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Assessment of nutrient quality, heavy metals and phytotoxic properties of chicken manure on selected commercial vegetable crops

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Abstract

Due to rapid expansion in the poultry industry, production of poultry manure has also consequently increased, resulting in unplanned disposal of this manure to the soil in some cases, with possible negative environmental consequences. In this study, 10 separate poultry manure samples were collected from different sites located in the central Eastern Cape, South Africa and characterized for chemical and phytotoxic properties. The poultry manures had an average neutral pH (range 6.94 – 7.97) whilst the electrical conductivity was highly variable from 2.45 dS/m to 12.3 dS/m between the 10 sites. The high conductivity values recorded in some of the manures indicate that caution may need to be practiced when directly applying these manure to the soil, to avoid buildup of soluble salts. All samples showed a very high concentration of total P (1963.1 mg/kg – 2644.1 mg/kg) with the plant available fraction ranging from 21.3% – 37.7% of the total P. All the heavy metals measured (Cr, Cu, Ni, Pb and Zn) were below the maximum permissible limits set by the U.S. Environmental Protection Agency. However,

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some of the poultry manure showed some level of phytotoxicity based on the plant bioassay, with some samples, recording a germination index less than 50% for the different crops evaluated. However, this bioassay may not be conclusive and there is need to evaluate this phytotoxicity in real world field applications as there is paucity of information on this aspect regarding poultry manure. Such filed studies can be used to evaluate alternative strategies such as planting and harvest intervals between application of these manures and planting or harvesting. It is also suggested that further biodegradation through composting or vermicomposting may be required to improve nutrient content and reduce the presence of phytotoxic compounds in some of the poultry manures before use as soil amendments.

Keywords: Agriculture, Environmental science

1. Introduction

The recent demand for low-cholesterol meat products and high protein sources as well as economic incentive has led to a tremendous expansion in the poultry industry worldwide (Manu et al., 2013). Due to this fast expansion in the poultry industry, production of poultry manure has also increased. In South Africa, it is estimated that approximately 4 million tons of poultry manure are produced annually, with the trend expected to increase (Ravindran and Mnkeni, 2016). Chicken manure, which is the most abundant poultry manure, is a mixture of faeces, waste feed, feathers and bedding material, and contains essential plant nutrients making it a possible organic source of nutrients. Currently, organic manures like poultry manure are receiving more attention as fertilizers due to the rising cost of inorganic fertilizers coupled with the limited ability of inorganic fertilizers to improve soil quality (Arancon et al., 2008). However, though beneficial as an organic amendment, the huge quantities being produced in poultry farms have resulted in unplanned disposal of this manure to the soil in some cases, where it poses environmental challenges like eutrophication, air pollution, emission of greenhouse gasses and production of phytotoxic substances (Ravindran and Mnkeni, 2016; Bolan et al., 2010).

Optimum utilization of animal manure requires knowledge of its composition in relation to its environmental implications and not only its positive benefits. Animal manure products like poultry manure have been observed to contain potentially harmful trace elements like arsenic, copper and zinc, which originate from the chemicals used to treat diseases in commercial chickens (Bolan et al., 2010). Adeli et al. (2008) reported that broiler chicken litter is a good source of trace elements that can potentially accumulate in the soil with repeated applications. It serves as a soil amendment for numerous economically important crops and also improves a number of soil properties including soil physical, biological and chemical properties (Araji et al., 2001; Stamatiadis et al., 1999). Kadian et al. (2008)

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suggested that manure has an important role to play in sustainable agriculture as it not only improves soil fertility but also overall soil quality. However, the quality of organic manures are site specific and it is thus important to understand the impact of local animal production practices on the quality of the manure produced (Wander, 2015).

