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\*Corresponding author: Manono B. O.  
Centre for Sustainability: Agriculture,  
Food, Energy, Environment, University of  
Otago, PO Box 56, Dunedin 9054, New  
Zealand; School of Environment and  
Natural Resource Management, South  
Eastern Kenya University, PO Box 170,  
Kitui 90200, Kenya  
E-mails: [ombasa.manono@yahoo.co.uk](mailto:ombasa.manono@yahoo.co.uk),  
[bmanono@seku.ac.ke](mailto:bmanono@seku.ac.ke)

Reviewing editor:  
Manuel Tejada Moral, University of  
Seville, Spain

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## SOIL & CROP SCIENCES | RESEARCH ARTICLE

# New Zealand dairy farm effluent, irrigation and soil biota management for sustainability: Farmer priorities and monitoring

B.O. Manono<sup>1,2\*</sup>

**Abstract:** Agricultural science has produced compelling data to show that soil biota may be exploited to increase agricultural efficiency. However, field application is entirely dependent on farmers' knowledge. This study assessed current New Zealand dairy farmer's soil management practices, knowledge on earthworms and soil microbes and their willingness to monitor and manage them for nutrient use efficiency. Farmers indicated that soil quality influences their farms' overall success with 84% acknowledging that it is enhanced by irrigation and effluent application practices. Although they indicated that earthworms and soil microbes are responsive to management, there were clear gaps in implementation at the farm scale level. For example only 6% of the respondents used soil microbes as soil quality indicators. Scientific findings are not transmitted adequately to farmers, who increasingly rely on scientific expertise to maintain or boost production. Farmers are willing to monitor and use earthworms and soil microbes in future soil management practices. However, they lack the expertise and skills necessary for this management. Therefore, scientists and policy makers should actively involve farmers to develop specialised, reliable and less technical decision support tools that match farmer's goals, aspirations, knowledge, constraints and opportunities for adoption.

### ABOUT THE AUTHOR

B.O. Manono works as a full time lecturer in the School of Environment and Natural resource Management, South Eastern Kenya University. Prior to that, he was a full-time researcher at the Centre for Sustainability: Agriculture, Food, Energy, and Environment (University of Otago) in New Zealand where he obtained his PhD in Agricultural Ecology. Manono obtained his Masters in Waste Management with Environmental Management from the University of the West of Scotland and a BSc from Maseno University in Kenya. Research reflected in this paper reflects his future research and professional interests, thus: (i) focussing on integrating crops, soil, water and land management to crop production priorities and future food security challenges, (ii) sharing innovative teaching and research with colleagues and resource users.

### PUBLIC INTEREST STATEMENT

Individual farmers are the most important decision-makers about what happens on land and the sustainability of food and fibre production. An understanding of the importance of soil biota for sustainable farming is a first step in taking good care of the land. Farmers, environmentalists, scientists, other industry stakeholders and the general public may have varied and often common interests on the issue of sustainable farming. This paper explores how New Zealand farmers relate with soil and land in view of the current demands for sustainable farming practices. Farmer knowledge and perception can enrich scientific understanding based on local experience by providing valuable insights not presently covered in scientific literature and in developing programs that consider farmer priorities. Improved farmer understanding of the importance of earthworms and microbes can enable development of suitable decision support tools, especially sustainability indicators to promote the potential contribution of soil biota in agricultural sustainability.



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A key finding of this study is that farmers' knowledge can help in prioritizing re-search options that fill scientific lacunae and at the same time produce information and guidelines that are readily accessible to the working farmer.

**Subjects: Agriculture; Agronomy; Biodiversity & Conservation; Land Reclamation Pedology; Social Sciences; Soil Sciences**

**Keywords: local farmer knowledge; soil biota; soil quality monitoring; interdisciplinary research; correspondence of science and farmer knowledge**

### 1. Introduction

Farmer's local Knowledge has been valuable in the maintenance and management of the environment and natural resources in developing countries (Sillitoe, 1998). This practical knowledge is traditionally learned by practice and transmitted through generations of families (Berkes, Folke, & Gadgil, 1995; Berkes, Colding, & Folke, 2000; Walters & Holling, 1990). In developed countries, farmers have readily adopted scientific knowledge into their soil and wider farm management practices (Morgan & Murdoch, 2000). Science is considered by many observers to be more reliable and generally applicable than farmer's knowledge in guiding sustainable environmental management and production (Moller et al., 2009; Stephenson & Moller, 2009). Nevertheless, uncritical adoption of reductionist science has contributed substantially to reduced sustainability in some industrial-scale agricultural systems, e.g. through soil degradation, pollution and loss of biodiversity. Furthermore, relying only on technical fixes based on expert knowledge might leave little space for farmer input and discourage the transmission and trust in farmer knowledge tuned to local farming conditions.

