Veni, Vidi, Vermi...

II. EARTHWORMS IN ORGANIC FIELDS RESTORE SOM & H_2O AND FIX CO_2

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Abstract

Earthworm proliferations (or depletions) of 57–122% (mean 85.6%) under adjacent (i.e., same soil/climate) organic vs. conventional fields related to improved soil quality and higher yields of 16–80% (mean 39.1%) in winter wheat, tropical paddy rice and sugarcane. Soil moisture differences ranged -11–41% (mean +12.0%) while soil carbon in SOM humus ranged 26–128% (mean 64.9%). Correlation (r >0.807) of earthworms is with crop yield and both soil H_2O & C storage hence atmospheric CO_2 reduction via photosynthesis / humification.

A 1,000 yr-old pasture at Haughley had highest earthworms (424 m^{-2}), stored 222 t ha^{-1} carbon in its soil organic matter (SOM), plus moisture capacity was 90.9% above an adjacent arable field.

Relating to global climate change, extrapolation to areas given over to each of the three crops if all organically converted gives CO_2 equivalents (CO_2e) of 49.2, 2.8 and 1.1 Gt (total 53.1 Gt) C storage for wheat, rice and sugarcane, respectively. Wheat alone, albeit projected, exceeds global emission (~40 Gt CO_2); rice matches Eurozone's (2.5 Gt); and sugarcane either Japan (1.2 Gt) or UK + Australia combined (0.5 + 0.4 Gt). Extra carbon stored (53.1 Gt CO_2e) would equal ~7.3 ppm atmospheric CO_2 reduction. Pasture management offers yet greater potential remedy, here calculated as optimal 222 t ha^{-1} x 3.6 Gha total grass = 800 Gt C (x 3.667 conversion factor = 2,934 Gt CO_2e) about equal to present atmospheric values of 3,000 Gt CO_2 and 400 ppm. Even at same human emission/consumption rates, humus solves carbon sequestration whilst providing food.

Keywords: broadacre crops, carbon, glomalin, climate, food security, soil health, humus, water.

Introduction

Global species extinctions causing biodiversity loss plus extreme nitrogen-cycle N_2 imbalance have both been recognized as much greater critical and imminent threats than risks of climate change (Rockström *et al.*, 2009). A possible solution to all three inter-related issues is local and broad-scale adoption of agro-ecology: which in essence is organic husbandry and/or permaculture (see Blakemore, 2016). Organic farming yields can equal or exceed 'conventional' farm yields but with less environmental costs: for example, consuming less energy and using no biocides whilst also improving C and N cycles and biodiversity (Drinkwater *et al.*, 1998; Hole *et al.*, 2004; Randerson, 2004; Pimental *et al.*, 2005; Halweil, 2006). A summary of such organic issues at IFOAM (2006) pointed out that whilst limited information is obtainable from temperate regions, data from tropical climates is more sparse. The present work helps redress this by researching organic farms in tropical Philippines and comparing these data to the classical long-term model farm at Haughley in temperate UK. Crop yield, soil health and earthworm abundance are criteria of sustainability that relate to issues of global climate change, carbon/nitrogen cycles and soil moisture, all of which contribute to reducing the threat of local species extinctions.

Earthworms are keystone species, fundamental to organic farming. They also provide essential terrestrial services being the basis of food-chains as well as the ultimate detritivores. They function as '*Nature's plough*' greatly modifying soil and producing humus (= SOM or soil organic matter composed mostly of carbon and nitrogen in ratio ~10:1) upon which Nature and Civilization depend (Darwin, 1881). Earthworms stimulate microbially active humus formation by processing dead roots, leaf-litter fall and manure to provide healthy soils with four key characteristics of: (1) good structural tilth at depth for plants, (2) improved water storage and purification, (3) improved atmospheric gas exchange and, (4) ample habitats for other soil organisms. They thereby contribute to nutrient recycling, above and below-ground plant yield and maintenance of biodiversity (Lee, 1985). Such effects are easier to demonstrate in controlled glasshouse pot experiments but actual field measurements under the complex interactions prevailing in organic field soils are crucial for better understanding (Blakemore, 1994).

Earthworms in the pioneering long-term, farm-scale organic Haughley Experiment in the UK that started in 1939 (Balfour, 1977) were studied by Blakemore (1981; 1996; 2000). Similar reviews are from Condron *et al.* (2000), Mäder *et al.* (2002) and Pfiffner & Balmer (2011), sometimes reporting mainly on organic tillage effects and reflecting the great number of studies conducted under conventional no-till systems yet based on herbicides that therefore pose environmental risks. Relations between agronomic practice and earthworms in Norway (Pommeresche & Løes, 2009) also considered a plot fertilization experiment at Møystad, Denmark started in 1922. Other long-term field trials are at Rodale Institute in US from 1947 (Rodale, 2015) and FiBL's DOK trial in Switzerland from 1978 (Pfiffner & Mäder, 1998). In Asia long-term trials tend to focus on crop yields rather than SOM or earthworms, and those considering organic farming methods are rare despite initial work by advocates such as Sir Albert Howard in India (Howard, 1943). Howard criticized small experimental plots (often 4 m x 5 m) typical for research stations that ignore worm migrations and other important soil biology factors and focus just on chemicals. E.g at Rothamsted where some field plots are also next to woodland (pers. obs., as in a sugarcane field in this study).

Pfiffner & Balmer (2011: fig. 1) charted a total of 14 studies looking at the impact of organic farming on earthworm biodiversity compared to non-organic farms; these included Mäder *et al.* (2002) and a meta analysis (Bengtsson *et al.*, 2005) that listed just eight earthworm studies (omitting several papers such as Blakemore, 2000) yet noted higher amounts of SOM often correlated with increased earthworm abundance. Presence of earthworms was associated with crop yields increased by an average 25% in 58 studies summarized by van Groenigen *et al.* (2014). A more limited meta-analysis by Tuck *et al.* (2014) deliberately excluded earthworms "*...due to small sample sizes (n<5)*" unreasonably ignoring a greater sampling effort needed for macrofauna that have concomitantly greater contribution to soil processes than do either meso- or microfauna. Note that an FAO/UNESCO soil bioassesment manual (Swift & Bignal, 2015: 9) suggest eight replicated macrofauna samples but accepted five as a sufficient minimum, whereas the current report used at least ten and as many as 33 earthworm samples from each crop soil site.

Few reports consider the relationship of earthworms with carbon sequestration, and fewer still from the tropics. A European report, Don *et al.* (2008) only summarize some processes by a single lumbricid in a temperate soil. Surprisingly, there is little information on earthworms in rice paddy (e.g. Xiang *et al.*, 2006; Blakemore, 2012; Krupakdee *et al.*, 2013), but reports of vermicast fertilizer on rice were summarized by Blakemore (2008). Some conclusions (e.g. by Owa *et al.*, 2003; Choosai *et al.*, 2010) are that earthworms increase rice productivity but species involved were unidentified or misidentified. Almost no research concerns earthworms under sugarcane nor whether factors other than high agrichemical use explain frequent absence of earthworms (and other biota) from canefields (e.g. Blakemore, 1994; Zou & Bashkin, 1998; Dlamini *et al.*, 2001). Routine field data for earthworm occurrence under other crops are also relatively sparse for the Philippine Islands (PI) – as newly investigated in the current study – as for elsewhere in the tropics.