Chicken manure production in poultry farms in the peri-urban areas of the central Eastern Cape, South Africa is steadily increasing. However, there seems to be little intentional use of chicken manure in smallholder farms in the Eastern Cape. The chemical characterization of this poultry manure can provide a starting point for establishing the fertilizer and nutritional value of chicken manure produced in the Eastern Cape, South Africa and thus provide a basis for promoting their utilization. Additionally, land application of animal manures and immature composts is reported to inhibit plant germination and growth through the production of phytotoxic substances such as ammonia, inorganic salts and organic acids (Gomez-Brandon et al., 2008; Tiquia and Tam, 1998). Therefore, apart from determining the chemical composition of poultry manure, it is important to characterize the phytotoxicity in order to determine the suitability or otherwise of the chicken manure for direct application as a soil amendment. This study thus had the objectives of chemically characterizing different poultry manures collected from farms in the central Eastern Cape and to determine their phytotoxicity using selected horticultural crops i.e. tomato, radish, onion and carrot as test crops.

2. Materials and methods

2.1. Collection of chicken manure

The chicken manure was collected from 10 different farms located in the Amathole district in the central Eastern Cape Province of South Africa as shown in Fig. 1. After collection, the manure was air dried at the research farm of the University of Fort Hare located in Alice, Eastern Cape Province, South Africa. The dried chicken manure was then kept under shade at room temperature for subsequent chemical and phytotoxic analysis.

2.2. Chemical analyses

Before analysis, the dried chicken manure was ground to pass through a 2 mm sieve. The pH and electrical conductivity (EC) were analysed potentiometrically in deionized water at a ratio of 1:10 (w/v) as outlined by Mupambwa and Mnkeni (2015). Total nitrogen (TN) and total carbon (TC) were determined using the dry combustion method employing a Truspec C/N auto analyser (LECO, 2003). For the determination of total P, Na, Mg, Ca and heavy metals (Cr, Cu, Ni, Pb and Zn), the samples were initially digested using aqua regia (3:1 v/v hydrochloric acid: nitric acid) in a MARS 5 microwave digester (CEM Corporation, Matthews, North

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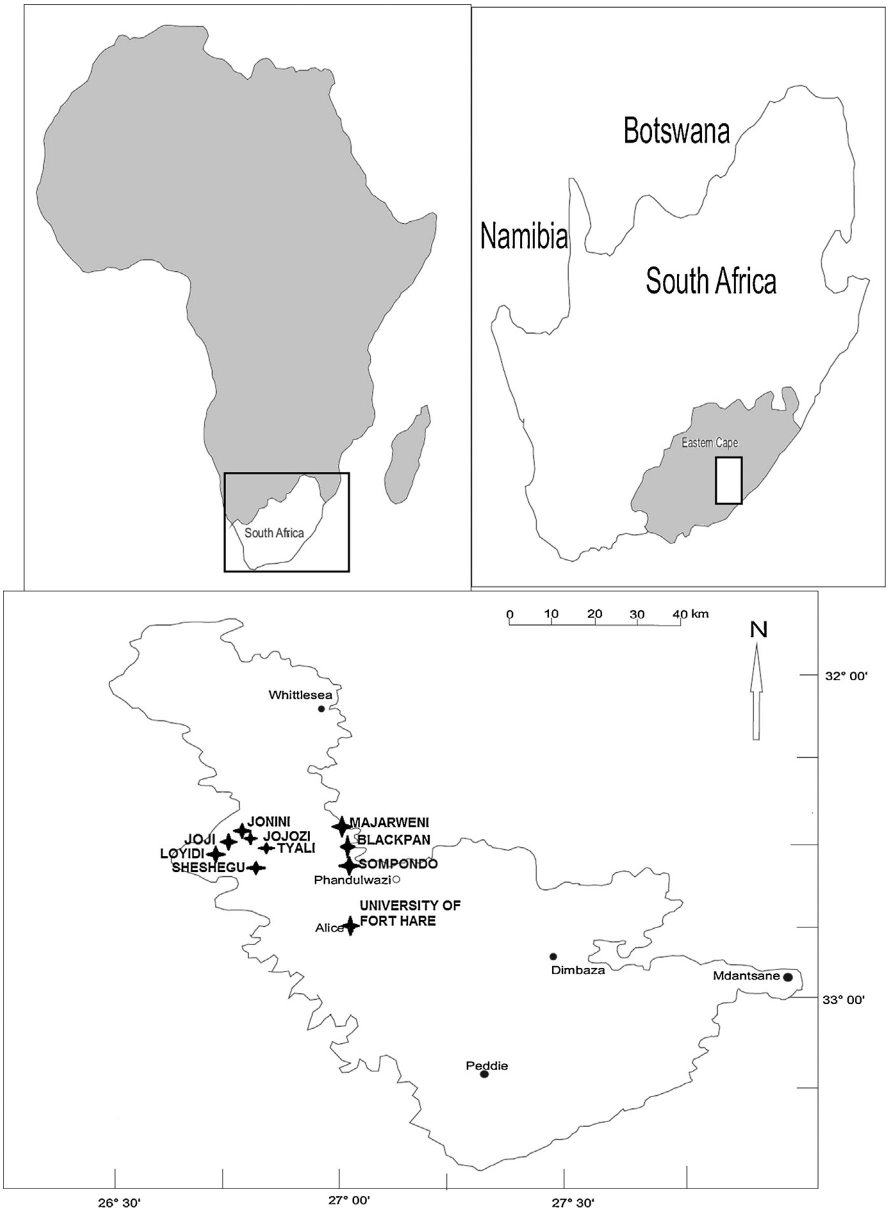

