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Influence of biodynamic preparations on compost development and resultant compost extracts on wheat seedling growth

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ABSTRACT

Biodynamic (BD) agriculture, a form of organic agriculture, includes the use of specially fermented preparations, but peer-reviewed studies on their efficacy are rare. Composting of a grape pomace and manure mixture was studied in two years (2002 and 2005) with and without the BD compost preparations. Water extracts of finished composts were then used to fertigate wheat seedlings, with and without added inorganic fertilizer. BD-treated mixtures had significantly greater dehydrogenase activity than did untreated (control) mixtures during composting, suggesting greater microbial activity in BD-treated compost. In both years there was a distinct compost effect on wheat shoot and root biomass irrespective of supplemental fertilizer. Shoot biomass was highest in all treatments receiving 1% compost extract. Wheat seedlings that received 1% compost extract in 2005 grew similar root and shoot biomass as fertilized seedlings, despite only containing 30% as much nitrogen as the fertilizer treatment. In both years seedlings that received fertilizer plus 1% compost extract produced 22–61% more shoot biomass and 40–66% more root biomass than seedlings that received fertilizer alone, even at higher rates. In 2002 a 1% extract of BD compost grew 7% taller wheat seedlings than did 1% extract of untreated compost. At 0.1% only BD extract grew taller plants than water, but in 2002 only. No effect on shoot or root biomass was seen at 0.1%. Our results support the use of compost extracts as fertilizer substitutes or supplements, testimonial reports on the growth promoting effects of compost extracts, and the occasional superiority of BD compost to untreated compost.

1. Introduction

Biodynamic (BD) agriculture was first presented as an alternative form of agriculture in 1924 by the Austrian philosopher Rudolf Steiner (Steiner, 1993). Since then it has gained considerable following, especially in Europe, Australia, New Zealand and India. Biodynamics shares much in common with organic methods of farming, including soil building, crop rotations, and composting. A key aspect of the BD method is the use of special preparations that are applied to the soil, crops and composts. The compost preparations consist of six fermented herbal substances (Table 1), which are added to compost piles at the rate of 5 g each to 1–13 mg of raw feedstock in order to promote the formation of a quality product (Koepf et al., 1990; Steiner, 1993). Proponents claim that these six preparations produce compost that develops faster with less loss of nitrogen, fewer odor problems, and greater nutrient holding capacity, by stimulating organisms present in the feedstocks (Koepf, 1993; Klett, 2006).

Many of the research reports supporting the efficacy of the BD preparations have appeared in non-refereed publications and in dissertations (Abele, 1973; Samaras, 1978; Spiess, 1978; König, 1988; Bachinger, 1996) and agency studies (Abele, 1978; Abele, 1987; Dewes and Ahrens, 1989). Recent peer-reviewed research showed that the compost preparations had a discernible effect on the finished product (Carpenter-Boggs et al., 2000). That is, BD compost maintained higher temperatures throughout the active composting stage, and finished BD compost contained 65% more nitrate, respired at a 10% lower rate, and had higher dehydrogenase enzyme activity than untreated compost; fatty acid analysis indicated that BD compost had a larger proportion of bacteria to fungi than the control compost (Carpenter-Boggs et al., 2000).

Boos et al. (1997) reported a trend towards higher initial temperature and lower respiration and ammonium in finished BD compost, indicating a faster decomposition process. Earlier research produced similar results with BD-treated compost having a narrower C:N ratio, more nitrate, greater cation exchange capacity,

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Table 1
The main ingredients and recommended amounts of the biodynamic preparations used in up to 14 t compost.

Preparation	Main ingredient	Use	Unit volume (cm^3)	Unit mass (g)
502	Yarrow blossoms (*Achilliea millefoilium* L.)	Compost	15	1.1
503	Chamomile blossoms (*Matricata recutita* L.)	Compost	15	3.0
504	Stinging nettle shoots (*Urtica dioica* L.)	Compost	15	4.4
505	Oak bark (*Quercus robur* L.)	Compost	15	3.9
506	Dandelion flowers (*Taraxacum officinale* L.)	Compost	15	4.7
507	Valerian flower extract (*Valeriana officinalis* L.)	Compost	2	1.2

higher respiration rate and a more even and prolonged heating period (Heinze and Breda, 1978; Ahrens, 1984; von Wistinghausen, 1986).

Biodynamics has received attention from the wine industry in recent years with many notable winegrape growers, particularly in France and California, converting to biodynamic practices (Meunier, 2001; Walker, 2003; Nigro, 2007). Today, an estimated 1000 hectares of vineyards are certified biodynamic in the United States, with many more wine growers experimenting with the method (H.G. Courtney, 2008, The Josephine Porter Institute, personal communication). Organic winegrape production is also on the increase, particularly in California where pest and disease pressures are low relative to the more humid grape growing regions in the eastern and midwestern US. Certified organic grapes (all) accounted for 2.4% of total US grape acreage in 2005 (Economic Research Service, 2008).

Wine production creates considerable volumes of organic waste called grape pomace, which includes grape seeds, skins, and stems. Composting has become the obvious solution for pomace disposal for many wineries. The resulting compost is often used on site in the vineyards to increase soil organic matter, soil nutrients, water holding capacity and porosity (Brinton and York, 2003).

Composts may also be extracted with water at widely ranging ratios of 1:1 (dry w/w) (Hoitink et al., 1997) to 1:60 (dry w/w) (Scheuerell and Mahafee, 2004) to 1:800 (dry w/w) (Kelley et al., 2004). Such extracts are sometimes treated with additional ingredients and/or diluted before application (Scheuerell and Mahafee, 2004). The resulting extract or tea is applied to plants or soil for putative fertility or disease control benefits (Litterick et al., 2004). The compost tea industry, although small, is estimated to be growing at 25 percent per year (Carpenter-Boggs, 2005). Not only winegrape growers, but orchardists, vegetable farmers, and even golf course managers are showing interest in using compost extracts (Goldstein, 2005). Despite growing industry interest and use of these methods, neither on-farm composting of grape pomace nor the use of compost extracts has received adequate scientific attention (Goldstein, 2005).

The purpose of this study was, firstly, to test the effect of BD compost preparations on the quality of compost produced on a commercial California vineyard. Secondly, water extracts of finished BD-treated and non-treated pomace composts with and without added fertilizer were tested for effects on wheat seedling growth.

2. Methods

2.1. Composting procedures

Composting experiments were conducted on a commercial certified BD winegrape vineyard (McNab Ranch, Hopland, CA) with average annual precipitation of 114 cm. Feedstocks consisted of grape pomace and dairy manure with straw bedding, mixed and managed according to the vineyard's standard protocol. In March 2002, these materials were mixed 1:1 by volume for an initial approximate C:N ratio of 30:1 and divided into four windrows with height, width, and length of $1.5 \times 3.6 \times 12.1$ m. Two windrows were treated with the BD compost preparations (Table 1) purchased from the Josephine Porter Institute (Woolwine, VA) and two (controls) were not treated. The BD treatment consisted of 5 g of each preparation numbered 502 through 507, with each preparation placed in a separate hole bored 0.3 m into the pile according to standard BD practice (Koepf et al., 1990). One set was inserted for every 10 tons of material. Preparation 507, a liquid, was lightly sprayed over the entire pile.

