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DOES LAND APPLICATION OF DRILLING WASTE POSE A THREAT TO NEW ZEALAND AGRICULTURAL SYSTEMS?

Chioma MaryAnn Okafor, Paramsothy Jeyakumar and Christopher W N Anderson

Fertiliser and Lime Research Centre, Massey University Private Bag 11 222, Palmerston North 4442, New Zealand.
Email: okaforchiomamaryann@gmail.com; c.w.n.anderson@massey.ac.nz

Abstract

Land application of drilling waste is a waste-disposal activity in Taranaki region New Zealand aimed towards a natural bioremediation of hydrocarbon-containing waste from oil exploration and production. The drilling muds are incorporated into re-shaped sand dunes and used for pasture growth. There is a rising concern from the public and dairy industries on potential heavy metal accumulation in soil and risk of transfer to food chain from land application of drilling waste which led to a halt in milk collection from landfarm-impacted sites in 2014. It was proposed that growing industrial hemp as a new and valuable commercial crop could provide an economic and sustainable environmental option for Taranaki landfarming.

This study investigated and compared heavy metal (Cd, Zn, Cu, and Ni) accumulation in soil and their concentration in hemp and ryegrass from four different soil treatments comprising 100% drilling waste, landfarm-impacted soil, a 50:50 mix of drilling waste/control soil, and a control soil to determine the potential threats of heavy metal from agricultural land amended with drilling waste. Heavy metal concentrations measured in soil or waste treatments did not exceed the soil toxic limits. In addition, heavy metal concentration in hemp and ryegrass in all soil treatments were within tolerable limits for agronomic crops except for Zn, and Cu concentrations in some treatments. The Zn and Cu concentrations in hemp grown in 100% drilling waste were 145, and 38 mg/kg, respectively. These concentrations in ryegrass were 129, and 26 mg/kg, respectively. There was no significant difference between heavy metal accumulation in hemp and ryegrass in landfarm-impacted soil and control soil. This suggests that remediation using hemp is in fact not necessary. However, in case of continued public and dairy industry perception, hemp as a non-food product with limited metal exposure pathways to animals could be replaced with the traditional food crop system (ryegrass).

Introduction

In New Zealand, landfarming is perceived to be a waste management strategy aimed at a natural bioremediation of hydrocarbon-containing waste from oil exploration and production through surface, sub-surface and mix-bury-cover application to land (Cavanagh, 2015). The public and dairy industries disagrees with this system and this led to the halt in milk harvest from any New Zealand landfarm sites in 2014 due to the concern about the likelihood of heavy metal accumulation and subsequent transfer through pasture, meat and milk (exposure pathways) (Kerckhoffs et al., 2015). In response to this, major stakeholders including

Taranaki Regional Council, Venture Taranaki, oil and gas explorers and affected farmers has called for an exploration of a remediation as a way of regaining trust of the dairy processors. Industrial hemp has been chosen as a promising economic and environmental option for the landfarm-impacted sites due to its ability to maintain high quality fibre, biomass and hurds under highly heavy metal contaminated soil (Linger et al., 2002). In addition, the impact of heavy metals and other contaminants on soil microbial activity which drives many nutrient cycles is poorly understood.

The main aim of this study was to evaluate the heavy metal (Zn, Cu, Cd and Ni) accumulation in ryegrass (*Lolium perenne L*.) and hemp (*Cannabis sativa L.)* grown on landfarm-impacted soil and compare the values with risk-based soil guidelines to determine the potential threat to food safety, animal welfare and trade. In addition, the potential of hemp as a phytoremediation option for landfarm-impacted soil in New Zealand was also explored. This study also investigated the influence of landfarming on soil microbial activity to ascertain the implications of drilling waste on soil quality.

Methods

The description of the various soil treatments is presented in table 1.

Table 1: Treatment description and origin

Treatments	Description
100% drilling waste	Hydrocarbon rich oil waste obtained from an oil exploration site.
50:50 mix of drilling waste and control soil	6 kg drilling waste was mixed with 6 kg control (uncontaminated) soil
Landfarm-impacted soil	12 kg control soil was mixed with 33kg drilling waste excavated from a poorly-mixed subsurface soil horizon at a landfarm site.
Control soil	Uncontaminated soil adjacent to a landfarm site.

A pot with a dimension 16.5 x 16.5 x 19cm containing 4kg 100% drilling waste and 50:50 mix of drilling waste/control and 5kg of landfarm-impacted soil and a control soil was used for each of ryegrass (*Lolium perenne L*), industrial hemp (*Cannabis Sativa L.)* and a non-planted control (without plants). Plants were harvested 54 days after planting, dried (60 – 70^0 C for three days) and crushed. Soil samples for each replicate pot were collected at the time of plant harvest, air dried at 30-40^{0}C for three days and then sieved (<2mm). Five core fresh soil samples were subsequently collected from each pot 70 days after plant harvest and kept at 3º C in a sterile plastic bag for dehydrogenase/microbial analysis.

