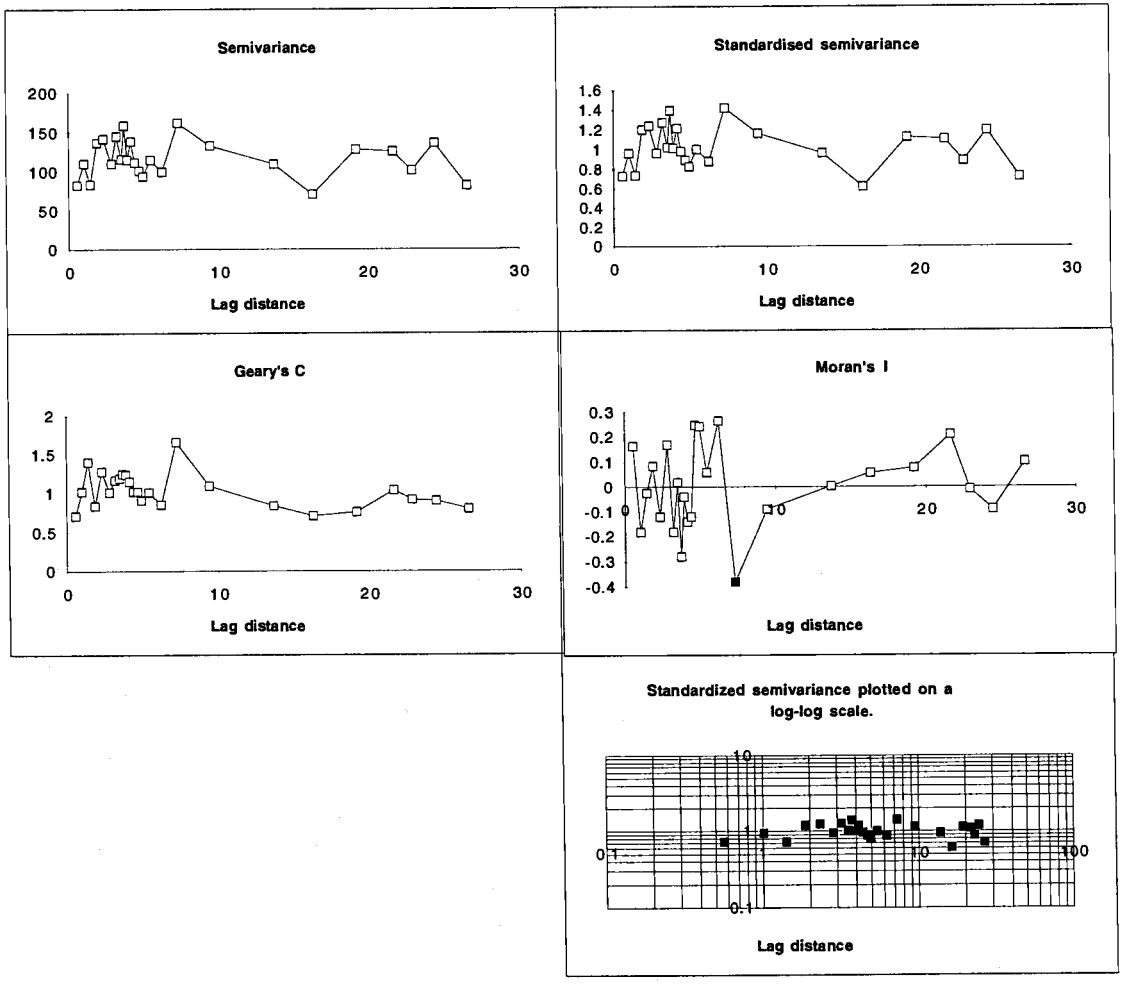


Figure 3.24. Random plot using log-normally distributed random numbers, antilogged to give a synthetic dataset in the range of net nitrogen mineralized.

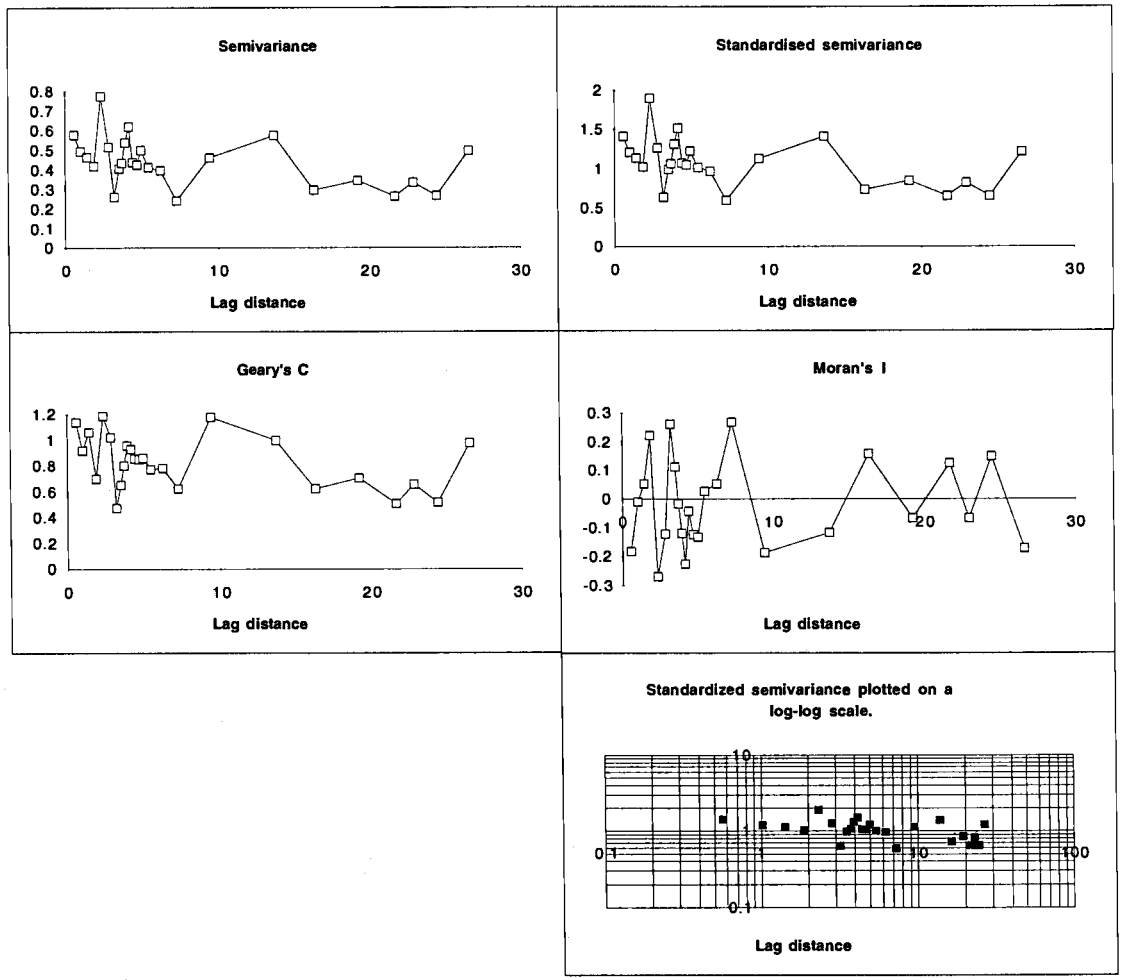


Figure 3.25. Random plot using random numbers of values between 0.98 and 3.02, similar to artificial landscapes.

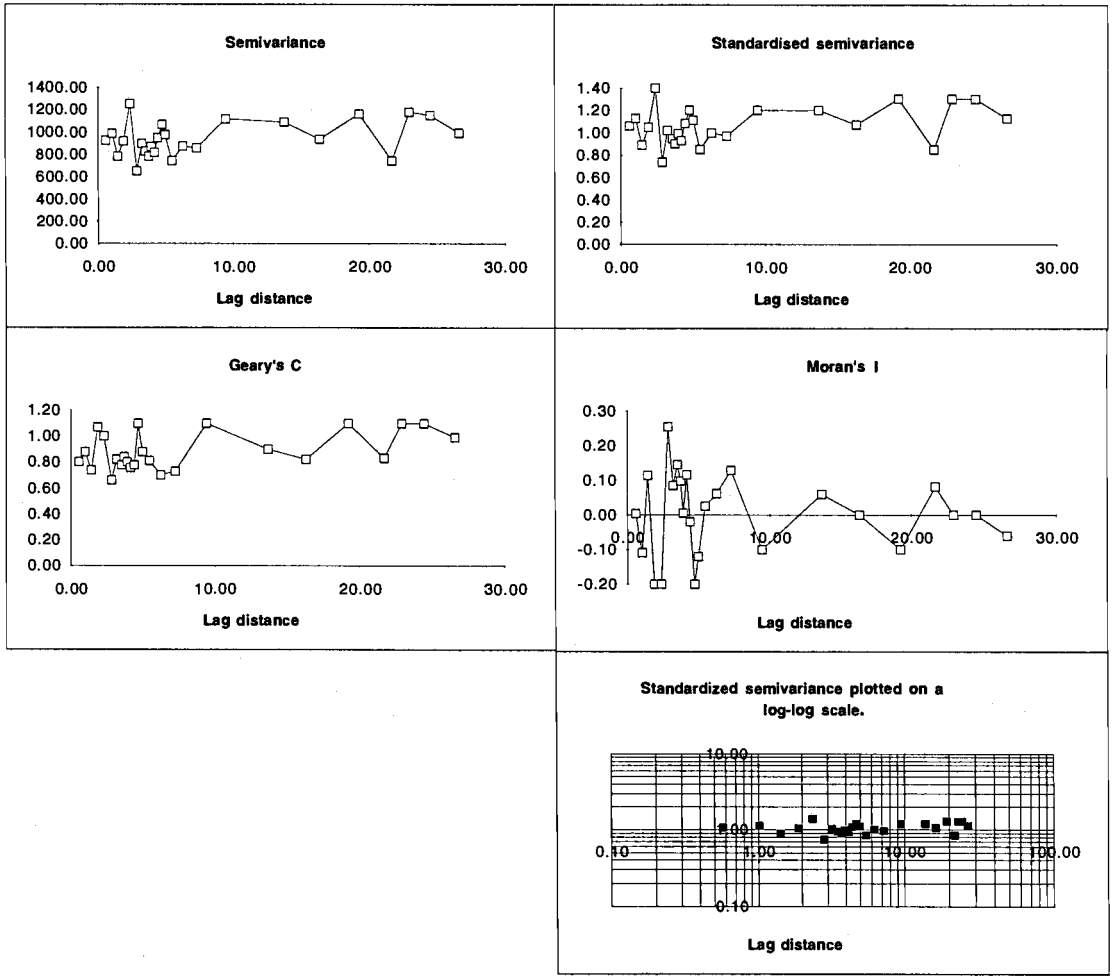


Figure 3.26. Random plot using normally distributed random numbers to give a synthetic dataset in the range of V.A. mycorrhizal infection.

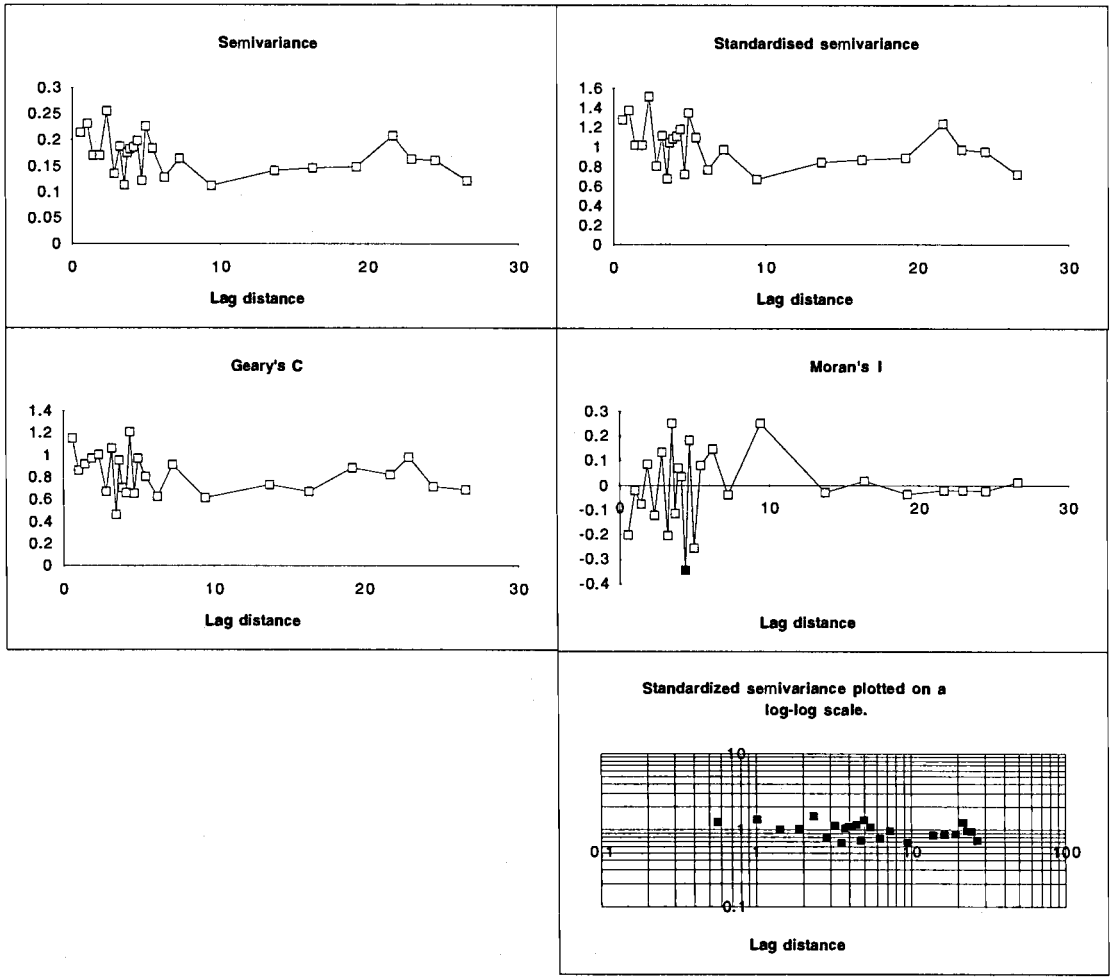
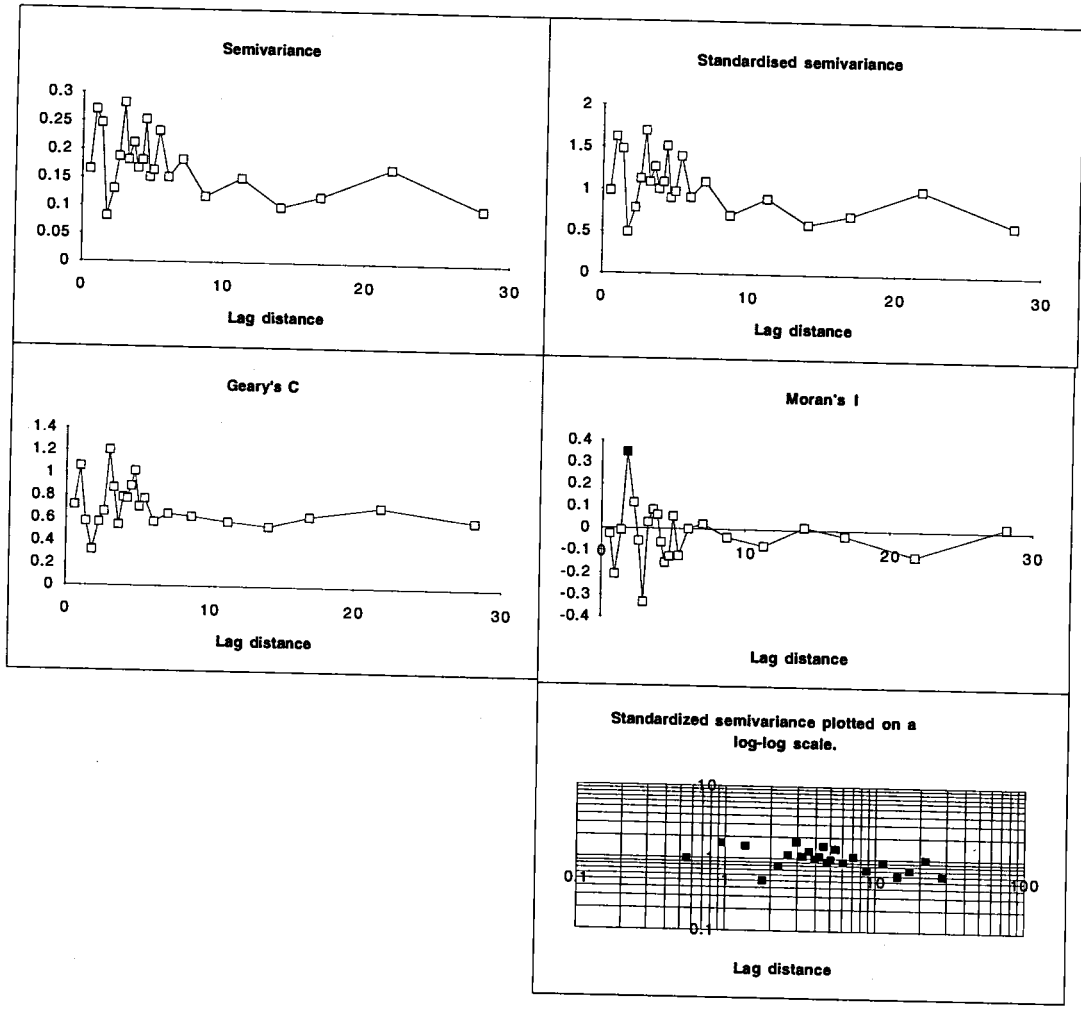
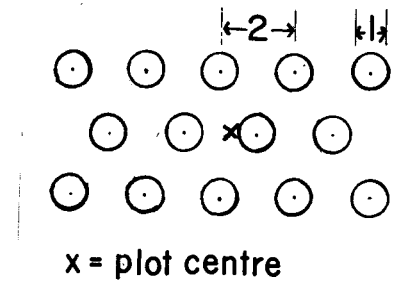


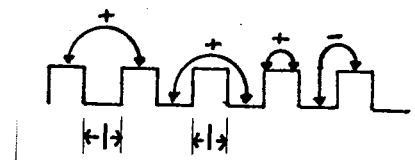
Figure 3.27. Random plot using normally distributed random numbers to give a synthetic dataset in the range of PH.



a.

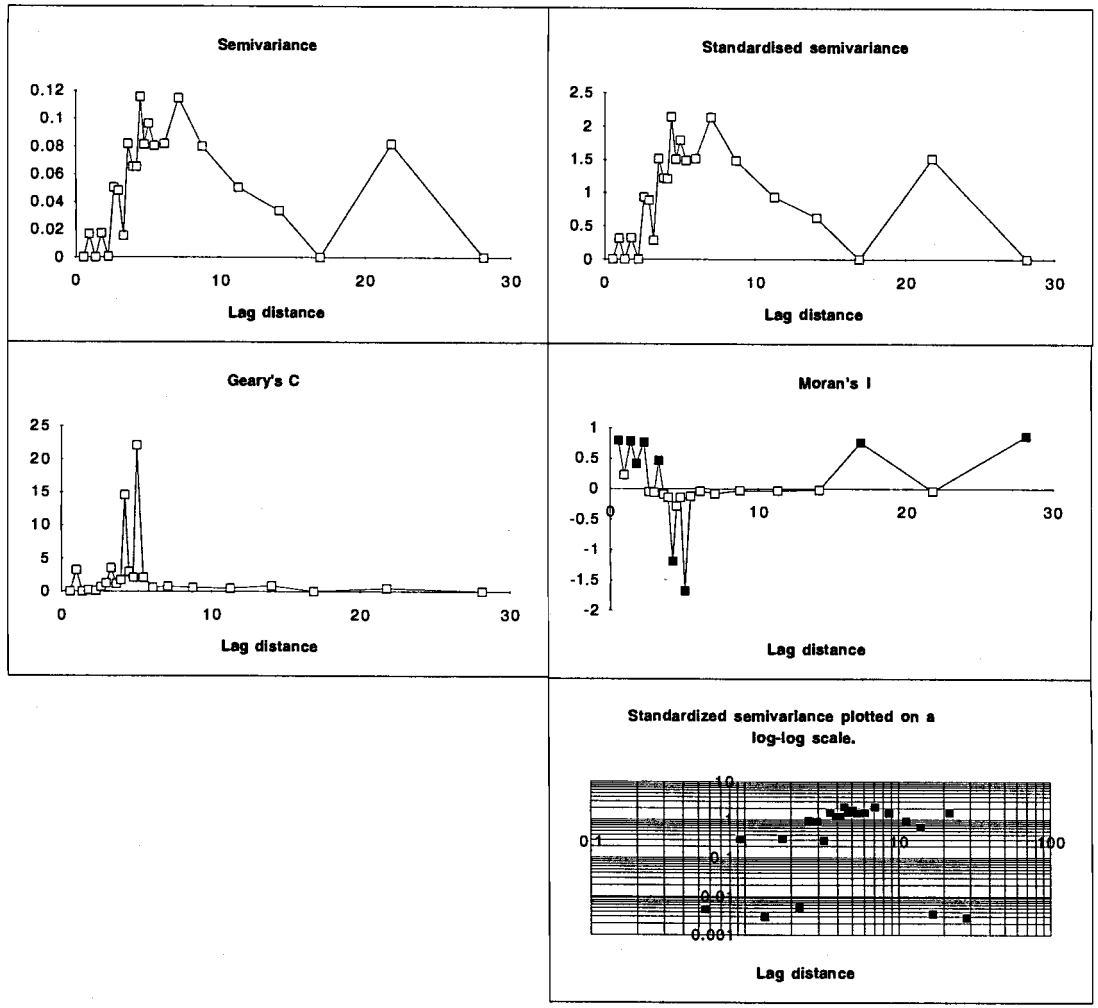


b.

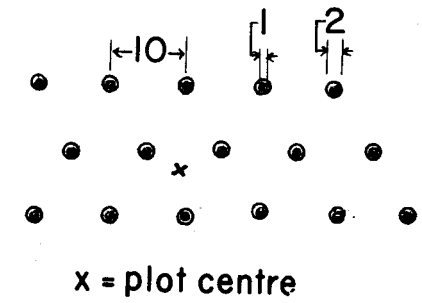


a. An example of the landscape plan sampled as seen from above.
b. The values of a transect of the landscape in a. plotted as a function of distance. Distances marked are scaled to metres. The arrows connect pairs of positions on the landscape which are either positively or negatively correlated according to their distance apart. Moran's I (left) detects some of these correlations.

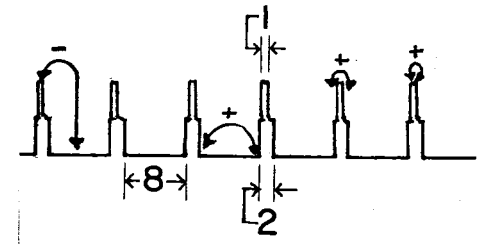
Figure 3.28. Simulated landscape with sagebrush at 2 m apart, canopy diameter 1 m.



a.

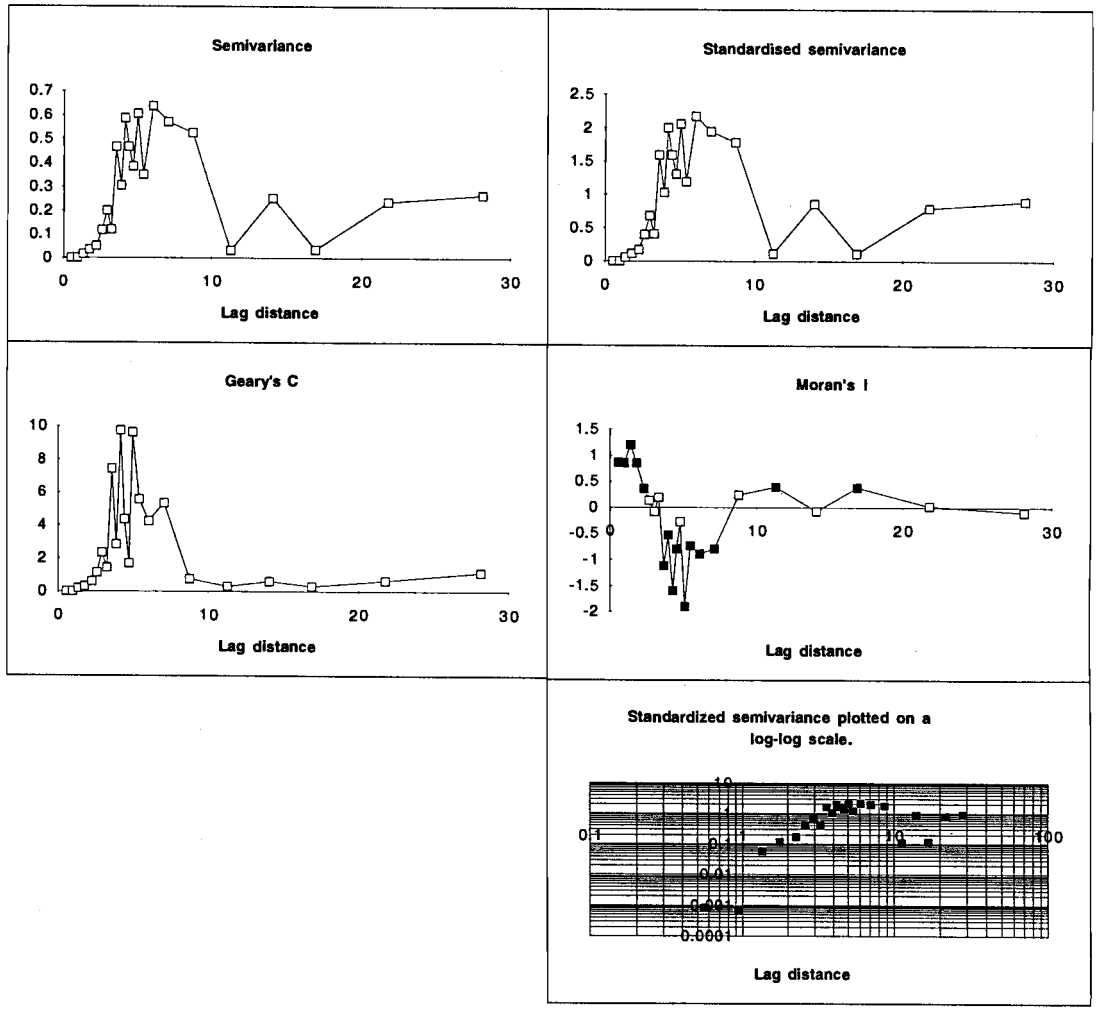


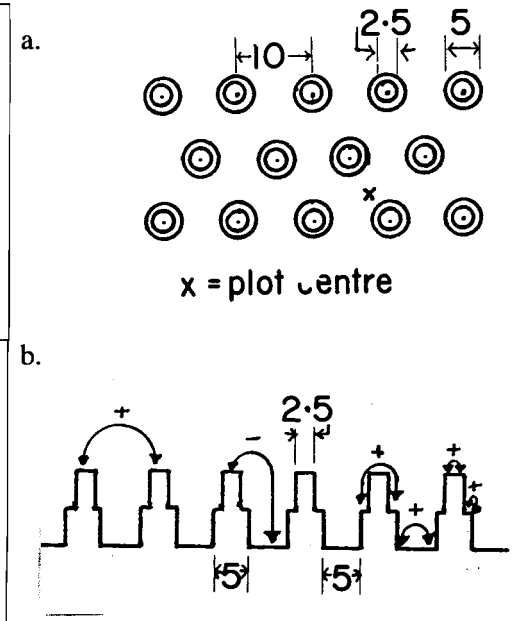
b.



a. An example of the landscape plan sampled as seen from above.
b. The values of a transect of the landscape in a. plotted as a function of distance. Distances marked are scaled to metres. The arrows connect pairs of positions on the landscape which are either positively or negatively correlated according to their distance apart. Moran's I (left) detects some of these correlations.

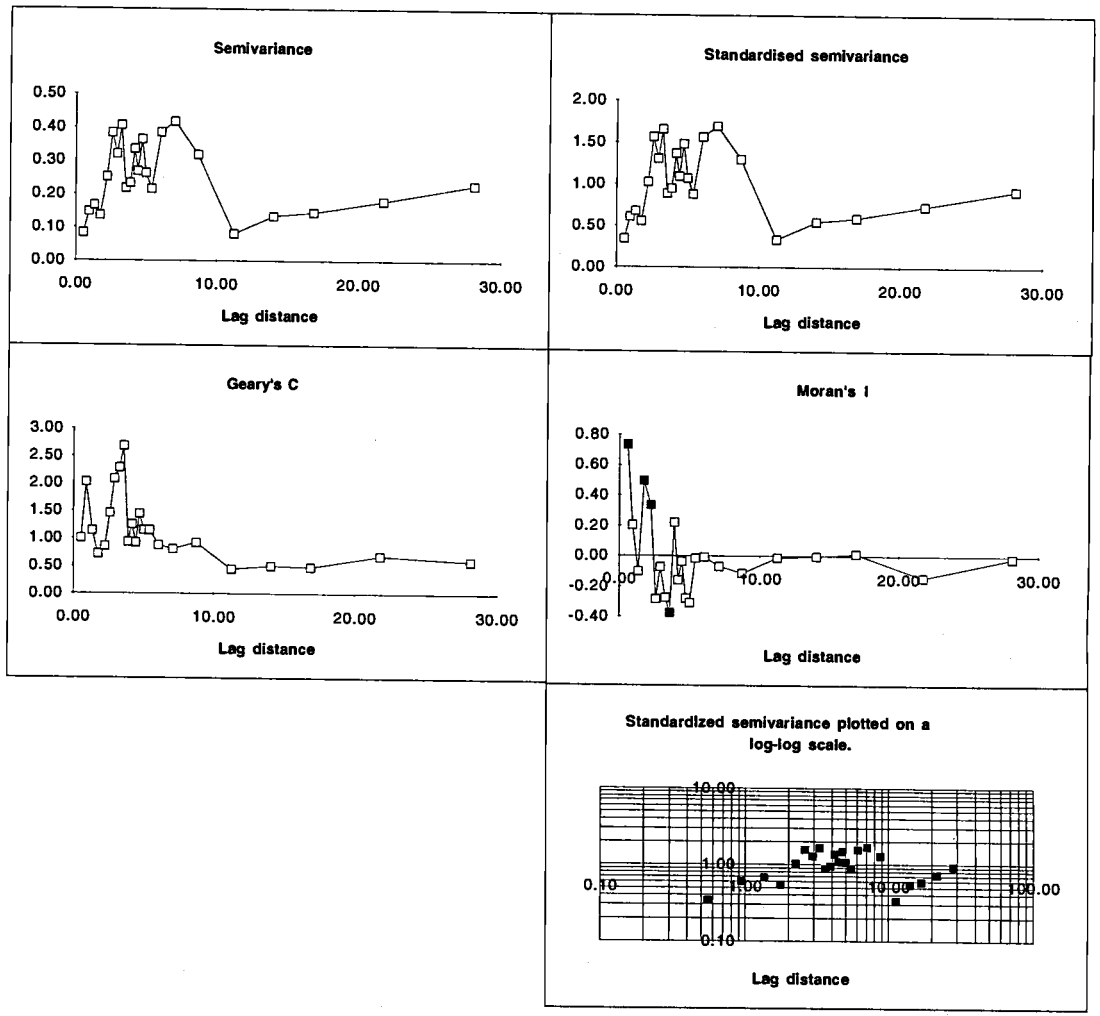
Figure 3.29. Simulated landscape with juniper at 10 m apart, canopy diameter 1 m and root crown 2 m.



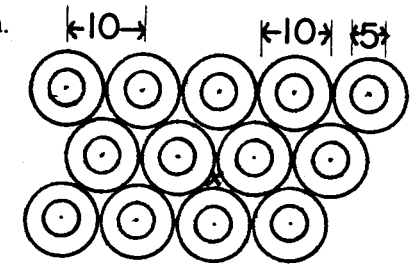


a. An example of the landscape plan sampled as seen from above.
b. The values of a transect of the landscape in a. plotted as a function of distance. Distances marked are scaled to metres. The arrows connect pairs of positions on the landscape which are either positively or negatively correlated according to their distance apart. Moran's I (left) detects some of these correlations.

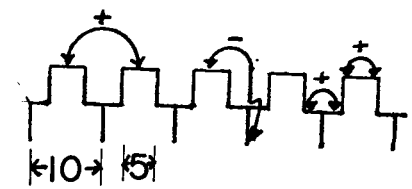
Figure 3.30. Simulated landscape with juniper at 10 m apart, canopy diameter 2.5 m and root crown 5 m.



a.

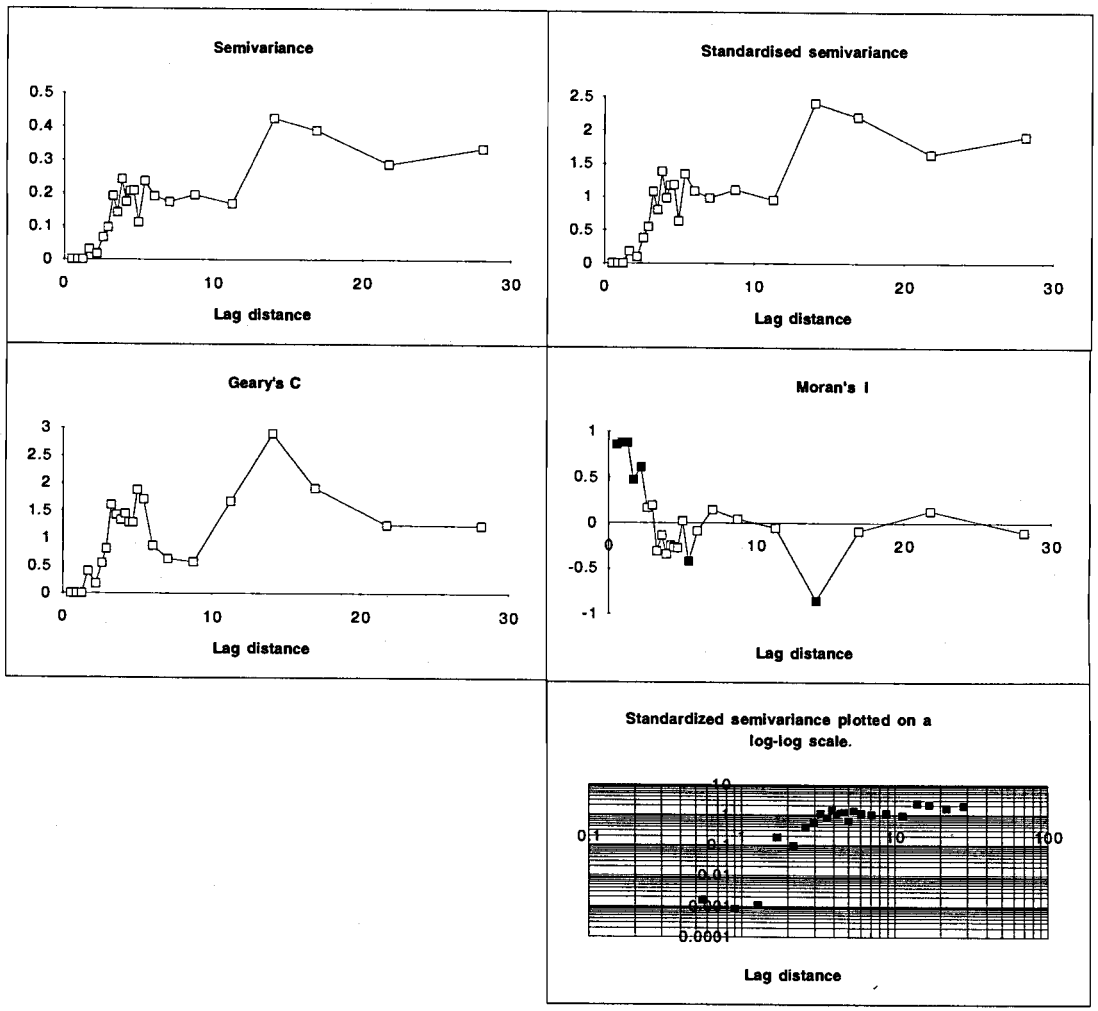


b.

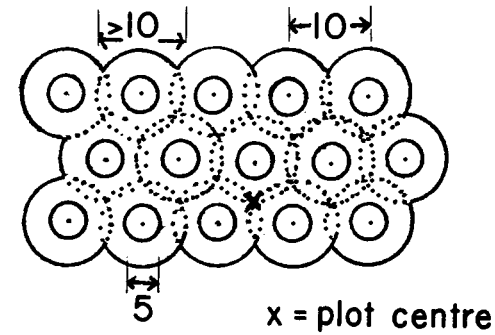


a. An example of the landscape plan sampled as seen from above.
b. The values of a transect of the landscape in a. plotted as a function of distance. Distances marked are scaled to metres. The arrows connect pairs of positions on the landscape which are either positively or negatively correlated according to their distance apart. Moran's I (left) detects some of these correlations.

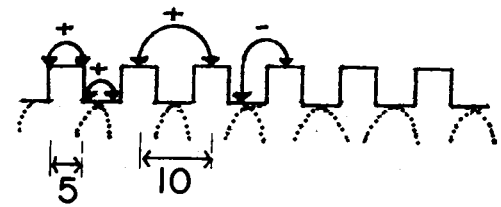
Figure 3.31. Simulated landscape with juniper at 10 m apart, canopy diameter 5 m and root crown 10 m, (the root crowns touch one another.)



a.

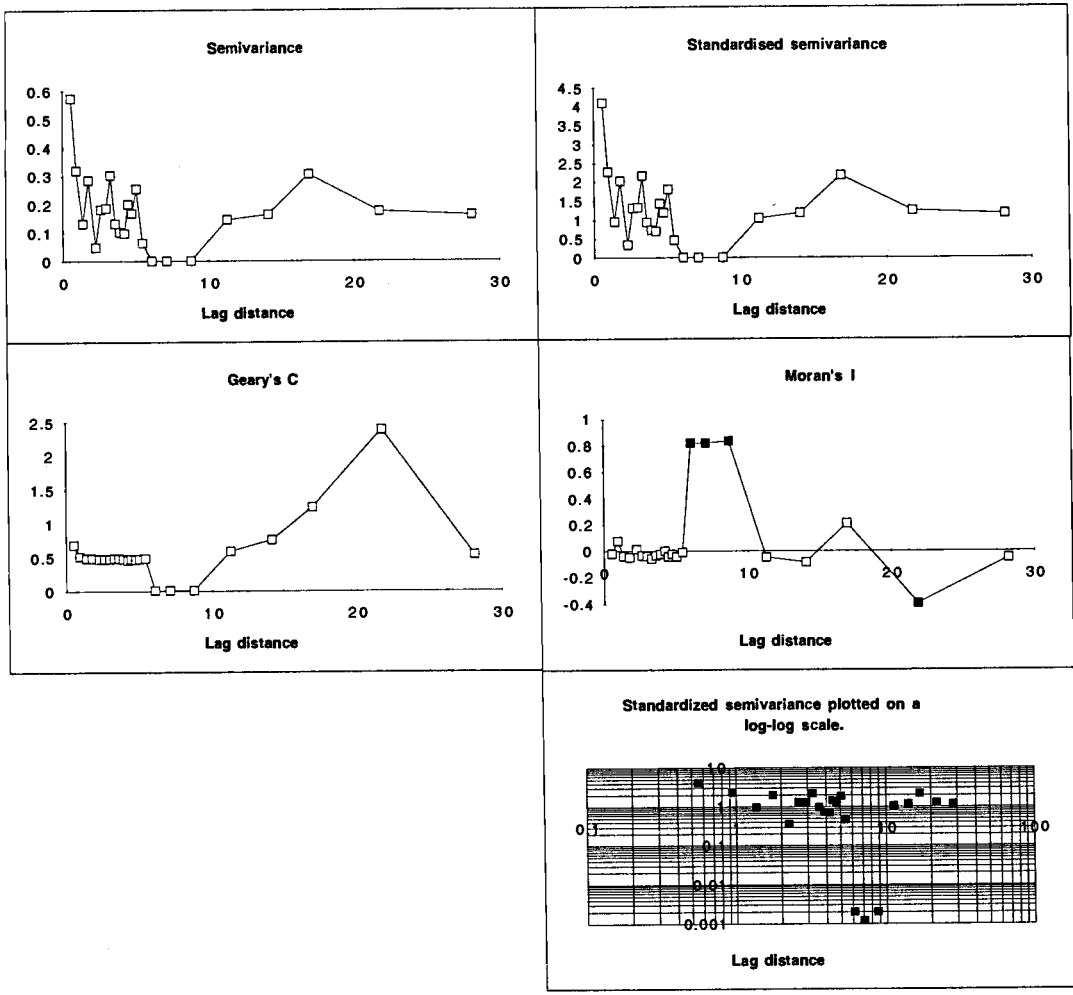


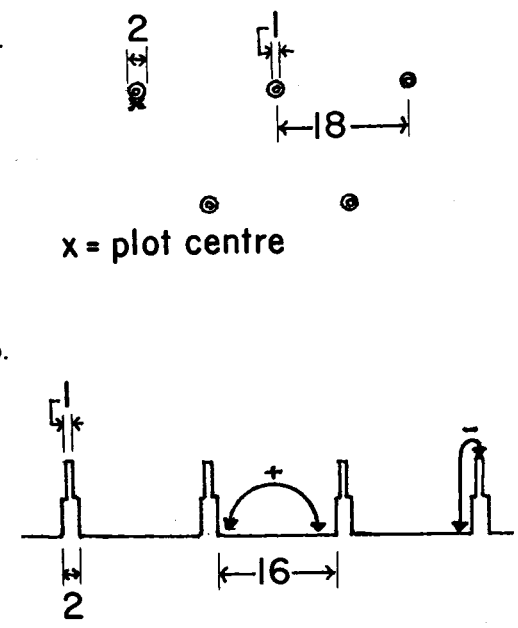
b.



a. An example of the landscape plan sampled as seen from above.
b. The values of a transect of the landscape in a. plotted as a function of distance. Distances marked are scaled to metres. The arrows connect pairs of positions on the landscape which are either positively or negatively correlated according to their distance apart. Moran's I (left) detects some of these correlations.

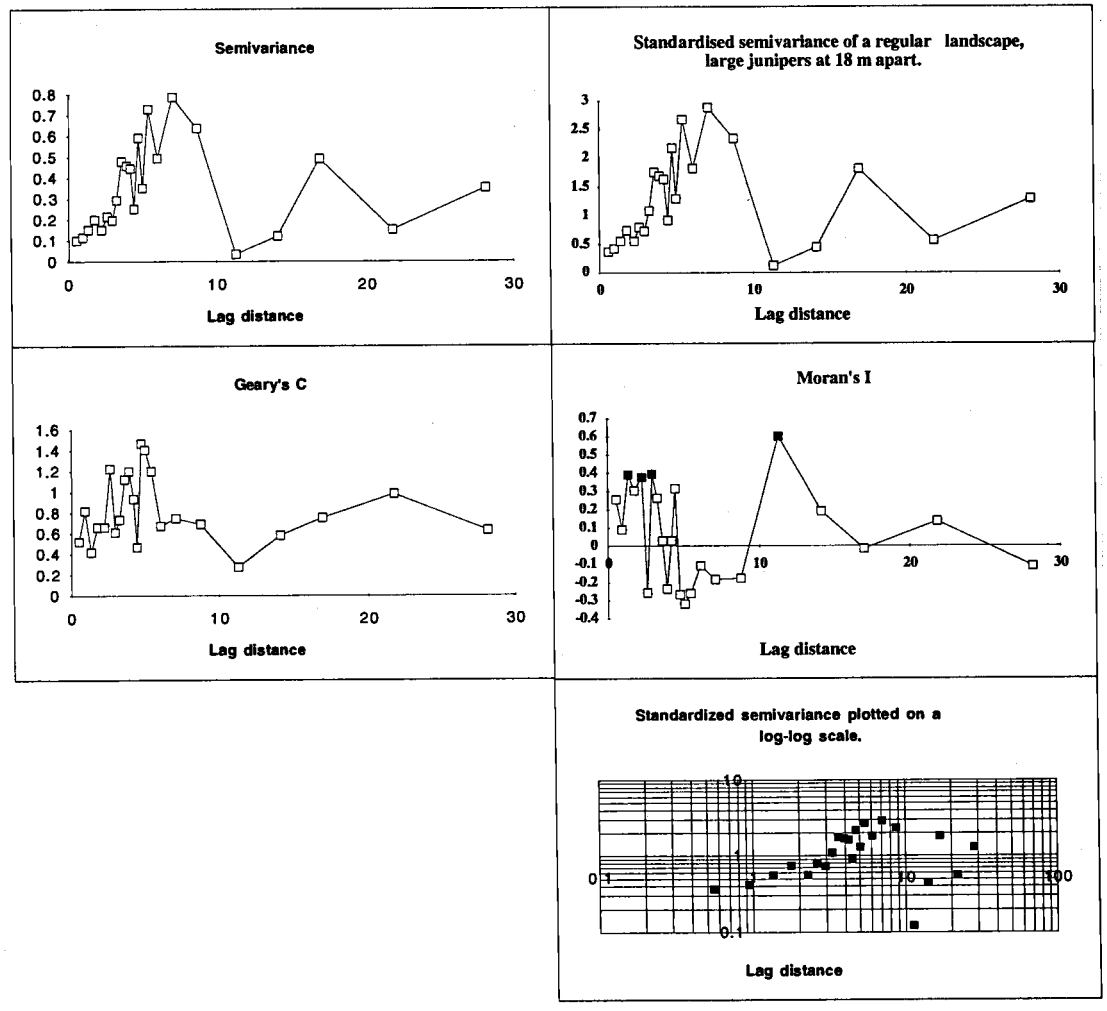
Figure 3.32. Simulated landscape with juniper at 10m apart, canopy diameter 5m and root crowns greater than 10 m, overlapping each other.

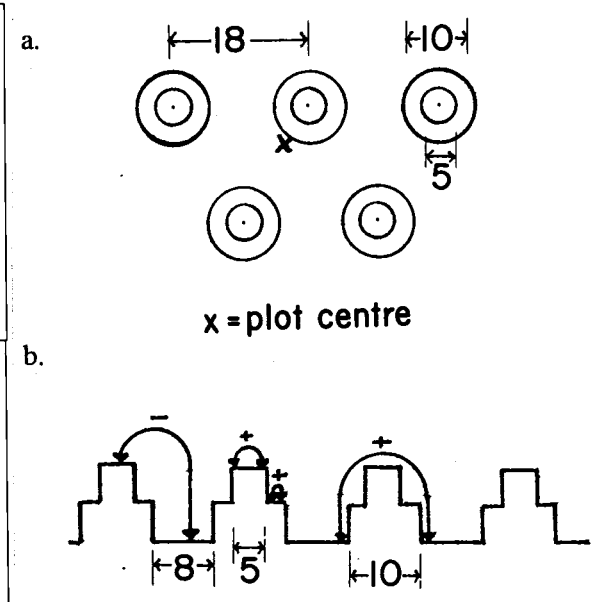




a. An example of the landscape plan sampled as seen from above.
b. The values of a transect of the landscape in a. plotted as a function of distance. Distances marked are scaled to metres. The arrows connect pairs of positions on the landscape which are either positively or negatively correlated according to their distance apart. Moran's I (left) detects some of these correlations.

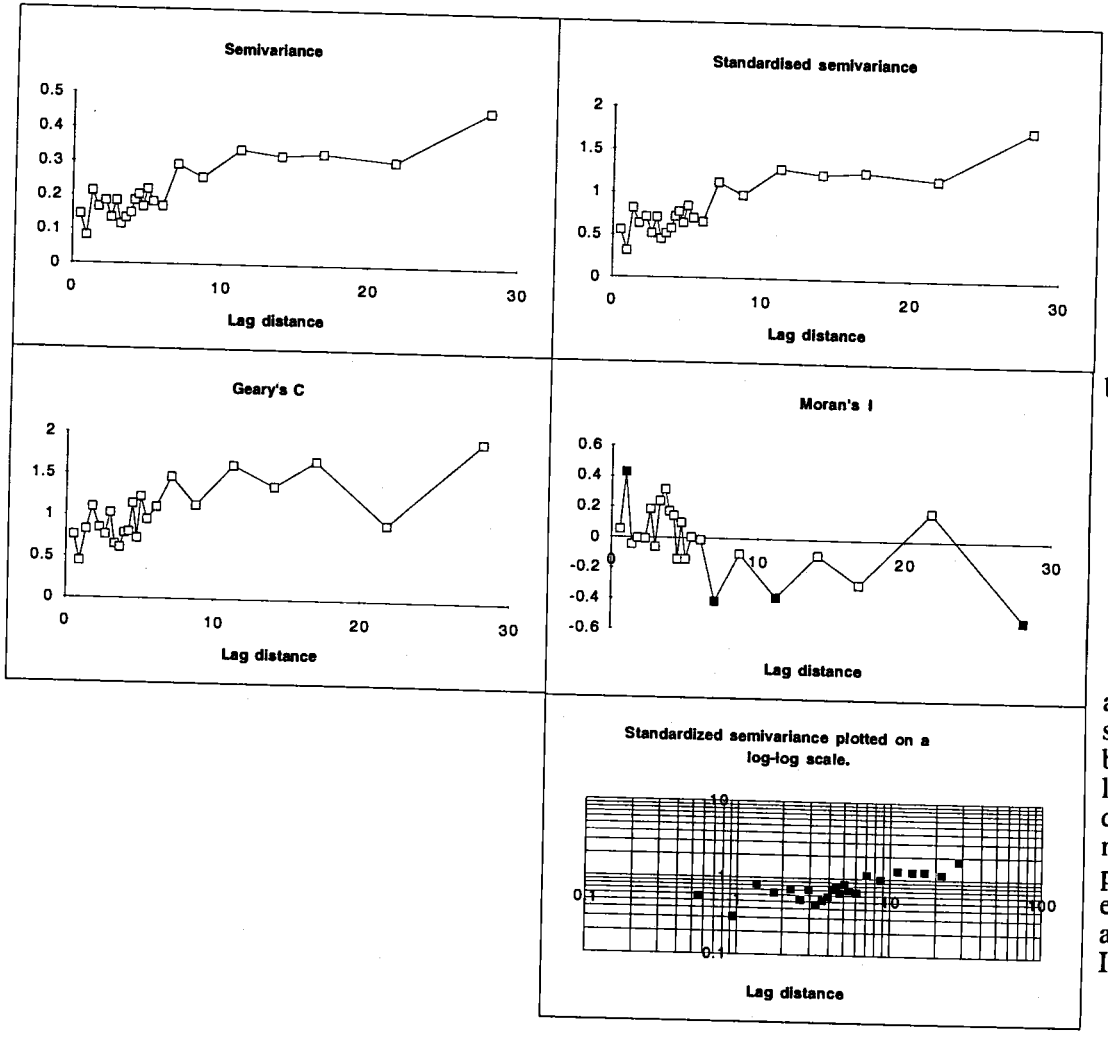
Figure 3.33. Simulated landscape with juniper at 18 m apart, canopy diameter 1 m and root crown 2 m.



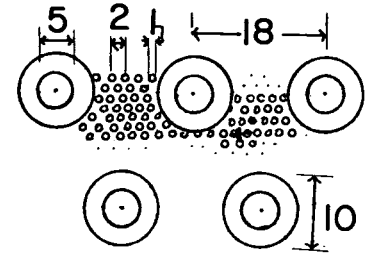


a. An example of the landscape plan sampled as seen from above.
b. The values of a transect of the landscape in a. plotted as a function of distance. Distances marked are scaled to metres. The arrows connect pairs of positions on the landscape which are either positively or negatively correlated according to their distance apart. Moran's I (left) detects some of these correlations.

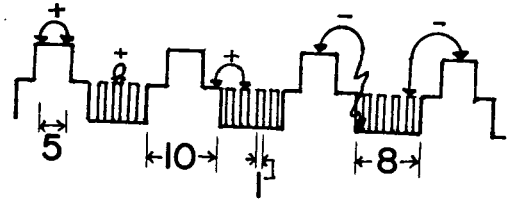
Figure 3.34. Simulated landscape with juniper at 18 m apart, canopy diameter 5 m and root crown 10 m.



a.



b.



a. An example of the landscape plan sampled as seen from above.
b. The values of a transect of the landscape in a. plotted as a function of distance. Distances marked are scaled to metres. The arrows connect pairs of positions on the landscape which are either positively or negatively correlated according to their distance apart. Moran's I (left) detects some of these correlations.

Figure 3.35. Simulated landscape with juniper at 18 m apart with canopy diameter 5 m and root crown 10 m, and sagebrush at 2 m apart with canopy diameter 1 m.

Table 3.1 Vegetation composition by community type.

	Sagebrush-grass		Juniper-sagebrush-grass	
	Number of samples	Percentage of total	Number of samples	Percentage of total
Bare ground	34	34	42	47
Grass	39	39	27	30
Sagebrush	27	27	16	18
Juniper	0	0	5	6
Total	100		90	

Table 3.2. Means, standard deviations and replication error as a percentage of the grand mean for December data.

	Mean measured values		Replication error		
Soil property	Grand December mean	C.V.	Mean	S.D. of mean	Replicate error as a % of mean
Moisture (% of oven dry soil)	18.48	0.26	1.49	2.27	8.06
pH	6.44	0.04	0.084	0.099	1.24
Initial N as NH4 (μg/gm oven dry soil)	1.26	5.44	0.12	0.16	9.52
Initial N as NO3 (μg/gm oven dry soil)	1.79	1.02	0.20	0.29	11.12
Incubated N as NH4 (μg/gm oven dry soil)	1.18	5.36	0.23	0.40	19.49
Incubated N as NO3 (μg/gm oven dry soil)	7.67	0.69	0.17	0.26	2.22
V.A. mycorrhizae (% infection)	35.1	0.39	4.85	2.23	13.81

Table 3.3. Matrices of significant (α = 0.05) Spearman Rank correlations and Bonferroni probabilities of untransformed data, (significances of $0.05 < p < 0.1$ are in brackets.)

Variable		Initial N as NH4		Initial N as NO3		Net N mineralized to NH4		Net N mineralised to NO3	
		Dec	May	Dec	May	Dec	May	Dec	May
Initial N as NO3	R 2 p	0.59 0.00002	0.65 0.00000						
Initial N as NH4	R^2 p								
Net N mineralized to NO3	R 2 p	(0.41 0.0983)	0.75 0.00000	0.62 0.00000	0.51 0.00000		-0.64 0.00000		
Net N mineralized to NH4	R^2 p		-0.93 0.00000		-0.62 0.00000				
Net N mineralized	R^2 p		0.46 0.00003	0.50 0.00212				0.92 0.00000	0.83 0.00000

Table 3.4. Matrices of significant ($\alpha = 0.05$) Pearson correlations and Bonferroni probabilities of log-normalized and normal data, (significances of $0.05 < p < 0.1$ are in brackets.)

Variable		Log initial N as NH4		Log initial N as NO3		Log net N mineralized to NH4		Log net N mineralised to NO3-	
		Dec	May	Dec	May	Dec	May	Dec	May
Log initial N as NO3	R 2 p	0.56 0.00006	0.66 0.00000						
Log net N mineralized to NO3	R 2 p		0.72 0.00000	0.58 0.00001	0.46 0.00002		-0.47 0.00001		
Log net N mineralized to NH4	R^2 p	-0.45 0.01326	-0.77 0.00000		-0.50 0.00000				
Log net N mineralized	R^2 p				0.66 0.00000	0.59 0.00001	0.36 0.00841	0.85 0.00000	0.66 0.00000

Table 3.5 Matrices of significant (α = 0.05) Spearman Rank correlations and Bonferroni probabilities of untransformed data, continued (significances of $0.05 < p < 0.1$ are in brackets).