Piles were turned with a front-end loader and compost samples were taken on days 0, 21, 55, 100 and 200. After turning, eight subsamples were taken along each side of the pile at a depth of 60–90 cm and thoroughly mixed together. Samples were stored at 4 °C prior to shipment to Woods End Laboratories (WEL, Mt. Vernon, ME) and Washington State University (WSU) for analyses. Temperatures were recorded in each pile at a depth of 90 cm every 4 h with a temperature data logger (Dickson, Addison, Illinois).

This procedure was repeated in March 2005 with a further four compost piles, with two reps for each treatment. Turning and sampling were carried out as above. Temperature in 2005 was measured twice weekly in eight places with a 90 cm probe (Rio Temp. Instruments, San Diego, CA). Daily temperature and rainfall data for the duration of each composting period were obtained from the UC Davis weather station located in Hopland CA, 3 miles south of McNab Ranch.

2.2. Chemical, physical, and biological analyses

The following analyses were carried out by WEL on 2002 samples. Compost samples were passed through a 10 mm sieve to remove any oversized material. Density was measured using TMECC Method 03.01-A (TMECC, 2002). Compost pH was measured according to EPA method 150.1 (Environmental Protection Agency, 1983). Total Kjeldahl nitrogen was measured using EPA method 351.3 (Environmental Protection Agency, 1983). Total carbon was measured by combustion at 550 °C. Organic matter was determined according to EPA method 160.4 (Environmental Protection Agency, 1983). Water holding capacity (WHC) was estimated by assigning an average of 300% WHC to the organic fraction and a 25% WHC to the ash (inorganic fraction) (method developed by W.F. Brinton, WEL). Respiration rate was determined by the alkaline trapping method 05.08 B (TMECC 2002) incubated at 34 °C. Total mineral nutrients P, K, Na, Ca, Mg were measured according to EPA Methods 202.1–265.3 (Environmental Protection Agency,1983). Analyses carried out by WEL in 2005 were bulk density, water holding capacity, and total mineral nutrients using methods above.

The remaining analyses were conducted at WSU. Moisture content on wet weight basis was determined by drying for 48 h at 65 °C. Ammonium–N and NO_3^--N were measured in 2002 in a filtered extract 0.1 M $MgSO_4$ using ion sensitive electrodes (ORION Research, Inc., Beverly, MA). In 2005, NH_4^+-N and NO_3^--N were measured in filtered extract of 1:5 (dry wt./vol) compost in 1 M KCl on a Lachat QuickCHem FIA + 8000 series autoanalyzer using the salycilate method for NH_4-N and the NH_4Cl_2 method for NO_3-N.

Dehydrogenase activity was measured in both years as a reduction of triphenyl tetrazolium chloride (TPF) using 1 g dry weight equivalent moist compost (Tabatabai, 1994) and analyzed on a Bio-Tek microplate autoreader model EL 311s. Electrical conductivity and pH were measured using 1:1 (dry wt/vol) compost in water. Total C and N were measured in 2005 using a Leco CNS 2000. Fecal coliform bacteria were estimated according to Turco (1994) in serial dilutions of lauryl tryptose broth. Positives were counted after incubation at 35 °C for 24 and 48 h and MPN calculated with an MPN calculator (http://www.i2workout.com/mcuriale/mpn/index.html). All laboratory analyses were conducted in triplicate and are presented on a dry weight basis.

2.3. Seedling bioassays

Growth response of wheat seedlings (*Triticum aestivum*) to aqueous compost extracts was measured in a separate experiment conducted in the greenhouse in 2003 and 2005 under controlled environmental conditions. In any given year, mature compost from replicate BD-treated piles was combined and compost from replicate control piles was combined, extracted, and used as the basis for the ten treatment combinations described below. An initial 1:20 extraction was made from the combined samples using 100 g dry weight equivalent compost in 2 L water. Samples were shaken for 30 min, rested 8 h., shaken an additional 30 min and strained through a 500 μm sieve. Initial extracts were diluted with water 1:5 and 1:50 to make total dilutions of 1% and 0.1%.

Wheat seeds were soaked in water for 8 h and 2 seeds planted in each 5 × 20 cm pot containing perlite on February 2nd 2003 and November 3rd 2005 in a greenhouse (daytime temperature 21 °C, nighttime temperature 16 °C and 16 h supplemental lighting). No soil or peat was added in order to avoid potential confounding effects of humic materials found in these materials and to precisely control all inputs. Five ml of treatment solution was applied once per day to 10 reps (pots) per treatment. Ten treatments consisted of BD compost extract diluted 1% with and without fertilizer, control compost extract diluted 1% with and without fertilizer, BD extract diluted 0.1% with and without fertilizer, control extract diluted 0.1% with and without fertilizer, fertilizer alone, and water only. Fertilizer used was Peter's Fertilizer supplied at a rate of 25 mg L^{-1} N, 24 mg L^{-1} P_2O_5, 46 mg L^{-1} K_2O, 0.14 mg L^{-1} Mg, 0.02 mg L^{-1} B, 0.01 mg L^{-1} Cu chelate, 0.14 mg L^{-1} Fe chelate, 0.07 mg L^{-1} Mn chelate, 0.025 mg L^{-1} Mo, and 0.007 mg L^{-1} Zn chelate.

In 2002, BD 1% compost extract contained 7.6 mg kg^{-1} N and 0.1% extract contained 0.76 mg kg^{-1} N. Control compost 1% extract contained 5.5 mg kg^{-1} N and 0.1% extract contained 0.55 mg kg^{-1} N. In 2005 BD compost 1% extract contained 7.6 mg kg^{-1} N and 0.1% extract contained 0.76 mg kg^{-1}N and control compost 1% extract contained 7.5 mg kg^{-1} N and 0.1% extract contained 0.75 mg kg^{-1} N. In 2005, two additional treatments were added, 2× and 4× original fertilizer rate. Root and shoot biomass and shoot height were recorded at 5 weeks after planting.

2.4. Statistical analysis

The compost experiment was analyzed as a split plot design with year as main plot and treatment (BD preps vs. no BD preps) as subplot. The main plot was a completely randomized design (CRD) and subplot a randomized complete block design (RCBD) with repeated measures (sampling time) and four replicates. Day was tested using d 0 data but treatment analysis did not include d 0. The seedling bioassay was designed and analyzed as a CRD with ten treatments (described under seedling bioassays) and ten replicates. All statistics were measured using the SAS System for Windows Version 8 ANOVA and Fischer's Protected LSD.

Figures present means calculated over 2 years. When treatment interactions are present this is noted in the text, however, for brevity and the focus of this paper, treatment means only are shown not year effects. Unless specifically stated otherwise, all statistical differences represent $p < 0.05$.

3. Results and discussion

3.1. Compost analyses

While the majority of parameters analyzed were not different between the BD and control treatments, dehydrogenase activity was significantly higher in the BD-treated compost ($p < 0.01$, Fig. 1). Dehydrogenase activity also declined significantly during the composting processes but a significant day × year interaction showed that unlike 2002, activity in 2005 increased substantially towards day 50 before falling off sharply (data not shown). Carpenter-Boggs et al. (2000) also observed higher dehydrogenase activity in BD-treated compost. Our results in corroboration with those of Carpenter-Boggs et al. (2000) indicate that the BD preparations may indeed have an effect on the microbial activity of compost. Greater dehydrogenase activity has also been observed in soils as a result of treatment with BD preparations (Bachinger, 1996) and BD management (Fliessbach et al., 2007). Dehydrogenase activity is used as a measure of microbial activity, as it is a key enzyme in the microbial oxidation of organic matter. It has been significantly correlated with a number of frequently measured parameters in composting, such as respiration, water soluble C and N, nitrification potential and organic matter loss (Tiquia et al., 2002; Benito et al., 2003).

