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Turnover of Chicken Manure in Some Upland Soils of Asia: Agricultural and Environmental Perspective

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1 ABSTRACT

Recycling of organic manure/waste is an important global issue to improve soil productivity for sustaining agricultural production as well as to preserve the environment. In Asia, rearing of poultry especially chicken is becoming one of the key industrial sectors and the wastes from clean-out operations may contribute largely to plant nutrients. Thus, some recent research works on the use of chicken manure (CM) in the uplands of tropical Asia are reviewed. Relative loss of the added CM-C was averaged 83% during a 90-day incubation and *in-situ* retention of labile organic-C was poor in 2 years, signifying long-term episodes to sequestrate its inherent low C. Ammonification of the added CM was rapid during 1-2 weeks followed by oxidation of NH_4^+. The high pH of CM remarkably influenced nitrification either after a lag phase or immediately after application, ensuing NO_3^- leaching to occur under favourable conditions. Net mineralization/nitrification was greater with CM than with other wider C/N ratio organic residues. CM-N recovery was relatively low, indicating immobilization and other N loss processes. Likewise, a large N_2O loss of added CM-N with or without other N sources under field (0.99%) and laboratory (6.66%) conditions was observed, along with presumable NH_3 volatilization. Composted CM/litter could reduce the loss by limiting the transformation of organic N. Application of CM (fresh/composted) either alone or with inorganic fertilizers demonstrated crop yield benefits and reduced the use of the latter as well as a noticeable residual effect to the succeeding crops.

Results suggest that strategic but agro-economically viable composting might have great advantages in synchronizing CM-N release with plant uptake and in reducing appreciable amounts of labile C and gaseous N loss under upland conditions and thus, in minimizing environmental risk.

Key words: Chicken manure, C & N turnover, gaseous loss, uplands, Asia

2 INTRODUCTION

Since ancient time, organic manure has been recognized as effective fertilizers for agricultural production. This century-long tradition has been shifted to inorganically based fertilizers to grow more foods to feed the ever-increasing population, importantly true for Asia. With the advancement of crop breeding, nutrients in excess of soil reserves are indispensable to maximize the yields. Poor management and intensive manipulation has been triggering largely to declining soil productivity. Maintenance and improvement of soil organic matter through organic recycling is deemed necessary to overcome these constraints. Despite its retention uncertainty in soil due to the influence of soil and environmental factors, it improves soil physical, chemical and biological properties, and the released nutrients can be used for growing crops (Risse et a., 2001). This indicates that organic amendment is an integral part of soil productivity and sustainable agriculture. Among the various natural/available sources of organic materials, poultry/chicken manure (CM) has long been known the most desirable ones because of its high N, P and K content. The organic-N in CM is readily available, ranging from 30-50% (Nicholson et al., 1996). The P and K, irrespective of amounts, are mostly available or adsorbed on the soil to be available afterwards for crop uptake. In addition, manures supply several micronutrients and serve as a soil conditioner. In intensive cropping, appropriate amount, timing and method of its application with integrated fertilization approaches can help reach targeted agro-economic benefit (Prasad, 1996).

Rearing of chicken/poultry at household levels has been long-practiced in Asia. Currently, Asia is producing ~51% plant available nutrients of the global total (~35.10^6 tonnes) from poultry manure (Sheldrick et al., 2003). With the growing demands of