Fig. 1. Map showing the 10 different sites in the central Eastern Cape Province of South Africa, where the chicken manure was collected.

Carolina). Following the digestion, the total P in the digests was determined using a continuous flow analyser (San 2 + + Skalar CFA, Skalar Analytical B.V. The Netherlands) whilst the rest of the elements were determined using the ICP-OES (Varian Inc., The Netherlands). The extractable P within the manure samples was determined using the Olsen method which employs 0.5 M sodium hydrogen carbonate adjusted to a pH of 8.5 using sodium hydroxide (Schoenau and O'Halloran, 2006). The extracted P was then analysed automatically using a continuous flow analyser (San 2 + + Skalar CFA, Skalar Analytical B.V., The

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Netherlands) employing the ammonium molybdate-antimony potassium tartrate-ascorbic acid method.

2.3. Phytotoxicity study

To study the phytotoxicity of the different chicken manures, a seed germination bioassay was conducted using different vegetable crops. This assay was determined using chicken litter extracts prepared with distilled water (solid to water ratio of 10:1) (Ravindran et al., 2016) and the seed germination bioassay was evaluated based on the method of Tiquia and Tam (1998). Distilled water was used as a control. The water and manure mixtures were shaken on a mechanical shaker for 1 hour and then filtered using Wahtman® No. 1 filter paper. Thereafter, two pieces of Whatman® filter paper were placed inside a sterilized petri dish and wetted with the chicken manure extract and 10 seeds of tomato (*Lycopersicon esculentum*), radish (*Raphanus sativus*), carrot (*Daucus carota*) and onion (*Allium cepa)* were placed on top of the filter paper and placed in an incubator with no light for five days. Seed germination, germination index (GI), relative seed germination (RSG) and relative root elongation (RRE) were calculated from the measurements taken as shown in the equations below.

$$\mathrm{RSG}(\%) = \frac{\text{Number of seeds germinated in the sample extract}}{\text{Number of seeds germinated in the control}} \times 100 \tag{1}$$

$$\mathrm{RRE}(\%) = \frac{\text{Mean root elongation in the sample extract}}{\text{Mean root elongation in the control}} \times 100 \tag{2}$$

$$\mathrm{GI}(\%) = \frac{\%\text{seed germination} \times \%\text{root elongation}}{100} \tag{3}$$

2.4. Statistical analysis

The data reported in this study are the means of three replicates (n = 3). The results were subjected to analysis of variance (ANOVA) and where significant differences were observed the means were separated using Duncan's multiple range test at $P \leq 0.05$. All statistical analysis was conducted using the JMP statistical package, version 12.0.1 (SAS Institute, Inc., Cary, NC, USA).

