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RESEARCH ARTICLE

Maize nitrogen recovery and dry matter production as affected by application of solid cattle manure subjected to various storage conditions

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Abstract

This study aimed to quantify the effects of contrasting composted methods of solid cattle manure (SCM) on dry matter (DM) yield and crop apparent N recovery (ANR) following manure application to maize land. Fresh SCM was stored as stockpiled, roofed, covered and composted heaps. After storage, the manures were incorporated in a sandy soil, and maize ANR both as a proportion of field applied N (ANR_F) and collected N from the barn (ANR_B), and DM yield was established at three successive growth stages: end of juvenile phase, start of grain filling, and physiological maturity.

During the storage period, on average 6% of the initial N_{total} was lost from covered, whereas this fraction was 12, 21 and 33% from roofed, stockpiled, and composted heaps, respectively. DM yield of maize increased with the application of all the manure types as compared to the unfertilized control, at the end of Juvenile (2.2 vs. 3.1-3.4 Mg ha^{-1}), grain filling (11.2 vs. 13.6-16.4 Mg ha^{-1}) and physiological maturity stages (13.9 vs. 15.3-15.9 Mg ha^{-1}). At a given growth stage, the greatest value was obtained from covered than roofed, stockpiled and composted manures. Maize ANR_F was the highest at start of grain filling (20, 29, 31, and 39% of the applied N for composted, stockpiled, roofed and covered treatments, respectively) but lower values were obtained at physiological maturity (12-21%). The respective values in case of maize ANR_B were 13, 23, 27 and 37% of total N taken from barn at the start of grain filling while it was also lower (8-20%) at physiological maturity. It is concluded that storage of SCM under an impermeable plastic cover reduce N losses, increased DM yield and ANR thereby improves on-farm N cycling as compared to traditional stockpiling or composting.

Keywords: Solid cattle manure, storage conditions, organic farming, maize, N fertilizer value, nitrogen cycling

1. Introduction

Solid cattle manure provides a valuable source of nitrogen (N) for plant nutrition, but may cause agro-environmental problems if its utilization is inefficient due to poor management (Schröder 2005; Scotti *et al*. 2015; Shah *et al*. 2016). After excretion in barns, solid cattle manure is either directly applied to the field or stockpiled and/or composted in the open air for a certain period of time prior to field application. When uncovered, the stored manure is subjected to ambient environmental conditions (i.e. rainfall, temperature, wind, and radiation), which influence gaseous emissions and leaching of N from the heaps (Kirchmann 1985; Pardo *et al*. 2015). These losses may not only contribute to environmental pollution but also reduce the N fertiliser value of the manure. Turning of the manure heap during composting exposes the inner fresh material to microbial colonisation which increases the manure decomposition rate and hence the temperature inside the heap. Additionally, the inner voids of the heap are exposed to the air, which will boost gaseous emissions (Amon *et al*. 2001; Parkinson *et al.* 2004; Sagoo *et al*. 2007; Hassouna *et al.* 2008). Some farmers stockpile solid cattle manure in a roofed building with the aim to protect it against precipitation and therefore to reduce especially leaching losses (Mosquera *et al.* 2006), however, this is not a common practice. All these storage methods result in substantial loss of N up to about 50% of the initial N content from the heaps (Shah *et al*. 2012b).

Attempts have been and are being made to reduce the solid cattle manure storage N losses. These include compaction and/or covering of manure heaps, use of chemical as well as biochemical additives, and application of additional straw (Sommer and Møller 2000; Chadwick 2005; Yamulki 2006; Ndegwa *et al*. 2008; Shah *et al*. 2013; Pardo *et al.* 2015). However, all these storage conditions not only affect the level of N losses but also determine the characteristics of the end product, which can be decisive for subsequent N release for crop uptake after manure application (Kirchmann 1985; Shah *et al*. 2012b; Rashid *et al.* 2013). Covered storage creates anaerobic conditions which transforms high molecular weight compounds (e.g. plant fibre, microbial and metabolic proteins) into easily degradable and low molecular weight compounds such as fatty acids and therefore increases the ammonium-N (NH_4^+-N) content of manure (Kirchmann and Witter 1989). The organic matter decomposed under this method comprises mainly of cellulose, hemicellulose and soluble compounds. Under aerobic conditions, a large part of the manure NH_4^+-N can be lost via NH_3 volatilisation or transformed into organic N. In addition, humified organic material of high stability with a low C/N ratio is produced (Kirchmann 1985). Consequently, microbial decomposition and N release from these stored manures might affect their N fertilizer value. Thus, we believe that it is indispensable to take also into account the downstream impacts of the storage methods i.e. on crop yield and N recovery after land application in order to improve on-farm N cycling within the livestock-manure-soil-crop continuum.