The Convention on Biological Diversity and the Millennium Ecosystem Assessment stress the need to incorporate local knowledge into land and resource management. The importance of farmers' knowledge for sustainable agriculture has long been emphasised, but in recent years there have been growing calls for it to be "rediscovered" and "reinserted" into farming where science has displaced it (Röling & Jiggins, 1994; Winter, 1997). The recent Intergovernmental Platform on Biodiversity and Ecosystem services (IPBES) has a special initiative in place to combine science and local knowledge to promote ecosystem services. This study applies this general approach to explore the scope of combining local knowledge and science approaches to promote soil quality and emphasise important elements of the biota, especially earthworms and soil microbes, for sustainable farming.

Adoption of sustainable practices, be they scientific, or based on learning by doing requires accurate observation, monitoring and judgement (Coughenour, 2003; OECD, 2001; Röling & Jiggins, 1994). Thus, successful management will greatly depend on how well farmers understand the ecological elements of their agro-ecosystems (Tilman, Cassman, Matson, Naylor, & Polasky, 2002). Farmers and farms are recognised as the main "sites of action" for sustainability and resilience, even though major shocks and drivers of local systems may be located in distant sectors of world food supply chains (Darnhofer, Fairweather, & Moller, 2010). Involving farmers in sustainable choices is particularly important (Menzel & Teng, 2010), just as participation is fundamental for promoting "environmentality" (Agrawal & Lemos, 2007). Incorporation of farmer knowledge enhances practicality and relevance, which are prerequisites in the "real world" of application (Moller & MacLeod, 2013; WinklerPrins & Sandor, 2003). This is because farmers place value in their own knowledge and experience in making management decisions (Beedell & Rehman, 2000; Lyon, 1996; Percy, 2005).

Knowledge is not in itself sufficient to ensure sustainable practices, which also require capacity and willingness to respond when and where necessary. It is therefore essential to understand farmer motivations, values, perspectives and priorities (Carolan, 2006; Carr & Wilkinson, 2005; Eshuis & Stuiver, 2005) and the ways in which they integrate these into day-to-day farming routines (Carr & Tait, 1991; Gillmor, 1986). Environmental orientation and commitment to sustainability have the potential to become the prime determinants of whether or not efficient soil quality management strategies are practiced.

Unlike the European Union, where fertilizer applications are under strict and regulated prescriptive plans (Bateman et al., 2006), fertilizer use in New Zealand farms is under-regulated. Thus, New Zealand farmers and agricultural advisers must make decisions to optimise fertiliser and soil quality management protocols even as the use of external ecological subsidies increases (MacLeod & Moller, 2006; Manono, 2014; PCE, 2004). The latest review of best fertilizer management programs incorporates consideration of nutrient budgets, management plans, effluent (the generated material containing cow excreta and urine diluted with wash down water after milking in the cow shed) spreading, cadmium contamination, nitrate management, GHG emissions, increased fertilization, water quality issues, climate change concerns, market indicators and public expectations (NZFMRA, 2007). The exclusion of soil organisms in this analysis suggests that their beneficial roles have little support from science despite the volume of knowledge attesting to their efficacy (Barrios, 2007; Coleman & Whitman, 2005; Wardle et al., 2004). Moreover, soil quality depends on the functioning of all soil components (Karlen, Ditzler, & Andrews, 2003; Parr, Papendick, Hornick, & Meyer, 1992) and it is therefore not possible to isolate soil biota from other aspects of soil management practices.