consumers for chicken products, it has become one of the important industrial sectors. These make available a huge quantity of manure (droplets, litter, etc.) with the increasing size and frequent cleanout operations, leading to environmental pollution. Disposal of animal wastes are not regulated with proper guidelines and legislation particularly in developing countries, unlike in the developed world (Westerman and Bicudo, 2005). The environmental consequences during storage, transport and agricultural land application are not well concerned though the number of chicken farms has been increasing. Intensive application of CM as a part of the food production usually causes accumulation of heavy metals, and surface and groundwater pollution in different ways of management, like direct dumping into surface water, runoff from feedlots or stockpiles, seepage from lands, lagoon, detention pond, etc. Microbial decomposition after excretion, during storage and land application, create odours of various noxious gases and responsible for the release of greenhouse gases (CAST, 1996). Concerning socio-economic conditions, human health and environmental pollution, several alternative uses of CM are imperative rather than only giving emphasis to make use as a fertilizer for agricultural production. Mismanagement at the farm level is one of the main difficulties. This may be overcome through gathering knowledge on the potential hazards and problems associated with the farming and to act with proper sense to solve the problems. Stabilization of N and C through strategic composting may decrease the environmental consequences (Khalil and Rosenani, 1999) and help maximize crop uptake of the released nutrients. Thus, the fate of CM with emphasis on C and N turnover in some tropical uplands of Asia is reviewed. It is to come up with a decision support for its essential but appropriate management and to compare with valuable findings reported elsewhere with a view to evaluating the agricultural benefits out of it in a sustainable but environment-friendly manner.

3 CHEMCIAL COMPOSITION & TRANFORMATIONS OF CHICKEN MANURE

3.1 Chemical and biochemical compositions

Proper utilization of organic manures for agricultural purpose depends on the type and amount of nutrients present and their chemical/biochemical composition. There are different forms of chicken manure (CM) like fresh droplets, litter (dry excreta mixed with litter for bedding), slurry (mixed dry and wet excreta) and compost. In the fresh but stable manure, amount of nutrients remains generally higher than litter or slurry (Tab. 1). As such, the differences in nutrients quantity presumably depends on the constituents of feeds, other supplements like bedding and water used by the chicken. Unlike the fresh or stable manure, low pH and wide C/N ratio generally designated the characteristics of composted litter, ranging from 6.0-7.0 and 11-15, respectively (Chastain et al., 2001). Percent N in fresh manure varied from 2.16-3.74%, which remained higher than slurry/litter. This was 0.094 –1.41% for composted ones with or without cover (Tyson and Cabrera, 1993). This indicates that fresh CM in either form contributes more to release N and other nutrients due to high concentration of nutrients, high pH and low C/N ratio. However, Abdelhamid et al. (2004) reported an improvement of nutrients content, C/N ratio and CEC with a small C loss (~10%) during composting by using various fractions of rice straw, poultry manure (PM) and oilseed rape cake. This denotes a development possibility of CM processing to get nutrients-rich and stabilized-C source for agricultural use.

Tab. 1: Chemical and biochemical properties of chicken manure

Chicken manure type	pH	%C	%N	C/N*	%P	%K	% Lignin	%Poly-phenol	References
FCM	7.8	22.8	2.16	10.6	1.12	1.64	7.2	1.61	Khalil et al. (2005)
FCM	8.0	-	2.54	-	0.43	1.02	-	-	Kogram et al. (2002)
SCM	7.6	-	2.39	-	0.46	2.02	-	-	
LCM	7.3	-	3.74	-	0.54	2.50	-	-	
Stable	-	21.8	2.43	9.0	1.25	1.85	-	-	Evers and Pothoven
Slurry	-	5.3	1.06	5.0	0.34	0.51	-	-	(1995)
Litter		20.6	1.58	13.0	0.87	0.92	-	-	

FCM = fresh chicken manure; SCM= small pellet chicken manure; LCM = Large pellet chicken manure; *Calculated

2.2 Carbon mineralization

Sequestration of atmospheric C into agricultural soils is a global concern to reduce greenhouse effects. Warm climate, high humidity and other favourable conditions of the tropics, however, enhance the depletion of soil organic C. It has been observed that microbial activity generally peaks during the first two weeks, releasing and assimilating N as their energy source. This process regulates N mineralization and immobilization, depending on the amount of N present in soils and added inputs. Khalil et al. (2005) also reported that addition of CM into soils had a greater influence on CO_2-C evolution than the wider C/N ratio organic residues (Fig. 1). Averaged relative added C loss from various upland soils was found to be in the order of CM (83%) > mungbean residue (52%) > wheat residue (46%). The larger C loss from CM may be attributed to the presence of high amount of labile but inherent low C, where aerobic conditions with high temperature (27-28^{o}C) facilitate the process. Similar influence was also noticed in the humid tropics cropped to cassava or maize-groundnut rotation (Kogram et al., 2002; Mubarak et al., 2003a). They reported that application of CM either alone or coupled with other fertilizers apparently enhanced soil pH and available P with a slight increase of organic matter content in two years.