After soil application, part of the inorganic N is immobilized by microbes, fixed by clay and/or adsorbed on negatively charged surfaces. This immobilized and retained N as well as the organic N fraction of applied manure has to be first mineralized or desorbed before it is available for plant uptake. All these N transformations are rather complex and controlled by manure type, their characteristics, and storage conditions (Kirchmann 1985; Thomsen and Olesen 2001; Shah *et al.* 2012a, b; Shah *et al*. 2016). It has shown in earlier studies that relatively greater amount of N can end up in plants from covered/anaerobically-stored as compared to the composted/aerobically-stored manures

(Kirchmann 1985; Thomsen 2001, Thomsen and Olesen 2000; Takahashi *et al*. 2004; Shah *et al.* 2012a, 2016). Of these studies evaluating DM yield and N recovery from stored manures, mostly focused on sheep manure (Thomsen 2001; Thomsen and Olesen 2000), poultry manure (Takahashi *et al*. 2004) and cattle manure on grasslands (Shah *et al.* 2012a), whereas only a little is known when stored cattle manures are applied to arable land (Shah *et al*. 2016). Due to lack of this information the farmers mix their animal manures in the soil just before sowing and use abundant chemical fertilizer to ensure maximum production. This over fertilization not only increases the cost of production but also contribute to the environmental pollution. Thus both from economic and environmental point of view, it is a crucial to estimate crop DM yield and N recovery from stored cattle manures during a growing season in order to optimize the doze of N fertilizer for sustainable crop production.

The objectives of this study were therefore to quantify the effects of contrasting storage methods of solid cattle manure on DM yield and apparent N recovery from both field applied N (ANR_F) and N collected from the barn (ANR_B), after application to maize land.

2. Materials and Methods

2.1. Description of the experimental site

The study was carried out at the Organic Experimental and Training Farm Droevendaal, located 1 km north of the city of Wageningen, the Netherlands (latitude 55°99'N and longitude 5°66'E). The climate is temperate maritime with average summer and winter temperatures of about1 9 °C and 2 °C, respectively. The mean annual rainfall is 765 mm with a relatively high inter-annual variability. Experimental field on the farm was not cultivated over the last 3 years and was covered with ryegrass. The soil (pH 5.23, C/N 18) was sandy (80% particles 50 to 2,000 μm and 4% particles <2 μm) and contained 1.1 g/kg N, 3.5% organic matter 80 mg/kg K, and 4.7 mg/kg P.

2.2. Manure storage treatments and total nitrogen losses

Fresh solid cattle manure (SCM) was collected from a naturally ventilated sloping-floor barn with young beef cattle, where chopped cereal straw were used as bedding material at a daily rate of 5 kg per livestock unit (1LU = 500 kg of live body mass). Immediately thereafter, portions of 10 Mg of SCM were put on a clean concrete floor outdoors to make conical heaps with a height of about 1.5 m and a base diameter of about 5 m. There were four SCM storage methods: (i) stockpiled heap in the open air, (ii) roofed heap: stockpiled heap under a plastic roof, (iii) covered heap: stockpiled heap covered with an impermeable plastic sheet, and (iv) composted heap with monthly turnings. All the treatments were arranged in a randomized complete block design with three replicates. The manure heaps were build-up in bunkers bounded by one course of concrete blocks around three sides (approximately 0.5 m high) and a ridge of sand forming the fourth side (30 cm high). For each of the covered heaps, an impermeable plastic sheet (0.15 mm thick polyethylene film) was lined at its bottom and at the top. The edges of the plastic sheet were covered with sand-filled plastic sacks in order to block the inflow of air into the heap. For each roofed heap, an artificial roof was built by installing a thick impermeable plastic sheet (0.15 mm thick polyethylene film) on four curved iron posts each with a height of 4 m in the middle. The manure was stored at composting facility of Wageningen University, the Netherlands for 160 days starting from the 1st week of December 2009 until the 2nd week of May 2010. At the end of the experiment, each heap was weighed to estimate the amount of remaining SCM in each treatment.

