Research Article

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# Biodynamic preparations, greater root growth and health, stress resistance, and soil organic matter increases are linked

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**Abstract:** The effects of biodynamic preparations were tested in the context of comparisons of conventional, organic, and biodynamic systems and diverse crop rotations in Washington and Wisconsin, USA. Wisconsin research also entailed testing a new nettle-and-manure-based field spray preparation (NCP). Focus was on winter wheat and maize and on soil quality. In Washington, preparations increased root growth of winter wheat, microbial biomass, and soil organic matter. In Wisconsin, applying a combination of preparations that included NCP increased root growth of maize, root health, and particulate organic matter in the soil. Relative to the organic treatments, root dry matter increases associated with the use of preparations varied from 12% to 39% and root length differences varied from 10% to 37% depending on the experiment, crop, year, and preparation application. The biodynamic + NCP treatment also induced substantial, positive yield compensatory effects for maize and wheat under stress condition years. The response slopes were practically identical for wheat and maize, indicating that the effect is of the same magnitude for both crops. Results were higher average grain yields and gross financial returns than for organic grain. The greater root production and root health stimulated by preparations is probably linked to greater vegetative growth, enhanced yield under stress conditions, and increased soil quality and carbon in soils.

**Keywords:** biodynamic preparations, roots, stress resistance, carbon retention, particulate organic matter

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## 1 Introduction

In 1924, Rudolf Steiner proposed that farmers should make a set of special preparations from herbs and manure. Since that time these preparations have been used by biodynamic farmers around the world and have found by practitioners to be useful (Koepf et al. 1976; Koepf et al. 1989). Six herbal preparations were intended to treat compost and manure; three sprays (horn manure, horn silica, and Equisetum) are used for directly treating soils and plants. These materials are specially fermented with the intention of concentrating living forces. The working principle is to stimulate life and health in manures, soils, and crops and thereby to produce food products with the highest quality.

Understanding how the preparations work and what they do has been elusive and controversial, in part because they are purported to utilize and strengthen life forces. The principles from which they are derived come from Rudolf Steiner's insights and experiences, and represent a different paradigm than our present, materially-based scientific culture (Steiner 1993; Koepf et al. 1976; Koepf et al. 1989). In Steiner's lectures on agriculture, cosmic forces are described as interacting with physical forces and substances on the Earth to support and give direction to life on the Earth. Organisms are reputed to have life bodies that enable development, growth, and reproduction, health, and integrity. After Steiner's time, picture forming methods were developed to demonstrate the impact and quality of life forces by testing the effects of extracts of plant tissues on crystallization of copper chloride. To summarize an extensive literature (see Anonymous 2019), extracts from healthy, ripe plant products produce more organized crystal patterns than extracts from unripe or decaying products; extracts from biodynamically-grown products produced more organized crystal patterns than from organically or conventionally grown products.

Also, empirical results from field research have been forthcoming. Turinek et al. (2009) reviewed the scientific literature and found supportive evidence that biodynamic preparations influence soil and crop biology in beneficial ways including by increasing yields, soil biological activity, and soil organic matter. Long term research trials in Sweden (Kjellenberg et al. 2005), Germany (Raupp and Oltmanns 2006), and Switzerland (Fliessbach and Mader 2000; Maeder et al. 2002; Fliessbach et al. 2007) showed that the biodynamic method increases soil organic matter-carbon and soil biological activity. Furthermore, Spiess (1978) found that multiple applications of biodynamic spray preparations increased yields of field crops.

Based on several European trials, Raupp and Koenig (1996) suggested that preparations can lead to compensatory plant growth and yield under sub-optimal conditions. Bachinger (1996) found that biodynamic preparations increased root growth in winter rye.

At question is how such preparations can affect crops and soils as they are applied in relatively small quantities. Stearn (1976) detected high levels of cytokinins in biodynamic field sprays horn manure and horn silica. He found that application of these substances stimulated growth of roots and shoots of maize and soybeans seedlings. A bioassay with wheat seedlings tested effects of biodynamic preparations (Goldstein and Koepf 1982). Results showed stimulatory effects of herbal preparations on root growth that mimicked different nutrient responses and compensated for deficiencies. Fritz and Koepke (2005) described effects of the horn silica spray on bush beans similar to the effects of gibberellins. Goldstein (1979) reviewed research on the preparations related to hormonal effects and Fritz (2013) discussed parallels between hormonal regulation of plants and the use of biodynamic preparations.

A key linking factor that may explain diverse results is that biodynamic preparations affect crop growth, crop yields, and soil organic matter by stimulating root production and root health. In this paper, we utilize information from two field experiments carried out by the author. Results of these trials do not prove but rather provide supporting evidence for the tenability of this hypothesis. Though the data is from older experiments, it was not previously published in a refereed journal, and it provides valuable information on the effects of biodynamic methods that is pertinent to resolving looming problems with carbon retention and global warming.

In the first experiment, carried out in Washington State, USA, biodynamic preparations were tested in the context of different crop rotations (Goldstein, 1986). In the second experiment, carried out in Wisconsin, USA, biodynamic and organic systems were compared in the context of testing a new biodynamic compound preparation. Biodynamic compound preparations are made from small, covered cow manure piles which are inoculated with relatively large quantities of biodynamic herbal preparations and allowed to compost. These compound preparations are used by biodynamic farmers both as compost starter inoculants and also as field sprays. Compound preparations utilize the herbal preparations invented by Rudolf Steiner, the originator of the Biodynamic movement. However, the production and use of compound preparations was introduced not by Rudolf Steiner, but first by biodynamic farmer M.K. Schwartz (birch pit preparation), and then by other researchers and practitioners (Koenig 2019). Published scientific literature on field research done to test their efficacy is apparently not available (Koenig 2019). The Wisconsin research compared various formulations of compound preparations that are presently in use. This included the Pfeiffer starter/field spray (developed by Ehrenfried Pfeiffer), Barrel Compost (Maria Thun), Super-500 (Australian farmers) as well as a new nettle-and-manure-based compound preparation developed by Herbert Koepf and Walter Goldstein.

The nettle and manure compound preparation proved early on to be the most effective compound preparation for increasing grain yields in the Wisconsin field trials. Therefore, we confined our root studies of field-grown plants only to a subset of treatments. These were the conventional, organic, biodynamic without compound preparations, and biodynamic with the nettle compound preparation treatments.

In this paper analyses focus mainly on the most relevant results from trials with the growth, roots, and yields of winter wheat in Washington, and maize and wheat in Wisconsin.

# 2 Methods

## 2.1 Washington State

A field experiment compared conventional, organic and biodynamic management between 1982 and 1985 in a dryland (average ca. 500 mm precipitation/year) winter wheat, pea, and barley cropping region near Pullman, Washington (Goldstein 1986). The experiment was carried out on an eroded hilltop on the Spillman Farm site (C content = 1.24%) which had been in cereal cropping for seven years. A preceding crop of spring barley was grown in 1981. The soil was a Palouse silt loam (mollisol), which, for cereal production is generally considered to be highly responsive to fertilization with mineral N but not to P or K. Eight rotational sequences were tested for agronomic performance; these were:

1. Winter wheat-spring barley-winter wheat (W-B-W),
2. Spring barley-pea-winter wheat (B-PE-W),
3. Spring barley-lupin-winter wheat (B-LU-W),
4. Spring barley-chickpea-winter wheat (B-CP-W),
5. Ley-lupin-winter wheat (L-LU-WW),
6. Ley-chickpea-winter wheat (L-CP-WW).
7. Lupin-ley-winter wheat (LU-L-WW),
8. Chickpea-ley-winter wheat (CP-L-WW).

Pulse crops were harvested for grain in 1983 but in 1984 the biologically managed pulses were plowed under in mid-July because they were very weedy, while the conventionally managed pulses were harvested for seed. The ley consisted of a mix of annual barrel medic 'Jemalong' and annual sweet clover 'Hubam' seeded in mid-April at 11 kg of seed/ha for each species. The ley seed was broadcast, harrowed, and packed with a roller harrow. All other crops were seeded with a drill. White lupin cultivar 'Astra' was seeded in 1983 and 'Kiev Mutant' was seeded in 1984; both in mid-April at a seeding rate of 66 plants/$m^2$. Winter wheat 'Daws' was seeded on October 20, 1982 an October 19$^{th}$, 1984 at 78 kg seed/ha. Spring barley 'Advance', chickpea 'PI 273879', and pea 'Alaska' were seeded in mid-April at 67, 168, and 224 kg of seed/ha, respectively. None of the seed that was purchased for use in this experiment had been organically grown, and to our knowledge the varieties were all developed under conventional farming conditions. All legumes were inoculated with appropriate rhizobia before planting obtained from the Nitragin Co., Milwaukee, WI.

