Biodynamic preparations: Short-term effects on crops, soils, and weed populations

Lynne Carpenter-Boggs, John P. Reganold, and Ann C. Kennedy

Abstract. *Biodynamic agriculture is an organic farming system that utilizes fermented herbal and mineral preparations as compost additives and field sprays. This study was conducted to determine whether biodynamic preparations affect lentil and wheat growth and yield, soil fertility, or weed populations in the short run. Each of four nutrient treatments, biodynamically prepared compost, non-biodynamic compost, mineral NPK fertilizer, and no fertilizer, were tested with and without biodynamic field sprays. Crop yield, crop quality, and soil fertility were similar in plots treated with mineral NPK fertilizers, biodynamic compost, or non-biodynamic compost. Use of compost raised soil pH from 6.0 without compost to 6.5 with compost. Compost application reduced the broadleaf weed population by 29% and reduced the grass weed population by 78%. Biodynamic sprays altered soil and grain N chemistry, but the effects are of unknown biological significance. Use of the biodynamic field sprays correlated with higher yield of lentil per unit plant biomass, lower grain C and crude protein contents, greater* NO_3^- *content in soft white spring wheat, and greater* NH_4^+ *content in soil. In general, soils and crops treated with biodynamic preparations showed few differences from those not treated. Application of composts with or without the preparations produced similar crop yields with lower weed pressure, compared with equal nutrients supplied by mineral fertilizer, but any additional short-term benefits from biodynamic preparations remain questionable.*

Key words: biodynamic farming, biological farming, compost, organic farming

Introduction

Biodynamic farming has much in common with other organic farming systems, including reliance on organic fertilizers, but differs primarily in the use of specialized preparations in compost and as field sprays (Steiner, 1974). The preparations consist of manure, silica, or plants, and most are treated or fermented with animal organs, water, and/or soil. The preparations were developed to improve soil and crop quality and to hasten composting (Koepf et al., 1976). Six preparations, numbered 502 through 507, are added to new compost piles. Three more preparations, numbered 500, 501, and 508, are highly diluted in water and applied directly to soil or crops as sprays. The primary purpose in using the preparations is to stimulate the processes of nutrient and energy cycling, rather than to add nutrients (Koepf et al., 1976).

The biodynamic preparations have not been well characterized chemically or microbiologically, athough cursory analyses were undertaken by Pfeiffer (1956). Both the initial materials and the finished preparations were analyzed for macro- and micro-nutrient elements and gross changes in bacterial numbers. The finished, fermented preparations often had increased levels of nitrate and readily extracted minerals such as Al, Ca, Fe, Mg, and Mo, as compared with the raw materials. Populations of both aerobic and anaerobic bacteria tended to be much greater after fermentation. Finished preparation 500, for instance, contained 5×10^8 bacteria g^{-1}, and a full set of compost preparations 502 through 507 had approximately 5×10^9 bacteria g^{-1}. The herbal ingredients of the biodynamic preparations (Table 1), such as yarrow (*Achillea millefolium L.*), chamomile (*Matricaria recutita L.*), stinging nettle (*Urtica dioica L.*), and valerian (*Valeriana officinalis L.*), contain a variety of bioactive compounds (Hornok, 1992). For instance, extracts of chamomile have antibacterial and antifungal properties (Foster, 1990). In addition, cytokinins, a class of plant hormones, have been detected in the field spray preparations (Stearn, 1976).

Plot studies of the biodynamic system have resulted in varying conclusions about effects on crop yield and soil quality. Some farmers and researchers have obtained higher yields (Spiess, 1978) and others lower yields (Reinken, 1986; Schlüter, 1985) using biodynamic methods compared with conventional agricultural methods. Recent research (Raupp and König, 1996) showed that the biodynamic preparations could cause different effects depending upon the average yield within the trial. With a low-input, low-yielding system, addition of biodynamic preparations 500 and 501 increased yield; with moderate-yield systems the effect was diminished, and in high-yield (high-

---

L. Carpenter-Boggs is Microbiologist, USDA-ARS North Central Soil Conservation Research Laboratory, 803 Iowa Avenue, Morris, MN 56267; J.P. Reganold is Professor, Dept. of Crop and Soil Sciences, 201 Johnson Hall, Washington State University, Pullman, WA 99164-6420; A.C. Kennedy is Microbiologist, USDA-ARS Land Management and Water Conservation Research Unit, P.O. Box 64621, 215 Johnson Hall, Washington State University, Pullman, WA 99164-6421. Corresponding author is L. Carpenter-Boggs (lcboggs@morris.ars.usda.gov).

Reprint from the **American Journal of Alternative Agriculture**,
Volume 15, Number 3, 2000, published by the
Henry A. Wallace Center for Agricultural & Environmental Policy at Winrock International

Table 1. Initial soil measurements at two experiment sites in eastern Washington in April 1995.

Property	Spillman farm	Palouse farm
pH	6.2	5.4
Organic matter (mg/g)	35	35
Available phosphorus (μg/g)	9	10
Available potassium (μg/g)	290	310
Nitrate (μg/g)	13	4
Extractable ammonium (μg/g)	7	2

input) systems, use of the preparations decreased yield.

