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Conversion of rural abattoir wastes to an organic fertilizer and its application in the field cultivation of tomato in India

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Abstract

Sophisticated capital intensive waste-recycling technologies are unviable in small rural abattoirs in India due to low volume of wastes (principally blood and rumen digesta) generated and lack of infrastructural facilities. We report recycling of slaughterhouse wastes as an organic fertilizer, 'bovine-blood-rumen-digesta-mixture' (BBRDM). Bovine blood and rumen digesta were mixed in 3:1 ratio in a metallic container, boiled and stirred continuously till the mixture was largely free of water. The mass was sun-dried for 3 days to obtain the final product. BBRDM was applied for field cultivation of tomato (*Lycopersicon esculentum* L., local variety 'Patharkuchi') in West Bengal state (India) during 2012–13 and 2013–14. We compared tomato yields obtained with BBRDM ($N:P_2O_5:K_2O$ 30.36:1:5.75) and conventional inorganic fertilizers [diammonium phosphate (DAP), $N:P_2O_5:K_2O$ 18:46:0 + potash, $N:P_2O_5:K_2O$ 0:0:44]. BBRDM was applied at a higher rate compared with DAP + potash to meet the farmers' desire for enhanced yields. 75 kg ha^{-1} was applied at the 2nd week while 150 kg ha^{-1} was applied at the 8th week after transplantation. Yields (total fruit weight) obtained from BBRDM-treated plants were higher in comparison with DAP + potash-fertilized plants by 46–48% as the former supplied 2.5 times more nitrogen (N) than the latter. The partial factor productivity of DAP + potash was 73–76% higher than BBRDM. Conversely, as BBRDM was produced through local entrepreneurship from slaughterhouse wastes, the cost of this organic product would be expected to be much lower than the commercial inorganic fertilizer. Furthermore, application of BBRDM negates the environmental cost of treating slaughterhouse effluent. Considering the same cost of applying 225 kg fertilizer ha^{-1}, higher yield with BBRDM should result in greater potential revenue for the farmer compared with yields with DAP + potash. The C/N ratio of BBRDM is 4.8, having relatively high N content. Accordingly, rapid release of plant-available N was observed in BBRDM-fertilized soils. The temporal increase in soil NH_4^+ may be attributed to lack of soil N immobilization. Local farmers are willing to accept the new fertilizer as a substitute for currently used chemical fertilizers.

Key words: waste, slaughterhouse, organic fertilizer, tomato, recycling

Introduction

India is the world's fourth largest beef producer and sixth largest domestic consumer. As of October 31, 2012, India is the largest exporter of beef globally and most of the exported beef is buffalo meat (Livestock and Poultry: World Markets and Trade). There are approximately 3600 legal, licensed slaughterhouses (Meat Sector – DSIR) and in parallel, numerous informal slaughterhouses in India (Hiranandani et al., 2010). The majority of the informal slaughterhouses that grew in the villages with traditional skill are more than 75 years old. They lack modern infrastructural facilities, hygienic practices as well as organized systems of waste disposal (Slaughter House Waste and Dead Animals). Wastewater of small abattoirs in India is generally discharged without any treatment directly into local water bodies or municipal/local sewage systems. This poses a serious threat to human health as well as to surface water quality. Concentrated effluents and the constituent blood rapidly choke the disposal channels (Manual on Municipal Solid Waste Management, 2000). Blood, not recovered from waste streams, contributes to the high chemical oxygen demand (COD). Guidelines of the Indian environmental regulatory authorities are seldom maintained in traditional rural Indian slaughterhouses. Slaughterhouse wastewater contains high concentrations of organic carbon (C), nitrogen (N) and phosphorus (P) (Zhan et al., 2009). The COD of a typical Indian rural slaughterhouse wastewater is in the range 4400–18,000 mg liter^{-1}. The major soluble contaminant in abattoir wastewater is blood having COD 375,000 mg liter^{-1} (Satyanarayan et al., 2005). The major solid waste of slaughterhouses is rumen digesta, a semi-solid mass made up of undigested to partially digested grass. The digesta in the rumen is not uniform, but stratified into gas and liquid particles of different sizes and densities (Awodun, 2008). Open dumping of rumen digesta by small informal rural slaughterhouses of India pose a health hazard to humans and adversely affect water sources. On average 20 buffaloes are slaughtered daily in one abattoir and 20 liters of blood as well as 20 kg of rumen digesta are obtained from one buffalo; it is expected that 400 liters of blood and 400 kg of rumen digesta will be generated daily.