Previous reports of higher or prolonged heating as a result of BD treatment (Boos et al., 1997; Carpenter-Boggs et al., 2000) were not observed in this study. Similar to Boos et al. (1997) significantly lower temperatures in the final three weeks of composting in BD-treated piles were observed on individual days. The differences were not consistent day to day but nevertheless may indicate the BD compost was more mature by d 200 of the study (Fig. 2). Temperature reached a high of 68 °C in 2002 and 58 °C in 2005. It is unclear why the compost did not heat as well in 2005 and did not reach peak temperature until the third turning. In both years, compost achieved peak temperatures above 40 °C indicating a thermophilic stage and below 70 °C, which can inhibit the microbial community and cause excessive nitrogen loss. Temperature did not drop below 40 °C in either year even after 190 days of measurements.

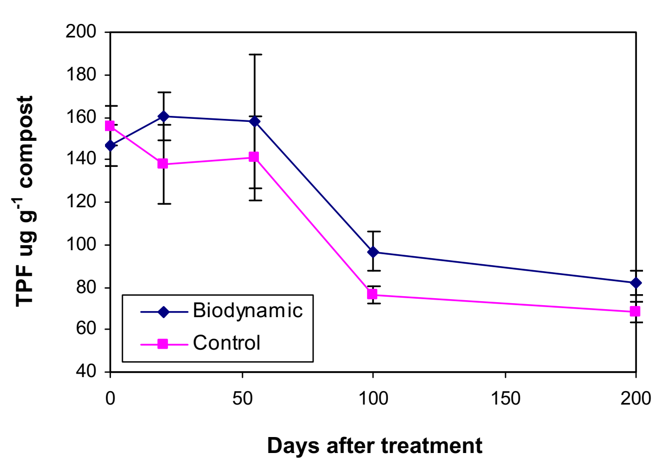

Fig. 1. Compost dehydrogenase activity at 60–90 cm depth as measured by the reduction of triphenyl tetrazolium chloride (TPF) ($n = 4$, 2002 and 2005). Biodynamic compost shows significantly higher activity ($p = 0.01$).

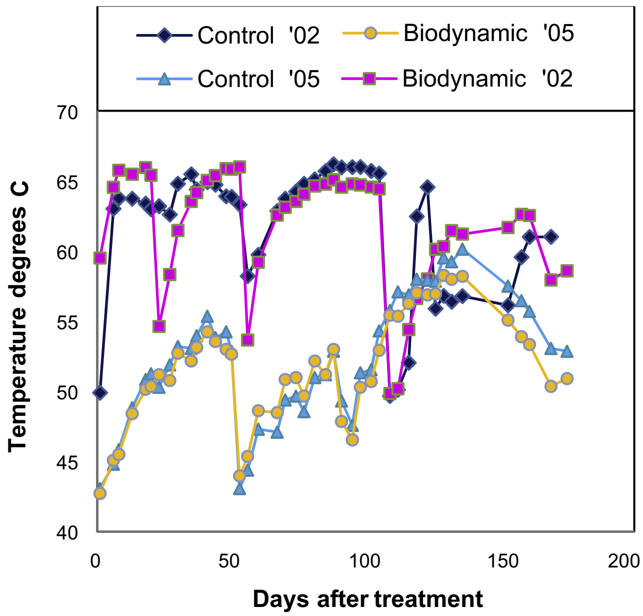

Fig. 2. Compost temperature recorded twice per week at a depth of 90 cm depth ($n = 4$, 2002 and 2005). Periodic drops followed by increases in temperature indicate turning events.

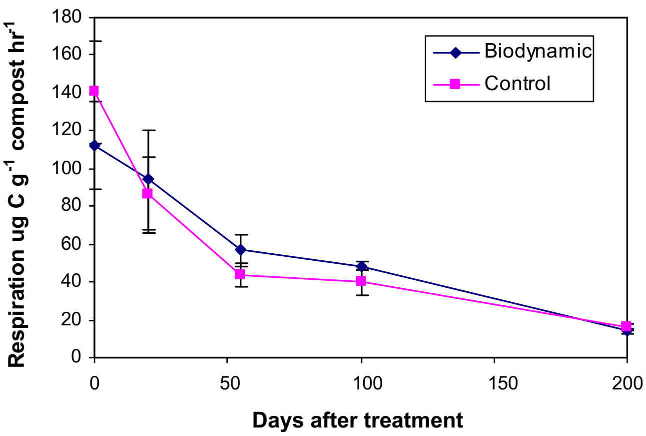

Fig. 3. Compost respiration per day at 37 °C at 60–90 cm depth ($n = 4$, 2002 and 2005).

All respiration measurements dropped significantly over time (Fig. 3). A decline in respiration towards the end of composting is expected as microbial activity decreases and the compost enters the maturation phase. There were no treatment differences in respiration rate. Again a significant day × year interaction indicated initial respiration rates were significantly greater and dropped faster over time in 2002 (data not shown).

Dehydrogenase activity divided by respiration is a metabolic quotient that may indicate the efficiency of functioning of the microbial community (Anderson, 1994). A higher enzyme activity coupled with lower respiration would indicate a higher metabolic efficiency in the microbial population. Similarly to Carpenter-Boggs et al. (2000), BD compost had 30% higher efficiency at d 200 in 2002 (data not shown), although the difference was not statistically significant. There were no differences in metabolic efficiency in 2005.

There was no significant difference in NO_3^--N (Fig. 4) or NH_4^+-N (Fig. 5) between treatments. Carpenter-Boggs et al. (2000) found finished BD compost to contain 65% more NO_3^--N than control

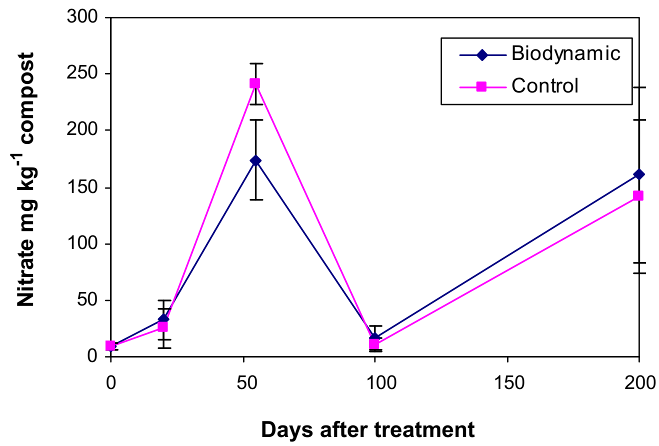

Fig. 4. Compost nitrate–N concentration at 60–90 cm depth ($n = 4$, 2002 and 2005).