Soil nutrient analysis (pH, CEC, extractable cations, sulphate-sulphur, Olsen P) was carried out using standard methods. Plant and soil samples were digested with 10 ml 70% nitric acid and Zn; Cu and Ni concentrations in each sample were quantified using MP-AES (Microwave Plasma 4200 AES, Agilent Technologies). The Cd concentration was determined using graphite furnace atomic absorption spectroscopy (GFAAS - Perkin Elmer AAnalyst600). Dehydrogenase activity was conducted using 3 ml of 3% 2, 3, 5 – triphenyl-tetrazolium chloride (3% TTC (Chander & Brooke, 1991) and quantified using a JENWAY 7315 spectrophotometer at 485nm. Analytical blank samples and a standard reference material (SRM: tomato leaves) were used in each analysis to assess the precision of the analysis. Descriptive statistics (Mean and standard deviation) and Analysis of Variance (ANOVA) was conducted using the Minitab® 17 (Minitab 17 Statistical Software, 2010). Turkey Pairwise comparison (95% confidence level) was used to group the different means for a significance difference.

Result

Soil nutrient properties

The pH level was high (6.6) in landfarm-impacted and 100% drilling (6.5) waste and was above medium range for New Zealand agricultural soil but was below in control soil (5.7) (Table 2). All the soil treatments have a low CEC below medium range. The Olsen P level in landfarm-impacted soil was the highest (42 mg/L - above the medium range) with the least observed in 100% drilling waste (17 mg/L - below the medium range). Sulphate sulphur concentration was highest (75 mg/kg) in 100% drilling waste with the least value observed in landfarm-impacted soil (9 mg/kg). 100% drilling waste generally has the highest extractable cations than the other two soil treatments (table 2) with the highest Ca^{2+} and (K^{+} Mg^{2+} and Na^{+}) observed in Landfarm-impacted soil and 100% drilling waste respectively.

Table 2: Physical and chemical properties of soil treatments (100% drilling waste, landfarm-impacted soil and control soil)

Soil sample	VW	pH	CEC	SO_4-S	Olsen P	Extractable cation			
	g/ml		me/100 g	Mg/kg	mg/L	me/100g			
						K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}
Landfarm-impacted soil	1.55	6.6	7	9	42	0.17	5.8	0.53	0.15
Control soil	1.59	5.7	7	10	21	0.07	2.0	0.62	0.21
100% drilling waste	0.98	6.5	11	75	17	1.06	4.9	1.05	0.54
Medium ranges[1]	0.60 – 1.00	5.8 – 6.2	12 – 25	10 – 12	20 – 30	0.40 – 0.60	4.0 – 10	1.00 – 1.60	0.20 – 0.50

Source: *Authors laboratory result*
VW = Volume weight (g/ml), SO_4-S = Sulphate sulphur (mg/kg). Medium ranges specific to 75mm sample depth for New Zealand pastoral soil

Heavy metal concentration in soil and plant treatment samples

Cd concentration in all soil treatments were 0.1 ± 0.0 mg/kg while Ni was below detection limit (BDL – 0.1 mg/kg). Cd, Cu, Ni and Zn concentration in all soil treatments were within typical values for cultivated New Zealand soil. They were also within soil quality guideline for safe application of biosolids. There was no significant difference ($P>0.05$) between Cd concentrations across all soil treatment (Figure 1) while a significant difference was observed for Cu and Zn across all soil treatment (Figure 1). The correlation coefficients (R) for Cd/Zn relationship in the landfarm-impacted soil and a control soil were found to be insignificant and negative ($P > 0.05$).

Heavy metal concentration in rye-grass (*Lolium perenne L.*) and hemp (*Cannabis sativa L.*) in all soil samples is summarised in table 4. Hemp showed nickel concentration below detection limit in all soil treatment. Nickel accumulation by ryegrass on landfarm-impacted soil and control soil were 0.8 ± 1.4 mg/kg and 3.2 ± 1.5 mg/kg respectively. There was no significant difference ($P > 0.05$) between Cd concentration in hemp and rye-grass on landfarm-impacted soil (0.1 ± 0.0 mg/kg and 0.1 ± 0.0 mg/kg) and a control soil (0.1 ± 0.0 mg/kg and 0.1 ± 0.0

[1] Hill Laboratory (no date)

mg/kg) respectively (Table 4). There was no significant difference (P > 0.05) between Zn and Cu concentration in hemp and ryegrass on landfarm-impacted soil and the control respectively. The heavy metals accumulation by hemp and ryegrass exceeded typical New Zealand value in all soil treatments except Cd for concentration in hemp and ryegrass in 50:50 mix of drilling waste/control soil and hemp in 100% drilling waste. The heavy metal concentrations in all soil treatments were within tolerable limits in agronomic crops except for Zn accumulation by hemp and ryegrass in 100% drilling waste and 50:50 mix of drilling waste/control soil and Cu accumulation by hemp (in 100% drilling waste and 50:50 mix of drilling waste/control) and ryegrass (in 100% drilling waste).