Materials and methods

In the current study, earthworm activity under organic husbandry is investigated on the simple premise that such management may encourage soil faunal biodiversity and improve soil quality, in particular soil carbon and water relationships that are key factors mitigating climate change effects. An earlier study of organic wheat/pasture at Haughley in the UK (Blakemore, 1981; 2000) is re-evaluated, re-interpreted, and compared to results from two small studies on major Filipino broadacre crops of rice and sugarcane to determine whether similar soil processes occur across a climatic spectrum. Greenhouse gas (GHG) fluxes–which by definition change constantly–are largely irrelevant overall, thus only net soil carbon sequestration is considered along with crop yields and earthworm populations. The reasonable premise is that plants and earthworms are natural monitors of soil quality and health. Controls in each case are represented by adjacent non-organically managed or 'conventional' fields that have the same soil origin and same climate.

Study sites

A. New Bells Farm, Haughley, Suffolk, UK (N: 52.236378, E: 0.978406)

This was the first ever ecologically designed agricultural research project on a full farm scale where, since 1939, three side-by-side management regimes had been maintained under the pioneering 'Haughley Experiment' (Balfour, 1975). This 100 ha site originally had nearly uniform alkaline clay-loam soils overlying glacial clay with flints and sand pockets on chalk beds; a site description is provided in Blakemore (2000). Figure 1 shows the sections surveyed in winter 1980/81, ~40 years after establishment, viz.:

- O – an Organic ley-arable rotation (organic closed-system established with no external imports)
- M – a conventional Mixed ley-arable with additional agrichemicals (non-organic) with its own herd
- S – a Stockless intensive arable systems with limited rotation using agrichemicals (non-organic).

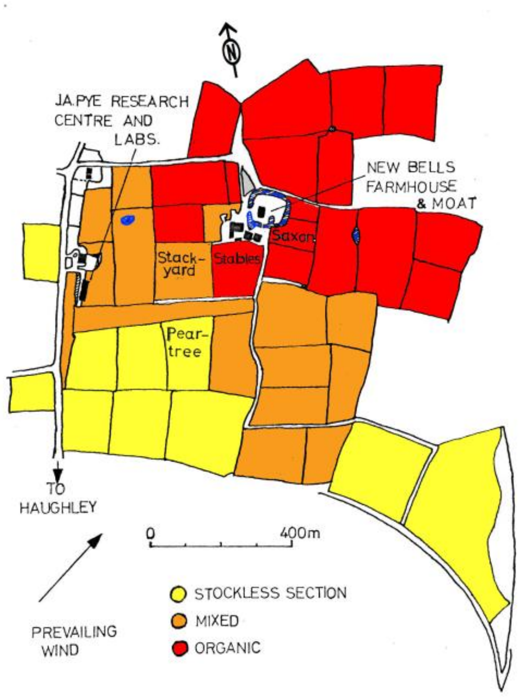

Figure 1. Haughley farm layout with study field locations (from Blakemore, 2000).

The organic section operated as an almost closed recycling system with natural inputs (sun, air, rain) and only cattle and other livestock products sold off-site. Fields and pastures were mulched with between 7-30 t ha^{-1} yr^{-1} of roughly composted farmyard manure (FYM) and crop residues. The Stockless section followed prevailing regional arable practices while the Mixed section was a compromise of both organic and agrichemical with a separate Guernsey herd. Some soil analyses were courtesy of J.A. Pye Research Centre. (farm managers in 1980s), other data were determined by the author. Results from Blakemore (1981; 2000) are here revisited to calculate actual mass of SOC to allow comparison with subsequent studies. Included is a 1,000 yr-old "Saxon" permanent organic pasture at Haughley that may be taken as an 'upper' control for the cropped fields.

B. Kahariam Farms, Bgy Adya near Lipa, Batangas, Luzon, Philippines (N: 13.87, E: 121.14)
An integrated 23 hectare farm certified organic since 2009 by OCCP (Organic Certification Center of the Philippines, http://www.occpphils.org/) and producing the first wholly organic rice seed in Southeast Asia (http://www.kahariamfarms.com/). It is also an on-the-job training, demonstration and research facility for national Universities and Department of Agriculture (DA). Apart from recycling farm residues from vegetables and chickens, extraneous input is from local racehorse stables that sometimes import alfalfa (= lucerne *Medicago sativa* L.) fodder from Australia. In addition to resolving the horse manure disposal problem, rapid processing through worms allows production of ca. 3 tonnes of vermicompost per day while supporting a resident *Eudrilus eugeniae* (Kinberg, 1867) population of >20 million and ca. 20 t biomass contained in an hectare of worm beds (Kahariam, 2015). Fresh vermicompost not used on the farm is sold commercially off-site.

Batangas district has Type III Climate Type (Corona Classification) with periodic typhoons but no pronounced maximum rain period. Sampling was between the hot, dry season either during the period from December to February or from March to May; annual rainfall and temperature means are 2,828.8 mm and 26 °C (max of 28 °C; min of 24 °C). Local soils are inceptisols classed as Ibaan Clay Loam.

Rice production methods on the organic farm are summarized by (BPI 2014). Farms immediately adjacent to Kahariam did not grow rice; however, rainfed paddy in adjacent San Guillermo village was taken as representative of local conventional (agrichemical) farming for comparative sampling on the next day as they routinely used synthetic N-P-K fertilizers and pesticides (amounts unspecified varying field to field and season to season – as per FAO and local DA and Philrice advice; with organic matter incidentally added from stubble, rice husks and occasional caribou grazing). Rice was at the same stage of tillering growth but initial irrigation of the organic rice possibly affected or negated soil moisture comparisons with the upland rice. Rice yields were based on farm records and local averages. Soil microbial plate counts were by BIOTECH, Los Baños. Chemical analyses courtesy South Tagalog Integrated Agricultural Research (STIARC) Lipa City (May, 2013).

C. Peñalosa Farms' Hacienda Remedios in Manapla, Negros Occidental (N:10.93, E:123.11)
This farm was NICERT (Negros Island Certification Services, http://nicert.org/) and OCCP certified organic for about 10 years and is a research site for Japan International Research Center for Agricultural Sciences (JIRCAS) (http://penalosafarms.com/). Vermicompost from pig, fowl and farm residues was used plus bagasse and rice hull charcoal with occasional direct field application of mill ash and sugar pressmud on ratooned sugarcane monoculture, paddy rice and vegetable beds. Mineral supplements (e.g. rock phosphate, dolomitic limestone) and microbial concoctions (e.g. N-fixing bacteria, fungi, & endophytic mycorrhizae) were also added to the compost ad hoc (R. Peñalosa pers. comm.; Penalosafarms, 2015). Weeds and pests are managed by combinations of organic/IPM control methods.

Climate is classified as Type 1 characterized by two pronounced seasons: dry from November to April and wet during the rest of the year. Soils are Silay fine sandy loams of volcanic origin classified as Aquic Hapludalfs. Ironically, the farm suffered peripheral damage from 2013 Typhoon Haiyan (known as Super Typhoon "Yolanda" in the Philippines) that had record gusting winds of 380 km h^{-1} and was partly attributed to effects of Global Warming that this earthworm project sought to redress.