A similarly antagonistic relationship was found in the application of N fertilizer and silica spray, similar to preparation 501. Direct application of silicon dioxide to plants has been shown to stiffen straw and prevent lodging of rice; this benefit lessened with higher additions of N (Idris et al., 1975). Uncomplementary interactions such as this may explain the lack of benefit from biodynamic treatment obtained by some researchers under ideal conditions, as well as the benefits claimed by farmers in practical, low-input situations. Greater plant silica content has been correlated also with decreased lodging in wheat (Gartner et al., 1984) and resistance of rice to insects, fungal pathogens, and slug damage (Elawad and Green, 1979; Wadham and Wynn Parry, 1981).

Penfold et al. (1995) found no differences in soil quality parameters under biodynamic, conventional, and organic management systems, except those likely due to differences in fertilization levels. Nguyen et al. (1995) found less available P and S in soils of some organic and biodynamic farms due to low levels of fertilization on those farms. In other studies, however, biodynamically treated plots improved soil quality, particularly some biological parameters. Goldstein (1986) found that biodynamically managed fields had greater microbial biomass, respiration, and organic matter, and longer wheat roots than conventionally or organically managed fields. Abele (1976, as translated by Koepf, 1993) found that application of biodynamic compost to soil resulted in greater soil C and N, microbial dehydrogenase enzyme activity, microbial biomass, and dehydrogenase to biomass ratio than applications of chemical fertilizers or non-biodynamic compost. In a study of commercial farms, biodynamic farms maintained better soil quality and were as financially viable as adjacent conventional farms (Reganold et al., 1993).

In companion studies, we found that biodynamic preparations used in compost increased compost temperature and affected its microbial community structure (Carpenter-Boggs et al., 2000). However, biodynamic compost and field sprays applied to soils did not affect soil microbial parameters differently than non-biodynamic compost (Carpenter-Boggs, 1997). We found also that soil microbial biomass and activity were greater on established biodynamic farms than on neighboring conventional farms (Carpenter-Boggs, 1997).

The objective of this study was to evaluate the effects of biodynamic preparations on yield and quality of soft white spring wheat and lentil, soil fertility, and weed populations in the Palouse region of eastern Washington. Biodynamic compost, non-biodynamic compost, mineral NPK fertilizers, and no fertilizer were used as fertility treatments in replicated field plots, with and without biodynamic field sprays. Although some parameters in this study were tested in earlier work by others, this study is unique because it differentiates the effects of biodynamic field sprays and compost preparations from the nutritional or biological effects of mineral or organic fertilization.

Materials and Methods

Study area

Field sites were the Palouse Conservation Farm, maintained by the Agricultural Research Service, U.S. Dept. of Agriculture, and the Spillman Research Farm, maintained by the Dept. of Crop and Soil Sciences, Washington State University. Both farms are near Pullman, Washington. Mean annual precipitation is 55 cm and mean annual temperature is 8.3°C. Soil on both farms is Palouse silt loam, a fine-silty, mixed, mesic Pachic Ultic Haploxeroll. Initial soil conditions are indicated in Table 1. Analytical methods are indicated below. A barley (*Hordeum vulgare* L.)–lentil (*Lens culinaris* L.)–wheat (*Triticum aestivum L.*) rotation is common in the Palouse region, and was present on study sites prior to and during this study. Conventional tillage was used at both sites prior to the study and intensive tillage was needed each spring during the study to incorporate compost uniformly.

Biodynamic preparations

The preparations used in this study were obtained from the Josephine Porter Institute for Applied Biodynamics (JPI, Woolwine, VA) and used within 1 month of purchase. The Institute's production methods are based on the original specifications of Steiner (1974), as well as on the experience and experiments of biodynamic organizations and farmers (Koepf et al., 1976, p. 206–219; Sattler and von Wistinghausen, 1992, p. 83–96). The methods for making the preparations are standardized and known to be consistent over time. Preparation 500 is decomposed manure; 501 is ground and fermented quartz; 502–506 are fermented plant materials; 507 is an extract of valerian flowers; and 508 is dried horsetail (Table 2). Preparations 500 and 502–506 are dark, crumbly materials similar to compost; 501 is a white powder; 507 is a brown liquid; and 508 is dried, chopped plant matter. One packaged "unit" of each field or compost preparation treats 0.4 ha of land or 13.6 Mg of compost material.

Composts

Biodynamic and non-biodynamic composts were developed concurrently beginning in October 1994 and 1995 at the Palouse farm site and were applied to Palouse and Spillman farm plots the following April prior to tillage. The raw material from the Washington State University Dairy Center was dairy barn waste, consisting of manure and pine-shaving bedding with 65% liquid content. The material was well mixed because it had been moved

Table 2. Biodynamic preparation main ingredients and amounts commonly used on 0.4 ha land or 13.6 Mg compost.

Preparation	Main ingredient	Use	Unit volume (cm^3)	Unit mass (g)
500[1]	Cow (*Bos taurus*) manure	Field spray	35	38
501[1]	Finely ground silica from quartz or feldspar	Field spray	2	1.8
502[1]	Yarrow blossoms (*Achillea millefolium* L.)	Compost	15	1.1
503[1]	Chamomile blossoms (*Matricaria recutita* L.)	Compost	15	3.0
504[1]	Stinging nettle shoots (*Urtica dioica* L.)	Compost	15	4.4
505[1]	Oak bark (*Quercus robur* L.)	Compost	15	3.9
506[1]	Dandelion flowers (*Taraxacum officinale*)	Compost	15	4.7
507	Valerian flower extract (*Valeriana officinalis* L.)	Compost	2	1.2
508	Horsetail plants (*Equisetum arvense* L.)	Field spray	300	40

[1] Preparations were fermented as described by Steiner (1974).

repeatedly with farm machinery and pressed to remove most of the liquid. We used one batch of raw material in 1994 and two different batches in 1995 to supply the necessary amount of compost and plant nutrients.

