Soil Quality & Profitability of Biodynamic & Conventional Farming Systems

By

John P. Reganold

1 gallon = 4.54 litres
2.2 lbs. = 1 kg
1 ounce (oz.) = approx. 28 gram

Soil quality and profitability of biodynamic and conventional farming systems: A review

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Abstract. *Biodynamic and organic farming are similar in that both are ecologically oriented and do not use chemical fertilizers and pesticides. The main difference is that biodynamic farmers add eight specific amendments, called preparations, to their soils, crops, and composts. Recently, there has been an increasing interest in biodynamic farming practices and systems because they show potential for mitigating some detrimental effects of chemical-dependent conventional agriculture. Only a few studies examining biodynamic methods or comparing biodynamic farming with other farming systems have been published in the referred scientific literature, especially in English. This paper summarizes data from previous studies, both published and unpublished (theses), that have compared biodynamic and conventional farming systems with respect to soil quality or profitability. These studies have shown that the biodynamic farming systems generally have better soil quality, lower crop yields, and equal or higher net returns per hectare than their conventional counterparts. Two studies that included organic management treatments with and without the preparations showed that the preparations improved biological soil properties and increased crop root growth. However, more research is needed to determine whether the preparations affect soil physical, chemical, and biological properties and crop growth and, if so, their mode of action.*

Key words: biodynamic farming, biodynamic preparations, soil quality, farm profitability, cropping systems, on-farm research, sustainable agriculture.

Introduction

Growing concerns about the environmental, economic and social effects of chemical-dependent conventional agriculture have led many farmers and consumers to seek alternative practices and systems that will make agriculture more sustainable. Alternative farming systems include ‘organic’, ‘biological’, ‘biodynamic’, ‘ecological’, and ‘low input’. However, just because a farm is “organic” or ‘Biodynamic,’ for example, does not mean that it is sustainable. To be sustainable, it must produce food of high quality, be environmentally safe, protect the soil, and be profitable and socially just (Reganold et al., 1990).

Recently, there has been increasing interest in biodynamic farming and gardening. For example, between 1989 and 1992 the number of biodynamic farms in France increased from 142 to 202 (Bio-Dynamic Farming and Gardening Association in New Zealand 1993). Although biodynamic farming is practiced in cool and warm climates on all continents, the highest proportions of biodynamic farms are found in Western Europe, Australia, New Zealand, and North America (Lampkin, 1990). A mid-1980s survey in Europe found 1,090 commercial biodynamic farms and gardens on 17,616 ha; 42% of these were in Germany and 15% in Holland (Koepf, 1989). The survey also found that the European biodynamic movement included 28 full-time advisors, 124 processors under contract; 47 wholesalers, about 3,000 retailers, 30 consumer groups, and many additional part-time biodynamic farmers and gardeners. A rough estimate is that there are at least 2,000 practicing biodynamic farmers (full or part-time) and gardeners in the United States today (Charles L. Beedy, Executive Director, Bio-Dynamic Farming and Gardening Assoc. Inc., Kimberton, Pennsylvania, personal communication, August 1994).

Biodynamics is considered by some to be the oldest organized alternative agriculture movement in the world. It began in 1924 following a series of lectures by Rudolf Steiner, the founder of anthroposophy, at the request of German farmers (Koepf, 1989). Within a few years, interest spread to several European countries. Ehrenfried Pfeiffer brought biodynamics to the United States from Europe before World War II. Today, farmers, gardeners, advisers, and scientists are organized into biodynamic associations, some of which have their own research facilities. A certification program was introduced in 1928 for marketing basic foodstuffs, which are now marketed under the trademarks Demeter and Biodyn. Most, if not all, certified biodynamic products (for example, those with the Demeter label) would meet the criteria for certified organic, but certified organic would not meet the Demeter standards, mainly because the biodynamic preparations are not used in organic farming.

Like organic farming, biodynamic farming uses no synthetic chemical fertilizers and pesticides, and instead emphasizes building up the soil with compost additions and animal and green manures, controlling pests naturally, rotating crops, and diversifying crops and livestock. A major difference is that biodynamic farmers add eight specific preparations to their soils, crops, and composts to enhance soil and crop quality and to stimulate the composting process (Koepf et al, 1976.)