Farmers require early warning signals and monitoring tools at the farm scale level to enable them assess the status of their soils. Unfortunately, most approaches reported in literature emphasise soil chemical and/or physical properties (Lal, Blum, Valentin, & Stewart, 1997; Oldeman & Van Lynden, 1997), rather than soil organisms. To qualify as biological soil indicators, data on the belowground biota should function as predictors of changes in organic matter, nutrient cycling, soil structure, and productivity (Ettema & Wardle, 2002; Janzen, 2006). Biological indicators should be stable over time when conditions are invariant and able to discriminate human-induced changes from natural background fluctuations (Van Straalen, Pankhurst, Doube, & Gupta, 1997). They must also be specific for environmental factors and sensitive to agricultural management measures. The awareness, knowledge and value farmers attach to soil management and biota have received little attention from the academic soil research community. Furthermore, the trust and level of understanding of scientific methods of soil management used by farmers have not been subjected to professional analysis.

While sustainable soil resource use require that farmers understand the best soil management practices, they can lack familiarity and experience with such practices (Park et al., 1997). Such practices are knowledge intensive, non-prescriptive, and demand attention to detail, observation and an understanding of basic scientific principles (OECD, 2001; Röling & Jiggins, 1994). Because of the complexity and need for farmers to adopt these practices in their day-to-day soil management practices, it is significant to seek their knowledge. It is with this background that this study investigated farmer awareness of soil quality, factors underlying their interactions with soil and their motivation in making soil management decisions. The aim was to establish strategies for monitoring and managing earthworms and soil microbes for farming sustainability through their relative use as soil quality indicators. The specific objectives were: (i) to assess the factors that farmers consider important for the success of their farming operations; (ii) to assess farmer awareness of earthworms, soil microbes and their roles in soil functioning and how they are impacted by soil management.

## 2. Methods

### 2.1. Study area and farmer recruitment

This study is based on responses to a questionnaire sent to dairy farmers in The Waimate District (44°38' to 44°54' S and 170°59' to 171°08' E) of the South Canterbury region, New Zealand. The district borders the Waitaki River in the south, the Pareora River in the north and the Hakataramea Valley to the west. The area supports a productive pastoral farming typical of the New Zealand agroecosystem landscape. Respondents were either owners and/or managers of farms with systems in place for collecting and storing excrement from milking sheds and yards. The effluent is redistributed onto paddocks (individual farm fields) either in conjunction with irrigation or separately. The questionnaire comprised 30 multiple choice questions designed after trials to take no longer than 25 min to complete. Where the response did not require a Yes or No answer, it elicited a response from a standardised five-point scale to demonstrate agreement to several propositions. A blank

space was left after each question for respondents to give an open-ended response or clarification. The study survey was approved by the University of Otago Ethics Committee (Permit No. 11/287). Participating farmers were given informed written consents, had their anonymity guaranteed, were reminded that they did not have to participate and that they could stop participation at any stage or refuse to answer certain questions. Forty-five questionnaires were sent out of which 34 responses were received. Some respondents did not answer every question. Therefore the percentages reported in the analysis are for individual questions.

### 2.2. Data analysis

Responses were analysed using Genstat (Release 16) software for Windows. As scores were ordinal rather than numerical scales, statistical tests for differences in responses to different issues were based on comparisons of frequency distributions. With just 34 responses spread across 5 categories, the power of tests for variation in perception between issues was low. This necessitated to test whether the number of farmers scoring below “neutral” (e.g. “neither agree nor disagree”) was significantly different from the number scoring above “neutral” for a given question, i.e. a random expectation of equal number of respondents scoring agreement or disagreement with the proposition (a simple  $\chi^2$  test was used). In some cases, Wilcoxon Matched Pair tests were used to test whether the proportion scoring “above” vs. “below” neutral differed significantly for a given salient pair of questions. This procedure was applicable here because the same farmer answered both questions in the comparison.

### 3. Results

#### 3.1. Factors farmers consider important in the success of their farming operations

Among the factors listed, farmers considered soil quality to be the most important contributor to the overall economic, social and environmental success of their farming operations (Table 1).

**Table 1. Factors farmers consider important in contributing to the social, economic and environmental success of their farming operations over the past five years**

Statement	% Response				
	Very important and important	Neither important nor unimportant	Very unimportant and unimportant	n = 34	p-value testing asymmetry <sup>†</sup>
Soil quality	100			34	**
Animal health and welfare	100			34	**
Animal production	100			33	**
Pasture management	100			34	**
Effluent storage and dispersal	93		7	30	*
Irrigation water supply, storage and use	92		8	25	*
Water quality in nearby streams/waterways	84		16	32	*
Scope of farm to be inherited by family members	82		18	34	*
Time to participate in community activities	74		26	34	**
The number and varieties of tree species apart from pasture	44		56	34	
Number and varieties of invertebrates species	44		56	34	
The number and varieties of bird species frequenting the farm	27		73	33	

<sup>†</sup>Simple  $\chi^2$  p-values from the test whether the number scoring very important and important differ from that scoring unimportant and very unimportant.