Complicated operations to treat this extremely complex waste (blood and rumen digesta) make the wastewater treatment process exceedingly costly. As an estimation, the annual cost for disposal of 58,000 tons of beef slaughter waste in the USA would be approximately US\$10 million (Mittal, 2006). Correspondingly, 11,000 tons of waste are expected to be generated daily from rural Indian abattoirs. Thus, development of alternative processing methodologies for waste of small slaughterhouses (blood and rumen digesta) is imperative to manage the unhygienic waste disposal and to stop numerous informal small-scale slaughterhouses from going out of business. Therefore, this problem has socio-economic connotations as well. We intend to provide a feasible solution to the challenge rather than merely highlighting the problem. For efficient management of slaughterhouse waste biomethanation and rendering systems have been suggested by the Government of India (Envis Newsletter, 2009). However the high capital costs (INR 38,000,000 for a high rate biomethanation plant and INR 40,000,000 for a dry rendering plant, to recover animal fat) make them unaffordable for small slaughterhouse owners. Moreover, most small rural slaughterhouses are widely scattered, thus precluding centralized operation. Consequently, sophisticated and capital intensive technologies are unviable in small rural abattoirs due to the low volume of waste generated and lack of infrastructural facilities.

A more pragmatic approach would be to make use of cheap, simple-technology based processes that would be financially and technically viable as well as acceptable to the small slaughterhouses (Envis Newsletter, 2009). Waste products (blood and rumen digesta) may be composted (Pagans et al., 2006) or used as chicken feed (Ekunseitan et al., 2013). However, odorous ammonia emissions (Pagans et al., 2006) in the first recycling method and potential risk of microbial infections to humans and poultry through the second method (Sapkota et al., 2007) may limit their applications. Soil application of slaughterhouse waste could be an advantageous ecological option to recycle these residues and to mitigate the adverse effects of pollution (Villar et al., 2004). The application of winery and distillery waste to soil as well as reuse of olive solid waste and compost as agricultural fertilizers were demonstrated methods for recycling the organic matter and nutrients (Bustamante et al., 2007; Killi and Kavdir, 2013).

Organic agriculture has the potential to meet the global food demand on one hand and to lessen the damaging environmental effects of conventional agriculture on the other (Badgley et al., 2007). Badgley et al. (2007) suggested application of organic manures in farming practice. Investigations on the application of abattoir waste as an organic fertilizer is therefore an appropriate proposition. Currently half of the nutrient demands for global agriculture are derived from natural and managed N fixation, organic recycling and atmospheric deposition (Smil, 2011). According to the 'Current World Fertilizers Trends and Outlook to 2016' of the Food and Agriculture Organization (FAO), among all Asian countries, the bulk of the increase of world demand for N, P and potash is expected in India (Food and Agricultural Organizations of United Nations, 2012). Essentially, taking into account the domestic and global demands for organic fertilizer, the small abattoir owners may be expected to emerge as important economic actors by selling the organic fertilizer produced through utilization of slaughterhouse waste and earning net profits. Agricultural application of the waste would circumvent the necessity of conventional treatment of slaughterhouse waste, which as observed previously is cost intensive. Therefore, use of slaughterhouse waste for agriculture can provide economic as well as environmental benefits.

Propositions to promote safe disposal of abattoir waste and recommendations to limit the methods of disposal to those internationally allowed were presented in a review (Adeyemi and Adeyemo, 2007). Adeyemi and Adeyemo (2007) suggested rendering of the waste which is a process of cooking that converts the semi-solid waste into a protein-rich substance that appears like sand or soil. Products derived from rendering permit storage for long periods of time. Rendering allows recycling of what would otherwise have been sizeable amounts of waste. Accordingly, we developed a cheap recycling methodology for slaughterhouse waste where a combination of bovine blood and rumen digesta, termed bovine-blood-rumen-digesta-mixture (BBRDM) was converted to a dry powder and applied as an organic fertilizer (Roy et al., 2013). The effectiveness of BBRDM was evaluated against diammonium phosphate (DAP) during pot cultivation of tomato, chili (*Capsicum annuum* L.) and brinjal (*Solanum melongena* L.). BBRDM was applied twice at the 2nd and 6th weeks. Fruiting was earlier by 2 weeks in BBRDM-cultivated plants compared with

DAP-treated crops. Yields (total fruit weight) were greater in soils treated with the organic fertilizer. Limited studies have been conducted on the effect of slaughterhouse waste on crop productivity. Agricultural application of processed slaughterhouse waste composts and meat powder were investigated in a field experiment with maize (*Zea mays* L.), mustard (*Sinapis alba* L.) and triticale (*x Triticosecale* Wittm. ex A. Camus.) in Hungary (Ragályi and Kádár, 2012). The hazardous slaughterhouse waste became a nonhazardous product following heat treatment making soil application possible (Ragályi and Kádár, 2012). Slaughterhouse waste compost was applied to sugar beet (*Beta vulgaris* L. var. *saccharifera* Alef.) and spring barley (*Hordeum vulgare* L.) cultivations without any harmful effects on the plants (Petróczki, 2004). The present study, to the best of our knowledge, is the first on the application of abattoir waste for cultivation of tomato.

