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**Title**

Spatial Patterns Confound Experiments in Orchard Crops

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## **Introduction**

Many of the processes studied by horticulturalists, such as yield, vary across space and measurements are therefore dependent upon the location in which they are taken. These issues are particularly important in the design of experiments involving the application of fertilizers where the potential for fertilizer movement between plots is particularly important. Such conditions, quantified as spatial autocorrelation, can dramatically reduce experimental precision; however, recognition of this effect is currently lacking in the tree crops, specifically, and the field of horticulture, in general. A greater understanding of the interaction between spatial autocorrelation and plot layout on the results of orchard experiments is needed. The objective of this study was to present an example of the magnitude of these issues to a broad horticultural audience by quantifying the precision, measured as Type I error rate, of ten experimental designs in a commercial orchard.

## **Methods**

We quantified the spatial autocorrelation, similarity or dissimilarity of observation values, of pistachio yields (Moran's I statistic) based on data collected from an average of 9,136 trees in each of four years. We, then, interpolated the data to ensure no missing values and simulated 40000 experiments superimposed on these data (1000 iterations of ten designs in each year). The ten designs represent commonly applied designs in horticultural and nutritional experiments (various blocking sizes) and theoretical alternative (grid-spaced) designs. Significance between groups was tested by ANOVA. Given that all trees were managed in the same manner in this orchard, a precise test by conventional standards should have, approximately, a 5% Type I error rate. Experimental designs tested here include many that have been used in fertilizer studies in which plot designs are frequently constrained by the methods of fertilizer application, the need to avoid cross plot contamination and logistical difficulties in fertilizer application and yield determination.

## **Results**

Two spatial autocorrelation patterns were apparent among years. General low yielding years showed high autocorrelation (Moran's  $I > 0.55$ ) and only a slight decline with distance—54 m (30% decline, 0.9 to 0.6). In high yielding years, autocorrelation was lower (Moran's  $I$  approximately 0.6) and decreased much more substantially (66% decline to  $< 0.2$ ) over the same distance.

Year and experimental layout affected Type I error rate. Type I error rates were higher on average in the two lower yielding years than the high yielding years. The error rate exceeded the normally prescribed 5% for all designs in more than one year and exceeded the 5% error rate in the majority of years for many of the designs, especially the block designs. In general, grid based or completely random designs were most effective at controlling Type I error. Error rates in blocked designs were generally higher and more variable than grid based designs; however, two blocked designs, very large (27 trees per block) and very small blocks (3 trees per block), had comparable Type I error rates. Designs commonly used in tree crop experiments and in fertilizer experiments (nine tree blocks, nine tree blocks with one tree unused for experimentation between experimental trees, and blocks based on rows) had the highest average error rates (average of 9%) and single year error rate (13%).

## **Discussion**

The results seen in this study demonstrate that spatial autocorrelation is a critical issue for researchers to consider when designing field experiments, particularly fertilization experiments. While the randomized complete block design remains the design most frequently used in orchard experiments, using a RCBD in this orchard over the four years of this simulation would have increased the probability of erroneous experimental results in many of the years. Three designs commonly applied in nutrient and yield trials performed the most poorly. Designs with large or small blocks may be relatively sound experimental methods in some orchards. The use of grid based designs or completely random unblocked designs were more appropriate for research in this orchard; however, financial and logistical constraints may prohibit their use in practice.

Given that autocorrelation patterns differ among sites, crops, and process of interest, the results of this experiment are not likely to be generally applicable to all circumstances. Findings of this study do however illustrate the importance of considering spatial autocorrelation in the experimental design in orchard systems, these effects are particularly relevant for fertilization trials.