Conventional weed control used herbicides on all crops and different rates of mineral fertilizers were applied to cereals. Conventionally managed cereals were sprayed with a tank mix of Bromoxynil at 0.44 kg a.i./ha for broadleaf control and difenzoquat at 0.59 kg a.i./ha for wild oat control. Before planting the conventional pulses and ley crops the soil was sprayed with a tank mix of Triflualin at 0.56 kg a.i./ha for broadleaf control and Triallate at 1.4 kg a.i./ha for wild at control, and the chemicals were incorporated with a light harrowing. Post-emergence harrowing with a spike-tooth harrow or rotary hoe was used in pulse and cereal crops which were managed organically and biodynamically. Leys were mowed twice to control weeds.

The W-B-W and B-PE-W rotations were split to contain side-by-side, unfertilized (rate 0) and fertilized (rate 2x) conventional plots and side-by-side, fertilized (rate 2x) organic and biodynamic plots. The B-LU-W and B-CP-W rotations were split to contain conventional, organic and biodynamic plots, and the subplots were split again to form four sub-subplots which received four rates of fertilization (0, 1x, 2x, 3x). Fertilization was applied before growing barley in 1983 and the same relative levels were applied again to the same sub-subplots before growing winter wheat in the fall of 1984. The L-LU-W, L-CP-W, LU-L-W, CP-L-W rotations were split to contain conventional and biodynamic plots and the subplots were split again to form four sub-subplots which received four rates of fertilization before wheat as above. Plot size for individual cereal plots tested was 2.44 x 6.1 meters. The wheat after ley crops grew poorly, probably because it was planted a week after incorporation of the ley crop and there were difficulties in stand establishment. Therefore, data of those rotations was not included in the analyses.

Manure for the biological plots was obtained from the Washington State University dairy farm in May of 1982 (lot 1) and in May of 1984 (lot 2). When manure was obtained it was mixed with a front end loader and then loaded into spreader trucks. Piles were unloaded from trucks into four roughly equal piles and subsequently shaped into four compost piles of similar shape using a front end loader. Biodynamic herbal preparations were inserted into every other pile (Koepf 1976; Koepf et al. 1986). The first lot of composted manure was used for biologically managed crops in 1982, 1983, and in the spring of 1984. The second lot was applied only to winter wheat in the fall of 1984. Samples were taken from compost piles in April of 1983 for the first lot of compost and in September of 1984 for the second lot. Eight samples were taken per compost pile with a shovel from the central area of the pile, and samples were bulked for each management system. Compost samples were analyzed for C, N, and P content. The 1983 samples were tested for degree of humification according to the method of Schlichting and Blume (1960). Biodynamic field sprays horn manure (500) and horn silica (501) were applied once each year to crops in accordance with Koepf et al. (1976). All biodynamic preparations were obtained from Josephine Porter (Stroudsburg, PA).

Different rates of fertilization were applied to cereals with the strategy being to apply similar amounts of total N to all three management systems. For winter wheat grown in the W-B-W rotation in 1982/1983, the conventional, fertilized treatment was fertilized with 112 kg N and 46 kg P/ha of mineral fertilizer; the organic and biodynamic treatments were fertilized with 22.4 t compost/ha. In 1983, conventional pulse and ley plots were fertilized with 28 kg N/ha and 12 kg P/ha as soluble, mineral fertilizer (ammonium nitrate and superphosphate), while biological plots were fertilized with 3.8 t of compost/ha (provided ca. 28 kg N and 9 kg P/ha). In 1983, the 0, 1x, 2x, and 3x rates applied to conventional barley corresponded to 0, 45, 90, and 135 kg N/ha, respectively. The 0, 1x, 2x and 3x rates of compost applied to 1983 grown barley corresponded to 0, 7.6, 15.3, and 22.9 t of compost/ha, respectively. In the fall of 1984, the 0, 1x, 2x, and 3x rates of fertilizer applied to conventionally grown wheat contained 0, 56, 112, and 168 kg of N/ha and no P was added. The 0x, 1x, 2x, and 3x rates applied to biologically grown wheat, corresponded to 0, 4.1, 8.2, and 12.3 t of compost/ha.

In 1985, winter wheat plots in the W-B-W, B-PE-W, and B-CP-W rotations were sampled at the jointing stage for numbers of tillers/plant, shoot dry matter, adventitious roots/plant, and root dry matter and total root length in the top 15 cm of soil. Three random samples, of apparent single plants, were taken per plot. Root samples were taken by driving a cylindrical, 15cm long, 8 cm diameter steel tube down over the wheat crown after the tillers had been counted and removed. Roots were washed and length was determined using the root intersect method (Newman 1966). Roots and shoots were dried in a force-air chamber at 60°C. Soil samples were taken from selected treatments in mid-April, 1985 to a depth of 15 cm. Microbial biomass and microbial respiration were determined on these samples according to Anderson and Domsch (1978). Total soil C and N were determined using a Leco Analyzer (Leco Corp, St. Joseph, MI).

To avoid any subconscious bias in obtaining data, almost all samplings, measurements, and analyses were carried out by persons who did not understand the meaning of the experiment, and samples and plots were coded.

The 1984/1985 year of winter what was the most important year since it would show the accumulated effects of three years of management systems. Very detailed research focused on a subset of the treatments. Conventional, organic, and biodynamic management were compared for 1) characteristics of fertilized (rate 2x) plants for all three systems and unfertilized plants for the conventional system at the jointing stage taken from the W-B-W, B-PE-W, and B-LU-W rotations; 2). Yield components and grain yields for fertilized (2x) and unfertilized (0x) conventional wheat and fertilized (2x) organic and biodynamic wheat in the B-LU-W, B-PE-W, B-CP-W, and W-B-W rotations; 3) yield components and grain yields of wheat for all four fertilization systems in the B-LU-W and B-CP-W rotations; 4) soil characteristics for unfertilized and fertilized (2x) conventional plots and fertilized (2x organic and biodynamic treatments in the W-B-W, B-PE-W, B-LU-W, and B-CP-W rotations, and 5) soil characteristics for fertilized (2x) and unfertilized plots from all management systems for the B-LU-W and B-CP-W rotations. Grain plots were harvested with a combine and yield was determined at 12% moisture.

Due to the complex nature of the experimental design, a number of separate analyses of variance with contrasts between treatments were utilized to obtain as much information as possible using SAS statistical Packages (SAS, Inc. Cary, NC).

## 2.2 Wisconsin Study

An experiment was carried out for 6 years near Elkhorn, Wisconsin in a precipitation zone of approximately 720 mm/annum. The experiment took place on the senior author's farm on an eroded hillside in a McHenry silt loam (alfisol) that had been in continuous, conventional maize production but was being converted to biodynamic/ organic production. In 1993 a crop of oats and alfalfa was harvested in a checkerboard grid laid out across likely sites on the farm. The site was identified as the most uniform site on the farm for the trial, and test plots for conventional, organic, and biodynamic systems were set out in 1994 on uniform, equally yielding parcels of soil in a randomized, complete block design with 4 replications. Average soil characteristics for pH, % organic matter, available P and K were 6.9, 2.43%, 18.5 ppm, and 110 ppm, respectively.