Immediately adjacent to the farm were non-organic farms routinely using urea and chemical pesticides on similarly ratooned fields with average N-P-K fertilization rates in Negros sugarcane in 2008 of 165-85-105 kg ha^{-1} yr^{-1} (from Bombio & Tahum, 2008 in Sugar Regulatory Administration website – http://www.sra.gov.ph/). Canefields were rainfed not irrigated. Several fields at similar growth/harvest stages were sampled in exactly the same way over two days for comparison as noted in the Results section below. Cane yields were based on farm records and local averages. Chemical analyses from Agro-Based Lab. and Sugar Regulatory Administration (SRA), Bacolod, Negros. Note that rice yield is often given in cavans (one cavan is 48 kg) and sugar yield is usually measured in 50 kg bags (Lkg).

Sampling of soils and earthworms

Compost and soil were bulked sub-samples at depths stated in Results, prepared as per standard routines for submission to chemical laboratories (e.g. Swift & Bignal, 2015). Earthworm estimates were from stratified random samples with provisos excluding 1 m from bunds or field boundaries (to reduce possible edge-effects) and avoidance of anomalies such as ant-nests or puddles. Conventionally, ten earthworm samples per field from 31.5 cm quadrats (i.e., 0.1 m^2 each) were collected to the depth of worm activity, effectively 0-30 cm in most cases. Numbers of worms based on 'head' counts (plus cocoons if found) and total wet-weights, both data expressed as means m^{-2} soil (that give even numbers for ten sample means). For Haughley, after three pilot samples for evaluation of coefficients of variation, ten samples of 25 cm side to 20 cm depth (corresponding to the depth of mouldboard plough) were taken at monthly intervals for three months from each of the three sections (i.e., ~33 sample units per treatment). However, as Blakemore (2000) noted: "*a sampling error of less than 10% of the mean cannot generally be obtained without excessive cost in sampling effort*". N-P-K data in (Blakemore, 2000) are not repeated here since they are less relevant with compost fertilizers where microbial activity governs mineralization in synchrony with plant demand (Balfour, 1977). No information was found on Balfour's (1975) planned earthworm studies at Haughley, thus the only data is from Blakemore (1981; 2000). Earthworm extraction was by hand-sorting in all cases (Figure 2). Soil analyses used standard Walkley-Black method for total C, and/or loss-on-ignition for soil organic matter (SOM). Often Walkely-Black underestimates total C with a correction factor of ca. x 1.3 required, but it is not applied too data in this report.

Figure 2. Handsorting earthworms in rice paddy at Kahariam (from Sterin *et al.*, 2014).

Conventions

Soil organic carbon was calculated from the formula SOC (t ha^{-1}) = soil carbon (%) x bulk density (g cm^{-3} or Mg m^{-3}) x sampling depth (cm). Where soil bulk density (BD) was not taken directly, it is estimated by the Alexander-B method, this being the most reliable and conservative of those listed by Valzano *et al.* (2005: tab. 6, fig. 2) as BD (in Mg/m^3 or g/cm^3) = [1.72 – (0.294 x √SOC)] using SOC% calculated directly or from mean SOM% x 0.58 vanBemmelen conversion factor. (Cf. Gattinger *et al.* 2010 use of equivalent BD estimations based on Post & Kwon's method). Average SOM in 0-10 cm is reported (Valzano *et al.*, 2005: 9) similar to that in 10-30 cm portion (differing by ±3%) thus validating comparisons of equivalent soil samples taken from these different depths. SOC x 3.667 = CO_2e t ha^{-1} (atmospheric CO_2 equivalent). Standard SI units are "Mg" (= 1,000,000 g), here as "t" = one tonne (British and SI = "metric ton" in USA) used for simple ease of comparison with other reports; thus "Mt" or "Gt" = megatonne or gigatonne, respectively; also yr = year. ANOVA and other statistics (e.g. Wessa 2015) are as noted in Results.

Percentage change (not % difference) is from mean value difference/original value x 100 = % under null hypothesis that organic farming has no effect on soil biodiversity, carbon, water nor crop yield.

Results

A. Haughley wheat (*Triticum aestivum* L.) and permanent pasture data from Blakemore (1981; 2000) are reinterpreted in Tables 1 and 2. Winter soil temperatures although measured in adjacent fields on the same day and at the same time (~5 minutes walk between fields) showed remarkable differences: perhaps recording for the first time thermal insulation effects of organic managed soils. There were corresponding and inter-related variations in moisture and SOM too (Table 1).

Table 1. Haughley field soil data with % relative changes; means (± s.e.)

	"Saxon" permanent pasture	"Stables" wheat	"Stackyard" wheat	"Peartree" wheat
System type	Organic	Organic	Mixed	Stockless
Nov. Temp., 10 cm depth	N/A	10.0 °C	10.0 °C	10.0 °C
Jan. Temp., 10 cm depth	**N/A**	**2.5 °C**	**1.5 °C**	**0.5 °C**
Colour (Munsell)	Black 10YR 2/1	Dark 10YR 2/2	Brown 10YR 5/3, mottled	Brown 10YR 4/2
Bulk density, air-dry (g cm^{-3})	0.91	0.84	0.81	1.05
%moisture (% change)	**42 (+90.9%)**	**31 (+40.9%)**	**24 (+9.9%)**	**22**
SOM by ignition (% change)	21 (+133%)	11 (+22%)	9 (0%)	9
pH (in water)	7.5	7.2	7.6	7.5
CEC (me $100g^{-1}$)	N/A	17.9 (± 0.05)	15.7 (± 0.01)	13.5 (± 0.4)
SOC (Walkely-Black) C%	**N/A**	**4.00 [a] (± 0.03)**	**2.34 [b] (± 0.03)**	**1.75 [c] (± 0.01)**
Relative change in organic C		+128.6%	+33.7%	-

N/A –not available. ANOVA superscripts (n>3; p<0.01 from http://statpages.org/anova1sm.html).

Table 2. Haughley monthly earthworm survey results and stats (from Blakemore, 1981, 2000)

	"Saxon" Organic permanent pasture	"Stables" Organic wheat	"Stackyard" Mixed (non-organic) wheat	"Peartree" Non-organic wheat
Number of observations (n)	7	32	32	33
Mean No. of worms (m^{-2})	424.0[a]	178.6[b]	97.5[c]	100.0[c]
Mean fresh weight (g m^{-2})	117.6[d]	66.2[e]	35.4[f]	34.7[f]
Relative change counts	+324%	+78.6%	-2.5%	-
Relative change weight	+238.9%	+90.8%	+2.0%	-

Earthworms values in Table 2 also differed correspondingly with ANOVA row superscripts after transformation [log (x+1)] at p<0.01 (except [d] & [e] at p<0.05); biomass of *Lumbricus terrestris* Linnaeus, 1758 matures were deliberately excluded as these would have positively skewed the results more in favour of the organic fields. Population of seven species in the permanent pasture equated to 4.2 million earthworms ha^{-1} and biomass (including *L. terrestris* matures) totalling 1.2 t ha^{-1} which is higher than average above-ground cattle or flock stocking rates.

Pearson's coefficient (Wessa, 2015) for earthworms m^{-2} vs. SOC% in Tables 1–2, albeit for only a few values, give r = 0.99 (n = 4; p<0.003), i.e., an highly significant correlation. Transformation to normalize the data [log (x+1)], as per Swift & Bignal (2001), gives r = 0.97 (n = 4; p = 0.03) which is a slightly lesser but still strong correlation.

Soil in the organic wheat field under 40 yr organic management had total organic C (4% x 0.84 g cm^{-3} x 20 cm) = 67.2 g cm^{-3} or t ha^{-1} while nearby conventional wheat soil had total SOC (1.75% x 1.05 g cm^{-3} x 20 cm) = 36.75 C g cm-3 or t ha^{-1} in 0-20 cm topsoil. Difference in carbon for organic vs. conventional (67.2 vs. 36.8) = 82.9%, i.e., 30.45 t ha^{-1} extra SOC or (x 3.667 =) 111.7 t ha^{-1} extra CO_2e storage in the organic wheat field soil.