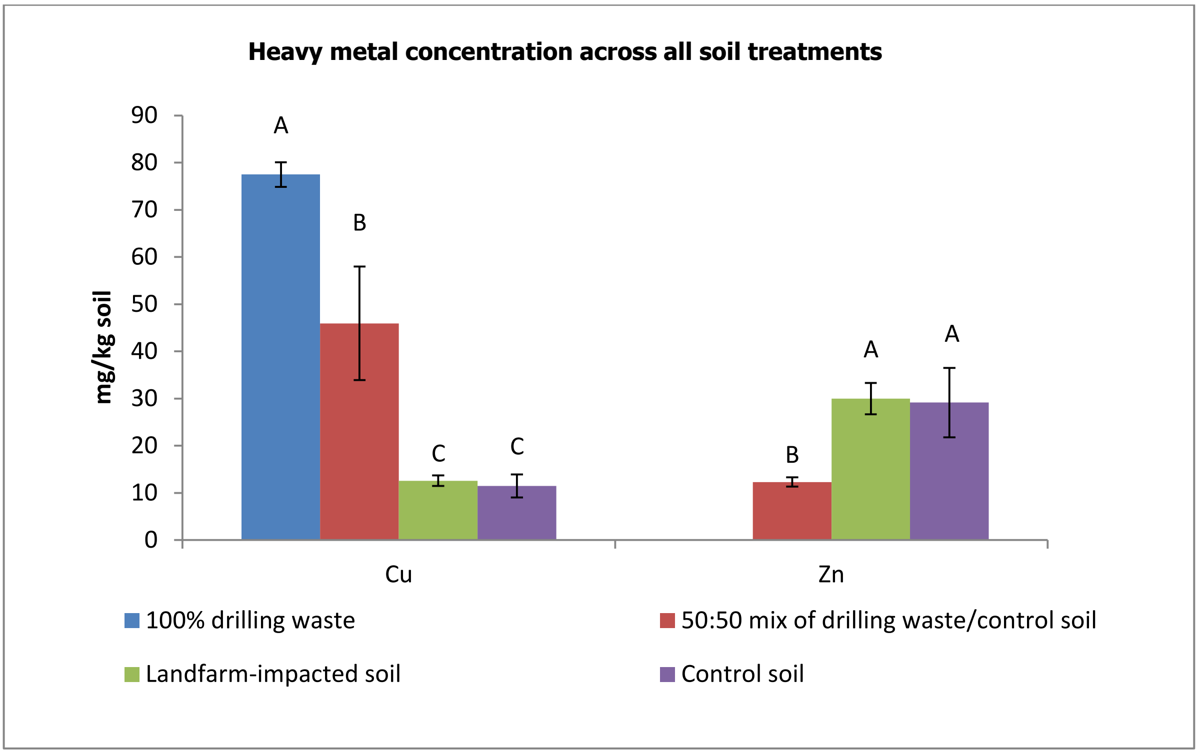

Figure 1: Comparison of heavy metal concentration in all soil treatments. Same Letters indicates no significant difference (P>0.05) across soil treatments for a heavy metal.

Dehydrogenase activity (DHA) in all soil treatments

Dehydrogenase activity in hemp and ryegrass pots for 50:50 mix of drilling waste/control (0.06 and 0.08 ug TPF/g) and 100% drilling waste (0.08 and 0.06 ug TPF/g) respectively was nominally indifferent. There was no significant difference (P > 0.05) between DHA of hemp and ryegrass in landfarm-impacted soil and control soil respectively.