\*The p-values signify significant differences at:  $p < 0.05$ .

\*\*The p-values signify significant differences at:  $p < 0.01$ .

Respondents also acknowledged that irrigation and effluent enhanced soil quality with 84% agreeing that both irrigation and effluent have multiple (synergistic) effects on soil quality (Table 2). Farmers were aware that irrigation and effluent dispersal increase the number and the activity of earthworms. The number agreeing differed significantly from those scoring “disagree” (for both irrigation and effluent; Table 2). In contrast, fewer respondents agreed that irrigation promotes soil microbial activity (Table 2). The difference between responses to the earthworm and microbial questions was statistically significant (Table 2).

**Table 2. Farmer views on soil quality, how soil quality is affected by irrigation and effluent dispersal, and the overall goal of fertilisation**

Issue	Statement	% Response					n = 34	p-value testing asymmetry <sup>†</sup>
		Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree		
Irrigation and effluent dispersal	Irrigation increases soil quality	23	55	19			31	**
	Irrigation increases number/activity of earthworms	25	66	9			31	**
	Irrigation promotes soil microbial activity	13	53	27	7		30	*
	Effluent dispersal increases soil quality	35	52	6	6		31	
	Effluent dispersal promotes earthworm numbers/activity	42	45	10	3		31	*
	Effluent & irrigation have multiple effects on soil quality	31	53	16			32	**
	Irrigated paddocks with effluent have higher quality pasture than non-effluent but irrigated paddocks	13	29	48	10		31	
	I leave cows to graze for longer in effluent paddocks than non-effluent paddocks	3	10	27	47	13	30	
	I spread effluent to prevent it from reaching waterways	3	10		43	43	30	*
	I spread effluent as a viable nutrient resource	42	55	3			31	***
Overall goal of fertilization	My goal is to maintain the current soil quality levels	47	32	6	15		34	*
	My goal is to build soil fertility levels for raising future productivity	38	44	12	6		34	**
	My goal is to arrest/stop previous soil quality decline	19	53	19	9		32	*
	My goal is to try to minimise how much fertilizer I add to the soil	24	52	15	9		33	*
	I deliberately add more than recommended to ensure high production			15	48	36	33	***

<sup>†</sup>Simple  $\chi^2$  p-values from the test whether the numbers scoring strongly agree and agree differed from that scoring strongly disagree or disagree.

\*The p-values signify significant differences at:  $p < 0.05$ .

\*\*The p-values signify significant differences at:  $p < 0.01$ .

### **3.2. Goals for fertilization and soil management**

Farmers fertilize their soils to attain three main objectives: (i) to minimise the amount of fertilizer added (ii) to maintain current soil quality and (iii) to build soil fertility for future productivity (Table 2). Even though the majority of respondents aimed at minimising fertilization costs (Table 2), this was not reflected in the actual fertilization, as farmers did not consider fertilizer costs in making this important decision (Table 3). This observation suggests that farmers are prepared to enhance their soil quality as much as costs will allow.

Nutrient management models underpinned the farmers' decision-making processes on fertilization (Figure 1); >50% of farmers used the "Overseer" model most times (Table 3). Farmer familiarity with soil quality indicators as used by scientists was highest for soil pH, moisture and nitrogen, indicators that are emphasised by extension workers and consultants. In contrast, their familiarity with biological and physical soil quality indicators were very low (Table 4).

### **3.3. Farmers' views on managing and monitoring earthworms and soil microbes**

Although farmers ranked biodiversity low in determining their farms' overall successes (Table 1), they were aware of the benefits of earthworms and soil microbes (Table 5). Their awareness of the roles played by soil microbes was lower than that of earthworms. Furthermore, only 6% of the farmers monitored soil microbes on their properties compared with 71% who used earthworms as indicators of soil quality (Table 6). This was caused by lack of awareness in microbial measurements in irrigated or effluent dispersed soils. In contrast, they did notice changes in earthworm numbers in lands subjected to these treatments (Table 6).