3. Results and discussion

3.1. Physico-chemical characterization

3.1.1. Electrical conductivity and pH of chicken manure samples

The results of chicken manure pH and EC are presented in Table 1. The highest pH was recorded in Sheshegu as 7.97 with the lowest in Sompondo as 6.94 representing only a maximum of 14.8% difference between all the 10 manure

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Table 1. Selected Physico-chemical characteristics of the different chicken manures collected from selected sites in central Eastern Cape province, South Africa.

Parameter	Chicken manure collection sites									
	Loyidi	Sompondo	Sheshegu	Majwareni	Jojozi	Joji	Black plass	Jonini	Tyhali	Fort hare
pH	7.34^{e}	6.94^{h}	7.97^{a}	7.67^{c}	7.22^{f}	7.52^{d}	7.91^{b}	7.17^{g}	7.20^{fg}	6.98^{h}
EC (dS/m)	5.78^{e}	4.32^{g}	7.04^{d}	2.45^{h}	12.30^{a}	8.15^{c}	6.76^{d}	5.25^{f}	8.85^{b}	5.17^{f}
Total C (%)	41.8^{a}	22.7^{d}	33.5^{bc}	30.4^{c}	35.7^{b}	41.1^{a}	31.9^{bc}	40.5^{a}	34.6^{bc}	40.3^{a}
Total N (%)	2.3^{d}	2.4^{cd}	2.9^{b}	1.6^{e}	2.6^{c}	3.2^{a}	2.4^{cd}	1.6^{e}	2.5^{cd}	1.8^{e}
C/N ratio	18.0^{c}	9.5^{f}	11.7^{e}	19.4^{c}	13.7^{d}	13.0^{de}	13.2^{de}	25.8^{a}	13.9^{d}	22.6^{b}
Olsen extractable P (mg/kg)	552.3^{e}	532.3^{cde}	850.5^{a}	807.9^{ab}	690.1^{cd}	745.3^{bcd}	689.6^{cd}	746.3^{abc}	762.3^{abc}	656.6^{d}
Total P (mg/kg)	2595.3^{a}	2136.7^{ab}	2377.3^{ab}	2294.6^{ab}	2361.5^{ab}	2145.7^{ab}	2169.8^{ab}	2644.1^{a}	1963.1^{b}	2632.2^{a}
Olsen P as % of total P	21.2^{d}	25.5^{cd}	38.3^{a}	35.3^{ab}	30.5^{abc}	36.5^{ab}	31.01^{abc}	27.7^{bcd}	37.7^{a}	23.4^{cd}

Means within the same row of each site manure followed by the same letters are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test.

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samples. pH is a good indicator of any soil amendment quality and a neutral pH is usually preferred as most nutrients within the manure will be bioavailable in that range. Ontario Ministry of Agriculture, (2009) suggested that plant growth is optimal at a pH of between 5.8 and 6.5 and sometimes up to 7.5 depending on plant species, making the chicken manure samples studied potentially good soil amendments. However, the effects of these chicken manures to soils will most likely depend on the soil type and application rates. Using poultry manure applied at 5 different rates in three soils, Dikinya and Mufwanzala (2010) reported different responses to changes in pH depending on soil type (buffering capacity) and application rate, indicating a need for field evaluations of organic amendments before their direct use in agriculture.

Another critical measure of manure quality is its potential to introduce salinity or potentially toxic salts into the soil, measured as electrical conductivity. High electrical conductivities indicate high salt concentrations which can result in disruption of soil physical properties, osmotic stress and ion toxicity, which all affect crop germination and most physiological processes in the plant (Cho et al., 2017; Mufwanzala and Dikinya, 2010). In this study, the EC of the manures varied significantly between sites ranging from 2.45 dS/m (Majwareni) to 12.30 dS/m (Jojozi) (Table 1), making some of these manures unsuitable for direct soil application. If manure EC is above 6.0 dS/m, the amended soil should be leached with water before planting seeds and only a few crops, especially at seedling stage, can tolerate this salt level (Ozores-Hampton et al., 2013). The EC (soluble salts) levels in chicken manure can vary considerably, depending on feedstock and farm practices and this could explain the wide variations observed in this study. However, the high EC values observed in some of the poultry manures in this study, may results in reduced crop growth when applied into soils similar to what was reported by Mufwanzala and Dikinya (2010) in which a significant decrease in the growth of spinach in all the different soils, when poultry manure was applied beyond 20%. However, as these responses are soil type, frequency of application, and rate of application dependent, more studies need to be undertaken to evaluate these in proper field experiments and not basing it on the bio-assay results only. In addition, incubation studies can also be critical in generating further information on a wide range of soils and application rates, under laboratory conditions, thus forming a basis for the field studies.

