rectly (4). In our experiment the peak temperature in the sample was directly measured while the laser power was slowly increased. As soon as melting occurred in the hottest portion of the sample, the absorption increased drastically, leading to "runaway" melting and subsequent melting phenomena [figure 2B of (1)]. The melting temperatures we reported are the last temperatures of the solid before melting set in. We stated (1, p. 554) that melting temperatures were recorded at the onset and not during melting. Temperatures measured during melting were very much higher and the emission spectra were of poor quality, which was most likely due to rapid temperature fluctuations caused by convection in the molten sample.

From figure 2B of our report, Heinz *et al.* inappropriately estimate temperature gradients in our sample based on the assumption that its outer portion did not convert to perovskite. No such statement was made in our report. We only stated that the sample surrounding the molten area was perovskite. More correctly: All of the sample surrounding the molten area had converted to perovskite. To avoid confusion, we would like to emphasize the statement in our report (1) that figure 2B represents conditions *after* a melting experiment, which are significantly different from those at the onset of melting.

Heinz *et al.* discount the drastic differences in their three previous estimates of melting. Curves showing zero, positive, or negative slopes, respectively, are clearly in disagreement with each other (2, 3, 4).

We fully agree with the statement of Heinz *et al.* that "A direct association of the peak temperature with a melting slope, without a characterization of the temperature distribution, is therefore unreliable."

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# Statistical Analyses of Soil Quality

J. P. Reganold *et al.* (1) compare the properties of soil from biodynamic and conventional farms in the North Island of New Zealand and conclude that the biodynamic farms have "better soil quality." They collected soil samples from comparable parts of adjacent farms [table 2 in (1)], but the statistical inference tests performed with data from those samples led to "pseudoreplication" (2). Although Reganold *et al.* state that soil-forming factors were the same for each farm in each pair or set, it seems most unlikely that one could characterize these factors sufficiently to justify the use of such statistical methods.

The comparison by Reganold *et al.* of the aggregated data is especially problematic. A valid statistical comparison (that would avoid pseudoreplication) would treat each farm pair or set as a replicate block and analyse the data on that basis. This can be done by analyzing the data in table 2 of the report by Reganold *et al.* with a two-way analysis of variance (ANOVA) using a block design [(biodynamic as opposed to conventional farm) × block], with $n = 7$ blocks (3). Such an analysis [(Table 1), which is similar to table 3 of (1)] shows that the overall means of the soil properties are slightly different from those presented by Reganold *et al.* (1). Of greater concern is the fact that only one soil property (mineralizable N) of the 12 that were identified in table 3 of their report as differing significantly ($P < 0.01$) between conventional and biodynamic farms actually appears to be so.

The three biological indicators used by Reganold *et al.* do not seem to be appropriate for measuring the quality of soil life under biodynamic farming. (i) Greater soil respiration was assumed to be beneficial. But a loss of $CO_2$ from soils can indicate ecosystem inefficiency, that is, energy loss from the soil system. High ecosystem respiration (especially per unit biomass) often results from stress and disturbance factors (4). (ii) The ratio of mineralizable N to C is indicative of microbial N availability rather than microbial activity. (iii) Although earthworms are susceptible to some aspects of conventional farming (5), the data about earthworms presented by Reganold *et al.* (1, p. 347) are not replicated because samples were taken from only one biodynamic and one conventional farm.

Finally, the apparent advantages of biodynamics farming may be a result of prac-

**Table 1.** Comparison of soil properties from biodynamic and conventional farms. Mean value of aggregated soils data reanalyzed by Wardle with a 7 × 2 block design. Differences calculated by Reganold *et al.* and by Wardle. Abbreviations: bio, biodynamic; con, conventional; NS, not statistically significant; and S, statistically significant.