Each of the three batches of dairy waste was thoroughly mixed with a front-end loader and separated into two equal piles, one treated with biodynamic preparations 502 through 507 and the other a control. In the biodynamic compost approximately 18 g total wet weight of preparations were added to approximately 3.5 Mg wet weight of raw material. According to directions from JPI for use of the biodynamic preparations, six holes were bored to the vertical center of the compost pile with a crowbar. Each of the biodynamic preparations 502–506 was then poured into a separate hole. Preparation 507 was stirred into 8 L water before application to compost. Half of the 507 solution was poured into the sixth hole, and half was sprinkled over the entire compost pile. The holes were then filled with soil from the surrounding field at the Palouse farm (Palouse silt loam, moisture content approximately 0.15 g g^{-1}), requiring approximately 1 L soil for each hole. To keep non-preparation factors constant among treatments, control compost piles also received inoculations of approximately 6 L soil and 8 L well water, applied similarly as in biodynamic piles but without the biodynamic preparations. According to JPI's instructions, compost piles were not turned after application of the preparations. Each pile was mixed with a front-end loader in the spring approximately 3 weeks before land application, to assure consistency.

Field treatments

The biodynamic and non-biodynamic composts were utilized in field trials of eight treatments (Table 3). Treatments were a factorial comparison of four nutrient sources and two spray treatments. Nutrient sources compared biodynamic compost and non-biodynamic compost with a positive control (purchased mineral fertilizers) and a negative control (no fertilizer). Sprays applied were either the biodynamic field sprays or a negative control (well water). Each treatment was replicated four times in blocks at each of two experimental farms and applied to the same plots over 2 consecutive years. Blocks separated landscape positions. Plot size was 1.5 m x 12.2 m.

Crops followed a barley–lentil–wheat rotation. Since there are no commercial biodynamic farms in this area, it is not clear whether the rotation used in this study would be suitable for local, long-term biodynamic management. Some tenets of biodynamic management, such as closed nutrient cycling within the agricultural system, are not feasible in a replicated plot study. Barley was the 1994 crop in the plot areas at both farms. Lentil (var. 'Brewer') was sown in all plots in May 1995, followed by soft white spring wheat (var. 'Penewawa') sown in April 1996 (Table 4). All seed was untreated.

Six-month-old composts were applied to field plots in April 1995 and 1996 prior to tillage and planting. Nutrient application levels (Table 4) were designed to meet the N needs of each year's crop (1995 lentil, 1996 spring wheat) and meet or exceed the P and K needs, according to soil tests and Washington State University Cooperative Extension fertilizer recommendations. Nitrogen availability from composts was used as the primary determinant of fertilization level. Final compost C:N ratio was 30:1 in 1995 and 31:1 in 1996. Composts contained on average 1.03% N, of which 7–8% was soluble NO$_3^-$ and NH$_4^+$. Rynk (1992, p. 78) states that 8–

Table 3. Field treatments at two experiment sites in eastern Washington in 1995 and 1996.

Treatment	Nutrient source	Field sprays
1	None	Water
2	None	BD[1] 500, 501, 508
3	Mineral NPK[2]	Water
4	Mineral NPK	BD 500, 501, 508
5	Non-biodynamic compost	Water
6	Non-biodynamic compost	BD 500, 501, 508
7	Biodynamic compost	Water
8	Biodynamic compost	BD 500, 501, 508

[1] BD = biodynamic.

[2] N, P, and K applied as NH_4NO_3, $NH_4H_2PO_4$, and KCl, respectively.

Table 4. Management practices and dates.

	1995	1996
Crop	Lentil	Soft white spring wheat
Variety	'Brewer'	'Penewawa'
Compost available N-P-K (kg 100 kg compost^{-1})	0.08-0.03-0.13[1]	0.13-0.02-0.28[1]
Application rate (dry Mg ha^{-1})	19	24
Fertilizer applied[2] (kg ha^{-1})	16-6-25[1]	31-5-66[1]
Compost application dates	19–21 April	2–4 April
Rototilling date	27 April	9 April
Planting date	4 May	23 April
Preparation application dates		
500	3 May	22 April
501	19 May	3 June
508	5 July	20 June
Weed control	Wheel-hoe, hand-pick	Wheel-hoe, hand-pick
Weed control dates	12–16 June	10–14 June, 8–12 July
Pest control	Tobacco infusion	None
Harvest dates	15–18 Aug.	3–4 Sept.

[1] Expressed as elemental N-P-K.

[2] Mineral fertilizer applied as NH_4NO_3, $NH_4H_2PO_4$, and KCl.