Variable		Numbers of soil arthropods		Numbers of fungivores		Numbers of predators		Biomass of springtails	
		Dec	May	Dec	May	Dec	May	Dec	May
Numbers of springtails	R^2 p							0.97 0.00000	0.81 0.00000
Numbers of fungivores	R^2 p	0.97 0.00000	0.88 0.00000						
Numbers of predators	R^2 p	0.74 0.00000	0.49 0.00000	0.71 0.00000	0.33 0.04334				
Total biomass of arthropods	R^2 p	0.74 0.00000	0.52 0.00000	0.72 0.00000	0.51 0.00000	0.68 0.00000	0.44 0.00016		
Total biomass of fungivores	R^2 p	0.67 0.00000	0.53 0.00000	0.64 0.00000	0.61 0.00000	0.58 0.00003			
Biomass of microarthropods	R^2 p	0.87 0.00000	0.68 0.00000	0.83 0.00000	0.63 0.00000	0.80 0.00000	0.57 0.00000		
Biomass of microfungivores	R^2 p	0.86 0.00000	0.62 0.00000	0.86 0.00000	0.68 0.00000	0.73 0.00000			
Biomass of micropredators	R^2 p		0.43 0.00000	0.67 0.00000	(0.33 0.0671)	0.96 0.00000	0.83 0.00000		

Table 3.6 Matrices of significant ($\alpha = 0.05$) Spearman Rank correlations and Bonferroni probabilities of untransformed data, continued (significances of $0.05 < p < 0.1$ are in brackets.)

Variable		Total biomass of arthropods		Total biomass of fungivores		Biomass of microarthropods	
		Dec	May	Dec	May	Dec	May
Total biomass of fungivores	R^2 p	0.89 0.00000	0.77 0.00000				
Biomass of microarthropods	R^2 p	0.81 0.00000	0.57 0.00000	0.73 0.00000	0.54 0.00000		
Biomass of microfungivores	R^2 p	0.77 0.00000	0.47 0.00000	0.74 0.00000	0.66 0.00000	0.91 0.00000	0.80 0.00000
Biomass of micropredators	R^2 p	0.64 0.00000	0.41 0.00000	0.56 0.00007		0.79 0.00000	0.68 0.00000

Table 3.7. Matrices of significant ($\alpha = 0.05$) Pearson correlations and Bonferroni probabilities of log-normalized and normal data, continued (significances of $0.05 < p < 0.1$ are in brackets.)

Variable		Log numbers of soil arthropods		Log total biomass of arthropods		Log total biomass of fungivores		Log biomass of microfungivores
		Dec	May	Dec	May	Dec	May	Dec
Log total biomass of arthropods	R^2 p	0.77 0.00000	0.55 0.00000					
Log total biomass of fungivores	R^2 p	0.75 0.00000	0.53 0.00000	0.90 0.00000	0.76 0.00000			
Log biomass of microfungivores	R^2 p	0.89 0.00000	0.64 0.00000	0.80 0.00000	0.50 0.00000	0.81 0.00000	0.63 0.00000	
Log biomass of micropredators	R^2 p	0.63 0.00000	0.48 0.00000	0.61 0.00000	0.42 0.00025	0.58 0.00002		0.61 0.00000

Table 3.8. Matrices of significant (α = 0.05) Spearman Rank correlations and Bonferroni probabilities of untransformed data, continued (significances of $0.05 < p < 0.1$ are in brackets.)

Variable		Vegetation cover		Moisture		PH
		Dec	May	Dec	May	May
VA	R^2 p				0.35 0.0187	
PH	R^2 p				0.37 0.00731	
Initial N as NH4	R^2 p					-0.46 0.00003
Net N mineralized to NO3	R 2 p		0.47 0.00001	0.74 0.00000		-0.52 0.00000
Net N mineralized to NH4	R^2 p				(0.32 0.09545)	0.42 0.00056
Net N mineralized	R^2 p		0.42 0.00033	0.75 0.00000		-0.48 0.00001
Numbers of soil arthropods	R^2 p	0.53 0.00038	(0.33 0.0646)			
Numbers of fungivores	R^2 p	0.50 0.00166	0.33 0.04418		0.35 0.0205	
Numbers of predators	R^2 p	0.49 0.0041				
Total biomass of arthropods	R^2 p	0.45 0.01655				
Total biomass of fungivores	R^2 p	(0.41 0.0779)				
Biomass of microarthropods	R^2 p	0.54 0.00034				
Biomass of microfungivores	R^2 p	0.50 0.0017				
Biomass of micropredators	R^2 p	0.45 0.01749				

Table 3.9 Matrices of significant (α = 0.05) Pearson correlations and Bonferroni probabilities of log-normalized and normal data, continued (significances of $0.05 < p < 0.1$ are in brackets.)

Variable		Community type		Vegetation cover		Log Moisture		Log PH
		Dec	May	Dec	May	Dec	May	Dec
VA	R^2 p						0.32 0.04837	
Log PH	R^2 p						0.33 0.03314	
Log initial N as NO3	R 2 p							-0.45 0.01165
Log net N mineralized to NO3	R 2 p				0.41 0.00038	0.67 0.00000		-0.48 0.00335
Log net N mineralized	R^2 p					0.71 0.00000		
Log total numbers of soil arthropods	R^2 p			(0.40 0.0698)	0.34 0.02242		0.34 0.02104	
Log total biomass of arthropods	R^2 p	-0.44 0.01907						
Log biomass of microfungivores	R^2 p			(0.40 0.0774)			(0.31 0.0932)	

Table 3.10. Means, standard deviations, and coefficients of variation, by plot, for sagebrush-grass and juniper-sagebrush-grass community types. Plots a,b,c and f were sampled in December, plot b was the incompletely sampled plot with 22 samples taken. Plots g,h,i,j,k and l were sampled in May. When N < 52, outliers have been removed from the dataset. ODS = oven dried soil.

	Sagebrush-grass					Juniper-sagebrush-grass				
Soil property	plot	N	Mean	S.D.	C.V.	plot	N	Mean	S.D.	C.V.
Moisture % ODS	a	52	16.89	3.234	0.192	b	22	17.00	4.386	0.258
	c	52	19.04	3.083	0.162	f	50	20.175	6.260	0.310
	h	52	2.485	0.574	0.231	g	52	2.994	0.888	0.296
	j	52	2.453	0.463	0.189	i	50	1.919	0.708	0.369
	l	52	2.617	0.710	0.271	k	52	2.055	0.585	0.285
PH	a	52	6.315	0.289	0.046	b	22	6.691	0.258	0.039
	c	52	6.446	0.248	0.039	f	51	6.451	0.225	0.035
	h	52	6.398	0.224	0.035	g	52	6.385	0.252	0.039
	j	52	6.340	0.232	0.037	i	52	6.317	0.196	0.031
	l	52	6.525	0.228	0.035	k	52	6.337	0.223	0.035
% V.A. mycorrhizal infection	a	52	30.58	10.14	0.332	b	22	41.05	14.26	0.348
	c	52	29.51	11.97	0.405	f	52	42.79	14.44	0.337
	h	52	40.85	16.90	0.414	g	52	41.63	13.54	0.325
	j	52	38.52	13.80	0.358	i	52	35.15	14.28	0.406
	l	52	37.85	21.09	0.557	k	52	38.38	13.50	0.352
Initial N as NH4 μg/gm ODS	a	52	1.079	2.383	2.208	b	22	0.783	1.882	2.404
	c	52	0.307	0.503	1.683	f	50	0.608	1.306	2.147
	h	52	2.438	2.453	1.006	g	52	1.541	2.892	1.876
	j	52	3.510	5.287	1.506	i	52	4.322	9.780	2.263
	l	52	1.377	2.045	1.485	k	52	2.010	1.868	0.929
Initial N as NO3 μg/gm ODS	a	52	1.836	1.382	0.753	b	22	1.299	1.928	1.484
	c	52	1.778	0.956	0.538	f	50	1.412	1.295	0.917
	h	52	0.837	1.338	1.599	g	52	0.595	0.302	0.507
	j	52	0.548	0.332	0.605	i	52	0.653	1.555	2.381
	l	52	0.502	0.409	0.816	k	52	0.427	0.242	0.566
Mineralized N as NH4 μg/gm ODS	a	52	-0.391	2.416	-6.177	b	22	-0.352	1.521	-4.319
	c	52	0.183	0.606	3.304	f	50	0.541	2.500	4.617
	h	52	-1.434	3.356	-2.340	g	52	-0.518	3.047	-5.885
	j	52	-2.565	5.430	-2.117	i	52	-3.132	9.048	-2.889
	l	52	-0.583	2.165	-3.716	k	52	-0.777	2.547	-3.279
Mineralized N as NO3 μg/gm ODS	a	52	6.961	4.472	0.642	b	22	3.002	2.108	0.702
	c	52	6.863	4.896	0.713	f	50	5.243	4.853	0.926
	h	51	6.427	4.177	0.650	g	52	8.462	4.914	0.581
	j	52	10.966	5.205	0.475	i	52	8.890	6.781	0.763
	l	52	7.640	4.529	0.593	k	52	9.090	4.590	0.505
Net N mineralized μg/gm ODS	a	52	6.570	4.276	0.651	b	22	2.650	2.697	1.018
	c	52	7.046	4.768	0.677	f	50	5.785	6.152	1.063
	h	52	4.763	3.804	0.799	g	52	7.944	4.506	0.567
	j	52	8.401	5.571	0.663	i	52	5.758	10.426	1.811
	l	52	7.058	3.771	0.534	k	52	8.313	4.067	0.489

Table 3.11. Means, standard deviations, and coefficients of variation, by plot, for sagebrush-grass and juniper-sagebrush-grass community types. Plots a,b,c and f were sampled in December, plot b was the incompletely sampled plot with 22 samples taken. Plots g,h,i,j,k and l were sampled in May. When N < 52, outliers have been removed from the dataset. Biomass units are μg/sample.

	Sagebrush-grass					Juniper-sagebrush-grass				
Soil property	plot	N	Mean	S.D.	C.V.	plot	N	Mean	S.D.	C.V.
Total numbers of arthropods	**a**	52	65.25	67.38	1.033	**b**	22	62.95	41.99	0.667
	c	52	75.15	65.77	0.875	**f**	52	74.0	76.22	1.030
	h	52	3.38	4.50	1.329	g	52	3.40	5.09	1.495
	j	52	6.46	9.93	1.536	i	52	2.56	2.65	1.034
	l	52	2.73	3.53	1.293	k	52	4.19	6.49	1.55
Numbers of fungivores	**a**	52	50.65	44.68	0.882	**b**	22	38.09	25.39	0.666
	c	52	55.87	43.87	0.79	**f**	52	49.67	51.02	1.027
	h	52	2.67	4.14	1.55	g	52	2.77	4.15	1.500
	j	52	5.21	7.91	1.52	i	52	1.94	2.37	1.221
	l	52	2.13	2.88	1.35	k	52	2.79	4.65	1.669
Numbers of predators	**a**	52	2.44	2.52	1.03	**b**	22	2.59	3.13	1.207
	c	52	3.71	5.36	1.443	**f**	52	2.98	4.19	1.407
	h	52	0.37	0.95	2.601	g	52	0.42	1.32	3.117
	j	52	1.19	2.41	2.021	i	52	0.33	0.65	1.983
	l	52	0.38	0.84	2.194	k	52	0.96	3.13	3.256
Total biomass (μg)	**a**	52	8085.6	30075.8	3.720	**b**	22	3070.5	2653.6	0.864
	c	52	4995.3	6727.6	1.347	**f**	52	3877.4	5580.3	1.439
	h	52	233.52	430.52	1.844	g	52	396.27	1099.1	2.774
	j	52	531.5	690.84	1.300	i	52	336.23	851.61	2.533
	l	52	329.56	518.02	1.572	k	52	651.75	1055.8	1.620
Biomass micro-arthropods (μg)	**a**	52	946.83	1054.4	1.114	**b**	22	1254.68	1167.45	0.93
	c	52	1477.8	3563.3	2.411	**f**	52	1204.8	1459.7	1.212
	h	52	56.11	130.94	2.333	g	52	73.98	152.38	2.060
	j	52	112.94	218.16	1.932	i	52	17.58	26.67	1.517
	l	52	35.40	65.18	1.841	k	52	115.33	350.51	3.039
Biomass of micro-fungivors (μg)	**a**	52	584.44	740.02	1.266	**b**	22	884.50	972.97	1.100
	c	52	619.12	728.92	1.177	**f**	52	850.87	1175.81	1.382
	h	52	29.85	92.48	3.099	g	52	54.50	125.79	2.308
	j	52	70.02	176.04	2.514	i	52	9.77	13.92	1.425
	l	52	17.29	47.23	2.732	k	52	56.08	157.28	2.805
Biomass of micro-predators (μg)	**a**	52	194.27	195.03	1.004	**b**	22	193.14	247.61	1.282
	c	52	269.21	370.22	1.375	**f**	52	218.17	300.82	1.379
	h	52	25.00	77.52	3.101	g	52	19.19	55.77	2.906
	j	52	40.33	92.53	2.295	i	52	6.63	19.12	2.881
	l	52	17.10	39.89	2.333	k	52	59.19	319.19	5.392

Tables of significant ANOVAs and probabilities of differences of means.
Table 3.12. Differences between the juniper-sagebrush-grass and the sagebrush-grass communities.

Variable		Sagebrush-grass	Juniper-sagebrush-grass	Probability
Moisture, May	Mean* ± 1 S.E.	2.56 (2.66 - 2.46)	2.25 (2.16 - 2.33)	0.01711
VAM	Mean ± 1 S.E.	35.25 ± 1.47	40.06 ± 1.86	0.044
Total number of soil arthropods	Mean* ± 1 S.E.	16.29 (14.49 - 18.30)	8.49 (7.25 - 9.91)	0.001
Total biomass of soil arthropods	Mean* ± 1 S.E.	458.4 (360.4 - 583.1)	148.9 (108.9 - 204.4)	0.005
Total biomass of fungivores	Mean* ± 1 S.E.	173.2 (137.4 - 218.2)	80.5 (60.9 - 107.9)	0.039
Biomass of microfungivores	Mean* ± 1 S.E.	68.4 (55.8 - 83.8)	31.5 (24.3 - 40.7)	0.017
Biomass of micropredators	Mean* ± 1 S.E.	20.33 (16.12 - 25.58)	9.91 (7.25 - 14.44)	0.064

* Means and ranges of ± standard error are back-transformed from the means and S.E. of the log transformed datasets.

Tables of significant ANOVAs and probabilities of differences of means.
Table 3.13. Differences between December and May.

Variable		December	May	Probability
Moisture	Mean* ± 1 S.E.	17.46 (16.79 - 18.12)	2.40 (2.34 - 2.46)	0.000
PH	Mean* ± 1 S.E.	6.49 (6.45 - 6.53)	6.36 (6.33 - 6.39)	0.031
Total number of soil arthropods	Mean* ± 1 S.E.	41.95 (36.34 - 48.4)	2.82 (2.47 - 3.20)	0.000
Total Biomass of soil arthropods	Mean* ± 1 S.E.	1311.9 (952.4 - 1807.0)	51.5 (41.1 - 65.4)	0.000
Total biomass of fungivores	Mean* ± 1 S.E.	719.5 (532.8 - 971.6)	18.9 (15.3 - 24.3)	0.000
Biomass of microfungivores	Mean* ± 1 S.E.	251.1 (193.4 - 326.0)	7.94 (6.46 - 9.70)	0.000
Biomass of micropredators	Mean* ± 1 S.E.	65.69 (48.40 - 89.01)	2.49 (1.86 - 3.26)	0.000
Nitrogen as initial NH4	Mean* ± 1 S.E.	0.52 (0.38 - 0.68)	1.66 (1.51 - 1.83)	0.000
Nitrogen mineralized to NH4	Mean* ± 1 S.E.	0.48 (-0.12 - -1.09)	-1.51 (-1.90 - -1.11)	0.006
Nitrogen as initial NO3	Mean* ± 1 S.E.	1.69 (1.56 - 1.83)	0.53 (0.48 - 0.60)	0.000
Nitrogen mineralized to NO3	Mean* ± 1 S.E.	6.06 (5.32 - 6.80)	9.95 (9.51 - 10.39)	0.000
Net nitrogen mineralized	Mean* ± 1 S.E.	6.38 (5.64 - 7.13)	8.20 (7.66 - 8.74)	0.043

*Means and ranges of ± standard error are back-transformed from the means and S.E. of the log transformed datasets.

Tables of significant ANOVAs and probabilities of differences of means.

Table 3.14. Significant interactions between season and community type.

Variable		Sagebrush-grass		Juniper-sagebrush-grass		Probability
		December	May	December	May	
Total Biomass of soil arthropods	Mean* ± 1 S.E.	3427.9 (2343.9 - 5013.1)	59.9 (43.7 - 82.10)	501.7 (294.9 - 853.1)	44.2 (32.1 - 60.5)	0.039
Nitrogen as initial NH4	Mean* ± 1 S.E.	0.26 (0.13 - 0.40)	1.72 (1.48 - 1.97)	0.86 (0.77 - 0.99)	1.61 (1.39 - 1.86)	0.066

* Means and ranges of ± standard error are back-transformed from the means and S.E. of the log transformed datasets.

Table 3.15. Means and significant differences of variables by vegetation cover; b = bare, g = grasses, s = sagebrush, j = juniper. Means followed by the same letter for any variable and season are not significantly different from one another using Tukeys difference of means test and α + 0.5. Log normalized variables have the means back transformed. ODS = oven dried soil. Biomass units are μg/sample.

Variable	Vegn. cover	December means		May means	
Moisture	b	16.4	*a*	2.30	*a*
μg/g ODS	g	18.3	*a*	2.17	*a*
	s	16.2	*a*	2.76	*b*
	j	15.4	*a*	2.91	*ab*
PH	b	6.4	*a*	6.4	*a*
	g	6.3	*a*	6.3	*b*
	s	6.6	*b*	6.4	*a*
	j	6.8	*b*	6.4	*ab*
VAM	b	32	*a*	35	*a*
infection	g	34	*a*	42	*bc*
	s	38	*ab*	43	*bc*
	j	45	*b*	37	*ac*
Initial N as	b	0.25	*a*	1.30	*a*
NH4	g	0.60	*a*	2.05	*b*
μg/g ODS	s	0.37	*a*	1.69	*b*
	j	0.86	*a*	2.73	*b*
Initial N as	b	1.11	*a*	0.48	*a*
NO3	g	1.61	*b*	0.43	*a*
μg/g ODS	s	1.92	*b*	0.68	*b*
	j	1.58	*ab*	0.93	*ab*
Mineralized	b	0.18	*a*	-1.70	*a*
N as NH4	g	-0.52	*a*	-2.09	*a*
μg/g ODS	s	-0.02	*a*	-0.71	*a*
	j	0.08	*a*	-1.70	*a*
Mineralized	b	3.75	*a*	7.13	*ac*
N as NO3	g	8.20	*b*	10.17	*bc*
μg/g ODS	s	6.17	*c*	11.61	*b*
	j	3.75	*ac*	5.95	*ac*
Net N	b	4.06	*a*	6.17	*a*
mineralized	g	7.77	*b*	8.20	*ab*
μg/g ODS	s	6.17	*ab*	10.06	*b*
	j	4.38	*a*	6.80	*ab*
N for means		December		May	
listed above		All		VAM	Other
	b	66		150	152
	g	66		111	112
	s	30		41	43
	j	16		5	5

Variable	Vegn. cover	December means		May means	
Total	b	23.7	*a*	1.23	*a*
numbers	g	58.3	*b*	2.97	*b*
of soil	s	88.8	*b*	3.56	*b*
arthropods	j	65.6	*b*	2.73	*ab*
Numbers	b	1.14	*a*	0.03	*a*
of	g	2.79	*b*	0.04	*a*
springtails	s	5.11	*b*	0.02	*a*
	j	2.67	*ab*	0.0	*a*
Numbers	b	18.4	*a*	0.93	*a*
of	g	41.3	*b*	2.21	*b*
fungivores	s	61.4	*b*	2.88	*b*
	j	43.9	*b*	2.24	*ab*
Numbers	b	0.89	*a*	0.17	*a*
of	g	2.20	*b*	0.50	*b*
predators	s	3.92	*c*	0.42	*ab*
	j	2.27	*bc*	0.32	*ab*
Total	b	606	*a*	16.6	*a*
biomass of	g	2539	*b*	68.4	*b*
soil	s	3747	*b*	51.4	*b*
arthropods	j	2129	*b*	8.0	*ab*
Biomass of	b	225	*a*	3.8	*a*
micro-	g	773	*b*	15.4	*b*
arthropods	s	1258	*b*	14.2	*b*
	j	995	*b*	8.0	*ab*
Biomass of	b	6.6	*a*	0.12	*a*
springtails	g	25.3	*b*	0.20	*a*
	s	48.5	*b*	0.06	*a*
	j	24.0	*ab*	0.0	*a*
Biomass of	b	112	*a*	2.26	*a*
micro-	g	399	*b*	8.38	*b*
fungivores	s	672	*b*	9.10	*b*
	j	759	*b*	5.86	*ab*
Biomass of	b	19.6	*a*	0.72	*a*
micro-	g	79.6	*b*	2.55	*b*
predators	s	143.7	*b*	2.47	*b*
	j	62.8	*ab*	2.95	*b*

Table 3.16. Effects of removal of one or two data points on the significant Moran's I correlations. As some correlograms lost original significant correlations, gained new ones, and retained some unchanged, they are represented in more than one category below, thus the proportions stated in each category relate to all (100%) of the in range or the out of range cases.

	In range (20 cases)	Out of range (31 cases)
Proportion of Moran's I correlograms losing one or more significant correlations.	70%	84%
Proportion of Moran's I correlograms gaining one or more significant correlations.	45%	55%
Proportion of Moran's I correlograms having one or more significant correlations unchanged.	65%	65%
Proportion of Moran's I correlograms showing a net loss of significant correlations.	30%	68%
Proportion of Moran's I correlograms showing a net gain of significant correlations.	15%	3%

Table 3.17 Maximum standardised semivariance occurring between distance lags of 0 to 30 m, and the distance lag in metres at which it was detected.

		Sagebrush-grass					Juniper-sagebrush-grass			
		December		May			December	May		
Variable	Plot	a	c	h	j	l	f	g	i	k
Moisture	Max sv	3.0	2.1	2.7	1.5	1.9	2.5	2.3	1.0	3.0
	distance m	14.9	6.9	16.9	16.9	10.7	21.2	13.9	8.3	2.0
PH	Max sv	2.0	1.7	1.7	2.1	2.7	2.4	1.4	1.9	2.2
	distance m	28.0	26.5	11.3	13.5	15.1	18.1	2.9	3.6	26.1
V.A. mycorrhizae	Max sv	1.2	1.6	1.4	1.9	2.0	1.6	1.6	2.7	1.9
	distance m	2.5	5.9	1.4	0.5	4.4	15.9	9.9	11.6	2.4
Initial N as NH4	Max sv	2.7	3.1	4.2	1.5	3.3	12.1	4.3	1.5	4.0
	distance m	4.8	3.9	11.3	22.7	3.2	15.9	3.8	22.2	27.3
Initial N as NO3	Max sv	2.2	2.0	2.5	2.7	2.7	9.5	2.0	1.6	2.9
	distance m	13.5	26.5	28.1	13.5	3.2	15.8	2.9	22.2	29.6
Mineralized N as NH4	Max sv	2.7	2.9	2.9	1.5	2.9	2.9	3.9	1.5	2.4
	distance m	4.8	3.6	11.3	22.7	3.2	6.0	3.8	22.2	2.0
Mineralized N as NO3	Max sv	3.1	2.4	2.4	1.4	2.0	1.8	2.0	2.1	2.3
	distance m	14.9	3.9	11.3	1.8	2.9	25.7	2.9	16.2	29.6
Net N mineralized	Max sv	3.9	2.1	1.8	1.4	1.8	2.1	1.5	2.0	2.2
	distance m	14.9	3.9	14.1	1.3	2.5	25.7	5.3	22.2	26.1
Total arthropod numbers	Max sv	2.4	2.7	2.4	3.8	5.8	2.1	1.9	3.8	2.3
	distance m	7.2	28.7	16.9	13.5	10.7	7.1	15.6	11.6	3.1
Biomass of microarthropods	Max sv	2.7	10.2	4.7	1.9	4.0	2.3	3.9	1.5	5.7
	distance m	13.5	26.5	16.9	0.5	25.5	7.1	13.9	0.5	2.0

Table 3.18. Estimated ranges of spatially dependent data from the standardised semivariance occurring between distance lags of 0 to 30 m, and the approximate lag distance in metres at which it was detected. Ranges in brackets were less distinct than other ranges, but mark an apparent summit of a step formation in the semivariance.

		Sagebrush-grass					Juniper-sagebrush-grass			
		December		May			December	May		
Variable	Plot	a	c	h	j	l	f	g	i	k
Moisture	Range m	1-2; 15	7	3; 17	2-3; 14-16	2; 10	7; 22	1.5; 12-14	1.5; 8-9	2
PH	Range m	3; 25-30	25-27	3; 11	4; 13	2; 11-13	(3); 18	3; (7-8)*	4; (20)	3-4; 25-27
V.A. mycorrhizae	Range m	2.5	(3); 6	1.5; (8)*; 9-11	(11); 27-30	4-5	2; 15-16	1.5; 10-15	(6)*; 9-12	(2-3)
Initial N as NH4	Range m	(2); 5	4	2.5; 11	(0.5); (2-3)*	3; 15	1.5; 28	4	7	3; 27-29
Initial N as NO3	Range m	(4-6); 14	4.5; 27	3-4; 28	6*; 13	2-3	3; 6-10	3	27	(2); 27-30
Mineralized N as NH4	Range m	2.5; 5	3-4	2; 11	(0.5); (3)*; 5	3; 15	3; 6; 28	3-4	(2); 7	2; 27-30
Mineralized N as NO3	Range m	15	4	11	2; 7*	2-3	6-10; 26	3	7; 16-17	3; 27-30
Net N mineralized	Range m	(2); 15	3-4	5; 14	(6)*	2-3	6; 28	3-5	(3); 16-17	2; 26
Total arthropod numbers	Range m	(4); 7	3; 28-30	1; 4; 17	(1); 13	2; 11	3-7	4; 16	(1.5); (5); 12	2
Biomass of microarthropods	Range m	3-4; 14	6; 23-25; 30	1; 17	5*; 13	2; 11; 25	(3); 6-7	3; 14	0.5-1.5; 5-12	2-3; (27)

* denotes the range at which a negative slope changes towards zero or positive, and occurs with a high nugget variance.

Table 3.19. Distance lags of significant Moran's I at 0 - 2 m.

		Sagebrush-grass					Juniper-sagebrush-grass			
		December		May			December	May		
Variable	Plot	a	c	h	j	l	f	g	i	k
	Moran's I	+ -	+ -	+ -	+ -	+ -	+ -	+ -	+ -	+ -
Moisture						0.5, 0.9	0.6, 1.0, 1.4		0.6, 1.0	
PH		*1.3*		*1.8*						
V.A. mycorrhizae				*1.4*				0.5		
Initial N as NH4		0.5		0.6 *1.8*				0.5, 1.0	0.6	
Initial N as NO3		0.9		0.6, 0.9		0.5			0.6, 1.0, 1.5	
Mineralized N as NH4		0.5, *1.7* 1.3		1.4			*1.9*	0.5 *1.0*	0.6	*0.9*
Mineralized N as NO3		0.9			1.0		1.0	0.5, 1.0	0.6, 1.0, 1.5, 2.0	0.9
Net N mineralized						0.5, *2.0* 1.2			0.6, 1.0, 1.5, 2.0	
Total arthropod numbers		0.5	1.1,1 .4, 1.8			0.5, 0.9, 1.2		1.8		*1.4*
Biomass of microarthropods		0.5, 1.3, 1.7	0.6, 1.1, 1.4, 1.8			0.5		0.5, 1.0, 1.3, 1.8	1.5	

Table 3.20. Distance lags of significant Moran's I at 2 - 10 m.

		Sagebrush-grass										Juniper-sagebrush-grass							
		December				May						December		May					
Variable	Plot	a		c		h		j		l		f		g		i		k	
	Moran's I	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Moisture		2.2, 2.8	*7.2*	3.6	*4.6*	4.7						3.6, 3.9		9.9		2.3, 2.6	*8.3*	3.4	
PH				3.9, 4.6, 4.9, 9.1				*5.5*	*3.1*					3.8, 7.6		2.6		2.4	
V.A. mycorrhizae				6.9			*8.7*				*5.1*		*2.2*			8.3			
Initial N as NH4		3.7, 4.0, 6.2, 7.2	*3.4, 4.2, 4.5, 4.8*	3.6		3.3, 5.4, 8.7		8.8		2.5, 4.4	*3.8, 4.0*	3.3			*3.5*	2.6	*4.4, 6.9*	5.9	
Initial N as NO3		2.8, 3.4		6.9, 9.1	*4.6*	3.6, 5.4	*3.3*	5.5		4.4	*3.5*	3.9	*9.7*		*3.5*	2.6, 3.6, 4.2, 4.5		5.9	
Mineralized N as NH4		3.7, 4.0, 6.2, 7.2	*3.4, 4.2, 4.5, 4.8*		*3.6*	3.3		5.5		2.5, 4.4	*2.9*	3.3, 3.9, 4.8	*6.0*	2.6	*3.5, 5.8*	2.6, 3.2	*6.9*	2.4, 3.4, 5.9	
Mineralized N as NO3				3.6	*4.6*	8.7				4.4	*2.9*		*6.0*		*3.5*	2.3, 2.6, 2.9, 3.9, 4.2			
Net N mineralized		2.2, 2.8	*7.2, 9.6*	3.6	*4.6*					4.4				3.8	*3.5*	2.4, 2.6, 2.9, 4.2			
Total arthropod numbers		3.7	*3.4, 7.2,*			2.3, 6.1, 8.7		2.8, 3.5, 5.2		2.9, 3.2, 3.5, 3.8, 4.1	*8.8*		*2.6, 4.8*	2.6					
Biomass of microarthropods			*2.5, 4.0, 4.2, 7.2*	3.1		2.6, 3.9, 5.4, 6.1		5.2, 7.2		3.5, 3.8			*3.6, 4.8*			6.9		4.7	*2.6*

Table 3.21. Distance lags of significant Moran's I at 10 - 30 m.

		Sagebrush-grass										Juniper-sagebrush-grass							
		December				May						December		May					
Variable	Plot	a		c		h		j		l		f		g		i		k	
	Moran's I	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Moisture			*13.5, 14.9, 25*				*16.9*	10.8, 20.6	*13.5*	26.7, 28.0	*23.4*	27.6	*25.0*	27.3					
PH				13.0	*26.5, 28.7*			16.9					*8.1*						*27.3, 28.4*
V.A. mycorrhizae									*25.8*					17.8					
Initial N as NH4							*11.3*				*15.1*		*27.6*					26.1	*27.3, 28.4*
Initial N as NO3		21.2	*13.5*	22.2		14.1				23.4						11.6	*22.4*		*27.4*
Mineralized N as NH4							*11.3*				*15.1*		*25.7, 26.9*						*27.4*
Mineralized N as NO3		17.0, 25	*13.5, 14.9*				*11.3, 14.1*					26.9	*25.7*			29.9	*16.3, 19.9*		*27.4, 28.4*
Net N mineralized		17.0	*13.5, 14.9*			11.3	*14.1*						*27.3*			29.9	*16.3, 19.9, 27.5*		*26.1*
Total arthropod numbers			*14.9*	13.0, 15.4	*26.5, 28.7*	14.1	*16.9*	29.1	*13.5, 18.7, 20.6, 23.5*		*10.7, 12.7, 25.5*				*13.9*				
Biomass of microarthropods			*13.5, 17.0*	13.1		21.8			*13.5, 20.6*	20.0	*10.7, 23.4, 25.5, 28.0*					29.5			

4. DISCUSSION

All of the plots from The Island showed more structure than the random artificial landscapes but less than the regular artificial landscapes. Therefore the spatial patterns of soil properties on The Island show more structural organisation than a random system, but are not in a highly regular pattern (Figures 3.2. to 3.4.).

The spatial structures observed were related to the spacing of vegetation including grasses, sagebrush and possibly juniper. Ranges and spatial correlations shown by the data occurred at scales of approximately 0.5 - 2 m and 3 - 7 m. These lag distances were similar to the mean nearest neighbour distances between grass clumps (0.4 m) and sagebrush plants (2 to 2.5 m). No other landscape feature was observed at these scales that could account for the spatial structure seen in the data at lags below 10 m. Nearest neighbour distances between junipers ranged from 15 to 20 m, but spatial structure with lags between 10 - 17 m and over 18 m occurred in both community types. Spatial structure at these scales must be related to more factors than just vegetation because junipers were absent from the sagebrush-grass community.

Many plots showed structure at more than one scale, related to the presence of one or more vegetation types. Each vegetation type had a range of scales of pattern. Both grass and sagebrush grows in non-circular clumps of individuals, so nearest neighbour distances range from a minimum reflecting distances between individuals in a clump and a maximum, the distance between clumps (Figures 3.2,

3.3 and 3.4). Also there was some overlap in the scales and ranges of the three vegetation types. For example, aggregations of grass clumps were spaced at similar distances as sagebrush plants. This may explain why semivariograms and correlograms showed peaks ranging continuously from 0.5 to 5 m. Very few log-log semivariograms showed three distinct steps. Many appeared to show overlapping steps but these could not be teased apart to show if this phenomenon was real or not. Ranges were best seen at lag distances where there was no apparent overlap.

Dale and MacIsaac (1989) discuss the problem of the larger scales of aggegates overwhelming the smaller grain that makes up the aggregates, particularly if that smaller grain is not very intense. The three tiered sampling design used in this study was most efficient in detecting scales from 0.5 to 10 m within one locality in each plot. Efficiency was reduced for small scale data collection in the larger subplot, but by nesting the intensely sampled area within the larger, less intensely sampled subplot, information as to how well the inner subplot represented the whole plot was gained. Given the number of sampling points in each plot, detail and precision at the larger scales was sacrificed to improve understanding of the smaller scale mechanisms.

Fractal dimensions were not examined because the spatial patterns were not self similar and the variation was discontinuous. Fractals in these cases did not contribute to understanding of the structure and ecology of the two community types, except as a null hypothesis, the hypothesis of self similarity was rejected. Burrough (1983a) concluded that soil properties were not ideal fractals because their

semivariance does not always increase monotonically with increasing distance, but rather increases in a series of steps. A series of steps was found in the semivariograms in this study, some taking the form of a series of sinusoidal waves. Because the sizes of these steps differed between plots within community types, it was not possible to objectively subdivide the semivariogram and calculate a series of fractal dimensions as Burroughs (1983b) suggests. Attempts to do this produced nonsensical results. However, log-log semivariograms provided useful qualitative information about the ranges of distances over which self-similarity occurred, the number of steps, and the relative importance of short and long range variation.

In the same plots more than one property showed the same structure, suggesting that they were related to each other or to a third process such as vegetation. Moisture, pH and net nitrogen mineralized had fewer significant Moran's I autocorrelation coefficients in the 0 to 2 m ranges (the scale of grass clumps) than other soil properties, suggesting the spatial patterns of these properties related more to sagebrush than to grass. Spatial structures from Moran's I correlations especially at the 2 to 10 m lags, coincided for the microarthropod and the nitrogen fractions data in eight of the nine cases. These two properties had high variation and heteroskedasticity which precluded any significant regression correlations between them. However, with the concentric nested sampling design used in this study, coinciding spatial correlations within a plot imply that the two parameters not only vary at the same scales, but occupy the same patch. Spatial

analyses can therefore detect relationships which appear insignificant using parametric analyses.

Similar spatial structures for soil fauna and nitrogen fractions occur at the scales of grasses and sagebrush. In this site the root and litter zone of grass and sagebrush provide a moister site in summer with less temperature fluctuation (Pierson and Wight, 1991; personal observations) for soil fauna than bare ground, together with a food base of organic matter. Fungivorous and microbivorous soil fauna graze on the decomposer fungi and microbes and release the nitrogen immobilized in the microbial biomass. Santos et al (1981) showed that decomposition was reduced in the absence of soil mites, and Whitford (1986) found a correlation between fungal feeding tarsonemid mites and net mineralization in semi-arid ecosystems. On the Island I believe that the spatial analyses showed that patches of nitrogen mobilization were produced by patches of soil fauna under sagebrush and grass.

Long range variation was present in both vegetation types, thus not uniquely associated with junipers. Further study to determine the processes underlying these larger scale patch dynamics would be valuable in order to separate out the effects of widely spaced junipers from other landscape processes such as burn sites or underlying rock formations.

In the community with junipers, short range variation was higher than long range in more cases than in the sagebrush-grass community. Higher short to long range variation occurred in the artificial landscapes with a sparse pattern and high

contrast (greater heterogeneity) between patch and interpatch (Figures 3.34 and 3.35). In the real landscape the observations of vegetation distribution showed a sparser cover of sagebrush and grass in the juniper-sagebrush-grass community, and this was reflected in the increased heterogeneity at ranges below 10 m. Further experimental study is needed to determine if this heterogeneity is a cause or effect of the differences in vegetation cover, or is incidental to it.

This study indicates that the invasion of junipers in the sagebrush-grass system coincides with a reduction in mean summer soil moisture and microarthropods, a higher rate of VAM infection and more short range heterogeneity. This suggests the contrasting spatial patterns observed in the sagebrush-grass and the juniper-sagebrush-grass communities are functionally different. Increased summer moisture stress in the community with junipers may contribute to sparser grass and sagebrush cover, which in turn reduces the overall input of organic matter to the soil, and diminishing the availability of suitable habitat patches for soil fauna. A higher rate of VAM infection in systems with juniper may be a response to increased moisture stress or reduced grazing pressure from the smaller numbers of fungivorous soil fauna, or a combination of both. These results suggest that when junipers are added to sagebrush-grass systems there may be a shift in the mechanism of nutrient cycling from soil fauna comminution and saprophytic decompositional release of nutrients from litter followed by root uptake, towards a system more dependent upon the scavenging of available soil nutrients by VA mycorrhizae. Ho and Trappe (1975) showed that spores of two Glomus species

were capable of reducing nitrate in vitro, and suggested that this would improve symbiotic effectiveness in nitrogen assimilation and translocation to the host if it occurs in vivo.

The higher initial ammonium, lower initial nitrate followed by net de-ammonification, higher nitrification and higher net release of soluble N after moist incubation in May when compared with December soils is consistent with a buildup of organic matter during the dry season and a decomposition phase during the wetter winter.

The co-occurrence of moisture, pH, nitrogen fractions and micro-arthropods at similar ranges and with coincidental significant Moran's I correlations within a plot indicate a spatial relationship between these properties, whether or not the parametric statistics showed correlations, and whether or not the ANOVA's showed differences in their means between the two community types. The greater ratio of short to long range variation in the juniper-sagebrush-grass compared to sagebrush-grass systems, indicates that the spatial patterns of these soil properties differ between the two community types. There was little difference between ranges and average patch sizes between communities, so the increased short to long range ratio when junipers are present suggests more contrast between the patches. Areas change more abruptly from "high" to "low" values with less gradation between them in the communities with juniper than those without. Ecologically, a landscape with more heterogeneity would be expected to support plants more limited spatially by the patch

size of the resource than a landscape with a gradation between patches of high and low resource.

5. CONCLUSIONS

1. The patterns in the data were not random and were at scales relating to the distances apart of grass clumps, sagebrush individuals and sagebrush rings. Correlations at scales relating to sagebrush distribution were the most frequent.

2. More variation was found in the juniper-sagebrush-grass community than in the sagebrush-grass community.

3. The short to long range variation was higher more often in plots with junipers present.

4. Long range variation at scales above 18 m was present in both community types. Long range variation at these scales may not have been due to the same process in the two communities. Frequency of fires, age of the stand, localized soil depth and legacy effect of dead junipers are some possible causes of spatial variation at >18 m scales.

5. The higher short range variation together with the increase in bare ground result from smaller or more sparse sagebrush-grass vegetation in the juniper-sagebrush-grass, and explain the differences in distribution of soil fauna, which in general favour the grass and sagebrush more than bare ground or juniper.

6. Fewer soil fauna, lower soil moisture in summer, higher rates of VAM infection, lower N mineralization under junipers and different species of micro-arthropods making up the functional guilds in the community with junipers suggest differences in the nutrient cycling mechanism. An explanation would be a move away from soil faunal comminution of litter and saprophyte decomposition towards more direct scavenging of nutrients from soil by VAmycorrhizae.

7. Moisture, pH and net N mineralized showed fewer correlations in the 0-2 m ranges than other properties. Soil arthropods showed correlations at all scales, indicating that the former three properties were governed at scales more strongly relating to sagebrush than grasses, whereas the fauna related to all vegetation scales. VAM operated at scales below 0.5 m, and may be very tightly bound with the immediate rhizosphere.

8. In view of 7. above, the soil fauna, of which the majority were fungivores, rely more on fungal hyphae (saprophytes or VAM) penetrating the whole root zone and litter area beneath the plants than on the immediate rhizosphere VA hyphae.

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APPENDICES

APPENDIX A

PROGRAM FOR CALCULATING LAG DISTANCES, SEMIVARIOGRAMS, MORAN'S I AND GEARY'S C

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/*******************************************************
 * Filename:  DISTANCE.C
 *
 * Purpose:  This program was written for Julia Jones.  It
 *    converts polar coordinates to cartesian coordinates
 *    and creates an output file of distances from each point
 *    to every other point.
 *
 *    Each record in the input ASCII file must contain the
 *    value of interest, the azimuth, and the polar distance
 *    separated by a space(s) or a comma.  The input file
 *    may not contain more than 100 records.
 *
 *    Polar coordinates are converted to cartesian coordinates
 *    using the following algorithm:
 *
 *        if (azimuth >= 0 and <= 90) then
 *         new_val = (90. - azimuth) * parameter
 *         y = sin(new_val) * distance
 *         x = cos(new_val) * distance
 *      end if
 *
 *        if (azimuth > 90 and <= 180) then
 *           new_val = (180. - azimuth) * parameter
 *           y = cos(new_val) * -distance
 *           x = sin(new_val) * distance
 *        end if
 *
 *        if (azimuth > 180 and <= 270) then
 *           new_val = (270. - azimuth) * parameter
 *           y = sin(new_val) * -distance
 *           x = cos(new_val) * -distance
 *      end if
 *
 *      if (azimuth > 270 and <= 360) then
 *           new_val = (360. - azimuth) * parameter
 *         y = cos(new_val) * distance
 *           x = sin(new_val) * -distance
 *      end if
 *
 *
 *    where parameter:  used to convert degrees to radians for
 *       use with the sin and cosine functions
 *       (parameter= pi / 180.)
 *
 *
 *    Distances are calculated for each point to every other point
 *    in the following way:
 *
 *        distance = sqrt((x2 - x1)(x2 - x1) + (y2 - y1)(y2 - y1))
 *
 *    An output file of distances is created for input to the
 *    semi-variogram program.  Each record in the output ASCII file
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*     contains a distance, and the value of the two characteristics
*     for which the distance was calculated.
*
*        An output ascii file is also created of X,Y cartesian coordinates
*        and the value of interest.
*
* Programmer:  Barbara Marks
*
* Date:  December 1991
*
* Modifications:
*        28-Oct-92  BJM
*                Creating a new file (filename.mean) which will
*                contain the mean and number of observations of the
*                variable soilchar.
*        20-Nov-92  BJM
*                Adding calculation of the variance of the input
*              soilchar values.  Variance will be written out
*                to the file containing the mean and #pts (see
*                modification 28-Oct).
*     6-May-92  BJM
*                Adding calculation of heteroskedasticity (b2).  This
*                value is written to the .mean file and read in by
*                the variogram program.
*************************************************************

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>

float dist[500000];
float x[600];
float y[600];
float soil1[500000];
float soil2[500000];

main()
{
        FILE   *fp,*fp2,*fp3,*fp4;
        int    i,j,k,npts;
        float  azimuth[600], distance[600],soilchar[600];
        float  value;
        float  parameter;
        float  x1,y1;
        float  mean;
        float  sum;
        float  sum_sq;
        float  variance;
        double b2;
        double val1,val2;
        double xdiff,ydiff;
        char   filename[50];
```

```
        char    file2[50],file3[50];
        char     string[200];
        char     *val;

/*
 * Set up the parameter that will convert degrees to radians.
 */
      parameter = 3.14159 / 180.;


/*
 * Ask for the name of the input data file containing value,
 * azimuth, distance and open the file.
 */
        printf ("\nEnter name of data file: ");
        gets(filename);

        if ((fp = fopen(filename,"r")) == NULL) {
                printf ("\nERROR! Can not open file: %s\n",filename);
                exit(1);
        }


/*
 * 10-29-92 BJM  Changing so the user is prompted for the
 * base name for the output files.  Three output files
 * will be created:  filename.dist, filename.xy, filename.mean.
 */

        printf ("\nEnter basename for output files: ");
        gets (filename);

        strcpy (file2,filename);
        strcat (file2,".dist");
        strcpy (file3,filename);
        strcat (file3,".xy");
        strcat (filename,".mean");

        if ((fp2 = fopen(file2,"w")) == NULL) {
                printf ("\nERROR! Can not open file: %s\n",file2);
                exit(-1);
        }

        if ((fp3 = fopen(file3,"w")) == NULL) {
                printf ("\nERROR! Can not open file: %s\n",file3);
                exit(-1);
        }

        if ((fp4 = fopen(filename,"w")) == NULL) {
                printf ("\nERROR! Can not open file: %s\n",filename);
                exit(-1);
        }
```

```
/*
 * Read the input file a record at a time and fill the arrays
 * soilchar, azimuth, and distance.
 */
        printf ("\nReading input file...\n");

        i = 0;
        sum = sum_sq = 0.0;

        while (!feof(fp)) {
                fgets(string,200,fp);
                if (feof(fp)) break;
                soilchar[i] = atof(strtok(string," ,"));
                azimuth[i] = atof(strtok('\0'," ,"));
                distance[i] = atof(strtok('\0'," ,"));
              sum += soilchar[i];
                sum_sq += (soilchar[i] * soilchar[i]);
                i++;
        }

        fclose(fp);

        npts = i;
        if (npts > 100) {
          printf ("\nFATAL ERROR! More than 100 points!");
          printf ("\nDimension arrays larger and re-run!");
          exit(1);
        }

        mean = sum / (float)npts;
        variance = (sum_sq - ((sum * sum) /(float)npts)) / (float)npts;

/*
 * 5-4-93 BJM  Adding calculation of 4th moment (heteroskedasticity)
 */
        val1 = val2 = 0.0;

        for (i=0; i < npts; i++) {
          value = soilchar[i] - mean;
          val1 += (value * value * value * value);
          val2 += (value * value);
        }
        b2 = (npts * val1) / (val2 * val2);

/*
 * Convert each polar coordinate to X,Y cartesian coordinate
 * and output the pair to a file.
 */
        printf ("\nCalculating x,y coordinates...\n");

        for (i=0; i < npts; i++) {
                if (azimuth[i] >= 0. && azimuth[i] <= 90.) {
                   value = (90. - azimuth[i]) * parameter;
```

```
                y[i] = sin(value) * distance[i];
                x[i] = cos(value) * distance[i];
            }
            if (azimuth[i] > 90. && azimuth[i] <= 180.){
                value = (180. - azimuth[i]) * parameter;
                y[i] = cos(value) * -distance[i];
                x[i] = sin(value) * distance[i];
            }
            if (azimuth[i] > 180. && azimuth[i] <= 270.) {
                value = (270. - azimuth[i]) * parameter;
                y[i] = sin(value) * -distance[i];
                x[i] = cos(value) * -distance[i];
            }
            if (azimuth[i] > 270. && azimuth[i] <= 360.) {
                value = (360. - azimuth[i]) * parameter;
                y[i] = cos(value) * distance[i];
                x[i] = sin(value) * -distance[i];
            }
            fprintf (fp3,"%f %f %f\n",x[i],y[i],soilchar[i]);
        }


/*
 * Calculate the distance from each X,Y to every other point in
 * the data set.
 */
        printf ("\nCalculating distances ...\n");

        k = 0;
      for (i=0; i < npts; i++) {
          x1 = x[i];
          y1 = y[i];
          for (j=i+1; j < npts; j++) {
         xdiff = (x1 - x[j]) * (x1 - x[j]);
         ydiff = (y1 - y[j]) * (y1 - y[j]);
            if (xdiff == 0. && ydiff == 0.) {
          dist[k] = 0.0;
                soil1[k] = soilchar[i];
                soil2[k] = soilchar[j];
            }
            else {
          dist[k] = sqrt(xdiff + ydiff);
                soil1[k] = soilchar[i];
                soil2[k] = soilchar[j];
            }
            fprintf (fp2,"%f %f %f %d %d\n",dist[k],soil1[k],soil2[k],
                 i+1,j+1);
          k ++;
        }
      }


/*
```

```
* 10-29-92 BJM Writing new .mean file
*/
        fprintf (fp4,"%d\n",npts);
        fprintf (fp4,"%f\n",mean);
        fprintf (fp4,"%f\n",variance);
        fprintf (fp4,"%f\n",b2);

        fclose (fp2);
        fclose (fp3);
        fclose (fp4);
}

/*****************************************************************
```

```
* Filename: VGRAM.C
*
* Purpose: This program was written for Julia Jones. It
*      calculates a raw and average semi-variogram from the
*      input data file.
*
*      The input data file must be an ASCII file and each
*      record must contain a distance and the values of the two
*      variables the distance represents. The values can be
*      separated by a space(s) or a comma. The distances must
*      be sorted in ascending order (small to large). The distance
*      file is created by the program 'distance'. To sort it, use
*      the unix command sort:
*
*              sort -n input_file > output_sorted_file
*
*      Three output files are created. The user is prompted for
*      the base name for the output files. The extensions .ave,
*      .diag, and .signif  are added to the basename.
*
*      The basename.ave file contains semi-variogram values for
*      distances within a certain groupsize(input by the user).
*      These values are calculated as follows:
*
*
*              SUM(groupsize) ((var1-var2) * (var1-var2)) /
*                    (2 * groupsize)
*
*
* Programmer: Barbara Marks
*
* Date: December 1991
*
* Modifications:
*      28 Oct 1992  BJM
*        (1) Removing .raw file
*        (2) Adding additional calculations of Moran's I
*              and Geary's C.
*
*       I(d) = [n * SUMiSUMj(y(i) - ymean)*(y(j) - ymean)] /
*          [W * SUMi(y(i) - ymean)*(y(i) - ymean)]
*
*
*     C(d) = [(n-1) SUMiSUMj(y(i) - y(j))*(y(i) - y(j))] /
*          [2 * W * Sumi(y(i) - ymean)*(y(i) - ymean)]
*
*
*     where: W       = groupsize
*          n       = number of points in original dataset
*          y(i),y(j) = values of the two variables the distance
*                  is calculated for
*          ymean    = mean of points in the original dataset
*
```

```
*
*
*          "ymean" and "n" area calculated in the program
*               distance.c and written to a .mean file.  The .mean
*               file is read by this program.
*
*
*     NOTE:  The input distance matrix to this program is not square.
*            The above formulas are based on a square matrix.  Therefore
*               the answers will be divided by 2 to adhere to the formulas
*            above.
*
*
*
*      20 Nov 1992  BJM
*        The calcuation of variance was added to the program distance.c
*        and written out to the .mean file.  The .mean file is read
*        in by this program.  Variance will be used to output a new
*        field to the .ave file:  semi-variance/variance.  Also,
*        removing the .err file and creating a new .diag file with
*        diagnostics.
*
*     6 May 1993  BJM
*        (1)  A new variable "b2" was added to the .mean file created
*               by the distance program.  Read this in.
*        (2)  Adding b2,u1,u2,s1,s2,sqrt(s2),upper and lower bound
*               on u1.  Equations are too complex to write out.  See:
*
*               Sokal, Robert R. and Neal L. Oden, 1978. "Spatial
*            Autocorrelation in Biology; 1. Methodology",
*                Biological Journal of the Linnean Society, 199-228.
*
*      (3)  Deleting standard deviation

*************************************************************
```

```
#include <stdio.h>
#include <string.h>
#include <math.h>

#define TRUE  1;
#define FALSE 0;

float   distance[200000];
float   var1[200000];
float   var2[200000];
short   index_i[200000];
short   index_j[200000];

main()
{
        FILE   *fp2,*fp3,*fp4;
        char    filename[50];
        char    filename2[50];
        char    filename3[50];
        char    line[80];
        char    ans[10];
        int     i,j,npts,num;
        int     groupsize;
        int     num_pts;
        int     index1[200];
        int     index2[200];
        float   vgram,ave_vgram;
        float   ave_distance;
        float   sum_vgram;
        float   sum_distance;
        float   mean,variance;
        float   variance2;
        float   sum1,sum2,sum3;
        float   morans_i,gearys_c;
        float   val1,val2;
        float   u1,u2,b2,s1,s2,w,num2,n3;
        float   stdev_u2;
        float  n,n2;
        float   up_bound,lo_bound;


/*
 * Prompt for the name of the file containing sorted distances
 * (the output file from the distance program, sorted).
 */
        printf ("\nEnter name of sorted distance file: ");
        gets (filename);

        if ((fp2 = fopen(filename,"r")) == NULL) {
                printf ("\nERROR! Can not open file: %s\n",filename);
                exit(-1);
        }
```

```
/*
 * Read the distance file. Each record contains a distance, and
 * the the 2 variables for which the distance was calculated.
 *
 *
 * 5-6-93 BJM  Two more variables were added to this file (created
 * by the distance program): the row numbers in the original dataset
 * of the two variables above (index_i, index_j).
 *
 */

        i = 0;
        while (!feof(fp2)) {
                fgets (line,80,fp2);
                if (feof(fp2)) break;
                distance[i] = atof(strtok(line," ,"));
                var1[i] = atof(strtok('\0'," ,"));
                var2[i] = atof(strtok('\0'," ,"));
                index_i[i] = atoi(strtok('\0',", "));
                index_j[i] = atoi(strtok('\0',", "));
                i++;
        }
        npts = i;
        printf ("\nnpts: %d",npts);
        fclose (fp2);


/*
 * 10-28-92 BJM  Get name of file containing the number of observations,
 * and the mean of the observations in the original data set.
 * (This file is produced by "distance.c".)
 * 11-20-92 BJM  Variance was added to .mean file.  Read this new
 * variable too.
 * 5-6-93 BJM  Heteroskedasticity (b2) added to .mean file.  Read this in.
 */

        printf ("\nEnter name of mean file: ");
        gets (filename);

        if ((fp2 = fopen(filename,"r")) == NULL) {
                printf ("\nERROR! Can not open file: %s\n",filename);
                exit (-1);
        }

        num_pts = atoi(fgets(line,80,fp2));
        mean = atof(fgets(line,80,fp2));
        variance = atof(fgets(line,80,fp2));
        b2 = atof(fgets(line,80,fp2));

        fclose (fp2);
```

```
/*
 * Prompt for the base name for the output file.
 */
        printf ("\nEnter base name for output file ");
        printf ("\n  (will add .ave, .diag, .signif): ");
        gets (filename);


        strcpy (filename2,filename);
        strcat (filename2,".ave");
        strcpy (filename3,filename);
        strcat (filename3,".diag");
        strcat (filename,".signif");


        if ((fp2 = fopen(filename2,"w")) == NULL) {
                printf ("\nERROR! Can not open file: %s\n",filename2);
                exit(-1);
        }

        if ((fp3 = fopen(filename3,"w")) == NULL) {
                printf ("\nERROR! Can not open file: %s\n",filename3);
                exit(-1);
        }


        if ((fp4 = fopen(filename,"w")) == NULL) {
                printf ("\nERROR! Can not open file: %s\n",filename);
                exit(-1);
        }