Most farmers are willing to use earthworms and soil microbes in future soil quality management practices (Figure 2) for perceived benefits (Figure 3). However, they acknowledged their lack of expertise and skills necessary for these monitoring and management procedures. They however agreed that this is technically and economically feasible (Figure 3).

## **4. Discussion**

### **4.1. Soil quality management**

This study adopted the Soil Science Society of America Ad-hoc Committee's definition of soil quality as "the capacity of a specific kind of soil to: function within natural or managed ecosystem boundaries; sustain plant and animal productivity; maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997). The study focused on the farmers' opinions on soil quality as a contributor to the success of their farms.

The importance that farmers attached to chemical properties such as nitrogen, pH, and soil moisture in soil quality and nutrient management mirror the nitrogen-biased emphasis in soil management programs prepared by field fertilizer consultants. The lack of familiarity with some soil quality indicators used by soil scientists and consultants suggests that farmers need to expand their knowledge for maximum benefit. Unlike chemical indicators, those that entirely depend on soil physical and biological processes are most undervalued or least understood by farmers. In this case, technical jargon may have introduced an element of confusion. It is therefore important that scientists should adopt definitions that are readily understood by farmers, especially those without tertiary agricultural training.

### **4.2. Correspondence between science and local farmer knowledge on issues of soil quality, earthworms and soil microbes**

Farmers depend on the specialised knowledge of fertilizer company consultants for their soil nutrient requirement analysis. Farmers use nutrient models to calculate soil nutrient requirements but majority are not aware of anything to be added to nutrient models to improve their reliability in nutrient management. For example, five farmers made the comments below about the "Overseer" model:



**Table 3. Factors farmers take into account when making decisions whether to fertilize, what they check for in earthworm measures in the paddock and the use and reliability of nutrient management models**

Issue	Farmer action	Frequency action taken into account					n = 34	p-value testing asymmetry <sup>†</sup>
		Always	Most times	Sometimes	Occasionally	Never		
Motivation to fertilize	Recommendations from soil tests	50	47	3			34	*
	Cost of fertilizer	9	29	29	18	15	34	
	Whether the paddock receives irrigation water or not	22	26	33		19	27	
	Whether the paddock receives effluent or not	50	30	20			30	*
	Stocking rate	33	39	15		12	33	*
	Whether the paddock has been infested by weeds or not	6	9	25	6	53	32	
	Weather/season	24	29	32	6	9	34	
Earthworm checks	I record their numbers	14	7	7	7	64	28	
	I check for the presence/absence of earthworm casts	14	39	14	7	25	28	
	I check for the number and size of earthworm burrows		11	39	11	39	28	
	I dig an inspection hole to check for earthworms	35	26	16	13	10	31	
Nutrient models	How often do you use nutrient models	22	48	22	4	4	27	*
	How reliable are nutrient management models	17	38	45			29	

<sup>†</sup>Simple  $\chi^2$  p-values from the test whether the number scoring always and most times differ from that scoring occasionally and never.

\*The p-values signify significant differences at:  $p < 0.05$ .

“Lucerne and clover fixes nitrogen so ‘Overseer’ is bad for nitrogen leaching. ‘Overseer’ focuses too much on nitrogen and needs to balance other potential benefits”.

“‘Overseer’ needs to be practical in management of soils, plants and animals”.

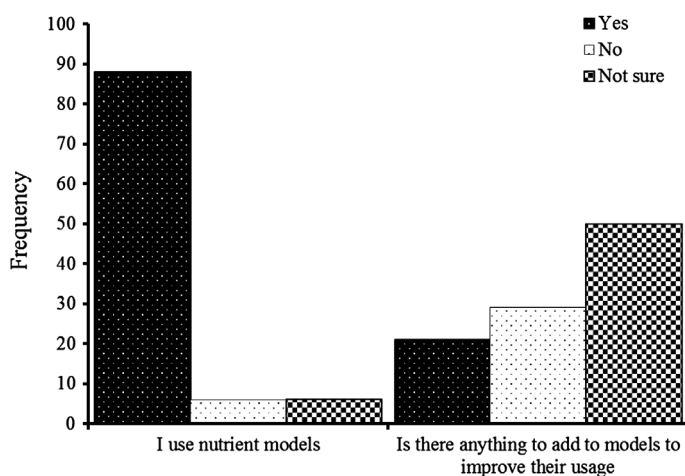
“Overseer should be more farm specific, soil type, farm type etc”.