12% of the total N content of compost becomes available to plants annually. Composted dairy wastes released 7.7–20.8% of the total N as available N in 10 months (Castellanos and Pratt, 1981). Considering the relatively high C:N ratio of composts used in this study, we predicted negligible N mineralization during the first 3–4 months after compost application. Soluble N was presumed to approximate available N during the first growing season, with 5% of total N mineralized in the second growing season after compost application. Extractable P and K (sodium bicarbonate extractant) in compost was assumed fully available. Dry commercial NH_4NO_3, $NH_4H_2PO_4$, and KCl were applied at rates of 38, 22, and 48 kg ha^{-1}, respectively, in 1995, and 82, 18.5, and 126 kg ha^{-1}, respectively, in 1996, to equal N, P, and K available in compost treatments (Table 4). All fertilizers and composts were uniformly surface-applied to plots in early spring and rototilled into soil to a depth of 15 cm.

Biodynamic field sprays 500, 501, and 508 were applied once during each field season according to JPI product instructions (Table 4). We used pre-potentized forms (specially pre-mixed) of preparations 500 and 501, which require less labor to apply than the standard forms. One packaged unit of preparations 500, 501, and 508 (Table 2), containing 38, 1.8, and 40 g moist weight, respectively, was applied as fine aqueous sprays in 11, 11, and 8 L water, respectively, to the total sprayed plot area of 595 m^2. Final application rates were 64, 3, and 67 mg of preparation m^{-2}, respectively, and 18, 18, and 13 ml water m^{-2}, respectively. Plots not receiving the biodynamic sprays were sprayed with an equal amount of well water.

Management practices not part of the experimental design were similar on all plots (Table 4). Plots were disked once each fall and rototilled once each spring to incorporate fertilizers and compost. Weeds were controlled by wheel-hoe and hand weeding. In 1996 weeds were removed after weed populations were estimated. Weed pressure after hand weeding was very light. No synthetic insecticides or herbicides were applied, but lentil was sprayed once in 1995 with a tobacco (*Nicotiana tabacum L.*) infusion to control aphids (*Acyrthosiphon pisum*) (David and Gardiner, 1953; Grainge and Ahmed, 1988; Ware, 1980, p. 24–25).

Crop, soil, and weed measurements

Crop measurements included grain yield; dry above-ground biomass; C, N, and NO_3^- content of grain; mycorrhizal colonization of roots; and populations of grass and broadleaf weeds. Mature lentil was harvested by hand-clipping in three 0.25-m^2 areas in the center rows of each plot. Wheat was harvested using a one-row grain harvester in one strip approximately 7 m in length from the center row of each plot. Harvested material was dried and separated into grain and biomass. Grain production per unit biomass was calculated separately for each plot. Grain C and N were determined with a Leco C and N analyzer (CHN-600, Leco Corp., St. Joseph, MI). Percent N was multiplied by 6.25 for lentil and 5.7 for wheat to calculate crude protein content (Kasarda et al., 1978). Nitrate content was measured in an extract of 1 g finely ground grain in 15 ml distilled water with an ion-selective electrode (Orion Research Inc., Beverly, MA). Mycorrhizal colonization was estimated using a gridline-intersect method with acid fuschin–stained roots (Sylvia, 1994). Populations of grass and broadleaf weeds were counted by hand in three 0.25-m^2 squares per plot on 3–5 June 1996, prior to any weed control.

Soil tests after treatment included NO_3^- and NH_4^+, cation exchange capacity, penetration resistance, pH, and electrical conductivity (EC). Cation exchange capacity was determined in 1995 only, while penetration resistance, pH, and EC were determined in 1996 only. Initial determinations of soil-available P (Morgan phosphorus test), available K, and organic matter were made by Holm Laboratory, University of Idaho (Murphy and Riley, 1962; Teech and English, 1944). Soil surface penetration resistance was measured 10 times in each plot to a depth of 1.3 cm with a pocket penetrometer (S-170 Pocket Penetrometer, Brainard-Kilman, Stone Mountain, GA) on 25 June 1996. Soils were sampled for laboratory analyses just prior to harvest. Six subsamples per plot were collected to a depth of 15 cm, mixed, and stored at 4°C. Nitrate and NH_4^+ were extracted from 5 g soil with 30 ml 0.1 M $MgSO_4$ and measured using a NO_3^- ion electrode (Orion Research Inc.) and NH_4^+ ion electrode (Phoenix Electrode Co., Maidstone, U.K.) on a microprocessor (Orion Research Inc.) (Dahnke and Johnson, 1990). Cation exchange capacity was determined by flooding samples with neutral 1 M $NH_4C_2H_3O_2$, then washing with

Table 5. **Yield and quality of lentil grown in field plots in eastern Washington in 1995, mean of two sites.**

Nutrient source	Leafy biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Grain per unit biomass (kg kg^{-1})	Carbon in grain (g kg^{-1})	Crude protein in grain (g kg^{-1})	Nitrate in grain (mg NO$_3^-$ kg^{-1})
Biodynamic compost	3,530	2,030 a[1]	0.62	431	259	69
Non-biodynamic compost	3,390	1,930 ab	0.63	430	260	69
Mineral NPK	3,240	1,740 b	0.60	431	256	68
None	3,520	1,960 ab	0.61	431	260	72
Biodynamic sprays						
Yes	3,320	1,960	0.65 a[2]	429 a[2]	257 a[2]	70
No	3,520	1,860	0.58 b	432 b	261 b	69
CONTRASTS	$p > F$					
Compost vs. no compost	NS	NS	NS	NS	NS	NS
Compost vs. mineral NPK	NS	0.03	NS	NS	0.05	NS
Any fertilizer vs. none	NS	NS	NS	NS	NS	0.06
Organic vs. biodynamic	NS	NS	NS	NS	NS	NS

[1] Means with different letters are significantly different at $P = 0.10$.