/*
 * Prompt for the number of points to group together for "average"
 * semi-variogram values.
 */
        printf ("\nEnter number of points over which to average variogram values: ");
        groupsize = atoi(gets(ans));


        num = 0;
        sum1 = sum2 = sum3 = 0.0;
        sum_vgram = sum_distance = 0.0;


        for (i=0; i < 200; i++) {
          index1[i] = 0;
          index2[i] = 0;
        }


        for (i=0; i < npts; i++) {
```

```
/*
 * Calculate the "raw" semi-variogram value
 */
        vgram = (var1[i] - var2[i]) * (var1[i] - var2[i]);

/*
 * Accumulate the sum of the "vgram" values and distances that fall
 * within a group.  Also, total up the distances;
 */
        sum_vgram += vgram;
        sum_distance += distance[i];

        num++;



/*
 * 10-28-92 BJM  Adding calculation of new variables:  Morans' I
 * and Geary's C.
 */

        sum1 += (var1[i] - mean) * (var2[i] - mean);
        sum2 += (var1[i] - mean) * (var1[i] - mean);
        sum3 += (var1[i] - var2[i]) * (var1[i] - var2[i]);


/*
 * 11-20-92 BJM  Write some stuff to the diagnostics file
 */
        fprintf (fp3,"\ni,var1,var2: %d,%f,%f",i,var1[i],var2[i]);


/*
 * 5-6-93 BJM  Adding stuff for calculation of s2, u2
 */
        index1[index_i[i]] ++;
        index2[index_j[i]] ++;

/*
 * If the group size has been reached, average the accumulated
 * sum, calculate some new indices and write the values to the output
 * files.
 */
        if (num == groupsize || i == npts-1) {

            ave_vgram = sum_vgram /(float) (2.0 * num);
            ave_distance = sum_distance / (float)num;

/*
 * 10-28-92 BJM  Calculate the new autocorrelation variables
 */
            morans_i = ((float)num_pts * sum1) / ((float)num * sum2);
```

```
            gearys_c = (((float)num_pts-1.0) * sum3) /
                        (2.0 * (float)num * sum2);

/*
 * 11-5-92 BJM  Dividing results by 2 because the input distance matrix
 * is not square as the formulas require.
 */
            morans_i = morans_i / 2.0;
            gearys_c = gearys_c / 2.0;
          variance2 = ave_vgram / variance;

/*
 * 5-6-93 BJM  Adding calculation of s1,s2,u2
 */

            s1 = (float)groupsize;
            s2 = 0.;
          for (j=0; j < 200; j++) {
              s2 += (float)((index1[j] + index2[j]) *
                      (index1[j] + index2[j]));
              index1[j] = 0;
              index2[j] = 0;
            }

            w = (float)groupsize;
            n = (float)num_pts;
            n2 = n * n;


            val1 = n * ((n2 - (3.0*n) + 3.0) * s1 - (n*s2) + (3.0*(w*w)));
            val2 = b2 * ((n2 - n) * s1 - (2.0*n*s2) + (6.0*(w*w)));


            u1 = -1.0 / (n-1.0);
            n3 = (n-1.0) * (n-2.0) * (n-3.0);
            u2 = ((val1 - val2) / (n3 * (w*w))) -
                (1.0 / ((n-1.0) * (n-1.0)));


          stdev_u2 = sqrt(u2);
            up_bound = u1 + (1.96 * stdev_u2);
            lo_bound = u1 - (1.96 * stdev_u2);

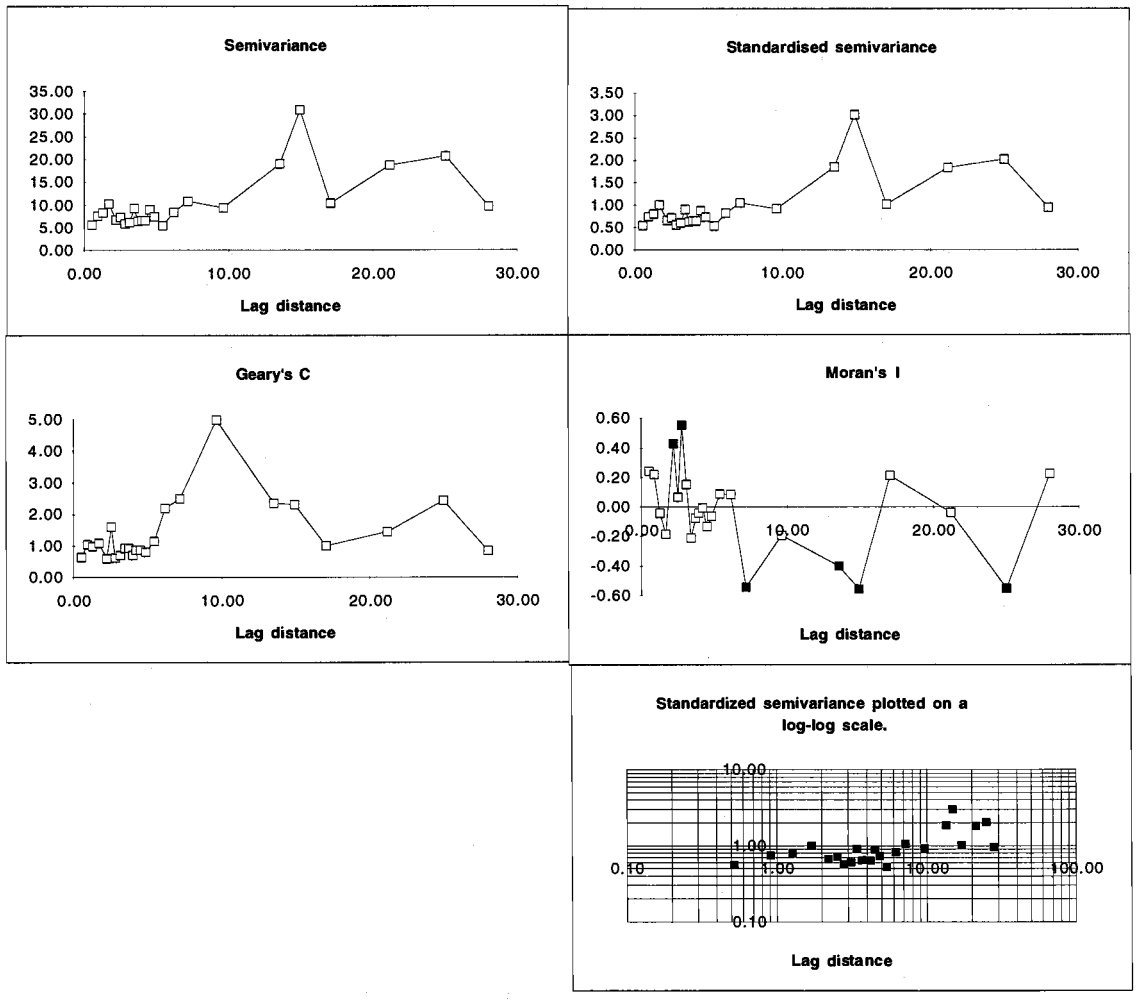

            fprintf (fp2,"%.4f %.4f %.4f %.4f %.4f %.4f %.4f\n",
              ave_distance,ave_vgram,variance2,gearys_c,morans_i,
              up_bound,lo_bound);
            fprintf (fp3,"\n****mean,sum1,sum2,sum3: %f %f %f %f",
                    mean,sum1,sum2,sum3);
            fprintf (fp4,"%.4f %.4f %.4f %d %.4f %.2f %.4f %.2f %.4f %.4f\n",
              ave_distance,morans_i,u1,num_pts,b2,s1,s2,w,u2,stdev_u2);
```

```
                sum_vgram = 0.0;
                sum_distance = 0.0;
                num = 0;
                sum1 = sum2 = sum3 = 0.0;
            }
        }