“Quantifying effluent components, feed pad multiplications around time and stock are off Paddock”.

“There is high nutrient loses using ‘Overseer’. However, we use it because it is the Ravensdown (one of the two major fertilizer companies in New Zealand) policy and plan”.

These comments, lack of suggestions for improving nutrient models and the high number of farmers that lacked skills and methods in “Overseer” analysis indicate they used “Overseer” not because they understood the principles behind it, but because it is a requirement of fertilizer companies. The software behind “Overseer” analysis is provided free of charge in New Zealand for any willing farmer (Monaghan et al., 2007), but each farmer must rely entirely on fertilizer companies for their “Overseer” nutrient analysis. In spite of this, farmers had a general agreement on its reliability. This raises important issues of concern. Should scientific information be relayed to farmers through fertilizer company (or field) consultants and what are the roles of research institutions?

**Figure 1. Farmer use of nutrient models and their views on whether there is room for improvement.**



The low score for biodiversity in determining a farm’s success, imply that farmer’s do not understand their benefits. Moreover, farmers may view biodiversity negatively, e.g. as weeds or pests. Nevertheless, farmers are aware of the economic value of earthworms and soil microbes in general. They are appropriately informed on these two components of soil biota; they look for changes in them and shift their management procedures accordingly. For example, farmers indicated that they promote earthworms in their properties through: (i) frequent pH checks; (ii) reduced tillage; (iii) seeking advice from soil consultants; (iv) aerating fields; (v) using “spray fertilizer”; (vi) draining wet patches in paddocks, and (viii) continuous grazing. Some of these practices have also been recorded in scientific literature (e.g. in Curry, 2004; Lee, 1985; Manono & Moller, 2015).

Farmers familiar with earthworm roles actually encouraged earthworms in their properties and had higher earthworm numbers compared to those that did not (data not shown). These are the same farmers who monitored and managed earthworms by digging inspection holes and checking for casts. Farmers who engage in these practices may act as leaders of agricultural progress in their localities. In spite of this earthworm awareness and interest, farmers were not able to distinguish earthworm species. Two farmers gave their comments on this aspect:

“I just check for worms not species but would like to know more about this little guys”.

“I only know two types of worms in my farm, the small ones and the big ones, which I call ‘Maori’ worms”.

Very few respondents commented on the impacts of soil management on earthworms, but two notable comments are:

“There is soft soil in irrigated and effluent paddocks for earthworms to walk on”.

“There is more developed and deeper humus in irrigated areas that provide better habitat for earthworms”.

There were only a few comments about soil microbes ranging from:

“I don’t know of any available microbial test”.

“Our soil advisor tells us that our soils are good”.

to,

“I check microbial activity from the breakdown of dung”.



**Table 4. Farmer familiarity with soil quality indicators as described by soil scientists and field consultants**

Indicator	Level of awareness				Mean score	n = 34	p-value testing asymmetry†
	I know a lot about this indicator and how it is used to describe soil quality	I have heard of this indicator and I know a little about how it is used to assess soil quality	I have only heard about this indicator but I don't know how it is used to assess soil quality	I have never heard of this soil indicator			
Total carbon content	6	41	28	25	1.3	32	
Total nitrogen content	53	35	3	9	2.3	34	*
Bulky density	13	28	50	9	1.4	32	
Soil moisture	71	24	3	3	2.6	34	*
Soil porosity	18	50	21	12	1.7	34	*
pH (Acidity or alkalinity)	79	15	3	3	2.7	34	**
CO <sub>2</sub> released (Soil respiration)		24	41	35	0.9	34	
Potential mineralisable nitrogen	6	21	41	32	1.0	34	
Soil thatch	6	35	32	26	1.2	34	
Earthworm biomass and density (numbers and weights)	29	35	32	3	1.9	34	
Microbial biomass		26	56	18	1.1	34	

†Simple  $\chi^2$  p-values from the test whether the number scoring option 1 and 2 differed from that scoring option 3 and 4.

\*The p-values signify significant differences at:  $p < 0.05$ .

\*\*The p-values signify significant differences at:  $p < 0.01$ .