3.1.2. Macro and micro nutrients

Total carbon (%) and total nitrogen (%) values were significantly different ($P < 0.05$) between the chicken manure collection sites (Table 1). Total carbon was lowest at the Sompondo site with 22.7% C and higher at the Loyidi site with 41.8% C, indicating a significant 45.7% difference between these two sites. Similarly, there was a significant difference between samples on the total N which ranged

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from 1.6% – 3.2% in the chicken manures. Other researchers who analysed different chicken manures have reported varied results; Ogunwande et al. (2008) reported total C of 26.5% and total N of 2.3% whilst Koutcheiko et al. (2007) reported total C of 37.5% and total N of 4.29%. The results of this study indicate that chicken manure can be a good source of organic carbon, which is important in improving soil quality while the N it supplies plays a crucial role in plant growth. It was also interesting to observe that the C/N ratio in the chicken manure was significantly different ranging from 9.5–25.8. A C/N ratio of below 15 in manures is considered suitable for direct application to soil whilst a C/N ratio above, this can result in N immobilization when the manure is directly applied to the soil (Bernal et al., 2009). However, this is unlikely to happen with the reported chicken manures, though treatments such as vermicomposting can improve the quality of these manures. Successful composting and vermicomposting of one of the manure samples mixed with waste paper was recently reported by Ravindran and Mnkeni (2017).

The total phosphorus was significantly different between sites falling within a range of 1963 mg/kg – 2644 mg/kg. The total P content in commercial poultry litter is usually high due to the fact that chickens only utilize a small portion of ingested P from the feed given to them, with the rest being excreted (Li et al., 2014). The high total P concentrations observed in the present study did not, however, translate into higher plant available P (Olsen P) as shown in Table 1. Of the total P present, the percentage of that which was plant bioavailable ranged from 21.2% – 36.5%, suggesting that the poultry manures studied could be important sources of short and longer term P release in soils. It would be interesting to evaluate the changes in plant available P rather than total P when chicken manure undergoes composting or vermicomposting.

This study only looked at 3 cations Na, Mg and Ca involved in determining the exchangeable sodium percentage and sodium adsorption ratio of a material (Table 2). It was interesting to observe that the concentration of all the cations were significantly different between manure collection sites, with Ca being the major cation in the manures. Cations are secondary and essential nutrients that influence soil chemical properties which ultimately impact plant growth (Hodges, 2010). The manure samples in this study had very low Na concentrations relative to the concentrations of Ca and Mg, which means that they are less likely to cause any soil dispersion due to high Na concentrations relative to other cations. In fact, the exchangeable bases observed in this study can be important in improving the fertility of soils when applied to the soil at optimized rates (Dikinya and Mufwanzala, 2010).

The heavy metal content of animal manures is largely a reflection of metal concentrations in feed consumed and the efficiency of food dry matter conversion

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Table 2. Selected cations and heavy metal concentrations in chicken manures collected from different sites in the central Eastern Cape Province, South Africa.