In continuation of the previous work, we now undertake the translation of the pot study to the agricultural field with the primary objective of evaluating the agronomic performance of BBRDM. To appraise its potential for enhancing tomato yields by substituting conventional chemical fertilizers, comparison of yields obtained by applying BBRDM and DAP + potash in field cultivation was done. Tomato is a comparatively sensitive indicator crop that responds to any mineral nutrient deficiencies, imbalances or phytotoxic properties associated with recycled waste as organic fertilizer (Killi and Kavdir, 2013). As of 2012, tomato featured among the seven most globally important food and agricultural commodities with a world production of 161,793,834 Mt and valued at 59,108,521 (International US$1000) (FAOSTAT). India produced 17,874,420 tons of tomato and West Bengal (the state where this study was carried out) is the seventh largest producer (1,125,600 tons, 6.3% of total produce) in India (out of 32 states and union territories) as notified by the Agricultural and Processed Food Products Export Development Authority, Ministry of Commerce and Industry, Government of India (APEDA AGRIXCHANGE). Therefore, with regard to the domestic and international market, it should further be of significance to use recycled abattoir waste as an organic fertilizer for tomato cultivation.

Materials and methods

Characterization of slaughterhouse waste, preparation and analysis of BBRDM

Characterization of waste (bovine blood and rumen digesta) through measurement of wastewater parameters was done as described (Roy et al., 2013). To obtain the C/N ratio of BBRDM, organic C of the fertilizer was determined according to the Walkley and Black's method and organic N was ascertained by estimation of total Kjeldahl N (Bustamante et al., 2007). To prepare BBRDM, fresh blood was collected in containers immediately following slaughtering of animals. Bovine blood and rumen digesta (ratio 3:1) were weighed in a metallic container. To fulfill the requirements of organic production, 'G.1.3. INDOCERT Organic Standards for Non-EU Country Operators, Version 2, 03/2012' (Indocert) was followed. Accordingly, sodium citrate (anti-coagulant) was not applied. The contents (blood and rumen digesta) were boiled for 90 min by placing the container on a coal-fired earthen stove. The mix (blood and rumen digesta) was continually stirred until the content was almost free of water. Finally the mass was dried under the sun for 3 days to obtain BBRDM. The product is a dry, solid, deep brown-colored powder and is easily spread (Supplementary Fig. 1). BBRDM was stored at ambient temperature during the period of study.

Experimental site and location

The field study was carried out (2012–13) in Kuldiya Baganchi village of Magrahat block (latitude 22°15′ 06.19″N, longitude 88°20′52.02″E, altitude 4 m) of South 24 Parganas district, West Bengal, a state in eastern India. In the following year (2013–14) the field experiment was done in Bankipur village of Magrahat block (latitude 22°14′25.24″N, longitude 88°22′42.09″E, altitude 4 m) of South 24 Parganas district, West Bengal state, India. Experimental plots were not cultivated earlier. The landscape had a flat topography without any slope. The total plot size was 500 m^2 (25×20 m^2). In both seasons experiments were laid out as a completely randomized block design with six replications for each treatment. The plot was divided into 12 sub-plots, each covering 5.04 m^2 soil surfaces. The sub-plots were arranged randomly, six of which were treated with BBRDM and another six were treated with DAP + potash. Organic fertilizer (BBRDM) was regarded as the test treatment while chemical fertilizer was considered as control treatment. DAP + potash was selected as controls as these fertilizers are generally applied to tomato plants by local farmers. Tomato plants were planted on November 14, 2012 (season 1) and November 28, 2013 (season 2). Plant seedlings in all sub-plots were arranged in four rows, eight plants in a row at a distance of 40 cm from each other along the single row. The distance between rows in each single sub-plot was 60 cm and the distance between sub-plots was 150 cm. There were 32 tomato plants per sub-plot i.e., 20,000 plants ha^{-1} (Agele et al., 1999; Balemi, 2008; Sortino et al., 2012).

Soil type, crop, time of study and weather conditions

The greater part of West Bengal state (India) lies in the Gangetic plain and is covered with alluvium. The soil of the study site in South 24 Parganas district is considered as saline–alkali soils of tidal origin (Thampi and

Mukhopadhyay, 1975). Soil color was ascertained by comparing the soil sample with the standard Munsell Soil Color Charts (Torrent and Barron, 1993). Soil pH was measured potentiometrically (Singh et al., 1999). Soil particle size distribution was determined by the hydrometer method (Department of Sustainable Natural Resources). Soil type was determined following the Triangular Classification Chart of the US Bureau of Soils and Chemistry System (Murthy, 1992). The liquid limit of soil was ascertained following the Casagrande method and the plastic limit of soil was analyzed as per American Society for Testing and Materials (ASTM) Standard D 4318–10e1 (ASTM International, Active standard ASTM D4318). Soil density was determined according to ASTM D7263-09-Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens (ASTM International, Active standard ASTM D7263). Soil water content was determined following ASTM D 2216-10-Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass (ASTM International, Active standard ASTM D2216).