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The eight preparations, designated by their ingredients or by the numbers 500 to 507, are made from cow manure, silica, flowers of yarrow, chamomile, dandelion and valerian, oak bark, and the whole plant of stinging nettle (Table 1). Some biodynamic farmers make the preparations themselves while others buy them from certifying biodynamic associations or experienced practitioners.

The thoughts behind the preparations are unconventional and based on a holistic approach to nature. When applied, extracts of the preparations are so highly diluted in water that physical or biological effects seem unlikely. Yet significant increases in yield have been reported in the biodynamic literature (Goldstein,1990).Biodynamic practitioners maintain that the preparations are not ‘witchcraft’, ‘snake oils’, ‘miracle cure-alls’, or part of a get-rich-quick scheme. Goldstein (1990) believes that people who doubt that the preparations benefit agriculture do so for the following reasons:

- Most people have probably not heard of biodynamics or biodynamic preparations.
- Biodynamics is based on spiritual-physical principles. Spiritual matters are difficult, if not impossible, to measure.
- The making of the preparations seems strange or unsanitary to many.
- Such small amounts of the preparations are applied to crops, soils, or compost that a response seems unlikely.
- No correct chemical/physical answer to why the preparations may work has been offered. Some have proposed that the preparations act as microbial inoculates; others, think they may have hormonal effects or maybe even radiative effects.

Besides the preparations, there are other differences between organic and biodynamic farming. Modern organic farming was started by Sir Albert Howard in England in the 1930s, emphasizing the use of compost instead of chemical fertilizers (Oelhaf, 1978). In 1924, Rudolf Steiner’s concept of a healthy agriculture took into account not only crop rotations, sound stocking rates, and organic manuring, but also cosmic factors, namely the influence of the moon and planets. For example, his observations led him to believe there was a relationship between the position of the moon relative to the sun (synodic rhythm), planting dates, and crop growth (Spiess, 1990).

Although there have been many articles, ranging from the sketchy to the detailed, describing studies of biodynamic practices, most of this information has not been reviewed according to rigorous scientific principles by traditional soil scientists, agronomists, or agricultural economists (Koepf, 1993). Few studies examining biodynamic farming methods or comparing biodynamic with other farming systems have been published in the referenced scientific literature, especially in English. Most such studies have been conducted and published in Germany and Sweden and are not available in English (Koepf, 1989, 1993).

This paper summarizes data from several previous investigations comparing biodynamic and conventional farms or research plots in Europe, Australia, New Zealand, the United States, and the Canary Islands. Since this review includes mostly English publications, it covers only a small portion of the literature on biodynamics. The objective of each study reported here was to determine the effects of biodynamic and conventional farming on soil quality or economic performance, two of several indexes of agricultural sustainability.

Table 1. The eight biodynamic preparations, which consist of fermented materials that wre used as field sprays or in manure or compost piles (Proctor, 1989).[1]

Preparation	Substance from which preparation is produced	Application of preparation
500	Cow manure fermented in a cow horn	A spray for soils before planting
501	Silica fermented in a cow horn	A spray for growing crops
502	Flower heads from yarrol (*Achillea millefolium*) fermented in the bladder of a stag	Preparations 502 through 507 are applied to manure or compost piles
503	Flower heads from German chamomile (*Matricaria recutita*) fermented in a cow intestine	
504	Stinging nettle (*Urtica dioica*) fermented in the soil	
505	Oak bark (*Quercus robur*; in North America *Quercus alba*) fermented in the skull of a domestic animal	
506	Flower heads of dandelion (*Taraxacum officinale*) fermented in a cow mesentry	
507	Juice pressed from valerian flowers (*Valeriana officinalis*)	

[1] Although not considered one of the eight main preparations, a ninth preparation, sometimes referred to as 508,is made by boiling the horsetail plant (*Equisetum arvense*) and is applied only in excessively wet years to prevent fungal diseases.

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Soil Quality Studies

High quality soils not only promote the growth of plants, but also prevent water and air pollution by resisting erosion and by degrading and immobilizing agricultural chemicals, organic wastes, and other potential pollutants. The quality of a soil is determined by a combination of physical, chemical, and biological properties such as the soil's texture, depth, porosity, capacity to store water and nutrients, organic matter content, and biological activity (National Research Council, 1993). In this section I report on studies examining different combinations of soil physical, chemical and biological properties of farms or research plots under biodynamic and conventional manage-ment. Some studies also include an organic treatment.