Permanent pasture total SOC (estimated from SOM% x 0.58 vanBemmelen) at (12.2% x 0.91 g cm^{-3} x 20 cm) = 222.0 g cm^{-3} or t ha^{-1} , substantially more carbon than either the organic wheat field (67.2) or the conventional wheat field (36.8); conversely, these amounts may be progressively depleted due to cultivation of pasture for cropland then further depleted under intensive agrichemical use. Total carbon storage estimate in the permanent pasture is equivalent to (222.0 x 3.667 =) 814 t ha^{-1} CO_2e.

In the Haughley study (Blakemore, 2000), winter wheat shoots were significantly higher by 16.2%

with 12.1% longer roots. Moreover, Balfour (1977) found crop yields in terms of both plant growth and nutrient status from the Organic section remained consistently as high and, despite the chemically grown fodder having higher water content, the organic dairy herd produced around 15% more milk than the mixed dairy herd over a 20-yr period.

From monthly chemical analyses, Balfour (1977) newly reported that the levels of available minerals in the soil fluctuate according to the season, maximum levels coinciding with the time of maximum plant demand; and that these fluctuations were far more marked in the Organic Section. A remarkable personal observation at Haughley was the completely different nature of soils in almost adjacent fields that presumably started from a near uniform condition prior to cultivation: whereas the pasture and organic soils were spongy, dry and friable, the intensive arable soil was compacted, cloddy and most difficult to both walk on and to handle.

Microbial counts were not available for Haughley soils at the time of the study and I find no records from Balfour (1977) of data for activity of the soil "micro-flora" she ascribes mineralization to.

B. Kahariam rice (*Oryza sativa* L.) results are summarized in Tables 3–5 (maize, *Zea mays* L. is included for comparison).

Table 3. Soil characteristics in Kahariam organic vs. San Guillermo conventional soils.

Field	pH	Organic matter (%)	Organic carbon (%)	Moisture content (%)	*BD g cm^{-3}	*SOC t ha^{-1}
Organic maize	5.59	3.17	0.441	14.29		
Organic rice-1	6.17	2.65	0.541	12.36	1.50	12.17
Organic rice-2	6.10	2.10	0.406	15.61		
Conventional-1	6.60	3.00	0.429	13.97	1.53	9.85
Conventional-2	6.69	3.37	0.441	18.06		
Mean org. rice		2.375	0.4735	13.985		
Mean con. rice		3.185	0.435	16.015		
Percentage change		-25.4	+8.9	-12.7	-1.9	+23.6

***BD and SOC are estimated from SOM % only for the two paddy fields sampled for earthworms.

Organic vs conventional paddy rice (Table 3 from study 15-16 May, 2013) had ~25% less SOM but ~9% more SOC; ANOVA result (from http://statistica.mooo.com, df = 3,4; F= 66.8) give p<0.01, i.e., significant overall but not between treatments (A vs. B p = 0.08; C vs. D p = 0.89). Total SOC t ha^{-1} was +23.6% (t = 0.56, p = 0.62) but also not significant.

Table 4. Kahariam organic vs. San Guillermo conventional soil data with mean worm counts.

Field	pH	Soil organic matter (%)	Soil organic carbon (%)	Moisture content (%)	Worms (m^{-2})	Worms (g m^{-2})
Organic maize	5.59	3.17	0.441	14.29	183	23.9
Organic rice-1	6.17	2.65	0.541	12.36	36^{a}	13.8^{b}*
Conventional-1	6.6	3.0	0.429	13.97	23^{a}	0.4^{c}*
Rice percentage change	-6.5	-11. 7	+26.1	-11.5	+56.5	+3,350

*ANOVA superscripts that differ = p <0.01.

Results in Table 4 show worm counts on 15th – 16th May 2013 were 56.5 % higher for organic paddy at Kahariam vs. conventional paddy at San Guillermo and ANOVA gave $p<0.01$ overall which is highly significant [df = 3, F = 6.82; t-tests http://studentsttest.com n = 10, $^{a}p = 0.26$ (NS) for numbers and $^{bc}p = 0.0003$ for biomass since conventional paddy worms were all quite small]. Earthworm species were mainly *Drawida impertusa* Stephenson, 1920 vs. *Ramiella bishambari* (Stephenson, 1914), respectively (see Blakemore *et al.*, 2014 and data in Appendix).

Organic matter and moisture levels differences were insignificant, and although carbon was 26.1% higher in the organic field corresponding with its 56.5% greater earthworm abundance these were only marginally significant statistically (ANOVA, $p<0.05$). Pearson's correlation for SOC vs. worms showed no correlation as the data were rather limited and heteroscedastic.

Table 5. Microbes at Kahariam organic vs. San Guillermo conventional farms 15-16 May 2013.

Field	Bacteria (CFU/g)	Fungi (CFU/g)	
Organic maize	10.4×10^{6}	4.45×10^{4}	
Organic rice-1	8.15×10^{6}	3.95×10^{4}	
Organic rice-2	4.8×10^{6}	2.75×10^{4}	
Conventional-1	4.05×10^{6}	0.49×10^{4}	
Conventional-2	4.95×10^{6}	3.95×10^{4}	
Mean org. rice	6.5 (±1.68)	3.4 (±0.60)	
Mean con. rice	4.5 (±0.45)	2.2 (±1.73)	
Percentage change	+44.4%	+54.6%	Average difference = +49.5%

Microbial plate counts differences in Table 5 were non significant in the rice paddies (from http://vassarstats.net/anova2u.htm df=2,1, row p = 0.13 NS). Mycorrhizae, although requested since they are important for rice, were not measured; however, mean bacterial and fungal counts of

+44.4% and +54.6% (mean + 49.5%) were effectively higher in the organic paddies.

In Philippines, rice yields are measured in cavans (1 cavan is 48 kg). Five years after becoming organic, Kahariam grows 90-120 cavans ha^{-1} rice; and, since rice production locally ranges 20-90 cavans ha^{-1}, using highest yields, the increase is above +33.3% (D. Rubio pers. comm.). From FAO (2015a), Philippine-wide rice yield was 3.89 t ha^{-1} in 2013 putting Kahariam's range (= 4.32-5.76 t ha^{-1}) at 11-48% higher than the national average with median value at 30% increase.

C. Peñalosa Hacienda Remedios, sugar cane (*Saccharum officinarum* L.) results are in Table 6 (paddy rice fields were sampled for comparison).

Table 6. Peñalosa's Hacienda Remedios canefields soil and worm data, 29-30th January 2014.

*Code/Lot	%Moisture	pH	SOM (%)	Worms m^{-2}	Code/Lot	%Moisture	pH	SOM (%)
NPCHTop	4.88	6.8	3.92	99	**NPCH**Sub	4.72	6.7	3.26
NPCMTop	4.91	6.8	3.53	17	**NPCM**Sub	5.23	7.2	2.63
NPCRTop	4.85	6.3	2.74	17	**NPCR**Sub	4.86	6.4	2.35
NNCRTop	4.52	4.6	2.73	29	NNCRSub	4.29	4.4	2.47
NNCMTop	4.23	5.2	2.34	11	NNCMSub	5.66	5.2	2.24
NP (Organic) mean	4.88	6.63	3.39	44.33		4.94	6.8	2.75
NN (Non-org) mean	4.38	4.90	2.54	20.00		4.98	4.8	2.36
Mean percentage change	11.5%	35.4%	34.0%	121. 7%		-0.8%	41.0%	16.6%

* NPC - Negros Peñalosa cane (organic fields are **bolded**), NNC - Negros non-organic cane, R - replant, M - mature, H – harvested; Top - top soil 0-10 cm, Sub - soil @ 15 cm depth.