Tomato (*Lycopersicon esculentum* L.), local variety 'Patharkuchi', tolerant to pests and diseases was selected for the field experiment. The study was done in the winter season from November 14, 2012 to February 28, 2013 (total 14 weeks in season 1) and from November 28, 2013 to March 15, 2014 (total 14 weeks in season 2). The mean maximum temperature during field cultivation (2012–13) was 27.1 ± 2.3°C, whereas the mean minimum temperature was 15.7 ± 2.2°C. The mean maximum humidity during the study was 86.4 ± 3.0%, while the mean minimum humidity was 40.8 ± 5.8%. The mean maximum temperature during field cultivation (2013–14) was 28.2 ± 1.3°C, whereas the mean minimum temperature was 16.2 ± 1.9°C. The mean maximum humidity during the study was 85.7 ± 2.5%, while the mean minimum humidity was 41.3 ± 4.6%. The total rainfall in season 1 was 0.5 ± 0.1 mm and the total rainfall in season 2 was 0.6 ± 0.1 mm.

Nursery operations and raising of seedlings

Tomato seedlings were grown in nursery beds located near the main experimental plot. The soil was ploughed and seedbed was raised. Seeds were sowed at a depth of 0.5–1 cm, in straight rows at an interval of 5 cm allowing 2 cm gap between successive seeds and watered immediately. The top soil was used as a light cover over the seeds. The seedlings were shaded from direct sunlight and watered every alternate day.

Preparation of main experimental field, transplantation of seedlings and staking

The experimental field was ploughed twice to make the soil to fine texture. The plots were shaped and ridges were made for growing tomatoes on the top of the bed. In between the plots, furrows were made to serve as irrigation and drainage channels. The seedlings were thoroughly watered before transplanting to the field. At the end of the 4th week following sowing, seedlings of approximately equal heights and about four or five leaf stage were transplanted to the experimental plot in the late afternoon. The experimental plot was watered after transplantation. Furrow irrigation was used for watering plants and sprinkle irrigation when required. The plants were staked 2 weeks after transplantation using thin bamboo sticks of 2 m length. Pruning, weeding by hand pulling as well as other horticultural operations were done when required (Law-Ogbomo and Egharevba, 2009).

Application of fertilizer

Well prepared BBRDM ($N:P_2O_5:K_2O$ 30.36:1:5.75) fertilizer was applied to the plants designated for BBRDM. The control plot was fertilized with DAP ($N:P_2O_5:K_2O$ 18:46:0) and potash ($N:P_2O_5:K_2O$ 0:0:44). BBRDM as well as DAP + potash (2:1) were applied in equal amounts. The first dose of 75 kg ha^{-1} was applied (evenly distributed along the furrows of each sub-plot by hand) at 2 weeks after transplantation of the plants to the main experimental field and the second dose 150 kg ha^{-1} was applied at the 8th week after transplantation (Gupta and Shukla, 1977; Balemi, 2008; Law-Ogbomo and Egharevba, 2009) Considering tomato to be an annual crop, the annual fertilizer application rates were 68.31 kg N ha^{-1}, 2.25 kg P_2O_5 ha^{-1}, 12.9 kg K_2O ha^{-1} for BBRDM and 27 kg N ha^{-1}, 69 kg P_2O_5 ha^{-1}, 33 kg K_2O ha^{-1} for DAP + potash.

Plant diseases

During this study common pests like aphids, bollworms, leaf miners, thrips, whiteflies, spider mites and nematodes were not significantly noticed and pesticide application was not done. Wilts, blight, leaf spots and mildews were not significantly observed during the cultivation. Cultural methods such as removal of weeds, old leaves and branches as well as overshadowed lower leaves were done regularly by hand. Organic neem oil as pesticide was sprayed twice at the 3rd and 9th week after the transplantation of the tomato plants to the main experimental field as a preventive measure (Hinman et al., 2012).

Measurement of yield parameters

Number of buds and flowers, numbers of fruits, average fruit weight and yield as mentioned in the Results section (Table 1) were measured or counted every week following transplantation of seedlings. Before harvesting the plants, numbers of ripened tomatoes per cluster were counted and the mean was calculated. Yield from each of the six sub-plots of both treatments were recorded

Table 1. Comparative analysis of flowering, fruiting and tomato yield during 14 weeks of cultivation. Yield per sub-plot represents cumulative weights during harvesting period. Details are provided in the Materials and methods section.