| Soil property | Mean value* | | Difference† | |
|---|---|---|---|---|
| | All bio farms | All con farms | Indicated by Reganold *et al.*† | *P* calculated by Wardle‡ |
| Bulk density (Mg $m^{-3}$) | 1.07 | 1.16 | S | 0.086 |
| Penetration resistance (0 to 20 cm) (MPa) | 2.76 | 3.04 | S | 0.217 |
| Penetration resistance (20 to 40 cm) (MPa) | 3.55 | 3.50 | NS | 0.836 |
| Carbon (%) | 4.67 | 4.25 | S | 0.259 |
| Respiration (μl $O_2$ $hour^{-1}$ $g^{-1}$) | 67.1 | 50.7 | S | 0.045 |
| Mineralizable N (mg $kg^{-1}$) | 140.3 | 106.2 | S | <0.001§ |
| Ratio of mineralizable N to C (mg $g^{-1}$) | 3.05 | 2.57 | S | 0.014 |
| Topsoil thickness (cm) | 22.6 | 20.0 | S | 0.013 |
| CEC (cmol $kg^{-1}$) | 21.6 | 19.7 | S | 0.306 |
| Total N (mg $kg^{-1}$) | 4717 | 4317 | S | 0.331 |
| Total P (mg $kg^{-1}$) | 1623 | 1639 | NS | 0.962 |
| Extractable P (mg $kg^{-1}$) | 50.2 | 63.6 | S | 0.341 |
| Extractable S (mg $kg^{-1}$) | 11.6 | 18.7 | S | 0.336 |
| Extractable Ca (cmol $kg^{-1}$) | 12.7 | 13.5 | NS | 0.599 |
| Extractable Mg (cmol $kg^{-1}$) | 1.77 | 1.50 | NS | 0.294 |
| Extractable K (cmol $kg^{-1}$) | 1.09 | 1.01 | NS | 0.704 |
| pH | 6.10 | 6.25 | S | 0.135 |

*Calculated from data in table 2 of (1). †Analysis of variance (ANOVA), $P < 0.01$, from table 3 of (1). ‡Value of *P* from two-way ANOVA. §Statistically significant at $P < 0.01$.

tices that may also be part of "organic," "low input," and Integrated Pest Management programs.

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*Response:* Wardle states that adjacent farm comparisons in table 2 of our report (*1*) are not statistically valid because of pseudoreplication (*2*). A discussion of pseudoreplication was omitted from our report because of space restrictions. Pseudoreplication in the strictest sense is unavoidable when comparing two adjacent farm fields, but this does not invalidate our analyses. Hurlbert (*3*, p. 199) states

> Replication is often impossible or undesirable when very large-scale systems (whole lakes, watersheds, rivers, etc.) are studied. When gross effects of a treatment are anticipated, or when only a rough estimate of effect is required, or when the cost of replication is very great, experiments involving unreplicated treatments may also be the only or best option.

The commercial farms in our study generally met the criteria of large-scale systems.

Some scientists "fear, however, that many reviewers may not read Hurlbert (or their statistics texts) carefully and either (i) judge as scientifically inadequate any nonreplicated study, or (ii) falsely levy the charge of pseudoreplication against studies that incorporate nonreplicated sample designs" (*4*, p. 184). Still, researchers must be careful when interpreting unreplicated treatments so that they do not give their conclusions "an unmerited veneer of rigor" (*3*). We did not make any major inferences from data on any single pair or set of adjacent farm fields (table 2 of our report), but only discussed trends or frequencies in the soils data for the individual farm pairs or sets. Major inferences were made from table 3 of our report, where the aggregated data were analyzed using a two-way ANOVA (*1*).

A block design is one appropriate method for analyzing our data. We chose to analyze the data with a two-way ANOVA that incorporated all the sample points in each field (usually five to six soil samples per field) and minimized the variation resulting from the different soil in each pair of matched fields. We believed our design better represented the soil variability of each field because each observation was included, and it seemed a logical progression from the individual data shown in table 2 of our report. Our approach included each sample point per treatment (biodynamic or conventional) by matched field pair [each pair having the same soil type and farm enterprise (citrus, livestock, and so forth)], whereas a block design would include the *mean* of the five or six observations per treatment by matched field pair. Wardle has used a block structure based on farm enterprise, but accounting for different soil types as well as farm enterprises is more suitable than analyzing the data on the basis of farm enterprise alone (*5*). The results of the analysis by Wardle (his table 1) are incomplete, as he did not use all of the means needed for the total number of blocks.