        fclose (fp2);
        fclose (fp3);
        fclose (fp4);
}
```

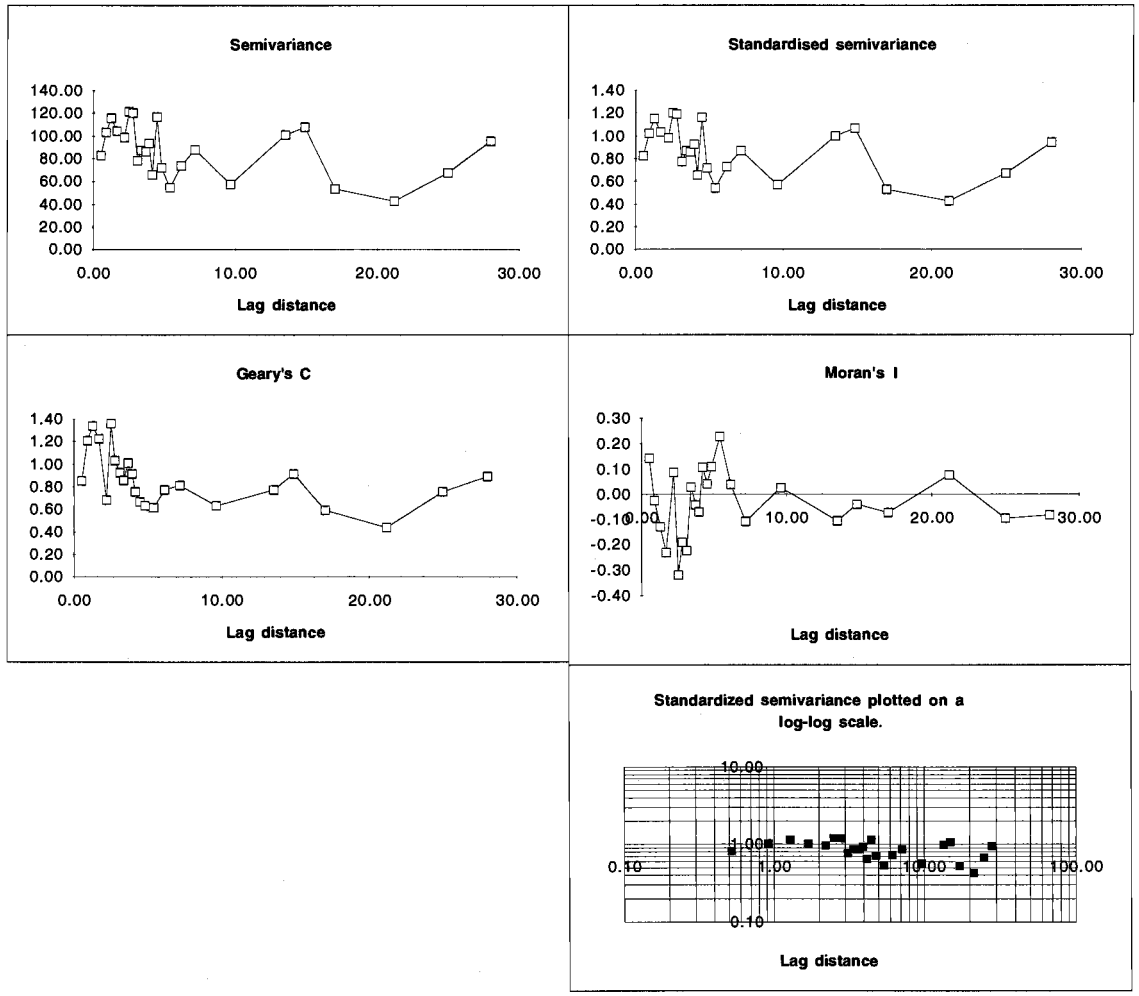
APPENDIX B

SEMIVARIOGRAMS AND CORRELOGRAMS FOR ALL PLOTS AND SOIL PROPERTIES



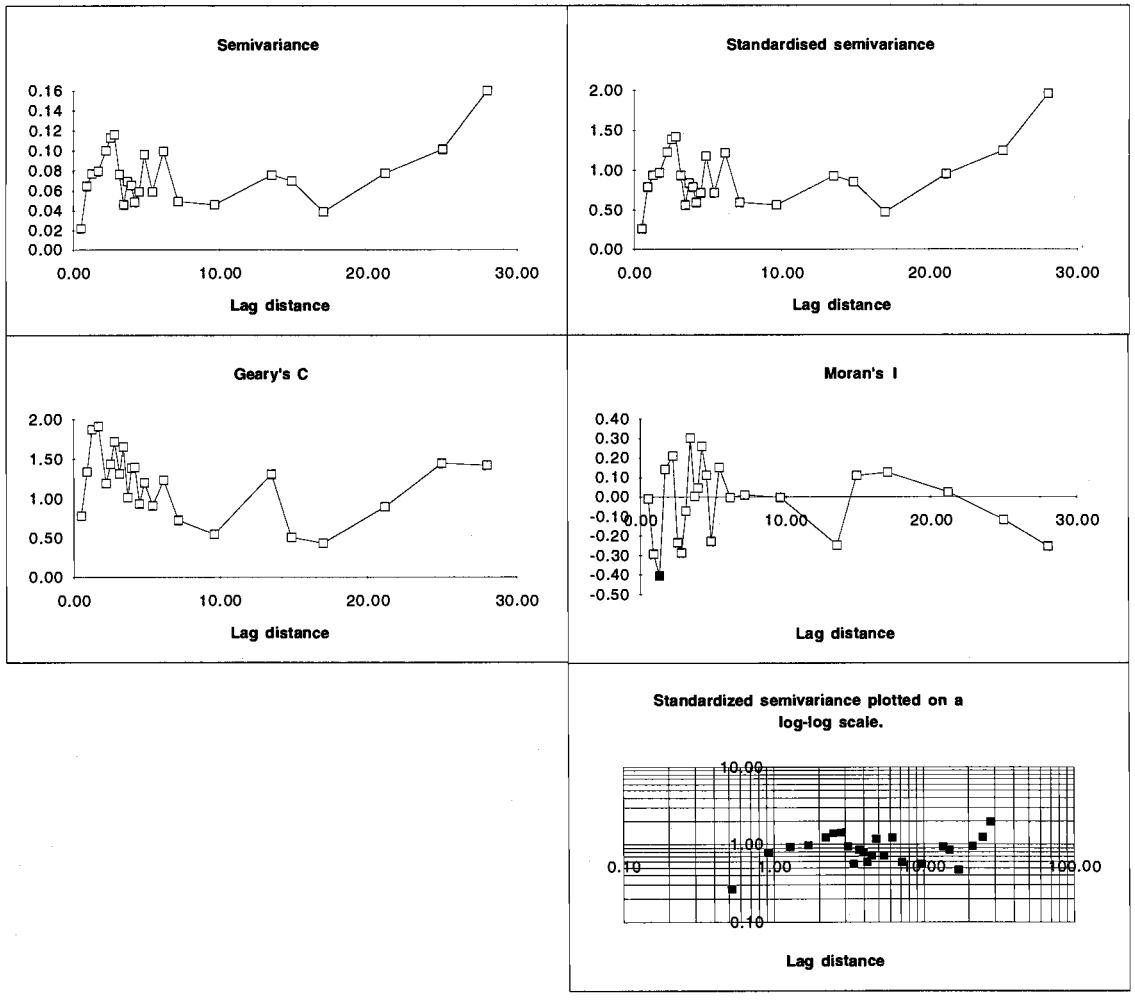
a. Moisture, plot A, December 1991, sagebrush-grass community.

Figure B.1



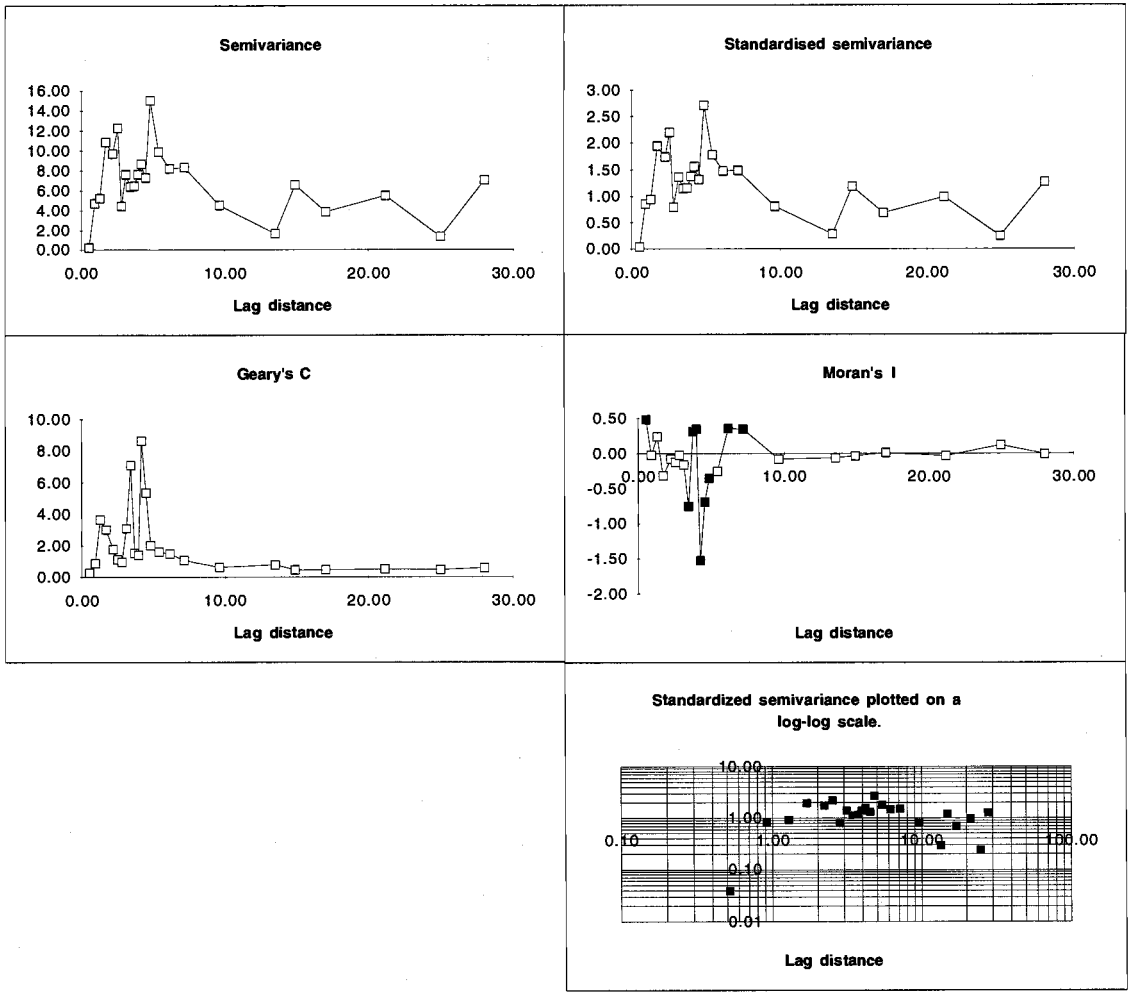
b. V.A. mycorrhizal infection, plot A, December 1991, sagebrush-grass community.

Figure B.1 continued



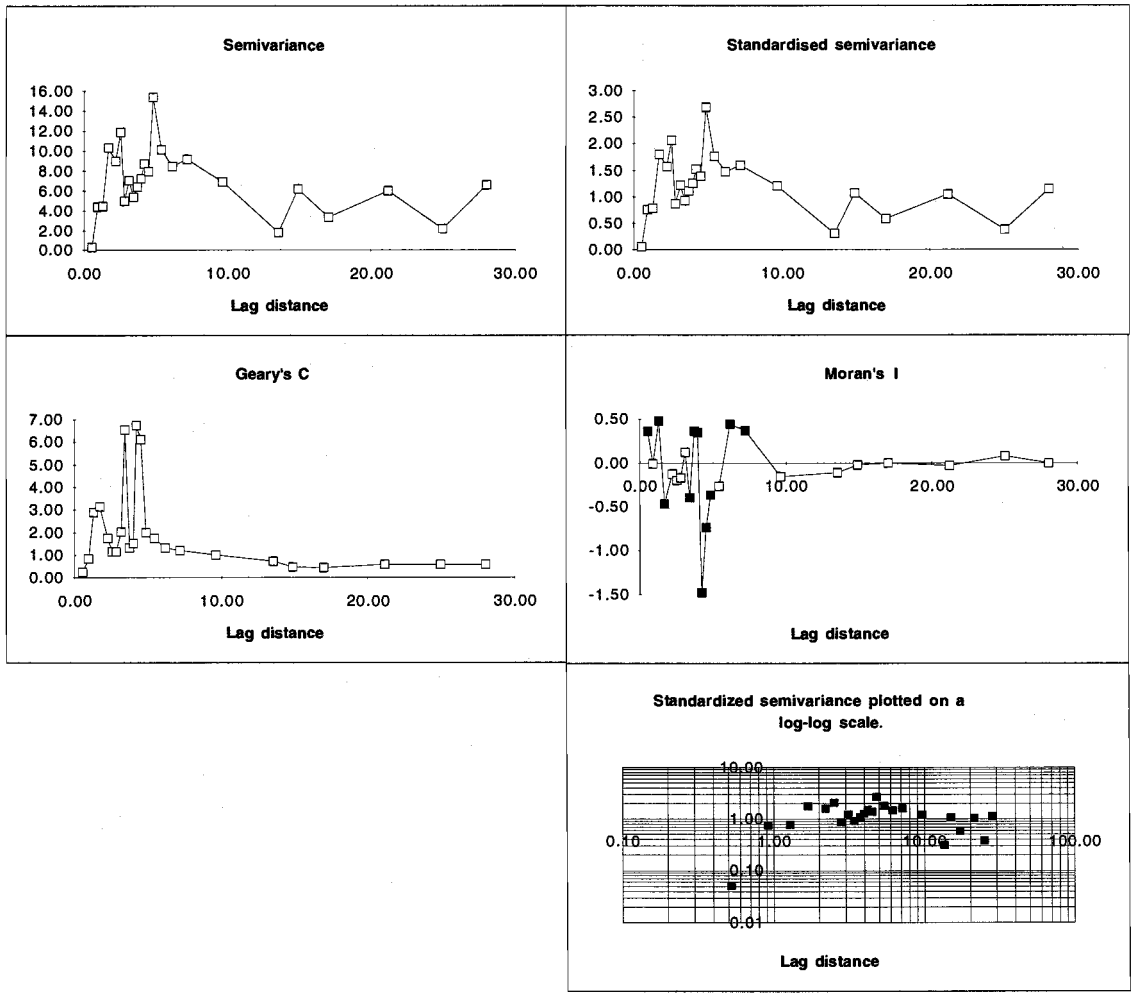
c. PH, plot A, December 1991, sagebrush-grass community.

Figure B.1 continued



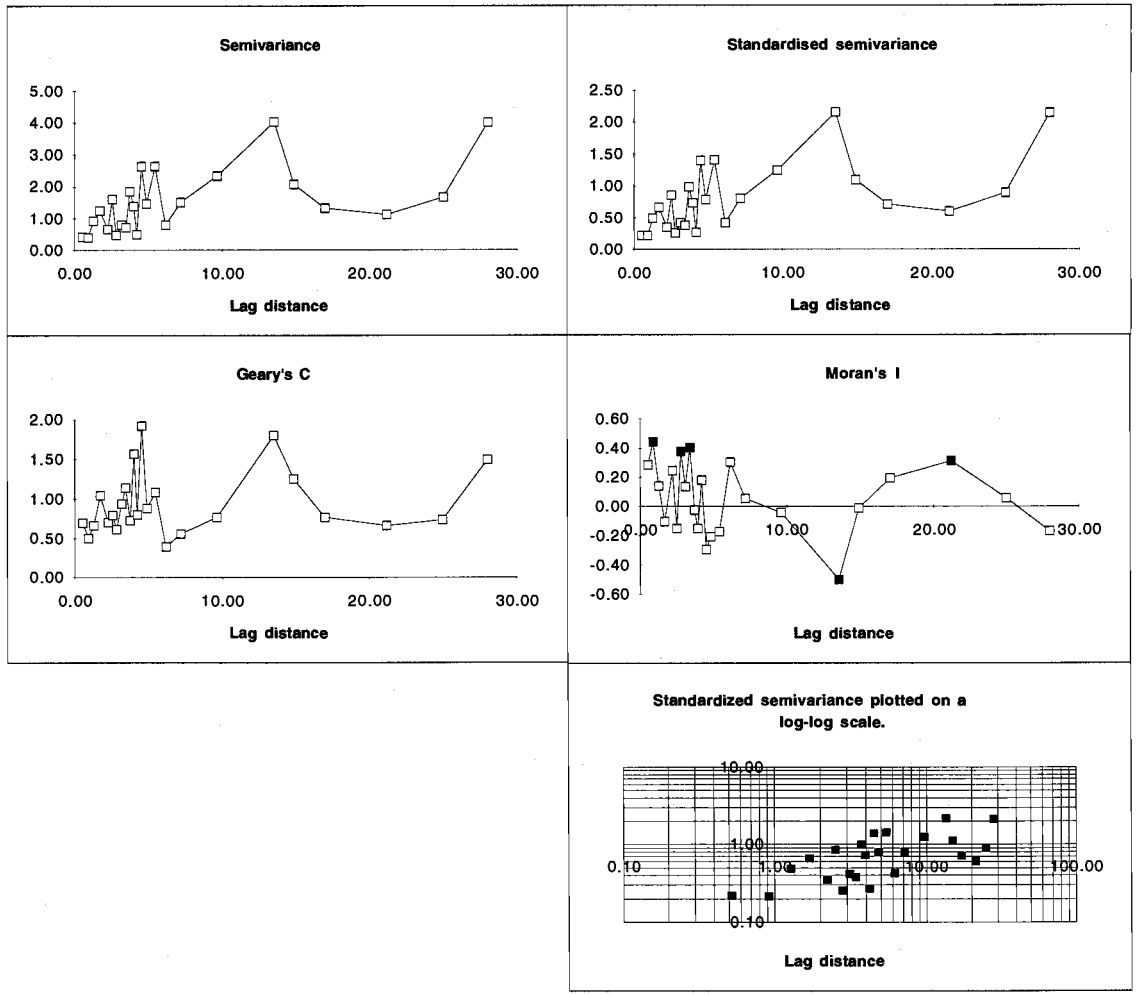
d. Initial Nitrogen as NH4, plot A, December 1991, sagebrush-grass community.

Figure B.1 continued



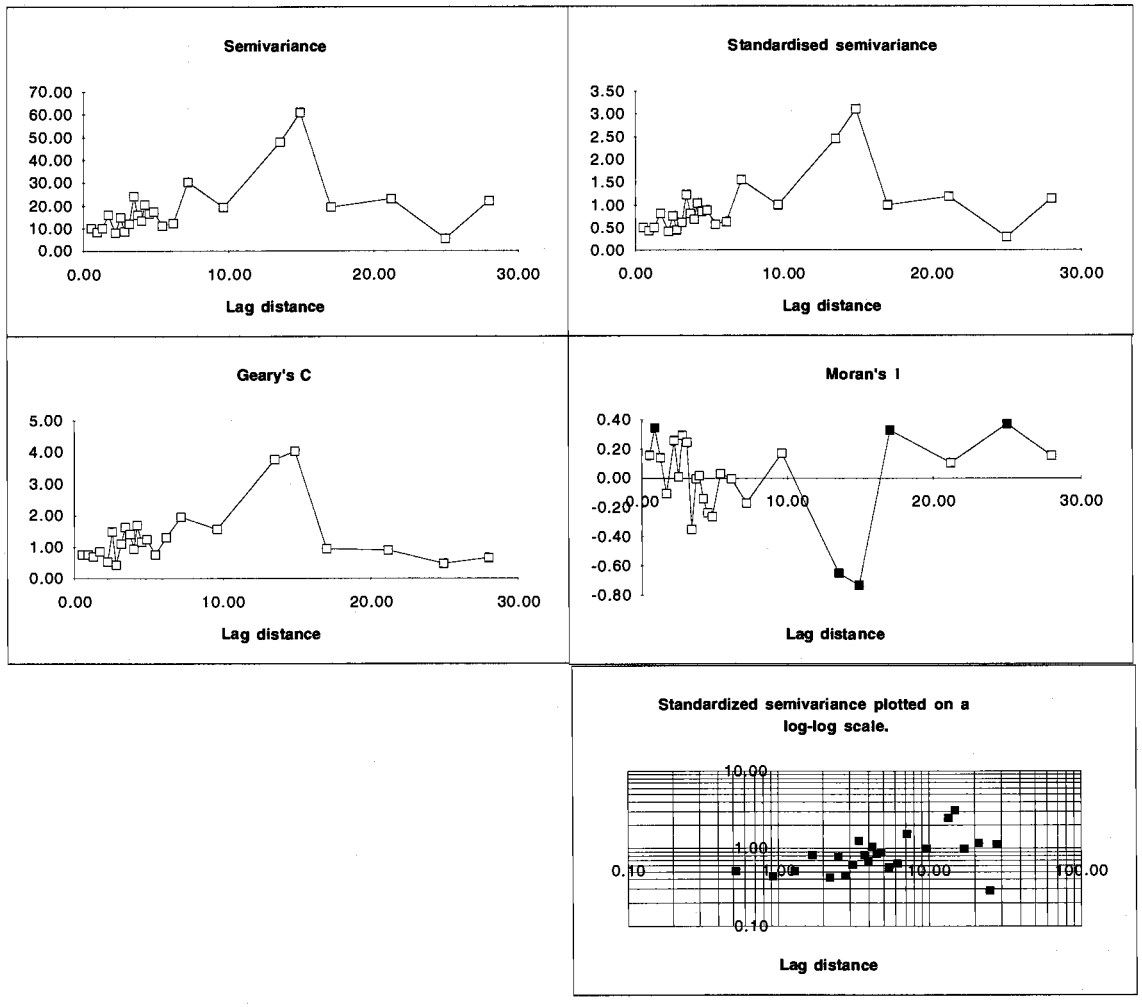
e. Mineralized Nitrogen as NH4, plot A, December 1991, sagebrush-grass community.

Figure B.1 continued



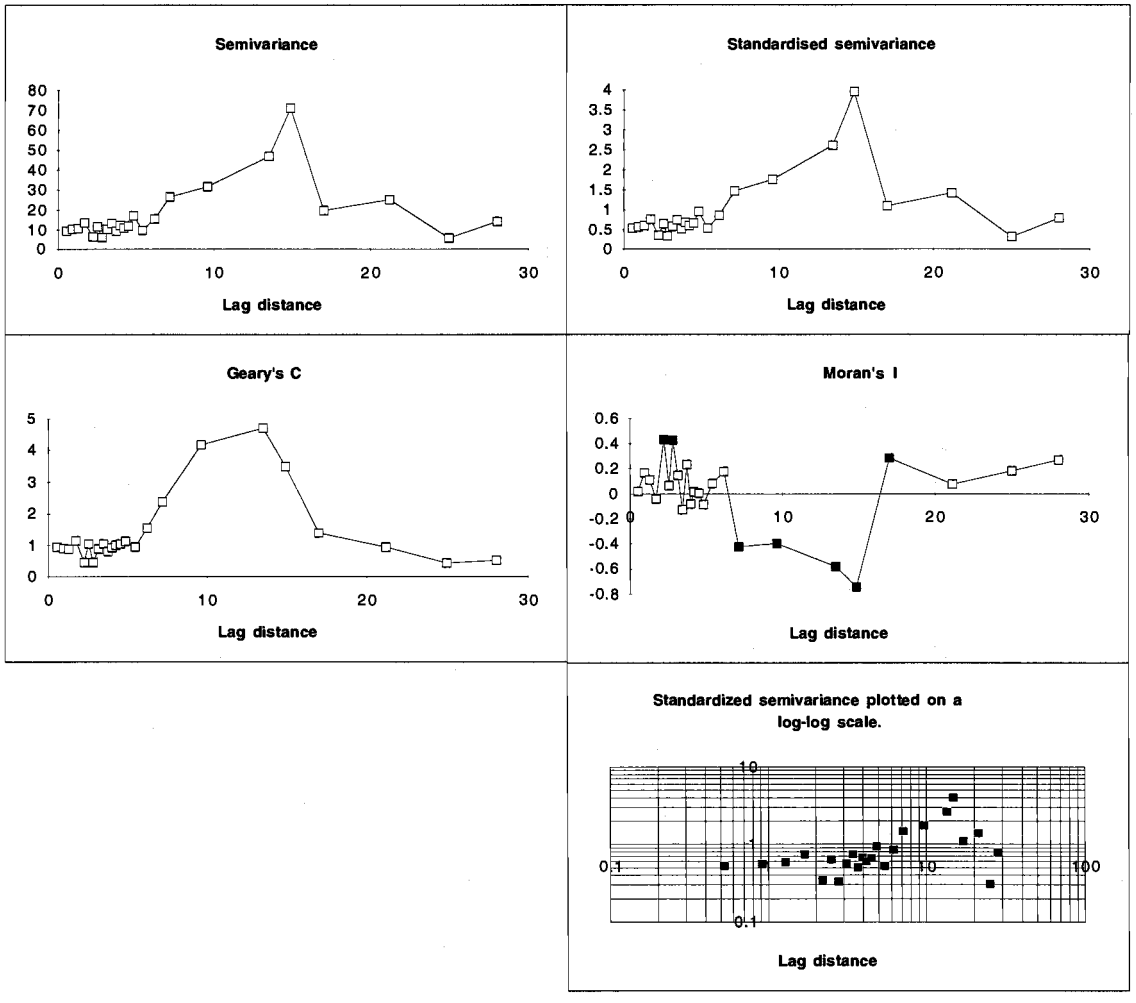
f. Initial Nitrogen as NO3, plot A, December 1991, sagebrush-grass community.

Figure B.1 continued



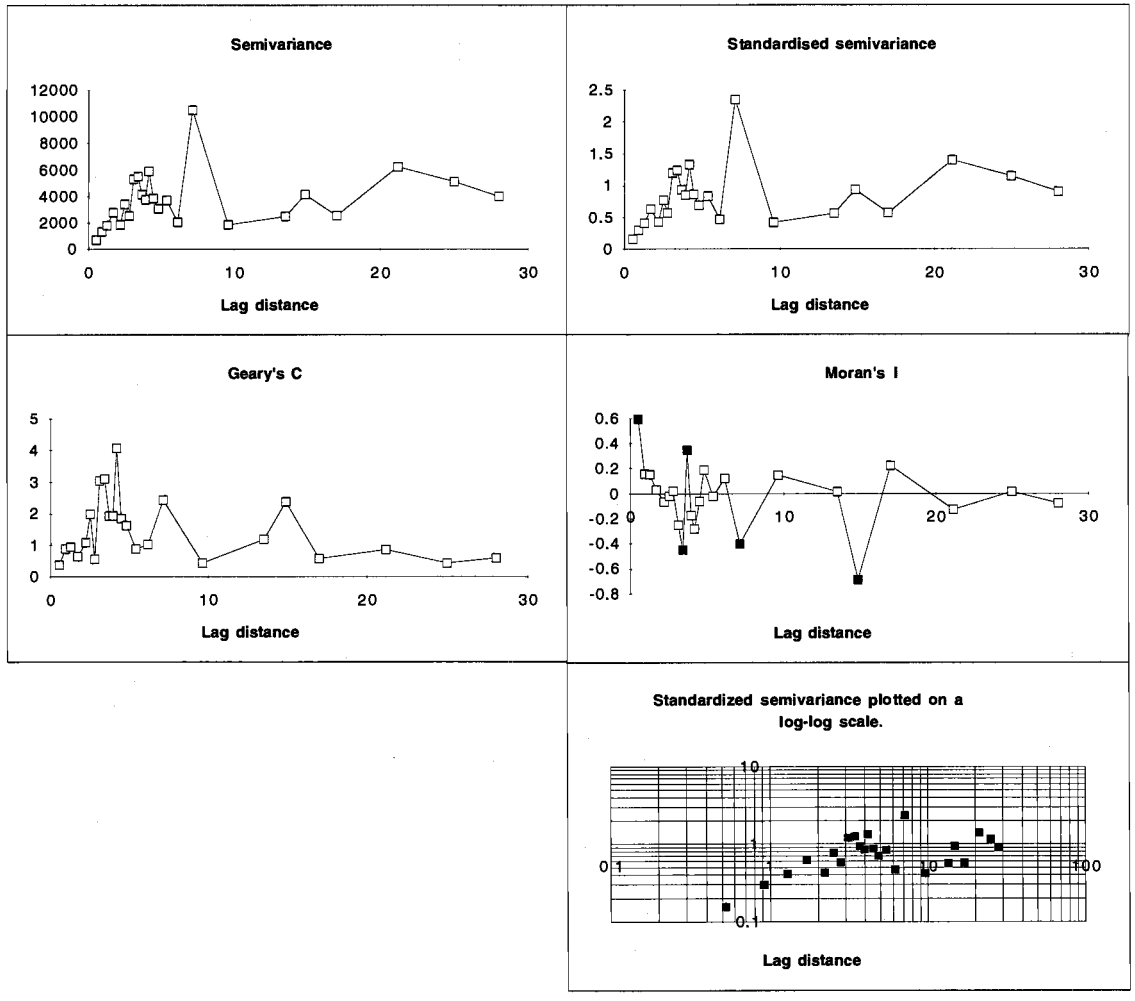
g. Mineralized Nitrogen as NO3, plot A, December 1991, sagebrush-grass community.

Figure B.1 continued



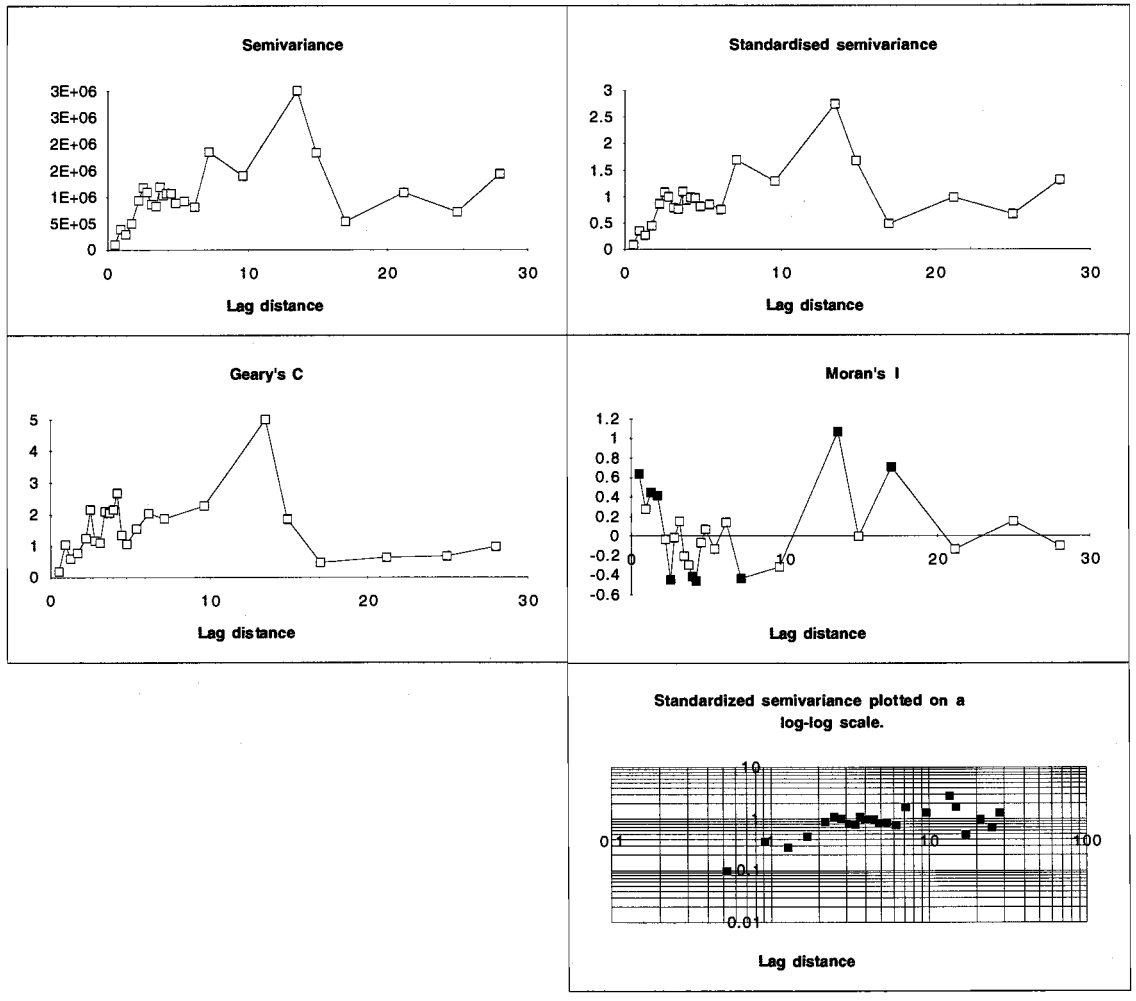
h. Net Nitrogen mineralized, plot A, December 1991, sagebrush-grass community.

Figure B.1 continued



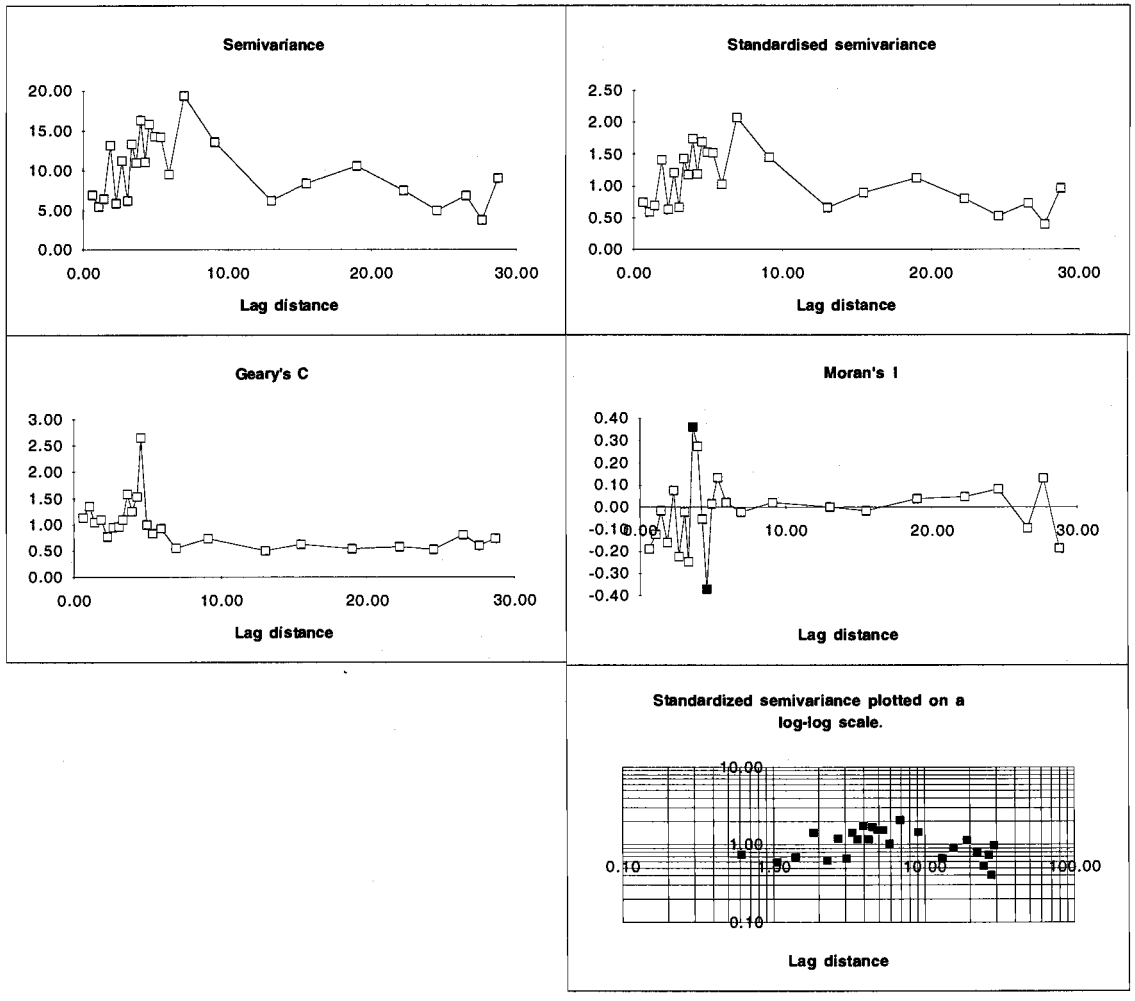
i. Total numbers of soil arthropods, December 1991, plot A, sagebrush-grass community.

Figure B.1 continued



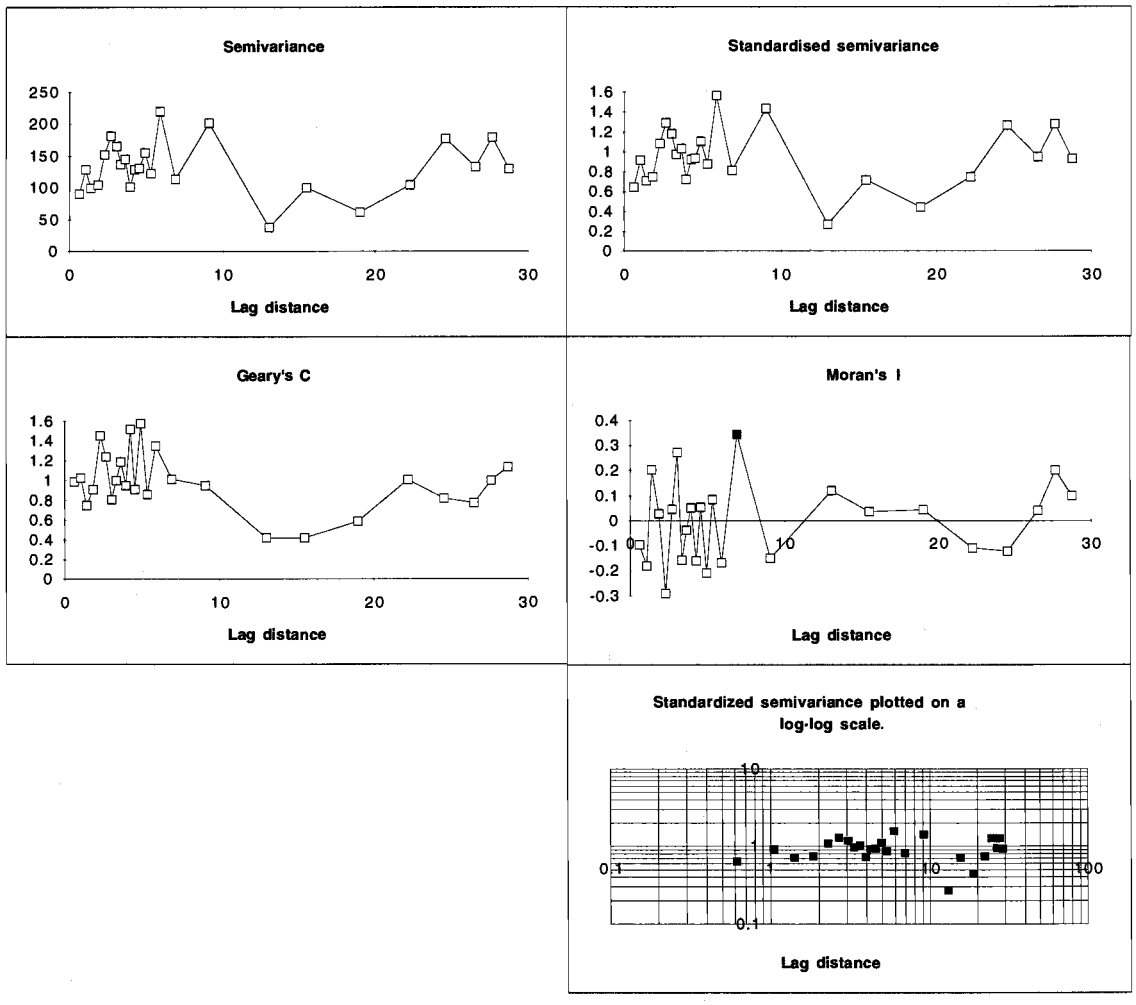
j. Biomass of micro-arthropods, December 1991, plot A, sagebrush-grass community.

Figure B.1 continued



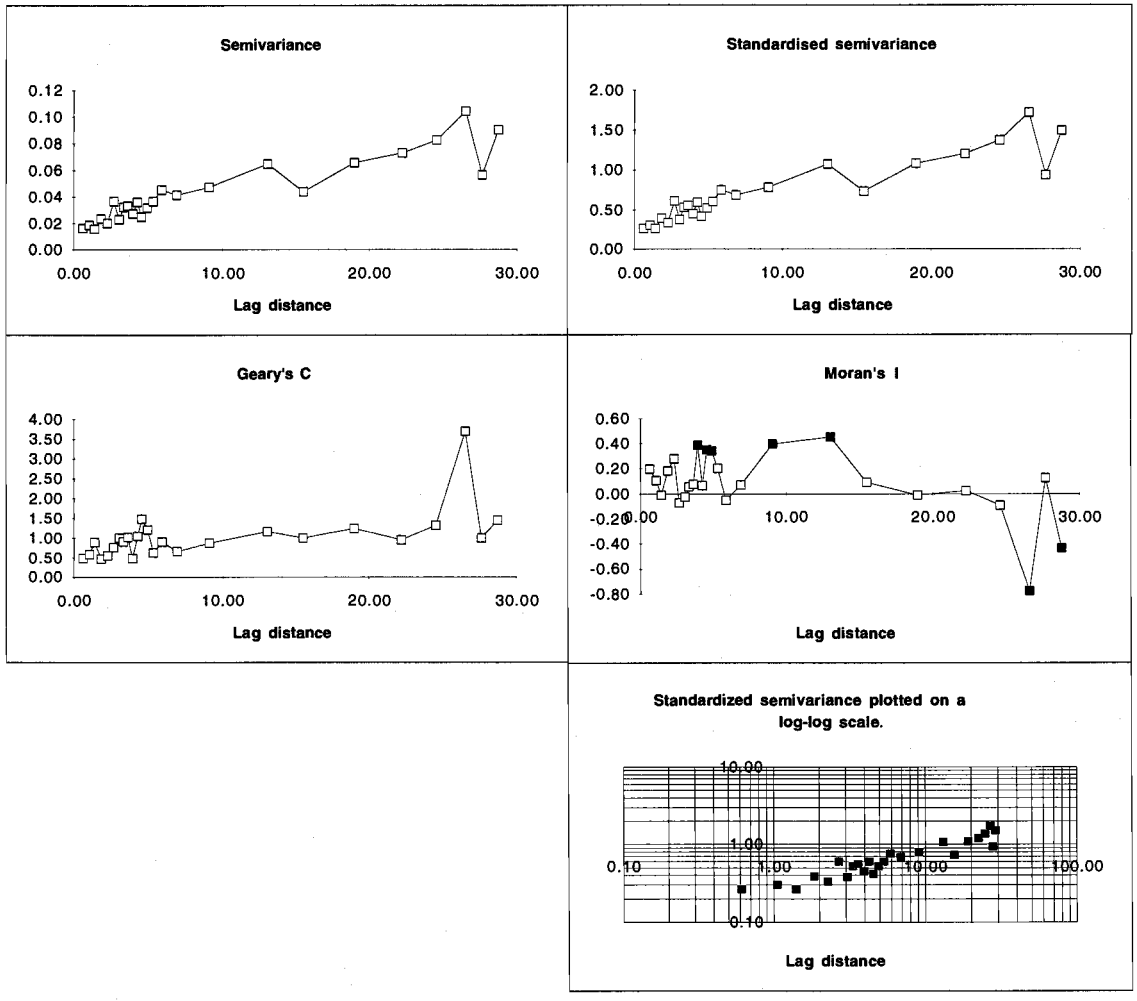
a. Moisture, plot C, December 1991, sagebrush-grass community.

Figure B.2



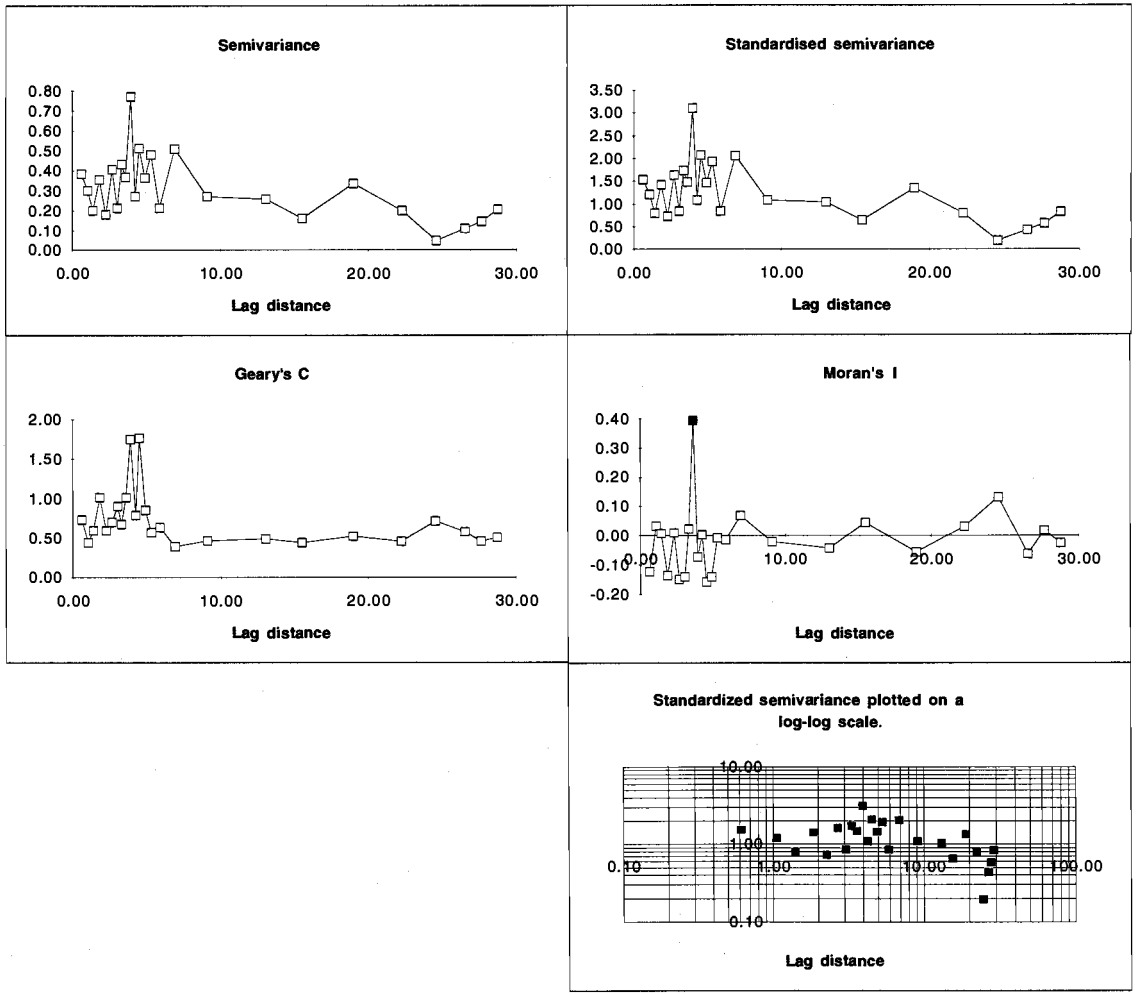
b. V.A. mycorrhizal infection, plot C, December 1991, sagebrush-grass community.

Figure B.2 continued



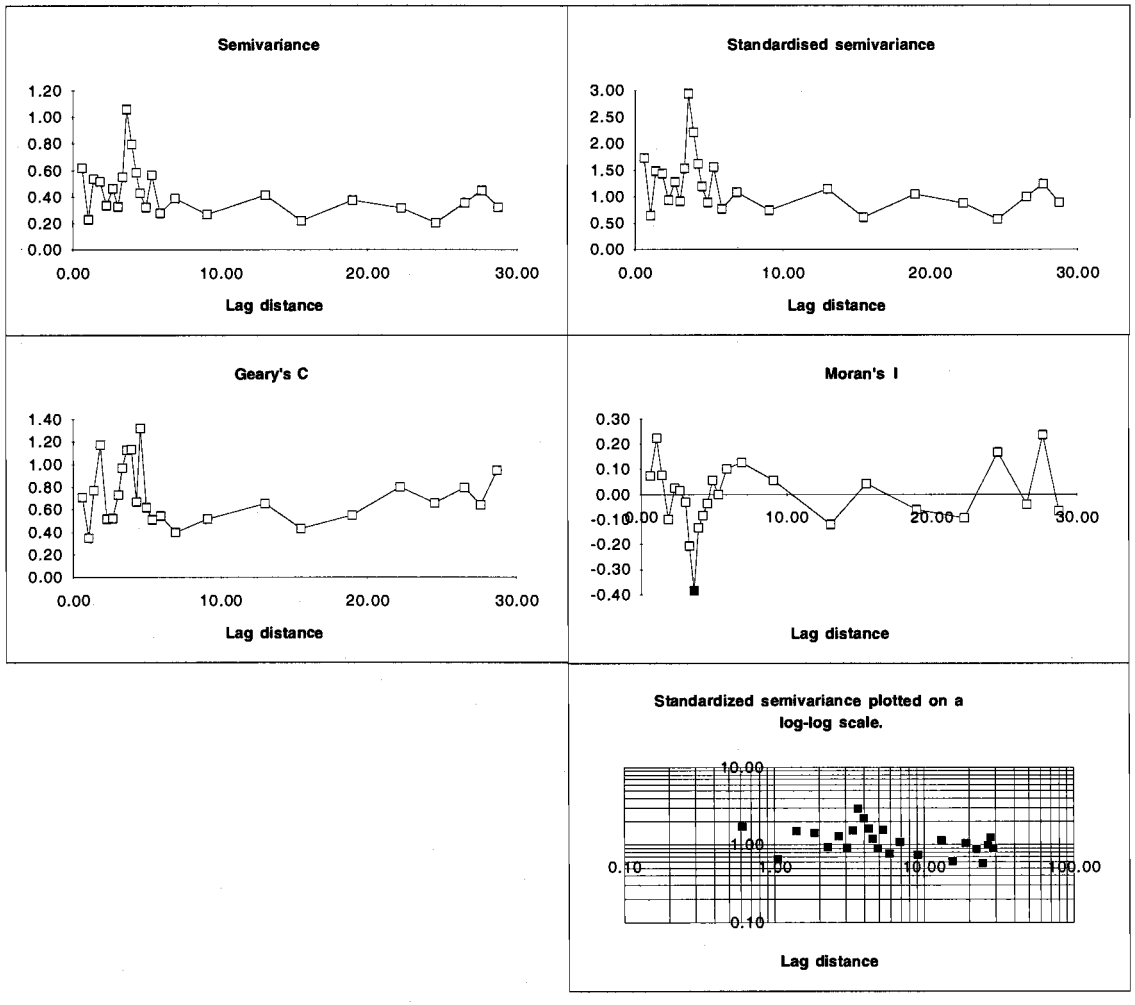
c. PH, plot C, December 1991, sagebrush-grass community.

Figure B.2 continued



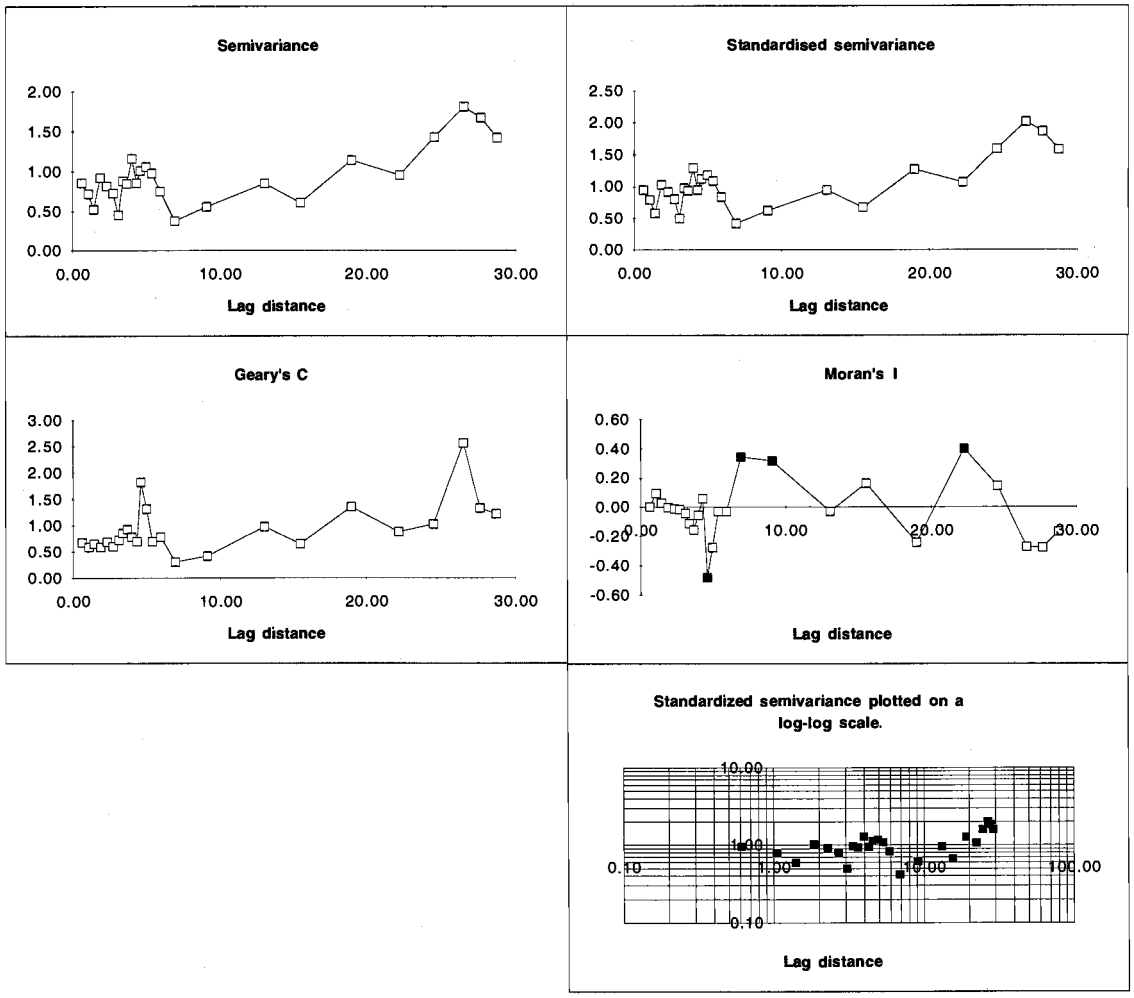
d. Initial Nitrogen as NH4, plot C, December 1991, sagebrush-grass community.

Figure B.2 continued



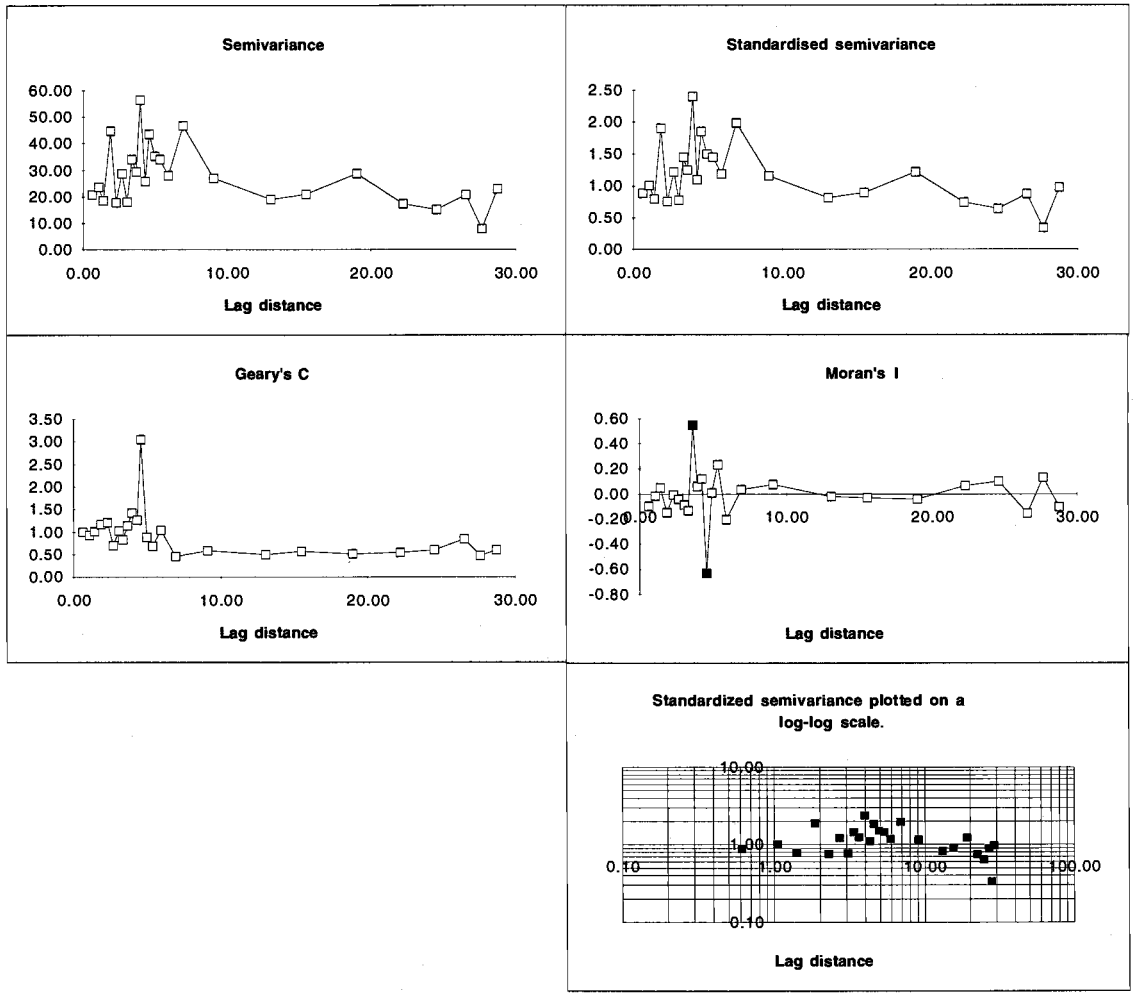
e. Mineralized Nitrogen as NH4, plot C, December 1991, sagebrush-grass community.

Figure B.2 continued



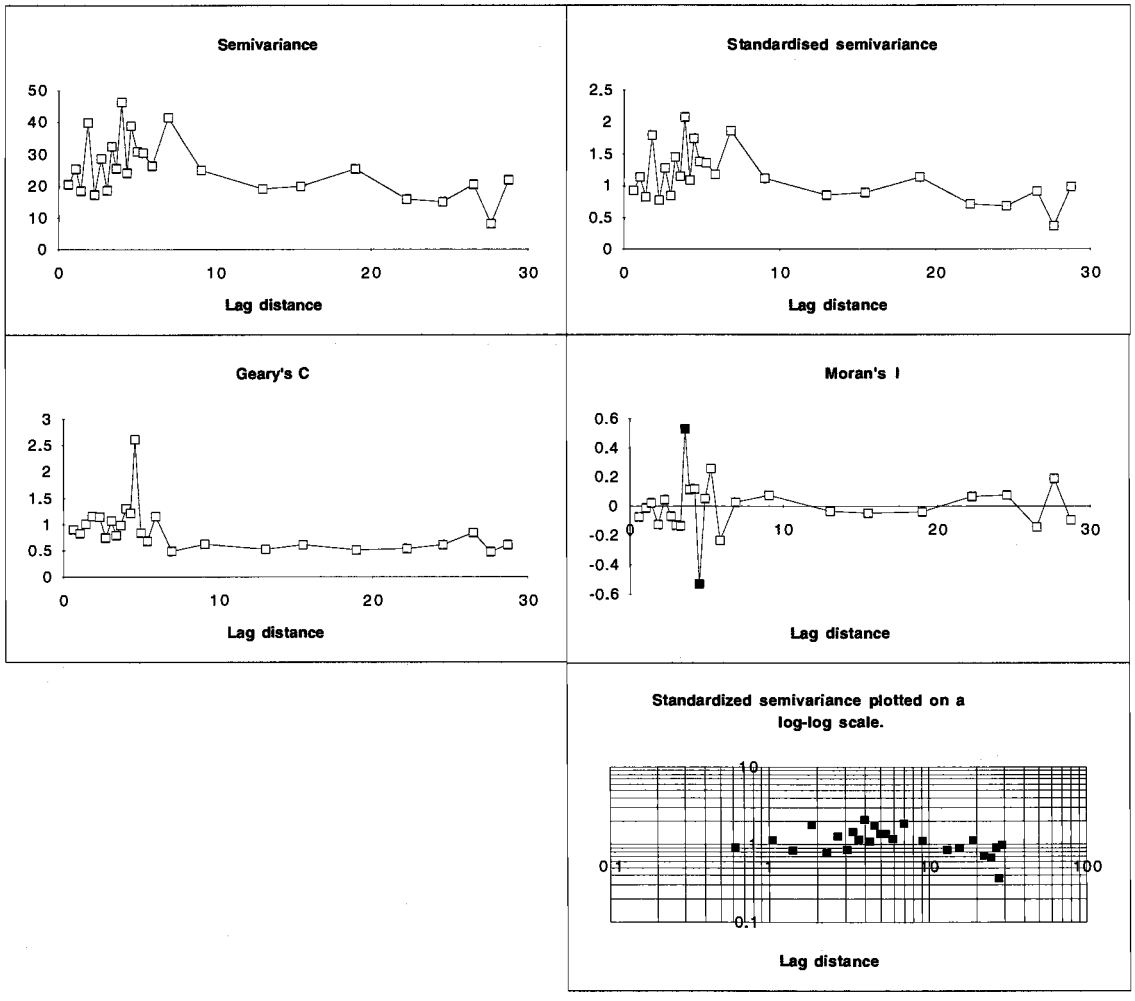
f. Initial Nitrogen as NO3, plot C, December 1991, sagebrush-grass community.

Figure B.2 continued



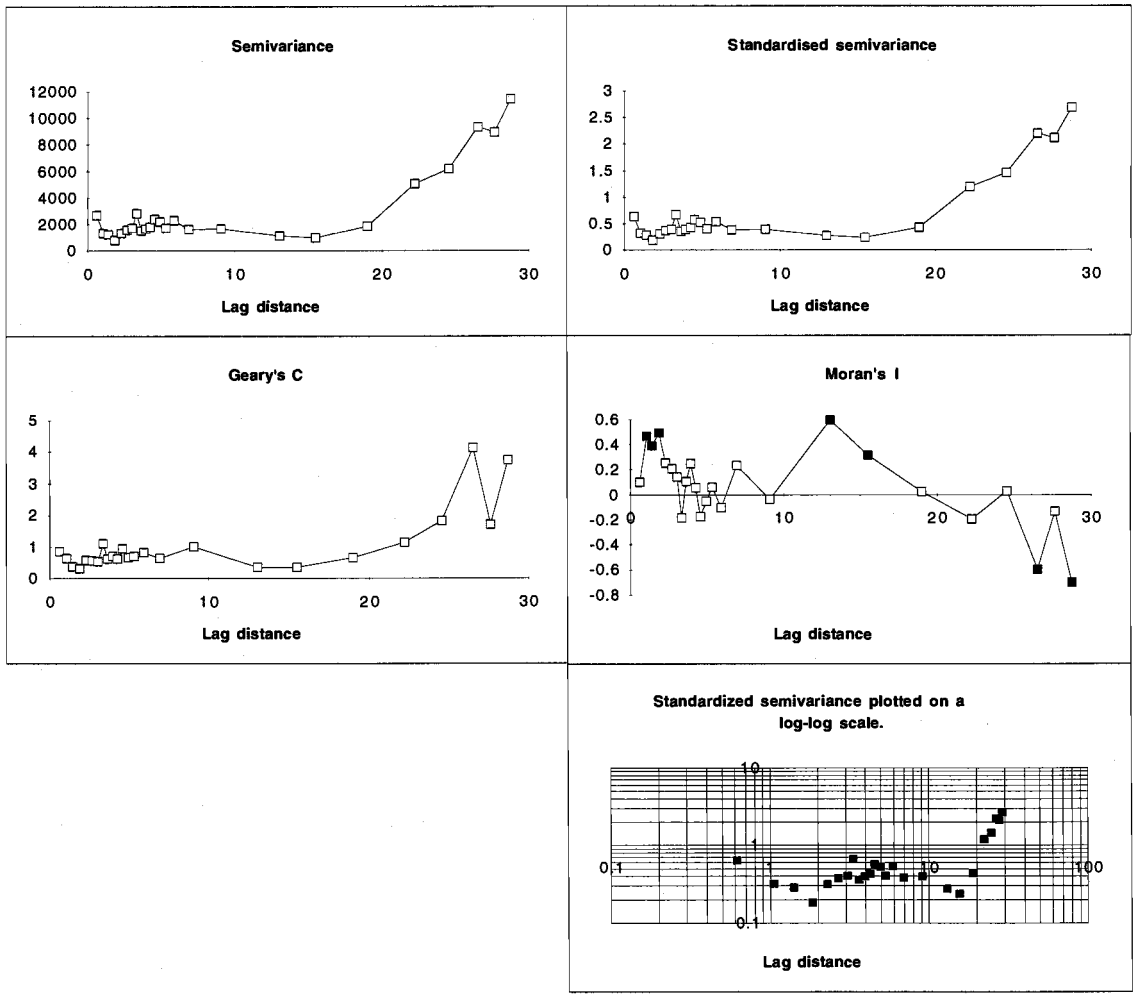
g. Mineralized Nitrogen as NO3, plot C, December 1991, sagebrush-grass community.

Figure B.2 continued