Parameter (mg/kg)	Chicken manure collection sites									
	Loyidi	**Sompondo**	**Sheshegu**	**Majwareni**	**Jojozi**	**Joji**	**Black plass**	**Jonini**	**Tyhali**	**Fort hare**
Ca	1114.8^{d}	1503^{c}	1549.5^{c}	1170.6^{d}	522.6^{f}	785.4^{e}	1180.1^{d}	1483.8^{c}	2412.1^{a}	2096.5^{b}
Na	131.4^{f}	375.8^{b}	216.8^{cd}	193.2^{de}	42.7^{g}	260.6^{c}	220.8^{cd}	464.5^{a}	200.4^{d}	147^{ef}
Mg	403.6^{b}	439.7^{a}	112.1^{ef}	90.2^{g}	31.7^{h}	130.9^{de}	144.9^{d}	351.3^{c}	107.9^{fg}	97.8^{fg}
Cr	nd	33.8^{a}	6.3^{e}	32.8^{b}	6.3^{e}	nd	22.8^{c}	nd	8.9^{d}	4.3^{f}
Cu	41.6^{gh}	39.3^{h}	93.0^{de}	54.1^{g}	134.4^{a}	89.8^{e}	105.9^{cd}	73.1^{f}	121.4^{ab}	117.4^{bc}
Ni	1.8^{c}	16.7^{a}	2.7^{c}	25.7^{a}	nd	nd	nd	nd	nd	nd
Pb	14.7^{d}	89.2^{b}	nd	6.3^{e}	nd	24.7^{c}	nd	nd	107.1^{a}	nd
Zn	330.1^{f}	383.8^{ef}	784.9^{ab}	749.8^{bc}	845.1^{a}	571.5^{d}	697.2^{c}	412.2^{e}	821.8^{ab}	762.9^{bc}

Means within the same row of each site manure followed by the same letters are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test. nd = not detected.

(Wang et al., 2013). Irshad et al. (2013) and Yadav and Garg (2009) suggested the investigation of metal content in animal manures because this can provide useful information to predict their bio-availability and also potential for contamination of soils. In this study, the presence of heavy metals Cr, Cu, Ni, Pb and Zn in chicken manure was investigated (Table 2). The heavy metal concentrations (mg/kg) showed the following ranges: Cr (non-detectable [nd] – 38), Cu (39.3 – 134.4), Ni (nd – 25.7), Pb (nd – 107.1) and Zn (330 – 845.1) (Table 2). Cr, Ni, and Pb were not detected in most of the collected chicken manures. Zhang et al. (2012) also reported similar levels of heavy metals in chicken manures. The U.S. Environmental Protection Agency (USEPA) does not restrict biosolid applications based on metal content (mg/kg) until the material has a total individual metal concentration of Cr > 1200; Cu > 1500; Zinc > 2800; Pb > 300 and Ni > 420 (USEPA, 1994). The recorded heavy metal content in collected chicken manures were thus within acceptable levels according to the USEPA range.

3.2. Phytotoxicity assessment of chicken manure extracts on commercial crop seedlings

According to Singh et al. (2014) and Jimenez et al. (2008) the main concern regarding the agronomic utilization of manure is that phytotoxic effects are often observed after application of manure or immature compost to soil. A number of toxicity bioassays have been developed to evaluate the phytotoxicity of manures. Several researchers have used this phytotoxicity technique for different sources of waste products such as animal (eg. goat, cattle, pig) manure, compost and vermicompost products, and different sources of waste water (Tiquia et al., 1996; Toumi et al., 2015; Ravindran and Mnkeni, 2017).

Results show that across all the crops the RSG % was within the range of 83.35-100% for tomato; 88.08% – 100% for radish, 80% – 100% for carrot and 75% – 112.5% for onion (Table 3). Among the 10 manure collection sites, RSG (%) values of 100 and above were recorded in five sites for tomato; eight sites for radish; six sites for carrot and nine sites for onion. The RSG (%) values for Jojozi, Joji and Tyhali site manure extracts were recorded as being 100 – 111.5 (RSG %) in all four crops. Unlike the RSG, significant differences ($p < 0.05$) were observed between poultry manures on RRE % (Table 4). For tomato, the RRE ranged from 44.9% – 121.4%; whilst for radish, carrot and onion it ranged from 28.4% – 91.1%; 50.5% – 107.5% and 56–113.9%, respectively. Garg and Priya (2006) reported that the salt content in effluent may be responsible for the size of root surface area. The EC (salinity) values of the manures studied were significantly different ($p < 0.05$) in collected manure extracts and these differences were reflected in the RRE effect in crop seedlings. It was interesting to note that, as the EC of the manures increased, the RRE and GI also decreased as observed for the Jojozi and Tyhali manures in this study. However, this is unlikely to be the case when these manures are applied directly to the soil as supported by Mufwanzala and Dikinya (2010). The RRE values was recorded as being < 100% in carrot and onion seedlings in only three sites Loyidi, Sompondo and Majwareni, and Loyidi, Majwareni and