Both at the start and end of the storage period, three manure composite samples (ca. 2 kg fresh wt.) were collected from each heap. Each composite sample consisted of 20-30 sub-samples taken by hand from different locations of a heap. The samples were stored at -18 °C until analysis in order to prevent N transformations. Before analysis, the samples were thawed at room temperature (20 °C) and soon afterwards (~20 minutes) chopped with a cutting machine in order to cut straw particles into small pieces (≤ 2 cm). From this material, representative sub-samples of about 100 g were analysed for total N, NH_4^+-N, nitrate-N (NO_3^--N), pH, DM and raw ash (Table 1). Total N was measured after Kjeldahl digestion (MAF_F 1986). Contents of NH_4^+-N and NO_3^--N were measured in a 1:10 manure/0.01 M $CaCl_2$ extract by means of segmented-flow analysis (Houba *et al.* 1989). The pH was measured in the same extract using a pH meter (inoLab pH meter level 1, WTW GmbH & Co. KG, Germany). DM was determined after drying the samples at 105 °C for 24 hours (Anonymous 1998). Subsequently, raw ash content was determined gravimetrically through ignition of the dried samples at 525 °C for 6 hours (Anonymous 1998) with organic matter (OM) being equal to the ignition losses. Total C was assumed to be 50% of the OM (Pettygrove *et al*. 2009). Total N losses from each heap during the storage period was determined by the mass balance method.

Table 1. Chemical composition of solid cattle manure (means and standard errors; n = 3) at the start of their application to maize land.

Treatments	DM	C_{total}	N_{total}	$N_{min.}$	$N_{min.}/N_{total}$	C/N	P_2O_5	K_2O	pH-
	(%)	(g kg^{-1}DM)			(%)	ratio	(g kg^{-1}DM)		$CaCl_2$‡
Fresh manure	21.7±0.5	357±2.2	29.7±0.7	3.7 ±0.4	12	12.0±0.3	14.1±0.9	42.4±1.8	8.0
Roofed manure	21.1±0.0	338±4.8	29.7±0.4	4.2±0.5	14	11.4±0.0	15.1±0.8	45.9±2.1	8.1
Stockpiled manure	21.2±0.3	339±2.4	27.3±1.1	2.9±0.2	10	12.4±0.4	12.2±0.9	36.8±1.5	8.1
Composted manure	22.2±0.3	339±3.9	27.2±1.4	2.2±0.2	9	12.5±0.6	19.0±0.5	53.6±1.1	8.3
Covered manure	20.5±0.2	340±3.3	30.4±0.4	5.1±0.3	17	11.2±0.2	18.5±1.0	51.7±2.0	7.8

‡ Standard errors < 0.1

2.3. Maize DM yield and N recovery

After the storage phase, all the stored manures together with fresh manure taken directly from the barn (total N 29.7 g kg^{-1} DM, mineral N 3.7 g kg^{-1} DM and C/N ratio 12) were incorporated (on May 11, 2010) in the top 10 cm of an arable field of the farm at an application rate of 170 kg N ha^{-1}. Treatments comprised: (i) control (unfertilised), (ii) fresh manure, (iii) stockpiled manure, (iv) roofed manure, (v) covered manure, and (vi) composted manure. All the treatments were arranged in a randomised complete block design with four replicates. The plot size was 15 m × 4.5 m. One week after manure incorporation (on May 19, 2010), maize seeds (cultivar: Lapriora) were sown at 6 cm depth and a density of 11 plants m^{-2}. In each plot, there were 6 rows of maize plants with a row spacing of 75 cm. The experimental area was weeded manually during vegetative growth period of maize.