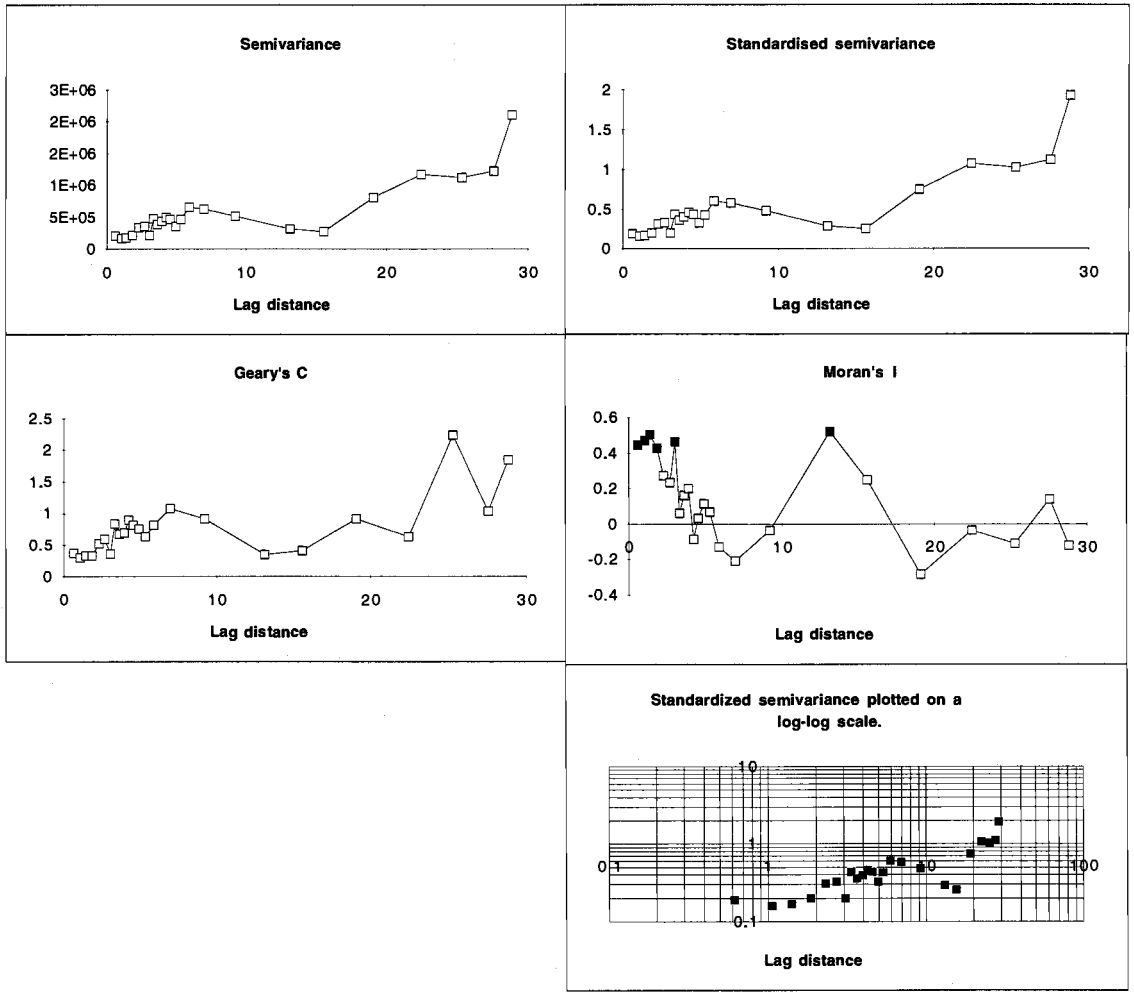
h. Net Nitrogen mineralized, plot C, December 1991, sagebrush-grass community.

Figure B.2 continued



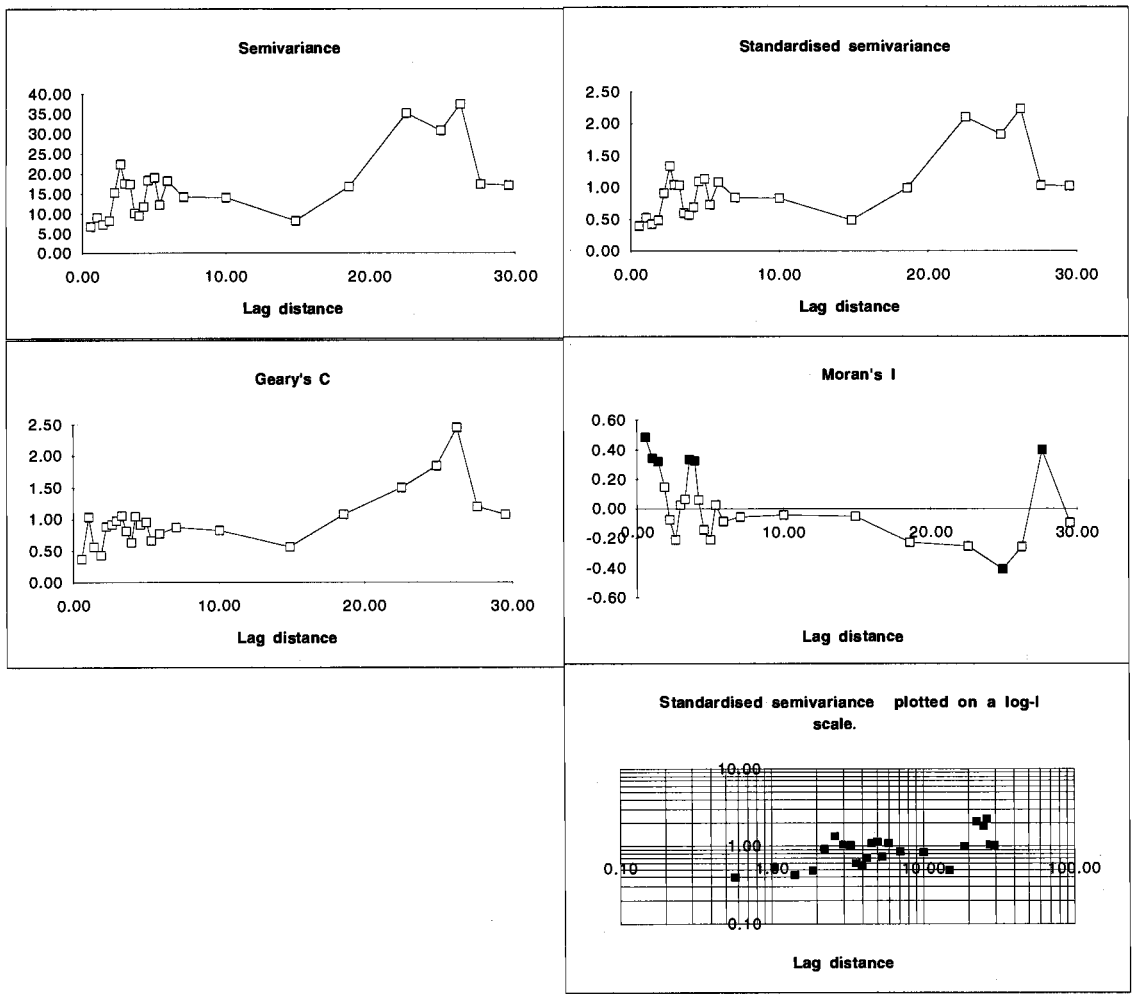
i. Total numbers of soil arthropods, plot C, December 1991, sagebrush-grass community.

Figure B.2 continued



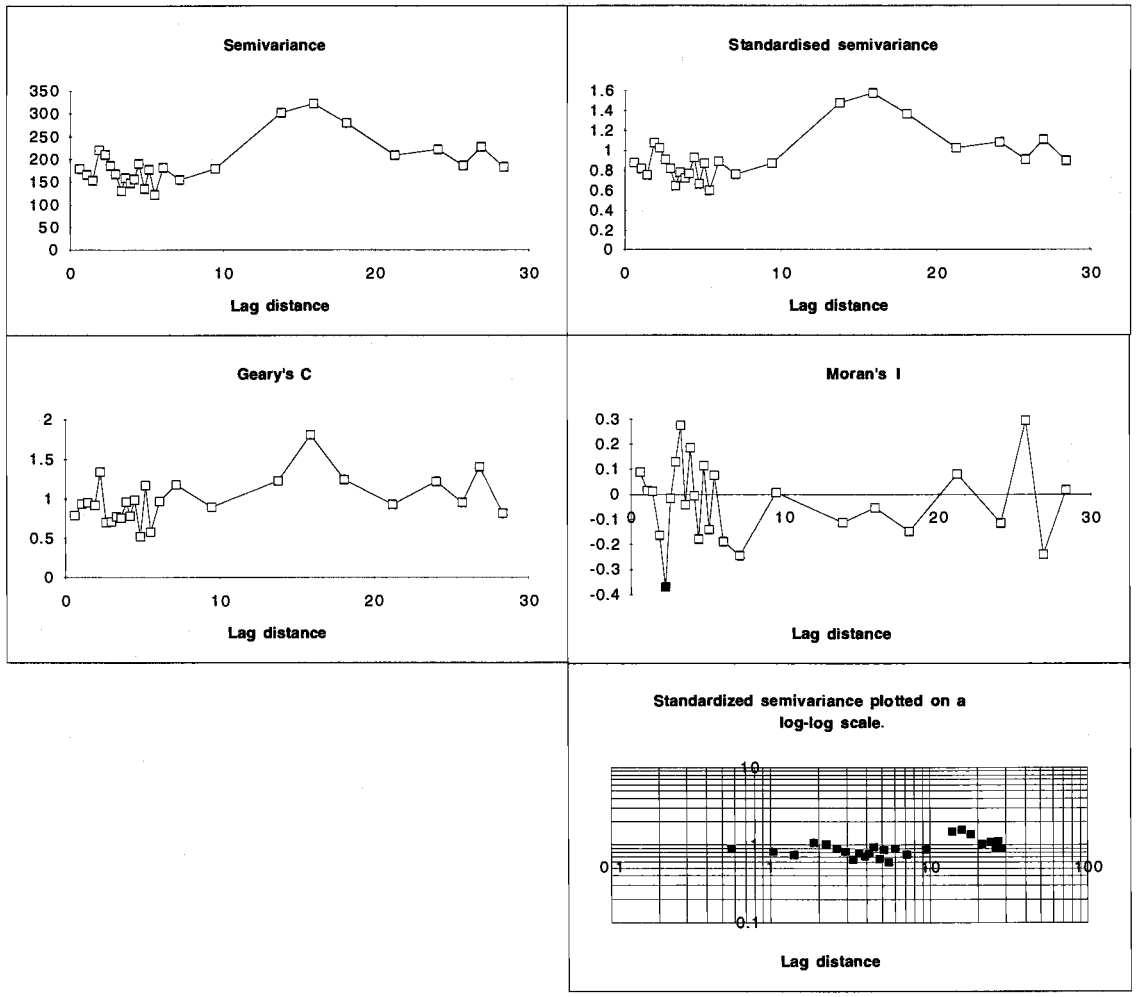
j. Biomass of micro-arthropods, plot C, observation 49 removed as an outlier.

Figure B.2 continued



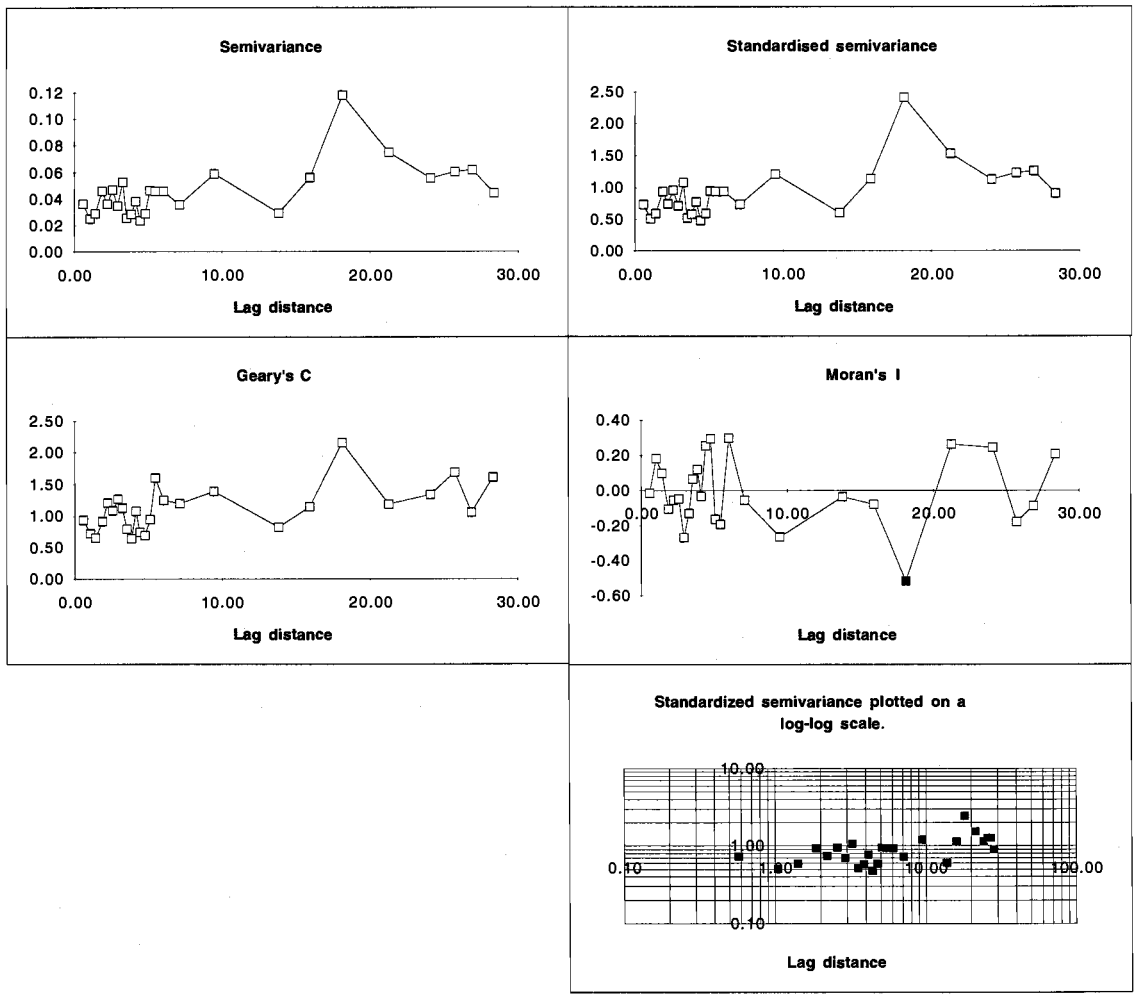
a. Moisture, plot F, observations 30,46 and 50 removed as outliers.

Figure B.3



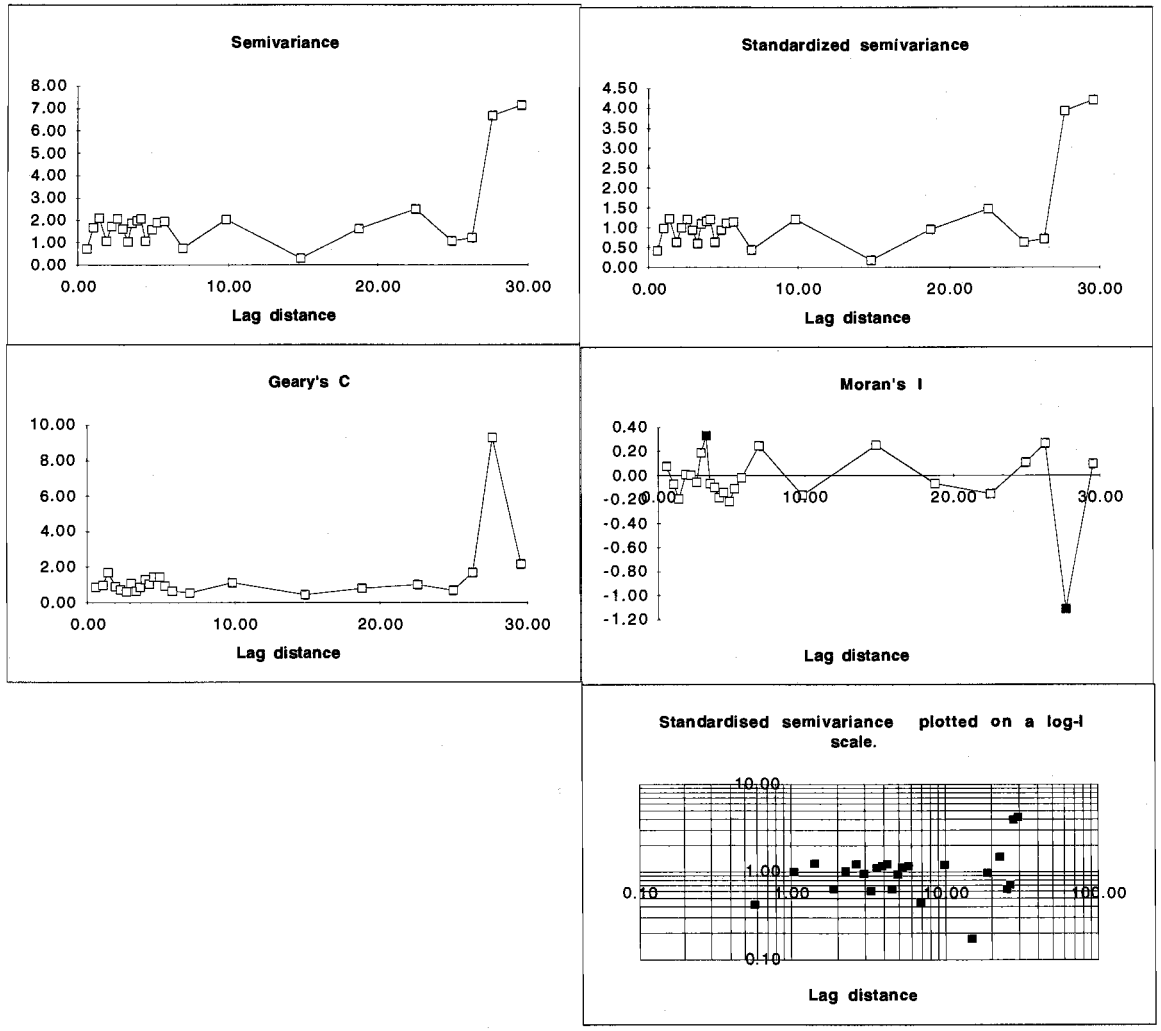
b. V.A. mycorrhizal infection, plot F, December 1991, juniper-sagebrush-grass community.

Figure B.3 continued



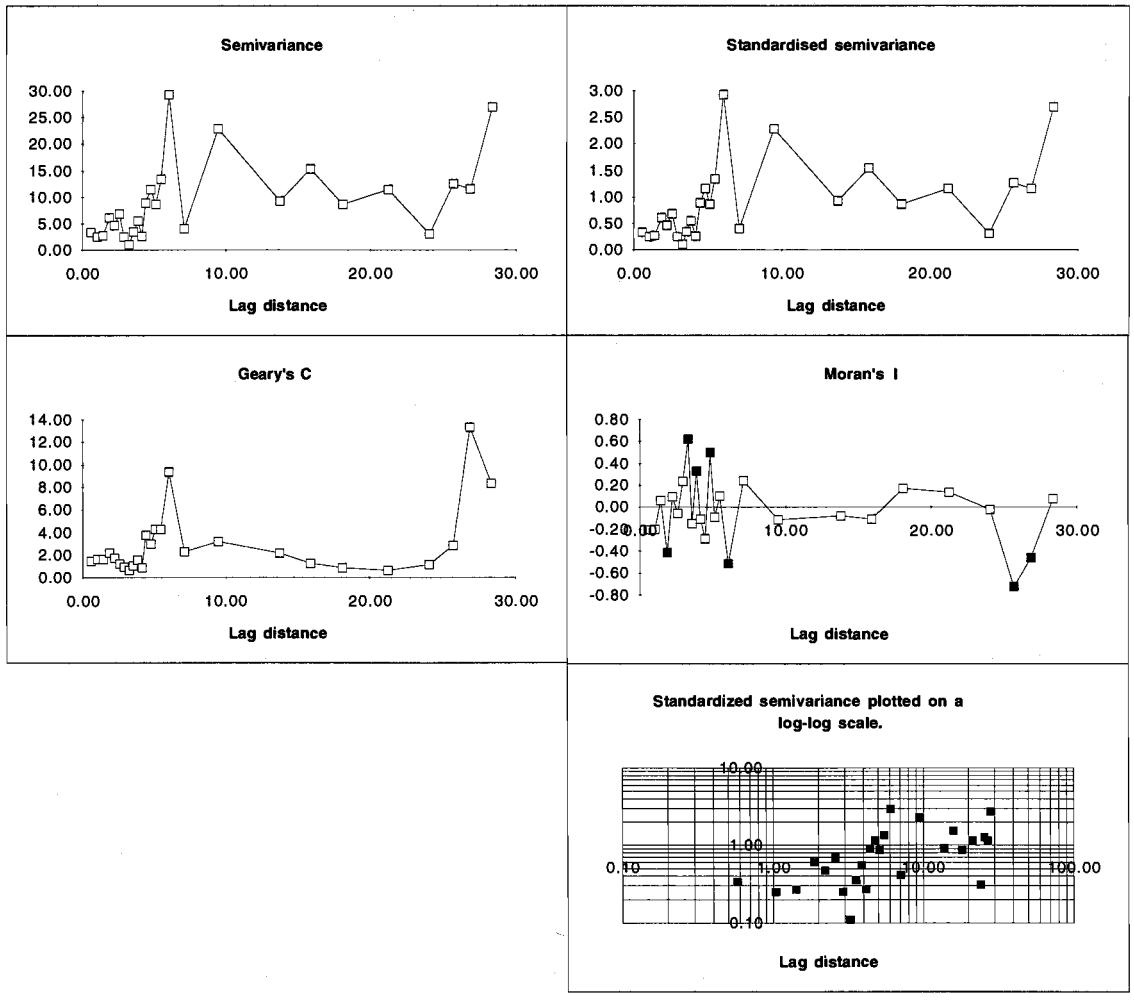
c. PH, plot F, December 1991, juniper-sagebrush-grass community.

Figure B.3 continued



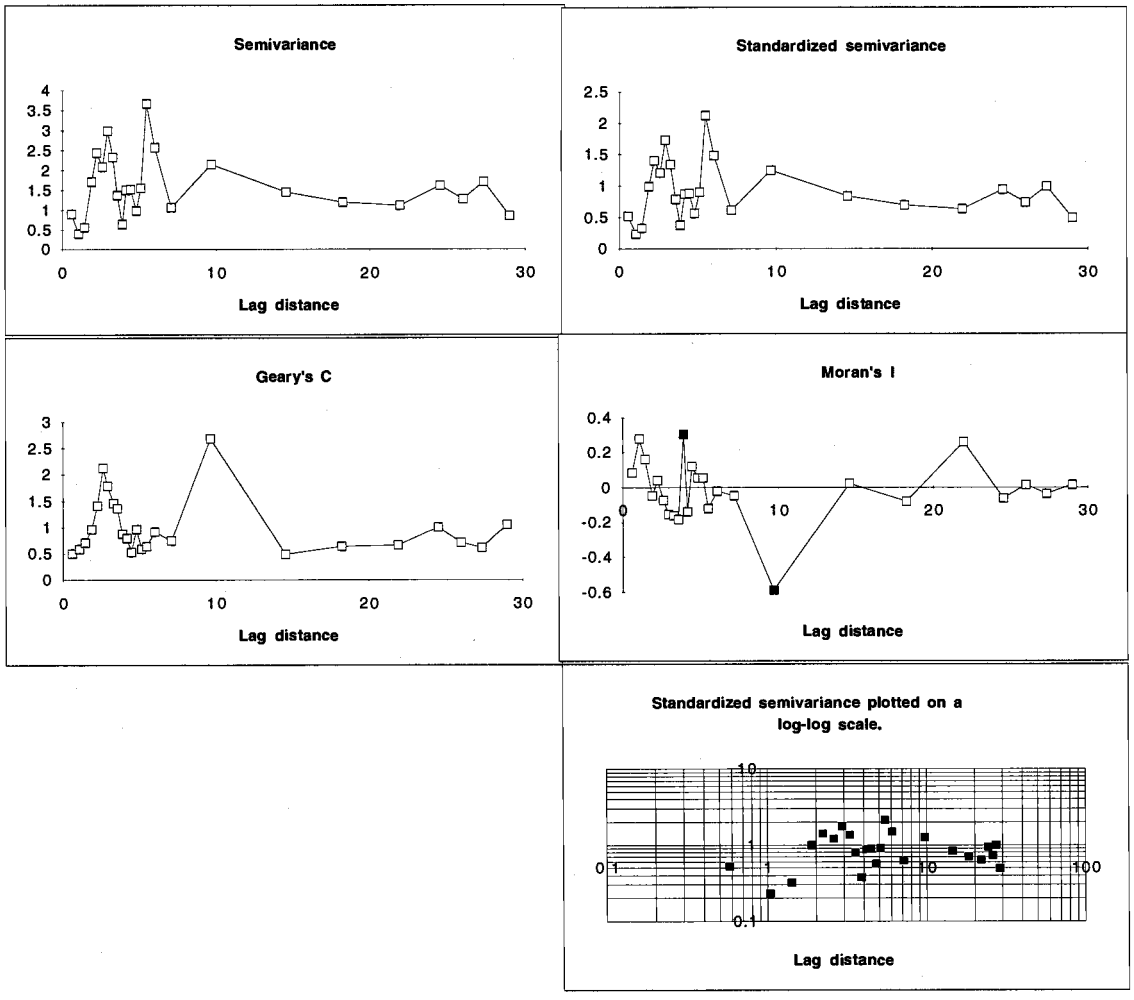
d. Initial nitrogen as NH4, plot f, observations 40,46 and 50 removed as outliers.

Figure B.3 continued



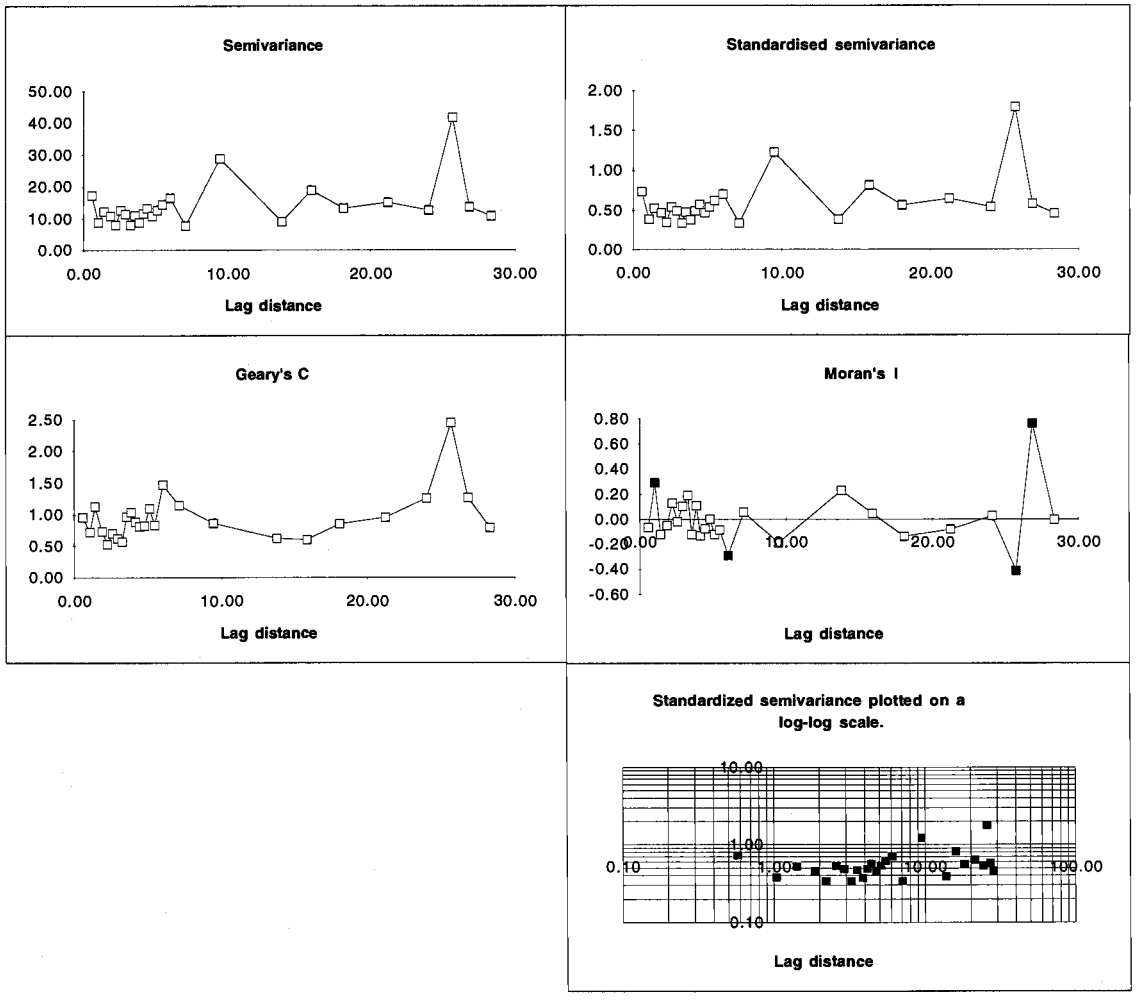
e. Mineralized Nitrogen as NH4, plot F, December 1991, juniper-sagebrush-grass community.

Figure B.3 continued



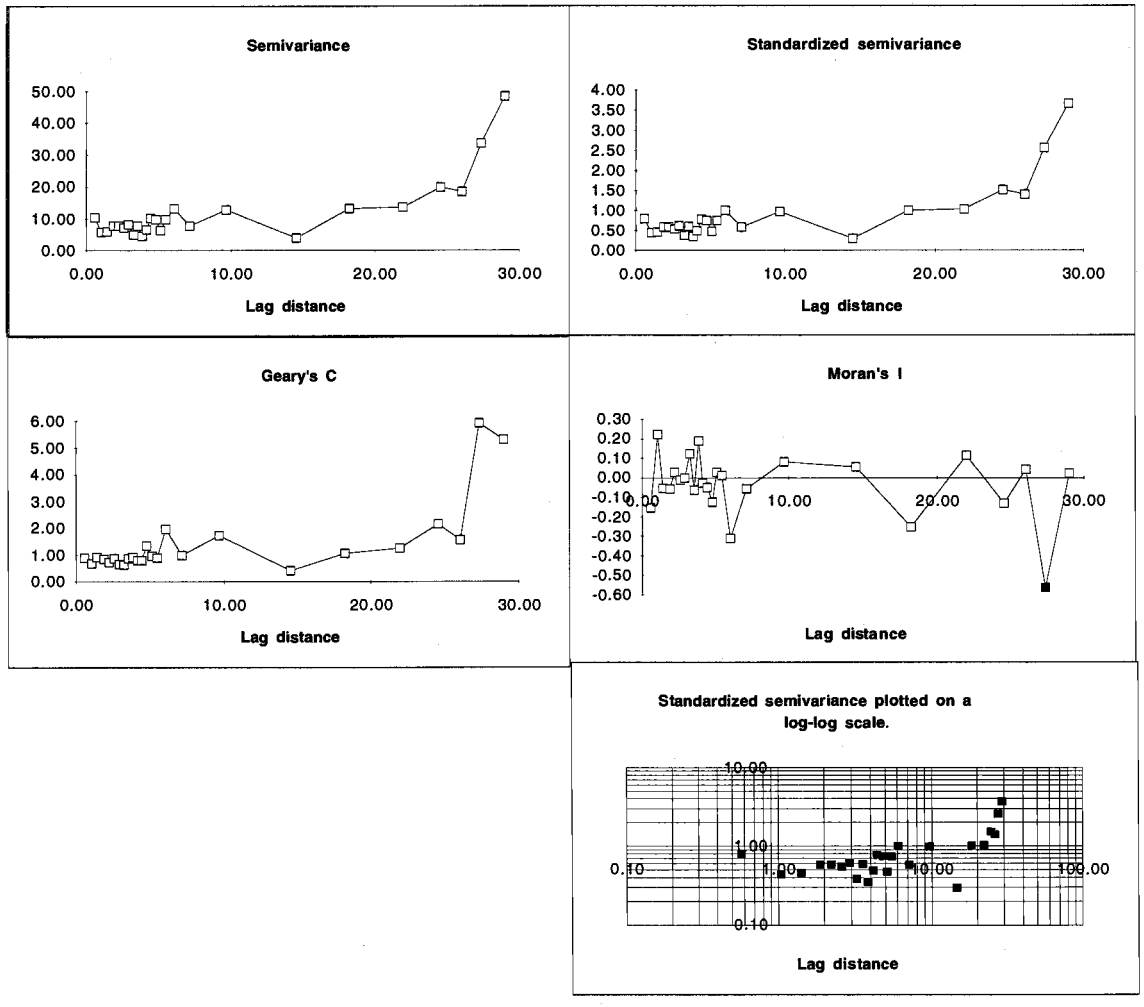
f. Initial Nitrogen as NO3, plot F, observations 46 and 50 removed as outliers.

Figure B.3 continued



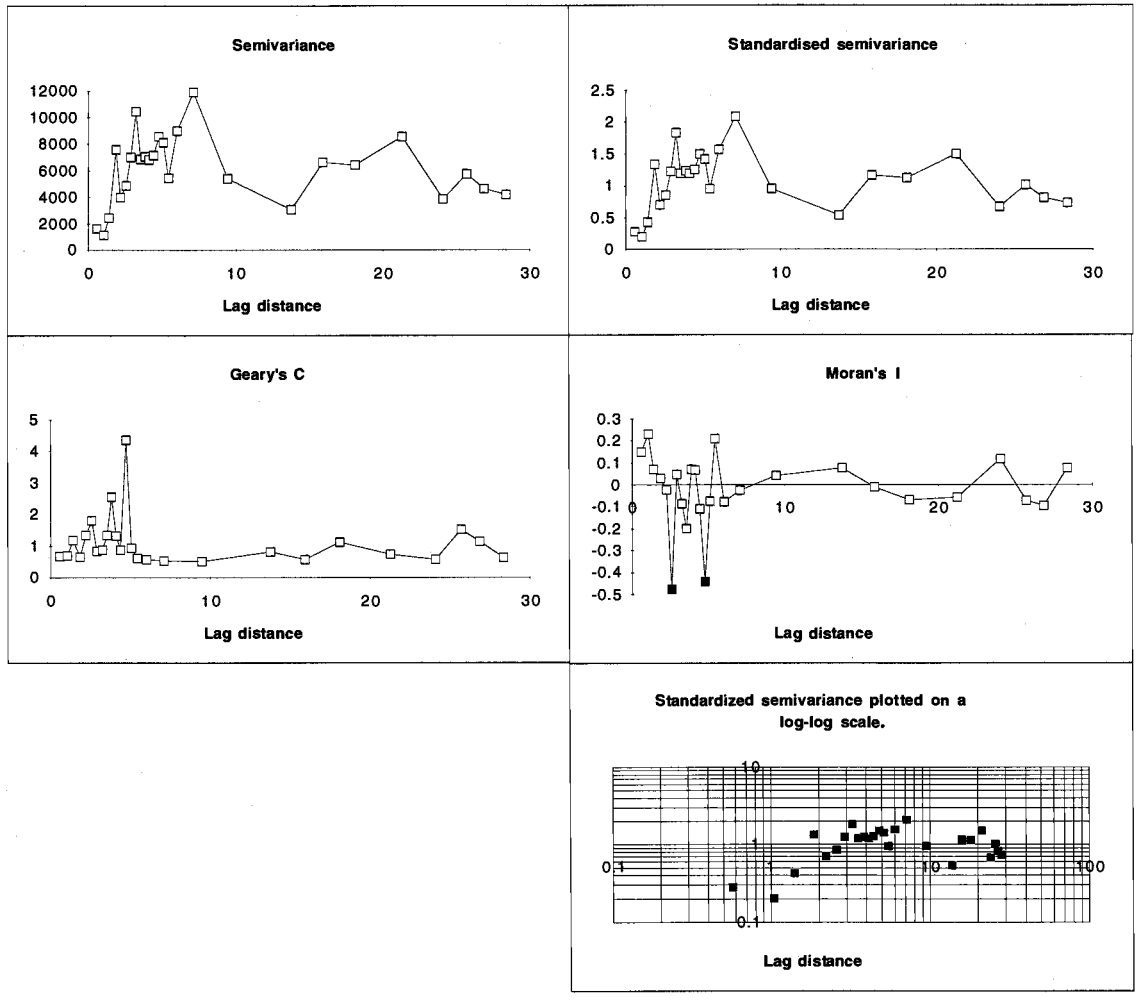
g. Mineralized Nitrogen as NO3, plot F, December 1991, juniper-sagebrush-grass community.

Figure B.3 continued



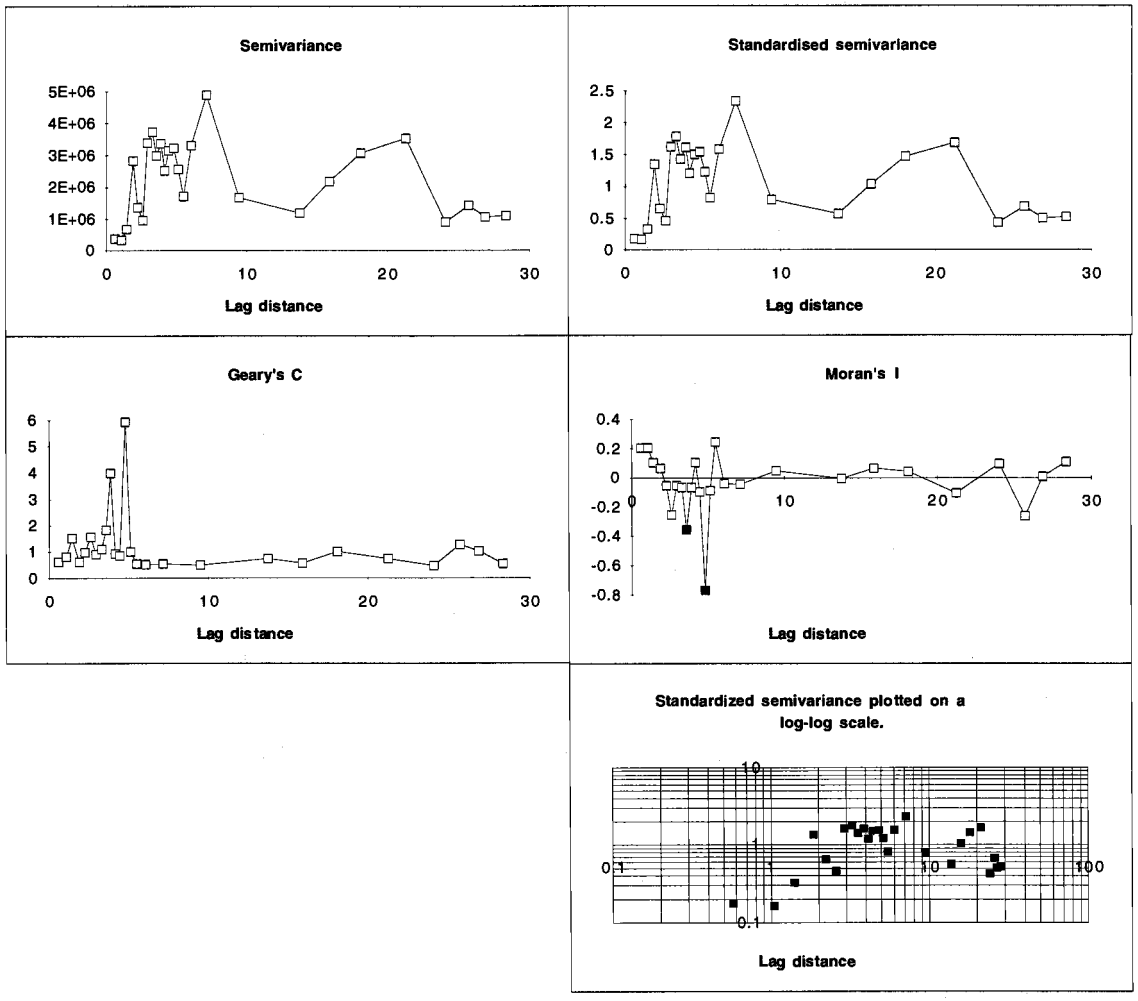
h. Net Nitrogen mineralization, plot F, observations 46 and 50 removed as outliers

Figure B.3 continued



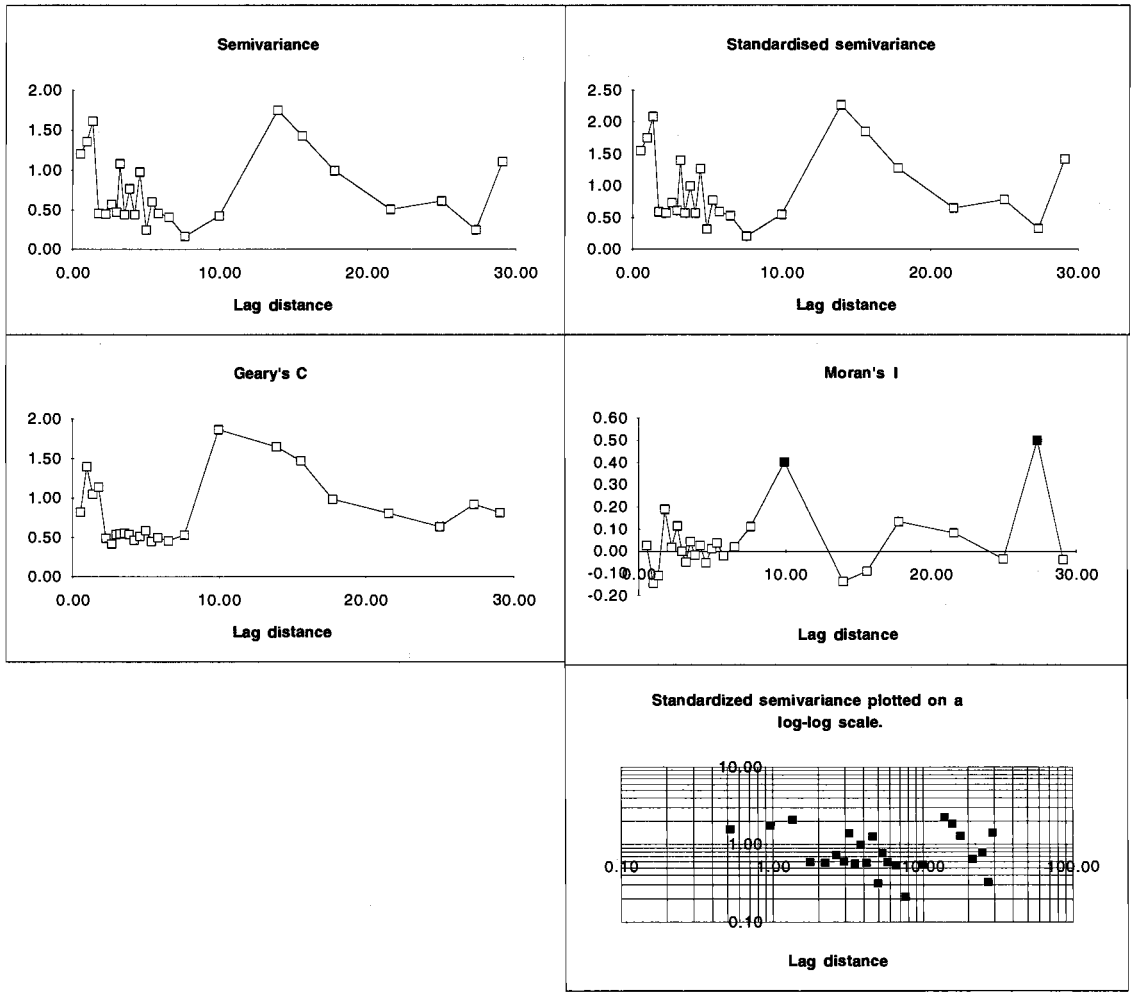
i. Total numbers of soil arthropods, plot F, December 1991, juniper-sagebrush-grass community.

Figure B.3 continued



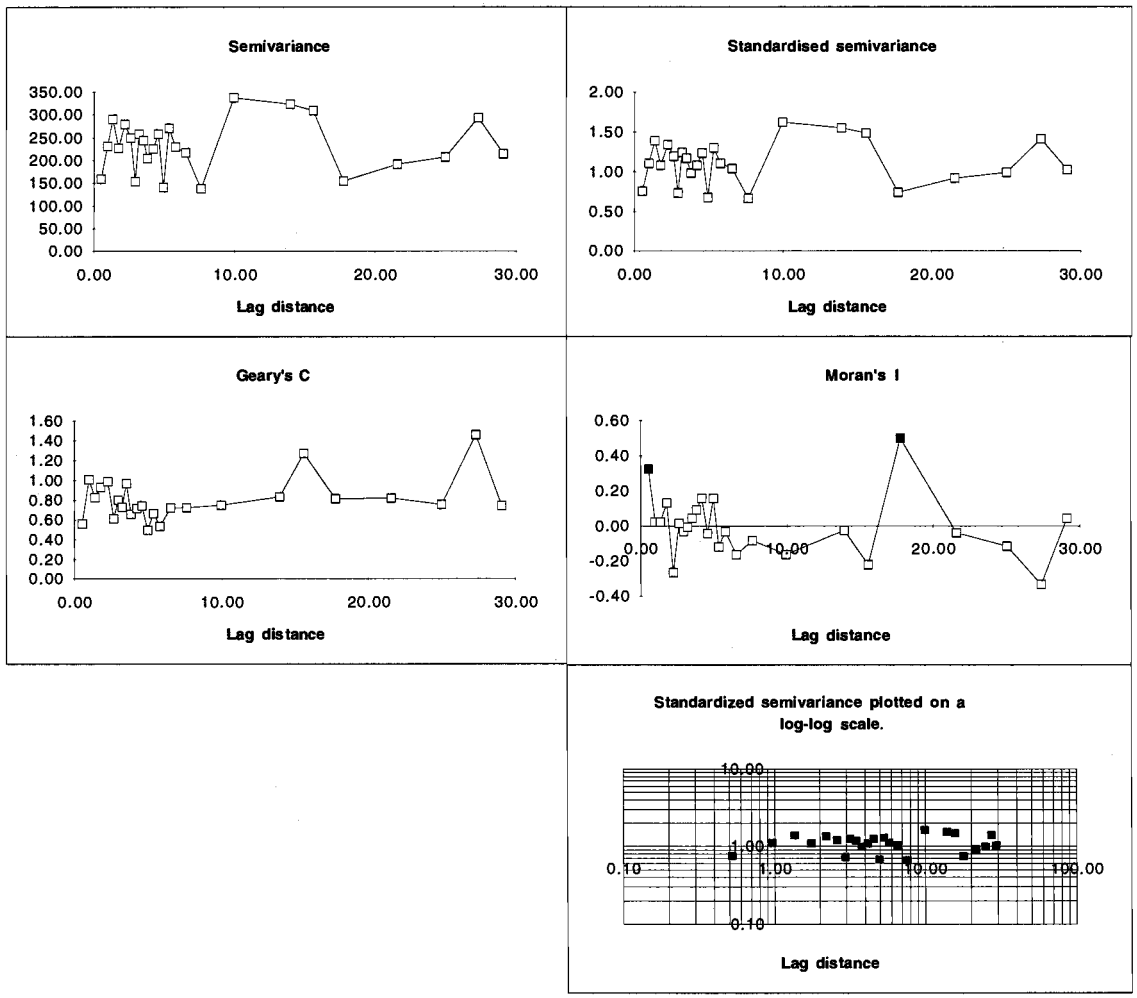
j. Figure Biomass of micro-arthropods, May 1992, plot G, juniper-sagebrush-grass community.

Figure B.3 continued



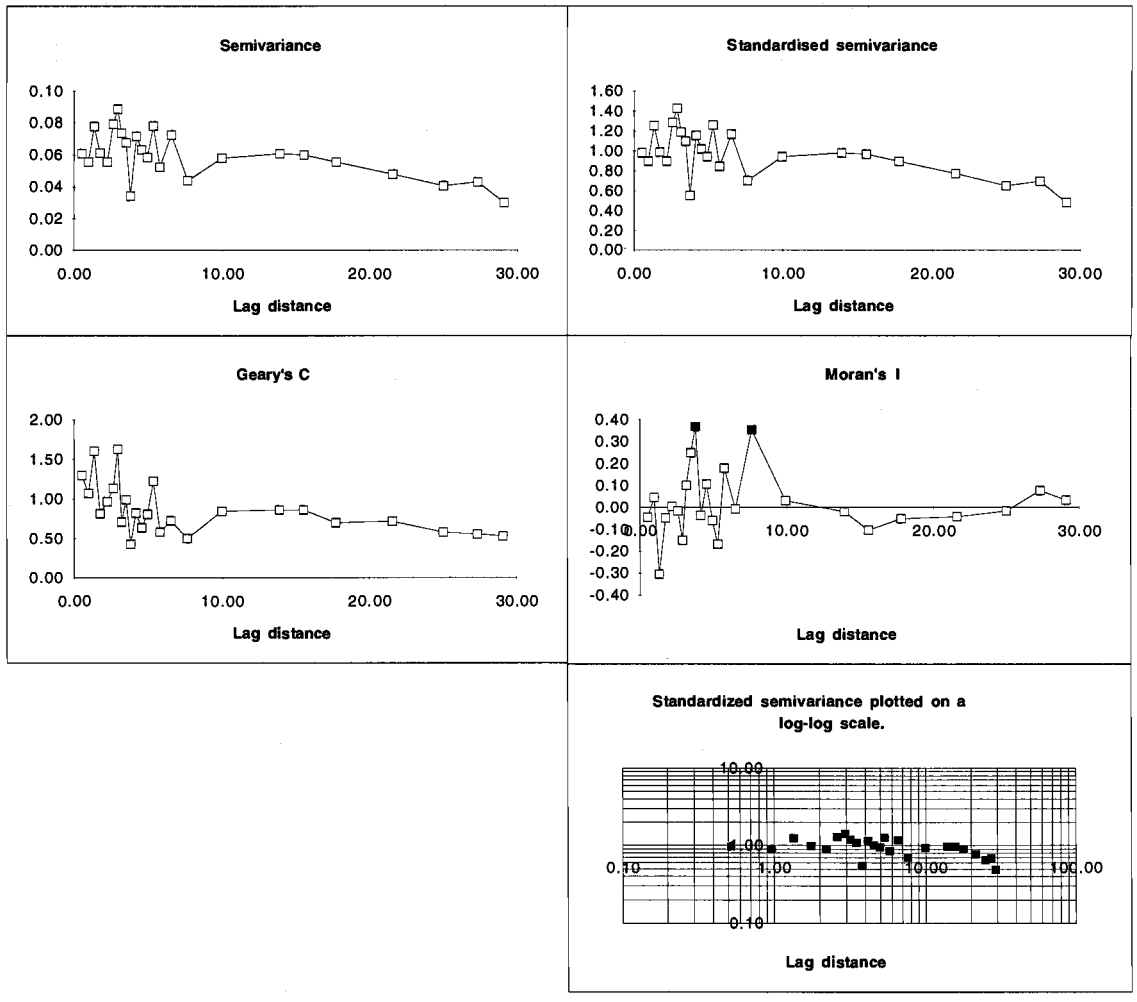
a. Moisture, plot G, May1992, juniper-sagebrush-grass community.

Figure B.4



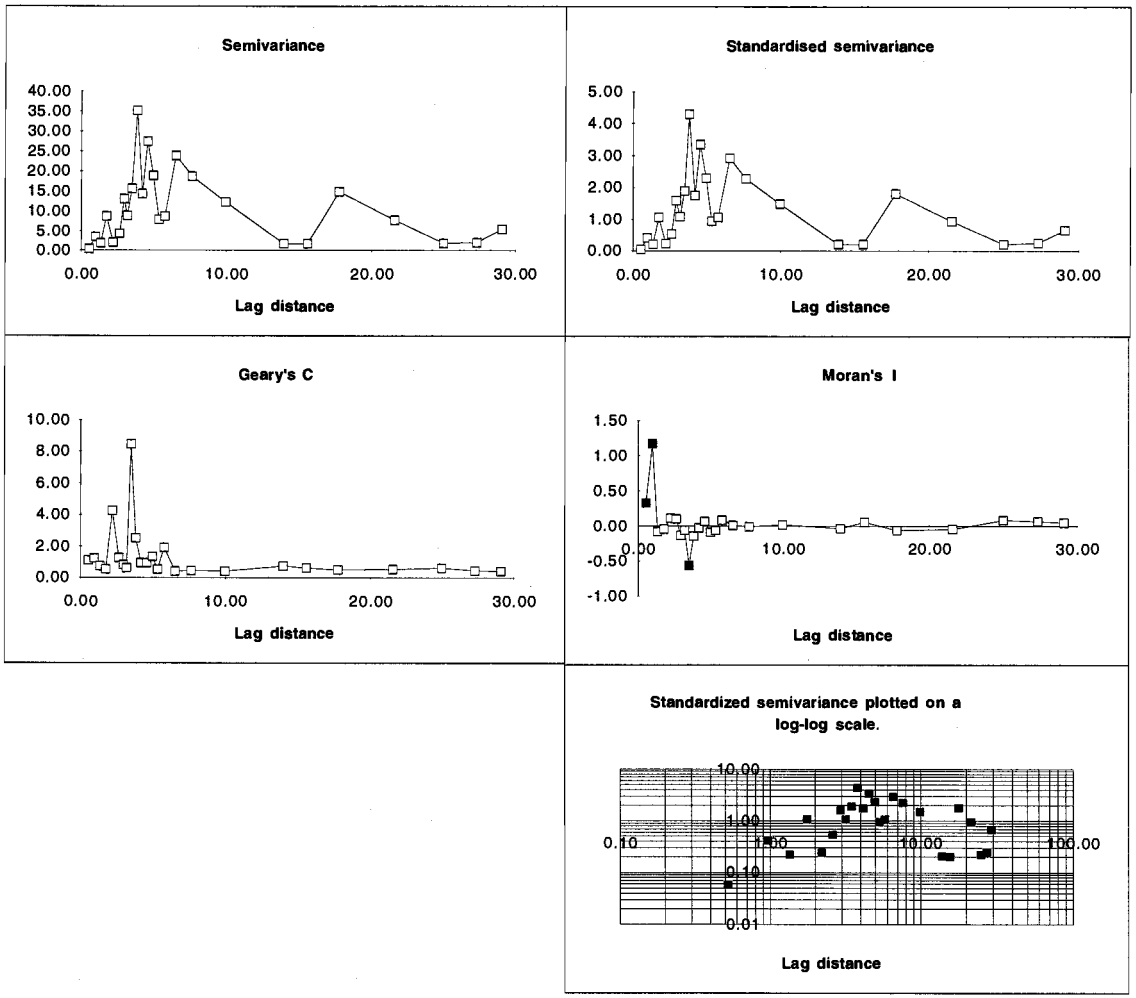
b. V.A. mycorrhizal infection, plot G, May 1992, juniper-sagebrush-grass community.

Figure B.4 continued



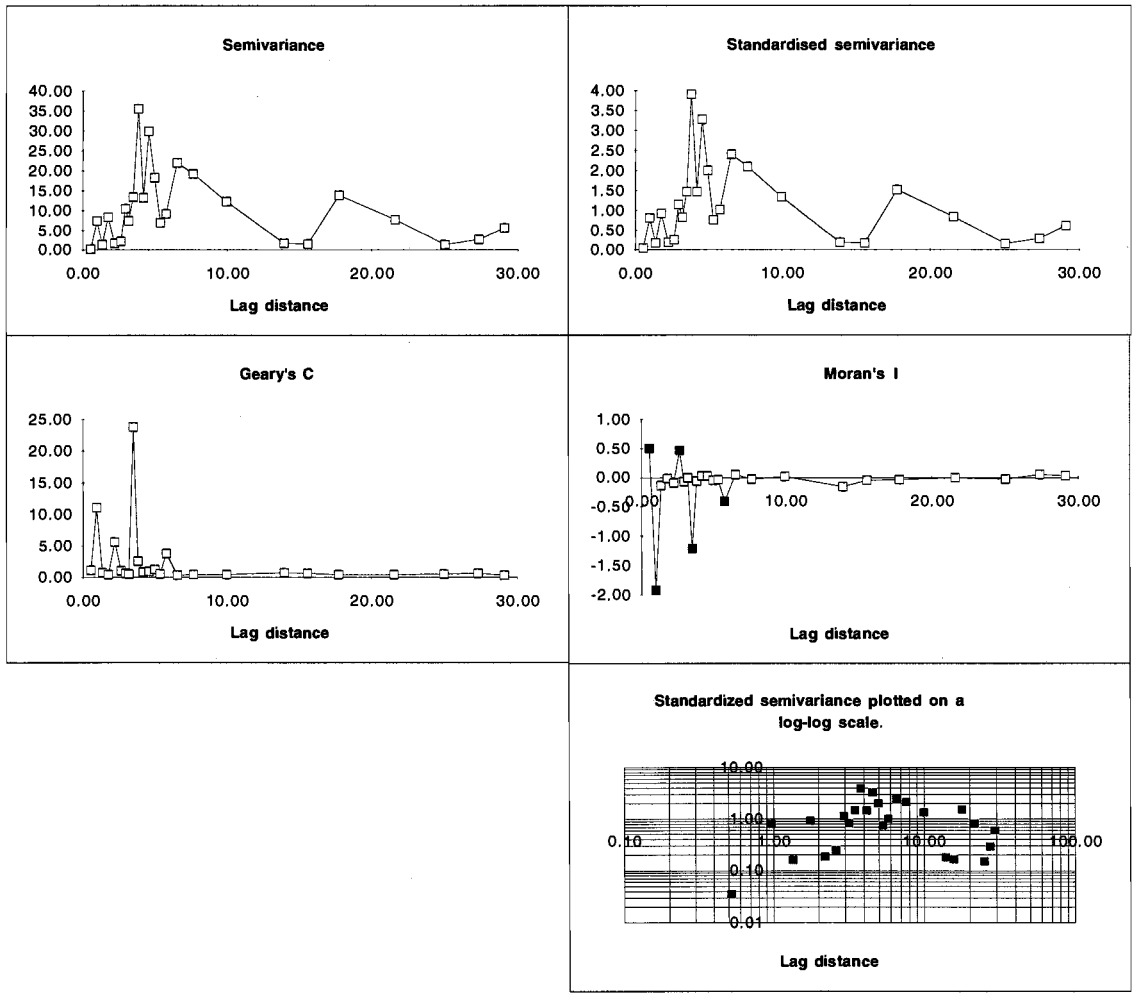
c. PH, plot G, May 1992, juniper-sagebrush-grass community.

Figure B.4 continued



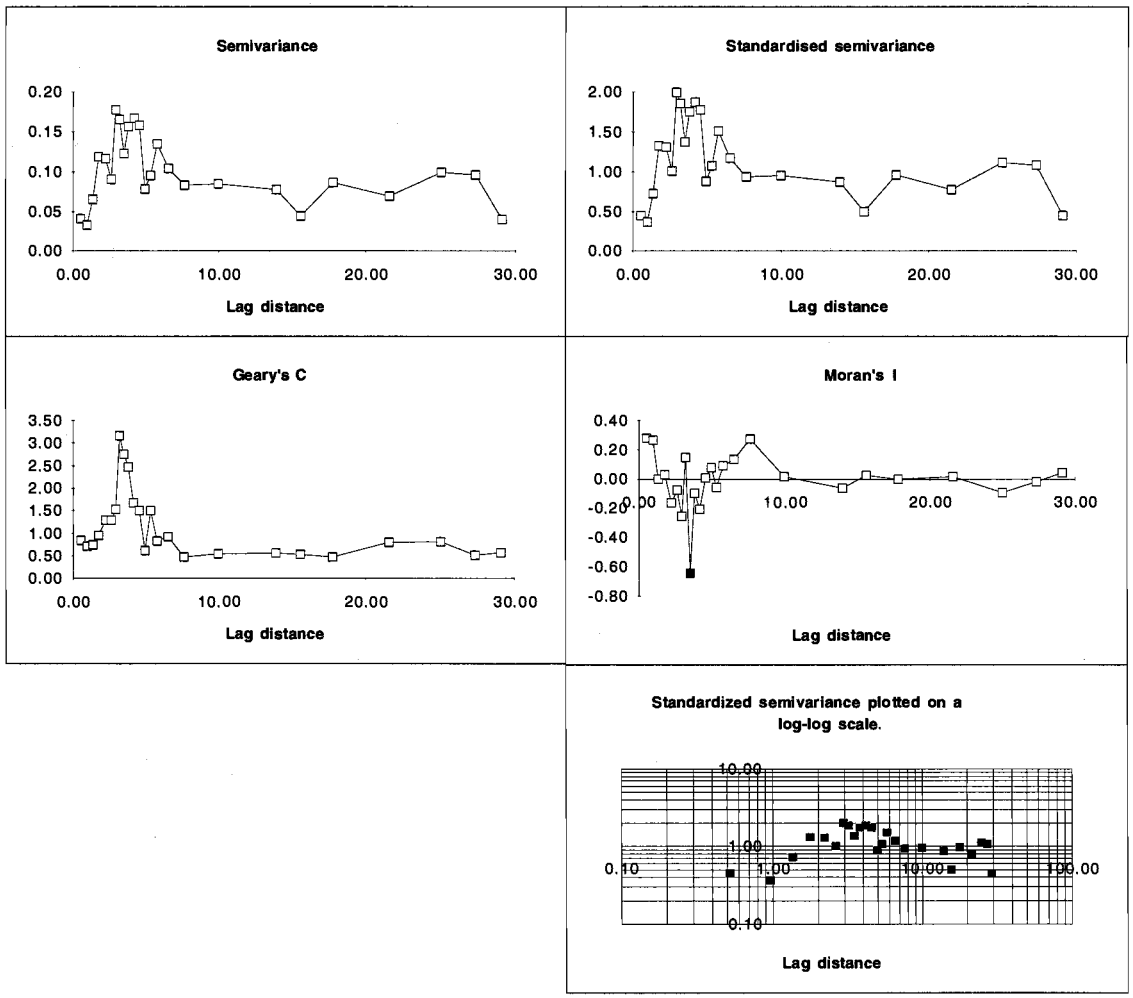
d. Initial Nitrogen as NH4, plot G, May 1992, juniper-sagebrush-grass community.

Figure B.4 continued



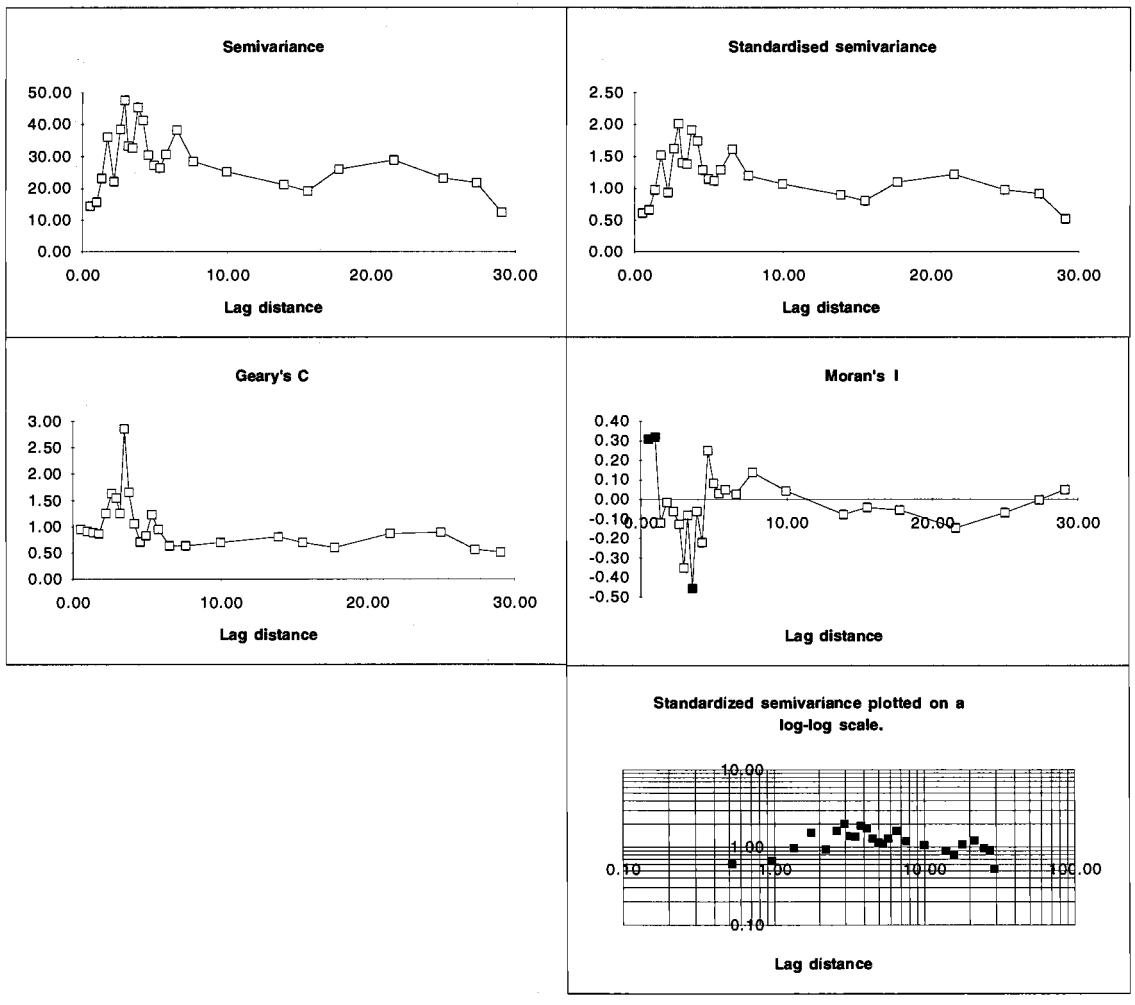
e. Mineralized Nitrogen as NH4, plot G, May 1992, juniper-sagebrush-grass community.