The experiment was set out as a six year rotation with each crop being grown each year. The rotation of the organic and biodynamic plots was maize, oats, sweet-clover, wheat, alfalfa + grass hay, alfalfa + grass hay. The rotation for the conventional plots was maize rotated with soybeans. Conventional management received annual applications of mineral fertilizer to corn (mostly 169-112-112 kg of N, P, and K per hectare). Manure compost was prepared from sheep manure produced by sheep on the farm. Each year in September two replicate piles with sheep manure and bedding of approximately the same size were constructed for the organic and various biodynamic treatments on a concrete pad. There were two piles that served the biodynamic check, the Barrel Compost, Prepared 500, NCP biodynamic treatments. These piles received biodynamic herbal preparations in accordance with Koepf et al. (1976). Two other piles were sprayed while being constructed with the Pfeiffer starter according to instructions included with the material. Following a composting, in the spring, before producing maize, 22 t/ha of composted sheep manure was applied to the organic and biodynamic plots from the appropriate piles. This application rate contained total N approximately equal to the 169 kg N/ha rate applied to the conventional treatment.

Maize was seeded at 76,200 seeds/ha and row spacing was 75 cm between rows. The maize cultivar used 'Golden Eagle' was developed at Michael Fields Agricultural Institute by inter-mating native American maize cultivars and Corn Belt dent cultivars and selecting them for agronomic and quality traits in a half-sib breeding program under biodynamic/organic conditions. Soybeans (Asgrow 900) were seeded at 66 kg/ha at a row spacing of 75 cm between rows. Biennial sweet-clover cultivar N29 was seeded together with oats at a rate of 128 kg/ha oats and 22 kg sweet-clover/ha. Winter wheat was seeded in the fall and alfalfa plus grass were over-seeded in the spring at 22 kg/ha of alfalfa and 22 kg/ha of orchard grass. The winter wheat cultivars used were Zarya and Glacier, and they were seeded in side by side subplots on 15 cm row spacing at seeding rates of 101 kg/ha. Zarya was developed at the Nemchinovka breeding station near Moscow, and Glacier was developed at the University of Wisconsin-Madison, both were bred under conventional farming conditions. Both cultivars were grown under biodynamic/organic conditions for one to several years before being included in the trial. Grain plots were combined with a plot combine and yields were determined at 15.5% moisture for maize and 12% moisture for wheat.

Tillage utilized disking, harrowing, rototilling, mechanical spading, and plowing for alfalfa and grass. Mechanical cultivation with inter-row cultivator, hand weeding or mowing controlled weeds in all systems and herbicides were not used in any of the systems.

The biodynamic plots were partitioned into subplots and five different biodynamic treatments were compared. This included a check with no compound preparations. In addition there were four treatments that also included compound preparations. Plots were approximately 4 m x 7 m in size for the organic and conventional and 4 m x 3.5 m for the biodynamic subplots. The biodynamic check treatment (BD) differed from the organic only by receiving biodynamic preparations according to normal practice and rates (Koepf et al. 1989). This entailed application of biodynamic herbal preparations to compost piles and application of horn manure and horn silica to soils and crops, respectively.

The four other biodynamic treatments were Barrel Compost, Nettle Compound Preparation (designated as BD+ or BD+NCP), Prepared 500, and Pfeiffer starter/field spray. These compound preparations were applied twice to each crop. The Thun barrel compost, the prepared 500 and the Pfeiffer field spray were all obtained from the Josephine Porter Institute, Woolwine, VA, and applied according to instruction. All treatments received a single application with horn silica. All treatments received herbal preparations in manure except the Pfeiffer starter/field spray where the manure received the Pfeiffer starter which contains herbal preparations. The barrel compost and NCP treatment were both mixed with horn manure for their first field spray and then applied alone for a second spray. The prepared 500 treatment (which is made by preparing horn manure with herbal preparations) was applied twice and normal horn manure was not applied. Mixing of preparations took place in a special, multiple barreled, stirring machine that could stir portions at the same time. Mixing consisted in creating reciprocating vortices (Koepf et al. 1989) for one hour when compound preparations were mixed with horn manure and for 15 minutes when applied alone.

The BD+NCP treatment was the same as the BD treatment except that it received two extra applications of a compound preparation field spray made from a fermented mix of cow manure, stinging nettle (*Urtica dioica* L.) and the biodynamic herbal preparations. For the BD+NCP treatment, 1.12 kg/ha of the NCP was mixed for one hour with normal rates of horn manure for the first spray or mixed for 15 minutes and applied alone for the second spray.

Preliminary evidence for the efficacy of nettle in the compound preparation mixture was first established by Herbert Koepf in wheat bioassays with treated manure that were conducted at the Biochemical Research Lab, in Spring Valley in the early 1970's (Koepf, unpublished data). In his lecture course in 1924 that founded the biodynamic movement, Rudolf Steiner (1993) repeatedly indicated the importance of nettle for treating manure, including that it was the only one of the six herbs used in preparing manure that could not be replaced by another plant. The actual formula for this preparation was developed at Michael Fields Agricultural Institute in laboratory trials by Walter Goldstein prior to the establishment of the Wisconsin Experiment. It was based on results with bioassays conducted with wheat seedlings grown in tap water and nutrient solutions with or without compound preparation extracts in accordance with Goldstein and Koepf (1982). In these laboratory trials, the nettle containing preparation, which contains manure, nettle, and herbal preparations showed greater growth stimulating and regulating effects than compound preparation made only with manure and herbal preparations or the barrel compost formulation made from cow manure, basalt and herbal preparations (Goldstein, unpublished data).

The nettle compound preparation was made in Wisconsin by mixing together and co-composting 40 kg of fresh cow manure and 1% by weight of nettle. The nettle was harvested when in flower and chopped to 2.5 centimeter long pieces. Following mixing, one set of biodynamic preparations (yarrow (*Achillea millefolium* L.), chamomile (*Matricaria chamomilla* L), stinging nettle (*Urtica dioica* L.), oak bark (*Quercus robur* L.), dandelion (*Taraxacum officinale* L.), and valerian (*Valeriana officinalis l.*)) were applied to the pile in the standard way. The mixture was allowed to compost in a wooden box inserted into the top 30 centimeters of a loamy topsoil with a loose fitting cover for at least ½ year before being used, and was remade periodically through the experiment.

Of all the treatments used in the study, root growth was examined on only four treatments (conventional, organic, the biodynamic check which did not receive compound preparations (BD), and the treatment that included the new nettle-containing biodynamic compound preparation (abbreviated in diagrams below as BD+ or BD+NCP). Root monoliths were excavated around the crown of three plants from each plot, three-times (June, July, and August) in 1998 and twice (July and August) in 1999. A metal box that was 46 cm long, 15 cm wide, and 15 cm deep was driven into the ground to a depth of 15 cm and a sample representative of the rooting distance from row to mid row was cut out from this and extracted. Root length and necrosis were determined on individual nodes of washed roots using the line intersect method (Goldstein, 2000) or ‘WinRhizo’ computerized measuring system (Regent Instruments, Quebec City, Canada), and roots were oven dried. Data from samplings for individual root nodes were summed (Goldstein 2000) to estimate root length and dry matter production. Root length was measured by WinRhizo in different diameter classes. In 1998 samples of roots excavated to 15cm, stover (stalks, tassels, leaves), and grain were harvested, dried, and weighed at harvest to determine dry matter partitioning.

In September of 1996, replicated soil samples to a depth of 20 cm were taken from plots in all phases of the organic, biodynamic, and conventional treatments including each of the different biodynamic variants. Dry aggregate size distribution was determined in accordance with Kemper and Rosenau (1986). Particulate organic matter (POM) was determined according to Cambardella and Elliot (1992) from all phases of the conventional, organic, and biodynamic + NCP systems. We chose to measure these parameters because aggregate size distribution should affect root growth and particulate organic matter should be affected by root deposition and turnover.

Results were analyzed using regression and analysis of variance tools available from Statistical Analysis Systems, Cary, N. Carolina. The four treatments were compared using contrasts.

**Ethical approval:** The conducted research is not related to either human or animal use.

# 3 Results

## 3.1 Washington Experiment

Compost and fertilization rates: The 1983 biodynamic compost had slightly higher dry matter and N contents than the organic compost. Thus the 1x rate applied to barley in the spring included 56 kg of N/ha for the biodynamic and 49 kg N/ha for the organic. With the second lot of compost in 1984, the biodynamic compost had lower dry matter but again higher N content than the organic compost. Therefore, the 1x rate of biodynamic compost added to winter wheat provided 75 kg N/ha, while the organic compost provided 68 kg N/ha. Levels of P added by both composts on both years were very similar. When the 1983 compost was tested for humification using the ratio of absorption at 472 to 664 nanometers, the biodynamic compost appeared considerably less humified than the organic compost (ratio 8.96 ± 0.65 and 6.86 ± 0.11, respectively). Furthermore, on both years, when spread, the biodynamic compost often appeared a darker color, but also less mineralized than the organic compost. For the second lot of compost, which had less bedding and more manure than the first lot, the biodynamic compost had a stronger ammonia-like smell when spread than the organic compost.