Sweden. In 1958, the Scandinavian Research Circle began a field plot experiment in Järna to study the effects of biodynamic, organic, and conventional management on soil and crop quality (Pettersson and von Wistinghausen, 1979). Eight non-replicated fertilizer treatments were applied to field plots. Each treatment had the same four-year crop rotation: summer wheat / clover-grass mixture/ potatoes/beets (Table 2). Routine soil tests have been carried out since 1958 at 3 to 5 year intervals detailed analyses were done of the topsoil (0-10cm) and subsoil (25-35 cm) in 1976, 1985 and 1989, and of the second subsoil layer (50-60 cm) in 1985 and 1989 (Pettersson et al., 1992).

In all three sampling years, the topsoil of the biodynamically treated and organically fertilized plots (K1-K4) generally was higher in organic matter, microbial activity, enzyme activity (dehydrogenase and urease), earthworm channel, total N, and pH than the topsoil of the control (K5) or chemically fertilized plots (K6-K8) (Pettersson et al., 1992). Among the organically fertilized treatments (K1-K4), treatment K4, the only one with both organic and inorganic fertilizers, had the lowest microbial activity, dehydrogenase activity, and earthworm channels for all three years. Extractable P levels were highest in the chemically fertilized treatments (K7 and K8) in all three years.

In the Pettersson et al. study (1992), average yields for all four crops over the 32 year period (1958-1989) were comparable for all treatments, except that the control (K5) was lower and the low NPK treatment (K6) somewhat lower. The variation in yield among the seven treatments other than the control was almost 20%, with the K8 treatment (high NPK) having the highest average yield and the K6 treatment (low NPK) the lowest.

Granstedt (1991) measured plant nutrient inputs and outputs on conventional and biodynamic farms in Sweden. He showed that the nutrient economy on biodynamic farms was more efficient and potentially more environmentally safe than on conventional farms.

Table 2. The eight treatments in the field plot experiment in Järna, Sweden (Pettersson and von Wistinghausen, 1979).

Treatment	Fertilizer application
K1	Compost manure with biodynamic preparations 502 through 507 and, from 1962 on, 1% levels of meat meal and bone meal (only bone meal after 1974); soils and plants treated with biodynamic preparations 500 and 501, respectively.
K2	Same as K1 but excluding biodynamic sprays 500 and 501
K3	Raw manure with 1% additions of horn and bone meal as of 1974
K4	Raw manure at half the K3 rate plus inorganic MPK fertilizer at half the K6 NPK rate
K5	Control (unfertilized)
K6	Organic NPK: From 1958 through 1973, compounded from $Ca(NO_3)_2$, NH_4NO_3, superphosphate, and K_2SO_4; from 1974 on, prepared blend (11-5-18) with trace minerals
K7	Inorganic NPK at twice the level as in K6
K8	Inorganic NPK at four times the N level and twice the P and K levels as in K6

Germany. A four-year plot experiment comparing biological soil properties under biodynamic, organic, and conventional vegetable management was carried out in Germany (Abele, 1987, as translated by Koepf, 1993). Each management system received annual applications of N at three different rates (50, 100 and 150 kg/ha), applied as chemical fertilizer to the conventional plots, as composted manure to the organic plots, and as composted manure with biodynamic preparations to the biodynamic plots. At all three N rates, organic matter and total N were significantly higher in the biodynamic plots than in the corresponding organic plots, and in both the biodynamic and organic plots than in the conventional plots. The biodynamic plots also were significantly higher than the organic plots, and the organic plots in turn significantly higher than the conventional plots, in dehydrogenase activity, microbial biomass, and dehydrogenase activity per unit of microbial biomass.

In another plot study on an experiment station in German, Reinken (1986) found higher organic matter levels and earthworm populations on biodynamically treated vegetable and apple plots than on conventionally treated vegetable and apple plots.

Austria. Forssner (1987) investigates soil animals, microbial activity, soil enzymes, and other soil properties on two pairs of matched biodynamic and conventional farms near Vienna. The biodynamically farmed soils had greater numbers of protozoa (testate amoebae and ciliates) and nematodes, higher microbial activity and humus content, and lower bulk density than the conventionally farmed soil. However, few differences could be asserted with high statistical confidence because of the low sample size.