		Soil treatments	
Plant growth parameters and yield	**Season**	**BBRDM**	**DAP + potash**
Number of buds	S^1	30 ± 3.56**	15 ± 2.39
	S^2	34 ± 3.44**	18 ± 2.45
Number of flowers	S^1	30 ± 3.56**	18 ± 2.86
	S^2	39 ± 3.03**	20 ± 3.05
Number of fruits	S^1	65 ± 4.93**	30 ± 4.59
	S^2	70 ± 4.5**	40 ± 4.33
Average fruit weight(g)	S^1	70 ± 4.39**	50 ± 3.54
	S^2	80 ± 4.03**	58 ± 3.42
Yield per sub plot (kg per subplot)	S^1	52 ± 6**	35 ± 2.8
	S^2	57 ± 4.6**	39 ± 5.1
Partial factor productivity for N (PFP_N) (kg yield kg^{-1} N applied)	S^1	459 ± 4	809 ± 9**
	S^2	515 ± 7	892 ± 8**

According to the Student's *t*-test **signifies that the difference between two treatments are highly significant at 1% level; *signifies that the difference between two treatments are significant at 5% level and no star signifies that the difference between two treatments are not significant. Error ranges indicate one SD from the mean. S^1, season 1; S^2, season 2.

separately and expressed in kg per sub-plot. Mean of these six values were calculated for each treatment. Amount of N supplied to each sub-plot (kg ha^{-1}) was estimated considering applied fertilizer nutrient ratios ($N:P_2O_5:K_2O$ 30.36:1:5.75) and a total application rate of 225 kg ha^{-1} (a split-application of 75 + 150 kg fertilizer ha^{-1}). Partial factor productivity for N (PFP_N) in each sub-plot was calculated by dividing the yield obtained in a specific sub-plot (Y) by the N fertilizer rate (F_N) (Zeng et al., 2012; Deng et al., 2014).

$$PFP_N = Y/F_N$$

PFP_N values of six sub-plots of each treatment were used to calculate mean PFP_N.

Harvesting

First harvest was done at the 10th week after planting. The mature red fruits were harvested from all plants in each treatment. Subsequent harvests were done four additional times at 7 day intervals, for a total of five harvest events per growing season.

Soil sampling method and measurement of available N

Soil samples were taken at 0–15 cm depth every week spanning the crop production cycle from start to end (Hartz and Johnstone, 2006; Tu et al., 2006; Huang et al., 2007; Walworth, 2010–2011). Six soil samples (six cores, 2.5 cm diameter) were air-dried, homogenized and sieved through 2.0 mm sieve to obtain one composite soil sample for BBRDM and DAP + potash treated plots (Sortino et al., 2012; Zhang et al., 2015). Soil samples were collected randomly from the space beneath the plant canopy as well as the interspace area of the ridges in the central four rows of each sub-plot and 1 m (approximately) away from the ends of the rows. All samples were immediately stored (8–10°C) in sealed plastic bags and transported to laboratory. The easily mineralizable and available N (NH_4^+N) of soil samples was estimated by the Subbiah and Asija method using alkaline $KMnO_4$ which oxidizes and hydrolyses the organic matter present in the soil. The liberated ammonia was condensed and absorbed in boric acid which was titrated against standard acid (Subbiah and Asija, 1956). This method does not measure soil nitrate and is suitable for Indian soils in general. Available soil N was measured before and every week during the cultivation. Analyses were performed in triplicate (Sortino et al., 2012).

Statistical analysis

All statistical analyses were done applying IBM SPSS Statistics 20 software. The Student's *t*-test compares one variable (yield parameter) between two groups (two treatments). Yield parameters of season 1 were compared using Student's *t*-test which compares the means of two treatments. Same parameters for season 2 were compared separately using Student's *t*-test. Significant difference of any parameter are noted in Table 1. Standard deviations were calculated for the mean values of all determinations and the *n* value is specified for each test in the relevant table/figure.

Results and discussion

Soil characteristics The color of the soil in both field cultivation sites was grey to brownish, fine textured and pH ranged from 7.0 to 8.0. The liquid limit was 40–45%, plastic limit was 21–23% and plasticity index was 19–23%. Soil particle size distribution was: sand 6–8%, silt 70–76% and clay 24–27%. The pre-tillage soil bulk density of the 0–15 cm surface layer was 1.83–1.91 g cm^{-3} and the water content was 29.2–31.7%. The soil type was clayey silt.

Yield parameters of tomato plants

Mean values of the yield parameters obtained in the two treatments are shown in Table 1. Student's *t*-test indicated that yield obtained from BBRDM-treated plants were higher by 48% (season 1) and 46% (season 2) in comparison with DAP + potash-fertilized plants. The enhancement in yield was, however, lower than that attained in our previous small-scale pot study (Roy et al., 2013). The onset of flowering and fruiting in BBRDM-treated plants were noticed to be 2 weeks in advance than in plants treated with DAP + potash.

To standardize results in a better way, yields based on N partial factor productivity (PFP_N) were considered. BBRDM supplied 68.31 kg N ha^{-1} while DAP + potash (2:1 mix) provided 27 kg N ha^{-1}. Compared with DAP + potash, BBRDM supplied 2.5 times more N per unit mass of fertilizer applied. However, BBRDM had lower PFP_N values than the inorganic fertilizer in both seasons (Table 1). PFP_N of DAP + potash was 76% higher in S1 and 73% higher in S2 in comparison with PFP_N of BBRDM. Notwithstanding, as BBRDM was produced through local entrepreneurship from slaughterhouse waste, the cost of this organic product would be expected to be much lower than the commercial inorganic fertilizer. Therefore, the farmer may expect higher revenue by purchasing 225 kg of BBRDM than buying the same amount of DAP + potash. Additionally, the lowered PFP may be compensated by other prospective advantages of applying organic fertilizer such as conservation of soil fertility, nutrient recycling, increased soil resiliency and overall environmental sustainability (Peigné et al., 2014). Furthermore, application of BBRDM negates the environmental cost of treating the slaughterhouse waste. The aim of the present investigation was to enhance the yield by replacing the conventional DAP + potash fertilization by organic fertilizer without altering the traditional fertilization practice. Hence, other rates of fertilizer application were not tested. This could be the subject of future field investigations.