Table 6 shows organic farm topsoil (0-10 cm) had 11.5% greater soil moisture than a neighbour's conventional non-organic fields; it was more alkaline by 35.4% (1.7 pH points) favouring microbial activity and natural mineralization: and had +34.0% more SOM. Means for subsoil (15 cm depth) were -0.8%, +41% and +16.6%. All differences associated with 122.7% higher earthworm counts.

Soil characters (Table 6) differ significantly by one-way ANOVA between organic and conventional for topsoil moisture, pH and SOM. [ANOVA results from http://statistica.mooo.com for topsoil moisture n = 3,2; F = 20.9; p = 0.02 i.e., significant difference; for subsoil moisture n = 6,4; F = 0.70; p = 0.4 (NS); pH (n = 6,4; F = 63.8; p<0.001; i.e., highly significant difference) and for SOM n = 6,4; F = 3.9; p = 0.08 (i.e., significance p<0.1>0.05)]. ANOVA for mean worm counts (n = 3,2; F = 0.56; p = 0.55) detected no significant difference. However, original worm count totals (n = 30,20; df = 1; F = 5.5; p = 0.023) gave significance at p<0.05 for organic vs. conventional.

2-way ANOVA (http://statistica.mooo.com) of Water vs. Worms ($F = 3.34$; $p = 0.10$ i.e. marginally significant); pH vs. Worms ($F = 3.07$, $p = 0.11$ i.e. not significant); OM vs. Worms ($F = 3.71$, $p = 0.09$), i.e., also marginally significant $p<0.1$.

Pearson-r correlation analysis (Wessa, 2015) gave indication for SOM vs. earthworms ($r = 0.75$, $p = 0.14$, NS); but not for Water vs. Worms ($r = 0.40$, $p = 0.50$, NS); nor pH vs. Worms ($r = 0.40$, NS). However, including the subsoil with topsoil data, a more confident correlation for SOM vs. earthworm counts ($r = 0.72$, $n = 10$, $p = 0.017$) were significance at $p<0.05$. These results skewed slightly due to a high count outlier of 99 worm m^{-2} in a canefield adjacent to a woodland that possibly acted as an earthworm refuge; but normalizing the data by transformation of the counts to [log (x+1)], as per Swift & Bignal (2015), gave $r = 0.72$, $p = 0.018$ for worms m^{-2} vs. SOC%. Converting SOM% to SOC% with vanBremelen factor (x 0.58) gave the same outcome.

Thus sugarcane fields organic for 10 yrs, had SOC estimated (by mean 3.40 SOM% x 0.58 =) as 1.97%; its conventional neighbour had SOC = 1.47% (2.54 SOM% x 0.58) with difference = 40.0%. Bulk densities of Organic vs. Conventional cane estimates were 1.31 vs. 1.36 g cm^{-3}, respectively, to give total SOC% (1.97 x 1.31 x 10 =) 25.8 vs. (1.47 x 1.36 x 10 =) 20.0 t ha^{-1}; differing by 129.1% or 5.8 t ha^{-1} extra C x 3.667 = 21.3 t ha^{-1} extra CO_2e in top 10 cm of the organic farm soil.

The organic sugarcane yield averaged 90 t ha^{-1} against a usual yield in northern Negros area of 50 t ha^{-1}, i.e. +80% (R. Peñalosa, pers. comm.). Mean Filipino cane yield in 2013 was 73.2 t ha^{-1} (FAO, 2015b) putting Peñalosa farm's organic yield at +23% above the national average.

Paddy fields at Hacienda Remedios sampled for comparison had mean SOM 2.28% and 24.0 earthworms m^{-2} (see Appendix). Various other earthworms populations were recorded under vegetable beds, banana plantations and a coconut groves, but insufficient time was available for further survey nor for comparison with conventional fields in the neighbourhood.

Vermicompost analysis data is given in Table 7. Total N, P_2O_5, K_2O were also obtained but, as with organic soils, are deliberately omitted as generally irrelevant for microbially active composts. The fresh Kahariam sample was as applied to fields and sold commercially. Peñalosa's field applications have organic matter ranging up to 65% with average about 40% (i.e., ca. 23% C) in combined composts/vermicomposts that were applied at 10-20 t ha^{-1} per yr for cane and 1.5-3.0 t ha^{-1} yr^{-1} for rice (R. Peñalosa pers. comm.).

Table 7. Summary of vermicompost characteristics (from Kahariam farm).

	Organic matter (OM %)	C:N ratio	Total C (%)*	H_2O (%)	pH	Bacteria CFU/g	Fungi CFU/g
Kahariam	36	15:1	ca. 21	30	6.8	$1.23x10^7$	$1.5x10^5$

*Total C is from OM% x 0.58 conversion factor.

Table 8 gives worm and related soil results from all three farms and their non-organic neighbours.

Table 8. Summary results of worm counts vs. means of SOM and soil moisture at all sites

Farm	Crop	Worms m^{-2}	SOM %	H_2O %
A. Haughley, UK	Organic pasture	424	21	42
	Organic wheat	178.6	11	31
B. Kahariam, PI	Organic maize	183	3.2	14.3
	Organic rice-1	36	2.7	12.4
C. Hacienda Remedios PI	Organic rice	24	2.3	4.3
	Organic sugar-1	99	3.6	4.8
	Organic sugar-2	17	3.1	5.1
	Organic sugar-3	17	2.6	4.9
A. Haughley, UK	Non-organic wheat-1	97.5	9	24
	Non-organic wheat-2	100	9	22
B. San Guillermo PI	Non-organic rice-1	23	3	14
C. Remedios Neighbour	Non-organic sugar-1	29	2.6	4.4
	Non-organic sugar-2	11	2.3	5
Means	**Organic**	122.3	6.2	14.9
	Non-organic	52.1	5.2	13.9
	Mean % change	**+134.8%**	**+19.5%**	**+7.0%**

Pearson-r correlation (http://www.wessa.net) and Linear Regression (http://www.alcula.com/calculators/statistics/linear-regression/) analyses in Figure 3 show strong positive relationship between worm abundance and both SOM and H_2O from Fig. 8. Similar result for the SOM vs. soil moisture demonstrate the intimately linked, mutual inter-relationships between all three factors (Fig. 3).