In order to study the dynamics of N uptake and apparent N recovery (ANR) in time, maize crop samples were taken at three successive growth stages: 55 days after sowing (DAS), i.e. at the end of juvenile stage, 98 DAS (start of grain filling) and 131 DAS (physiological maturity). These growth stages were based on Gungula *et al*. (2003). During the first two harvests, 10 plants were selected randomly from the two inner rows (rows 2 and 5) of each plot, and were manually cut at ground level using a sharp knife. At final harvest, all the plants in the remaining two middle rows (rows 3 and 4) were cut mechanically at 10 cm height by a mechanical maize harvester and the actual number of harvested plants per plot was counted. At this growth stage, stubble DM and N yields represent about 4% of their respective harvested yields above 10 cm (M. Ali, personal communication) which were added to the obtained DM and N yields in order to enable a fair comparison with the first two growth stages. The outer two rows (rows 1 and 6) were not used for the experiment in order to exclude border effects. At each harvest, fresh maize biomass was measured in the field and subsequently chopped with a cutting machine in order to take representative fresh samples of about 500 g. Subsequently, the samples were oven-dried at 70 °C for 48 hours, ground to pass 1 mm sieve and analysed for total N content through Kjeldahl digestion (MAF_F 1986). Maize apparent N recovery in the field (ANR_F) was calculated as:

$$ANR_F\ (\%) = \frac{(N_m \times DM_m) - (N_0 \times DM_0)}{TN_a} \times 100 \qquad (1)$$

Where N_m is maize N content (mg N (kg DM)$^{-1}$) in the manured plots, DM_m is maize DM yield (kg ha^{-1}) in the manured plots, N_0 is maize N content (mg N (kg DM)$^{-1}$) in the unfertilised plots, DM_0 is maize DM yield (kg ha^{-1}) in the unfertilised plots and TN_a is total amount of N applied with manure (kg ha^{-1})

Thereafter, maize apparent N recovery of the N collected from the barn (ANR_B) was calculated as:

$$ANR_B\ (\%) = \frac{(TN_{barn} - TNloss_{storage}) \times ANR_F}{TN_{barn}} \times 100 \qquad (2)$$

Where TN $_{barn}$ is total amount of manure N taken from the barn (kg), $TNloss_{storage}$ is total N lost during storage (kg) and ANR_F is maize apparent N recovery in the field (%).

2.4. Maize composition

The dried maize samples were ground with a ball-mill (Retsch, Germany) and subsequently extracted in 5 ml of 80% ethanol for 20 minutes at 80 °C. The supernatant was discharged, the residues were centrifuged and the obtained pellets were washed three times with 80% ethanol before vacuum drying in order to remove already existing soluble sugars and to accurately analyse starch (converted to glucose) in the samples. Starch was enzymatically converted to glucose with thermostable α-amylase (Serva 13452) in water at 90 °C, and subsequently at 60 °C with amyloglucosidase (Fluka 10115) in 50 mM citrate buffer with pH = 4.6. The obtained starch extracts were analysed on a Dionex ICS5000 HPLC equipped with a CarboPac1 (250 x 2mm) column eluted with 100 mM NaOH and 12.5 mM sodium acetate.

Cell wall contents, i.e. cellulose, hemicellulose and lignin, in the maize plant samples were determined gravimetrically after extracting the dried samples with H_2SO_4 as outlined in Dence (1992) (the NDF/ADF method).

2.5. Statistical analysis

Total N losses from the heaps during storage, and maize DM yield, N uptake and ANR data after manure application in the arable field were statistically

If the overall main effects were significant, differences among the treatments were further compared using Fisher's protected least significant difference (LSD) test at 5% probability level. The differences in starch, cellulose, hemicellulose and lignin yields at various maturity stages of maize were also statistically tested as described above.

3. Results and Discussion

3.1. N losses during storage of SCM

Mass balances during the manure storage phase revealed that highest total N losses occurred in the composted heaps and lowest in the covered heaps (Figure 1, $P < 0.05$). On average, about 6% of the initial N total was lost from the covered heaps whereas this fraction was 12% from the roofed, 21% from the stockpiled, and 33% from the composted heaps (Figure 1). These higher N losses from the stockpiled and composted heaps as compared to the others can be associated with a higher degree of aerobic decomposition stimulated by diffusion of air into these heaps due to (1) the presence of straw in both heaps and (2) regular turning of the composted heap (Parkinson *et al*. 2004).