[2] Means with different letters are significantly different at $P = 0.05$.

1-propanol and extracting with 1 M KCl. Displaced NH$_4^+$ ions were measured using an NH$_4^+$ ion–selective electrode (Phoenix Electrode Co.) on a microprocessor (Orion Research Inc.) (Corey, 1990). Soil pH was measured with a microprocessor pH/millivolt meter (Orion Research Inc.). Electrical conductivity was measured with a dissolved solids detector (Hanna Instruments, Woonsocket, RI). Both pH and EC were measured in a 1:2 soil:distilled-water mixture.

Statistical analysis

Data are means of all plots at both sites receiving the indicated nutrient source or spray. Statistical comparisons were made using the General Linear Model, Tukey's honestly significant difference (HSD) test, and treatment contrasts (SAS/STAT, 1988). Contrasts allow comparison of groups of treatments (e.g., all treatments using any compost vs. treatments using NPK fertilizers) that HSD tests cannot compare. The contrast section of Tables 5–8 also includes organic vs. biodynamic, which compares means of treatments 5 and 8 (Table 3). Data sets not fulfilling the assumptions of parametric statistics (grassy weed populations, soil NH$_4^+$, and soil NO$_3^-$) were transformed, or analyzed using nonparametric statistics where data transformations were ineffectual. Significant differences are indicated on data tables at two levels of probability, $P \leq 0.05$ and $P \leq 0.10$.

Results and Discussion

Crop yield and quality

Lentil grain yield was lowest in plots receiving mineral NPK fertilizer; the yield was 14% lower than grain yield in plots receiving biodynamic compost, but not significantly lower than control or non-biodynamic compost treatments (Table 5). Contrasts suggest that either type of compost increased grain yield over mineral NPK. Lower yields in mineral-fertilized plots than in compost plots may be due to a larger or more timely release of nutrients from compost than from mineral fertilizers, or improved soil structure or moisture after compost addition. Slightly lower yield in mineral-fertilized plots suggests a negative effect of the mineral NPK, such as salt toxicity, or reduced bacterial N-fixation due to the mineral fertilizer application.

Biodynamic field sprays did not significantly affect either lentil biomass or grain yield, but production expressed as grain per unit leafy biomass was on average 12% higher in biodynamically sprayed plots than in plots sprayed only with water. This may indicate that biodynamically sprayed lentil expended a greater proportion of plant resources toward grain production. Average grain production per unit leafy biomass of lentil appears too high, considering the average grain and biomass yields; a larger difference between the expected and actual average is an indication of higher variability of this ratio among plots. The ratio is closer to the expected value in the wheat data because of lower variability in this ratio in 1996. There was no difference in this ratio among treatments in 1996 (Table 6). Wheat grain and biomass production was lowest in plots receiving no fertilizer. Wheat grain production was greater on the Spillman farm than on the Palouse farm (data not shown), but on both farms the plots receiving either compost or mineral fertilizer yielded similar amounts of grain and biomass.

Chemical parameters of lentil and wheat were affected by farm site, nutrient source, and use of biodynamic field sprays. More crude protein was produced from lentil and wheat on the Spillman farm than on the Palouse farm (data not shown). Contrasts showed that grain crude protein content was lower in lentil supplied with mineral NPK than with compost (Table 5). Concentrations of C and crude protein in lentil grain were also lower in plots receiving biodynamic field sprays. Wheat plots supplied with biodynamic compost had a lower N concentration, and thus less crude protein than unfertilized plots (Table 6). This is likely a dilution effect whereby yield is often inversely proportional to N concentration, particularly in N-limited

Table 6. **Yield and quality of soft white wheat grown in field plots in eastern Washington in 1995, mean of two sites.**

Nutrient source	Leafy biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Grain per unit biomass (kg kg^{-1})	Carbon in grain (g kg^{-1})	Crude protein in grain (g kg^{-1})	Nitrate in grain (mg NO_3^- kg^{-1})
Biodynamic compost	4,510 a[2]	3,030 a[1]	0.67	409	102 b[1]	13.0
Non-biodynamic compost	4,890 a	3,220 a	0.66	409	103 ab	13.6
Mineral NPK	4,530 a	3,110 a	0.69	409	105 ab	13.6
None	2,820 b	1,840 b	0.67	408	108 a	13.8
Biodynamic sprays						
Yes	4,020	1,960	0.67	409	104	13.9 b[2]
No	4,360	2,960	0.68	409	105	13.0 a
CONTRASTS	$p > F$					
Compost vs. no compost	0.005	0.02	NS	NS	NS	NS
Compost vs. mineral NPK	NS	NS	NS	NS	NS	NS
Any fertilizer vs. none	0.001	0.001	NS	NS	NS	NS
Organic vs. biodynamic	NS	NS	NS	NS	NS	NS

[1] Means with different letters are significantly different at $P = 0.10$.
[2] Means with different letters are significantly different at $P = 0.05$.