Table 3: Heavy metal concentration in Hemp and Ryegrass plants grown on all treatments applied

	Cd (mg/kg)		Zn (mg/kg)		Cu (mg/kg)		Ni (mg/kg)	
Treatments	**Hemp**	**Ryegrass**	**Hemp**	**Ryegrass**	**Hemp**	**Ryegrass**	**Hemp**	**Ryegrass**
50:50 mix of drilling waste/control	0.1*	0.1*	201.5*	128.8*	23.1*	12.1*	**BDL**	**BDL**
100% drilling waste	0.1*	0.3*	144.7*	163.8*	37.6*	25.9*	**BDL**	**BDL**
Landfarm-impacted soil	0.1 ±0.0[A]	0.1 ±0.0[A]	69.0 ±14.9[A]	60.0 ±2.0[A]	13.3 ±1.4[A]	9.6 ±2.3[A]	**BDL**	0.8 ±1.4
Control soil	0.1 ±0.0[A]	0.1 ±0.0[A]	53.8 ±26.7[A]	57.1 ±16.0[A]	11.7 ±4.0[A]	9.7 ±2.5[A]	**BDL**	3.2 ±1.5
(Edmeades, 2013)[2]	0.03 – 0.29		10 – 20		5 – 10		0.10 – 0.20	
(Kabata-Pendias & Pendias, 2001)[3]	0.05 – 0.5		50 - 100		5 - 20		1 - 10	

Source: *Authors laboratory results*

Data marked with (*) indicates absence of replicate pots for the particular treatment, BDL – Below detection limit (0.1mg/kg). Means of samples with same letters are not significantly different (P = 0.05) between plants for each metals, MPL = Maximum permitted levels in complete rations for ruminant; ng = not given

Discussion

Cd, Zn, Ni and Cu concentration in all soil treatment were within soil quality guideline for safe application of biosolids (NZWWA, 2003). This finding is supported by Cavanagh (2015) and Edmeades (2013) that reported a zero threat of heavy metals from landfarm-impacted soil. Application of drilling waste to agricultural soils also offers an opportunity for Cu/Zn deficiency amendment. Heavy metal concentrations in 100% drilling waste and 50:50 mix of drilling waste/control shows that this medium is unsuitable for plant growth. These two medium is not a practical system in New Zealand but was applied to test plant growth on a hypothetical situation which has proven their irrelevance in assessing risks to agricultural soil.

Studies have shown that increasing or decreasing Cd and Zn concentration in soil may have either synergistic or antagonistic effect on plant growth (Tamboli & Rai, 2015; Tkalec et al., 2014; Nan et al., 2002). Tamboli & Rai (2015) affirmed that low soil Cd concentration reduces Zn antagonistic effects while high Cd adversely affects plant growth showing synergistic effect of the two metals. Antagonistic effects of Cd and Zn was observed in the landfarm-impacted soil and a control soil in which lower Cd or Zn concentration in soil led to a higher Cd or Zn accumulation in ryegrass and hemp.

The result of this study suggests that land application of drilling waste to soil elevated soil pH. Most heavy metals are soluble at low soil pH and insoluble at high pH (USDA[4], 2014). Differences in soil pH among control soil, landfarm-impacted soil and 100% drilling waste did not change soil Cd concentration. Elevated Zn, Cu, Cd (ryegrass in 100% drilling waste)

[2] Typical New Zealand value
[3] Tolerable limit in agronomic crops
[4] United States Department of Agriculture

and Ni (in ryegrass in landfarm-impacted soil and control) concentration in hemp and ryegrass above their corresponding soil concentrations suggests bioavailability of these metals in contaminated soil. The result of this study also suggests that high sulphate sulphur concentration results to Zn and Cu bioavailability in soil and a resultant low concentration in soil with no changes to Cd, and Ni concentrations. Our result supports Skwierawska et al. (2012) and Kaya et al. (2009) studies. Our study also shows that application of drilling waste to soil increased Olsen P level in landfarm-impacted soil. Increased Olsen P level in soil is an indication of reduced risk of heavy metal toxicity and increased crop yield due to reduced soil acidification (Zhou et al., 2015). This is evident in our finding that observed no risk of heavy metals in landfarm-impacted soil with increasing Olsen P level. However, the increasing Olsen P level did not affect soil microbial activity and this requires further study.

Our finding suggests no alterations to soil microbial activities as a result of drilling waste application to land, and the hemp and ryegrass cultivation. This may be attributed to the reduction of microbial activity in landfarm-impacted soil with time as a result of nutrient or hydrocarbon exhaustion (Cavanagh et al., 2014).

Conclusion

Land application of drilling waste to agricultural soil does not promote heavy metal accumulation in soil and plant and therefore does not pose risk to food safety and animal welfare in New Zealand agricultural system. This is also evident in the observed stability of microbial activity in all the soil treatments. However, the major concern is on the exposure pathways via plant uptake (ryegrass) influenced by soil pH and sulphate sulphur concentration of the drilling waste.

In case of continued halt in milk collection and public perception of landfarming, hemp as a non-food product with no exposure pathways to animal and dairy products could be an alternative crop (that will replace the traditional ryegrass system) with potential economic and environmental value in landfarm-impacted soil. Quantifying the heavy metal balance in landfarm-impacted soil will support the use of drilling waste for landfarming.

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