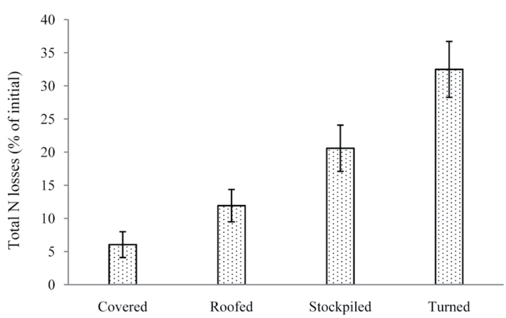


Figure 1. Total N losses from solid cattle manure when subjected to various storage conditions. Error bars represent the standard error of the means (±).

In case of the composted heaps, turning increased air exchange through the materials and stimulated aerobic decomposition processes which will stimulate the process of NH_3 emission (Amon *et al*. 2001; Parkinson *et al*. 2004). Covered storage reduced these N losses by about a factor five relative to composted heap. This could be ascribed to blockage of air circulation through the heaps which minimize aerial losses and creates near-anaerobic conditions (Kirchmann 1985; Hansen *et al.* 2006). Further, the formation of nitrate and nitrite is restricted under anaerobic conditions and thereby also the occurrence of denitrification losses (Kirchmann 1985). Consequently, mineral N content in covered manure was greatly increased at the end of the storage period (Table 1). This increase is important from an agronomical viewpoint especially in case of organic agricultural practices where the use of artificial fertiliser is prohibited. However, due to increased mineral N content along with a high pH of covered manure, compensatory losses may occur through increased NH_3 emissions after its land application, when left untreated (e.g. Amon *et al*. 2001; De Vries *et al*. 2015). Benefits of manure covering can be maximised through soil incorporation (Webb *et al*. 2012), irrigation or using additives like lava meal which adsorb ammonium-N (Shah *et al*. 2012c). Visual observations during the experimental work revealed that the surface of the roofed heaps remained open and porous, especially during the first month of the storage, allowing NH_3 to diffuse easily into the atmosphere. On the other hand, the stockpiled heaps in the open air were subjected to the exposure of weather (wetting and drying), which lead to the formation of a surface crust and thereby creating a physical barrier to gaseous N emissions.

3.2. Crop dry matter yield and N recovery

Maize DM yield, ANR_F and ANR_B are presented in Table 2. The DM yield increased ($P < 0.05$) with the manure application as compared to the unfertilized control (Table 2). Among the manure types, it was the highest in case of covered and the lowest from composted manure, on all crop growth stages. Similarly, maize ANR_F was lower from composted manure as compared to covered manure irrespective to the growth stage. The reasons for this appeared to be (i) the relatively greater loss of readily degradable N compounds already during composting resulting in lower mineral N contents (Table 1), and (ii) conversion of a part of the remaining N into chemical forms that are more stable than those originally present before composting (Kirchmann 1985; Kirchman and Witter 1989; Thomsen 2001). When losses during storage were included in the calculations to arrive at an apparent N recovery for the whole manure handling chain with the barn as starting point (ANR_B), almost three times lower value was observed for composted than for covered manures (ANR_B = 13 vs. 37% at grain filling stage, respectively; Table 2). Interestingly, despite an observed 6% loss of the initial total N during the covered storage, ANR_F from covered manure was higher than from fresh manure taken directly from the barn (i.e. ANR_B= 37 vs. 27 at grain filling stage, respectively; Table 2). This clearly indicates that a significant fraction of the initial organic N of covered manure was mineralised during storage phase. Consequently, total mineral N increased by 41% after covered storage with respect to fresh manure and thereby increased the N fertiliser value of this currently underutilised manure storage practice. Interestingly, the apparent N ended up in above ground biomass varied among the maize growth stages as observed at each harvesting event (Table 2). Maize ANR_F appeared to be highest at the start of grain filling (20, 29, 31, and 39% of the applied N for composted, stockpiled, roofed and covered treatments, respectively; Table 2), but lower values were obtained at physiological maturity stage (12-21%).