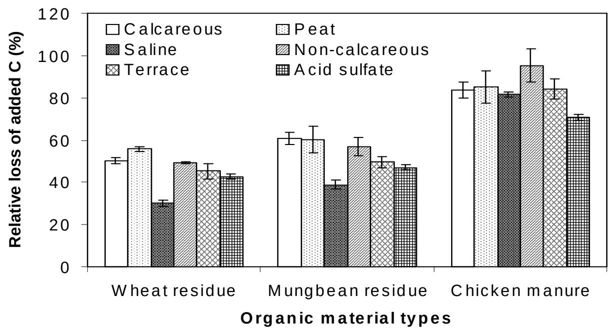

Fig. 1: Relative loss of added C during a 90-day incubation from six contrasting soils of subtropical Asia (Khalil et al., 2005).

Addition of organic materials displays priming effect and slowly decomposable organic materials might render the reduced loss of it under aerobic conditions (Khalil et al., 2005). Inherent soil organic C and C/N ratio vis-à-vis the amount of C in the organic materials could influence the process. However, mineralization of non-hydrolysable C might be independent of organic materials in a long-term study. By contrast, temperate soils are usually high in organic matter, loosing less added C. Irrespective of climatic conditions, however, retention of biomass during or after cropping is an added advantage to improve soil organic matter. Hartz et al (2000) found that mineralization of manure C averaged 35% of the initial C content in 24 weeks grown with fescue, while compost C mineralization averaged only 14% and the slow phase was attained within 4 (compost) or 16 weeks (manure). Composted (Abdelhamid et al., 2004) and wider C/N ratio organic materials (Curtin et al., 1998) could greatly enhance soil C deposition through stabilizing humic materials, which is of paramount importance. Even composted N-rich manure as a (partial/full) substitute of inorganic fertilizers could balance the energy-driven process by reducing the CO_2 released during fertilizer production and help in curving its atmospheric build-up.

3.3 N mineralization

Manure contains N in organic forms, and information on the rate and extent of its mineralization to predict N availability is important. This is to maximizing crop N uptake

and avoiding excess N application, and thereby minimizing the environmental impact beyond the agricultural sector. During 1-2 weeks, application of CM into soils markedly increases ammonification, attributing to the higher amounts of soluble carbohydrates, a lower C/N ratio and lower amount of lignin. These result in higher microbial activity (Griffiths et al., 1994) and thus a faster decomposition of the added CM. Generally, it favours all the microbial groups, and stimulates particularly the ammonium-producers in the acid soils (Acea and Carballas, 1996). Khalil et al. (2002b) reported that CM treated sandy clay loam (Ultisol) soil decreased NH_4^+-N at a faster rate (10.4) than the subsequent nitrification (7.3 mg N kg^{-1} soil day^{-1}) during a 25-day aerobic incubation study, indicating somewhat immobilization and other N losses (Fig. 2a). The CM showed a lag period of 15 days for nitrification, remaining higher than with the wider C/N ratio organic materials. The subtropical soils responded similarly, where acidic soils predominantly accumulated NH_4^+, contributing to increased mineral N (Khalil et al., 2005). Biochemical composition of organic materials also regulated C and N mineralization but its effect was soil specific, demonstrating the highest with CM. In contrast to acidic soils, high pH soils exhibited large net nitrification. However, addition of CM enhanced overall the nitrification process, resulting in a larger availability of mineral N as NO_3^- over time (Fig. 2b).