According to the local farmers in our study area, deficient fertilization was a reason for lowered tomato yields. We aimed to enhance the yield obtained by application of the organic fertilizer in comparison with chemical fertilization. Therefore, a higher level of organic fertilizer was purposely selected, considering local farmers' desire for improved productivity and slaughterhouse owners' demand for utilization of the highly polluting effluent. Moreover, tomato is a high fertilizer demanding crop (Colla et al., 2002; Riahi et al., 2009). Our reasoning is supported by reports of previous workers. There are several reports on enhanced tomato yields following increased N fertilization. Three NP fertilizers rates (urea + DAP) were applied to the cultivation of two tomato cultivars in Ethiopia (Balemi, 2008). Highest fertilization rate produced highest fruit yield. Similarly, two tomato cultivars were grown in Nigeria at three levels of NPK fertilizers (Law-Ogbomo and Egharevba, 2009), with an observed increase in marketable yield when fertilizer rate was enhanced. In another study, three levels of N and P were applied to tomato cultivation in India (Gupta and Shukla, 1977). Each successive increment in N dose resulted in significant increase in plant height and Bartlett's earliness index. Yield was highest at the highest level of N fertilization.

Although our study appears confounded through application of dissimilar levels of N, there are several studies on tomato cultivation where different levels of N were applied similar to our approach. In some experiments enhanced rate of organic fertilization improved tomato yields. For example, total as well as marketable yields of the two tomato cultivars in Tunisia were higher when COMP (mixed compost consisting of olive husk, horse manure, poultry manure, mixed compost extract and humus) and MIX (sheep manure, mixed compost, mixed compost extract and humus) were applied in comparison with humus application (Riahi et al., 2009). Riahi et al. (2009) attributed the improvement in yield to the increased compost rate, similar to our results (enhanced yield with increased N fertilization through BBRDM). The form and rate in which olive solid wastes were applied to soils in Turkey (Killi and Kavdir, 2013) (supplying different soil N levels, similar to our experimental design), played a major role in ascertaining the efficacy of the waste as organic fertilizers and in soil quality improvement.

On the other hand, there are reports where enhanced organic N fertilization did not increase tomato yields. In contrast to our results, tomato yields obtained from the organic and low input systems in the USA were not statistically different from those attained from the conventionally managed system, although the organic system possessed highest soil total C, N, soluble P, exchangeable Ca and K levels (Colla et al., 2002). In contrast to our results, a blend of compost-based fertilizer (CBF) and urea supplying higher amount of N did not consistently produce better tomato yield than the synthetic fertilizer alone (Taiwo et al., 2007) in Nigeria. The total N applied to organically grown tomato in Italy was higher than that applied to the conventionally grown crop. Despite increased fertilization and in contrast to our results, there was no statistical difference between the yields obtained in organic and inorganic systems (Campanelli and Canali, 2012). Three organic fertilizers, municipal bio-refuse (CVD), bio-organic fraction of CVD (SBO), insoluble residue of CVD (IOR) and a

Table 2. Comparison of tomato yields obtained with BBRDM with that attained using various organic fertilizers in other cultivation systems.

Amount of nitrogen (kg ha^{-1})	Type of organic fertilizer	Yield (t ha^{-1})	Yield (kg kg^{-1} nitrogen applied)	Reference #
237	Poultry manure + cover crops	47–81.9	237–345	Colla et al. (2002)
175	CBF	4.35	25	Taiwo et al. (2007)
588	COMP	87.5 (F)	149 (F)	Riahi et al. (2009)
		82.5 (R)	140 (R)	
702	MIX	92.3 (F)	131 (F)	Riahi et al. (2009)
		87.7 (R)	125 (R)	
176	Off-farm organic fertilizers	62.3	354	Campanelli and Canali (2012)
68.31	BBRDM	33	483	Present study

CBF, compost-based fertilizer, derived from maize stover, cassava peels and poultry manure in ratio (1:3:1 v:v:v); COMP, mixed compost (50% olive husk + 30% horse manure + 20% poultry manure) + mixed compost extract + codahumus 20; MIX, sheep manure + mixed compost + mixed compost extract + codahumus 20; F, Firenze var.; R, Rio Grande var.