Wheat shoot and root characteristics at jointing: Wheat plants from unfertilized and fertilized (112 kg N/ha) conventional plots and from fertilized (9.2 t compost/ha) organic and biodynamic plots were examined at the jointing stage. Management affected shoot weights and tillers/plant at p = 0.1%, total root length at p = 1%, and adventitious roots/plant a p = 5%. The two biologically managed treatments produced more shoot dry matter (p = 0.1%), tillers/plant (p = 0.1%), adventitious roots/plant (p = 1%), and total root length (p = 1%) than the unfertilized, conventionally managed treatment. Biological management also produced more shoot matter (p = 0.1%), tillers/plant (p = 1%), adventitious roots (p = 5%) and total root length (p = 5%) than the fertilized, conventionally managed treatment. The biodynamically treated plots produced 15% more (p = 6%) tillers/plant, 13% greater root weight (NS), 9% more adventitious roots (NS), and 18% more (p = 5%) total root length than the organic plots. Though the fertilized, conventionally managed wheat generally produced higher values for parameters than the unfertilized wheat, the differences were not significant at p = 10%.

**Table 1:** Effects of management on wheat characteristics at jointing in 1985

| Management | Fertilization rate | Shoot weight | Root weight | Tillers/plant | adventitious roots/plant | total root length |
|---|---|---|---|---|---|---|
| | | g | g/cm³ | no. | no. | cm/cm³ |
| Biodynamic | 2x | 17.4 | 1.11 | 9.4 | 37.6 | 1.44 |
| Organic | 2x | 17.2 | 0.98 | 8.2 | 34.4 | 1.22 |
| Conventional | 0 | 10.8 | 0.94 | 6.7 | 30.0 | 1.01 |
| Conventional | 2x | 12.8 | 0.98 | 7.2 | 31.6 | 1.09 |
| LSD 5% | | 2.8 | n.s. | 1.2 | 4.8 | 0.21 |

## 3.2 Wheat yield components

The biologically managed wheat produced more (p = 0.1%) spikes and spikelets/m2 and higher (p = 1%) weight/seed than the conventionally managed wheat which was either fertilized or unfertilized. Wheat which had been managed biologically also out-yielded the fertilized (p = 5%) or unfertilized (p = 1%) wheat which was grown conventionally. The biodynamically grown wheat produced approximately 10% more (p = 5%) spikes than the organically grown wheat (194 and 176 spikes/m2, respectively) and approximately 11% more (p = 5%) spikelets (2807 and 2537 spikelets/m2, respectively). However the biodynamically grown wheat produced 29% less (p = 5%) seeds/spikelet than the organically grown wheat (1.7 and 2.38 seeds/spikelet, respectively). Yields for the organic and biodynamic treatments did not differ at p = 10%. Inspection of a significant (p = 0,1%) interaction between rotations and management for spikelets/m2 showed that the largest positive differences between biodynamic and organic management were when wheat followed peas (704 spikelets/m2) or lupins (254 spikelets/m2), and the smallest differences were when wheat followed chickpeas (68 spikelets/m2) or barley (51 spikelets/m2). Somewhat similar trends were found with spikelets/m2 and grain yields.

The same kind of results with yield components and final grain yield were shown when all three systems were compared in the context of two rotations (B-LU-W and B-CP-W) and four fertilization rates (Goldstein 1986). Wheat which was managed biodynamically vs. organically had 7% higher (p = 5%) respective numbers of spikes/m2 (222 vs. 207), and 11% more spikelets/m2 (3,296 vs. 2,972). The biodynamic, organic and conventional wheat produced 1.94, 2.08, and 1.57 seeds/spikelet, respectively. The organically grown wheat tended (not significant at p = 5%) to produce more seeds/spikelet and higher weight/seed than the biodynamically grown wheat. The grain yields for the biodynamic, organic, and conventional wheat were 2.28, 2.36, and 1.31 t/ha, respectively. Though the two biological systems out-yielded the conventional system, grain yields between the biodynamic and organic systems were not different at p = 10%. Fertilization significantly affected spikes/$m^2$ (p = 1%), spikelets/$m^2$ (p = 0.1%) spikelets/$m^2$ (p = 0.1%), and weight/seed (p = 0.1%), and management x fertilization effects were significant for all of these characteristics at p = 5%. Wheat which followed lupins produced more spikes and spikelets than wheat after chickpeas, but seed weighed less and grain yields did not differ.

Increasing fertilization with mineral fertilizer for the conventional wheat caused a linear (p = 1%) increase in the numbers of spikes and spikelets/$m^2$ and linear decreases of weight/seed. Increasing fertilization with compost caused a linear (p = 1%) increase in the numbers of spikelets/$m^2$ for the biodynamically managed wheat. The weight/seed of biodynamically fertilized wheat responded quadratically (p = 1%) with an initial increase followed by a decrease in weight. Fertilization of the biodynamic plots with 12.3 t of compost increased the numbers of spikes/$m^2$. The addition of compost to the organic plots did not significantly (p = 5%) influence any wheat characteristics, nor cause linear or quadratic responses at p = 10%.

Effects on soil characteristics: Soil results for the W-B-W, B-P-W, B-LU-W, and B-CP-W rotations are shown in Table 2. Management affected respiration, biomass, and percentage C at p = 0.1% and affected percent N at p = 5% (Table 2). The biologically managed soils had higher N contents (p = 5%), respired more (p = 0.1%), and possessed more microbial biomass (p = 0.1%) than soils from the conventional plots which were either fertilized or not fertilized. Soil which was managed biodynamically had 7% higher microbial biomass (p = 1%) than for organic management. The management x rotation interaction for respiration (p = 5%) and for microbial biomass (p = 0.1%) showed that for the biological management systems the highest values occurred for the W-B-W rotation which had received two doses of manure during the trial.

The same parameters were measured for the B-LU-W and B-CP-W rotations for all management systems which were either fertilized at the 2 x rate or unfertilized. This comparison allowed us to better examine effects of fertilization. Direct effects of management affected only respiration (p = 5%) and the biologically managed soils respired more (p = 0.1%) than soils from the conventional system (0.40 and 0.33 μg CO2-C/g soil/hour, respectively). However, there were interactions between management and fertilization that were significant at p = 5% for respiration and biomass and at p = 6% for percentage C (Table 3). The use of lupins and chickpeas as green manures in biological management did not increase respiration or biomass versus combining the legumes in conventional management. However, application of compost caused biologically managed soils to respire more and to have more microbial biomass than the conventional soils. When compost was applied it caused biodynamic plots to have higher microbial biomass than the organically managed plots. Soils from the organic plots had higher percentage of C than the biodynamic and conventional plots under unfertilized conditions, but under fertilized conditions the percent C was highest for the biodynamic (1.63%), lowest for the conventional (1.41%) and intermediate for the organic (1.57%). Fertilization with compost in the organic system did not affect C content but significantly increased respiration (17%) and microbial biomass (9%). However biodynamic prepared compost had much stronger effects on soil by increasing soil C (12%), respiration (28%), and microbial biomass (19%), differences which were all statistically significant.