I am, however, willing to reanalyze the data using a block design that accounts for different soil types. As was stated in our report, the seven farm pairs or sets in our study (*1*) included 22 fields that were sampled for soil analyses (*6*). All fields were paired (that is, a biodynamically managed field was compared with a conventionally managed field), and each pair had the same soil type (and farm enterprise). Thus, there were 11 pairs of fields based on 11 different soil types and, therefore, 11 replicate blocks. Rather than listing the data for all 11 field pairs in table 2 of our report, we chose to simplify and present the results by grouping them into the seven different enterprises as represented by the farm pairs or sets (*7*).

The reanalyzed data using the appropriate 11 × 2 block design [Table 1 (*8*)] support our original conclusions: The biodynamic farms had significantly better biological and physical soil quality than did their conventional neighbors. In comparing the original values of *P* with those of the reanalyzed block design, they are similar for three of the four physical properties [that is, bulk density, penetration resistance (20 to 40 cm), and topsoil thickness] and all of the biological properties (that is, soil C, microbial respiration, mineralizable N, and ratio of mineralizable N to soil C), from which the conclusions about soil quality were made. The results of the nine chemical properties were mixed in the original two-way ANOVA; that is, there were five significant differences with two higher for the biodynamic and three higher for the conventional, and four nonsignificant differences. The reanalyzed block design shows only two differences at $P < 0.06$ (one for each system), indicating soils of similar chemical

**Table 1.** Comparison of soil properties from biodynamic and conventional farms. Mean values of aggregated soils data reanalyzed with an 11 × 2 block design. Abbreviations: bio, biodynamic; con, conventional.

| Soil property | Mean value* | | *P*† |
|---|---|---|---|
| | All bio fields | All con fields | |
| Bulk density (Mg $m^{-3}$) | 1.07 | 1.15 | 0.028 |
| Penetration resistance (0 to 20 cm) (MPa) | 2.80 | 3.14 | 0.138‡ |
| Penetration resistance (20 to 40 cm) (MPa) | 3.57 | 3.50 | 0.779‡ |
| Carbon (%) | 4.92 | 4.35 | 0.034 |
| Respiration (μl $O_2$ $hour^{-1}$ $g^{-1}$) | 71.2 | 51.3 | 0.003 |
| Mineralizable N (mg $kg^{-1}$) | 147.3 | 110.9 | <0.001 |
| Ratio of mineralizable N to C (mg $g^{-1}$) | 3.11 | 2.68 | 0.002 |
| Topsoil thickness (cm) | 22.6 | 20.4 | 0.003‡ |
| CEC (cmol $kg^{-1}$) | 22.6 | 20.8 | 0.153 |
| Total N (mg $kg^{-1}$) | 4868 | 4331 | 0.059 |
| Total P (mg $kg^{-1}$) | 1657 | 1747 | 0.391‡ |
| Extractable P (mg $kg^{-1}$) | 52.4 | 73.9 | 0.138‡ |
| Extractable S (mg $kg^{-1}$) | 10.9 | 22.2 | 0.391‡ |
| Extractable Ca (cmol $kg^{-1}$) | 14.1 | 14.5 | 0.703 |
| Extractable Mg (cmol $kg^{-1}$) | 1.91 | 1.77 | 0.391‡ |
| Extractable K (cmol $kg^{-1}$) | 1.15 | 1.09 | 0.813 |
| pH | 6.14 | 6.29 | 0.052 |

*Calculated from soil samples taken from 11 pairs of fields (*6*). †Value of *P* from two-way ANOVA using an 11 × 2 block design (*12*). ‡*P* is from a nonparametric Friedman test (*13*) because the assumption of normality was not met. Although the values of *P* from the nonparametric test are more appropriate, they generally differed little from those calculated in the block design.

# Statistical Analyses of Soil Quality

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