Table 7. **Soil tests (0 to 15 cm, August 1995) of field plots in eastern Washington in 1995, mean of two sites.**

Nutrient source	Ammonium (mg kg^{-1})	Nitrate (mg kg^{-1})	Mycorrhizal colonization (% root length)	Cation exchange capacity (cmol kg^{-1})
Biodynamic compost	12	42	80 b[1]	17.8
Non-biodynamic compost	15	46	82 b	17.8
Mineral NPK	12	39	75 b	17.5
None	12	47	89 a	17.8
Biodynamic sprays				
Yes	12	42	82	17.8
No	13	45	81	17.6
CONTRASTS	$p > F$			
Compost vs. no compost	NS	NS	NS	NS
Compost vs. mineral NPK	NS	NS	NS	NS
Any fertilizer vs. none	NS	NS	0.03	NS
Organic vs. biodynamic	NS	NS	NS	NS

[1] Means with different letters are significantly different at $\alpha = 0.10$.

soil (Campbell et al., 1981; García del Moral et al., 1995). In soft white wheat, lower concentration of crude protein is associated with improved milling quality (Wade, 1972). The small differences here may or may not be biologically significant. Contrasts showed that NO_3^- content in lentil grain was highest in unfertilized plots (Table 5). Nitrate content of wheat was higher in plots sprayed with the biodynamic field preparations than in wheat from unsprayed plots (Table 6). However, the small differences in NO_3^- content here probably would not affect food quality or storage of lentil or wheat grain.

All measured parameters of lentil and wheat yield and quality were similar in organic (treatment 5) and biodynamic (treatment 8) management (Tables 5 and 6).

Soil fertility parameters

In 1995, mycorrhizal colonization of lentil was greatest in plots that received no applied nutrients (Table 7). Mycorrhizal associations are most beneficial under low soil phosphorus conditions, and the extent of colonization often decreases in soils with P fertilization (Jasper et al., 1979).

Soil NH_4^+ and NO_3^- were similar among all treatments in 1995 (Table 7). In 1996, soil NH_4^+ concentrations were similar among plots receiving a nutrient source, but lower where none was applied (Table 8). Soil NH_4^+ was statistically higher in biodynamically sprayed plots, but the difference of 0.6 mg kg^{-1} is probably not biologically significant.

Soil electrical conductivity was higher

Table 8. Soil tests (0 to 15 cm, August 1996) and weed counts (6 June 1996) of field plots in eastern Washington, mean of two sites.

Nutrient source	Ammonium (mg kg^{-1})	Nitrate (mg kg^{-1})	Mycorrhizal colonization (% root length)	Electrical conductivity (dS m^{-1})	Soil pH	Penetration resistance (kg cm^{-2})	Grass weeds (m^{-2})	Broadleaf weeds (m^{-2})
Biodynamic compost	4.0 ab[1]	6.3	68	0.14 b[2]	6.5 a[2]	1.9	1.2	610 ab[1]
Non-biodynamic compost	4.0 ab	6.2	59	0.15 b	6.4 a	2.2	1.8	580 b
Mineral NPK	4.1 a	7.8	67	0.26 a	5.9 c	1.8	7.5	820 ab
None	3.1 b	6.3	68	0.12 b	6.2 b	1.9	6.2	860 a
Biodynamic sprays								
Yes	4.1 a[1]	6.8	65	0.17	6.2	2.0	2.5	670
No	3.5 b	6.6	66	0.16	6.3	1.9	5.9	770
CONTRASTS	$p > F$							
Compost vs. no compost	NS	NS	NS	NS	0.001	NS	0.07	0.01
Compost vs. mineral NPK	NS	NS	NS	0.002	0.001	NS	NS	0.04
Any fertilizer vs. none	0.01	NS	NS	NS	NS	NS	NS	0.05
Organic vs. biodynamic	NS	NS	NS	NS	NS	NS	NS	NS

[1] Means with different letters are significantly different at $P = 0.10$.

[2] Means with different letters are significantly different at $P = 0.05$.

in mineral NPK–fertilized plots than in compost treatments or the control (Table 8), but all soils were well below the critical saline EC level of 4 dS m^{-1} (McBride, 1994). Cation exchange capacity was greater on the Spillman farm and penetration resistance was greater on the Palouse farm (data not shown), but both parameters were similar among treatments (Tables 7 and 8). Soil pH was higher on the Spillman farm than on the Palouse farm, both at the initiation of the study (Table 2) and in 1996 (data not shown); at both sites soil pH increased with application of compost (Table 8). Decomposition of N-containing organic material can temporarily increase soil pH as NH_2 groups are mineralized to NH_4^+ (Dyal et al., 1939), but the primary effect on soil pH was likely due to the application of large quantities of pH 8.4 compost. Soil pH was lowest in plots receiving mineral NPK. Some acidification could have resulted from nitrification of ammoniacal fertilizer (Russell, 1961, p. 534).

All measured parameters of soil fertility were similar in organic and biodynamic management (Tables 7 and 8). This further suggests that both biodynamic and non-biodynamic compost had similar effects on soil properties, and biodynamic field sprays did not have significant additive or synergistic effects with biodynamic compost.

Weed populations

Application of compost in wheat reduced weed populations of both grass and broadleaf weeds, compared with no compost application (Table 8). Broadleaf weed populations were 29% lower and grassy weed populations were 78% lower in compost-amended plots than in plots receiving mineral fertilizer or no supplemental nutrient source. Smaller weed populations did not confer a yield advantage to compost-amended plots in this study because weeds in all plots were removed after counting. Compost can reduce weed populations through both physical and chemical mechanisms, by smothering weed seedling growth early in the season and releasing chemicals that are toxic to plants throughout the growing season (Ligneau and Watt, 1995). Compost remained on the soil surface after application for approximately 1 week in both 1995 and 1996, until weather conditions allowed tillage for compost incorporation. Compost may have smothered young weeds during this period.