# 4 Results

## 4.1 Wisconsin Study.

Five years of data are available for wheat (1995-1999) and maize (1994-1998). In 1999, the maize crop was unfortunately damaged badly by deer before harvest and yield data was not used. From 1995 to 1998, if winter wheat grain yields are expressed relative to the biodynamic + NCP treatment, other yields were 10% lower for the organic, 6% lower for the biodynamic check treatment without compound preparations, 5% lower for the biodynamic with barrel compost, 1% lower for the biodynamic with prepared 500, and 2% lower for the biodynamic with barrel compost, 1% lower for the biodynamic with prepared 500, and 2% lower for the biodynamic with Pfeiffer preparations. From 1994 to 1998, corn yields relative to the

**Table 2:** Effects of management on soil characteristics in 1985 over the

**W-B-W, B-P-W, B-LU-W, and B-CP-W rotations**

| Management | Fertilization rate | C | N | CO2 respiration | Microbial Biomass |
|---|---|---|---|---|---|
| | | % | % | μg CO2-C/g soil/hour | μg C/g soil |
| Biodynamic | 2x | 1.6 | 0.149 | 0.49 | 602 |
| Organic | 2x | 1.57 | 0.144 | 0.46 | 564 |
| Conventional | 0 | 1.42 | 0.129 | 0.34 | 471 |
| Conventional | 2x | 1.42 | 0.126 | 0.33 | 484 |
| LSD 5% | | 0.08 | 0.018 | 0.04 | 29 |

**Table 3:** Effects of management on soil characteristics in 1985 averaged over the B-LU-W, and B-CP-W rotations at the 0 and 2x fertilization rates

| Management | C % | | CO2 respiration μg CO2-C/g soil/hour | | Microbial Biomass μg C/g soil | |
|---|---|---|---|---|---|---|
| | Rate 0 | Rate 2x | Rate 0 | Rate 2x | Rate 0 | Rate 2x |
| Biodynamic | 1.46 | 1.63 | 0.36 | 0.46 | 472 | 560 |
| Organic | 1.57 | 1.57 | 0.36 | 0.42 | 482 | 526 |
| Conventional | 1.42 | 1.41 | 0.33 | 0.34 | 477 | 495 |
| LSD 5% | 0.07 | | 0.04 | | 30 | |

NCP treatment were 7% lower for the organic, 6% lower for the biodynamic without compound preparations, 7% lower both for the biodynamic +barrel compost and the biodynamic with prepared 500 and 4% lower for the biodynamic with Pfeiffer preparations. Aside from the +NCP treatment the other compound preparations rarely showed statistically significant effects on grain yields relative to the checks.

Yield of Wheat: The BD+NCP system resulted in 337 to 607 kg /ha more grain than did the organic system. The differences in % yield between the BD+NCP treatment and the organic treatment were 9% in 1995, 23% in 1996, 5% in 1997, 11% in 1998, and 21% in 1999 (see Figure 1). In three years the differences were significant at p = 5%. In 1998 the biodynamic check treatment significantly out-yielded the organic.

Regression analysis shows a significant negative relationship between the yield of the organic treatment and the effect of the biodynamic treatment (Figure 2).

Yield of Maize*:* Five years of trials showed average yields of 5.58, 6.71, 6.77, and 7.15 t/ha of grain for the conventional, organic, BD, and BD+NCP treatments, respectively (Figure 3). The conventional yielded the lowest in 1994 and 1995. Organic yielded lower than

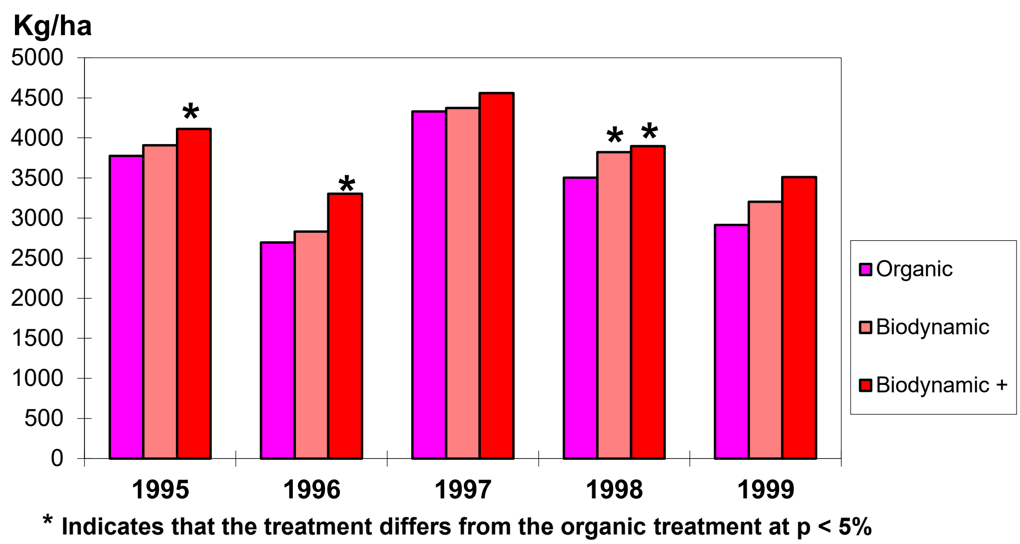


**Figure 1:** Grain yields of winter wheat as affected by different farming systems (Elkhorn, 1995-1999)

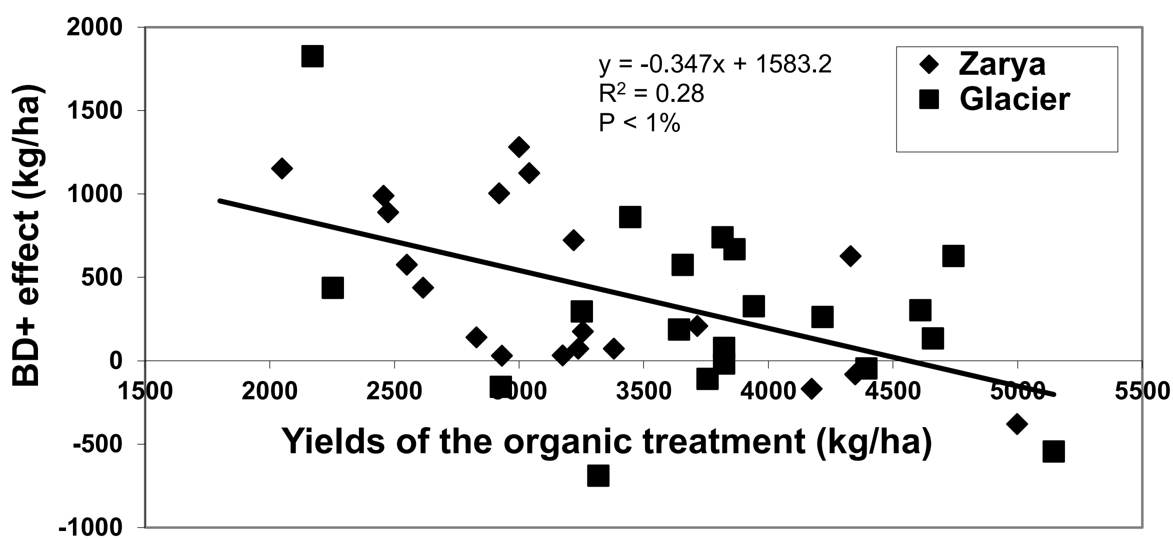


**Figure 2:** The effects of the BD+ treatment on the yields of winter wheat relative to the organic treatment (1995-1999)

BD+NCP in 1994 (p = 5%) and in 1995 (p = 10%). Yields from the conventional plots lagged behind the organic and biodynamic plots throughout the experiment. The biodynamic check generally yielded intermediate to the organic and the BD+NCP systems.

As had been the case with wheat, the largest differences between organic and BD+NCP treatments occurred in those years where yields were low (Figure 4). For maize these happened to be the first two years of the conversion period. When the organic plots yielded below 7.78 t//ha, the BD+NCP treatment had a positive effect on maize yields. A negative effect occurred when maize yields were higher than this. If the organic maize yielded 2.5, 5, 7.5, or 10 t/ha, the expected yield increase from using the preparations was predicated to be 1.95, 1.02, 0.1, or −0.82 Mg/ha, respectively.