These farmer observations and experiences underpin their interest in earthworms compared to soil microbes. The fact that farmers were not interested in earthworm species identities suggests that farmers consider all worm taxa to contribute to soil quality.

Although soil microbes are highly responsive to changes in soil C and N (Bardgett, 2005; Lutzow et al., 2006), they are minute and therefore not accessible to the lay person. A challenge for science is to quickly develop creative options that link soil biota to conspicuous above ground productivity. Indicators of microbial and macrofaunal activity must be made relevant to the goals of the farmers. The potential benefits of improved biological activity in soils should be matched to the farmers' goals, aspirations, knowledge, constraints and opportunities for application. This is important because even if it can be supported by strong quantitative evidence, it will remain largely ineffective if it conflicts with other more important issues. Indicators are informative rather than predictive, and should be used only as tools to detect changes in soil that indicate effects beyond the normal soil operating range. It is therefore important to develop decision support tools that will assist farmers to evaluate their options for using earthworm and soil microbial quality indicators.

#### 4.3. Methodological constraints

Caution should be taken when interpreting the outcome of this study because of the small sample size and homogeneous properties of the farmer respondents. Nevertheless, 76% of farmers contacted responded to questionnaires, whereas the average for normal rural surveys is 53% (Rosin, Cook, Hunt, Fairweather, & Campbell, 2007). This is a model study that should be expanded to other regions. The study findings reveal a need for further social science research to address the complex issue of soil management at the farm-scale level. Farmer involvement may help in prioritising options for filling gaps in scientific knowledge and producing advice for practical use.

**Table 5. Farmer responses on the roles of earthworm and soil microbes in enhancing soil quality**

Soil organism	Role	Frequency					n = 34	p-value testing asymmetry <sup>†</sup>
		A lot	Moderate	A little	Not at all	Don't know		
Earthworms	Soil aeration	76	18	3		3	34	*
	Water regulation	53	21	12		14	34	
	Create channels for root growth	32	23	26		17	34	
	Soil formation and mixing	53	23	21		3	34	**
	SOM decomposition	71	15	9	3	3	34	**
	Nutrient cycling	44	18	29	3	6	34	
	Stimulate microbial activity	29	35	18	9	9	34	
	Bury and shred plant residues into humus	29	35	12	3	21	34	
Soil microbes	Nitrogen fixation	41	34	9	3	12	32	
	Water retention	15	24	30	9	21	33	
	Moisture maintenance	27	33	18	3	18	33	
	Plant structure and succession	12	33	18	9	27	33	
	SOM decomposition	39	45	12		3	33	**
	Soil formation	22	31	3	3	41	32	
	Nutrient cycling	27	24	21	3	24	33	
	Soil aeration	18	18	15	3	45	33	
	Food source for soil organisms	21	21	21	6	30	33	
	Chemical degradation in the soil	6	19	13	3	60	32	

<sup>†</sup>Simple  $\chi^2$  p-values from the test whether the number scoring a lot and moderate differ from that scoring a little and not at all.

\*The p-values signify significant differences at:  $p < 0.05$ .

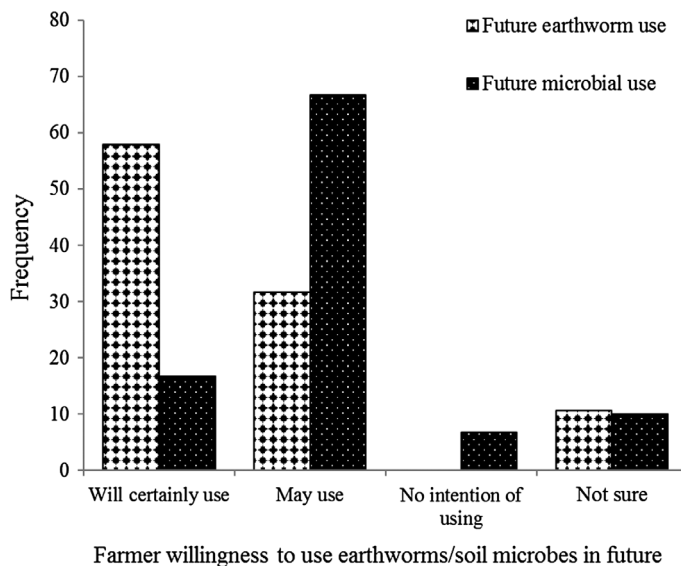
\*\*The p-values signify significant differences at:  $p < 0.01$ .