Austrialia. In a comparison of a biodynamic and an adjacent conventional farm in Australia, Forman (1981) examined soil properties, yields, and plant nutrient contents. The two farms were in the Breeza Plains area in New South Wales. The seven-year old biodynamic farm used a crop rotation of

wheat/ rye/fallow/wheat/fallow/wheat/wheat.
a wheat/ wheat/fallow rotation. Before the conventional paddock was put into arable crops, it first had been farmed for 10 years, then was in pasture for about 35 years. Organic matter, extractable P, and pH were all significantly higher on the biodynamic farm than on the adjacent conventional farm (Table 3). Levels of K were similar; only Mg and Na were lower on the biodynamic farm.

Forman also conducted a greenhouse pot trial with wheat using soil samples from the biodynamic paddock and the

The biodynamic paddock was in

conventional paddock. Both soils received various combinations of two biodynamic preparations (500 and 507) and two inorganic fertilizer nutrients (N and P). A total of 16 treatments (including a control), each replicated three times, was applied to pots from both biodynamic and conventional soils. Over all treatments, Forman found that the biodynamic soil had higher wheat seedling emergence counts 7 and 8 days after sowing and a much higher rate of tiller formation 13 days after sowing

scattered timber before being cultivated. The 11-year old conventional farm used

than the conventional soil (Table 3). It also had significantly higher dry matter wheat yields (48 days after sowing), and higher yields per unit of water added (water use efficiency) than the conventional soil. Plants grown in the biodynamic soil had a significantly higher N content and uptake, P uptake, and Ca content than plants grown in the conventional soil, but P content was significantly higher in the conventional soil.

Table 3. Mean values of soils data from adjacent paddocks and plant data from pot trials, New South Wales Farm Pair, Australia (Forman, 1981).

Soil[1] and Plant Properties	**Biodynamic Farm**	**Conventional Farm**
Soil Properties in Field Study		
C(%)	1.43*	0.94
Total Nitrogen (%)[2,3]	0.23	0.13
Extractable P (mg/kg)	44.9*	27.8
Extractable Mg (cmol/kg)	1.65	1.86*
Extractible K (cmol/kg)	1.33	1.39
Extractable Na (cmol/kg)	2.17	4.63*
pH	6.12*	5.57
Pot Study		
Seedling emergence count (7 days after sowing)[3]	111	48
Seedling emergence count (8 days after sowing)[3]	210	165
Plants showing tiller development (13 days after sowing)[3]	86	13
Mass of dry matter wheat produced (g) per pot (48 days after sowing)	2.57*	1.57
Mass of dry matter wheat produced per amount of water added (mg/ml)	1.32*	0.98
Plant N content (%)	2.09*	1.84
Plant N uptake (mg)	55.2*	30.4
Plant P content (%)	0.36	0.46*
Plant P uptake (mg)	9.4*	6.9
Plant Ca content (%)	0.33*	0.25
Plant K content (%)	3.31	3.17
Plant Mg content (%)	0.13	0.12

*Indicates a significantly higher value ($p<0.01$, usig a two-sided t-test for the field study ad a two-way ANOVA in a randomized complete block design for the pot study).
[1]Based on a sampling depth of 0-10 cm.
[2]Total N means are each based on analysis of only two bulked samples per paddock; all other soil properties are averages for 25 separate samples per paddock.

[3]Not statistically analyzed.

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Penfield (1993, 1994) established a long-term research project in 1989 at the Roseworthy Campus of the university of Adelaide in Australia to investigate soil characteristics, crop yields, and economics of four farming systems: biodynamic, conventional, integrated (low input), and organic. The systems are being compared in a 16 ha campus farm paddock previously in pasture, with two replicated 2-ha plots per treatment. A wheat crop is grown in all treatments every four years. After four years, the four treatments showed few statistically significant differences in organic C, VA mycorrhizae, microbial biomass and activity, earthworms, water infiltration, soil erosion, or extractable P (Penfold, 1994).