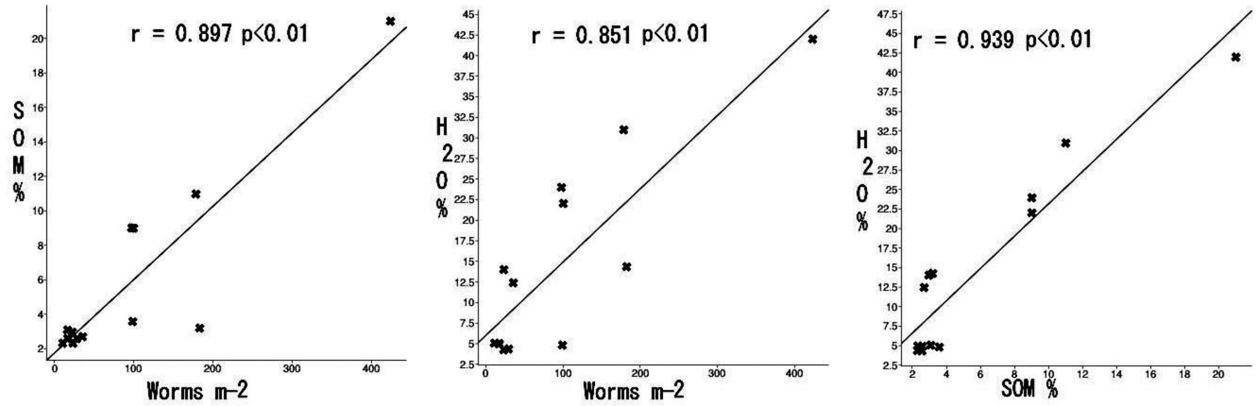

Figure 3. Linearregression of scatter plots and Pearson's Correlation for data from Table 8.

Table 9 summarizes farm data obtained in the author's current and previous studies including a pasture field trial at Samford in Queensland, Australia (Blakemore, 1994; 1997).

Table 9. Organic soil, yields with earthworm abundance (cf. controls) & farm species diversity

Farm (author)	Pasture/Crop	SOC %	H_2O%	Yield %	Worms%	Total Spp
1 Samford (Blakemore 1994)	Pasture	-	7.2	26.6	81.8*	23
2 Haughley (Blakemore 2000)	Wheat	128.6	40.9	16.2	78.6	8
3 Kahariam (current study)	Rice	26.1	-11.5	33.3	56.5	21
4 Penalosa (current study)	Sugarcane	40.0	11.5	80.0	121.7	12
	Overall Mean	**64.9%**	**12.0%**	**39.1%**	**84.7%**	**13 Spp**
	Crop Means		**13.6%**	**43.2%**	**85.6%**	

*At Samford, earthworms ca. 100 m^{-2} were added to each (0.5 m^{-2}) treatment plot one year before harvest with control population mean at 27.5 m^{-2} (Blakemore, 1994: tabs. 2.6; 5.1; 5.11), other sites had populations determined by vagaries of nature and respective management regimes.

Correlation (Pearson's r = 0.807, n = 4; http://www.wessa.net/) indicates a positive relationship of earthworms with pasture/crop yield (mean 39.1%), confirming van Groenigen *et al.* (2014). Cursory survey of a few days on both Philippine farms found abundances similar to Haughley but greater diversity: also with ~23 species identified (including several new native species and new exotic records). Kahariam organic farm had 21 and Peñalosa's about a dozen, including vermicomposter *Eudrilus eugeniae* that was dominant in wormbeds at both sites (see Blakemore, 2015, 2016a and species data in Appendix to this paper). The farm at Samford, Australia had highest biodiversity (23 spp). Average numbers of species per site is 13 spp, double the six or fewer mainly lumbricids claimed in previous summary of earthworm biodiversity studies (e.g. Lee, 1985).

Discussion

The current study supports a natural and viable option for both mitigation and adaptation to biodiversity loss and global climate change, even if human emissions continue at present rates. It considers the status of resident earthworm populations and crop yields as evidence of healthy soils and sustainability of organic farming methods in both temperate and tropical soils. Shortcomings in the current study, e.g. brevity of survey, lack of glomalin data, and failure to weigh all Filipino samples nor yet completely identify them (Appendix), were mainly due to lack funding for basic support in the field; nevertheless statistically significant results were achieved quickly and economically. Biological variation is invariably present in Nature, giving marginal significance of some results at $p<0.1$ level for the smaller data sets, but this is also why conventional agronomic trials use sterilized mesocosm/pot soils: to avoid the "complication" of excessive yield when an earthworm is present. Analyses of the main study crops (viz. wheat, rice, sugarcane) and of a few incidental plots (e.g. maize, bananas, vegetables) show definite trends indicative of research meriting further investigation, should funding be suitably prioritized. However, as International Foundation for Organic Agriculture (IFOAM) President Andre Leu (quoted from Lappé, 2014) points out: "*Fifty-two billion dollars is spent annually on agriculture research worldwide, but less than 0.4 percent* [i.e., ca. $200 million] *is spent on organic farming systems*". Following the Paris COP21 meeting in December, 2015 this situation may soon change and the role of organic farming in carbon sequestration, food security and biodiversity be widely recognized and more broadly supported (via http://4p1000.org that is committed to ensuring at least 50% adoption of agroecology approach by 2020).

Although the comparisons of organic and conventional farming for temperate wheat and tropical sugarcane were found statistically valid and meaningful, the data for the Filipino rice paddy are perhaps less certain being based on fewer samples, also the absolute SOC values were much lower than the other two crops. This may be accounted for its relatively recent conversion to organic (since 2009), the lower compost applications (initially 3 t ha^{-1}, then reduced to 1.5 t ha^{-1} without apparent loss of yield) and, perhaps most significantly, the difficulties in comparison between paddy that are periodically inundated, drained or in a fallow phase. Particular management differences were that the conventional rice was rainfed (upland) while the organic had supplementary river ram-pump and windpump irrigation options. Conventional yields may have also been depleted by an obvious problem in their rice paddies of Golden Apple Snail (*Pomacea spp*.) that were not found on the organic fields which were also mostly unaffected by Filipino's common Black Bug [*Scotinophara coarctata* (Fabricius, 1798)] infestations. Whether this resistance was due in part to more resilient plants with synergistic trophobiosis (e.g. Paull, 2007) is unknown. Suppression of insect pests such as aphids and psyllids in response to vermicompost applications are noted in a comprehensive review (Magdoff & Weil, 2004). In Europe, Zaller *et al.* (2013) found that presence of earthworms in mesocosms also reduced mollusc herbivory by 60% compared to worm-free controls. Such factors may be important additional benefits for vermicomposting/organic farming in themselves meriting further research funding.

Surprisingly, only a few other other rice studies have considered earthworms: one (Sahrawat, 1983) gave organic C (%) variations in Filipino rice paddy soils from 0.63-5.46% (mean 2.0%) – all higher than the Kahariam findings (of 0.54%). While not considering organics per se, long-term fertilizer treatments for 16 yrs on paddy in China, had seven species of earthworms that were depleted under a wholly chemical treatment (*Xiang et al.*, 2006) but that positively correlated to SOC and total N of plots and also with rice paddy yield. Their SOC values (1.65-1.78%) were also higher than Kahariam's (0.54%) but approached the Peñalosa rice SOC value (2.28%). From their data it is calculated that Chinese paddy plots fertilized with manure had total SOC 2.06 t ha^{-1} extra compared to unfertilized plots. This is equivalent to 7.56 t ha^{-1} extra CO_2e for the Chinese organic fertilizer rice paddy.

Soil bulk densities for Kahariam organic vs. conventional paddy (Table 2) are estimated at 1.50 vs. 1.53 g cm^{-3}, to give total SOC (0.541 x 1.50 x 15=) 12.17 vs. (0.429 x 1.53 x 15=) 9.85 t ha^{-1} ; which differ +23.6% or by 2.33 t ha^{-1} extra C or 8.5 t ha^{-1} extra CO_2e which is similar to the Chinese figure of 7.56 t ha^{-1} extra.