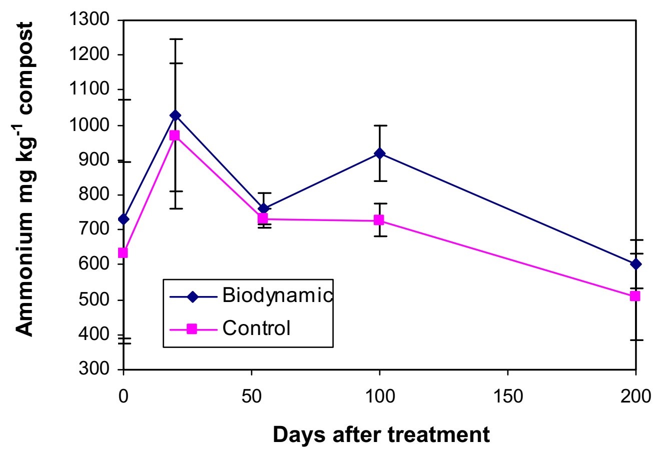

Fig. 5. Compost ammonium–N concentration at 60–90 cm depth ($n = 4$, 2002 and 2005).

compost. Our data do not replicate this result, but our data do represent different feedstocks under different climatic conditions. Significant NO_3^--N developed in both of our treatments, although NO_3^--N development was somewhat erratic and in 2005 final compost contained only 33 g N kg^{-1} compost as opposed to 379 g N kg^{-1} compost in 2002. In 2002 NH_4^+-N dropped significantly between d 0 and d 200, but after initially rising between d 0 and d 25, it remained unchanged in 2005. A drop in NH_4^+-N during composting is expected as NH_4^+ is converted to NO_3^- through nitrification. In 2005 final NH_4^+-N was 719 g N kg^{-1} as opposed to 390 g N kg^{-1} in 2002.

There were no treatment effects on compost pH. Compost pH rose initially and then dropped towards the end of composting (data not shown). Compost pH usually increases during composting as organic compounds are consumed and N is mineralized to NH_4^+ before dropping as the compost matures (N'Dayegamiye and Isfan, 1991; Frederick et al., 1996; Benito et al., 2003). Compost pH was significantly higher in 2005 than 2002, exceeding 8.6 at d 100 and then dropping again as the compost matured (data not shown). Ammonia is volatilized from compost at a pH 8.2 and higher. Conversely, high pH can be caused by ammonia. Nitrification is also inhibited by high pH. The erratic development of NO_3^--N in 2002 and minimal development of NO_3^--N in 2005 in combination with the high pH during composting, particularly in 2005, suggests N-loss as ammonia. Ammonia loss during composting usually occurs when the C:N ratio of the initial feedstocks is too low.

In this case the exact cause of higher pH in 2005 is uncertain as the C:N ratio of the compost was actually slightly higher in 2005. While the goal was initial C:N ratios of 30:1 when the feedstocks were combined, in 2002 actual C:N ratios of mixed feedstocks averaged 19:1 at d 0 and dropped to 15:1 by d 200 (data not shown). In 2005, the C:N ratio of mixed feedstocks started at 23:1 and dropped to 17:1 by d 200. There were no differences between treatments.

Compost pH can also be influenced by the initial pH of the feedstocks. Grape pomace is usually a highly acidic material, with a pH as low as 3.5 (Brinton and York, 2003). The initial pH of the grape pomace used in this study was 6.5 in 2002 and 4.3 in 2005. Manure pH was 7.8 in 2005 but was not measured in 2002. The initial average pH of the combined feedstocks was 8.0 in 2002 and 7.6 in 2005. Compost materials that contain high initial total N frequently have excessive pH (Frederick et al., 1996; Charest and Beauchamp, 2002; Paredez et al., 2002). In this study, total N was 16.3 g kg^{-1} in 2002 versus 16.7 g kg^{-1} in 2005 – no significant difference. However, the dairy manure used in 2002 had been stockpiled over the winter, whereas the manure used in 2005 was delivered straight from the dairy and so may have contained larger amounts of urea. Ammonium and NO_3^--N were significantly lower at the start of composting in 2005 while total N was similar. While we did not measure urea it seems likely the difference between total N and inorganic N was accounted for by urea as fresh manure is frequently high in this compound.

Charest and Beauchamp (2002) found that higher rates of urea added to paper sludge correlated with greater ammonification and high pH. Under oxygen limiting conditions, alternative electron acceptors such as nitrate are used by facultative anaerobic microorganisms in the denitrification process, which consumes protons and raises pH. Hellman et al. (1997) found significant methane production during composting, also a proton consuming metabolic pathway. Conversely, if conditions become anoxic, pH may decrease as acids, such as nitric acid, are formed. Although we did not measure the oxygen status of the piles, the compost in 2005 may have been too wet or insufficiently turned, promoting denitrification and pH increase. High pH as a result of overly wet compost has been observed by Brinton and York (2003). Hopland, CA received only 41 cm precipitation in 2002 but received 239 cm in 2005, more than twice the annual average. Average daily temperature during the composting period were somewhat lower in 2005, 25 °C as opposed to 27 °C for the same period in 2002. The compost was not covered at any time and therefore was affected by rainfall.

The possibility of overly wet composting conditions in 2005 is only partially supported by the compost moisture data in that the piles were slightly too wet in both years during active composting. There were no significant differences in moisture content of the composts between treatments at any time or between years, although moisture fell significantly over time (data not shown). Water holding capacity (WHC), however, was significantly higher in 2005 at d 0, 20 and 50 although these differences evened out by d 100 and 200 (data not shown). This means that moisture expressed as percent saturation of WHC was actually lower in 2005 during the first 50 days of composting. In 2002 percent saturation of WHC was 92% at d 0 and fell to 88% by d 100 but remained between 84% and 83% during the same period in 2005. By d 200 in 2002 and 2005, moisture had fallen to 62 and 60% of WHC respectively. Ideal moisture for maximum biological activity is 60–80% of WHC (WEL, 2000). This suggests that these composts were somewhat wetter than optimum between d 0 and d 100 in both years, although slightly closer to optimal in 2005.

There were no differences in mineral elements by treatment at the start or end of composting (Table 2). Potassium was significantly higher in 2005 and Na and Mg were higher in 2002 at the end of composting suggesting some accumulation of salts. Electrical conductivity ranged from 2.5 to 3.5 mS cm^{-1} at the start of composting, increasing to 11.5 mS cm^{-1} in 2002 but remaining unchanged in 2005. There were no differences between treatment and year in numbers of fecal coliforms detected at d 200 of composting. Most probable number fecal coliform bacteria at d 200 were 915 and 2649 MPN g^{-1} for BD and control compost and 799 and 2765 MPN g^{-1} in 2002 and 2005 respectively. Higher numbers in 2005 reflect greater fecal coliforms detected in one control pile. Nevertheless, these numbers represent a reduction of 99.8% from initial counts at d 0.

Table 2
Compost mineral nutrients at d 0 and 200 of composting ($n = 4$, 2002 and 2005).

Parameters (mg kg^{-1})	BD Compost	Control compost	2002	2005
Day 0				
P	3228	3063	3675	2615
K	16,750	15,738	15,333	17,163
Na	1530	1423	2150	800
Ca	9605	10,763	10,150	10,218
Mg	3495	3900	4250	3145
Day 200				
P	3633	3768	4100	3300
K	19,157	19,663	16,350	22,470
Na	1758	2058	2520	1265
Ca	12,262	12,520	11,525	13,258
Mg	5190	5275	6000*	4465

Means with designed * represent significant differences at $p < 0.05$.