There were no statistically significant differences in weed populations due to biodynamic sprays, although sprayed plots had on average less than half the number of grass weeds as their unsprayed counterparts (Table 8). Weed populations were similar with organic and biodynamic management.

Conclusions

Applied composts and mineral fertilizers both supplied ample nutrients for lentil and wheat production, although lentil yield in mineral NPK–fertilized plots was less than expected. No significant differences were observed in crops, soils, or weed populations between fertilization with biodynamic vs. non-biodynamic compost, or between organic vs. biodynamic management. Soil pH increased with application of either compost, and compost reduced populations of both grass and broadleaf weeds in wheat. Carbon and N were lower in lentil and NO_3^- was higher in wheat where biodynamic field sprays were used, compared with their non-use. These findings are of unknown biological significance. Biodynamically sprayed lentils also yielded more grain per unit of leafy biomass production, although grain and biomass yields alone were not affected.

These studies confirm that yields of lentil and wheat obtained with organic nutrient sources can be comparable to yields from mineral fertilization, but additional benefits to crops and soils from biodynamic compost and field preparations are uncertain in the short run. Given that most of the statistically significant findings of this study correlated biodynamic field sprays with lower N in lentil grain, higher NO_3^- in wheat grain, and higher soil

NH_4^+, further research examining the effects of biodynamic field spray preparations on N dynamics in crops and soils may be warranted. Long-term studies are also needed, as the effects of repeated applications of low levels of preparations may be incremental or cumulative and may not be apparent in short-term studies.

Acknowledgements. This research was supported with funds from the National Science Foundation Graduate Fellows Program and Dept. of Crop and Soil Sciences, Washington State University. Laboratory equipment and assistance were provided by the USDA-ARS Land Management and Water Conservation Research Unit, Pullman, WA. Trade names and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the product by the USDA. All programs and services of the USDA are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, age, marital status, or handicap.