By contrast, nitrification can be immediate under controlled and field conditions with fresh CM (Khalil et al., 2002a) and with fresh/composted poultry litter (Preusch et al., 2002). Freshly added poultry litter/manure mineralized 30 to 64% of the total organic N whereas it was 1 to 9% of the composted one (Hartz et al., 2000; Preusch et al., 2002; Vest and Merka, 2004) as well as increased CEC (Abdelmajid et al., 2004). In deed, composted materials contain high N as fulvic and humic acids, reducing decomposition and transformation of organically bound-N to mineral N. Thus, the slower pattern of N release with composted/processed manure, either directly or through remineralization of immobilized N over time, pose a less environmental risk.

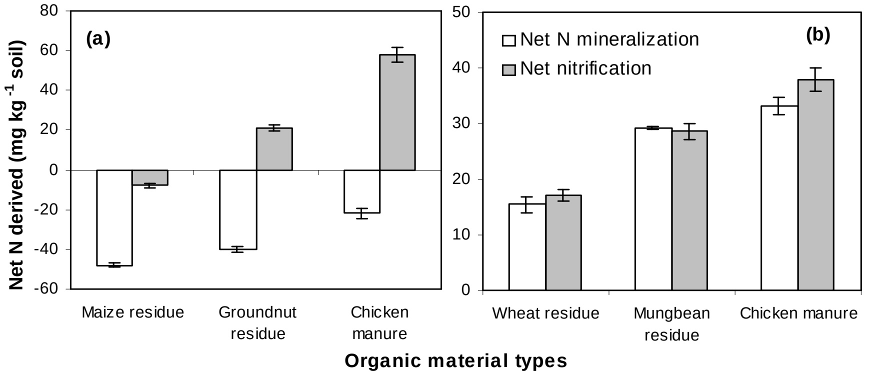

Fig. 2: Net N mineralization and net nitrification of the added organic-N (a) to an ultisol of the humid tropics during a 25-day incubation and (b) to six contrasting soils of the subtropics during a 90-day incubation (Reproduced from Khalil et al., 2002b; 2005).

4. ATMOSPHERIC POLLUTION DUE TO CHICKEN MANURE

4.1 Ammonia volatilization

Atmospheric ammonia (NH_3) has large impact to environmental degradation through acid rain formation and eutrophication. The high labile N in CM and its subsequent transformation contribute largely to N loss via NH_3 volatilization. Besides, it creates odour annoyance during the growth periods of chicken, manure storage, transport and field application. Fresh CM contains also pathogens detrimental to plant seedlings in particular and weed seeds, competitors to available nutrients for plants. Under field conditions (probably also representative for Asia), NH_3 fluxes ranged from 3.3 to 24% of the total N applied during the winter and summer, respectively (Sharpe et al., 2004). Its loss was rapid immediately after litter application and stopped within 7 to 8 days (Fig. 3). Precipitation events could reduce its loss but could also increase NO_3 leaching and runoff to streams and rivers. As such, composting has received much interest for agricultural use though it displays 30 to 50% reductions in mass but a material more uniform in nutrients composition (Dao, 1999). NH_3 volatilization from poultry litter dramatically increases with an increase of pH (>7), moisture content, wind speed, NH_3

concentration, temperature, etc. This large loss reduces the agronomic value of the end product. Chemical amendments, cabonaceous and/or high N materials (Abdelhamid et al., 2004; Huang et al., 2003) could help reduce this remarkable N loss occurring from CM. However, compost might enhance denitrification while NH_3 volatilization decreased (Mahimairaja et al., 1994). These signify the importance of appropriate management and strategic composting of CM in order to decrease the gaseous N loss occurring before and after field application.