3.2. Seedling bioassays

Compost extracts from this study were also tested for their effects on growth of wheat seedlings. Wheat growth in all treatments including water controls was greater in 2003 than in 2005, indicating different growth conditions between the two years. We attribute this to the fact that in 2005 the study was conducted in November and December as opposed to February and March, and while the greenhouse was heated and lit with supplemental lighting, the 2005 experiment would have received lower incidence of natural light. In both years, wheat that received water only was smallest, and plants receiving inorganic fertilizer plus 1% compost solution were largest (Fig. 6). In both years seedlings that received fertilizer plus 1% compost extract produced 22–61% more shoot biomass and 40–66% more root biomass than seedlings that received fertilizer alone, even at higher rates (Figs. 7 and 8). Wheat seedlings that received 1% extract of either BD or control composts in 2005 grew similar root and shoot biomass as fertilized seedlings, despite the 1% compost extracts containing only 30% as much nitrogen as the fertilizer treatment.

All 1% compost extracts with or without fertilizer resulted in greater shoot height, and root biomass in both years than water only controls. This effect was not seen as consistently in the shoot biomass data; of the unfertilized treatments only 1% BD compost produced greater shoot biomass than water in 2002. In 2002 the 1% + fertilizer resulted in greatest growth with a similar trend for individual growth parameters at the 0.1% + fertilizer level. In 2005 the 1% compost extract alone resulted in similar growth to the highest level of fertilizer and the addition of fertilizer to the compost extract had no further effect on growth. In both years there was a distinct compost effect on shoot and root biomass. Shoot biomass was highest in all treatments receiving 1% compost extract. In 2005 root biomass equaled the highest fertilizer rate in all 1% compost treatments. There were no differences between 0.1% compost extract and water with the exception that 0.1% BD compost extract grew taller plants than water in 2002.

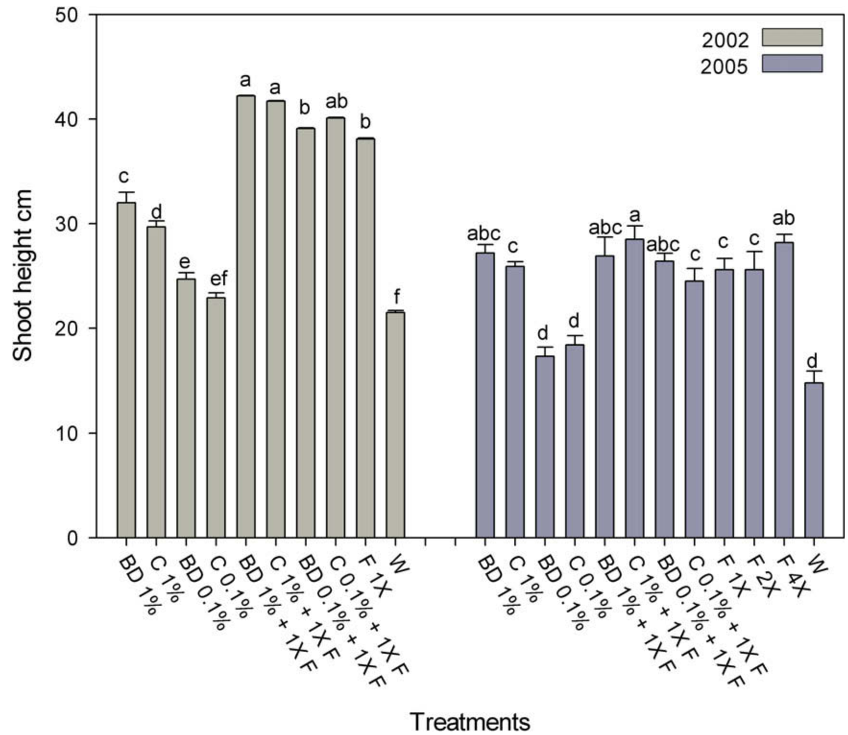

Fig. 6. Wheat shoot height after 5 weeks with compost extracts of 1% and 0.1% dilutions in 2002 and 2005 ($n = 10$). Treatment codes: BD 1% (BD compost 1% extract); C 1% (control compost 1% extract); BD 0.1% (BD compost 0.1% extract); C 0.1% (control compost 0.1% extract); BD 1% + 1XF (BD compost 1% extract + 25 ppm fertilizer); C 1% + 1XF (control compost 1% extract + 25 ppm fertilizer); BD 0.1% + 1XF (BD compost 0.1% extract + 25 ppm fertilizer); C 0.1% + 1XF (control compost 0.1% extract + 25 ppm fertilizer); F 1X (fertilizer only 25 ppm); F 2X (fertilizer only 50 ppm); F 4X (fertilizer only 100 ppm); W (water). Means with different letters represent significant differences at $p < 0.05$ within each year.

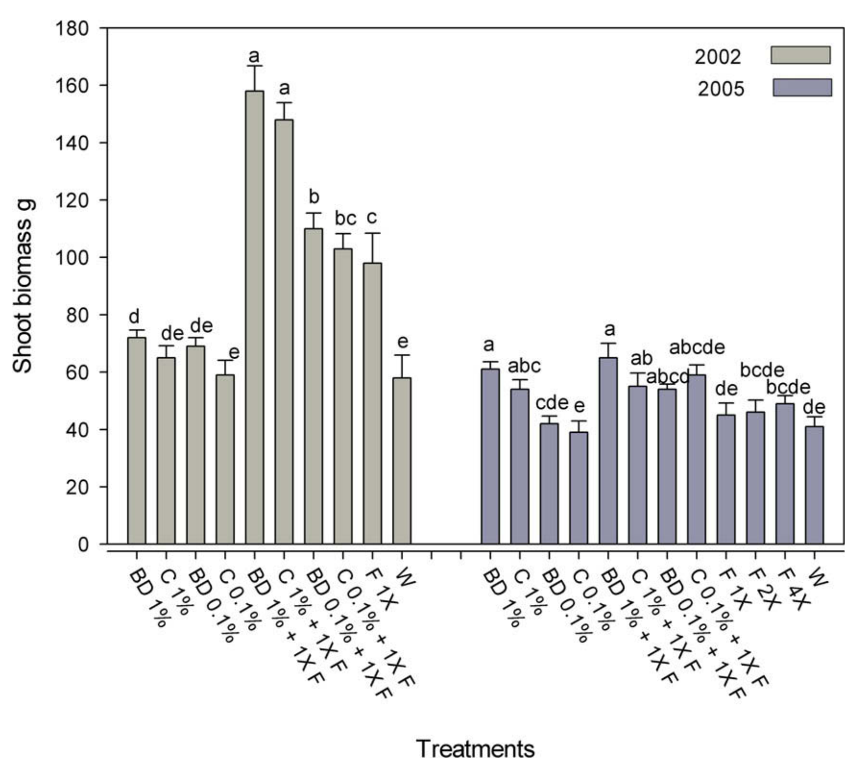

Fig. 7. Wheat shoot biomass after 5 weeks with compost extracts of 1% and 0.1% dilutions in 2002 and 2005 ($n = 10$). Treatment codes: BD 1% (BD compost 1% extract); C 1% (control compost 1% extract); BD 0.1% (BD compost 0.1% extract); C 0.1% (control compost 0.1% extract); BD 1% + 1XF (BD compost 1% extract + 25 ppm fertilizer); C 1% + 1XF (control compost 1% extract + 25 ppm fertilizer); BD 0.1% + 1XF (BD compost 0.1% extract + 25 ppm fertilizer); C 0.1% + 1XF (control compost 0.1% extract + 25 ppm fertilizer); F 1X (fertilizer only 25 ppm); F 2X (fertilizer only 50 ppm); F 4X (fertilizer only 100 ppm); W (water). Means with different letters represent significant differences at $p < 0.05$ within each year.