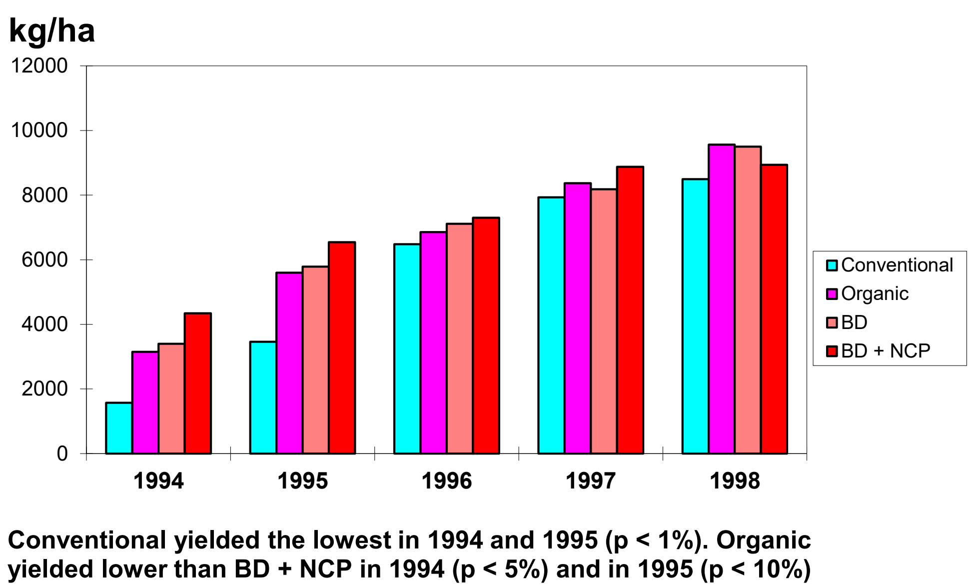


**Figure 3:** Effects of different management systems on the yields of maize var. Golden Eagle

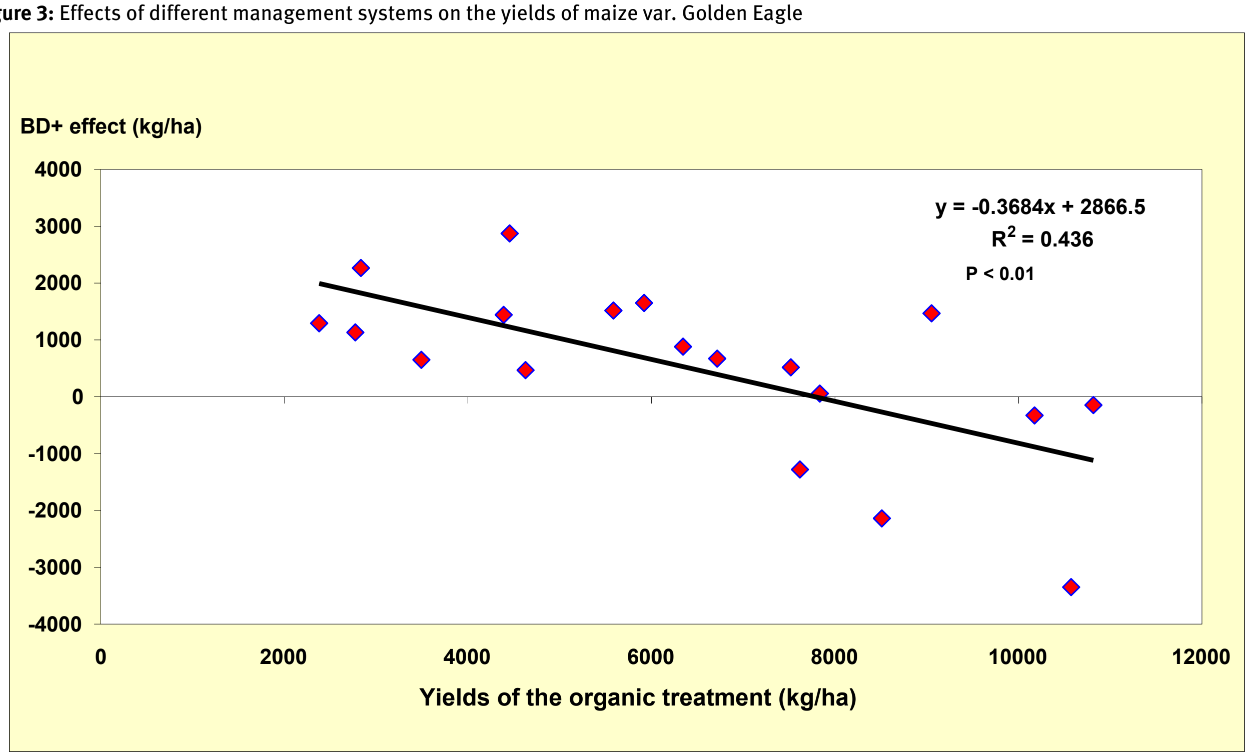


**Figure 4:** Effects of the biodynamic + treatment relative to organic on the yields of maize (1994-1998)

The negative affect of yield balancing on BD+NCP yield was most apparent in 1998, the same year in which we conducted dry matter partitioning at harvest. When dry matter was harvested and partitioned in this year the biodynamic treatment appeared to produce more roots and stover but, than organic but was unable to produce more grain yield (Figure 5). Harvest indices were 47.1% for conventional, 49.6% for organic, 48.9% for biodynamic, and 44.6% for biodynamic + NCP.

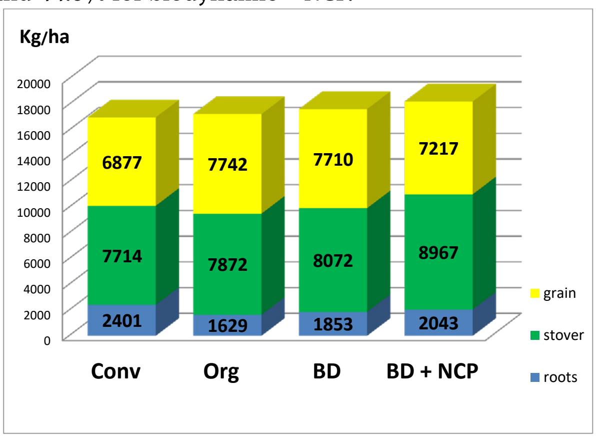


**Figure 5:** Partitioning of biological yield in 1998

The root to stover + grain relationship was 16.5% for conventional, 10.4% for organic, 11.7% for biodynamic, and 12.6% for biodynamic + NCP.

Maize Roots: In 1998, the organic system had significantly less total root length than the conventional treatment (Figure 6). The two biodynamic treatments were intermediate for length. There were no significant differences in the length of healthy and diseased roots between treatments.

The conventional and BD+NCP treatments produced significantly more root weight than the other two systems (Figure 7). The organic treatment produced only 75% and 69% of the root weight achieved by the BD+ and conventional treatments, respectively.

In 1999, maize grown in BD+NCP had significantly more total root length and healthy root length than did the organic and conventional treatments. Both of the biodynamic treatments had significantly more root weight than the organic and conventional treatments (Figure 8).

Though the biodynamic treatments had much greater root length in 1999, and they appeared to grow more rapidly between July and August samplings, they maintained the same proportions of coarser and finer roots as the other treatments (Figure 9).

The results of the two years of root work are summarized in Figure 10 relative to the organic treatment. The biodynamic and biodynamic + NCP treatment, respectively, increased maize root length 10% and 10% in 1998, but 23% and 37% in 1999. The biodynamic and biodynamic + NCP treatment, respectively, increased maize root weight 12% and 33% in 1998, but 28% and 39%in 1999.