reference commercial product (RCP) were applied at different N levels, similar to our study of tomato greenhouse cultivation in Italy (Sortino et al., 2012). SBO, providing the least amount of N to the soil, allowed precocious start of all flowering and fruiting stages and significantly improved plant growth and tomato fruit production compared with CVD and IOR. SBO performed better than RCP although the latter supplied more organic N to soil than the former. Water solubility of the organic fertilizer appeared to be more important than organic N content in enhancing yields (Sortino et al., 2012). As evident from Table 2, BBRDM, applied in the present cultivation system, is a better organic fertilizer for tomato cultivation than other cultivation systems as higher tomato yield was attained supplying lower amount of N. BBRDM application did not require potassium or urea supplementation in the soil as was necessary in previous studies (Taiwo et al., 2007; Javaria and Khan, 2011) by earlier workers with slaughterhouse compost as an organic fertilizer. Table 2 and these reports (Colla et al., 2002; Taiwo et al., 2007; Campanelli and Canali, 2012) indicate that apart from the N fertilization rate, there may be other important factors, for example water solubility of the fertilizer (Sortino et al., 2012), C and N contents of the fertilizer that affect the final tomato yield. This aspect is discussed in the following section, in relation to our present experimental study.

Some researchers comparing the efficacy of organic and inorganic fertilizers during pot and field cultivation of tomatoes have applied equivalent levels of N in both systems. Higher yield of tomato in pots upon application of liquid residue of lipopeptide biosurfactant production compared with application of chemical fertilizers was reported from China (Zhu et al., 2013). Similarly, higher tomato yield in pots by application of municipal solid waste compost and water extract tea in comparison with application of conventional NPK fertilizers was attained in Canada (Radin and Warman, 2011). On the other hand, during field studies, Bulluck and Ristaino (2002) did not consistently report higher tomato yields in plots fertilized with cotton-gin trash, swine manure and rye-vetch in the USA compared with chemical fertilizer. Similarly, higher tomato yields were not observed when compost made up by olive residues, sludge and straw was applied in Italy compared with a chemical fertilizer (Rinaldi et al., 2007). The results of the field studies prompted us to increase the BBRDM application rate in anticipation of a higher yield.

It may be criticized that residual mineral N in soil enhanced the environmental risks due to runoff, leaching or gaseous N release. In India tomato is generally cultivated in the dry winter season hence the chance of excess agricultural runoff is negligible. The possible harmful effects of residual BBRDM are, however, insignificant compared with the catastrophic environmental degradation caused by the direct release of blood and rumen contents into water streams as is being practiced in the rural slaughterhouses. Although BBRDM application may substitute use of chemical fertilizers, further research is required to ascertain if residual soil N from BBRDM is higher than that remaining after chemical fertilizer application.

Status of soil N during cultivation

Figure 1 illustrates that soil NH_4^+ levels in BBRDM were higher than DAP + potash logically due to the higher input of N. Soil NH_4^+ peaks were observed following the application of BBRDM and DAP + potash on the 2nd and 8th weeks (Fig. 1). The temporal increase in soil NH_4^+ may be attributed to lack of soil N immobilization as supported by reports of previous investigators.

In the trials (Marinari et al., 2010) conducted in Italy, the N inputs in the organic system (guano) were greater than in the conventional one (NH_4NO_3), similar to our methodology. The peak of N release during N mineralization (short-term, 200 days) in soils supplied with guano was observed after 4 weeks (Marinari et al.,

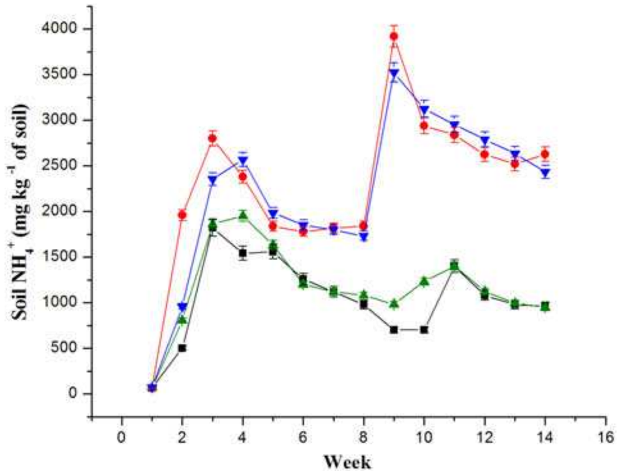

Figure 1. Status of soil available nitrogen (NH_4^+) during tomato cultivation. Fertilizers (BBRDM and DAP + potash) were added at the 2nd week (175 kg ha $^{-1}$) and at the 8th week (50 kg ha^{-1}). Available nitrogen (NH_4^+) was measured as described by Subbiah and Asija (1956). For details of the method, please see the complete article, particulars of which are given in the list of references (Subbiah and Asija, 1956). Error ranges indicate one standard deviation from the mean ($n = 3$). Fx1 Soil treated with DAP (S^1), Fx2 Soil treated with BBRDM (S^1), Fx3 Soil treated with DAP (S^2), Fx4 Soil treated with BBRDM (S^2).