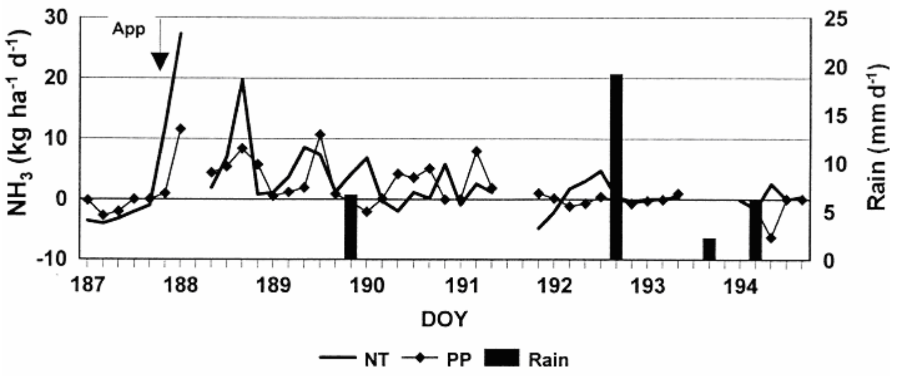

Fig. 3: Ammonia volatilization rates and rainfall during the summer of 2000. DOY, day of year; NT, no-till; PP, paraplowed (Sharpe et al., 2004).

4.2 Nitrous oxide emission

Nitrous oxide (N_2O) is formed mainly during nitrification and denitrification. It has enormous contribution to global warming and ozone layer depletion. Soils, fertilizers and other environmental factors largely affect its production and release. Under upland conditions, N_2O emissions from the soil systems are considerably influenced by irrigation and/or rainfall events through changing physico-chemical conditions or by affecting the soil diffusivity and microbial activity and subsequent gas production and efflux (Delgado and Mosier, 1996). Easily decomposable organic materials could promote N_2O emission (Flessa and Beese, 1995; Khalil et al., 2001a) and enhance further with added animal manure (Akiyama and Tsuruta, 2003; Khalil et al., 2001b). It has been observed that total N_2O emission during a 25-day aerobic incubation was more than doubled with a soil amended with CM, relating to rapid N mineralization and nitrification after a lag phase (Khalil et al., 2002b) and an indication of priming effect.

Fig. 4a shows that the relative N_2O loss of the added CM-N was several-fold higher (6.7%) than from the crop residues-N (1.6-2.5%) but lower than inorganic fertilizers like urea and KNO_3 (8.2-8.6%).

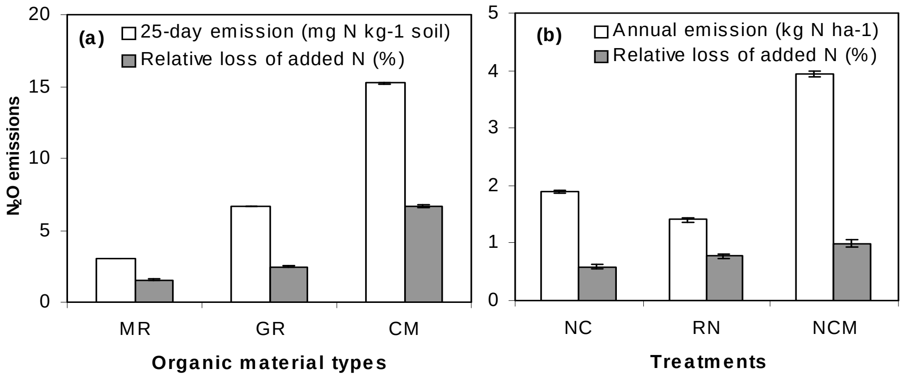

Fig. 4: Total N_2O emission and its relative loss of the added N (a) from an ultisol during 25 days under laboratory conditions and (b) during one-year with groundnut-maize rotation in the ultisol of the humid tropics (MR = maize residue, GR = groundnut residue, CM = chicken manure, NC = inorganic N + crop residues (322 kg N ha^{-1}), RN = inorganic N only (180 kg N ha^{-1}) and NCM = ½ RN + crop residues + chicken manure (400 kg N ha^{-1}); Reproduced from Khalil et al., 2002a,b).