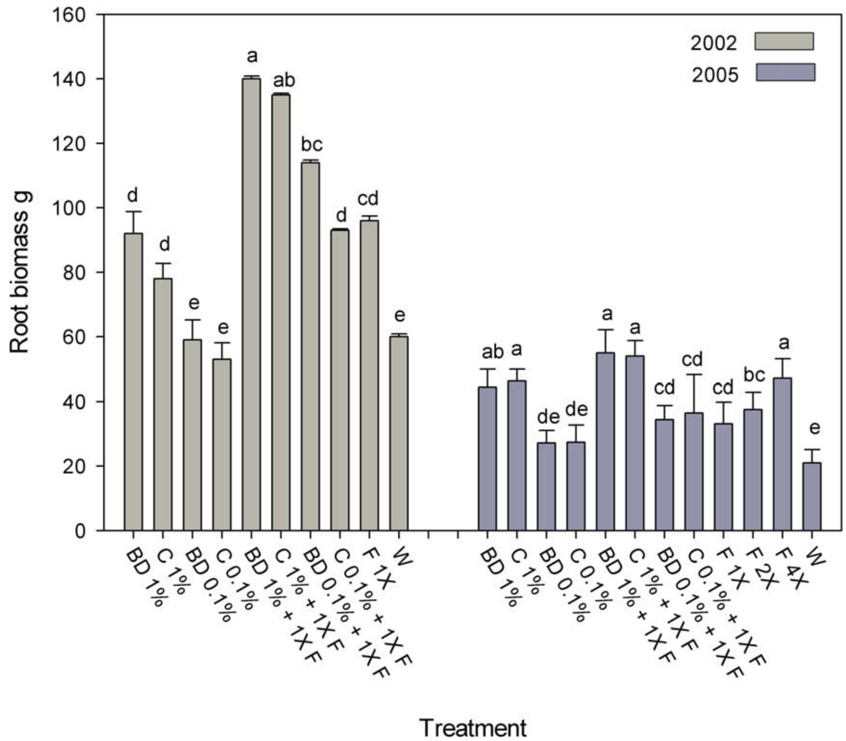

Fig. 8. Wheat root biomass after 5 weeks with compost extracts of 1% and 0.1% dilutions in 2002 and 2005 ($n = 10$). Treatment codes: BD 1% (BD compost 1% extract); C 1% (control compost 1% extract); BD 0.1% (BD compost 0.1% extract); C 0.1% (control compost 0.1% extract); BD 1% + 1XF (BD compost 1% extract + 25 ppm fertilizer); C 1% + 1XF (control compost 1% extract + 25 ppm fertilizer); BD 0.1% + 1XF (BD compost 0.1% extract + 25 ppm fertilizer); C 0.1% + 1XF (control compost 0.1% extract + 25 ppm fertilizer); F 1X (fertilizer only 25 ppm); F 2X (fertilizer only 50 ppm); F 4X (fertilizer only 100 ppm); W (water). Means with different letters represent significant differences at $p < 0.05$ within each year.

The 1% extraction rate used in this study is close to typical extraction rates used in making compost tea and represents a considerable reduction in application rates typically applied as bulk compost. California winegrape grower Kirk Grace reported (Grace 2005) that he gets excellent results from grape pomace compost tea applied through his drip irrigation system to vines at 94 L per hectare (a 2.4% extraction using 0.9 kg compost per 38 L) and contrasts that figure with the 2–9 metric tons per hectare bulk compost he would typically apply.

Controlled studies on the nutritive effects of compost teas are rare. Hargreaves et al. (2008) showed compost tea (10% extraction) to be as effective as compost applied to the soil in growth of raspberry canes. Keeling et al. (2003) showed growth promoting effects on wheat and oilseed rape beyond expected nutritive response when combining mature compost extracts with fertilizer at a 17% dilution. They did not see any response at greater dilutions than this. Our data indicate compost teas or extracts can be as effective as fertilizer applications at an extraction rate of 1% in promoting growth of young wheat seedlings in the greenhouse, despite the 1% compost extracts containing only 30% as much nitrogen as the fertilizer treatment. The potential for compost tea/extracts for supplementing or replacing other fertilizer seems promising and warrants further testing both in greenhouse situations and in the field.

Evidence is mounting that growth promotion by compost extracts may be due to effects other than nutrient additions. Sikora and Enkiri (1999) found greater N use when fertilizer was supplied together with compost at lower N contents than fertilizer alone, suggesting constituents other than N were responsible. Humic substances may cause hormone-like effects or stimulate root respiration leading to increased nutrient uptake both in controlled conditions and in the field (Day et al., 2000; Atiyeh et al., 2002; Zhang et al., 2003). These growth promoting properties could give appreciable benefit to farmers, especially under constrained nutrient budgets imposed by low-input farming systems.

In 2002, wheat growth was greater with BD compost extracts than with the analogous control compost extracts. At the 1% dilution, BD compost extract grew taller (7%) wheat and at the 0.1% rate BD compost grew taller wheat than water alone (Fig. 6). BD compost extract resulted in greater (30%) root biomass than did the control compost extract and a 0.1% extract of BD compost with added N resulted in 18% greater root biomass than the 0.1% control (Fig. 8) although these differences was not significant. So, although nutrient analyses of composts were statistically similar between treatments, greater growth promotion by BD compost extracts compared to control compost extracts in some cases may suggest that the BD composts were higher in water-extractable plant growth-promoting substances.

A concurrent study at McNab Ranch on the effects of BD- and control-treated vineyards indicated a more balanced canopy for producing high-quality winegrapes with BD-treated vines (Reeve et al., 2005); the BD-treated winegrapes also had significantly higher ($p < 0.05$) Brix and notably higher ($p < 0.1$) total phenols and total anthocyanins. These effects were also likely due to growth promoting effects of BD preparations.

3.3. Possible modes of action of the biodynamic preparations

Biodynamic agriculture has met with considerable criticism for its claims that such small quantities of substances could affect plant growth or compost development. There is some evidence that microbial inoculants (at rates of 0.039–5% by dry wt.) speed up the initial processes in composting (Rosal et al., 1995; Razvi and Kramer, 1996; Lei and VanderGheynst, 2000). These effects tend not to be maintained and additions of soil and or compost, although in substantially larger amounts (30–40% by dry wt.), are just as effective. At the dose of 5 g per preparation per 11 Mg (0.00005%) material, it is unlikely that the preparations are effective microbial inoculants.

A more plausible potential mode of action for the preparations may be through hormonal effects. Studies have found plant growth stimulatory substances in the BD preparations. For example, the field spray 500 was found to contain high levels of cytokinins (Stearn, 1976). Goldstein and Koepf (1992) found that root length and morphology of wheat seedlings were influenced by addition of the preparations to nutrient solutions as did Fritz and Köpke (2005) with beans. Deffune and Scofield (1995) compared purchased humic acids; humic acids extracted from preparations 500, 505, and 507; fresh 500, 505, and 507; and the plant growth regulator indole-3yl-acetic acid (IAA) in nutrient solution at three dilutions. All caused a positive growth response in wheat seedlings relative to the control, with humic acids most effective at 0.2×10^{-3} mg L^{-1} and the BD preparations and IAA most effective at both 0.2×10^{-11} mg L^{-1} and 0.2×10^{-25} mg L^{-1}.

