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Effects of irrigation, dairy effluent dispersal and stocking on soil properties of the Waimate District, New Zealand

B.O. Manono [a,*], H. Moller [a,1], R. Morgan [b]

[a] Centre for Sustainability: Agriculture, Food, Energy, Environment, University of Otago, PO Box 56, Dunedin 9054, New Zealand
[b] Department of Geography, University of Otago, P O Box 56, Dunedin 9054, New Zealand

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ABSTRACT

Application of water and effluent to boost agricultural production is increasing in New Zealand, particularly in the Waimate District; a drought prone region traditionally associated with extensive sheep farming, but now converting to dairying. To determine how this intensification affects soil properties, we sampled soil from 615 locations across 41 farms in the District between April and September 2012. Effluent applied soils had between 8% and 15% higher amounts of soil carbon, nitrogen and phosphorus, while application of water alone increased these nutrients by between 17% and 35%. Soils where both effluent and irrigation water were applied had the highest amounts than the untreated “control” locations. Irrigation and effluent dispersal affected soil structure by reducing bulk density in the range of 14% to 26% but increased soil water content by 29% to 100%. The effect of water application was more pronounced in cattle grazed soils. For example, phosphorus increased by 63% in dairy compared to a decrease of 5% in sheep farms when irrigated. When compared with untreated locations, total earthworm density was higher by 42% in effluent locations and 72% in irrigated locations. Maximum density and biomass occurred where both effluent and irrigation were applied. Earthworm densities and biomasses were higher on sheep farms than on dairy farms. Soils with a lower abundance of *Lumbricus rubellus* earthworms, had higher total carbon and nitrogen whereas those with greater earthworm biomass had a higher water holding capacity. The study however failed to find evidence of linear and directly proportional relationships between earthworm measurements and other soil properties.

1. Introduction

New Zealand agriculture has been intensifying over the last 150 years (Brooking et al., 2011), but has accelerated in the past 40 years (MacLeod and Moller, 2006). In the Waimate District, this has been marked by increased land conversions from sheep farming to dairying (Houlbrooke et al., 2011), facilitated by large scale irrigation schemes (Manono, 2014). Soil nutrient increases following irrigation (Rixon, 1966a; Entry et al., 2002) are normally attributed to improved soil structure, porosity and hydraulic characteristics (Borda and Siddall, 2004). In contrast, when water is applied beyond the infiltration rate, runoff can occur (Trout et al., 2007; McDowell et al., 2011), increasing nutrient leaching (Cameron et al., 2002) and redistribution of nutrients into lower soil horizons (Degens et al., 2000). In fact irrigation can cause a deterioration in soil quality (Yilmaz et al., 2003; Urama, 2005) through salinization (Caballero et al., 2001), organic matter loss and increased decomposition and mineralisation (Metherell, 2003). Moreover, increased stocking rates degrade soil physical conditions from animal trampling (Houlbrooke et al., 2008).

In New Zealand, effluent (material containing cow excreta and urine diluted with wash down water after milking) generated at dairy sheds has been traditionally treated on a two-pond system before being discharged to waterways (Sukias et al., 2001). However, since the introduction of the Resource Management Act (1991), land application is the preferred treatment option. As effluent contains a large reserve of nutrients (Di et al., 1998; Silva et al., 1999; Bolan et al., 2004), it is expected that it will boost soil biological activity and nutrient levels (Degens et al., 2000; Brussaard et al., 2007; Wall et al., 2008). In spite of this, a review of effluent studies in New Zealand reports a reduction of soil biochemical properties in response to effluent application (Speir, 2002). Although there are uncertainties on the effects of effluent application on soils, particularly in combination with irrigation water, it is commonly believed that applying effluent on irrigated land improves soil quality. Managing both effluent and water application can be challenging since it presents greater risks of net degradation of soils (Ministry for the Environment, 2007).

* Corresponding author at: School of Environment and Natural Resource Management, South Eastern Kenya University, PO Box 170–90200, Kitui, — Kenya.
E-mail addresses: ombasa.manono@yahoo.co.uk, bmanono@seku.ac.ke (B.O. Manono), henrik.moller@otago.ac.nz, ecosyst@ihug.co.nz (H. Moller), rkm@geography.otago.ac.nz (R. Morgan).
[1] Current Address: Ecosystems consultants, 30 Warden Street, Opoho, Dunedin, 9010, New Zealand.

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Table 1
Numbers of Soil Sampling Locations (SSLs) for each soil management treatment level.

Farm type	Irrigated dairy farms				Un-irrigated dairy farms		Sheep farms	
Number of farms	24				12		5	
Total sampled paddocks	113				72		20	
Treatment method	Untreated[a]	Effluent only[b]	Irrigation only[c]	Effluent and irrigation[d]	Untreated[a]	Effluent only[b]	Irrigated sheep[e]	Un-irrigated sheep[f]
Number of treated paddocks	15	10	44	44	36	36	10	10
Total sampled locations	45	30	132	132	108	108	30	30

[a] Dairy grazed paddocks that receive neither irrigation water nor effluent (n = 153).
[b] Dairy grazed paddocks that receive effluent but not irrigation water (n = 138).
[c] Dairy grazed paddocks that receive irrigation water but not effluent (n = 132).
[d] Dairy grazed paddocks that receive both irrigation water and effluent (n = 132).
[e] Sheep grazed paddocks not receiving irrigation water (n = 30).
[f] Sheep grazed paddocks receiving irrigation water (n = 30).