New Zealand. To examine the effects of biodynamic and conventional farming systems on soil quality, Reganold et al. (1993) examined seven biodynamic farms on the North Island of New Zealand, each of which was matched with one or two adjacent conventional farms on the basis of soil characteristics and crop or livestock enterprises (total of 16 farms). The farms included a range of representative enterprises in New Zealand: market garden (vegetables), pipfruit (apples and pears), citrus, grain, sheep/beef and dairy. Farm fields within each pair or three farm set had the same crop or livestock enterprise and soil type. The biodynamic farms had been biodynamically managed for at least 8 years; the oldest for 18 years. The biodynamically managed surface soils (0-10 cm), had significantly higher organic matter content and microbial activity, lower bulk density, easier penetrability, and thicker topsoil than their conventional neighbors (Table 4). Differences in chemical properties were mixed: cation exchange capacity and total N were higher on the biodynamic farms, while available P, available S and soil pH were higher on the conventional farms. Levels of Ca, Mg, and K were similar in the two systems.

The physical condition of the soils on all 16 farms has since been assessed (Reganold and Palmer, unpublished data) using a soil structure index developed by Peerlkamp (1967), as modified by McLaren and Cameron (1990). The structure index ranges from 1 (poorest condition) to 10 (most favorable). The index for the biodynamically farmed soils averaged 7.4, whereas the conventionally farmed soils were significantly lower at 5.7 (Table 4).

Reganold et al. (1993) analyzed only the vegetable farm pair for earthworms and found the biodynamically cropped soil to have more than 8 times as many earthworms (more than 25 times by mass) as the conventionally cropped soil. In later measurements on two of the other farm pairs in the study of Reganold et al. (1993), Levick (1992) found 12 times as many earthworms on the biodynamic citrus farm and 84 times as many earthworms on the biodynamic pipfruit farm compared with their conventional counterparts. Levick also found that the biodynamically farmed soils had significantly higher water infiltration rates, porosity, organic C and soil respiration, and lower bulk density ad penetration resistance than the conventionally farmed soils.

Table 4. Mean values of aggregated soils data (Reganold et al. 1993).

Soil Property[1]	All Biodynamic Farms	All Conventional Farms
Bulk density (Mg/m^3)	1.07	1.15*
Penetration resistance (0-20 cm) (MPa)	2.84	3.18*
Penetration ressistance (20-40 cm) (MPa)	3.55	3.52
Soil Structure Index[2]	7.4*	5.7
Topsoil thickness (cm) (includes surface and subsurface (A) horizons	22.8*	20.6
C (%)	4.84*	4.27
Respiration ($\mu L\ O_2\ h^{-1}\ g^{-1}$)	73.7*	55.4
Mineralizable nitrogen (mg/kg)	140.0*	105.9
Ratio of mineralizable N to C (mg min N/g C)	2.99*	2.59
Cation exchange capacity (cmol/kg)	21.5*	19.6
Total N (mg/kg)	4840*	4260
Total P (mg/kg)	1560	1640
Extractable P (mg/kg)	45.7	66.2*
Extractable S (mg/kg)	10.5	21.5*
Extractable Ca (cmol/kg)	12.8	13.5
Extractable Mg (cmol/kg)	1.71	1.68
Extractable K (cmol/kg)	0.97	1.00
pH	6.10*	6.29*

* Indicates a significantly higher value ($p<0.01$, using a two-way ANOVA).
[1] Based on a sampling depth of 0-10 cm, except where noted.
[2] Unpublished data (Reganold and Palmer, 1994) based on soil structure index developed by Peerlkamp (1967), as modified by McLaren and Cameron (1990).

United States. Goldstein (1986) compared the effects of biodynamic, organic, and conventional management on biological soil properties and crop growth characteristics in a three-year field plot study in a dry-land grain production area of Washington State. The biodynamic plots (manure compost and preparations) and the organic plots (manure compost only) were significantly higher in organic matter and microbial respiration and biomass than were the conventional plots (N and P fertilizer). The biodynamic plots were significantly higher in microbial biomass and slightly higher in organic matter and microbial respiration than the organic plots. The biodynamic plots also had more growth of winter wheat roots than either the organic or the conventional plots.

Canary Islands. Garcia et al. (1989) studied soil fertility and foliar composition on a 5-year old, 6-ha biodynamic avocado plantation in Tenerife (largest of the Canary Islands). They compared the results with similar soil data (gathered 5 years earlier) from 31 conventional avocado plantations and similar foliar data from 15 plantations. They found that the surface soils (0-25 cm) of the biodynamic plantation were significantly higher in pH, organic matter, and available P, Ca, Mg, and K than those of the conventional plantations. Foliar levels of N, P, K, Mg, and Cu were similar in the two types of plantations; Ca and Mn were significantly lower in the biodynamic avocados, although they fell within the range considered normal, and foliar Zn was significantly higher in the biodynamic avocados.