Figure B.4 continued



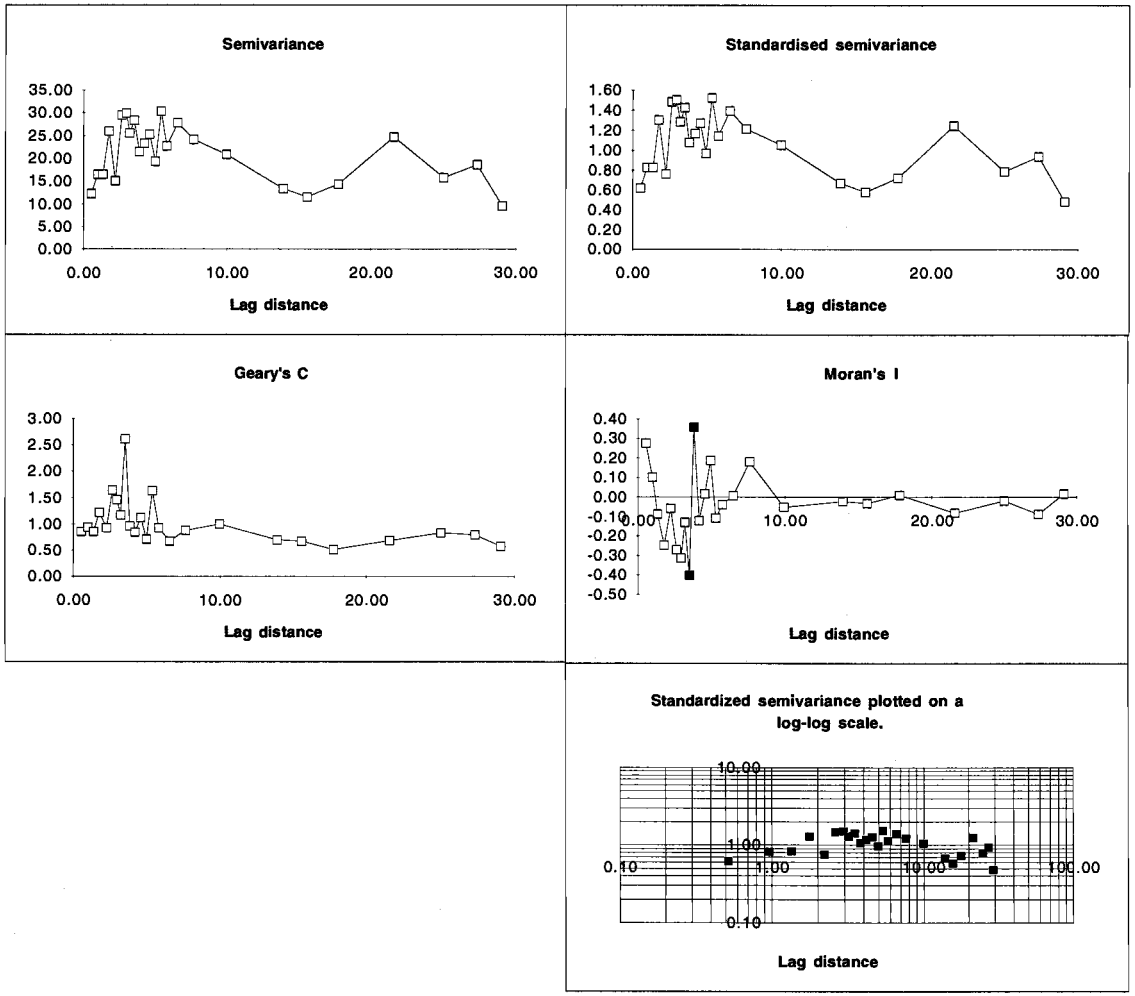
f. Initial Nitrogen as NO3, plot G, May 1992, juniper-sagebrush-grass community.

Figure B.4 continued



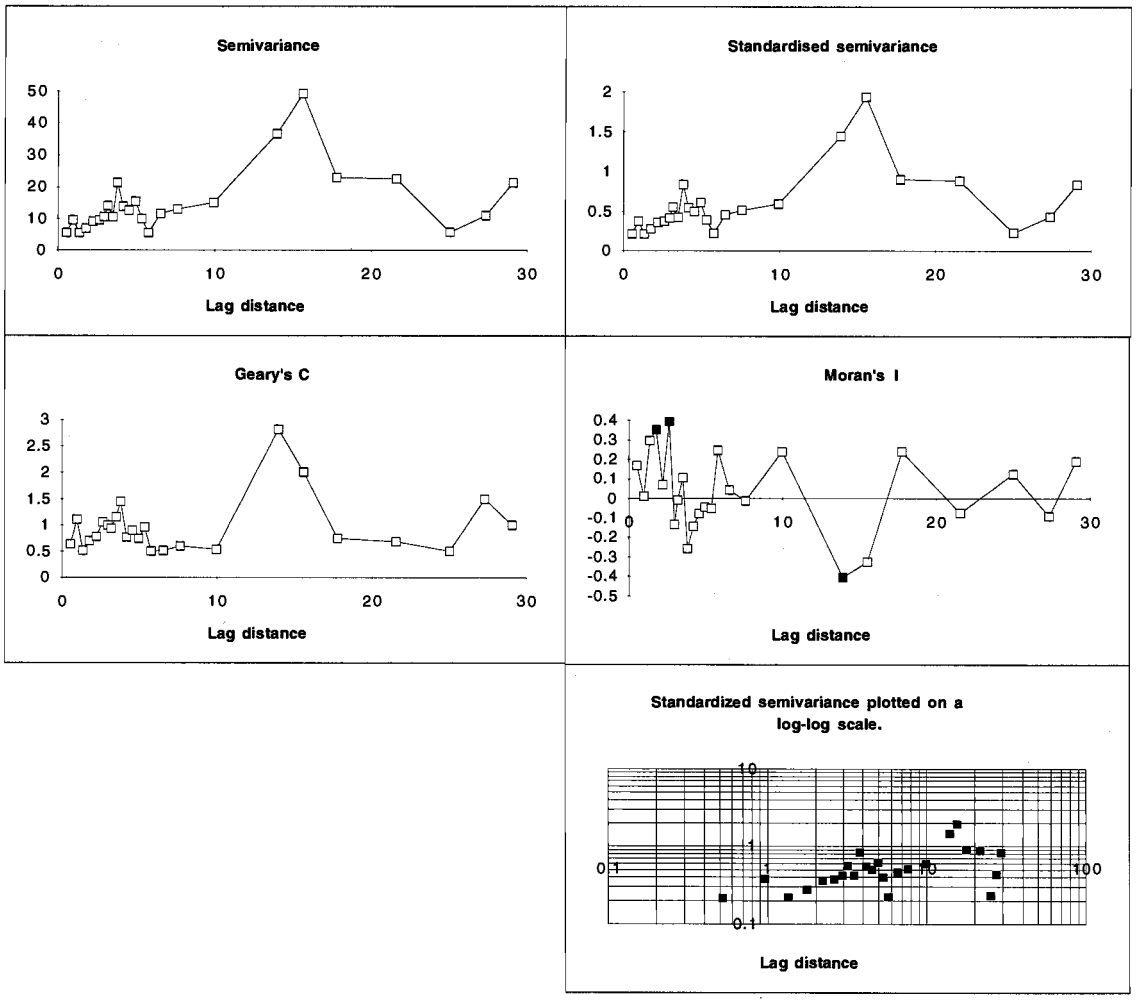
g. Mineralized Nitrogen as NO3, plot G, May 1992, juniper-sagebrush-grass community.

Figure B.4 continued



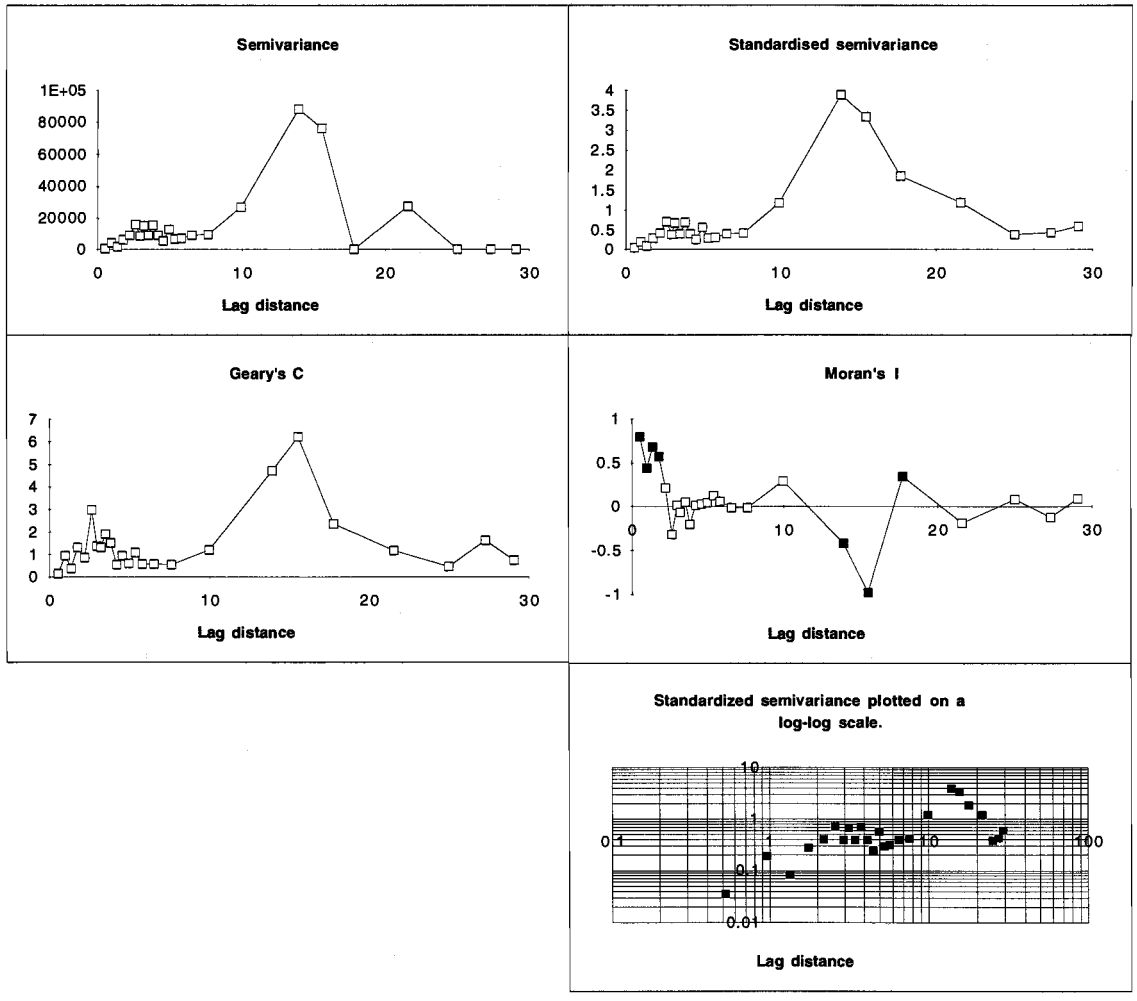
h. Net Nitrogen mineralized, plot G, May 1992, juniper-sagebrush-grass community.

Figure B.4 continued



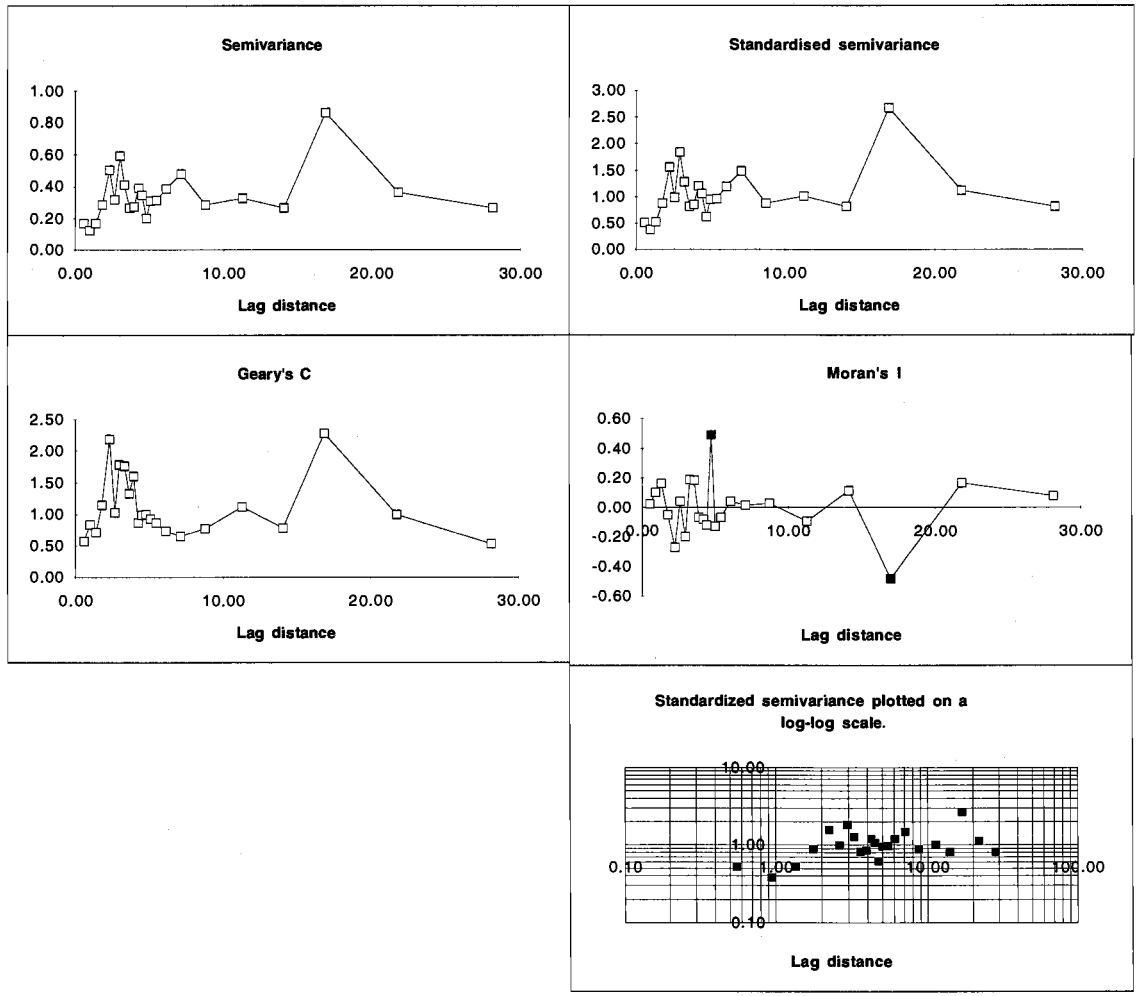
i. Total numbers of soil arthropods, May 1992, plot G, juniper-sagebrush-grass community.

Figure B.4 continued



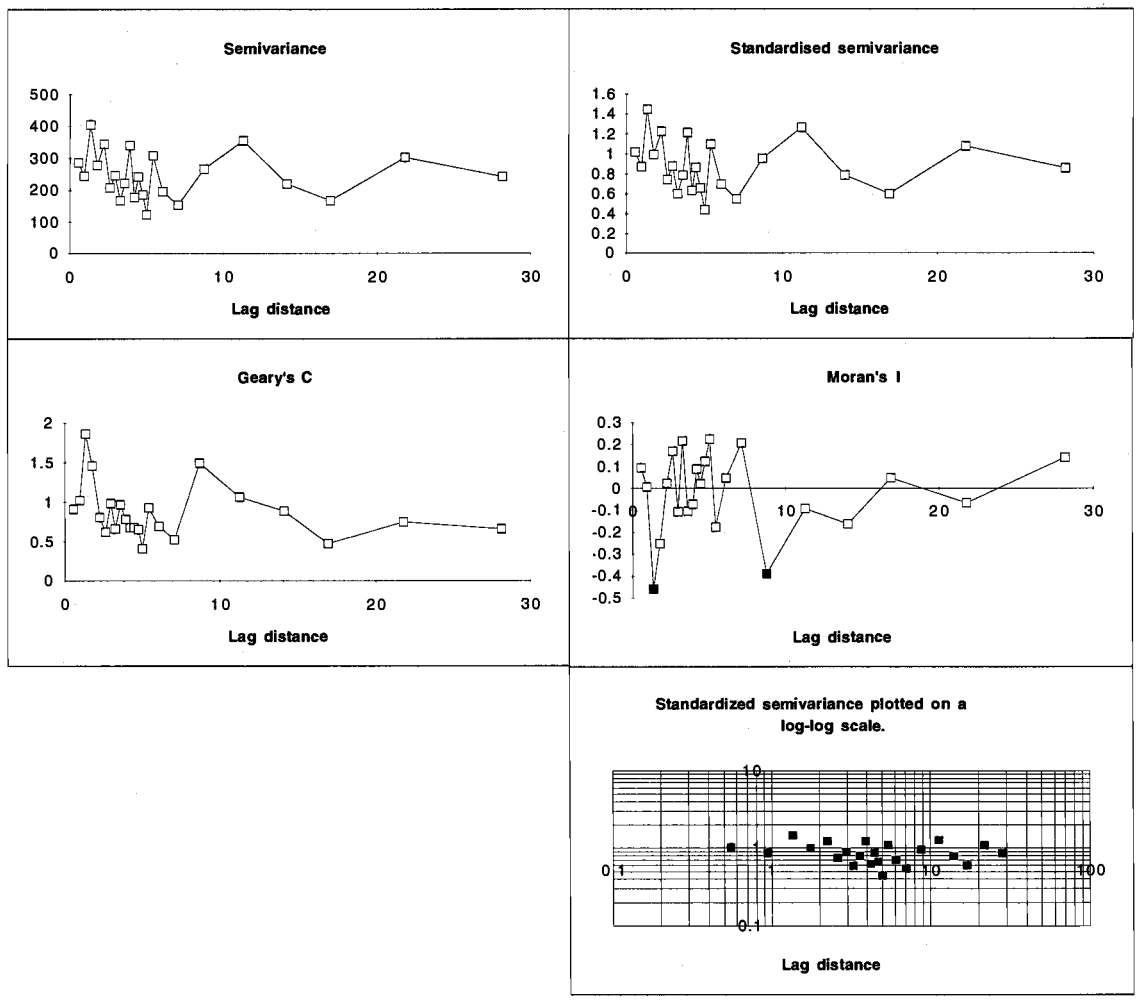
j. Figure Biomass of micro-arthropods, May 1992, plot G, juniper-sagebrush-grass community.

Figure B.4 continued



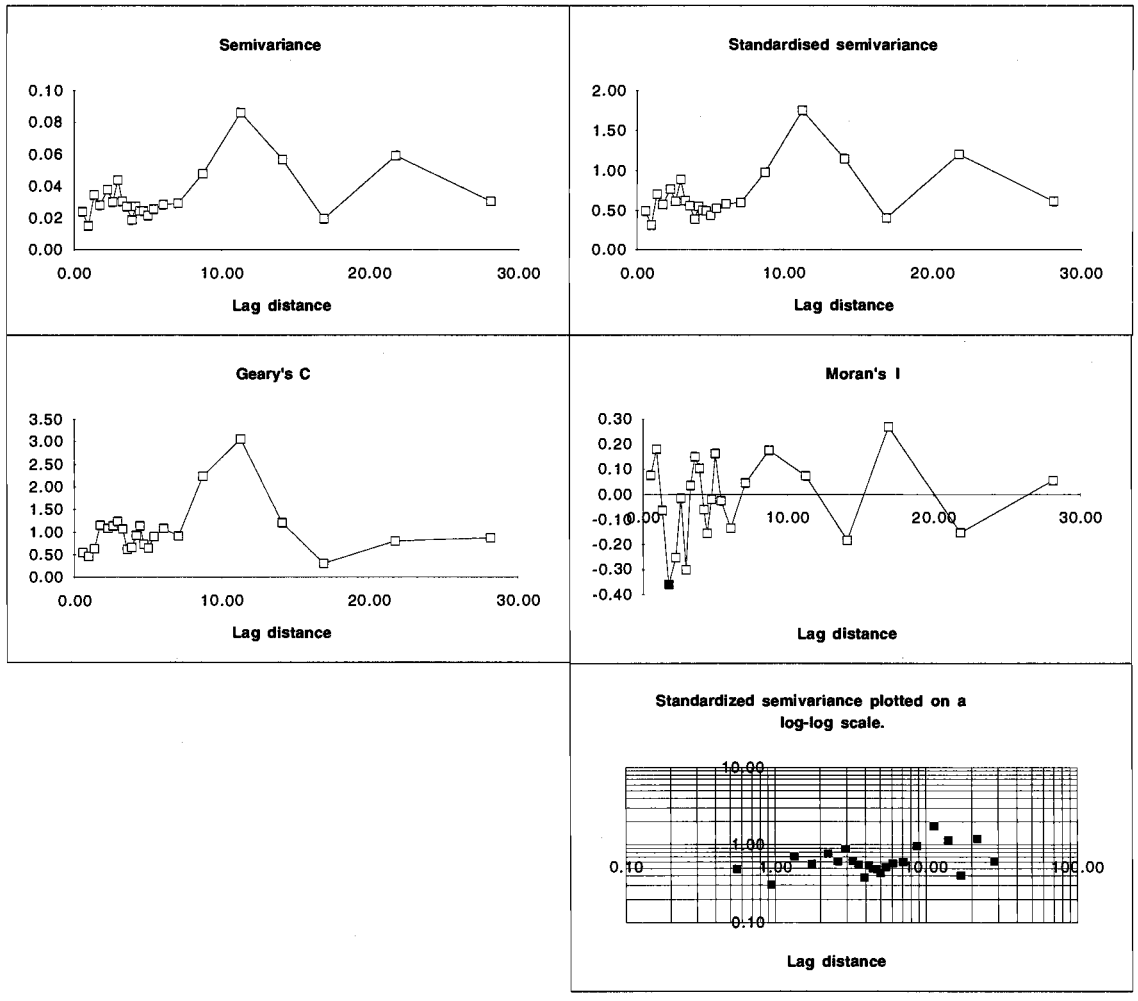
a. Moisture, plot H, May1992, sagebrush-grass community.

Figure B.5



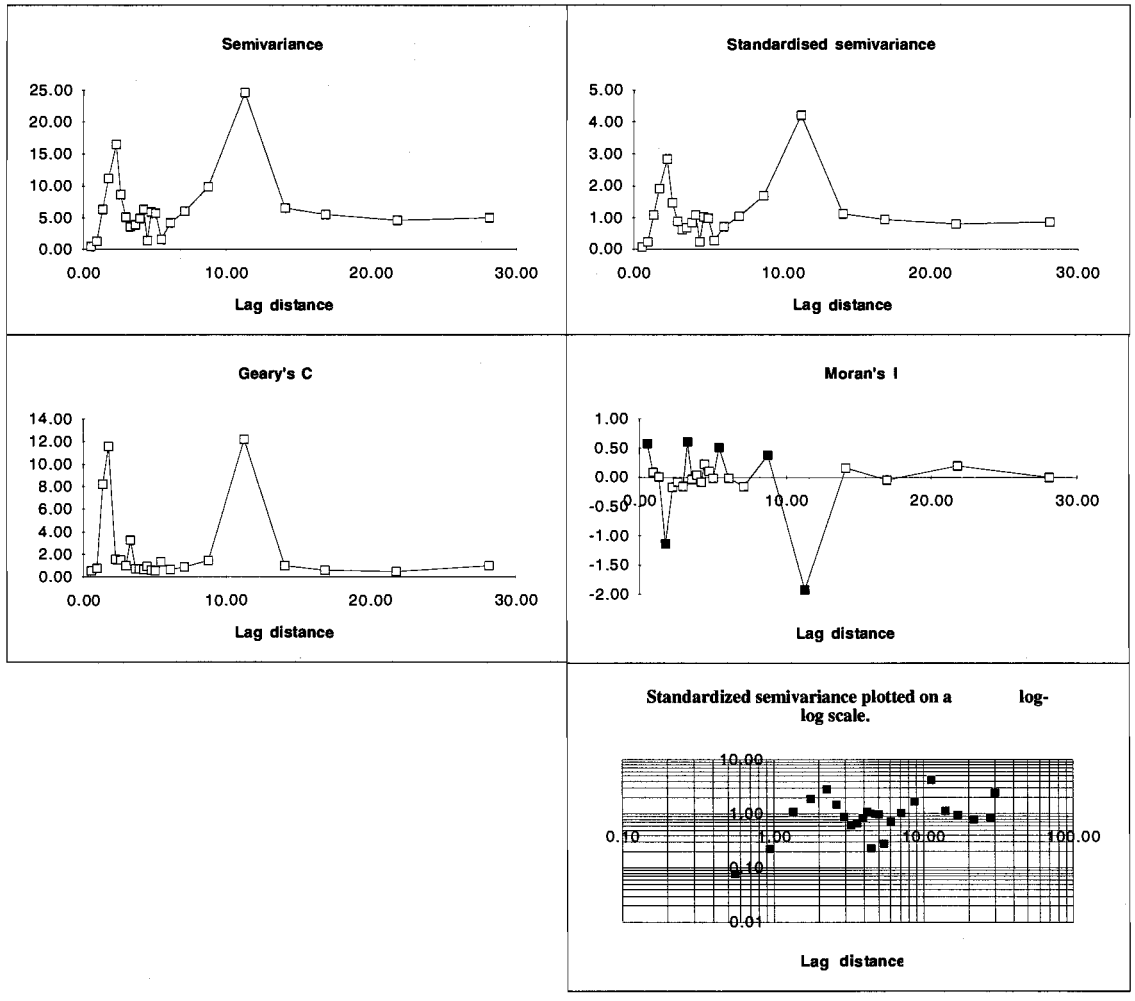
b. V.A. mycorrhizal infection, plot H, May 1992, sagebrush-grass community.

Figure B.5 continued



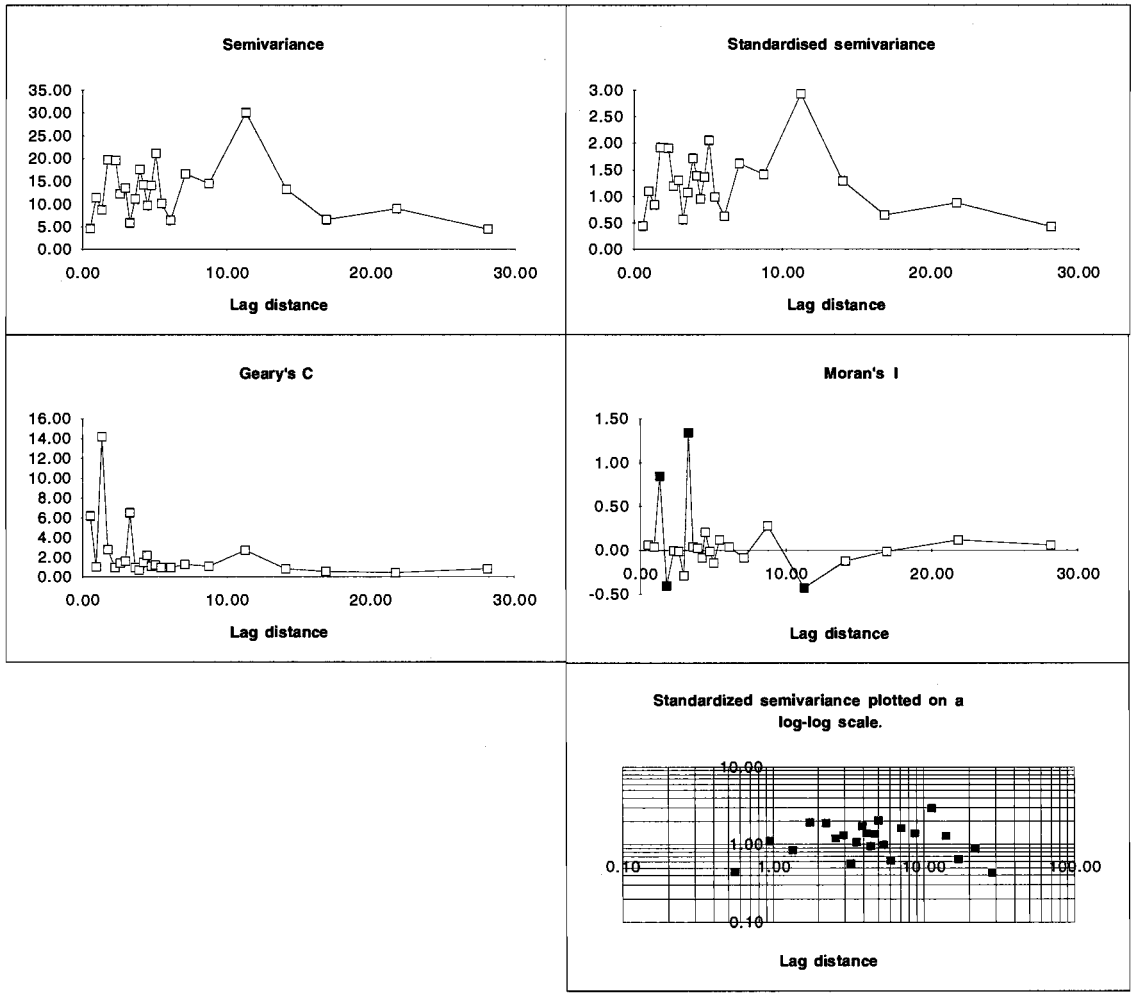
c. PH, plot H, May 1992, sagebrush-grass community.

Figure B.5 continued



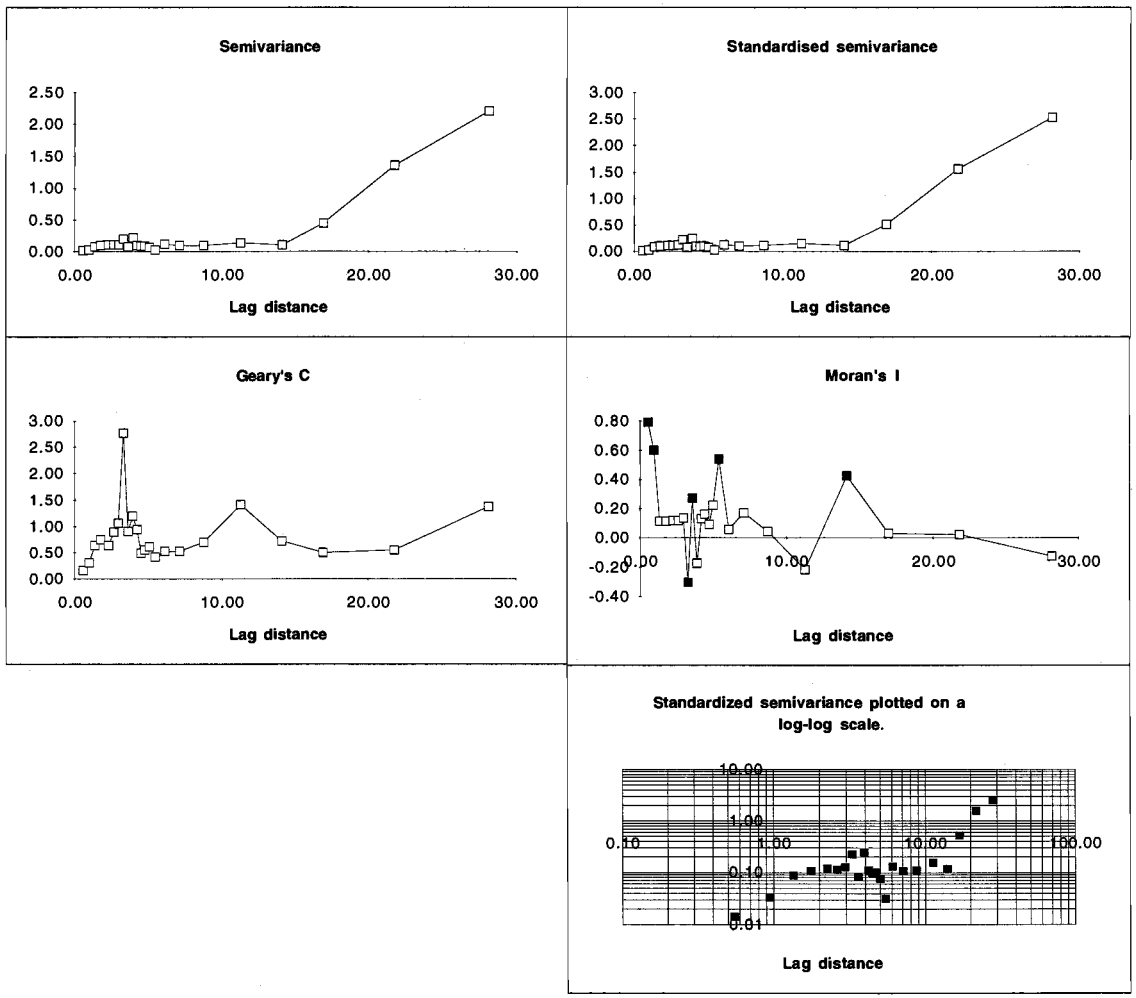
d. Initial Nitrogen as NH4, plot H, May 1992, sagebrush-grass community.

Figure B.5 continued



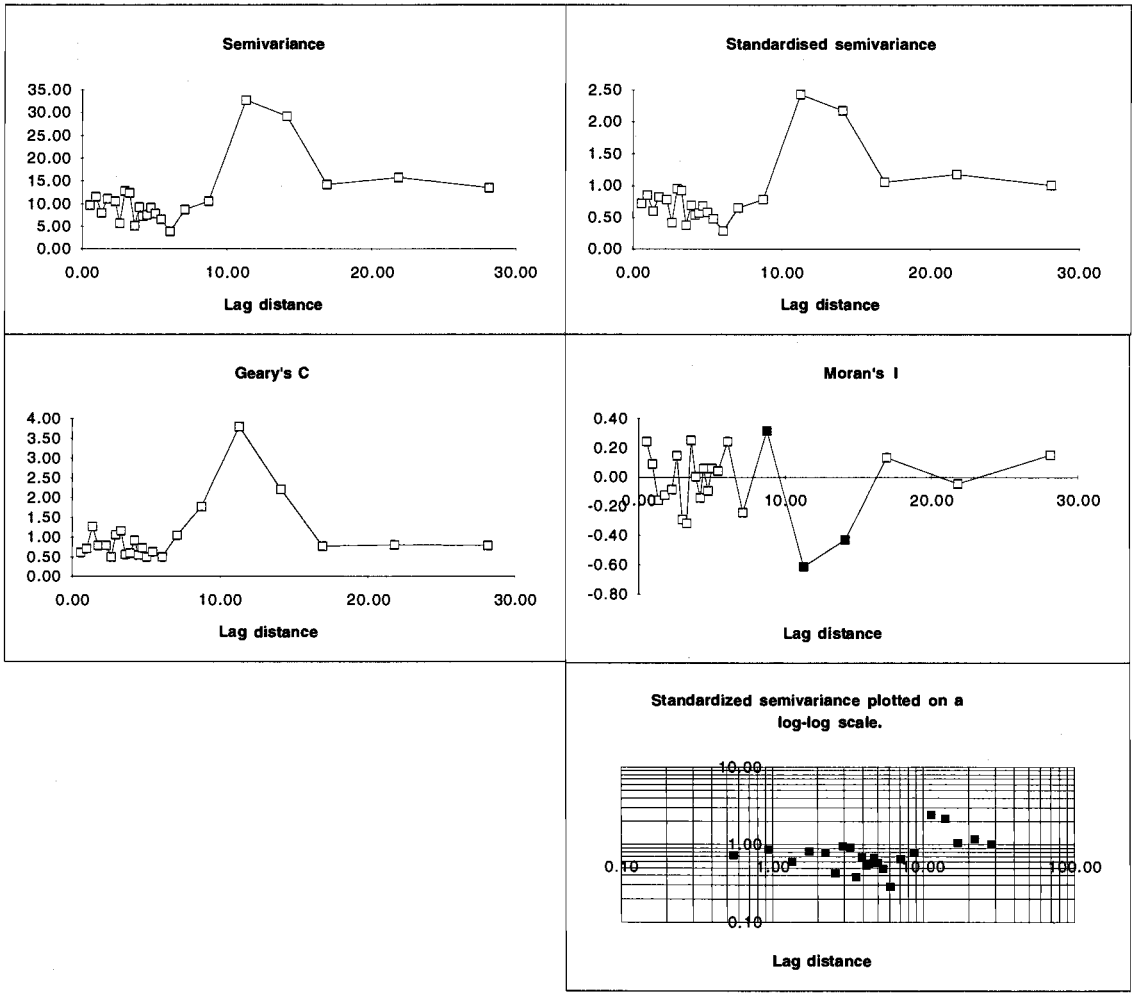
e. Mineralized Nitrogen as NH4, plot H, May 1992, sagebrush-grass community.

Figure B.5 continued



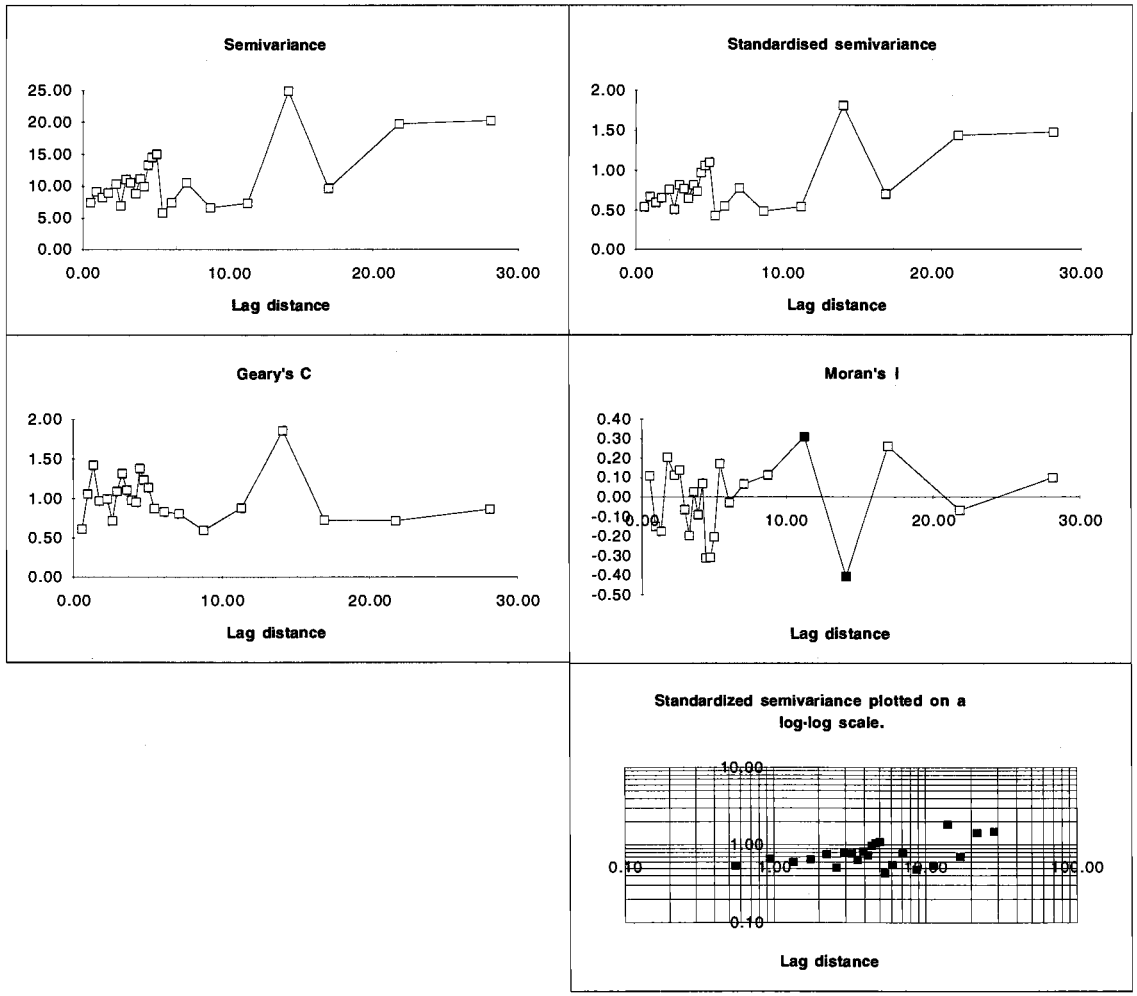
f. Initial Nitrogen as NO3, plot H, May 1992, sagebrush-grass community.

Figure B.5 continued



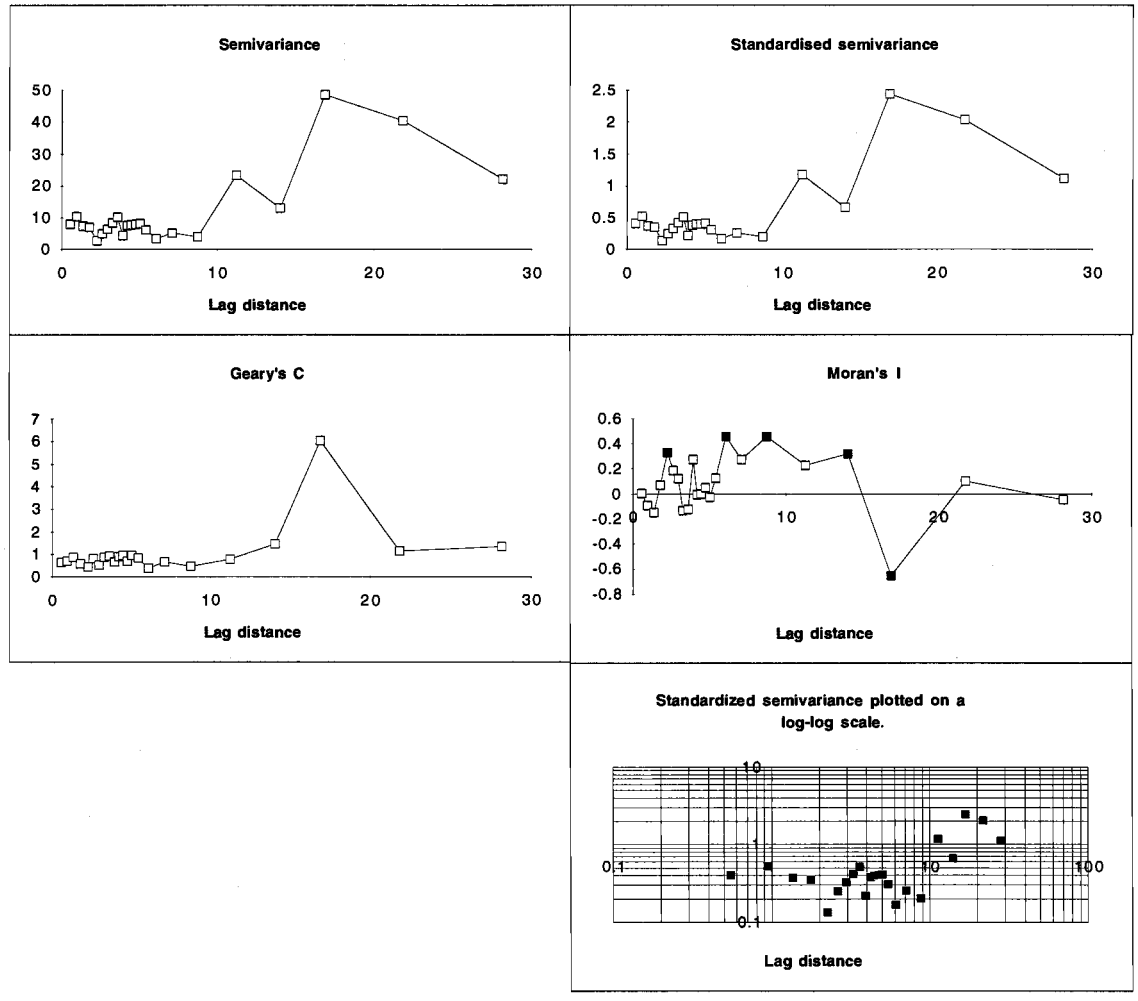
g. Mineralized Nitrogen as NO3, plot H, May 1992, sagebrush-grass community.

Figure B.5 continued



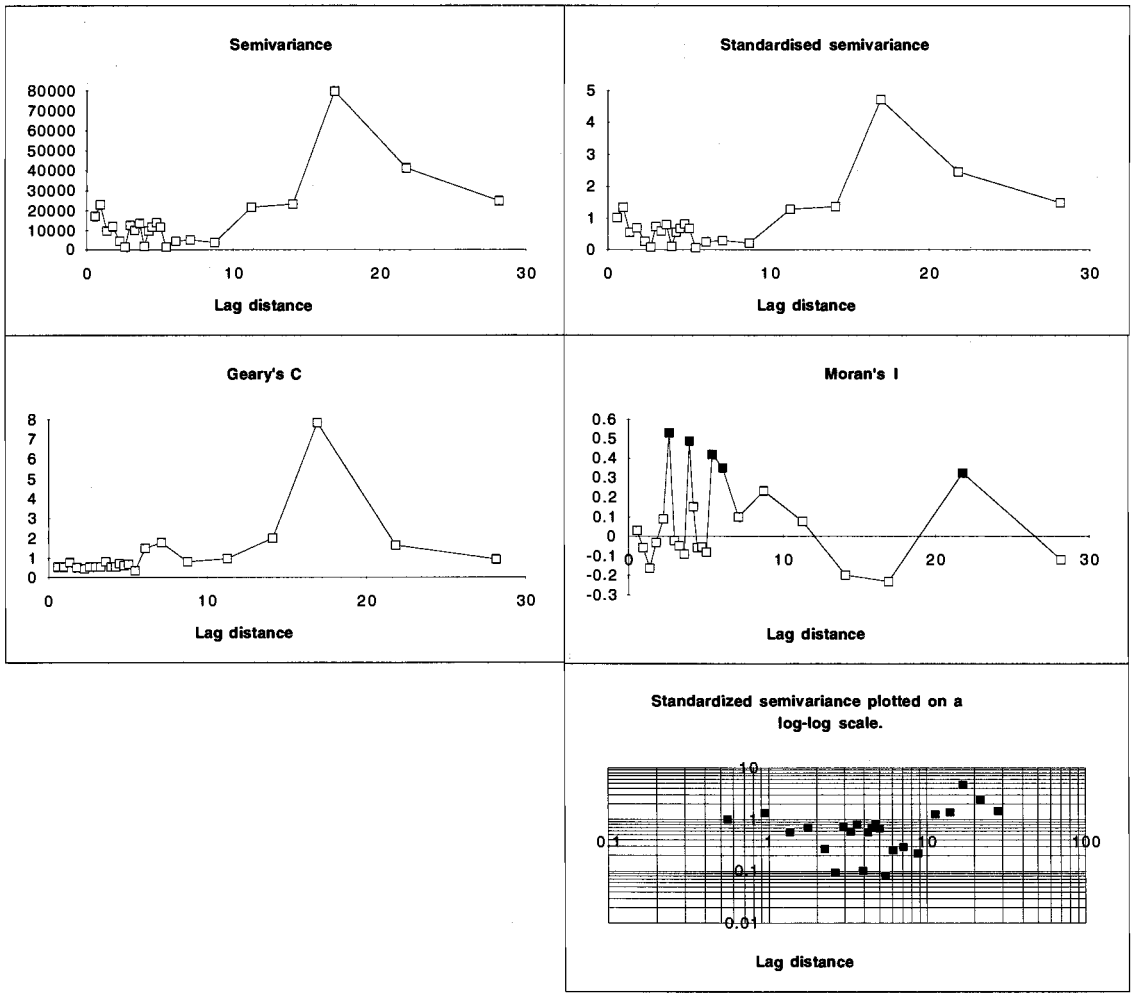
h. Net Nitrogen mineralized, plot H, May 1992, sagebrush-grass community.

Figure B.5 continued



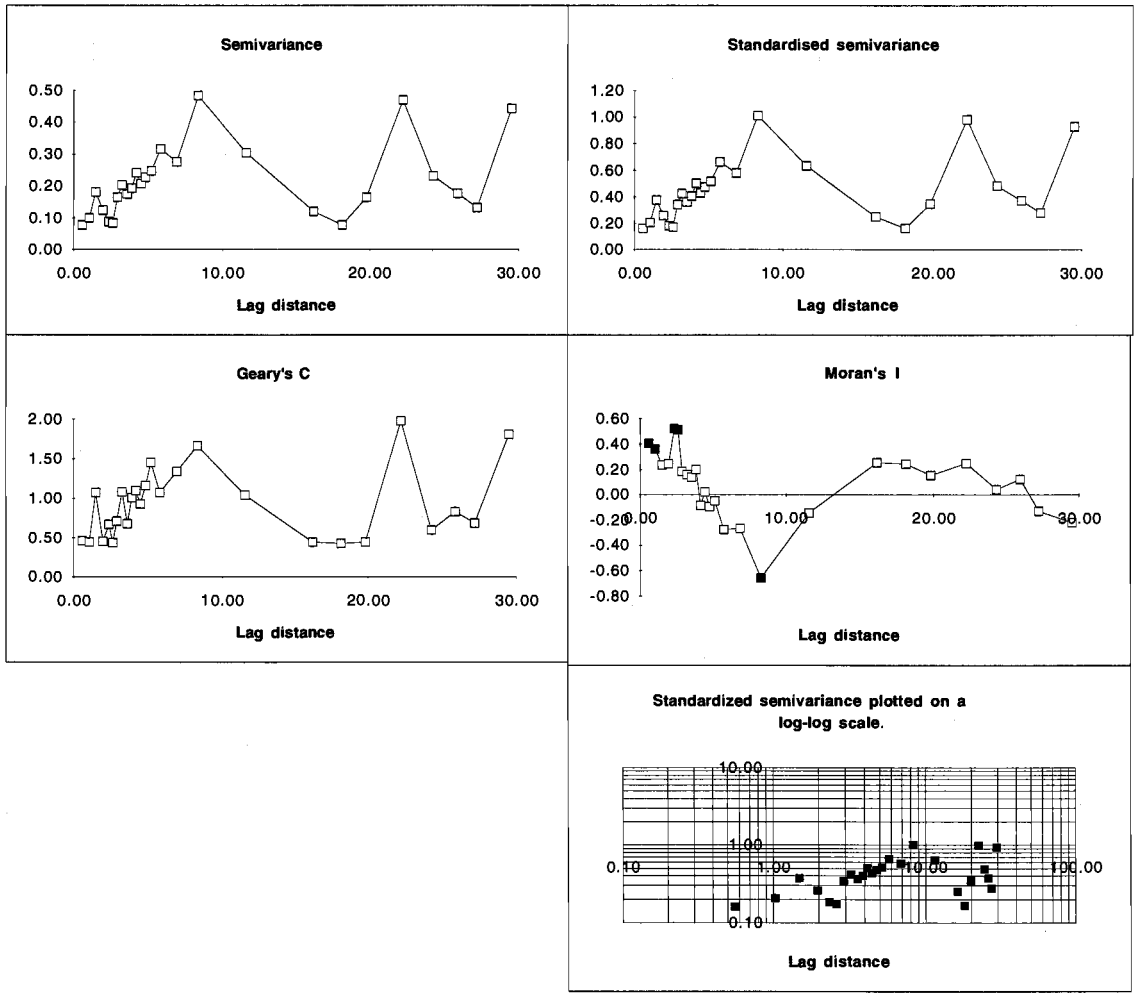
i. Total numbers of soil arthropods, May 1992, plot H, sagebrush-grass community.

Figure B.5 continued



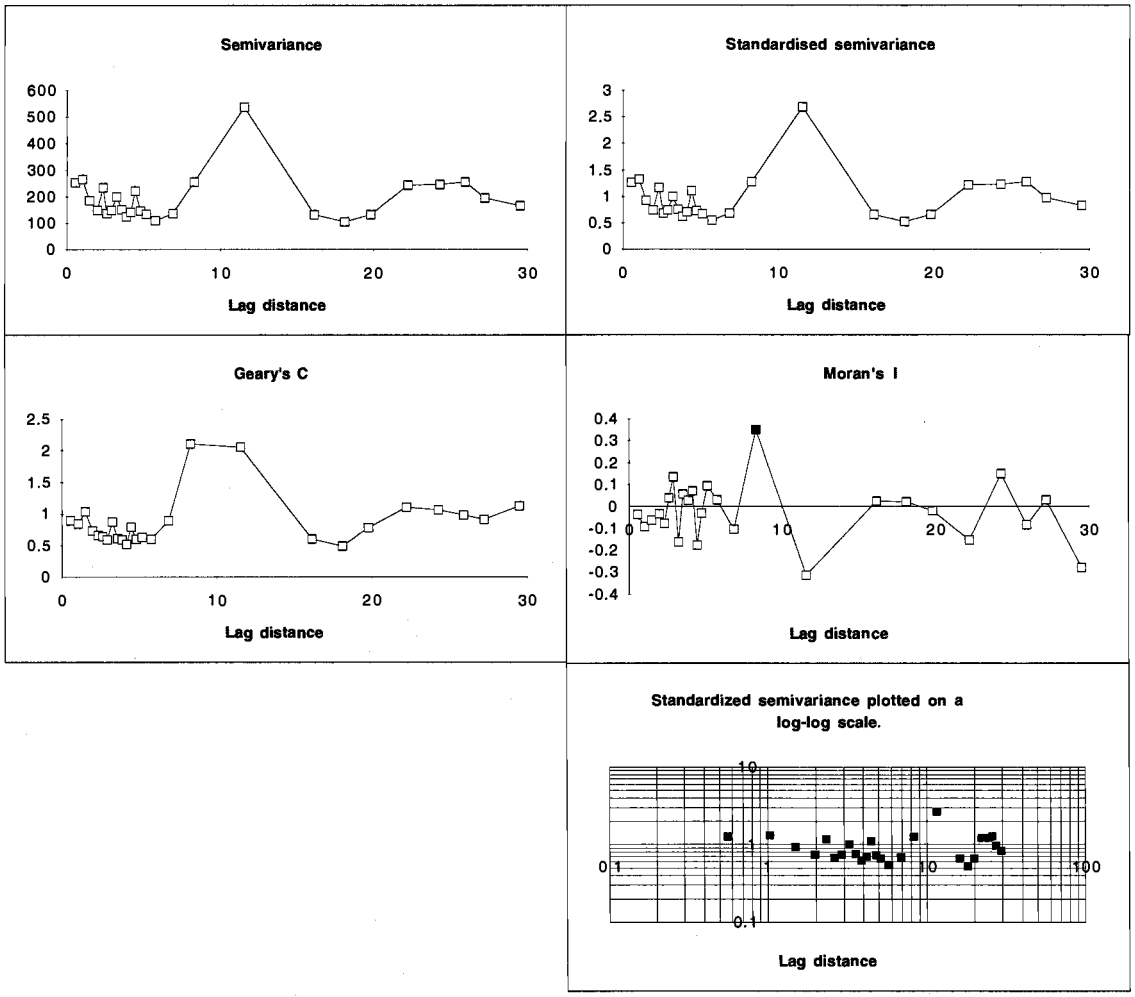
j. Biomass of micro-arthropods, May 1992, plot H, juniper-sagebrush-grass community.

Figure B.5 continued



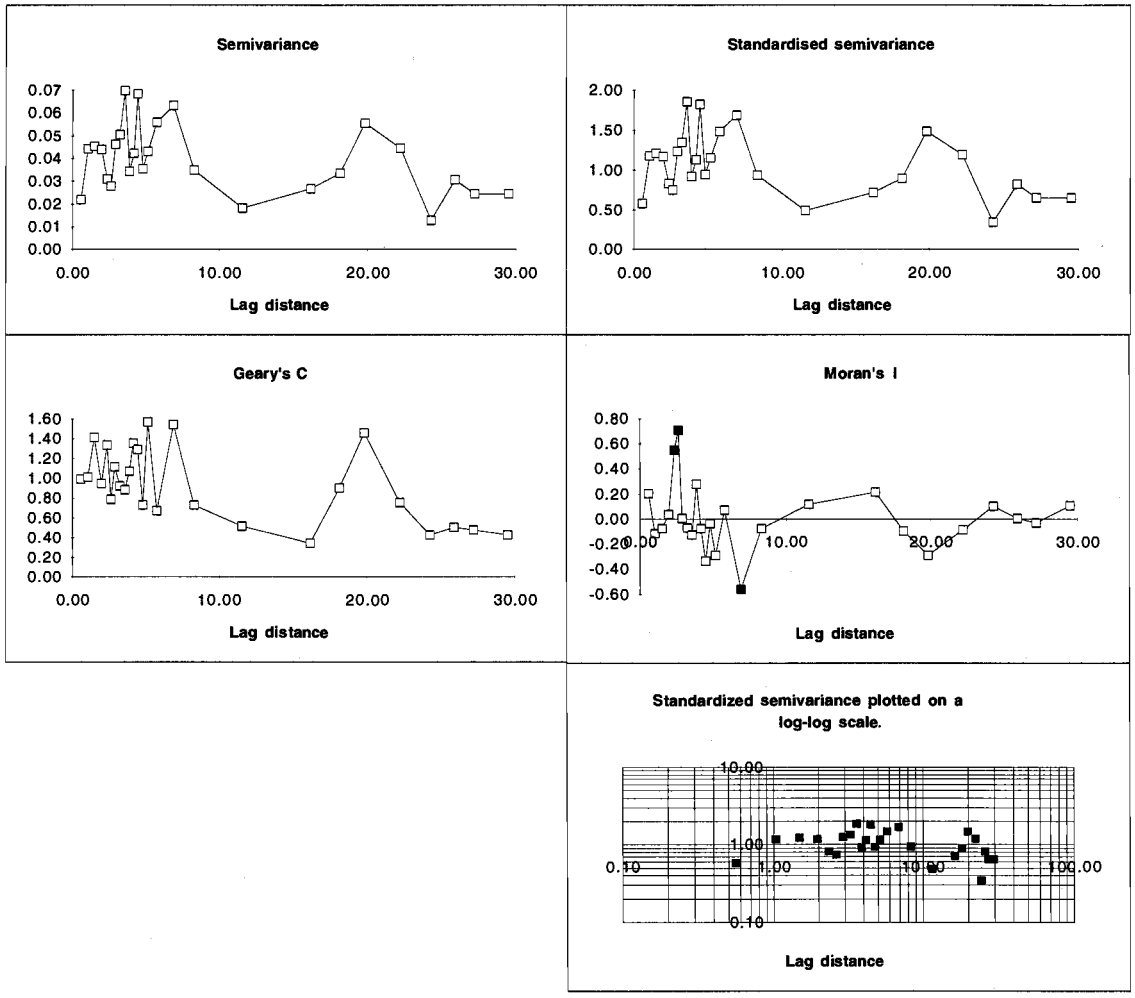
a. Moisture, plot I, May1992, juniper-sagebrush-grass community.

Figure B.6



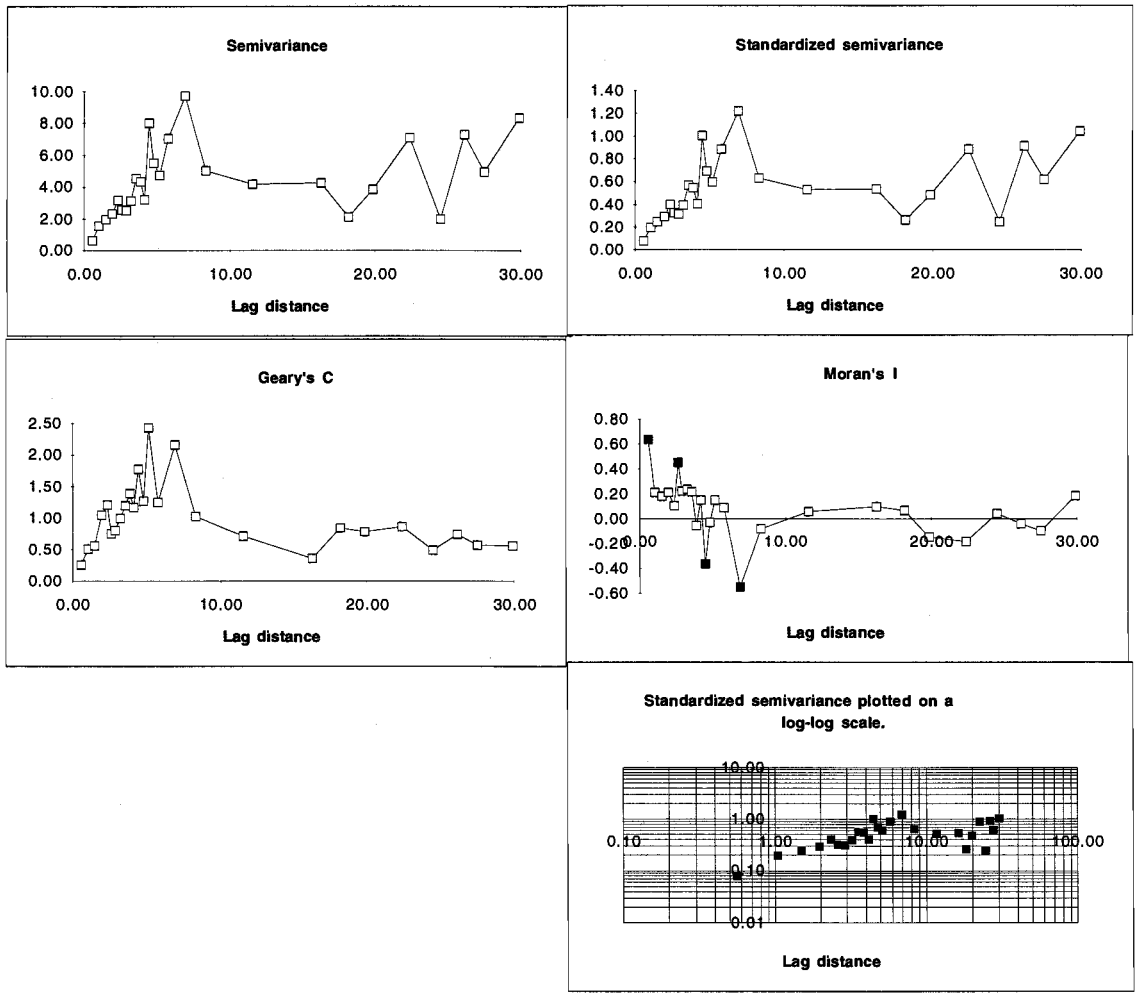
b. V.A. mycorrhizal infection, plot I, May 1992, juniper-sagebrush-grass community.

Figure B.6 continued



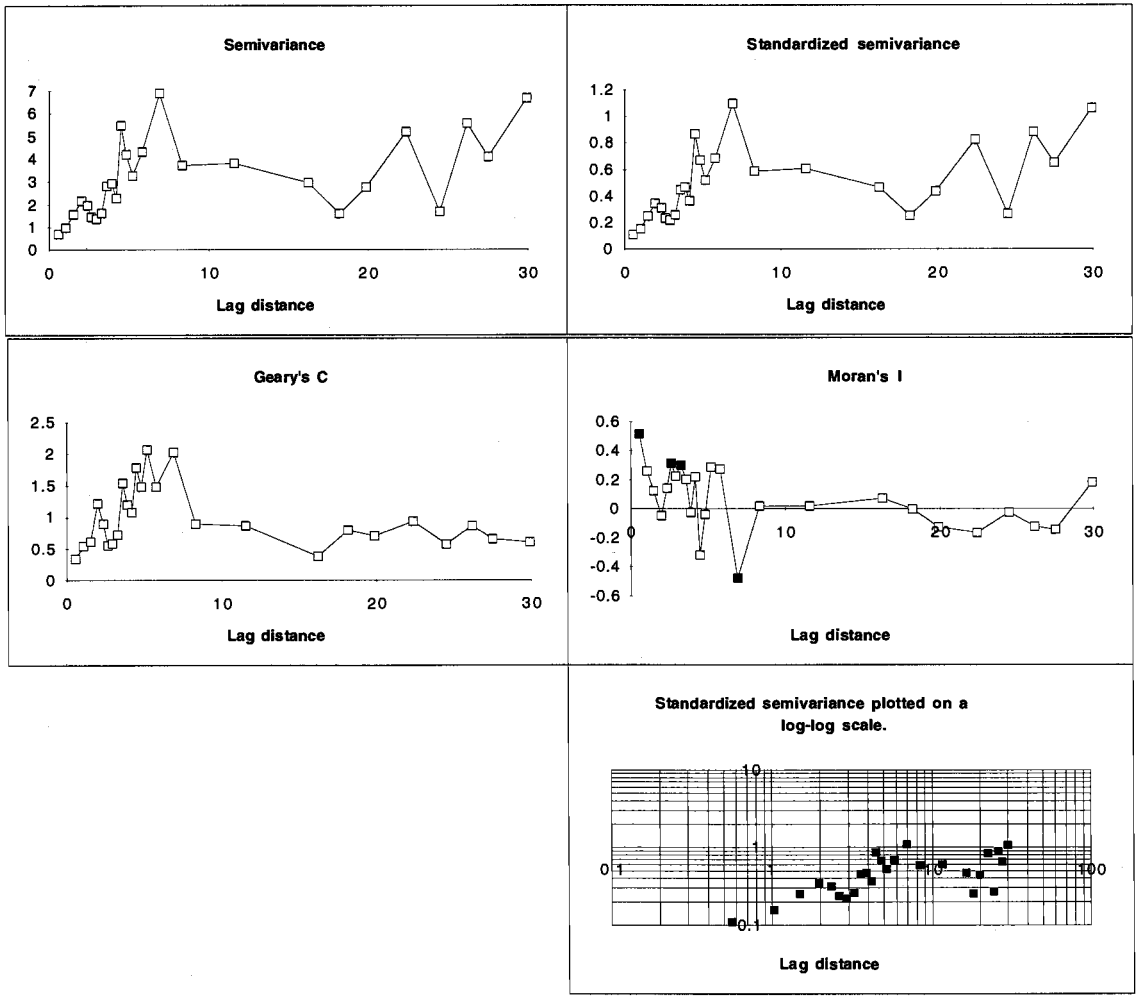
c. PH, plot I, May 1992, juniper-sagebrush-grass community.

Figure B.6 continued