By contrast, relative N_2O loss of the added CM and crop residues-N coupled with half-rate of inorganic from a groundnut-maize rotation was several-fold lower (0.99%) than under laboratory conditions (Fig. 4b). However, this value is higher than the lower limit of the global estimate (1.25 ± 1%), but insignificant from an agronomic standpoint. Slow nitrification with composted manure/litter might release small N_2O, and even the residual effect could be minimum (Ginting et al., 2003). In contrast, anaerobic microsites could develop within soil aggregates/organic materials, and solubilized-C serves as an energy source for denitrifiers, and thus denitrification-induced N_2O could be large (Flessa and Beese, 1995; Stevens et al., 1997). As such, synchronization of the accumulated NO_3^- with plant uptake can be beneficial to reduce the above losses.

4.3 Methane emission

Methane (CH_4) is another important greenhouse gas and strict anaerobic conditions favour its production. Under upland conditions with moisture content below field

capacity, generally, loss of C as CO_2 during heterotrophic microbial respiration is dominant and steady under favorable environmental conditions. Simultaneous CH_4 oxidation and emission under aerobic conditions could make a balance of atmospheric CH_4 enrichment (Khalil et al., 2001a; Khalil et al., 2004) and importantly residual effects might be minimum (Ginting et al., 2003). Thus, CH_4 emission is not important relating to environmental consequences under upland conditions. An exception is the cultivation of irrigated rice, where anaerobic conditions exist for a long time. These conditions may favour CH_4 emission, including lowland/monsoon rice fields. However, application of mature compost to wetlands might also help reduce the emission (Khalil and Rosenani, 1999).

5 SOIL AND WATER POLLUTION DUE TO CHICKEN MANURE

Excessive use of chicken manure/litter can cause non-point pollution through NO_3 leaching into groundwater and runoff to surface-water bodies, even at a normal rate if crops do not uptake the N released from the systems (Gale and Gilmour, 1986). Avoiding intensification of CM in the production area and/or composting might be the better of decreasing the water pollution (Bosch and Napit, 1992; Tyson and Cabrera, 1993). Under irrigated rice cultivation, however, care must be taken to apply CM (fresh or composted) with proper management but at a lower rate. Incorporation of CM rather than surface application limits runoff, reducing the loss of nutrients if denitrification is not occurring largely. Moreover, continuous and intensive application of organic manure might enhance accumulation of heavy metals in soil particularly Cu, Zn and Mn along with P and K (Gascho et al., 2001). Its deposition was directly related to broiler litter rate, suggesting limits of its application to 4.5 Mg ha^{-1}.

6 INFLUENCE OF CHICKEN MANURE ON CROP PRODUCTION

Despite some environmental consequences, CM has large beneficial effects to agricultural production. The tropical soils are generally low in organic matter (~1%) and addition of organic residues is imperative to conserve the soil and its productivity. It might be a continuous process, as the high temperature and intensive rainfall events, generally, enhance the decomposition process. Despite that, yield response of the applied crop residues and CM was high in Malaysia (Tab. 2). Application of inorganic N at a half-rate with the CM and crop residues into crop fields showed superiority over other treatments with full dose of N with or without crop residues, indicating a saving of 50% inorganic N fertilizer. However, overall CM-N loss was high, with an estimated N (mineral N eqv.) recovery efficiency of 8.1 and 23.9% over latter, respectively (Khalil et al, 2002a; Mubarak et al., 2003b). Similarly, Kogram et al. (2002) found increased yields of cassava with the fresh CM, which was about 44 and 273% greater than chemical fertilizers and control, respectively in the second year of cropping in Thailand. They have mentioned the CM as an alternative source of nutrients for cassava production, however, the sole application of organic manure reduced the yields over first-year application presumably due to nutrients deficiency. In Japan, Abdelhamid et al. (2004) received yield benefits of faba bean with low C/N ratio compost, even at a low rate and sandy loam soil responded better than clay loam soil. In Vietnam, CM is also considered as high value-fertilizers for coffee, pepper, or orchards like longan and grape-fruits (Dan et al., 2004).