Table 2. Mean dry matter (DM) yield, nitrogen (N) uptake, and apparent N recovery expressed as fraction of total N applied to the field (ANR_F) and as fraction of total N taken from the barn (ANR_B) at various growth stages of maize.

Treatment	End of the juvenile				Start of the grain filling				Physiological maturity			
	DM yield	N uptake	ANR_F	ANR_B	DM yield	N uptake	ANR_F	ANR_B	DM yield	N uptake	ANR_F	ANR_B
	(Mg ha^{-1})	(kg ha^{-1})	(%)		(Mg ha^{-1})	(kg ha^{-1})	(%)		(Mg ha^{-1})	(kg ha^{-1})	(%)	
Zero	2.2^{a}†	68^{a}			11.2^{a}	155^{a}			13.9^{a}	166^{a}		
Fresh	3.1^{b}	100^{b}	19^{a}		14.4^{bc}	204^{c}	28^{b}		15.9^{b}	195^{bc}	17^{ab}	
Roofed	3.2^{b}	102^{bc}	20^{ab}	18^{b}	14.7^{bc}	208^{c}	31^{b}	27^{b}	15.3^{b}	186^{b}	12^{a}	11^{a}
Stockpiled	3.2^{b}	98^{b}	18^{a}	14^{ab}	15.5^{cd}	205^{c}	29^{b}	23^{b}	15.6^{b}	191^{bc}	15^{a}	12^{a}
Composted	3.1^{b}	97^{b}	17^{a}	11^{a}	13.6^{b}	190^{b}	20^{a}	13^{a}	15.2^{b}	187^{b}	12^{a}	8^{a}
Covered	3.4^{b}	107^{c}	23^{b}	26^{c}	16.4^{d}	222^{d}	39^{c}	37^{c}	15.9^{b}	201^{c}	21^{b}	20^{b}

† Values in the same column with different letters as superscript differ significantly ($P < 0.05$)

The respective values in case of maize ANR_B were 13, 23, 27 and 37% of total N taken from the barn as established at the start of grain filling, while it was also lower (8-20%) at physiological maturity (Table 2). During the 33 days of the grain filling stage, on average 1500 kg NDF ha^{-1} and 15 kg N ha^{-1} was lost from the manure storage treatments (Figures 2ab; Table 3ab). Consequently, both maize ANR_F and ANR_B were decreased at physiological maturity with respect to the start of grain filling (Table 2). Moreover, only small differences were found in final starch yield between all manure treatments at physiological maturity (Figures 2bc, Table 3a). The aboveground DM mass increased during the period of grain filling stage in case of zero, fresh, roofed and composted treatments, but decreased in case of covered treatment and remained unchanged in the stockpiled treatment (Figure 2ad). This can be attributed to the higher availability and crop uptake of N in the covered treatment that had probably enhanced the leaf area of maize, which resulted in a higher DM yield as compared to the other manure storage treatments at the start of grain filling stage (Table 2). Nevertheless, this later has created shading of the bottom leaves in the canopy. Due to shading effects, faster senescence of the bottom leaves occurred. This has resulted in NDF and N losses during grain filling phase (Figure 2ab). Consequently, the calculated maize ANR at physiological maturity was lower than at the start of grain filling (Table 2).

During the grain filling phase, starch accumulation in the cob is mainly reliant on export of assimilates from the source leaves (Prioul and Schwebel-Dugué 1992). Since this process largely depends on the presence of sufficient photosynthetically active (green) leaves in the top of the canopy and the sink strength of the cob, the differences in N availability between the treatments had only marginal effects on final starch yield at physiological maturity (Figure 2bc).

Table 3a. Mean dry matter (DM), nitrogen (N) and starch yields of silage maize at various growth stages.