Soils. Results from the aggregate size distribution study were simplified by classifying aggregates into 4 categories, blocky peds > 8mm; intermediates sized peds between 0.25 and 8 mm in diameter; fine soil < 0.25 mm in diameter. The soil of the conventional plots was 53% blocky, 39% medium peds, and 8% fine. The soil of the organic plot was 39% blocky, 50% medium, and 11% fine. The soil of the biodynamic without compound preparation

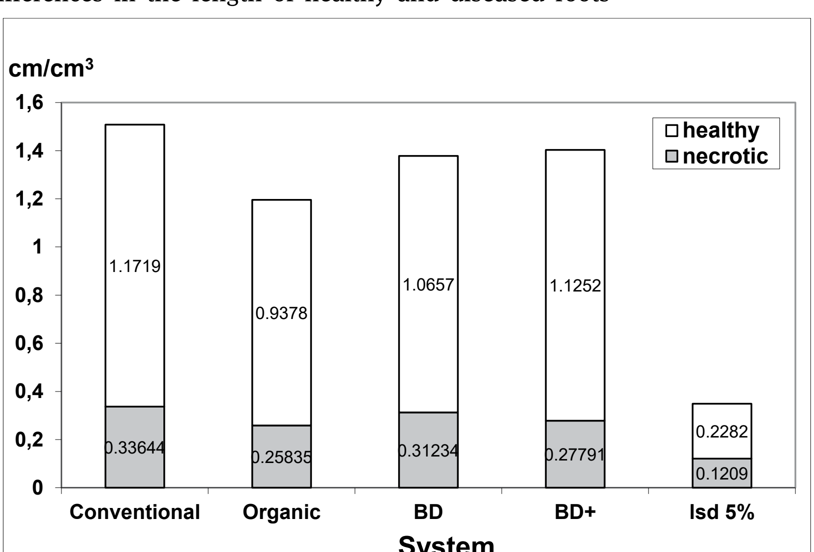


**Figure 6:** Effect of farming systems on root length in 1998

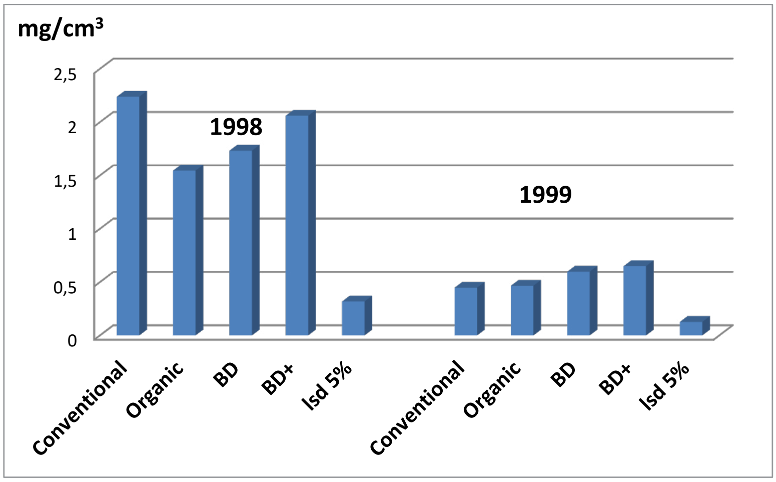


**Figure 7:** Root dry matter production in August of two years as affected by systems

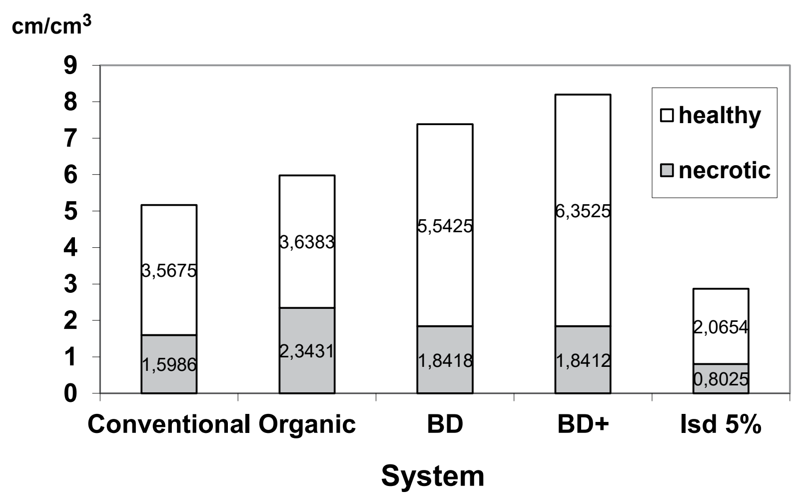


**Figure 8:** Effects of farming system on root length in 1999

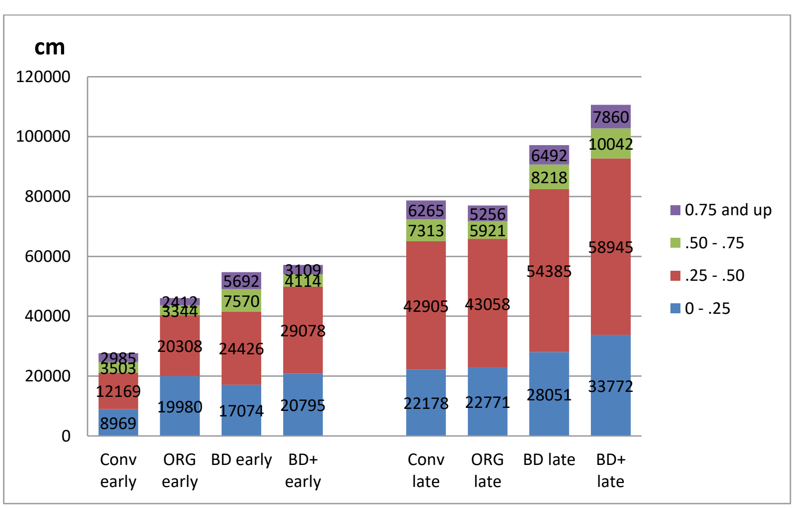


**Figure 9:** Distribution of root length by root diameter size distribution (in mm) in 1999 at early (July) and late (August) sampling dates.

plots was 40% blocky, 49% medium, and 11% fine. The soil of the biodynamic + NCP plots was 39% blocky 52% medium, and 10% fine. So there was no difference between the biological treatments but the conventional soils were blockier. The content of particulate organic matter for the conventional, organic, and biodynamic + NCP was 4,213, 4,289, and 4,664 kg C/ha, respectively. The difference in quantities between the biodynamic + NCP treatment and conventional was 11%; the difference between the NCP and the organic was 9%. Both differences were significant at p = 5%.

**Discussion:** Washington results: Use of lupins rather than chickpeas in the rotation increased the spike and spikelet production by winter wheat but depressed seed weight. Fertilization of conventional and biodynamic managed plots had the same effect but fertilization did not affect the organic wheat. There was a protracted drought at the end of the growing season of 1984/1985 and the increased production of these wheat organs probably caused greater moisture depletion and more stress on the plants at seed fill. This probably caused poorer seed set and seed weight than for the organic treatment.

Effects of biodynamic preparations appeared in the Washington studies when both compost and field sprays were combined. However, there were no differences between unfertilized biodynamic and organic plots for crop characteristics. Furthermore, larger effects on soil C, respiration, and microbial biomass occurred with biodynamic fertilization than with organic fertilization. Mineral fertilizer had stronger effects on yield components than compost, and biodynamic compost had stronger effects than organic compost. Use of peas and lupines in rotations caused production of more spikes and spikelets than use of chickpeas and barley, and the effects of preparations were more marked where wheat followed lupins and peas. Thus, the positive effects of preparations appeared under conditions which had the most positive effect on wheat growth. This suggests that the major effect of the preparations was probably due to either greater application of preparations or solely to the compost preparations. More N was added with biodynamic compost than organic, but the difference was not large (14 kg N/ha for the 2x rate in 1984) and it is difficult to explain the differences on the basis of total N applied when the low availability of N from compost is considered. Sensorial observations of the finished compost and measurement of humification coupled with measured crop and soil responses suggest that the herbal preparations altered the composting process and this was to the benefit of the wheat.