Tab. 2. Direct/residual effects of fresh or composted chicken/poultry manure on yields of different crops grown in Asia.

Country /Soil	Fertilizer type	Fertilizer rate (kg ha^{-1})	Crops (unit of yield)	Grain/cobs /pod yields	Reference
Malaysia /Sandy clay loam	Full N Full N + GR-N 1/2N + GR-N + CM-N	150 150 + 70 75 + 70 + 168	Maize (kg ha^{-1})	1240b 1210b 1820a	Khalil et al. (2002a)
Thailand /Loamy sand	SCM LCM FCM FCM CF Control	2500 2500 3125 6250 46.9:20:38 -	Cassava (fresh root yield, t ha^{-1})	20.6bc 18.1bc 22.6b 31.3a 21.7b 8.4d	Kogram et al. (2002)
Japan /Clay loam	70% RS + 20% PM + 10% ORC 60% RS + 20% PM + 20% ORC 50% RS + 20% PM + 30% ORC 40% RS + 30% PM + 40% ORC Control	(Compost rates were: 0, 10, 20, 40, 80, 120, 200 t ha^{-1} but used mean values)	Faba bean (g pot^{-1})	5.3b 5.1b 6.0ab 6.7a 3.4c	Abdelhamid et al. (2004)
India /Clay	100% NPK 75% NPK + 25% residual FYM 75% NPK + 25% residual PC 75% NPK + 25% residual PM	120:60:30	Wheat (kg ha^{-1})	2441b 3053a 2931a 3143a	Ghosh et al. (2004)
Malaysia /Sandy clay loam	Full N only Full N + MR-N 1/2N + MR-N + residual CM	30 30 + 72 15 + 72	Groundnut (kg ha^{-1})	940b 1070b 1240a	Khalil et al. (2002a)

GR = groundnut residue, CM = chicken manure, RS = rice straw, PM = poultry manure, ORC = oilseed rape cake, SCM = small pellet chicken manure, LCM = large pellet chicken manure, FCM = fresh chicken manure, CF = chemical fertilizers, FYM = farm yard manure, PC = phosphocompost, MR = maize residue

Noticeable residual effect of organic manure has also been reported elsewhere. In the semi-arid tropics of India, Ghosh et al. (2004) observed that application of 75% NPK in combination with PM to preceding crops and only 75% NPK to succeeding wheat produced significantly higher grain of wheat than those receiving 100% inorganic fertilizer, a saving of 25% NPK fertilizers. This indicates the beneficial effect of integrated nutrient approach with PM to maintain soil productivity and to increase crop yields by supplementing all nutrients readily to crop (Edward and Daniel, 1992). The findings are in line with Khalil et al. (2002a), showing the added advantage of CM supplied into the preceding crop to the succeeding crops in the humid tropical soil. This relates to the residual effect of compost and manure resulted in high soil microbial biomass C, potentially mineralizable N and high pH (Ginting et al., 2003). However, timely application of manure following appropriate method and required rate based on the synchrony of available nutrients in soils for plant uptake are important. Amount of

P, as its deposition over time was high (Gascho et al., 2001; Kogram et al., 2002), rather than N has to be considered to calculate the amount of fertilizers so as to avoid its supply in excess of actual needs or contamination of water-bodies. Additional N needed to enhance crop growth can be supplemented with inorganic N fertilizers, as and when necessary.

7 CONCLUSIONS

It has been revealed that disappearance of the added chicken manure-C is generally rapid and thus, N transformations. This makes available a considerable amount of mineral N and other nutrients for plant uptake. Loss of N in various gaseous forms and into ground/surface water-bodies during processing and field application is the main constraint. This causes environmental pollution and provides poor agronomic benefits with regard to agricultural production. Despite some environmental consequences, utilization of nutrients from chicken manure for soil productivity and agricultural production could play a large role in reducing the application of inorganic fertilizers. Thus, research works on strategic composting are imperative to mitigate the constraints as well as to achieve agro-economic benefits out of the integrated plant nutrition systems.

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