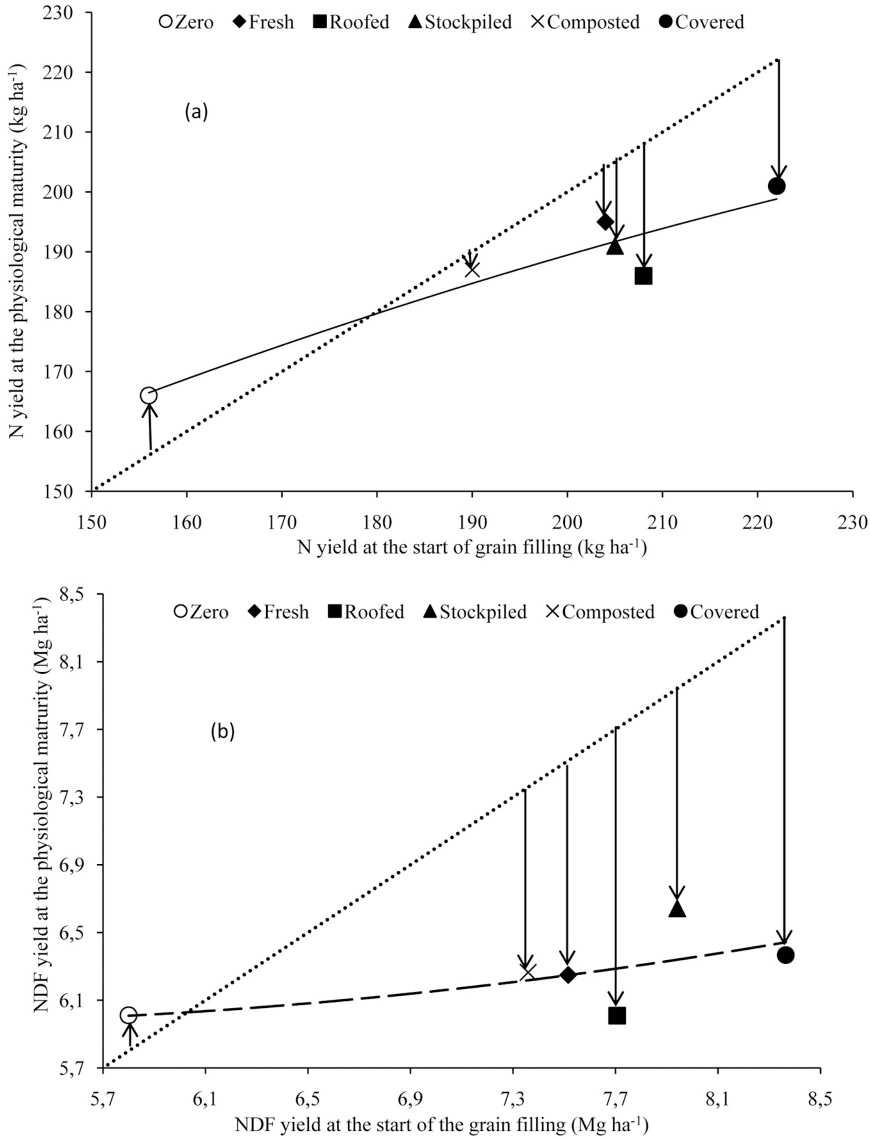
Growth stage	Zero			Fresh			Roofed			Stockpiled			Composted			Covered		
	DM (Mg ha^{-1})	N (kg ha^{-1})	Starch (kg ha^{-1})	DM (Mg ha^{-1})	N (kg ha^{-1})	Starch (kg ha^{-1})	DM (Mg ha^{-1})	N (kg ha^{-1})	Starch (kg ha^{-1})	DM (Mg ha^{-1})	N (kg ha^{-1})	Starch (kg ha^{-1})	DM (Mg ha^{-1})	N (kg ha^{-1})	Starch (kg ha^{-1})	DM (Mg ha^{-1})	N (kg ha^{-1})	Starch (kg ha^{-1})
End of juvenile	2.2^{a}†	68^{a}	5^{a}	3.1^{a}	100^{a}	7a	3.2^{a}	102^{a}	8^{a}	3.2^{a}	98^{a}	7^{a}	3.1^{a}	97^{a}	7^{a}	3.4^{a}	107^{a}	7^{a}
Start of grain filling	11.2^{b}	155^{b}	670^{b}	14.4^{b}	204^{b}	907^{b}	14.7^{b}	208^{c}	1100^{b}	15.5^{b}	205^{c}	1457^{b}	13.6^{b}	190^{b}	1031^{b}	16.4^{b}	222^{c}	1243^{b}
Physiological maturity	13.9^{c}	166^{b}	4753^{c}	15.9^{c}	195^{b}	5535^{c}	15.3^{b}	186^{b}	5274^{c}	15.6^{b}	191^{b}	5036^{c}	15.2^{c}	187^{b}	5039^{c}	15.9^{b}	201^{b}	5363^{c}