Studies of wheat at the jointing stage showed that biodynamically treated wheat had 13% more root weight, 9% more adventitious roots, 18% more root length, and 15% more tillers. Only the tiller and root length differences were statistically significant. Nevertheless, these and other results suggest that the use of biodynamic preparations,

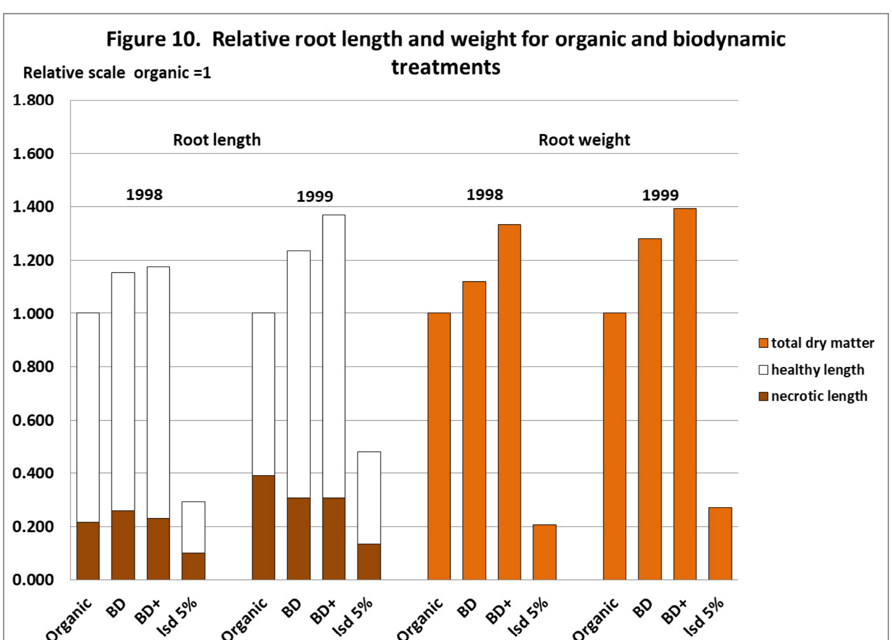


**Figure 10:** Relative root length and weight for organic and biodynamic treatments

especially the compost preparations, stimulated plant growth resulting in greater root growth and production of tillers and spikelets but failed to produce higher grain yields. The observation of more root growth and length at the 2x rate of biodynamic fertilization than organic fertilization is probably linked with similar effects of biodynamic compost with preparations on soil C, respiration, and biomass parameters as greater root growth means greater root exudation, seasonal deposition and post-harvest residues which feed microbes.

## 4.2 Wisconsin

The biodynamic and biodynamic plus nettle compound preparation induced strong increases in root length, root dry matter production and root health. The biodynamic + NCP treatment also induced substantial positive yield compensatory effects for maize and wheat under stress condition years. These results confirm the finding of Raupp and Koenig (1996) that preparation use can induce a yield balancing effect. The response slopes were practically identical for wheat and maize, indicating that the effect is of the same magnitude for both crops. If future research proves the yield balancing effect of biodynamic preparations is valid, this may be significant for combating the negative effects of global climate change.

The results also confirm the work of Spiess (1979) who found, as we did, that multiple applications of biodynamic field sprays were necessary to cause increases in yields that were statistically significant.

The lack of any difference in soil macrostructure found between the different biological treatments imply that the large differences in root growth between these treatments cannot be attributed to differences in soil macrostructure. In a separate study (Goldstein et al. 1999), L. Carpenter-Boggs (Washington State University), measured nitrate and soluble C in the 1999 maize plots before planting and after harvest at 0-20 and 20-40 cm depths. Conventional corn had the lower nitrate, dehydrogenase, soluble C, and microbial biomass levels in the topsoil at both sampling dates than did the biological farming treatments. The organic treatment had the highest levels for these traits before planting but after the harvest the biodynamic treatments had similar values but 23 to 25% more soluble C. This increase in soluble-C probably is a result of the greater quantities of plant roots in the biodynamic systems.

The increase in particulate organic matter associated with the biodynamic + NCP treatment is consistent with increased root production. Though compost applications can affect POM (Fronning et al. 2008), the organic and biodynamic treatments received the same amounts of compost so the differences between those systems are not due to applied amounts of organic matter fertilizer.

Both studies. Preparations appeared to have strong effects on root and vegetative growth. The Washington study showed 13% greater root dry matter (NS) and 18% greater root length ($p = 5\%$) of winter wheat associated with the use of biodynamic herbal preparations in manure and the spray preparations horn manure and horn silica. This difference also manifested in greater vegetative growth (more tillers, spikes, and spikelets). In the Wisconsin study the biodynamic and biodynamic + NCP treatment, respectively, increased maize root length 10% and 10% in 1998, but 23% and 37% in 1999 relative to the organic treatment. The biodynamic and biodynamic + NCP treatment, respectively, increased maize root weight 12% and 33% in 1998, but 28% and 39% in 2019 relative to the organic treatment. It should be noted that root weight differences between the organic and biodynamic (14%) or biodynamic + NCP treatment (25%) at grain harvest (see Diagram 5) differed from the respective 12% and 33% differences established for the August sampling (see Diagram 7). Biodynamic + NCP also increased the percentage of healthy roots. Those differences were not always statistically significant, but they together present a coherent pattern. The increase in root production was shown to parallel increased stover production in 1998.

One major benefit of this increased root production and enhanced vegetative development may be greater stress tolerance. Though root studies were not carried out in each year of our study we hypothesize that greater root growth and health associated with the biodynamic + NCP system was the cause in the Wisconsin experiment for greater yields in difficult growing seasons and overall higher average yields. On the other hand, in the case of Washington wheat in 1985 and Wisconsin maize in 1998, the investment in greater production of roots and vegetative organs associated with the best biodynamic treatment did not always result in higher yields. In fact in these years it resulted in slightly lower yields, even if the difference was not statistically significant.

Despite that, this 'yield-balancing' effect could be important for reducing financial risk. The average yield of the organic wheat from 1995 to 1999 was 3,444 kg/ha while the BD+ NCP wheat yielded 3,877 kg/ha for a difference of 433 kg/ha (12.6%). At the present price of food grade organic wheat in the USA ($17.50/bushel; $0.64/kg) this amounts to $278.38 more income per hectare (or $112.66 more per acre). On average between 1994 and 1998 the organic maize yielded 6,707 kg/ha and the BD+ NCP maize yielded 7,198 kg/ha, for a difference of 491 kg/ha (7.3%). At the present USA price of organic maize of $9.36/bushel ($0.363/kg) the income difference would be $180.80 more /ha (or $73.17/acre). We assume that there would be extra costs associated with purchasing and applying preparations for the BD+NCP management package, but we have not calculated a full budget that would include those costs. Nor have we considered in our calculations any kind of price incentive for biodynamic grain over organic grain.

Another side of the significance of these results is that roots play a major role in carbon sequestration. For example, maize roots have been shown to have a relatively high carbon retention rate in soils; higher than shoot derived residues (Plenet et al. 1993) and manure (Zhang et al. 2015). It has been estimated that the mean carbon residence of carbon from roots is 2.4 times what it is for carbon from shoots (Rasse et al. 2005). As the stabilization of root carbon is not solely due to greater chemical recalcitrance, different mechanisms for its stabilization have been proposed (Rasse et al. 2005). One mechanism is particulate organic matter (POM). POM is often built around decaying roots and it represents an intermediate turnover storage pool for soil organic matter (Cambardella and Elliott 1992). Increases in root production due to preparation use, of the magnitude reported here, would be expected to parallel increased production of the particulate organic matter pool. This might thereby contribute to enhanced carbon retention in the soil and thereby help explain increased soil organic matter reported in previous trials with the biodynamic method and cited in the introduction.

The limitations of the experiments described above were that they were small plot trials, replicated on few sites. Due to the significance of these root findings it is important that elements of this research are reduplicated by others to confirm whether the effects of preparations documented here are valid and applicable in other regions and whether increased root growth is the cause of greater stress resistance, soil carbon accumulation, and soil quality found in long term trials with biodynamic management.

## 5 Conclusions

In trials in Washington State and Wisconsin, and in the context of diverse crop rotations and manure compost applications, biodynamic preparations were shown to have direct stimulating effects on cereal growth resulting in greater root production and vegetative growth. Intensive use of preparations led to a yield stabilizing effect for wheat and maize. Greater root production and root health were associated with the use of biodynamic preparations. Relative to the organic treatments, root dry matter increases varied from 12% to 39% and root length differences varied from 10 to 37% depending on the experiment, crop, year and preparation application. A new nettle based biodynamic preparation was tested in combination with other preparations and found to be efficacious at increasing root length and inducing yield stabilization. Investment in roots caused better growth and greater grain yield under some but not all conditions. Increased root growth associated with the use of biodynamic preparations paralleled increases in soil organic matter and biological activity including increased particulate organic matter. Results confirm previous research by others that have found that preparations can increase soil carbon, root growth, and yield stability and that multiple applications of preparations are more likely to induce statistically significant yield increases. In light of problems with global climate change and greenhouse gasses these outcomes should be further tested. It is important to ascertain the societal and economic value of biodynamic preparations and whether increased root growth associated with their use is the key factor linking stress resistance, soil carbon sequestration and biological activity.

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