Economic Studies

Researchers in the studies reported here used enterprise gross margin as a measure of economic performance, except for Vereijken (1986; 1990). Gross margin is the difference between gross revenue and variable or operating expenses. Variable costs include fertilizers, pesticides, fuels, labor, and biodynamic preparations, among others. Fixed costs such as debt servicing were excluded.

Germany. Schlüter (1985), at the University of Stuttgart-Hohenheim, Germany, analyzed farm management, labor, yields, and profitability of 16 biodynamic farms from seven production regions in the southwest German state of Baden-Württemberg. (I base this review on a condensed English translation of her dissertation by Koepf [1986].) Schlüter's team gathered data from farm records and from interviews with the farmers every three months for two years (1980-1981). The farms had been under biodynamic management for an average of 14.5 years (6 to 51 years) and averaged 28 ha in size (15 to 49 ha). The biodynamic farms produced cereal crops, row crops (potatoes, sugar beets and field vegetables), maize for silage, other arable forage (clover/grass, mixtures of legumes with cereals), and livestock (cattle, pigs, poultry, dairy). Results from the biodynamic farms were compared with annual official statistics from the Baden-Württemberg Ministry of Food, Agriculture and Environment for conventional farms in each production region.

The yields of all the cereal crops on biodynamic farms for 1979/1980 and 1980/1981 were lower by 13%; the average being almost equal to conventional farm yields on the good soils and considerably lower on the poorer soils. Koepf (1986) points out that part of this difference may have been due to preference of biodynamic farmers and their customers for certain lower yielding cultivars with desired baking qualities, and to the production of spelt (*Triticum spelta*, or German wheat), hulless oats, and hulless barley for human consumption. Potato yields were similar in the two farming systems. Milk yields per cow on biodynamic farms were almost 15% lower than on the conventional farms. Again, Koepf (1986) notes that this difference may have resulted because biodynamic farmers who wished to qualify for Demeter (biodynamic) certification were allowed to buy commercial feeds only up to 10% of the dry matter content of the ration.

The costs and returns for the biodynamic and conventional farms in the Schlüter study are shown in Table 5. The biodynamic and conventional farms had similar gross revenues Gross revenues in German marks (DM) per ha from all crops were higher on the biodynamic farms, whereas gross revenues from animal husbandry (beef, pork, milk and eggs) were 25 to 54% lower on the biodynamic farms (Koepf, 1986). However, because the biodynamic farmers had lower costs than the conventional farmers, their profits were higher (Table 5). In the two years studied, biodynamic products received an average premium of 59% (range 15 to108%) over the price of similar conventional products (Koepf, 1986).

On research plots at an experiment station in German, yields of all vegetable crops for a six-year period averaged 16% less on biodynamic plots than on conventional plots (Reinken, 1986). However, since the prices received were higher for biodynamic than for conventional vegetables, profits were significantly higher for most biodynamic vegetables, including spinach, celery, red beet, white cabbage, and carrot.

Table 5. Gross revenue, expenses, and profits of biodynamic and conventional farms in Germany in 1980 and 1981 (Koepf, 1986).

Farm size:	10-20 ha		20-30 ha		30-40 ha	
	Bio	**Con**	**Bio**	**Con**	**Bio**	**Con**
Number of farms	4	928	4	1,689	4	1,612

Average size of farms (ha)	17.7	16.2	22.1	25.0	38.4	37.6
Gross revenue (DM $ha^{-1}yr^{-1}$)	6,369	6,625	6,874	5,774	3,507	4,689
Expenses (DM $ha^{-1}yr^{-1}$)	3,934	5,093	3,713	4,505	2,415	3755
Profit (DM $ha^{-1}yr^{-1}$)	2,435	1,532	3,161	1,269	1,092	934

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Reinken (1986) found that average yields of three varieties of apples for the six-year period were 30 to 38% lower on the biodynamic plots than on the conventional plots. Profitability for apples was not reported. Labor requirements for apple growing were an average of 27% higher on the biodynamic plots, but the biodynamic apples received a premium of 27% over the price of conventional apples.