Another possible mode of action could be through bacterial regulation effects. Bacteria detect and react to extremely low levels of signal molecules in their environment, as shown in work on quorum sensing (Miller and Bassler, 2001). Many higher plants have been shown to produce signal-mimicking compounds, thereby affecting bacterial density relationships (Brelles-Marino and Bedmar, 2001). Whether the preparations also contain such signaling compounds is a possibility that has not been evaluated.

4. Summary and conclusions

The BD-treated compost had greater dehydrogenase activity in both years suggesting that BD compost had greater microbial activity. This result is consistent with the literature. No other differences were detected as a result of treatment. Composting in both treatments resulted in a 99.8% reduction in fecal coliforms over the 200 d process, confirming the efficiency at which these organisms are reduced during composting. In 2005, compost analysis showed a lack of NO_3^- formation. These findings were likely due to excessive pH in the compost. High pH could have been caused by fresher manure with a higher concentration of urea. Composting conditions were also somewhat wet in both years which could have contributed to the problem.

In 2002, wheat growth with BD compost extract or BD compost extract plus fertilizer was always greater or the same as wheat growth with the control compost under the same conditions. A 1% water extract of BD-treated compost grew significantly taller (7%) wheat seedlings in 2002 than similar extracts of untreated compost and at the 0.1% rate BD compost grew significantly taller wheat than water alone (Fig. 6). BD compost extract resulted in greater (30%) root biomass than did the control compost extract and a 0.1% BD compost extracted with added N resulted in 18% greater root biomass than the 0.1% + fertilizer control (Fig. 8). Wheat growth in 2005 was similar between BD and untreated compost showing that possible differences as a result of BD treatment are not consistent year to year. Whether or not any small differences as a result of BD compost preparations would incur a practical benefit to the grower needs to be further investigated.

Irrespective of compost treatment, a marked compost effect on growth of wheat seedlings was observed. While 1% compost + fertilizer resulted in greatest growth in 2002, a 1% compost extract alone in 2005 was as effective as the highest fertilizer rate in terms of shoot height. In addition, shoot biomass was greatest in all treatments receiving 1% compost with or without added fertilizer, and root biomass in all 1% compost treatments equaled the highest fertilizer rate in 2005. Our data support anecdotal reports on the effects of compost teas on plant performance.

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References

Abele, U., 1973. Vergleichende Untersuchungen zum konventionellen und biologisch-dynamischen Pflanzenbau unter besonderer Berücksichtigung von Saatzeit und Entitäten. Ph.D dissertation, University of Gießen, Germany.
Abele, U., 1978. Ertragssteigerung durch Flüssigmistbehandlung. KTBL-Schrift 224. Landw.-Verlag, Münster-Hiltrup.
Abele, U., 1987. Produktqualität und Düngung–mineralisch, organisch, biologisch-dynamisch. Angewandte Wissenschaft Heft 345. Landwirtschaftsverlag, Münster-Hiltrup, Germany.
Ahrens, E., 1984. The effects of biodynamic preparations on the transformation of moistened wheat straw in the laboratory. Lebendige Erde 5, 196–207.
Anderson, T.-H., 1994. Physiological analysis of microbial communities in soil: application and limitations. In: Ritz, K. et al. (Eds.), Beyond the Biomass. British Society of Soil Science, London, UK, pp. 67–76.
Atiyeh, R.M., Lee, S., Edwards, C.A., Arancon, N.Q., Metzger, J.D., 2002. The influence of humic acids derived from earthworm-processed organic wastes on plant growth. Bioresour. Technol. 84, 7–14.
Bachinger, J., 1996. The effects of different types of fertilization (mineral, organic, biodynamic) on the temporal dynamics and spatial distribution of chemical and microbiological parameters of C and N dynamics in the soil and also of crop and root growth of winter rye. Ph.D thesis, University Gieβen, Germany.
Benito, M., Masaguer, A., Moliner, A., Arrigo, N., Palma, R.M., 2003. Chemical and microbiological parameters for the characterization of the stability and maturity of pruning waste compost. Biol. Fert. Soils 37, 184–189.
Boos, M., Friedel, J.K., Raupp, J., Römhel, V., 1997. Verfahren zur Probenahme und Untersuchung der Stallmistkompostierung unter Feldbedingungen mit Anwendung der Biologisch-dynamischen Präparate. Wiss.–Tagung Ökol. Landbau 4, 615–620.
Brelles-Marino, G., Bedmar, E.J., 2001. Detection, purification and characterization of quorum-sensing signal molecules in plant-associated bacteria. J. Biotechnol. 91, 197–209.
Brinton, W., York, A., 2003. Sustainable composting in the vineyard. Part I – Basics of the process. Practical Winery and Vineyard 25, 16–27.
Carpenter-Boggs, L., 2005. Diving into compost tea. Biocycle 46 (7), 61–62.
Carpenter-Boggs, L., Reganold, J.P., Kennedy, A.C., 2000. Effects of biodynamic preparations on compost development. Biol. Agric. Hortic. 17, 313–328.
Charest, M.–H., Beauchamp, C.J., 2002. Composting of de-inking paper sludge with poultry manure at three nitrogen levels using mechanical turning: behavior of physico-chemical parameters. Bioresour. Technol. 81, 7–17.
Day, K.S., Thornton, R., Kreeft, H., 2000. Humic acid products for improved phosphorus fertilizer management. In: Ghabbour, E.A., Davies, G. (Eds.), Humic Substances, Versatile Components of Plants, Soils and Water. Royal Society of Chemistry, Cambridge, UK, pp. 321–325.
Deffune, G., Scofield, A.M., 1995. Effects of humic acids and three bio-dynamic preparations on the growth of wheat seedlings. In: Cook, H.F., Lee, H.C. (eds.) Soil Management in Sustainable Agriculture. Proceedings of the Third International Conference on Sustainable Agriculture, Wye College, University of London, UK. pp. 364–371.
Dewes, T., Ahrens, E., 1989. Einfluss den biologish-dynamischen Preparat 500 auf merkmale der mikrobiellen Aktivitat eines schluffigen Sandes. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft (Commun. German Soil Sci. Soc.) 59, 553–558.
Economic Research Service, 2008. Organic Production. USDA Economic Research Service <http://www.ers.usda.gov/Data/Organic/index.htm> (accessed 26.05.08.).
WEL, 2000. Journal of the Woods End Research Laboratory. 4, 1-6.
Environmental Protection Agency, 1983. Methods for chemical analysis of water and wastes. EPA 600/4-79-020. U.S. Environmental Monitoring and Support Lab, Environmental Protection Agency, Cincinnati, OH. <http://infotreck.er.usgs.gov/pls/portal30/NEMI_PORTAL.RPT_methods.show>.
Fliessbach, A., Oberholzer, H.-R., Gunst, L., Mäder, P., 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agric. Ecosyst. Environ. 118, 273–284.
Frederick Jr., C.M., Forney, L.J., Huang, A.J.-F., Drew, S., Czuprenski, M., Lindberg, J.D., Adinarayana Reddy, C., 1996. Effects of turning frequency, leaves to grass mix ratio and windrows vs. Pile configuration on the composting of yard trimmings. Compost Sci. Util. 4, 26–43.
Fritz, J., Köpke, U., 2005. Effects of light, manuring and biodynamic horn silica applications on dwarf beans (*Phaseolus vulgaris* L. var. nanus) on germination characteristics of newly formed seeds. Planzenbauwissenschaften 9.S, 55–60.