Table 3. Relative seed germination (%) of different vegetable crops in extracts of different chicken manures collected from the central Eastern Cape Province, South Africa.

Manure collection sites	Bioassay crop			
	Tomato	Radish	Carrot	Onion
Loyidi	100^{a}	100^{a}	100^{a}	75^{b}
Sompondo	94.4^{ab}	100^{a}	93.3^{a}	100^{ab}
Sheshegu	94.4^{ab}	88.8^{b}	86.6^{a}	100^{ab}
Majwareni	83.3^{b}	100^{a}	93.3^{a}	112.5^{a}
Jojozi	100^{a}	100^{a}	106.6^{a}	112.5^{a}
Joji	100^{a}	100^{a}	100^{a}	112.5^{a}
Blackplass	88.8^{ab}	100^{a}	106.6^{a}	100^{ab}
Jonini	94.4^{ab}	100^{a}	100^{a}	100^{ab}
Tyhali	100^{a}	100^{a}	100^{a}	112.5^{a}
Fort hare	100^{a}	88.9^{b}	80^{a}	112.5^{a}

Means within the same column of each site manure followed by the same letters are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test.

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Table 4. Relative root elongation (%) of different vegetable crops in extracts of different chicken manures collected from the central Eastern Cape Province, South Africa.

Manure collection sites	Bioassay crop			
	Tomato	Radish	Carrot	Onion
Loyidi	77.4^{bc}	60.3^{cd}	107.5^{a}	105^{a}
Sompondo	86.9^{bc}	49.4^{d}	100.2^{a}	86.6^{ab}
Sheshegu	98.3^{ab}	28.4^{e}	96.8^{a}	62.9^{b}
Majwareni	121.4^{a}	77.0^{abc}	105.2^{a}	100.8^{a}
Jojozi	48.4^{d}	63.5^{bcd}	90.2^{ab}	90.8^{ab}
Joji	44.9^{d}	60.3^{cd}	64.1^{bc}	58.7^{b}
Blackplass	87.1^{bc}	91.1^{a}	61.6^{c}	113.9^{a}
Jonini	78.5^{bc}	81.0^{ab}	56.9^{c}	82.1^{ab}
Tyhali	46.2^{d}	54.6^{d}	58.8^{c}	56^{b}
Fort hare	65.8^{cd}	65.2^{bcd}	50.5^{c}	79.5^{ab}

Means within the same column of each site manure followed by the same letters are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test.

Blackplass, respectively. Poku et al. (2014) and Dawuda et al. (2011) reported that chicken manure application increased root length and vegetative growth of carrot. However, Ravindran et al. (2016) reported that the effluent and extract effects may vary from crop to crop. In the present study, tomato and radish crop seedlings had < 50 GI % in Jojozi, Joji and Tyhali; and in Sompondo and Sheshegu manures, respectively.