An early study by the Baden-Württemberg Ministry of Food, Agriculture and Environment in Germany (MELU, 1977), as translated and reported in Koepf (1989) and Lampkin (1990), reported results similar to those of the Schlüter and Reinken studies on yields and economic performance. The MELU study surveyed pairs of biodynamic and conventional farms from 1971 to 1974. It found that although the biodynamic farms' grain yields were from 10 to 25% lower, their variable costs were lower and their net returns were about the same to about 40% higher than their conventional counterparts. If the premium prices received by the biodynamic farmers were replaced by the conventional prices, their net returns would have been about 0 to 20% lower than those of their conventional neighbors (Lampkin, 1990).

The Netherlands. Research on alternative and conventional farming systems began in 1979 on a 72-ha experimental farm in Nagele (Vereijken, 1990). Three farming systems were set up as whole farms: a 22-ha biodynamic farm, a 17-ha conventional farm, and a 17-ha integrated farm (minimal inputs of fertilizers and pesticides). Economic data from 1982 to 1985 (Vereijken, 1986) and from 1985 to 1987 (Vereijken, 1990) indicated that gross revenue was the highest for the biodynamic farm because of the high premiums paid for the biodynamic products. However, total production costs also were higher for the biodynamic farm than either the conventional or the integrated farm, which resulted in the biodynamic farm having the lowest net income.

These results contrast sharply with other results discussed in this paper. As pointed out by Lampkin (1990), a major flaw in the Nagele study is that the biodynamic unit was established as a labor-intensive mixed dairy and arable system (11-year crop rotation) in an area that is almost exclusively arable. The conventional and integrated units were set up as arable farms with the same four-year crop rotation. Labor costs for the biodynamic farm were almost three times higher than for either the conventional or integrated farm, causing most of the difference in net returns. Lampkin (1990) concludes that a less labor intensive organic system could have been developed that would have been more competitive given the conditions in the region.

Australia. In the Penfold study (1993) discussed earlier, conventional yields were highest (3.5 ton/ha) and biodynamic yields were lowest (2.3 ton/ha) in 1992, when all four treatments were in wheat (Table 6). However, the biodynamic treatment had the highest total gross margin per ha for the first four years (1989-1992), followed by the conventional, organic, and integrated treatments (Table 6). This included a 20% premium on organic and biodynamic wheat from the 1992 harvest. The biodynamic and conventional treatments had the highest gross margins mainly because they had three cash crops, whereas the organic and integrated treatments had only two.

New Zealand. Reganold et al. (1993) compared the economic performance of biodynamic and conventional farms in the same study that analyzed soil quality. They examined farmers' annual accounts from 1987 to 1991 for 11 of the 16 farms. These results also were compared to representative conventional farm data in annual

Table 6. Rotations (1989-1992), wheat yields (1992), and gross revenue, variable costs, and gross margin (1989-1992) of biodynamic, conventional, integrated, and organic plots in Australia (Penfold, 1993; 1994).

		Biodynamic	Conventional	Integrated	Organic
Rotation:	1989	oats/medic for hay	wheat	oats/medic for hay	oats/medic for hay
	1990	legume-based pasture	peas	legume-based pasture	wheat (mulched)
	1991	oats/vetch for hay	legume-based pasture	legume-based pasture	green manure crop
	1992	wheat	wheat	wheat	wheat
Wheat yield (1992) (t/ha)		2.3	3.5	2.7	2.9
Total over rotation 1989-1992 (A$/ha)					
Gross revenue		1,399	1,196	823	992
Variable costs		391	436	553	352

Gross margin	1,008	760	270	635

reports by the Ministry of Agriculture and Fisheries (MAF) for all major farming systems in New Zealand. On a per hectare basis the biodynamic farms were as profitable as the neighboring conventional farms and re representative conventional farms (Table 7). Most of their products were sold as certified organic or biodynamic at premium prices up to 25% above the market prices of similar conventional products. Most of the biodynamic farms had less year-to-year variability in gross revenue than the conventional farms (Reganold et al., 1993). Economic stability is a significant characteristic of sustainable farming systems.

Table 7. Average annual gross revenue, variable costs, and gross margin of biodynamic and conventional farms in New Zealand, 1988 to 1991 (Reganold et al., 1993).