Goldstein, J., 2005. Needed: Compost tea research findings. Comp. Sci. Util. 13, 87–89.

Goldstein, W.A., Koepf, H.H., 1992. A contribution for the development of tests for the biodynamic preparations. Elemente der Naturwissenshaft 36, 41–56.

Grace, K., 2005. California vineyard finds large role for compost. Biocycle 46 (6), 25–27.

Hargreaves, J., Adl, M.S., Warman, P.R., Rupasinghe, H.P.V., 2008. The effects of organic amendments on mineral element uptake and fruit quality of raspberries. Plant Soil 308, 213–226.

Heinze, H., Breda, E., 1978. Tests on the composting of farmyard manure. Bio-Dynamics 125, 12–22.

Hellman, B., Zelles, L., PalojÑrvi, A., Bai, Q., 1997. Emission of climate-relevant trace gases and succession of microbial communities during open windrow composting. Appl. Environ. Microbiol. 63, 115–123.

Hoitink, H.A.J., Stone, A.G., Han, D.Y., 1997. Suppression of plant disease by composts. Hort Science 32, 184–187.

Keeling, A.A., McCallum, K.R., Beckwith, C.P., 2003. Mature green waste compost enhances growth and nitrogen uptake in wheat (*Triticum aestivum* L.) and oilseed rape (*Brassica napus* L.) through the action of water–extractable factors. Bioresour. Technol. 90, 127–132.

Kelley, S., Mason, N.C, Hoffman, L., Storch, S., McGrath, M., 2004. Aerated compost tea and other alternative treatments for disease control in pumpkins. Organic Farming Research Foundation Final Project Report. http://ofrf.org/funded/reports/kelley_03f18.pdf.

Klett, M., 2006. Principles of Biodynamic Spray and Compost Preparations, 2nd ed. Floris Books, Edinburgh, Scotland, UK.

Koepf, H.H., 1993. Research in Biodynamic Agriculture: Methods and Results. Biodynamic Farming and Gardening Association, Inc., Kimberton, Pennsylvania, USA.

Koepf, H.H., Pettersson, B.D., Schaumann, W., 1990. Bio-Dynamic Agriculture: Practical Applications of the Bio-Dynamic Method. Anthroposophic Press, Hudson, New York.

König, U.J., 1988. Untersuchungen tagesrhytmischer und entwicklungsdynamischer Phänomene an ausgewählten Kulturpflanzen bei der Anwendung biologisch-dynamischer Spritzpräparate. Ph.D dissertation, University of Göttingen, Germany.

Lei, F., VanderGheynst, J.S., 2000. The effect of microbial inoculation and pH on microbial community structure changes during composting. Process Biochem. 35, 923–929.

Litterick, A.M., Harrier, L., Wallace, P., Watson, C.A., Wood, M., 2004. The role of uncomposted materials, composts, manures, and compost extracts in reducing pest and disease incidence and severity in sustainable temperate agricultural and horticultural crop production – a review. Crit. Rev. Plant Sci. 23, 453–479.

Meunier, M., 2001. Biodynamic wine and its progress in different countries. The Australian Grapegrower and Winemaker 444, 77–78.

Miller, M.B., Bassler, B.L., 2001. Quorum sensing in bacteria. Annu. Rev. Microbiol. 55, 165–199.

N'Dayegamiye, A., Isfan, D., 1991. Chemical and biological changes in compost of wood shavings, sawdust and peat moss. Can. J. Soil. Sci. 71, 475–484.

Nigro, D., 2007. Green revolutionaries: west coast winegrowers fight to save the environment. Wine Spectator 32 (5), 59–69.

Paredez, C., Bernal, M.P., Cegarra, J., Roig, A., 2002. Biodegradation of olive mill wastewater sludge by its co-composting with agricultural wastes. Bioresour. Technol. 58, 1–8.

Razvi, A.S., Kramer, D.W., 1996. Evaluation of compost activators for composting grass clippings. Compost Sci. Util. 4, 72–80.

Reeve, J.R., Carpenter-Boggs, L., Reganold, J.P., York, A.L., McGourty, G., McCloskey, L.P., 2005. Soil and winegrape quality in biodynamically and organically managed vineyards. Am. J. Enol. Viticult. 56, 367–376.

del Rosal, E., Benítez, I.C., Millán, M.C., González, J.L., Medina, M., 1995. Changes in the organic fractions of composting azotobacter-inoculated grape marc. Acta Hort. 388, 117–122.

Samaras, I., 1978. Nachenrntenverhalten unterschiedlich gedüngter Gemüsearten. Ph.D dissertation, University of Gießen, Germany.

Scheuerell, S., Mahafee, W., 2004. Compost tea as a container medium drench for suppressing seedling damping-off caused by *Pythium ultimum*. Phytopathology 94, 1156–1163.

Sikora, L.J., Enkiri, N.K., 1999. Growth of tall fescue in compost/fertilizer blends. Soil Sci. 164, 62–69.

Spiess, H., 1978. Konventionelle und biologisch-dynamischen Verfahren zur Steigerung der Bodenfruchtbarkeit. Ph.D dissertation, University of Gießen, Germany.

Stearn, W.C., 1976. Effectiveness of Two Biodynamic Preparations on Higher Plants and Possible Mechanisms for the Observed Response. M.S. Thesis, Ohio State Univ., Columbus, OH.

Steiner, R., 1993. Agriculture: Spiritual Foundations for the Renewal of Agriculture. Anthroposophic Press, Hudson, New York.

Tabatabai, M.A., 1994. Soil enzymes. In: Weaver, R.W., Angle, J.S., Bottomley, P.S. (Eds.), Methods of Soil Analysis. Part 2. Microbiological and Biochemical Properties. Soil Science Society of America, Madison, Wisconsin, pp. 775–834.

Tiquia, S.M., Wan, J.H.C., Tam, N.F.Y., 2002. Dynamics of yard trimmings composting as determined by dehydrogenase activity, ATP content, argenine ammonification and nitrification potential. Process Biochem. 37, 1057–1065.

TMECC, 2002. Test Methods for Examination of Composting and Compost. U.S Composting Council, Hauppauge, NY.

Turco, R.F., 1994. Coliform bacteria. In: Weaver, R.W., Angle, J.S., Bottomley, P.S. (Eds.), Methods of Soil Analysis. Part 2. Microbiological and Biochemical Properties. Soil Science Society of America, Madison, pp. 145–158.

von Wistinghausen, E., 1986. Phosphatverfügbarkeit im Boden und Stallmist und ihre Beeinflussung durch biologisch-dynamische Massnahmen. Verlag Lebendige Erde, Darmstadt, Germany.

Walker, L., 2003. Biodynamics are horning in. Wines and Vines 84, 16–21.

Zhang, X., Ervin, E.H., Schmidt, R.E., 2003. Physiological effects of liquid applications of a seaweed extract and a humic acid on creeping bentgrass. J. Am. Soc. Hort. Sci. 128, 492–496.