**Table 6. Responses on whether farmer currently monitors and manages earthworms and soil microbes and how these soil organisms are impacted by soil management practices in their farms**

Current practice in usage of earthworms, soil microbes and Overseer model	Frequency		
	Yes	No	Not sure
I use earthworms as indicators of soil quality	71	26	3
I know the species of different earthworm types		94	6
I actively encourage earthworms in my farm	56	15	29
I have noticed earthworm changes in irrigated paddocks	42	19	38
I have noticed earthworm changes in effluent paddocks	39	32	29
Birds are a threat to earthworms survival and reproduction	28	41	31
I use microbial measurements as indicators of soil quality	6	88	6
I have noticed microbial changes in irrigated land	11	11	78
I have noticed microbial changes in effluent paddocks		14	86

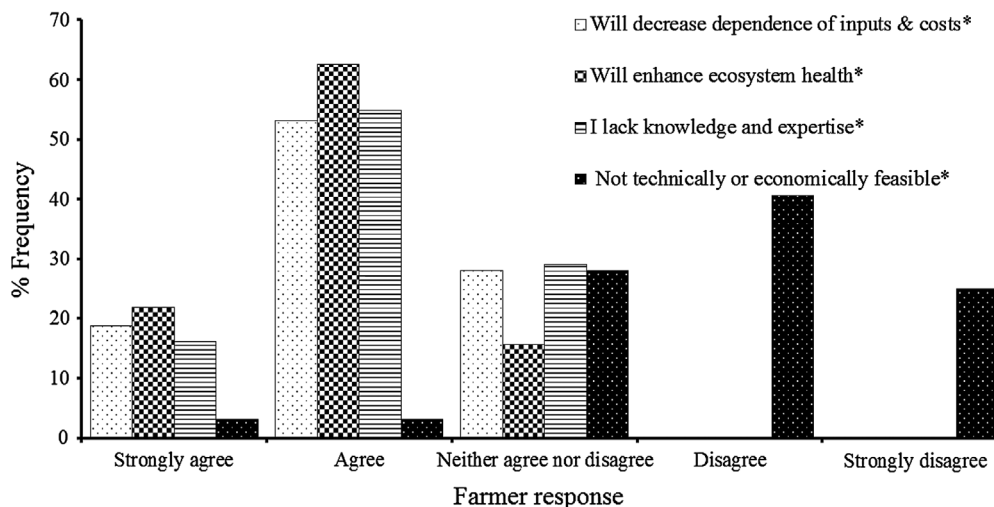
**Figure 2. Farmer willingness to manage and monitor earthworms and soil microbes in future, their willingness to use earthworms is not significantly different from their willingness to use soil microbes (Wilcoxon Matched pair test  $p = 0.180$ ).**

Notes: The difference between the respondents agreeing and those disagreeing with the questions on future earthworm and soil microbial use was significant.



**Figure 3. Farmer responses on benefits of monitoring and managing earthworms, soil microbes and their activities.**

Notes: The  $p$ -values from tests of whether the numbers that strongly agreed and agreed differed from those that disagreed or strongly disagreed are significant at: \* $p < 0.05$ .



### 5. Conclusion

The increasing world population and associated food demands call for more agricultural production from less land with fewer impacts on the environment. This necessitates actions on multiple issues concerning complex interactions between above and below ground systems and soil management. Agronomists, soil fertility and ecology experts should coordinate their efforts with farmers to optimise agricultural ecosystem services through soil management. A multidisciplinary approach is necessary in addressing these critical gaps.

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#### Competing Interest

The authors declare no competing interest.

#### Author details

B.O. Manono<sup>1,2</sup>  
 E-mails: [ombasa.manono@yahoo.co.uk](mailto:ombasa.manono@yahoo.co.uk), [bmanono@seku.ac.ke](mailto:bmanono@seku.ac.ke)  
 ORCID ID: <http://orcid.org/0000-0001-9150-2126>

<sup>1</sup> Centre for Sustainability: Agriculture, Food, Energy, Environment, University of Otago, PO Box 56, Dunedin 9054, New Zealand.

<sup>2</sup> School of Environment and Natural Resource Management, South Eastern Kenya University, PO Box 170, Kitui 90200, Kenya.

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