Given that 165 million ha are planted to paddy rice, it may be speculated that if all converted to organic with similar results then 165 x 8.5 = 1.40 billion tonnes extra CO_2e sequestered. Moreover, these values are for 0-15 cm topsoil and may reasonably be doubled for 0-30 cm (as per Valzano *et al.* 2005: 9, 67) to give total of ca. +2.8 Gt CO2e above conventional paddy storage levels, equal to annual emissions of either the EU 'Eurozone' or India (2.0-2.5 Gt in 2010 as reported by wikipedia.com on data from EDGAR database created by EU Commission and Netherlands Environmental Assessment Agency in 2013 http://edgar.jrc.ec.europa.eu/news_docs/pbl-2013-trends-in-global-co2-emissions-2013-report-1148.pdf).

Regarding the sugarcane data, given that 26.5 million ha are planted to sugarcane globally in 2013 (FAO 2015b) with most production in Brazil, India, China and Thailand, if trash burning ceased and all fields converted to organic with somewhat similar results to those presented herein, then 26.5 ha x 21.3 t ha^{-1} CO_2e = 564.5 million t extra CO_2e. Furthermore, these values are for 0-10 cm topsoil and may be reasonably doubled for 0-30 cm depth (the actual value Peñalosa farm's SOC at 15 cm =~62.6 t ha^{-1}) to give total of ca. 1.1 Gt CO_2e above conventional canefield levels, which is approximately the same as Japan's annual fossil fuel carbon emissions of ca. 1.17 Gt. This raises possibilities of carbon credit schemes to offset emissions from developed countries in exchange for tropical organic growers conversion to organic production (such exchanges between countries were recently ratified at COP21 in Paris in 2015).

Reinterpretation of the Haughley data (Blakemore, 1981; 2000) confirmed its significance, with 111.7 t ha^{-1} extra CO_2e storage in the organic wheat field soil; and it becomes even more meaningful as the need to remedy atmospheric carbon and concomitant climate change becomes more critical (see http://4p1000.org/). This is especially pertinent since 220 million ha globally were planted to wheat in 2013 (FAOSTAT 2013). If all were to be converted to organic with similar results then 111.7 x 220 = 24,574 million tonnes or 24.6 Gt extra CO_2e sequestered in topsoil – almost exactly double the OECD members' emission rate (of 12.6 Gt CO_2 yr^{-1}). These values for ca. 0-20 cm topsoil may reasonably be at least doubled for >20 cm layer (e.g. Valzano *et al.*, 2005) to total ca. 49.2 Gt CO_2e above comparable arable wheat C stock, which is much greater than entire global CO_2 emission of ca. 40.0 Gt CO_2 projected for 2014 (CDIAC, 2015).

In comparison to Haughley, a long-term agronomic plot trial established in Pendleton, Oregon in 1931 of winter wheat-summer tilled fallow with organic or synthetic fertilizers found after 70 yrs that the major soil carbon pool – including glomalin – was dependent on arbuscular mycorrhizal fungi (Wuest *et al.*, 2005). These authors (on page 164) also found statistically significant correlation (here recalculated as $r = 0.89$, $n = 9$, $p<0.001$) between glomalin and earthworm counts that were maxima of 2.59 mg g^{-1} and 144 worms m^{-2} in organic fertilized plots (cf. 178.6 worms m^{-2} in organic wheat at Haughley). These authors failed also to weight their worms.

Reinterpretation of this Pendleton data (Wuest *et al.*, 2005) also shows a correlation between earthworms and total soil organic C ($r = 0.70$, $n = 9$, $p<0.03$) with recalculation of total topsoil C (including glomalin) in the plot fertilized with manure (22.4 t ha^{-1} yr^{-1} = 111 kg ha^{-1} yr^{-1} N equivalent) of 15.9 g kg^{-1} total carbon. This would translate as approximately 32 t ha^{-1} SOC (from 1.59 C% x 1.35 estimated BD g cm^{-3} x 15 cm sample depth) which is comparable to the Haughley winter wheat organic field value of 67.2 t ha^{-1} to 20 cm depth SOC. Incidentally, Pendleton's 70 year organic fertilizer treatments sustained higher grain yields (by +5-53%) and a greatly increased water infiltration rate (of 2.34 mm min^{-1}) compared to any other of their plot treatments; also similar to the case at Haughley.

In a long-term study commencing in 1892 at the Magruder experimental plots in Oklahoma, an untreated plot without any fertilizer continues to produce winter wheat grain yields >1 t ha^{-1} although its SOM has declined from 4 to 1% (Girma *et al.*, 2007). This exemplifies scale of loss of SOM under cultivation that may be redressed by crop rotation and adding FYM as at Haughley.

Yet another long-term trial at Järna, Sweden that lasted 32 years was reported (Granstedt & Kjellenberg, 1997) as having higher soil fertility and higher yields of wheat and potatoes in organic (biodynamic) treatments than in conventional inorganic NPK fertilizer treatments. Humus, organic C and earthworm activity were also improved, similar to the results in the current studies.

Also supporting the findings presented herein, a meta-study by Rodale Institute concluded that if all cropland were converted similar to their regenerative model it would sequester 40% of annual CO_2 emissions; adding pastures to that model would add another 71%, effectively overcompensating for the world's yearly carbon dioxide emissions (Rodale, 2015). Moreover, their side-by-side trial after 30+ years, slightly less than the Haughley trial that was 42 years when reported (Blakemore, 1981), showed organic : conventional yields to be equivalent over a range of crops with organics higher in drought years; the energy input lower (by "1,300 MJ/acre/yr"); greenhouse gases lower by ("500 lbs CO_2/acre/yr"); and profits higher (by "US$368/acre/yr"). Earlier results from Rodale were reviewed after 20 years (Pimental *et al.*, 2005). Such findings refute a recent report (Seufert *et al.*, 2012) that, while proclaiming all organic yields lower than conventional chemical yields, considered neither earthworms ecology, economics nor carbon *per se*.

According to FAO, permanent pastures occupied an estimated 3.6 billion ha (36,000,000 sq km) in 2000, representing 26% of the world land area and 70% of the world's agricultural area. If all pasture managed similar levels of carbon to the findings from the Haughley study its total SOC (222 t ha^{-1} x 3.6 Gha =) ca. 800 Gt C or 3,000 Gt CO_2e matches almost exactly the current atmospheric concentration of 3,000 Gt CO_2. The pasture at Samford, Qld, had 3.6% SOC at 0-10 cm and 1.2% at 10-28 cm (C. Thompson, pers. comm.) this gives about 72 t ha^{-1} SOC at 0-28 cm.

Darwin (1881) conservatively estimated 17-40 t ha^{-1} yr^{-1} of earthworm casts for the whole of the UK; if average wormcast SOM is ca. 12% then x 0.58 conversion factor = 1.2-2.8 t ha^{-1} yr^{-1} C that for 3.6 Gha pasture globally would be ≈10 Gt C yr^{-1} or ca. 100 Gt yr^{-1} every 10 yrs for organically converted pastures. It seems the great evolutionary scientist and first soil ecologist had already unintentionally provided a direction to help fix our unanticipated contemporary CO_2 problems too.