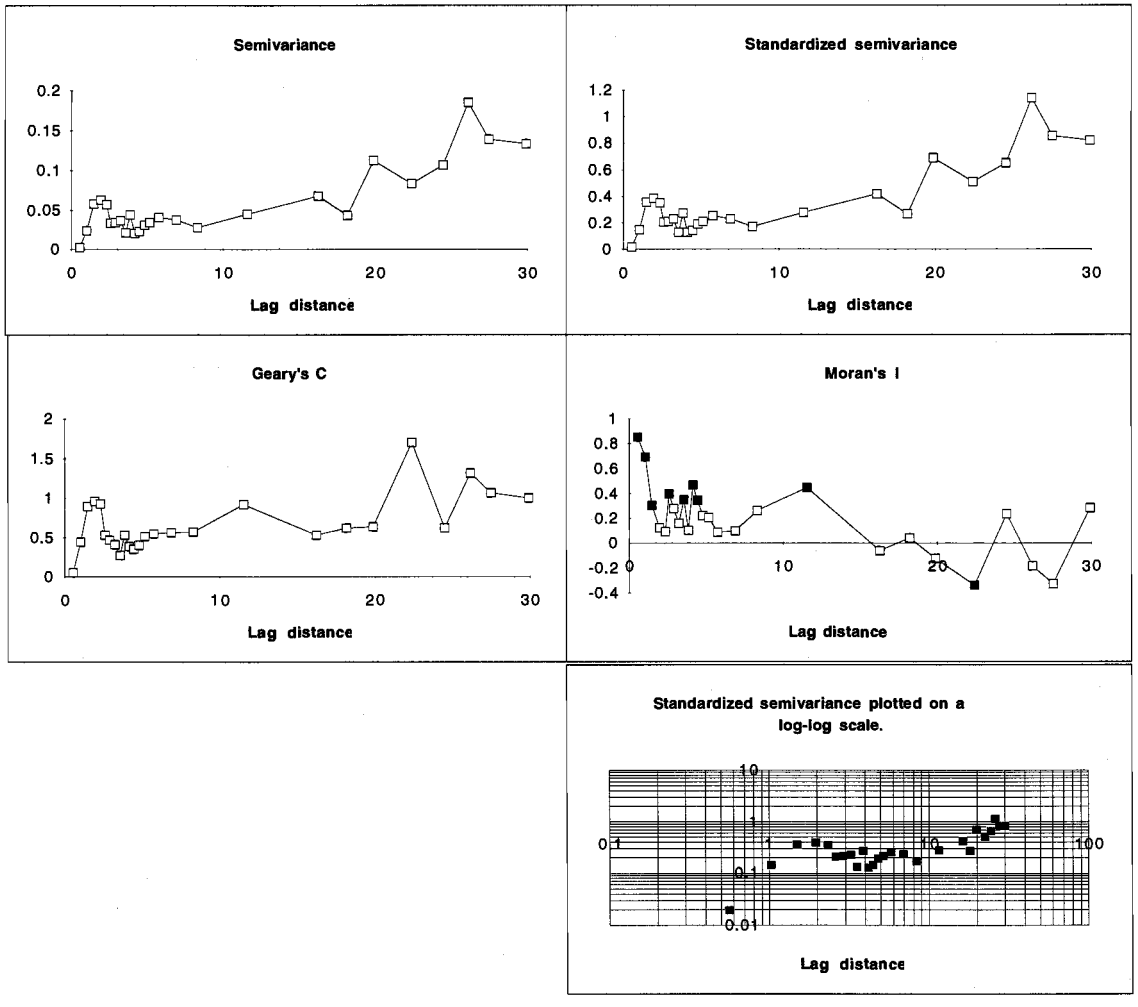
d. Initial Nitrogen as NH4, plot I, observations 36 and 52 removed as outliers.

Figure B.6 continued



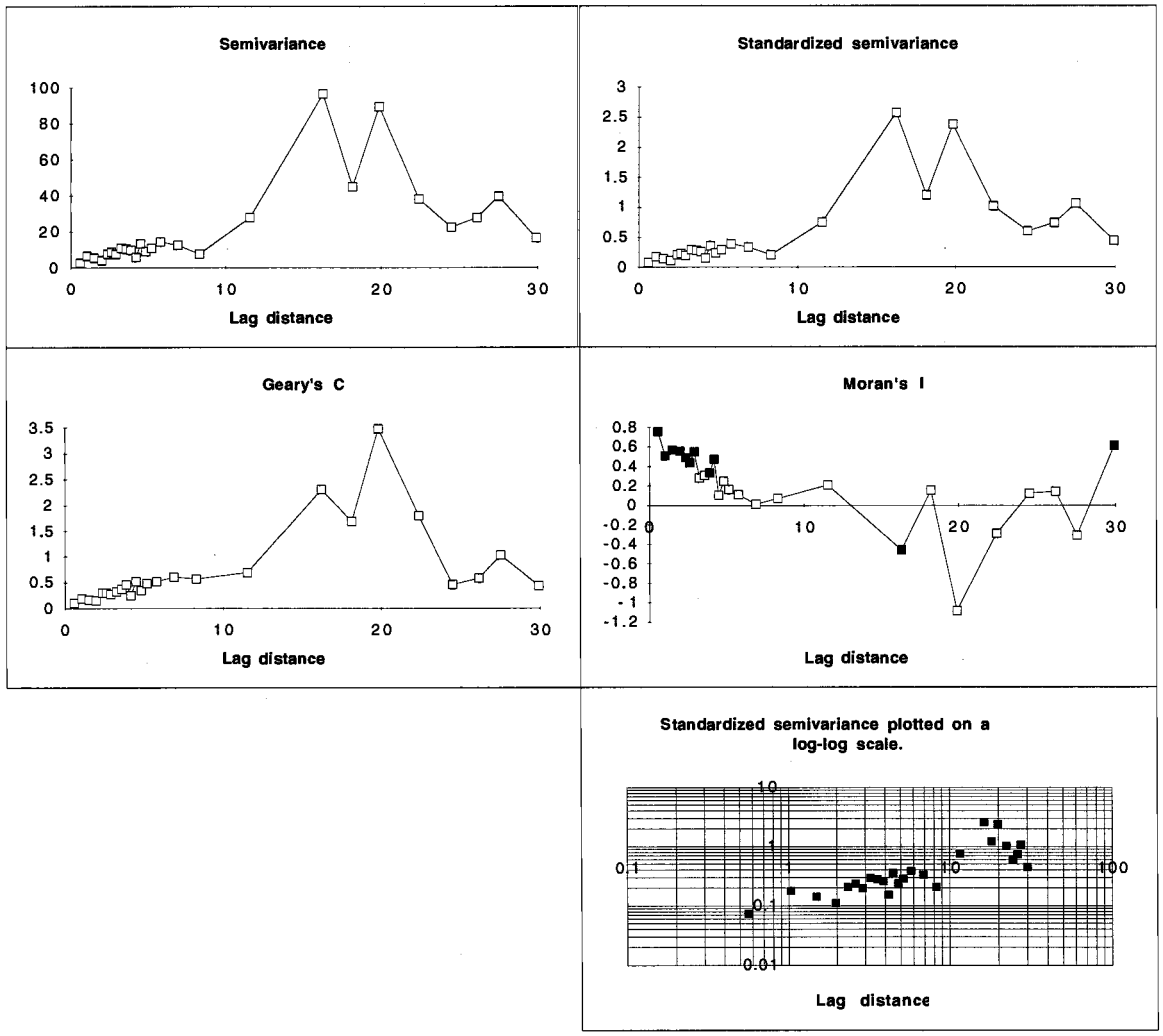
e. Mineralized Nitrogen as NH4, plot I, observations 36 and 52 removed as outliers.

Figure B.6 continued



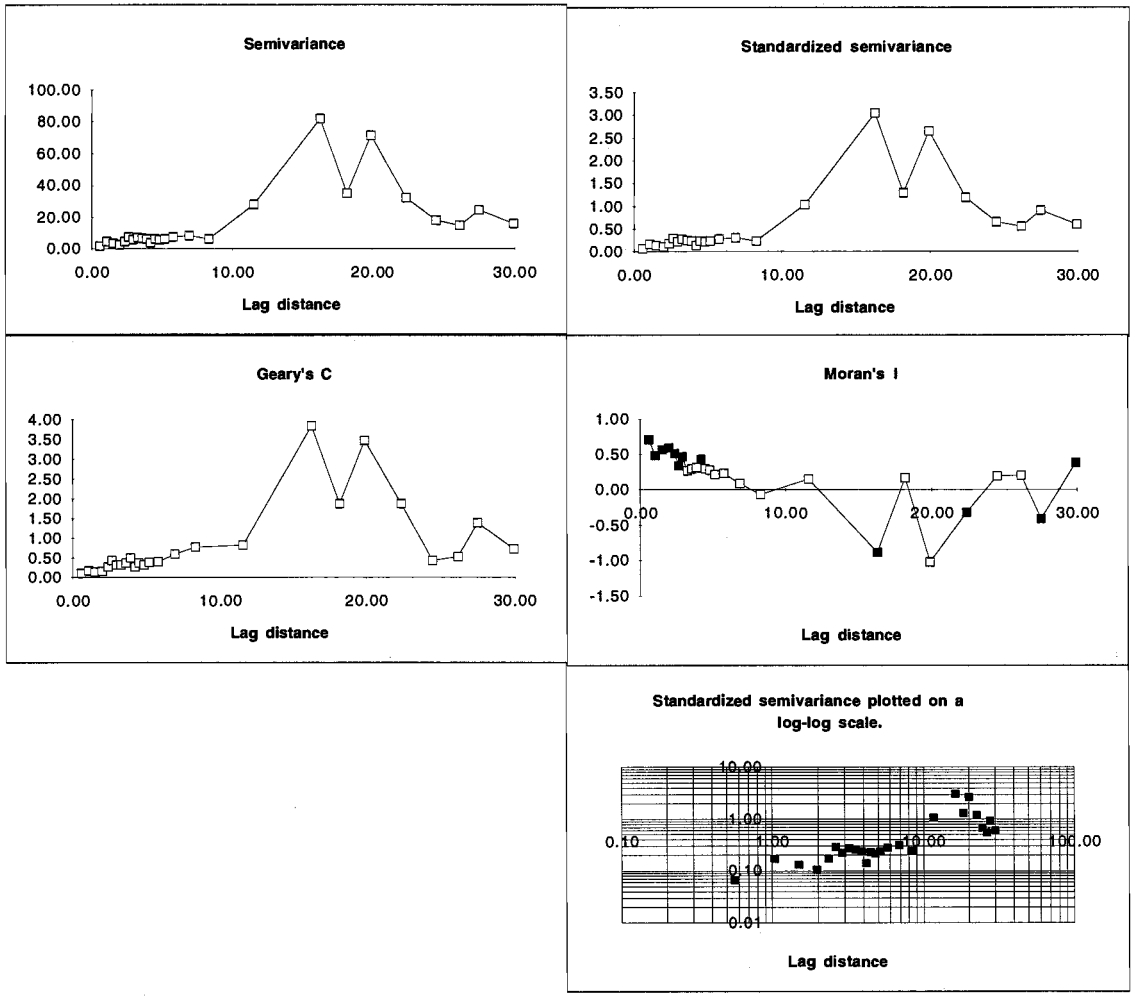
f. Initial Nitrogen as NO3, plot I, observations 36 and 52 removed as outliers.

Figure B.6 continued



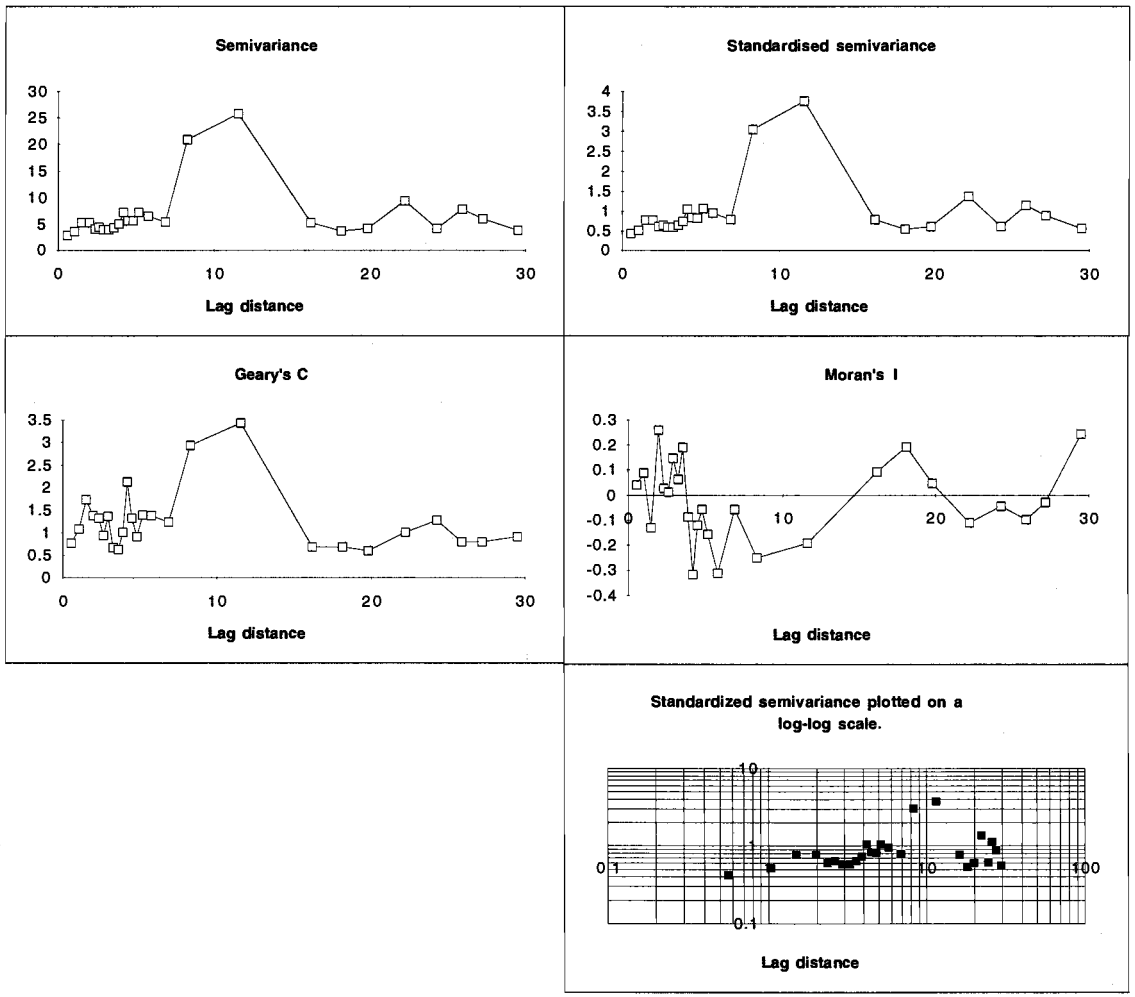
g. Mineralized Nitrogen as NO3, plot I, observations 36 and 52 removed as outliers.

Figure B.6 continued



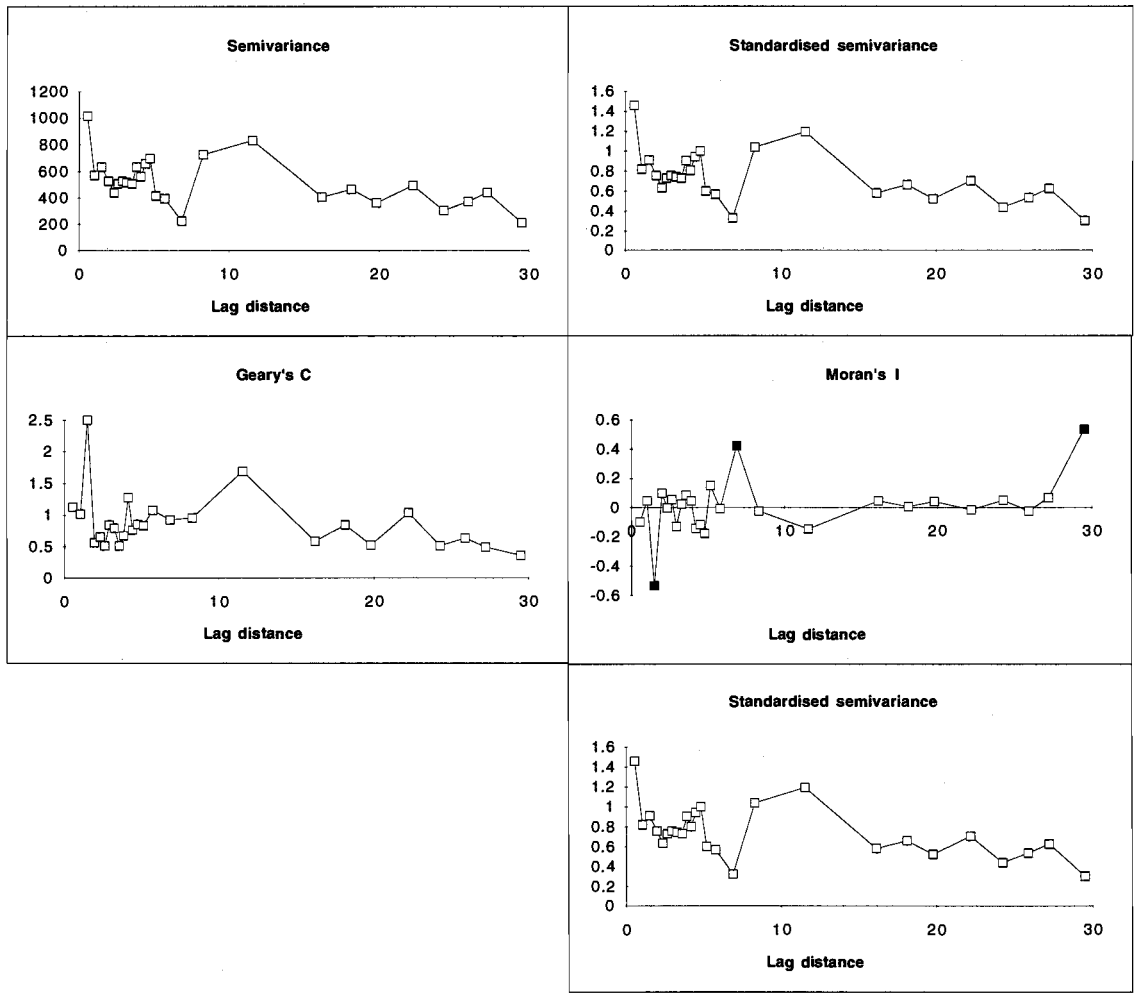
h. Net Nitrogen mineralised, plot I, observations 36 and 52 removed as outliers.

Figure B.6 continued



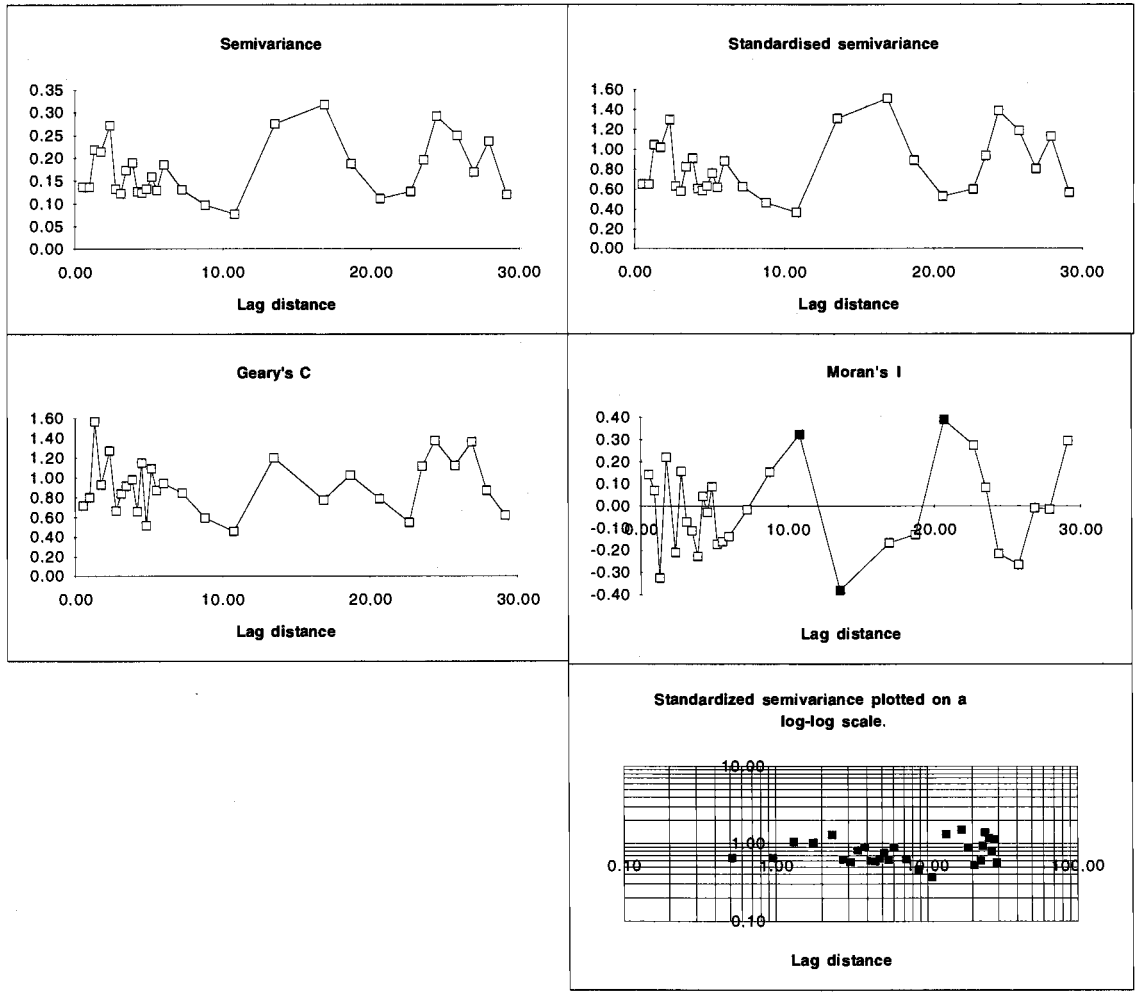
i. Total numbers of soil arthropods, May 1992, plot I, juniper-sagebrush-grass community.

Figure B.6 continued



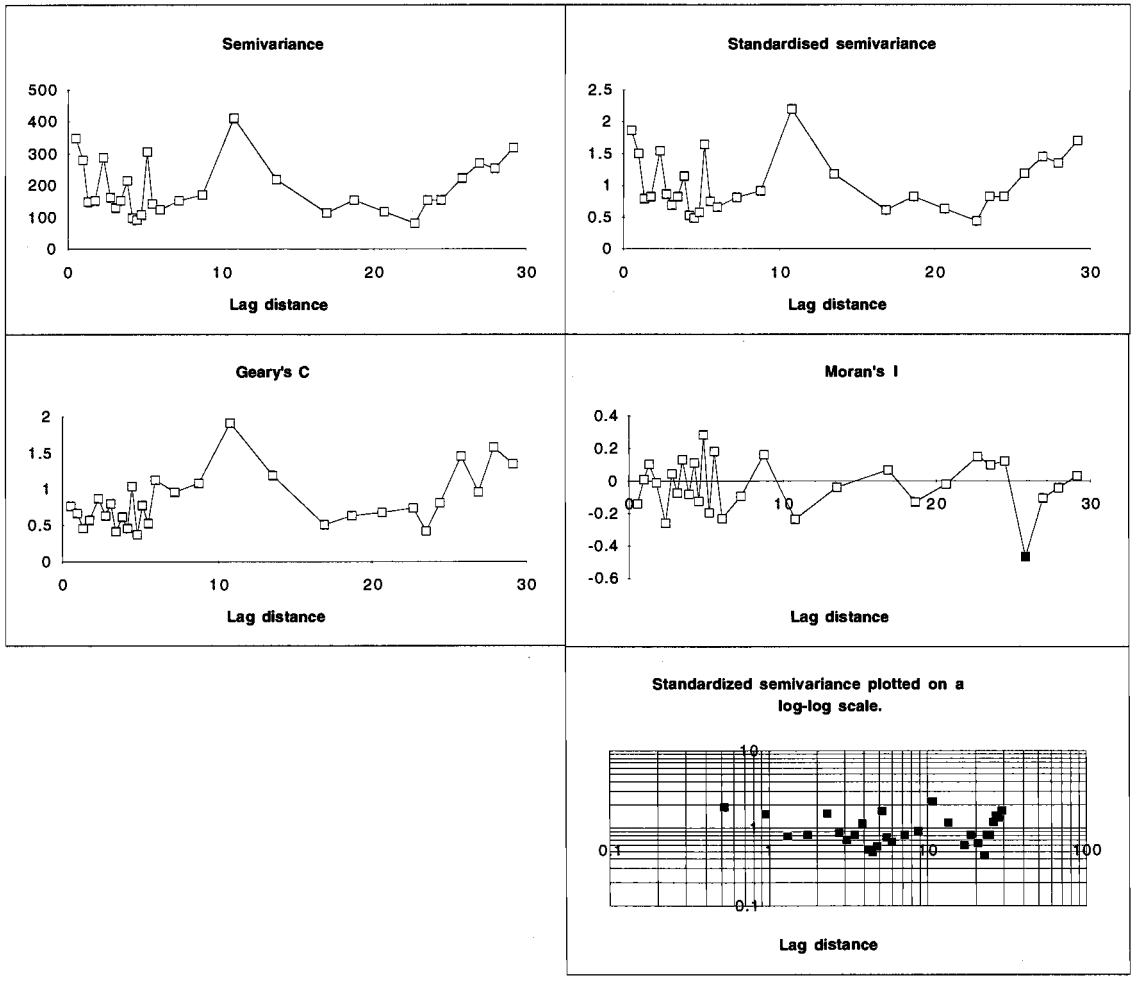
j. Biomass of micro-arthropods, May 1992, plot I, juniper-sagebrush-grass community.

Figure B.6 continued



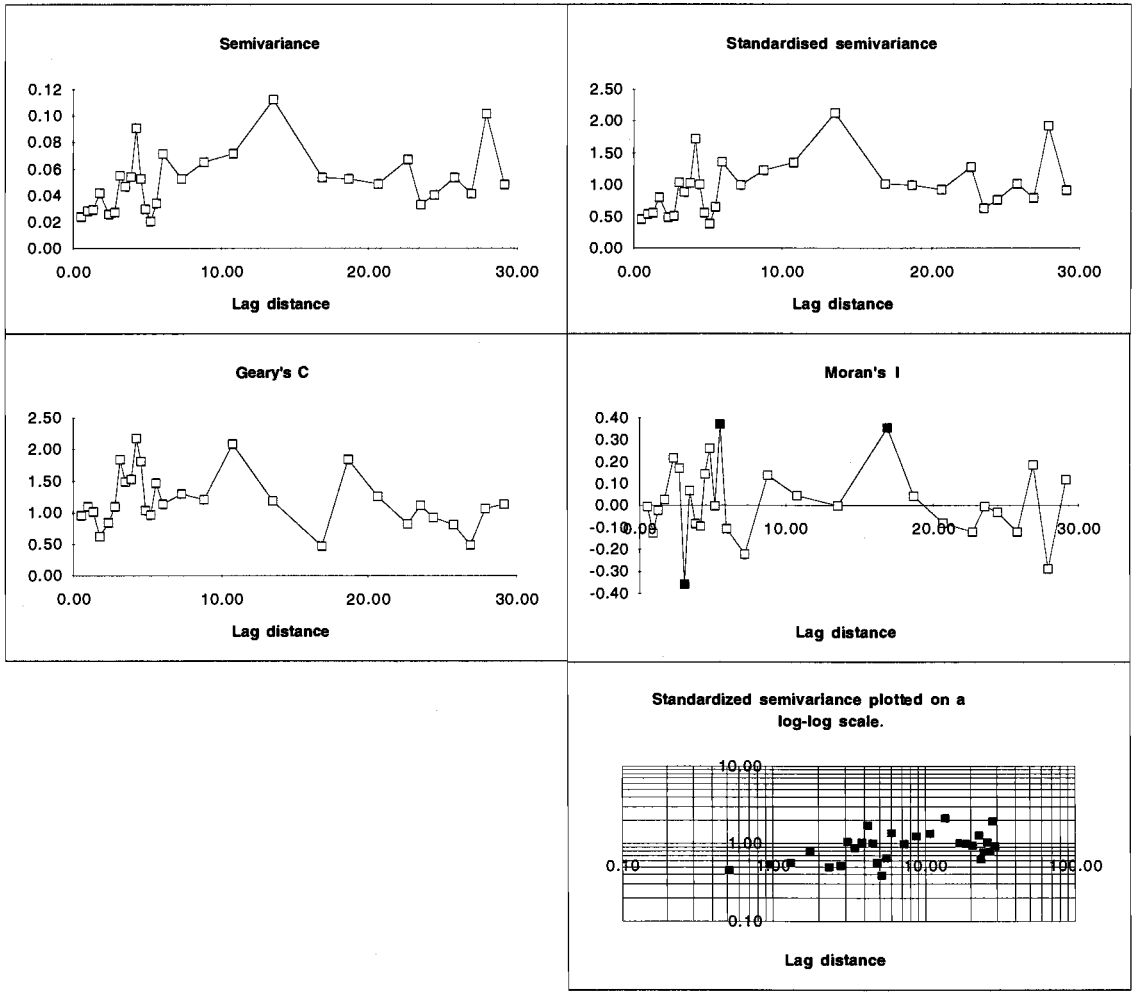
a. Moisture, plot J, May1992, sagebrush-grass community.

Figure B.7



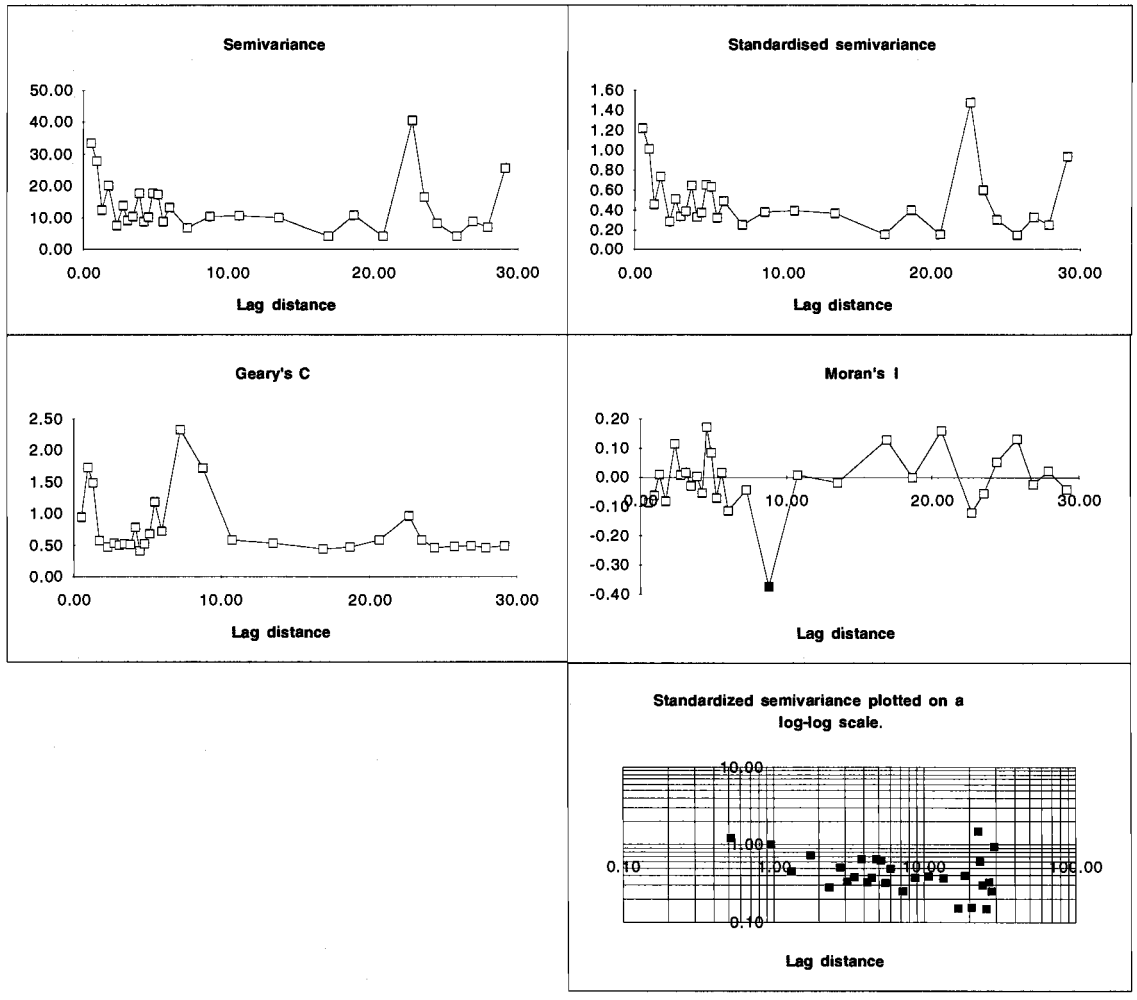
b. V.A. mycorrhizal infection, plot J, May 1992, sagebrush-grass community.

Figure B.7 continued



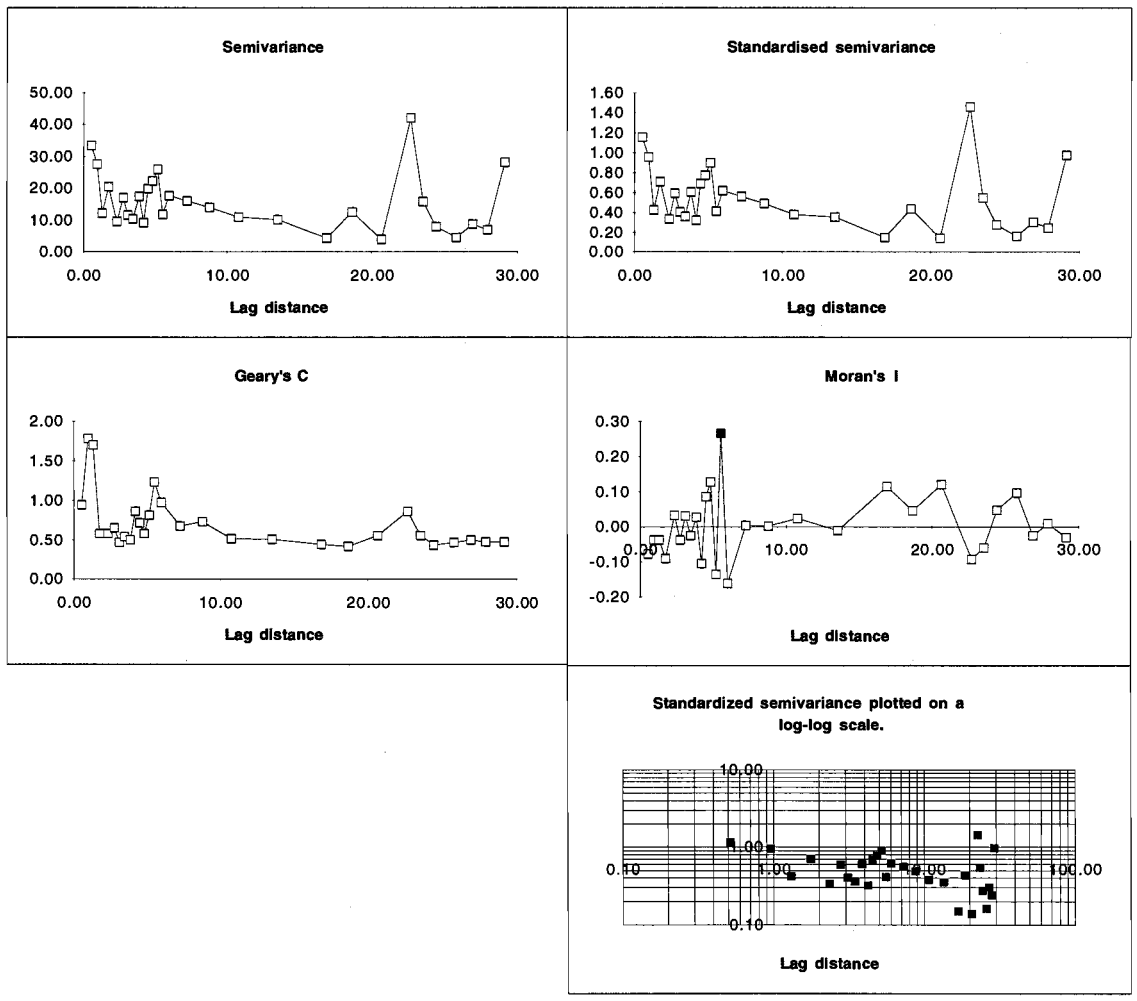
c. PH, plot J, May 1992, sagebrush-grass community.

Figure B.7 continued



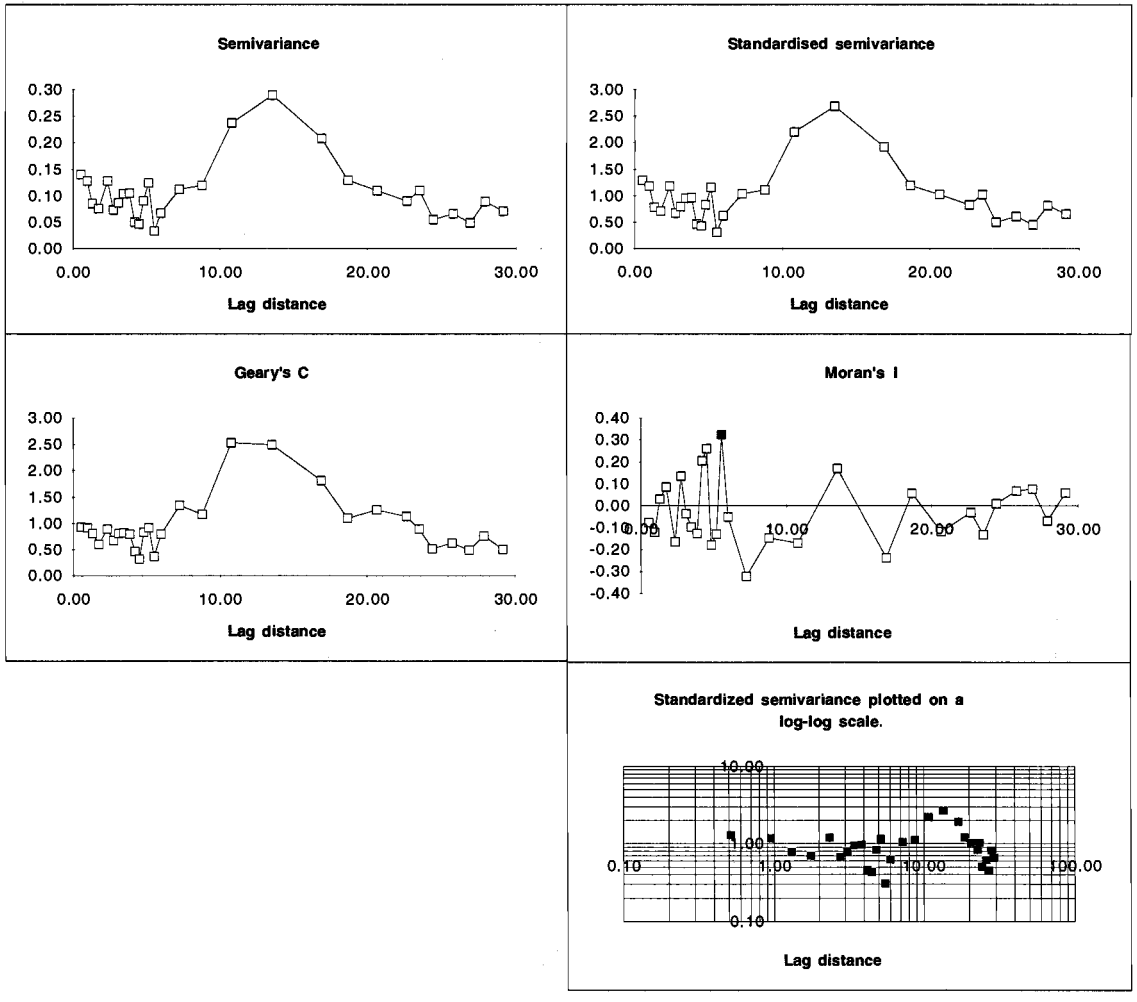
d. Initial Nitrogen as NH4, plot J, May 1992, sagebrush-grass community.

Figure B.7 continued



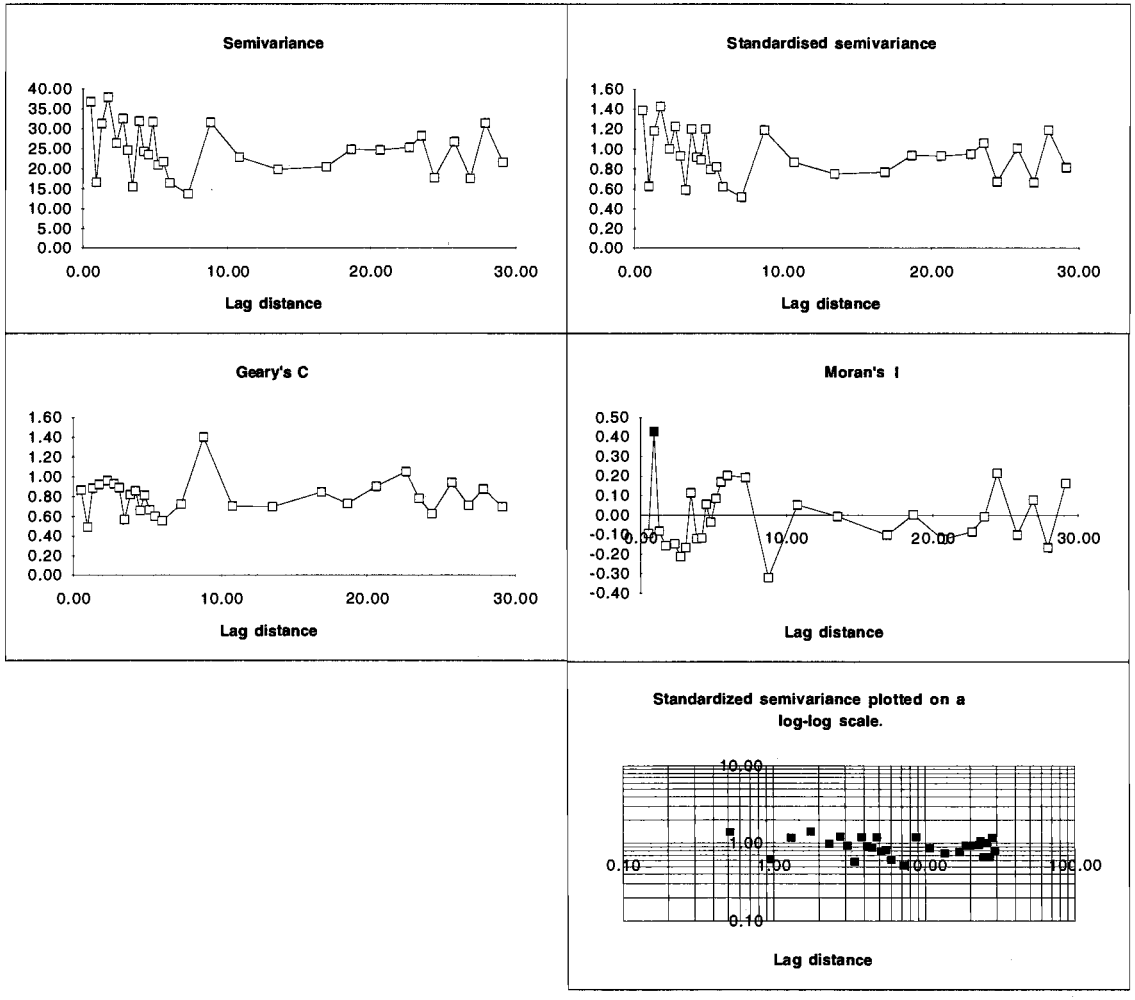
e. Mineralized Nitrogen as NH4, plot J, May 1992, sagebrush-grass community.

Figure B.7 continued



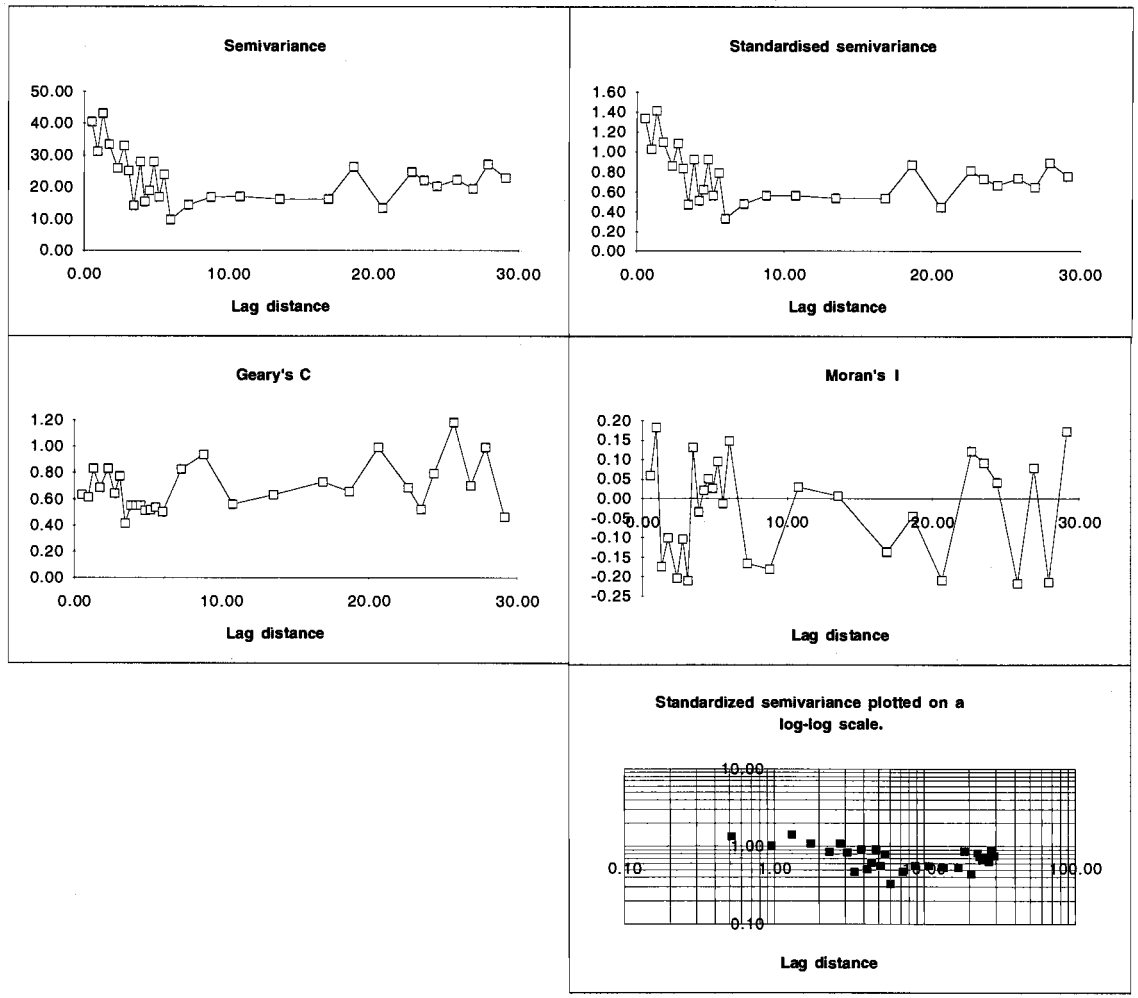
f. Initial Nitrogen as NO3, plot J, May 1992, sagebrush-grass community.

Figure B.7 continued



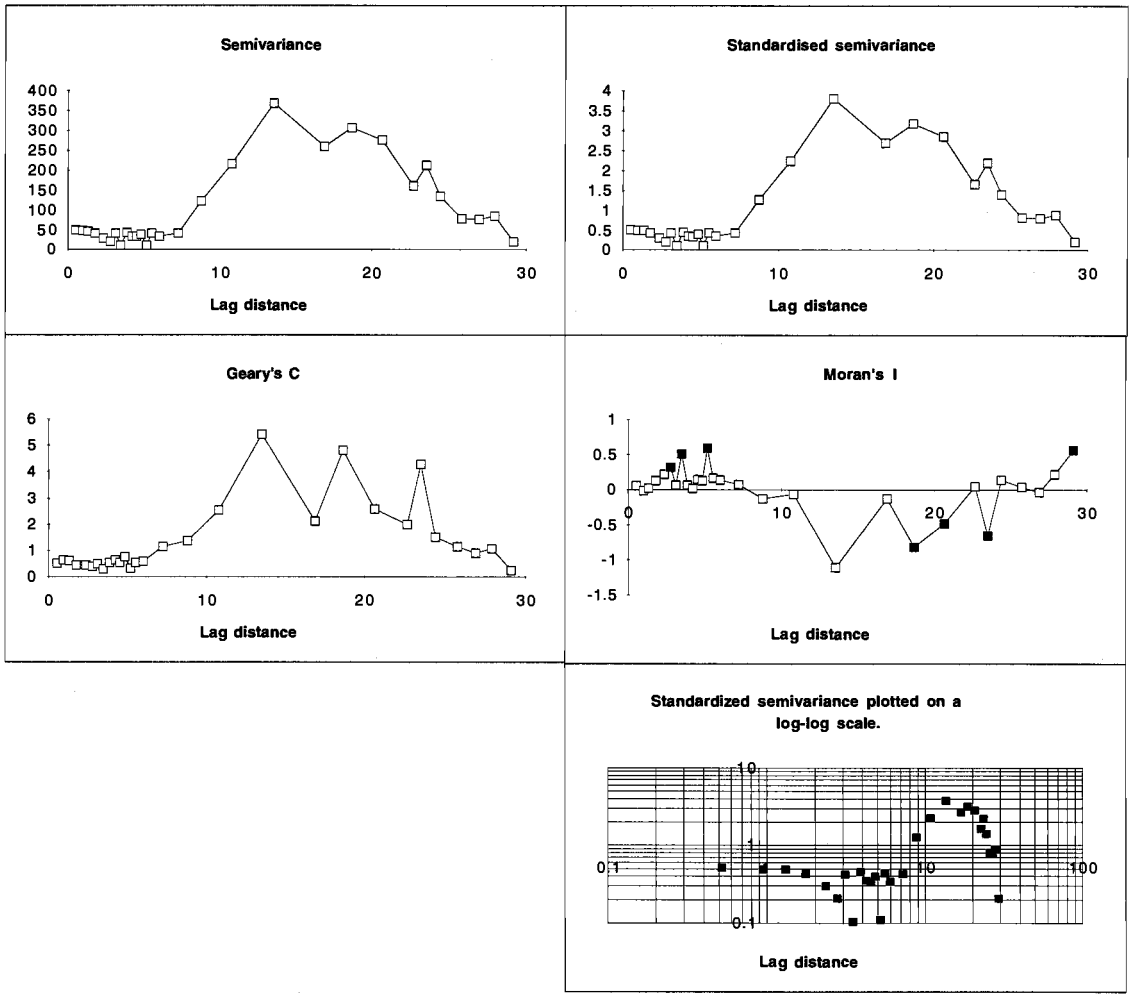
g. Mineralized Nitrogen as NO3, plot J, May 1992, sagebrush-grass community.

Figure B.7 continued



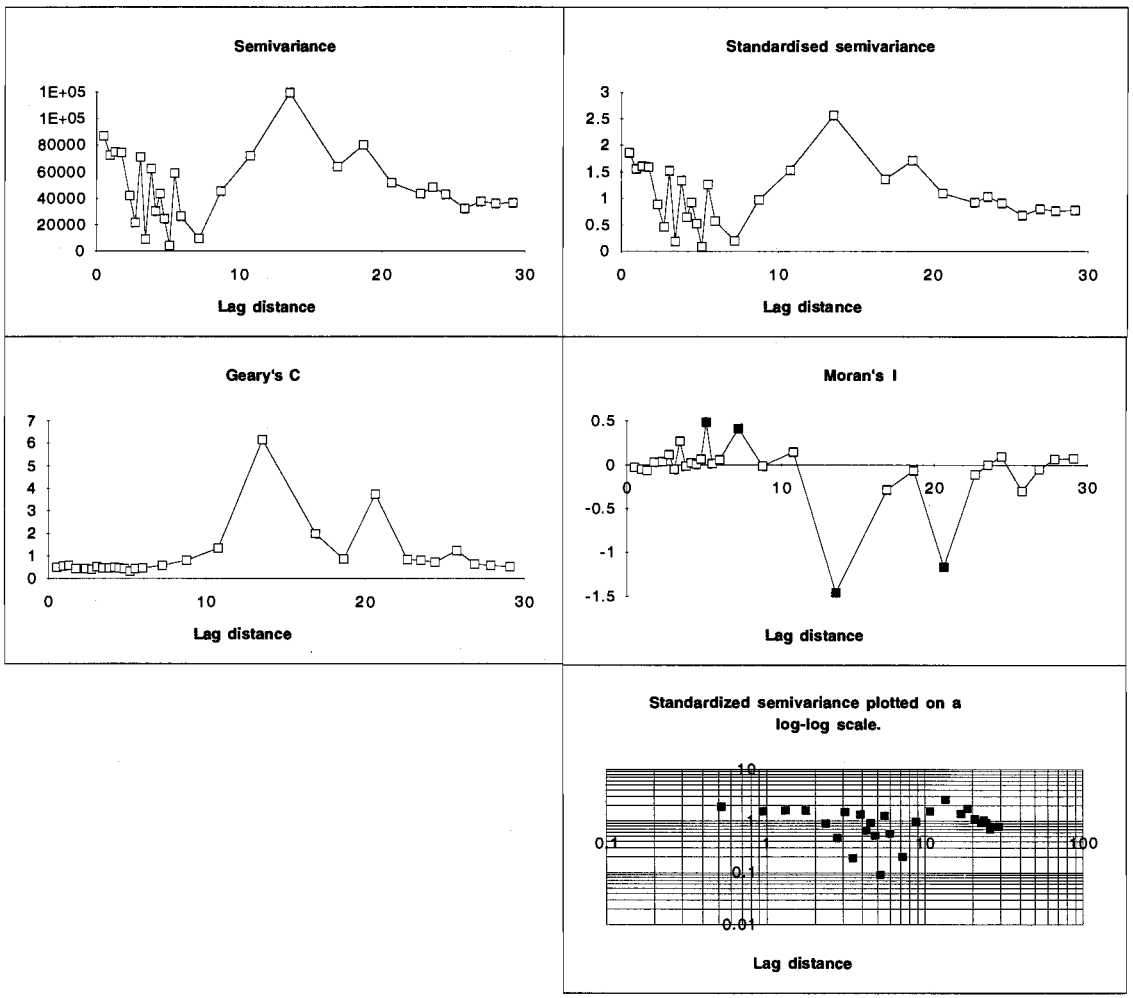
h. Net Nitrogen mineralized, plot J, May 1992, sagebrush-grass community.

Figure B.7 continued



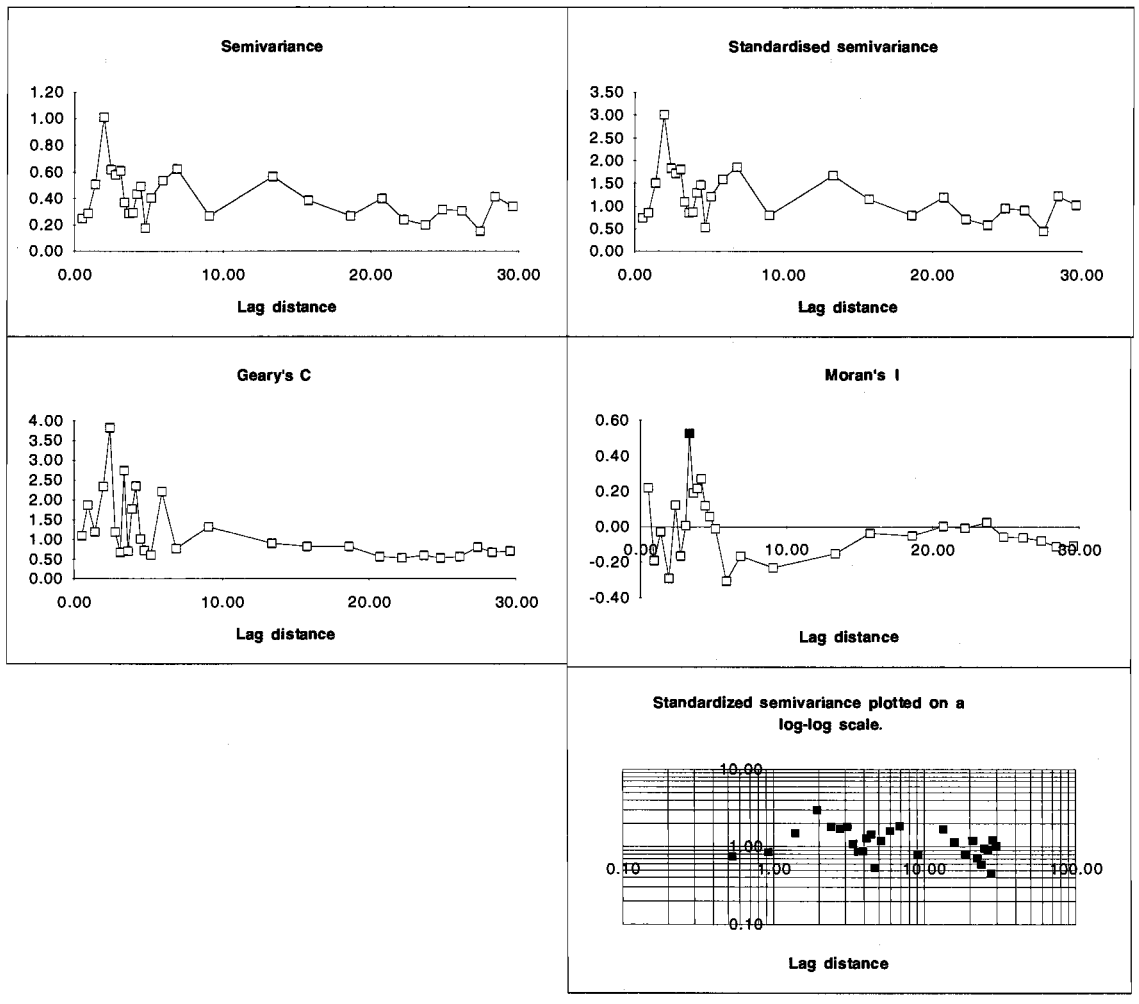
i. Total numbers of soil arthropods, May 1992, plot J, sagebrush-grass community.

Figure B.7 continued



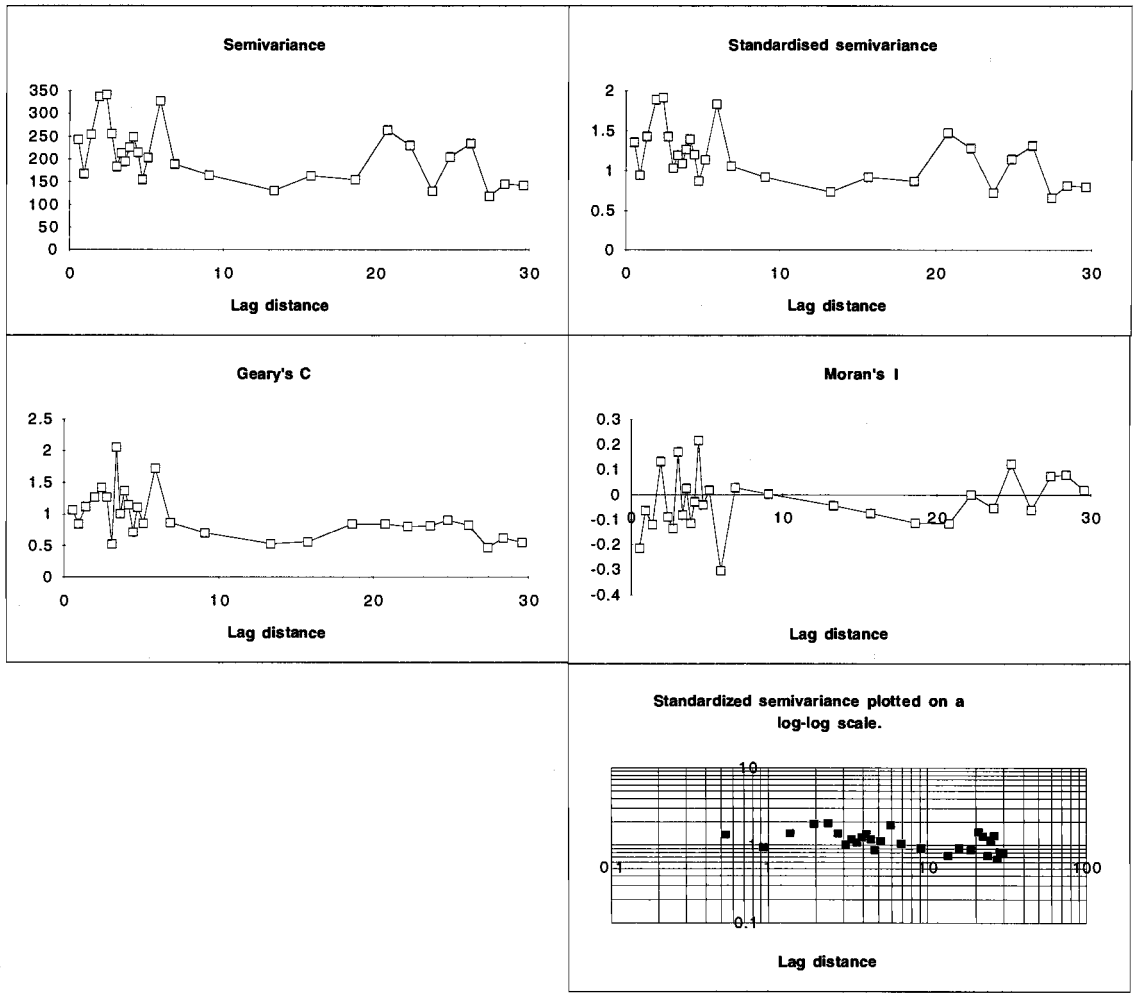
j. Biomass of micro-arthropods, May 1992, plot J, juniper-sagebrush-grass community.

Figure B.7 continued



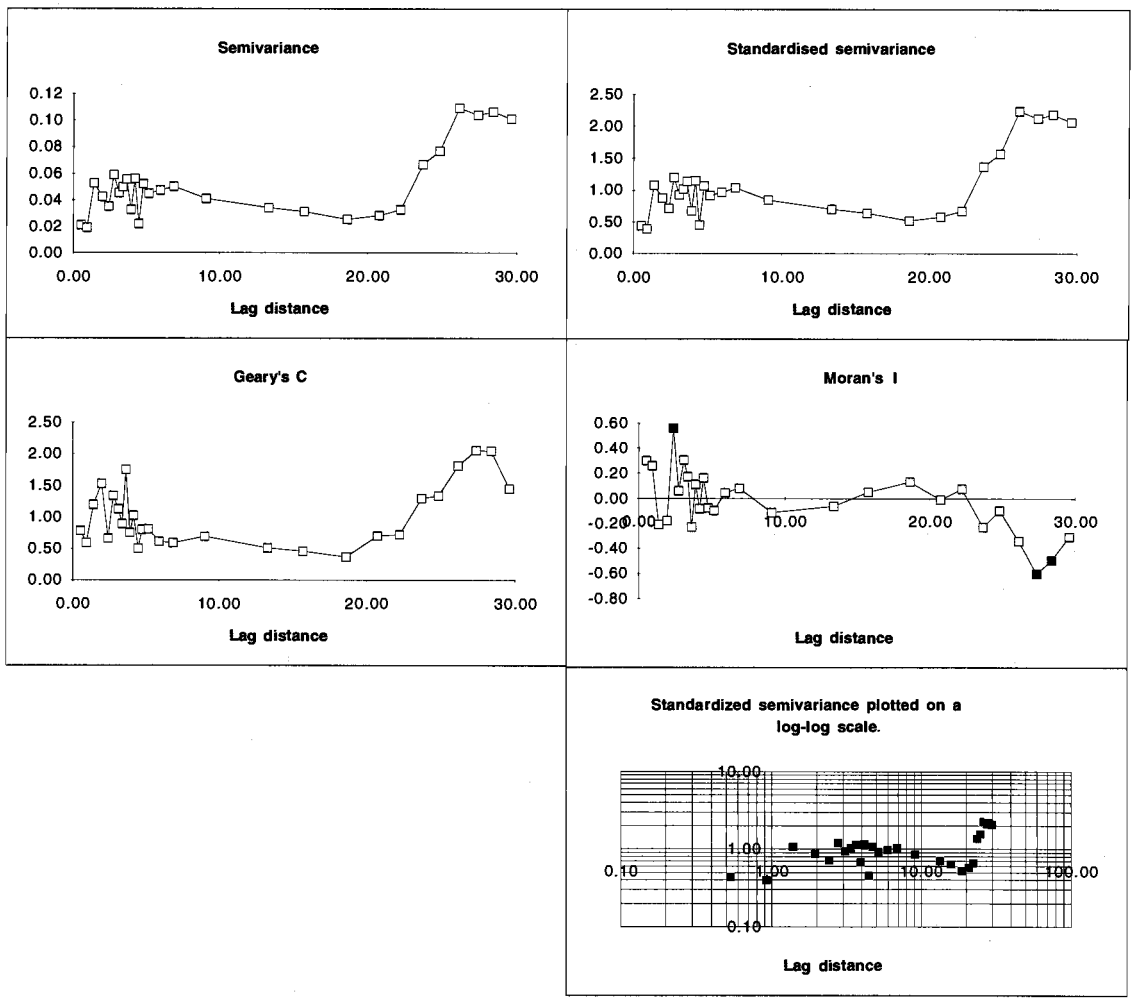
a. Moisture, plot K, May1992, juniper-sagebrush-grass community.

Figure B.8



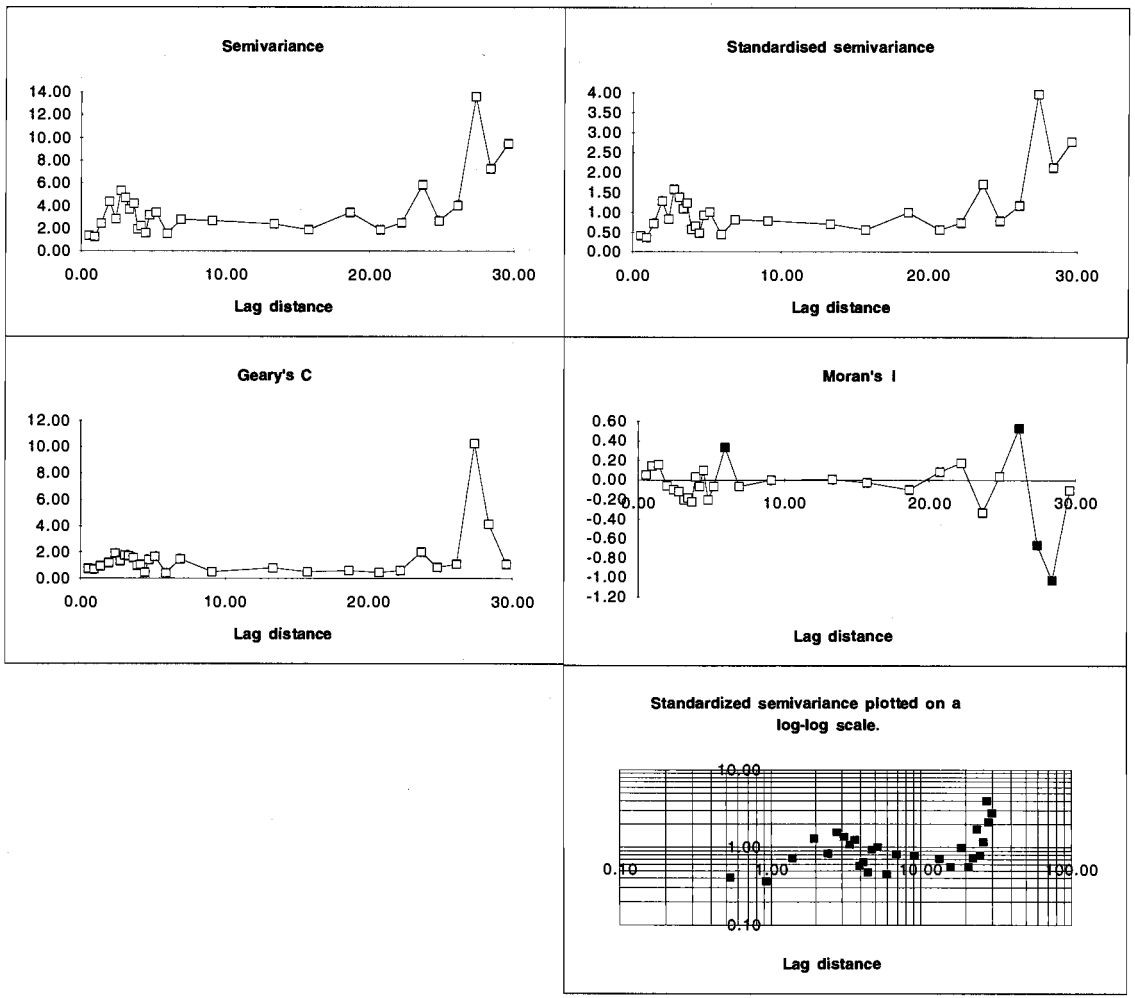