	Average (NZ$ ha^{-1} yr^{-1})		
Farm enterprise	**Bio**	**Con**	**MAF**[1]
Market gardens			
Gross revenue	14,094	18,845	___[2]
Variable costs	4,977	8,088	___[2]
Gross margin	9,117	10,757	___[2]
Citrus orchards			
Gross revenue	13,434	___[3]	13,481
Variable costs	6,254	___[3]	8,974
Gross margin	7,180	___[3]	4,507
Mixed farms			
Gross revenue	703	1,337	1,027
Variable costs	311	537	436
Gross margin	392	800	591
Livestock farms			
Gross revenue	463	393	328
Variable costs	46	83	84
Gross margin	417	310	244
Dairy farm set #1			
Gross revenue	2,283	___[4]	1,355
Variable costs	833	___[4]	426
Gross margin	1450	___[4]	929
Dairy farm set #2			
Gross revenue	1,696	2,237	1,817
Variable costs	918	503	513
Gross margin	778	1,734	1,304

[1] Representative conventional farm based on New Zealand Ministry of Agriculture and Fisheries.
[2] There are no MAF models for market gardens.
[3] Only two years of financial data were available, so averages are not reported here.

Summary and Discussion

The farming goals of biodynamic practitioners include protection and enhancement of soil to produce high quality products. To stimulate life in the soil and in plants, they use eight specific amendments, called preparations, on their soils and crops and in their composts. Their system includes practices such as green and animal manuring, composting, biological pest controls, reduced tillage, complex crop rotations, and diversified crops and livestock.

This paper has summarized the few studies available in English that hae compared soil quality or farm profitability in biodynamic and conventional farming systems. These studies found that the biodynamic farming systems generally had better soil quality, lower crop yields, and equal or greater net returns per hectare than their conventional counterparts. The economic studies showed that biodynamic farming systems can and do work. Many biodynamic farmers stay in business because of the price premium received for their products. Although the studies reported here included these premiums, they did not count the environmental and health costs of the two farming systems, which are external to the farm's accounts. The log-term profitability of many conventional farms seems questionable when these externalities are included. Indirect costs such as offsite damage from soil erosion, surface and ground water pollution, hazards to human and animal health, and damage to wildlife from conventional farming practices are presently borne by society. When these external costs are included in the costs of production, the profitability and benefits to society have been shown to be the greater for some alternative farming systems (Holmes, 1993).

Some of the studies on soil quality were conducted on a single pair or multiple pairs of commercial farms. Conducting paired-farm research to compare the effects of agricultural systems on soil requires three things: 1) neighboring farms that are now managed by different systems but that previously were under similar management; 2) side-by-side fields where soil-forming factors are equalized; and 3) sufficient time for each management system's respective practices to have influenced soil properties (Reganold, 1988; Reganold et al., 1993). Pseudoreplication, where replicates are not statistically independent, in the strictest sense is unavoidable when comparing two fields form a single farm pair, as in the Forman (1981) study. As Hurlbert (1984, p.199) explains: "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 the studies discussed here meet the criteria or large-scale systems. Still, when possible, it is better to use multiple farm pairs in a block design to have proper replication. How statistical difficulties in farming systems comparisons can be overcome through proper design and analysis is discussed by Wardle (1994) and Reganold (1994).

Plot studies, too need adequate replication for proper statistical design. For example, the plot studies by Penfold (1993) and by Pettersson and von Wistinghausen (1979) would have been improved if they had four replicates per treatment instead of two and one, respectively. Yet these studies still are valuable, because they demonstrate different farming systems and provide long-term results.

An interesting question raised by the soil studies is whether soil quality is affected by the biodynamic preparations in particular, or whether the effects are from the organic amendments applied in the biodynamic system The research of Goldstein (1989) and Abele (1987), which included siilar organic farming treatments with and without the preparations, illustrate that the biodynamic preparations positively influence biological soil properties and crop root growth. Much work on the preparations has been done by biodynamic researchers. The results have been variable, particularly regarding the effect of the preparations on manure decomposition, soil biology, crop yields, and the keeping quality of different products (Goldstein, 1990). However, very little has been published in the refereed scientific literature and not all the work was of high scientific quality. More research is needed that specifically examines whether the biodynamic preparations affect the soil's physical, chemical, and biological properties and crop yield and quality, and if so, their mode of action. The results of such studies need to be published in refereed scientific journals.

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