References

1. Abele, U. 1976. Eine Forschung auf dem GebieteinesZerfallsdesflüssigenDüngemittels unter unterschiedlichen Behandlungen und seinem Effekt auf Boden, Betriebsergebnisse und Betriebsqualität (Research on decay of liquid manure under different treatments and its effect on soil, plant yields, and plant quality). Kuratorium für Technik und Bauwesen in der Landwirtschaft, Darmstadt, Germany.
2. Campbell, C.A., H.R. Davidson, and G.E. Winkleman. 1981. Effect of nitrogen, temperature, growth stage and duration of moisture stress on yield components and protein content of Manitou spring wheat. Can. J. Plant Sci. 61:549–563.
3. Carpenter-Boggs, L. 1997. Effects of biodynamic preparations on compost, crop, and soil quality. Ph.D. diss. Washington State University, Pullman. (Dissertation Abstracts 98-35832.)
4. Carpenter-Boggs, L., J.P. Reganold, and A.C. Kennedy. 2000. Effects of biodynamic preparations on compost development. Biol. Agric. Hort. (in press).
5. Castellanos, J.Z., and P.F. Pratt. 1981. Mineralization of manure nitrogen—correlation with laboratory indexes. Soil Sci. Soc. Amer. J. 45:354–357.
6. Corey, R.B. 1990. Physical–chemical aspects of nutrient availability. In R.L. Westerman (ed.). Soil Testing and Plant Analysis. 3rd ed. Soil Science Society of America, Madison, WI. p. 11–24.
7. Dahnke, W.C., and G.V. Johnson. 1990. Testing soils for available nitrogen. In R.L. Westerman (ed.). Soil Testing and Plant Analysis. 3rd ed. Soil Science Society of America, Madison, WI. p. 127–139.
8. David, W.A., and B.O.C. Gardiner. 1953. Systemic insecticidal action of nicotine and certain other organic bases. Ann. Appl. Biol. 40:91–105.
9. Dyal, R.S., F.B. Smith, and R.V. Allison. 1939. The decomposition of organic matter in soils at different initial pH. J. Amer. Soc. Agron. 31:841–850.
10. Elawad, S.H., and V.E. Green, Jr. 1979. Silicon and the rice environment: A review of recent research. Il Riso 28:235–253.
11. Foster, S. 1990. Chamomile: *Matricaria recutita* and *Chamaemelum nobile*. Botanical Booklet Series 307. American Botanical Council, Austin, TX.
12. García del Moral, L.F., A. Boujenna, J.A. Yañez, and J.M. Ramos. 1995. Forage production, grain yield, and protein content in dual-purpose triticale grown for both grain and forage. Agron. J. 87:902–908.
13. Gartner, S., C. Charlot, and N. Paris-Pireyre. 1984. Microanalyse de la silice et résistance à la verse mécanique du blé tendre. Physiologie Vegetale 22:811–820.
14. Goldstein, W.A. 1986. Alternative crops, rotations and management systems for the Palouse. Ph.D. diss. Washington State University, Pullman. (Dissertation Abstracts 87-11988.)
15. Grainge, M., and S. Ahmed. 1988. Handbook of Plants with Pest-control Properties. John Wiley, New York.
16. Hornok, L. (ed.). 1992. Cultivation and Processing of Medicinal Plants. John Wiley, New York.
17. Idris, M., M.M. Hossain, and F.A. Choudhury. 1975. The effects of silicon on lodging of rice in presence of added nitrogen. Plant Soil 43:691–695.
18. Jasper, D.A., A.D. Robson, and L.K. Abbot. 1979. Phosphorus and the formation of vesicular–arbuscular mycorrhizas. Soil Biol. Biochem. 11:501–505.
19. Kasarda, D.D., C.C. Nimmo, and G.O. Kohler. 1978. Proteins and the amino acid composition of wheat fractions. In Y. Pomeranz (ed.). Wheat Chemistry and Technology. 2nd ed. American Association of Cereal Chemists, St. Paul, MN. p. 227–299.
20. Koepf, H.H. 1993. Research in Biodynamic Agriculture: Methods and Results. Bio-Dynamic Farming and Gardening Association, Kimberton, PA.
21. Koepf, H.H., B.D. Pettersson, and W. Schaumann. 1976. Bio-Dynamic Agriculture: An Introduction. Anthroposophic Press, Spring Valley, NY.
22. Ligneau, L.A.M., and T.A. Watt. 1995. The effects of domestic compost upon the germination and emergence of barley and six arable weeds. Ann. Appl. Biol. 126:153–162.
23. McBride, M.B. 1994. Environmental Chemistry of Soils. Oxford University Press, New York.
24. Murphy, J., and J. Riley. 1962. A modified single solution for the determination of phosphate in natural waters. Anal. Chim. Acta 27:31.
25. Nguyen, M.L., R.J. Haynes, and K.M. Goh. 1995. Nutrient budgets and status in three pairs of conventional and alternative mixed cropping farms in Canterbury, New Zealand. Agric. Ecosyst. Environ. 52:149–162.
26. Penfold, C.M., M.S. Miyan, T.G. Reeves, and I.T. Grierson. 1995. Biological farming for sustainable agricultural production. Austral. J. Exper. Agric. 35:849–856.
27. Pfeiffer, E. 1956. The biodynamic method, what it is and what it is not. In Biodynamics, Three Introductory Lectures. Bio-Dynamic Farming and Gardening Association, Kimberton, PA.
28. Raupp, J., and U.J. König. 1996. Biodynamic preparations cause opposite yield effects depending upon yield levels. Biol. Agric. Hort. 13:175–188.
29. Reganold, J.P., A.S. Palmer, J.C. Lockhart, and A.N. Macgregor. 1993. Soil quality and financial performance of biodynamic and conventional farms in New Zealand. Science 260:344–349.
30. Reinken, G. 1986. Six years of biodynamic growing of vegetables and apples in comparison with the conventional farm management. In H. Vogtmann, E. Boehncke, and I. Fricke (eds.). The Importance of Biological Agriculture in a World of Diminishing Resources: Proceedings of the 5th IFOAM International Scientific Conference at the University of Kassel (Germany), August 27–30, 1984. Verlagsgruppe, Witzenhausen, Germany. p. 161–174.
31. Russell, E.W. 1961. Soil Conditions and Plant Growth. 9th ed. Longmans, Green, London.
32. Rynk, R. (ed.). 1992. On-farm Composting Handbook. NRAES-54. Northeast Regional Agricultural Engineering Service, Ithaca, NY.
33. SAS/STAT 1988. User's Guide. Release 6.03 ed. SAS Institute, Cary, NC.
34. Sattler, F., and E. von Wistinghausen. 1992. Bio-Dynamic Farming Practice. Bio-Dynamic Agricultural Association, Stourbridge, West Midlands, U.K.
35. Schlüter, C. 1985. Arbeits- und betriebsw-

irtschaftliche Verhältnisse in Betrieben de alternativen Landbaus (Labor and economic relations on alternative farms). Eugen Ulmer, Stuttgart, Germany.

36. Spiess, H. 1978. Conventional and biodynamic methods for increasing soil fertility. Ph.D. diss. Giessen University. Verlag Lebendige Erde, Darmstadt, Germany. (Deutsche Nationalbibliographie C1979. 08:558. Gr. 14.1.)
37. Stearn, W.C. 1976. Effectiveness of two biodynamic preparations on higher plants and possible mechanisms for the observed response. M.S. thesis. Ohio State University, Columbus, OH.
38. Steiner, R. 1974. Agriculture: A Course of Eight Lectures Given at Koberwitz, Silesia, 7th to 16th June, 1924. Bio-Dynamic Agricultural Association, London.
39. Sylvia, D.M. 1994. Vesicular–arbuscular mycorrhizal fungi. In R.W. Weaver, J.S. Angle, and P.S. Bottomley (eds.). Methods of Soil Analysis. Part 2, Microbiological and Biochemical Properties. Soil Science Society of America, Madison, WI. p. 351–378.
40. Teech, M., and L. English. 1944. Rapid microchemical soil test. Soil Sci. 57:167.
41. Wade, P. 1972. Flour properties and the manufacture of semi-sweet biscuits. J. Sci. Food Agric. 23:737–744.
42. Wadham, M.D., and D. Wynn Parry. 1981. The silicon content of *Oryza sativa* L. and its effect on the grazing behaviour of *Agriolimax reticulatus* Müller. Ann. Bot. 48:399–402.
43. Ware, G.W. 1980. Complete Guide to Pest Control with and without Chemicals. Thomson Publications, Fresno, CA.