b. V.A. mycorrhizal infection, plot K, May 1992, juniper-sagebrush-grass community.

Figure B.8 continued



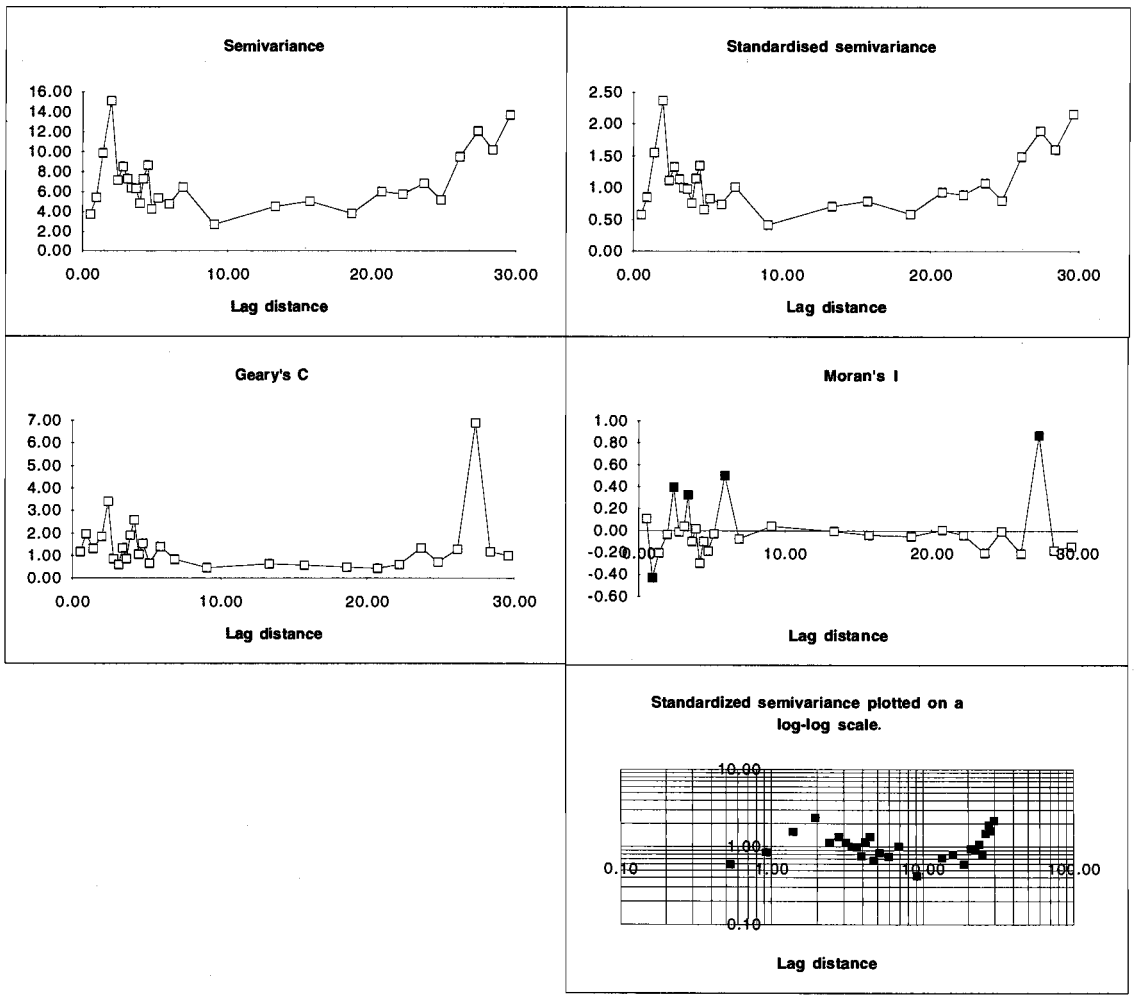
c. PH, plot K, May 1992, juniper-sagebrush-grass community.

Figure B.8 continued



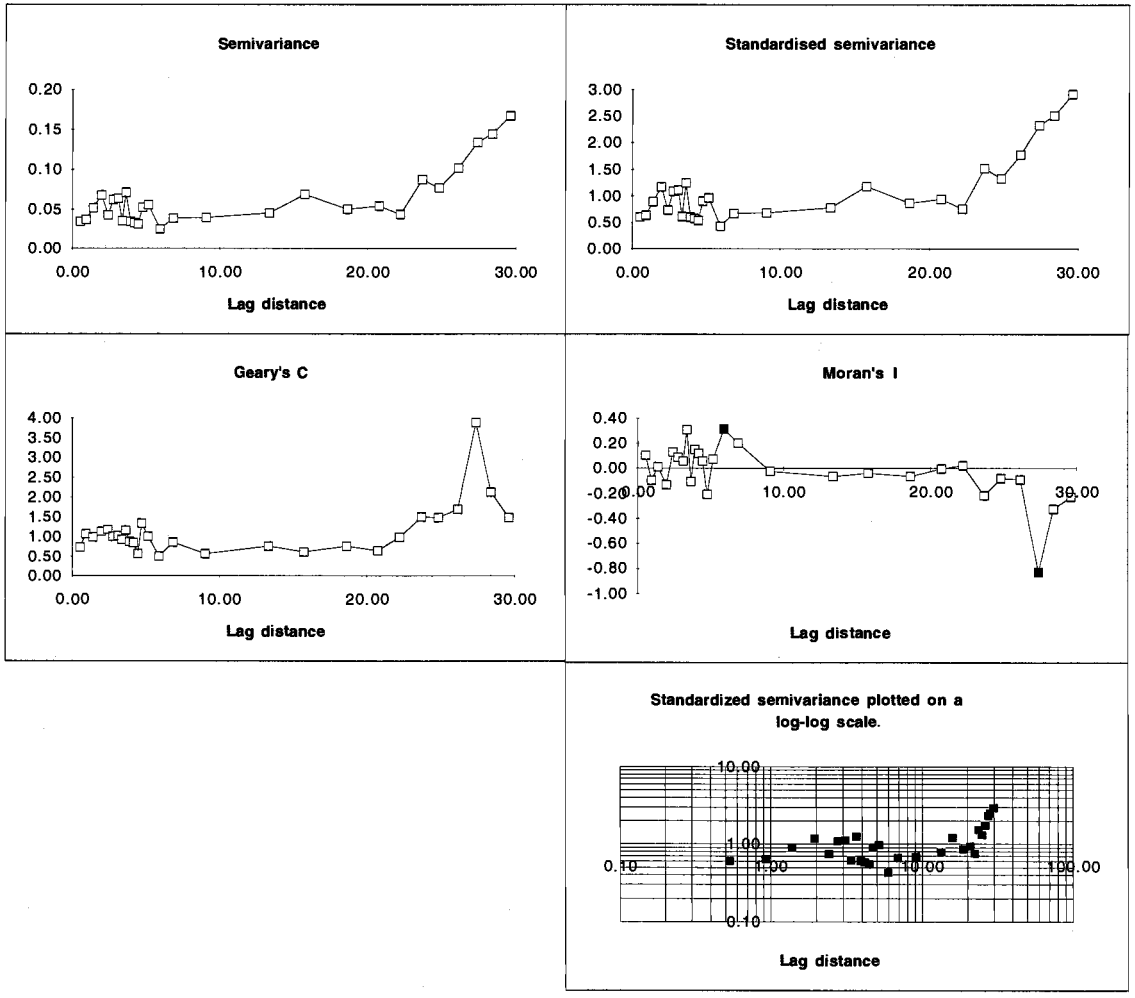
d. Initial Nitrogen as NH4, plot K, May 1992, juniper-sagebrush-grass community.

Figure B.8 continued



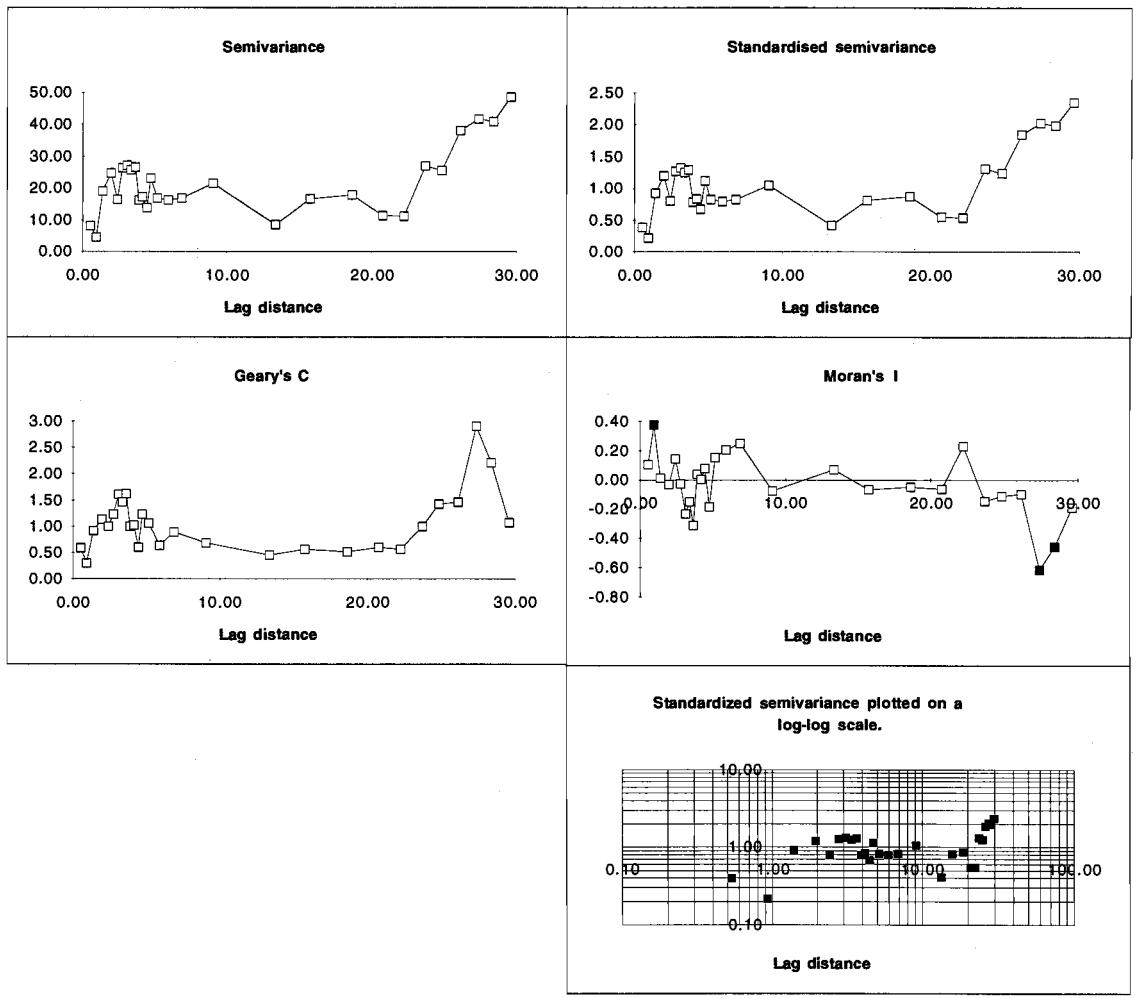
e. Mineralized Nitrogen as NH4, plot K, May 1992, juniper-sagebrush-grass community.

Figure B.8 continued



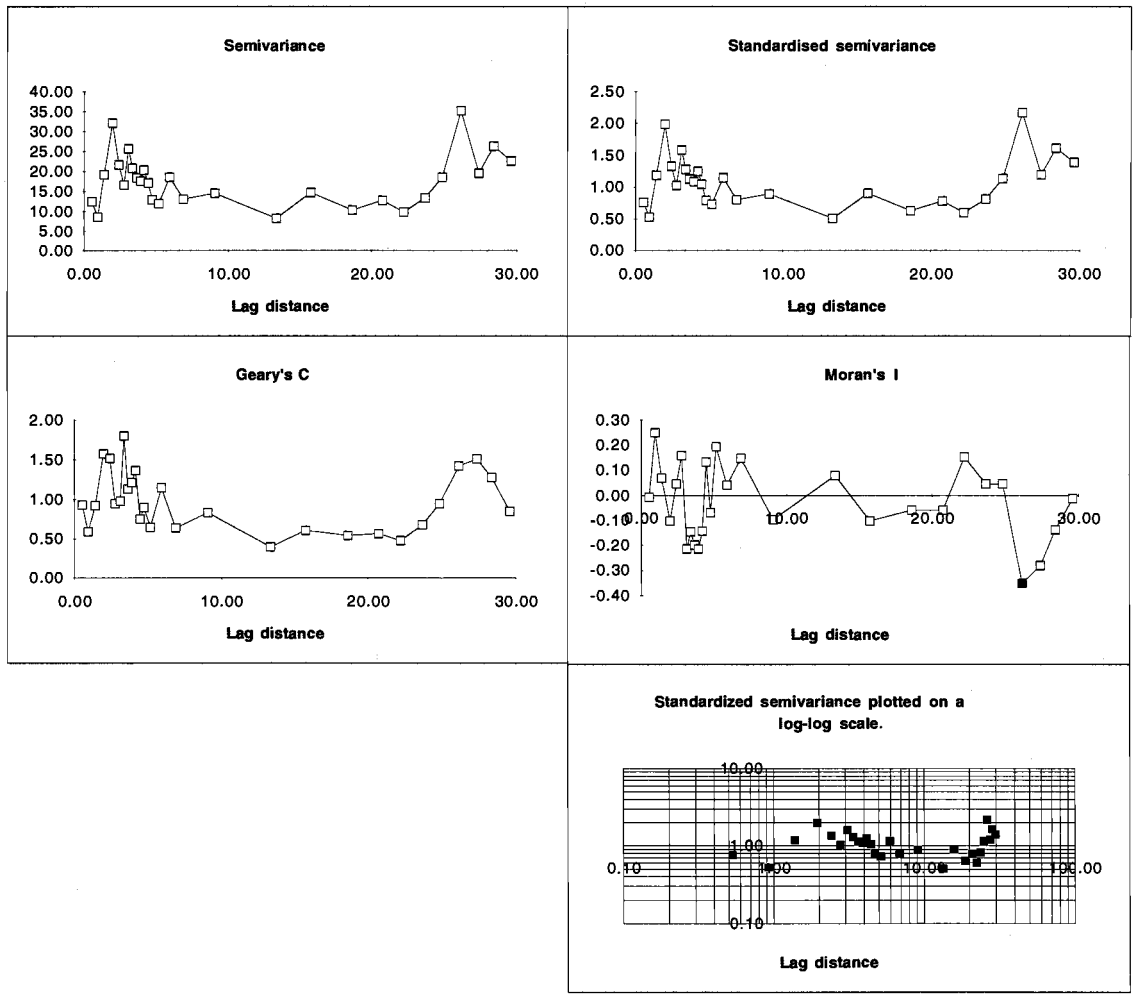
f. Initial Nitrogen as NO3, plot K, May 1992, juniper-sagebrush-grass community.

Figure B.8 continued



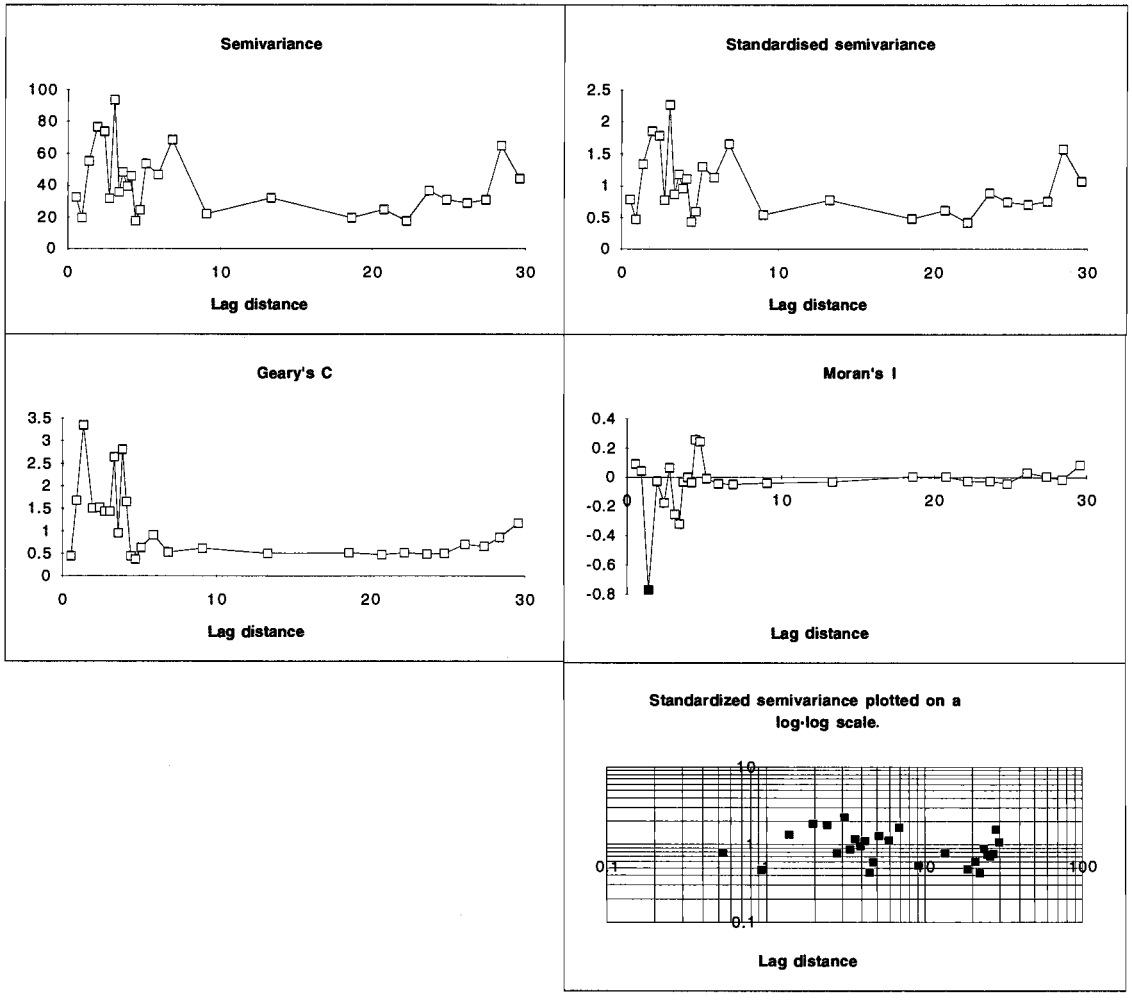
g. Mineralized Nitrogen as NO3, plot K, May 1992, juniper-sagebrush-grass community.

Figure B.8 continued



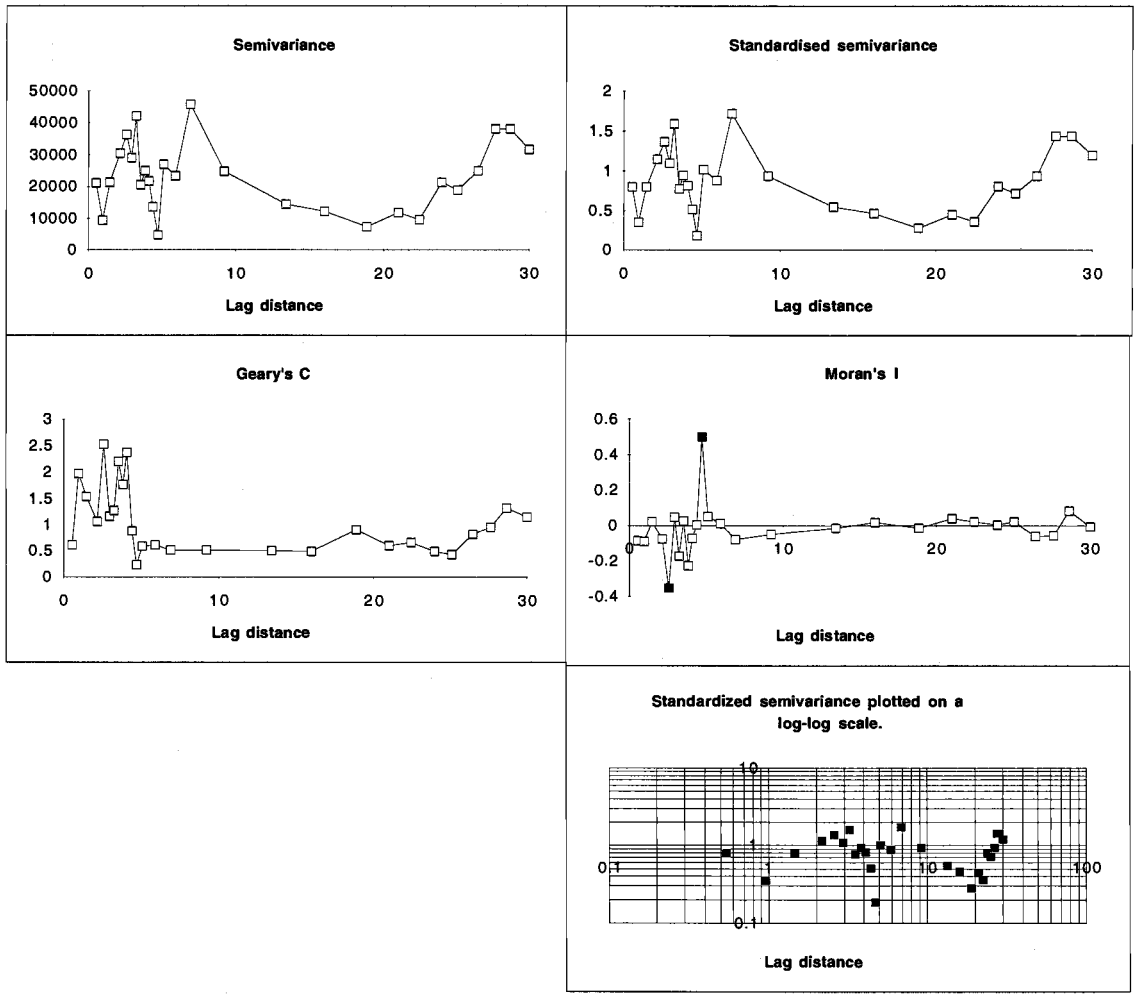
h. Net Nitrogen mineralized, plot K, May 1992, juniper-sagebrush-grass community.

Figure B.8 continued



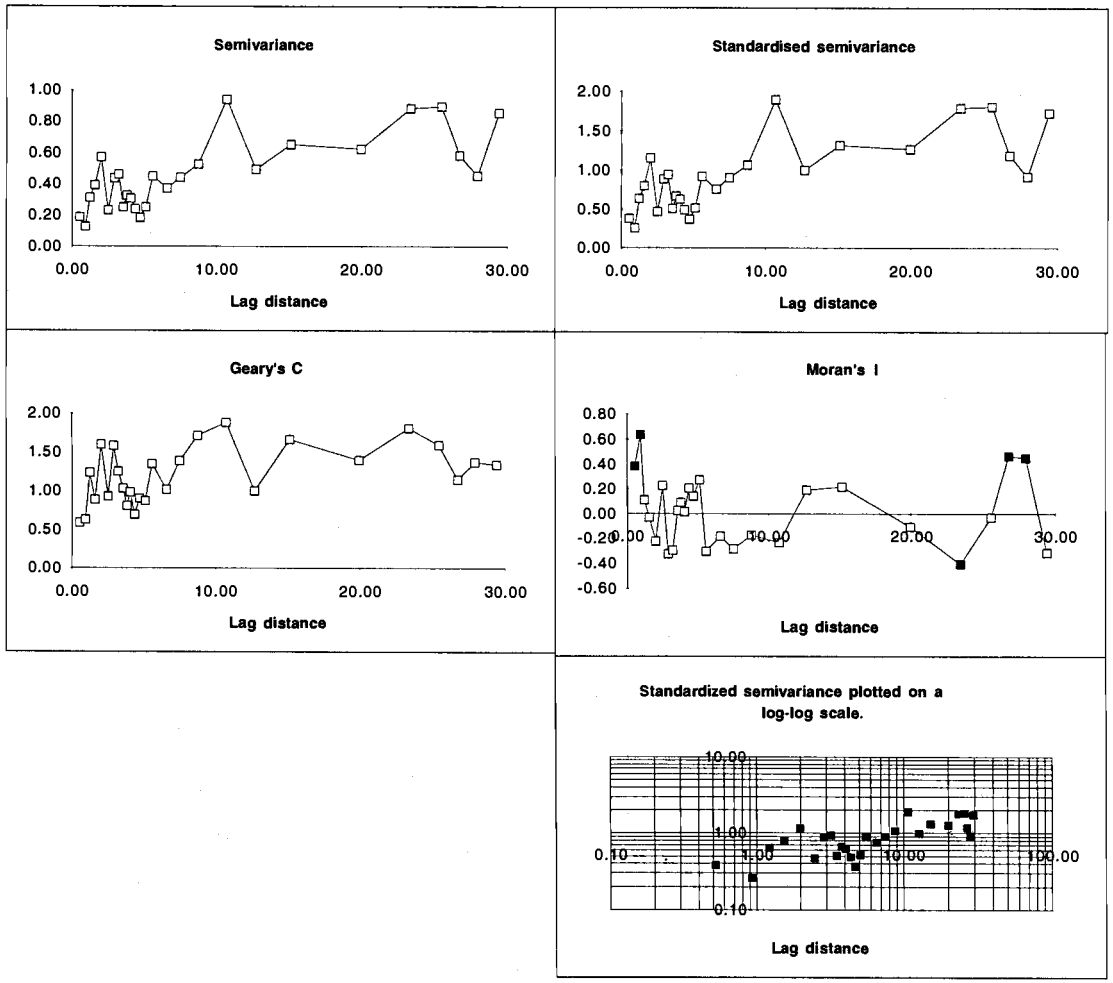
i. Total numbers of soil arthropods, May 1992, plot K, juniper-sagebrush-grass community.

Figure B.8 continued



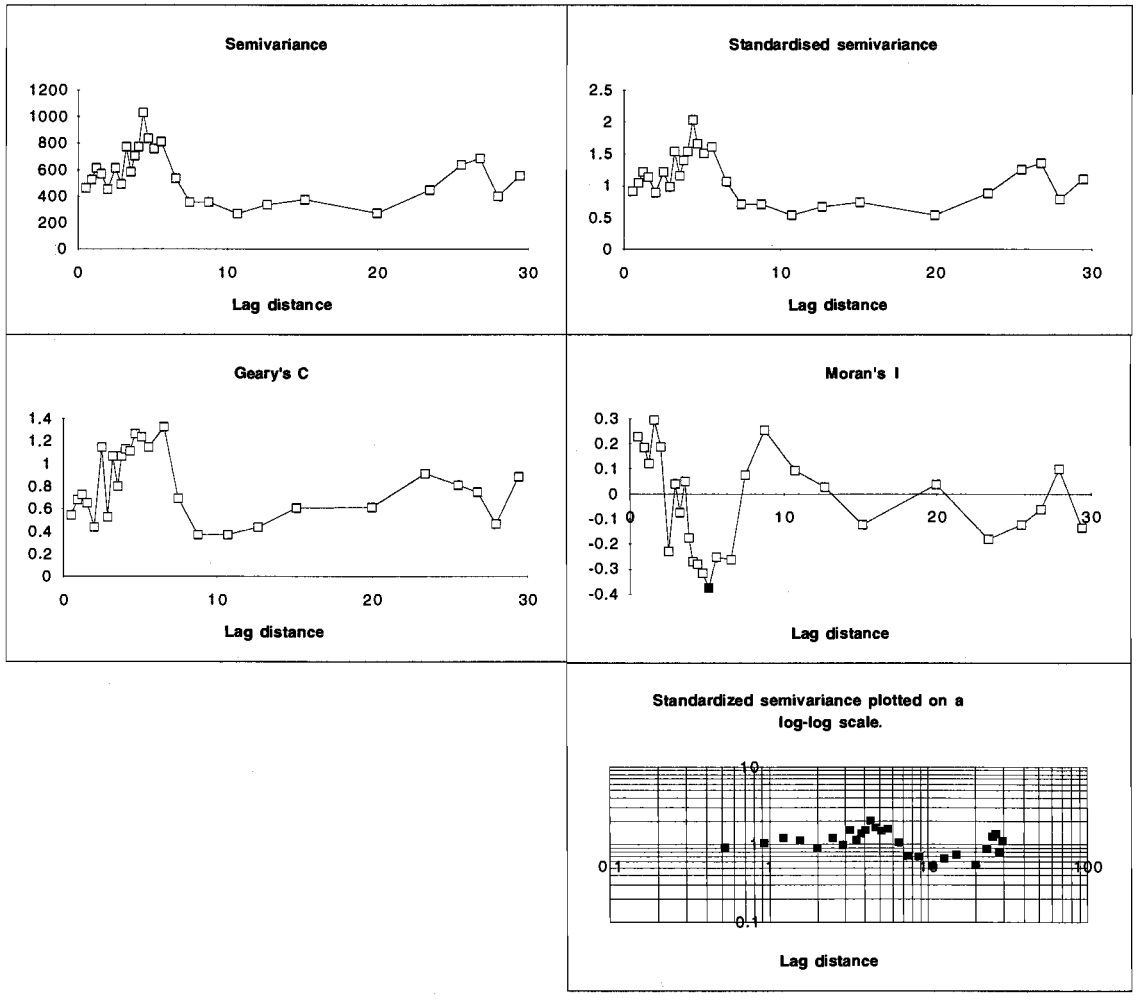
j. Biomass of micro-arthropods, plot K, observation 22 removed as an outlier.

Figure B.8 continued



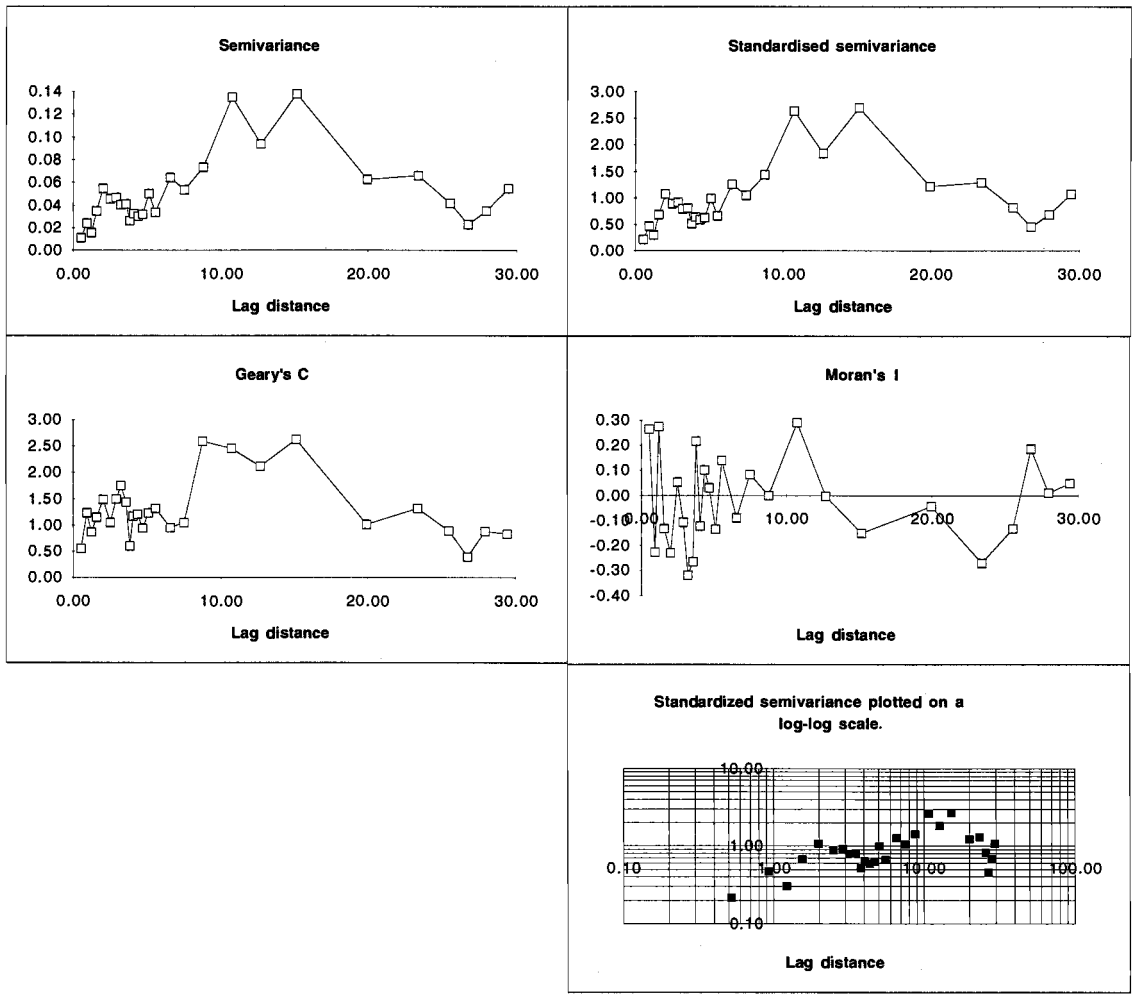
a. Moisture, plot L, May1992, sagebrush-grass community.

Figure B.9



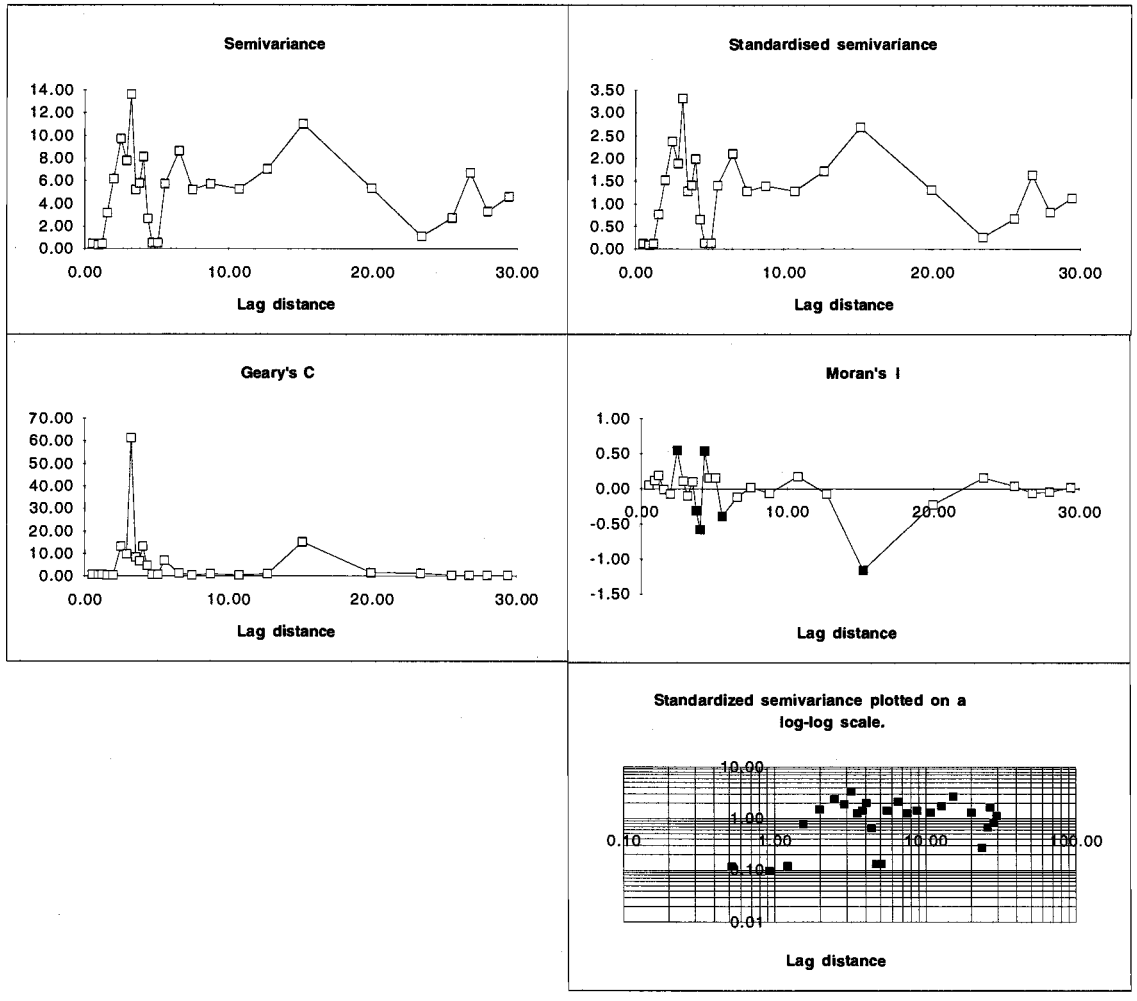
b. V.A. mycorrhizal infection, plot L, May 1992, sagebrush-grass community.

Figure B.9 continued



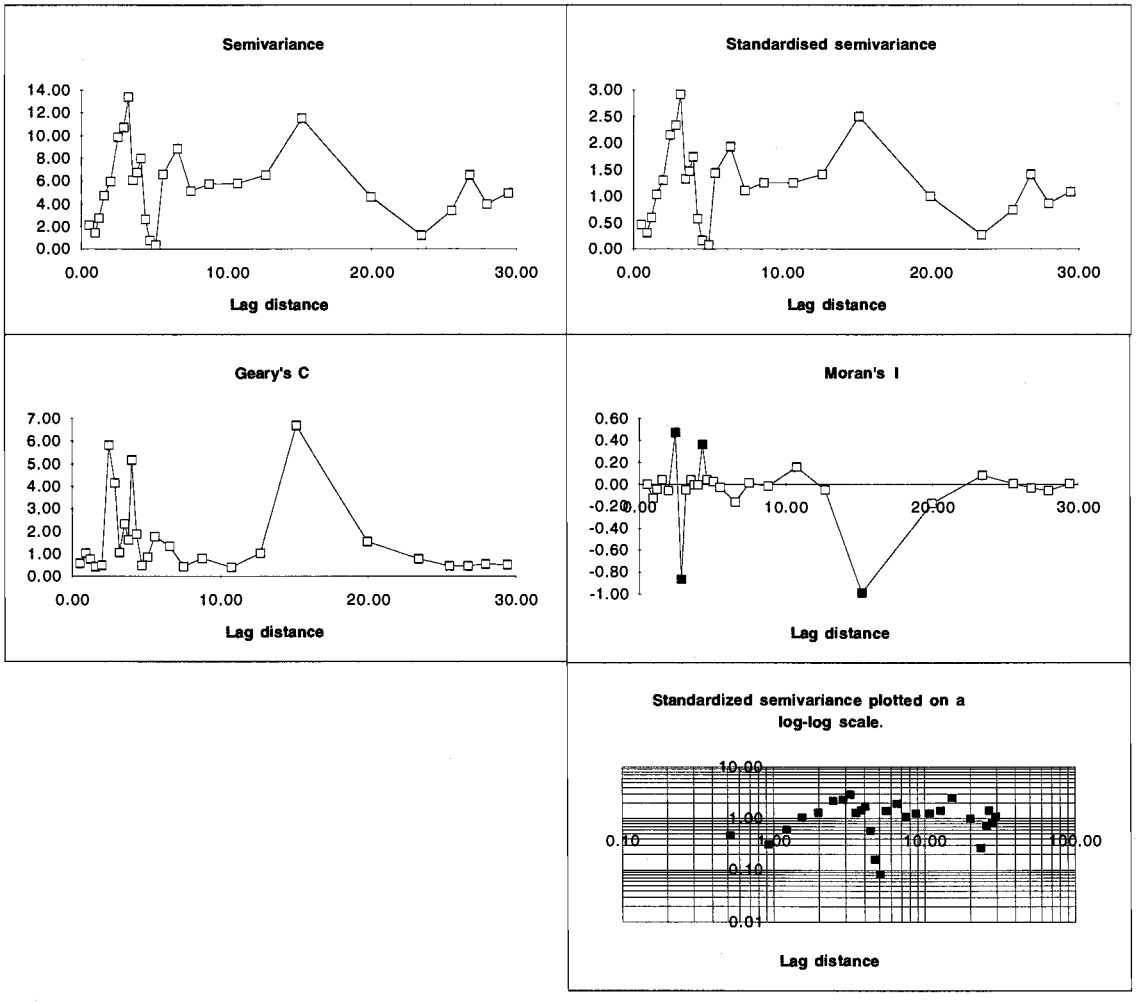
c. PH, plot L, May 1992, sagebrush-grass community.

Figure B.9 continued



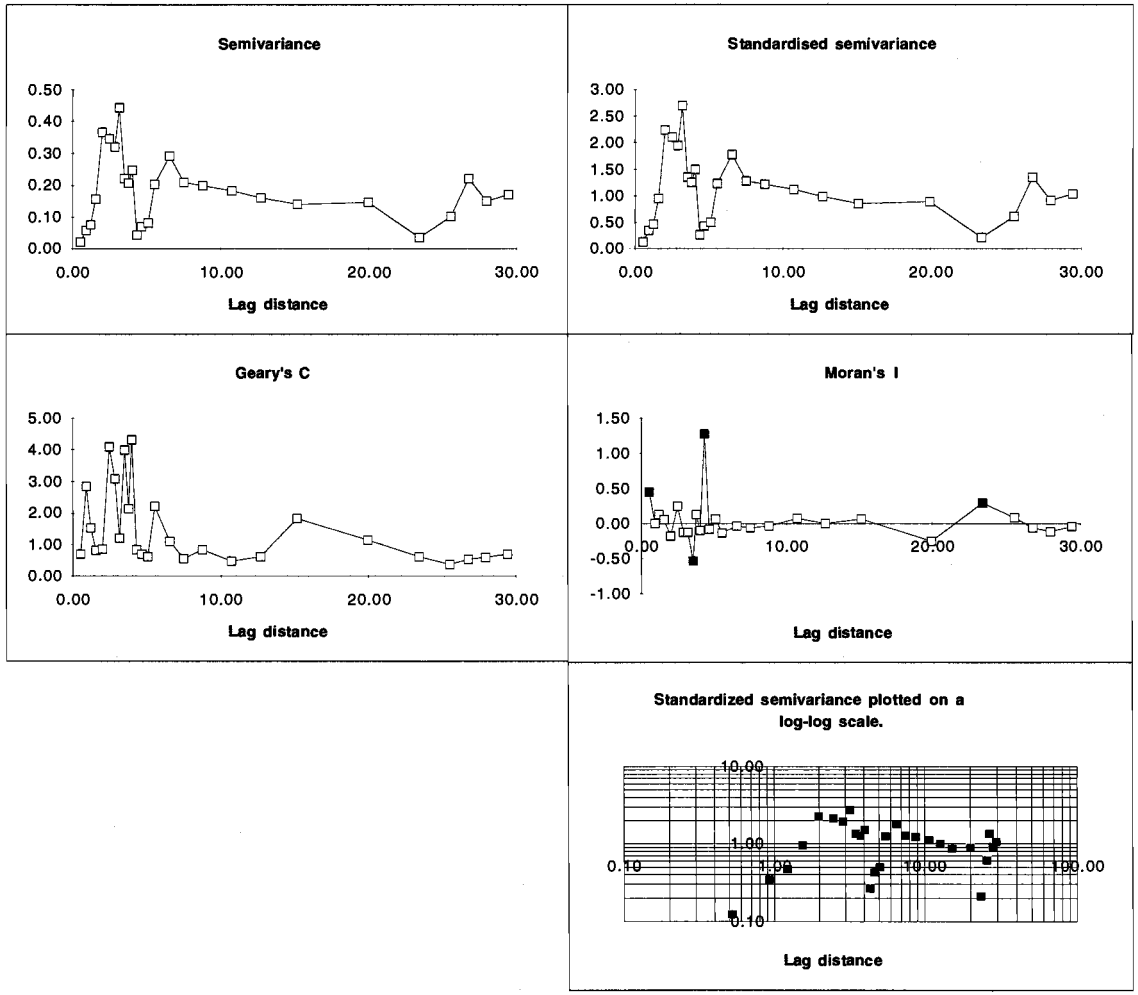
d. Initial Nitrogen as NH4, plot L, May 1992, sagebrush-grass community.

Figure B.9 continued



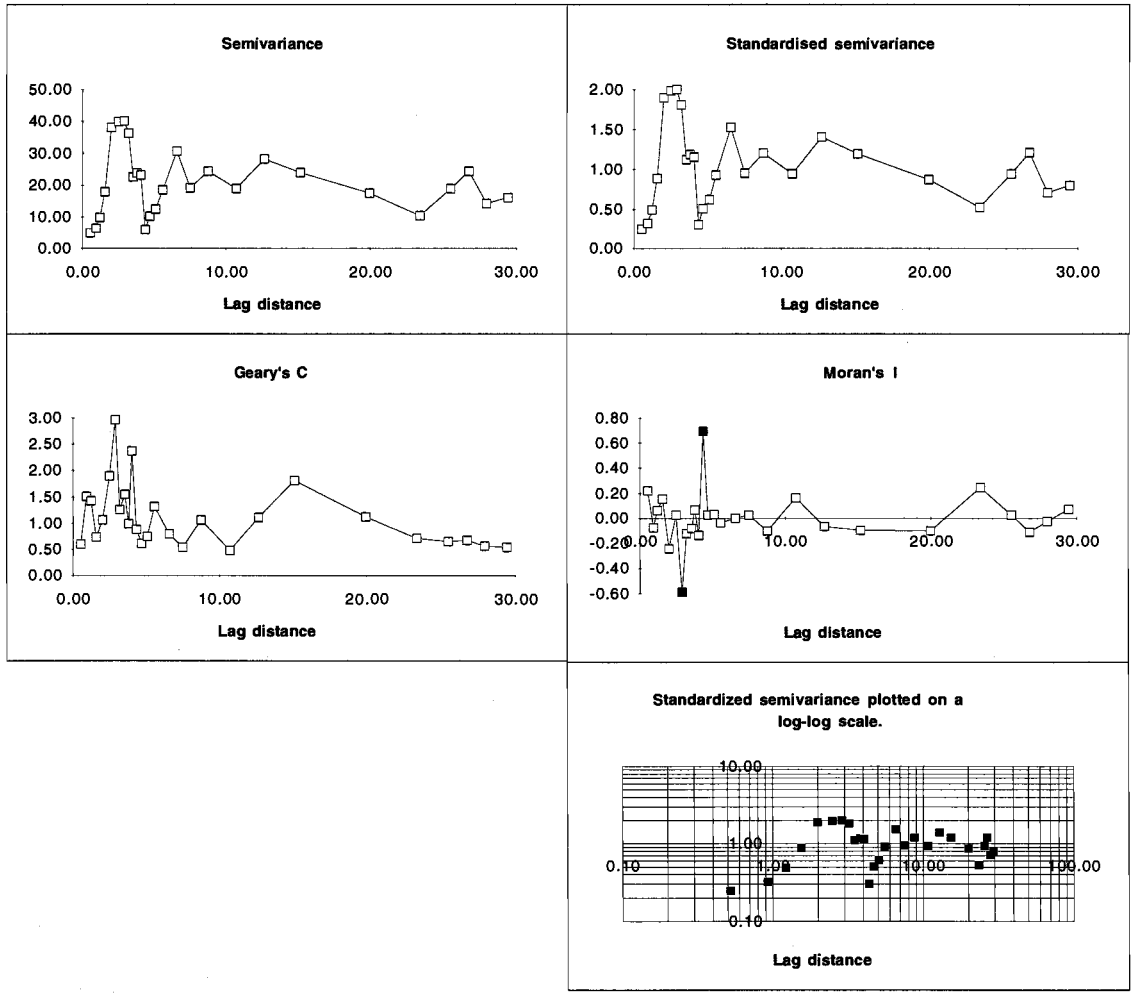
e. Mineralized Nitrogen as NH4, plot L, May 1992, sagebrush-grass community.

Figure B.9 continued



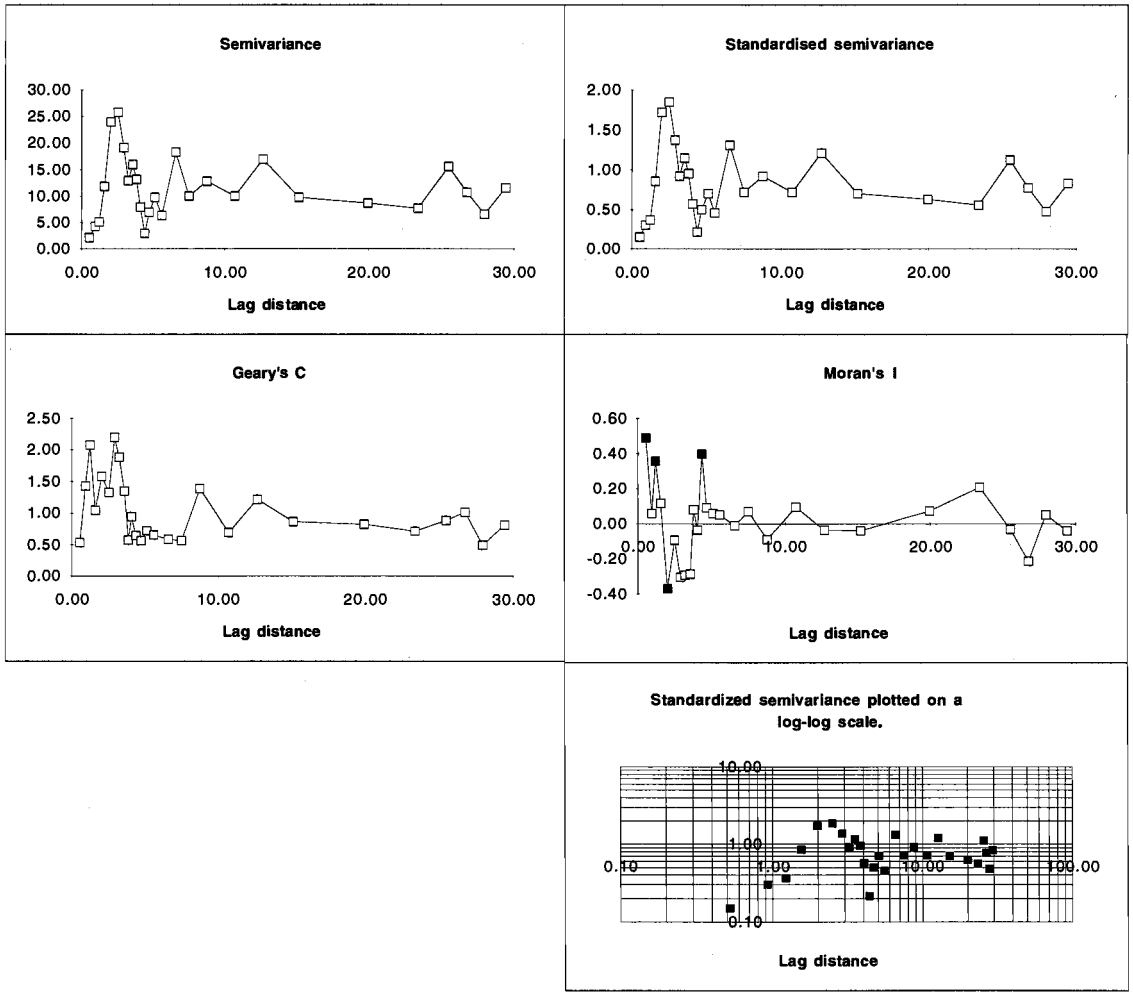
f. Initial Nitrogen as NO3, plot L, May 1992, sagebrush-grass community.

Figure B.9 continued



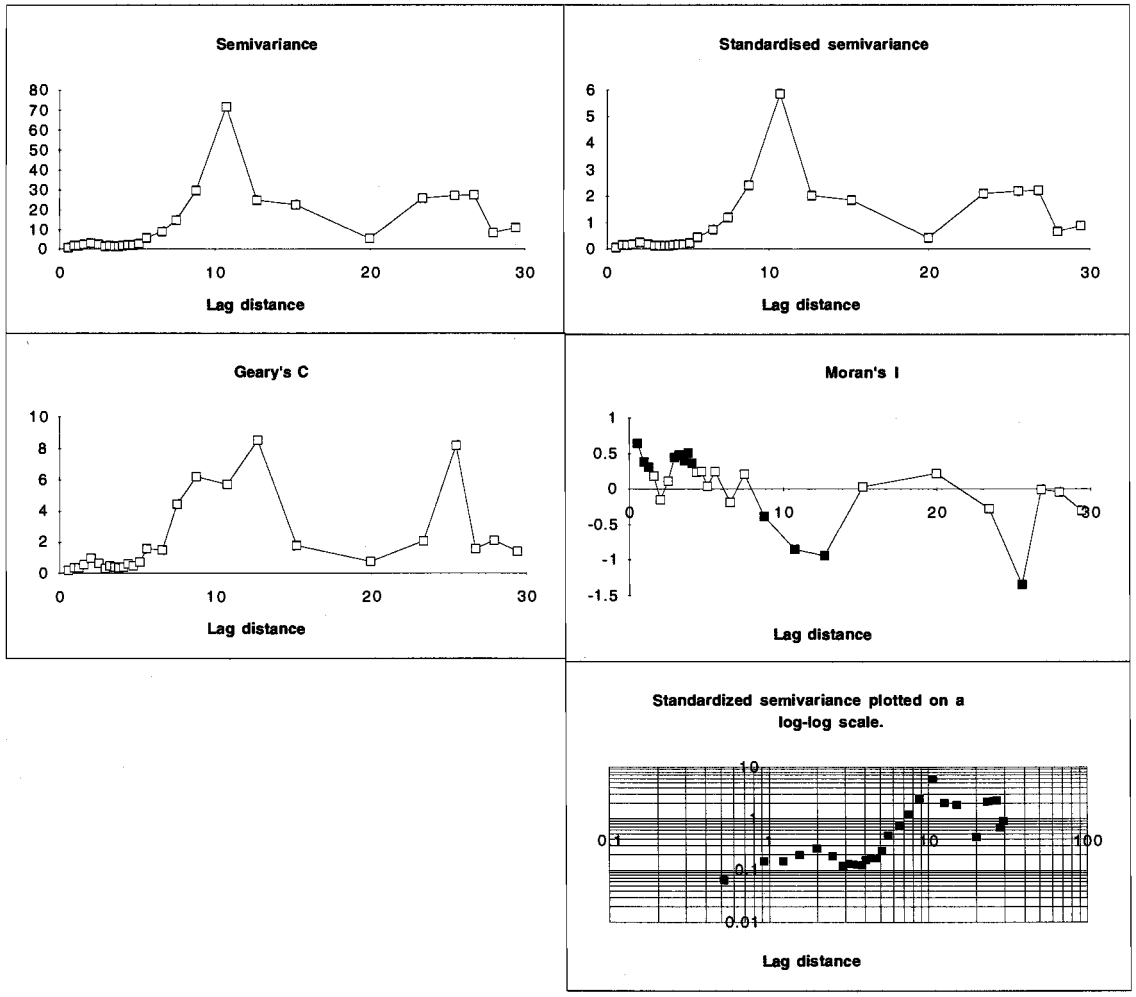
g. Mineralized Nitrogen as NO3, plot L, May 1992, sagebrush-grass community.

Figure B.9 continued



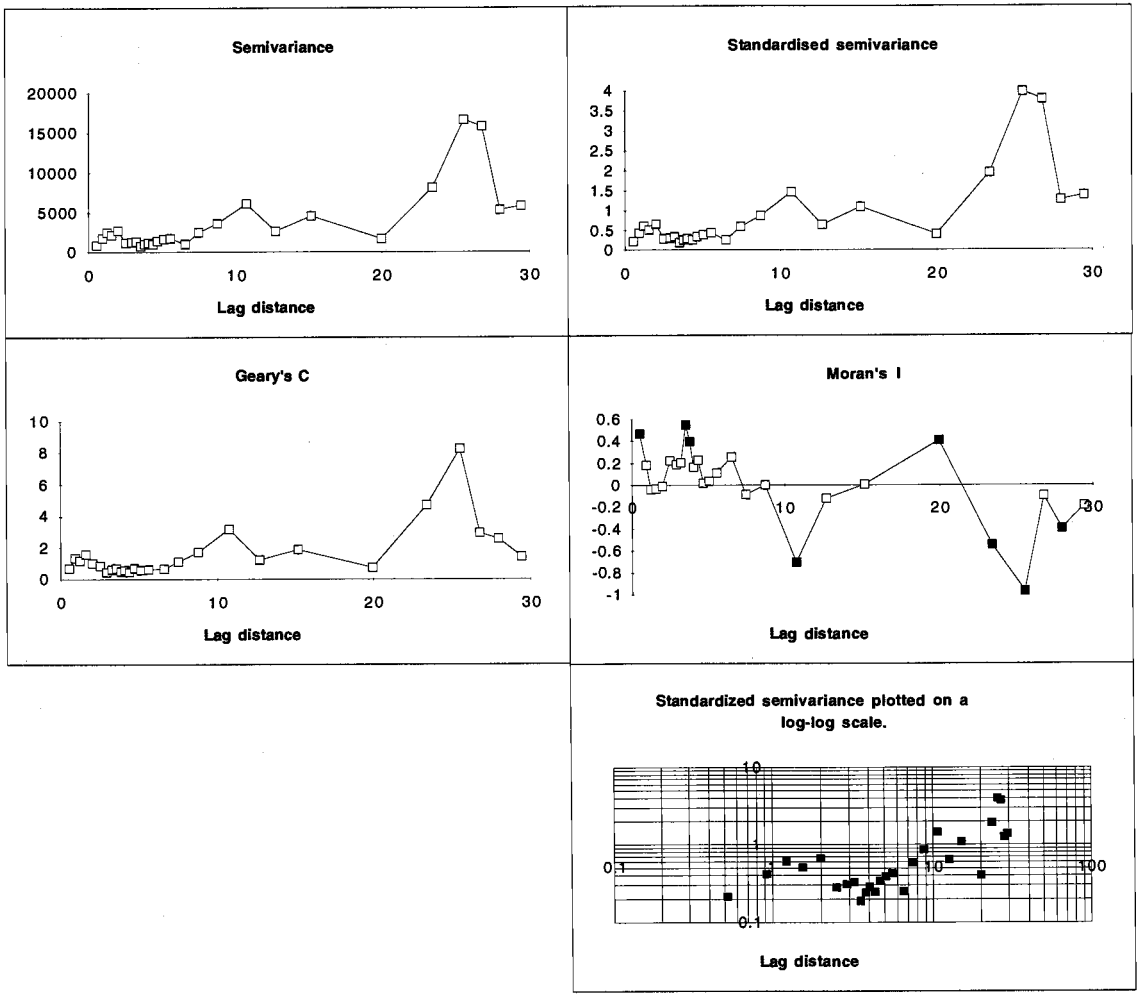
h. Net Nitrogen mineralized, plot L, May 1992, sagebrush-grass community.

Figure B.9 continued



i. Total numbers of soil arthropods, May 1992, plot L, sagebrush-grass community.

Figure B.9 continued



j. Biomass of micro-arthropods, May 1992, plot L, juniper-sagebrush-grass community.

Figure B.9 continued