Phytotoxicity quantification is mainly based on germination index (GI) and this value is derived from the performance of crop seedlings, relative seed germination and relative root elongation during the assay period. Paradelo et al. (2008) suggested that GI values less than 50% indicated a phytotoxic medium while those between 50% and 80% indicated moderate phytotoxicity and GI values greater than 80% indicated lack of phytotoxicity. Studies by Majlessi et al. (2012) and Ravindran et al. (2016) also supported this categorization. Phytotoxicity in manure has been attributed to the presence of heavy metals, ammonia, salts and low molecular weight organic acids that might not have been metabolized (Zucconi et al., 1985). In the current study, of the 10 manure collection sites phytotoxicity (<50% GI) was indicated in three sites for tomato, two sites for radish, one site for carrot and onion. Moderate phytotoxicity (> 50%, but < 80% GI) was observed on four sites for tomato, six for radish, four for carrot and four for onion (Table 5). Limited or no phytotoxicity (> 80% GI) was observed on three sites for tomato, two for radish, five for carrot, and five for onions. Thus, on average, 62% of the

Table 5. Germination index (%) of different vegetable crops in extracts of different chicken manures collected from the central Eastern Cape Province, South Africa.

Manure collection sites	**Bioassay crop**			
	Tomato	**Radish**	**Carrot**	**Onion**
Loyidi	77.4^{abc}	60.3^{abc}	107.5^{a}	107.5^{a}
Sompondo	82.4^{ab}	49.4^{bc}	94.3^{ab}	94.3^{ab}
Sheshegu	92.9^{ab}	25.4^{c}	85.1^{ab}	85.1^{ab}
Majwareni	101.1^{a}	77.04^{ab}	98.1^{ab}	98.1^{ab}
Jojozi	48.4^{cd}	63.5^{ab}	95.7^{ab}	95.7^{ab}
Joji	44.9^{d}	60.3^{abc}	62.2^{bc}	62.2^{bc}
Blackplass	77.5^{abc}	91.1^{a}	64.4^{abc}	64.4^{abc}
Jonini	74.2^{abcd}	81^{ab}	55.7^{bc}	55.7^{bc}
Tyhali	46.2^{cd}	54.6^{bc}	58.8^{bc}	58.8^{bc}
Fort hare	65.8^{bcd}	58.4^{abc}	40.4^{c}	40.4^{c}

Means within the same column of each site manure followed by the same letters are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test.

chicken manures were either phytotoxic or moderately so (< 80% GI) indicating that some curing in the form of composting or vermicomposting may be necessary to degrade or reduce the toxic effects of phytotoxic compounds before the manures can be safely used as soil amendments. This could be done by the combined composting and vermicomposting of chicken manure mixed with other organic bulking materials, which can metabolize these phytotoxic compounds whilst forming organ-metallic complexes with heavy metals, reducing their bioavailability. For example, Ravindran and Mnkeni (2016) showed that chicken manure mixed with waste paper to achieve a C: N ratio of 40 could be combine composted and vermicomposted to produce a well humified end product with little or no phytotoxity after 10 weeks. The combination of thermophilic composting and vermicomposting using *Eisenia fetida* has also been shown to have the additionl advantage of significantly reducing the concentrations of oxytetracycline and its metabolites (4-epi-oxytetracycline [EOTC], a-apo-oxytetracycline [a-Apo-OTC] and b-apooxytetracycline [b-Apo-OTC]) in chicken manure thus rendering the resultant end product environmentally safer (Ravindran and Mnkeni, 2017).

4. Conclusions

The results of this study indicated that the chicken manures studied can be effective sources of essential nutrients like N and P, and also soil organic carbon. The results further showed that the levels of heavy metals in the chicken manures were within

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acceptable levels and would not pose an environmental threat when directly applied to the soil. The manures, however, differed significantly in their chemical and phytotoxic properties. It is thus important to characterize poultry manure before direct soil application. The phytotoxicity observed on some of the chicken manures pointed to the need for further biodegradation through composting and/or vermicomposting to improve nutrient content and reduce the phytotoxicity to levels that can be tolerated by the plants. There is also a need to evaluate the actual impacts of the chicken manures on crop phytotoxicity under field conditions when the manures are applied directly to the soil.

Declarations

Author contribution statement

Balasubramani Ravindran: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Hupenyu A. Mupambwa: Analyzed and interpreted the data; Wrote the paper.

Silwana Sibongiseni: Performed the experiments.

Pearson N.S. Mnkeni: Conceived and designed the experiments; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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