Earthworms have an ability to modify the soil environment (Jones et al., 1994). Earthworms have also been linked positively with soil properties (Andersen, 1983; Bossuyt et al., 2005; Lavelle et al., 2006; Fonte et al., 2007), and their introduction to areas devoid of earthworms has contributed to increased nutrient levels (Stockdill, 1982; Hoogerkamp et al., 1983). In New Zealand, management impacts on earthworm communities at field level are well documented (Fraser et al., 1996; Schon et al., 2008; Manono, 2014; Manono and Moller, 2015). Their large size and limited movements make them easy to capture and sort and therefore attractive as potential tools for farmers to use as indicators of soil quality. The challenge is to determine how land use changes impact soil properties commensurate with earthworm community changes. If effects of land-use change associated with soil properties and earthworm measurements are established, soil quality indicators can be developed that farmers can readily manage and monitor to assess and mitigate negative management impacts.

Conversion to dairying under irrigation and effluent dispersal in the Waimate District has happened rather recently; at a large scale, and the trend is projected to continue (Manono, 2014). This raises concern about the long term ability of the soil to effectively provide key soil based ecosystem services and positive interactions with the environment (PCE, 2004). How soils change after conversion and then over time within irrigation and effluent management regimes remains largely unknown. The present assumption that these practises enhance the supply of nutrients to plants and provide a net benefit to the soil system may be incorrect, or the putative benefits may be insignificant. Consequently, there is an urgent need to investigate the impacts of irrigation, effluent dispersal and farm conversions on these soil properties.

The objective of this study was to determine the effect of irrigation, effluent dispersal and farm conversion on soil property changes and whether these changes can be predicted from earthworm measurements. Because effluent contains a large reserve of nutrients (Bolan et al., 2004) and water application improves soil structure, porosity and hydraulic characteristics (Borda and Siddall, 2004), we hypothesised that irrigation and effluent dispersal will enhance the soil's water content, total carbon, nitrogen and phosphorus but reduce its bulk density (Hypothesis 1). In New Zealand, dairy farming has a high intensity and pasture turnover compared to sheep farming (Carey et al., 2010, Norton et al., 2010), through increased use of abiotic inputs sourced outside the farm (Macleod and Moller, 2006) and increased use of nitrogenous fertiliser (Ledgard et al., 2003). Therefore, we hypothesised that soils in dairy grazed land will have significantly higher levels of these nutrients than sheep farms (Hypothesis 2). Lastly, as earthworms have been positively correlated with soil properties (Paoletti, 1999; Lavelle et al., 2006) we hypothesised that the nutrient

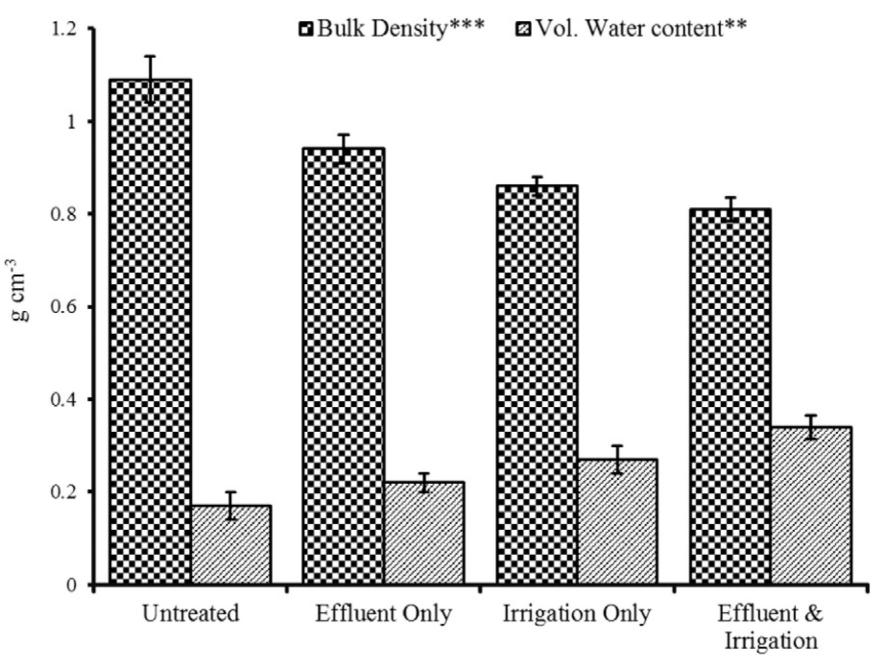

Fig. 1. Bulk density and volumetric water content values for dairy only management treatments. Significant differences are: ***, $p < 0.001$ and **, $p < 0.01$. Replications are: untreated, n = 153; effluent only, n = 138; irrigation only, n = 132 and effluent and irrigation, n = 132).