However Darwin's figures, as with those calculated herein are likely wide underestimations of the potential of earthworms to influence the storage of soil carbon at depth. There seems some major discrepancy in the calculations of total global carbon in soils which is given by COP21's International "4 per 1000 (2016)" Initiative as just 1,500 Gt whereas NASA (2011) has 2,300 Gt carbon. The NASA figure is taken from the US Department of Energy and their original source for the soil carbon budget is "Houghton (2007)". Accessing Houghton (2007: 316), it is stated:

"*The amount of carbon contained in terrestrial vegetation (550±100 Pg) is on the order of the amount in the atmosphere (800 Pg). The organic matter in soils is two to three times this amount [1500–2000 PgC in the top meter and as much as 2300 Pg in the top 3 m (Jobággy* [sic lapsus] *& Jackson 2000)]*"

Then, from Jobbágy & Jackson (2000), I found they based their analysis on >2,700 soil profiles in three global databases to give 2,344 Pg C in the top 3 m, or 56% more than 1,502 Pg estimated for the first meter. This likely explains 4p1000 *vs*. NASA discrepancy, i.e., 1 m *vs*. 3 m soil depths.

The top 1 m of soil comprises inorganic (~950 Gt) *vs*. organic (~1,550 Gt) forms (Lal, 2008 on data partly from Batjes, 1996) from whence it was calculated: "*[Carbon] amounts to 2157–2293 Pg* [= Gt] *of C in the upper 100 cm. Soil organic carbon is estimated to be 684–724 Pg of C in the upper 30 cm, 1462–1548 Pg of C in the upper 100 cm, and 2376–2456 Pg of C in the upper 200 cm.*".

Nevertheless, no-one seems to account for actual soil surface area miscalculations which Jobággy & Jackson (2000: tab. 3) give at 121 x 10^{12} m^2 from "land area values based on Whittaker (1975) and Jackson *et al*. (1997)". These calculations by Jobággy & Jackson (2000: tabs. 3-4) take mean soil carbon figures for biomes (including tundra and deserts but naturally excluding icefields such as Antarctica and Greenland) and multiply by a **flat earth** area which is often erroneously given as 148,300,000 km^2 (= 14,830,000,000 ha = 148 x 10^{12} m^2) or supposedly about 30% of total global surface area. This is a mistake when it is realized that topographical terrain is not flat but undulating and especially the soil micro-relief surface area even down to the size of worm casts/burrows is many times greater. Moreover, Blakemore (2016b) suggests soil carbon values have much higher totals when calculations are standardized with glomalin and taken to depths >3 m.

Conclusions

The current study reports potential for organically managed pasture and broad-acre crops of wheat, rice and sugarcane to increase yield whilst maintaining carbon/water storage and biodiversity in soils. Earthworms are seen as both monitors and mediators of these processes in the field (as often demonstrated from pot experiments), whilst the contributions from vermicomposting species are important for processing and recycling all biodegradable “wastes” into a valuable organic fertilizer resource called vermicompost that far surpasses charcoal additives heavily promoted as “biochar”.

Highlighted is a need for standard methods of earthworm and soil sampling to allow ease of comparison of biodiversity, soil moisture and carbon budgets (including glomalin) – issues addressed in an accompanying and complementary paper (Blakemore, 2016b). Actual true global soil terrain surface area is also required as noted in the latter paper.

Taking recent atmospheric CO_2 concentration as 400 ppm and total carbon as ~800 Gt (= 3,000 Gt CO_2 from NASA 2011), an estimate is that 1Gt C = 0.5 ppm CO_2. Thus the potential extra C sequestered in land under the three crops tested here, should they all be converted to organic, would be in the order of (wheat 49.2 + rice 2.8 + sugar 1.1 =) 53.1 Gt CO_2e (x 0.273 conversion factor) = 14.5 Gt C which equates to ca. 7.25 ppm reduction or roughly 7 points off Mauna Loa’s current value of atmospheric CO_2 of 400 ppm.

As shown for all three crops in the current study, organic farming can provide substantially higher yields with advantages of lower input costs (in terms of agrichemicals, spray safety equipment, irrigation, etc.; plus manures, sugar-mill & vegetable wastes are freely available), whilst also supporting more abundant soil biodiversity **and** sequestering carbon (cf. Seufert *et al.*, 2012). Organic farming is often more labour intensive which, nevertheless, helps resolve dual problems of rapid urbanization with high rural unemployment. Since organic produce has longer shelf-life (e.g. Granstedt & Kjellenberg, 1997: fig. 3), food spoilage and hunger are also reduced. Moreover, when all organic wastes are entirely recycled then environmental pollution and contamination are removed as downstream externalities. Other social, economic and ecological impacts are less harm to farmworkers and their families (who in the Philippines as in other developing countries often live in or near sprayed fields and draw water locally), to consumers and to the environment from poisonous biocides plus fewer problems with runoff pollutants or eutrophication of waterways and coastal coral reefs that are considered important in places like Qld and PI. Darwin’s humble earthworm may be thus seen as key to providing all these naturally beneficial services with the challenge now to confirm these organic yields, soil carbon data and earthworm abundances on a broader scale and in greater depth.

Indeed, as Lady Eve Balfour –originator of the Haughley Experiment and co-founder / president of the UK’s Soil Association – said in Introduction to *Harnessing the Earthworm* (Barrett, 1947):

'*When the question is asked, "Can I build top-soil?" the answer is "Yes", and when the first question is followed by a second question, "How?" the answer is "Feed earthworms*"'.

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Appendix

Earthworms collected in 2013-2014, using Blakemore (2000, 2012, 2016a) for Families and species IDs wherein proper taxonomic authority/synonymies may be found plus several mtDNA barcodes.

No.	Code	Earthworm FAMILY/Spp.	Kahariam organic farm	Peñalosa Negros organic farms
I	E	EUDRILIDAE		
1	E	*Eudrilus eugeniae*	x	x
II	N/E	MEGASCOLECIDAE		
2	N?	*Amynthas spp.* (unidentified)	x	x
3	E	*Perionyx excavatus*	x	
4	N	*Pheretima cf. decipiens*	x?	x?
5	N	*Pleionogaster adya**	x	
6	N	*Pleionogaster sp. nov.2**	x	
7	E	*Metaphire bahli*	x	x
8	E?	*Metaphire cf. tschiliensis**	x	
9	E	*Metaphire houlleti*		x
10	E	*Pheretima philippina lipa**	x	
11	E	*P. philippina victorias**		x
12	E	*Polypheretima elongata*	x	x?
13	E	*Polypheretima* cf. *stellari*		x?
III	E	OCTOCHAETIDAE/BENHAMIINAE		
14	E	*Dichogaster modigliani*	x	
15	E	*Dichogaster saliens**	x	
16	E	*Dichogaster annae*	x	
IV	E	OCNERODRILIDAE		
17	E	*Eukerria sp.* (unidentified)	x	
18	E	*Ocnerodrilus* sp? (unidentified)*	x	
19	E	*Ramiella cf. bishambari*	x (+ in Conv. rice)	x (in Org. rice and canefields)
V	E	GLOSSOSCOLECIDAE		
20	E	*Pontoscolex corethrurus***	x	x
VI	E/N?	MONILIGASTRIDAE		
21	E	*Drawida barwelli*	x	
22	E	*Drawida impertusa*	x	x
23	E?	*Drawida sp.* (unidentified)*	x	
VII	E/N?	ENCHYTRAEIDAE		
24	E?	*Enchytraeus spp.*	x	x
Total spp			21	12

Codes: N–native; E–exotic; x–present; *native spp new to science or new exotic records for Philippines; e.g., *Dichogaster saliens* (Beddard 1893) is a new Filipino record; **South American *Pontoscolex corethrurus* is present but not dominant as it often is in soils of declining quality.