2010), analogous to the N release peak observed upon BBRDM application (Fig. 1). Similar to our observation, soil NH_4^+ content was drastically increased by slurry addition to soil in Canada (Chantigny et al., 2001). Upon addition of *Sesbania sesban* (Jacq.) W. Wight residues to soil in Kenya, the percentage of inorganic N in the soil peaked and then decreased in a 100 day study (Nyberg et al., 2002) similar to our observations (Fig. 1). Hartz et al. (2010) applied fishery waste, feather meal and seabird guano to agricultural soils of the USA and the products mineralized 60–80% of N within 4–8 weeks, analogous to our results. On the other hand, some investigators noted decrease in soil-available N upon addition of organic fertilizers. For most of the manure treatments to agricultural soils (Bechini and Marino, 2009), immobilization of mineral N occurred in the first weeks, followed by slow remineralization of immobilized N in a study carried out in Italy. This observation contrasts our results (Fig. 1). The report (Bechini and Marino, 2009) was, however, supported by other investigators. Alburquerque et al. (2012) noted initial decreases in inorganic-N during short-term study (56 days) which was ascribed to microbial immobilization. In a study conducted for 120 days in Spain (Bustamante et al., 2007), authors concluded that soil immobilization processes, upon application of winery and distillery waste could have succeeded over N losses by ammonia volatilization or by denitrification. Agricultural soils fertilized with Biolyzer (derived from plant materials) had appreciably lower N availability (Hartz et al., 2010).

The amount of soil mineral N at the end of the incubation was highly correlated with the total N content of the fertilizers. The C/N ratio of the readily degradable fraction of the fertilizers had an important effect in controlling soil N dynamics in the short-medium period (Martín-Olmedo and Rees, 1999; Bustamante et al., 2007; Galvez et al., 2012). BBRDM having C/N ratio of 4.8 is a high-quality organic fertilizer. High-quality organic fertilizers (Class I) have >2.5% N (Gentile et al., 2011) and these fertilizers resulted in net N mineralization alike BBRDM in our study. Lower ratios signify a higher quality manure and faster mineralization of nutrients (Nyberg et al., 2002). Conversely, application of manure with high C/N ratios could cause immobilization of N (Nyberg et al., 2002), which was not observed in our experiment. The C/N ratio of the organic fertilizer was implicated by previous investigators in determining whether soil N immobilization or mineralization would occur upon addition of the organic fertilizer. For example, the C/N ratios of the organic fertilizers applied (Bustamante et al., 2007) that caused immobilization varied from 9.8 to 18.2. Similarly the fertilizers of Bechini and Marino (2009) possessed high C/N ratios. Fishery waste, feather meal and seabird guano showing mineralization (Hartz et al., 2010) had lower C/N ratios compared with Biolyzer (Hartz et al., 2010) showing immobilization. In yet another study authors observed mineralization and nitrification of organic N from sheep wool waste which was richer in organic N (over 5%) than manure and compost (Vončina and Mihelič, 2013). The C/N ratio of tithonia was lower than maize and thus had a quicker mineralization rate (Gentile et al., 2011). High-N waste products from agricultural and fishery industries (for example fish powder) demonstrated N mineralization and were the most practical alternative for in-season N fertilization during vegetable production in the USA (Hartz and Johnstone, 2006). The NH_4^+ concentration of soils fertilized with pine biochar (labile C content less than 1% of total C) peaked immediately following application without exhibiting immobilization (Angst et al., 2014).

Generally, the present field observations were supportive of our previous pot study. The preceding pot experiment (Vončina and Mihelič, 2013), supported the authors' field observations where sheep wool proved to be a good source of N. Similarly, Galvez et al. (2012) observed that in both field as well as laboratory studies a significant fraction of available N was released in the first 30 days after application.

Conclusions

Through this study, the exceedingly problematic slaughterhouse waste was converted to an organic fertilizer which was gainfully utilized for the production of tomatoes. This work embodies a practical and feasible method for recycling of organic waste in agriculture. The produce of tomatoes was appreciable and the local farmers are willing to accept the new fertilizer as a substitute for currently used chemical fertilizers. Soil N mineralization kinetics in BBRDM-treated soil was supportive of the enhanced plant N availability. This waste management approach will make the small-scale slaughter houses compliant with environmental norms. This appropriate, affordable and efficient methodology for recycling of waste generated by small abattoirs can be a model in many developing countries with similar dispersed small-scale traditional slaughtering practices with no hygienic waste disposal system. However, the safety of the fertilizer in terms of presence of pathogens and heavy metals as well as fruit quality in terms of lycopene content, nitrate, heavy metal levels and potential toxicity should be evaluated before large-scale application of BBRDM is practiced. This aspect will be the subject of our next communication.

Supplementary Material

For supplementary material accompanying this paper, visit http://dx.doi.org/10.1017/S1742170515000289

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