† Values in the same column with different letters as superscript differ significantly (P < 0.05)

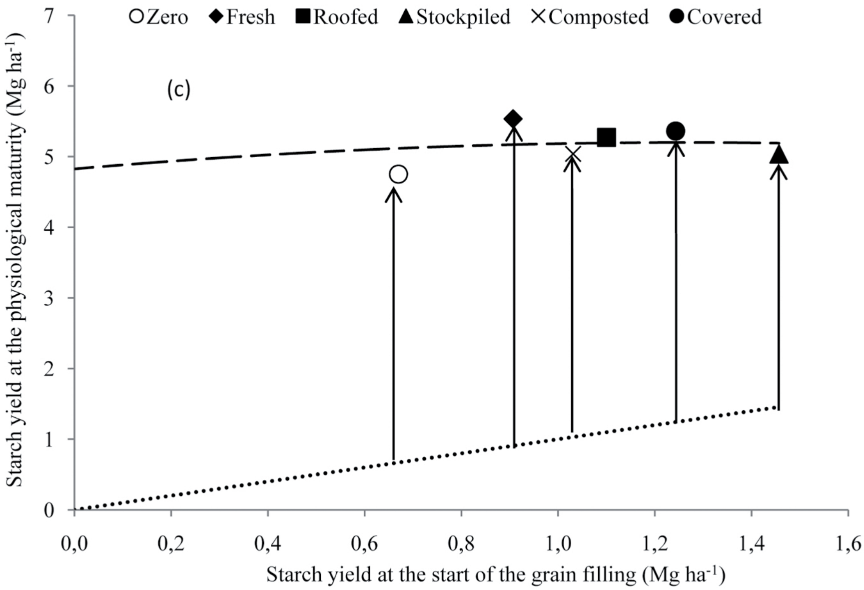
Table 3b. Mean neutral detergent fibre (NDF = cellulose + hemicellulose + lignin) yield (kg ha^{-1}) of silage maize at various growth stages (Cellulose = CEL, Hemicellulose = HEM and lignin = LIG)

Growth stages	Zero			Fresh			Roofed			Stockpiled			Composted			Covered		
	CEL	HEM	LIG	CEL	HEM	LIG	CEL	HEM	LIG	CEL	HEM	LIG	CEL	HEM	LIG	CEL	HEM	LIG
End of juvenile	563^{a}†	605^{a}	99^{a}	783^{a}	912^{a}	119^{a}	819^{a}	883^{a}	151^{a}	832^{a}	912^{a}	125^{a}	833^{a}	864^{a}	123^{a}	861^{a}	984^{a}	146^{a}
Start of grain filling	2712^{b}	2738^{b}	340^{b}	3510^{c}	3563^{c}	442^{c}	3507^{c}	3865^{c}	334^{b}	3537^{c}	4080^{c}	324^{b}	3262^{c}	3389^{c}	308^{b}	3871^{c}	4089^{c}	404^{b}
Physiological maturity	2713^{b}	2948^{c}	349^{b}	2954^{b}	2962^{b}	333^{b}	2765^{b}	2931^{b}	313^{b}	2994^{b}	3328^{b}	320^{b}	2888^{b}	3047^{b}	329^{c}	2935^{b}	3043^{b}	389^{b}

† Values in the same column with different letters as superscript differ significantly (P < 0.05)



○Zero ◆Fresh ■Roofed ▲Stockpiled ×Composted ●Covered
(a)
N yield at the physiological maturity (kg ha-1)
N yield at the start of grain filling (kg ha-1)
150
160
170
180
190
200
210
220
230
○Zero ◆Fresh ■Roofed ▲Stockpiled ×Composted ●Covered
(b)
NDF yield at the physiological matrurity (Mg ha-1)
NDF yield at the start of the grain filling (Mg ha-1)
5,7
6,1
6,5
6,9
7,3
7,7
8,1
8,5



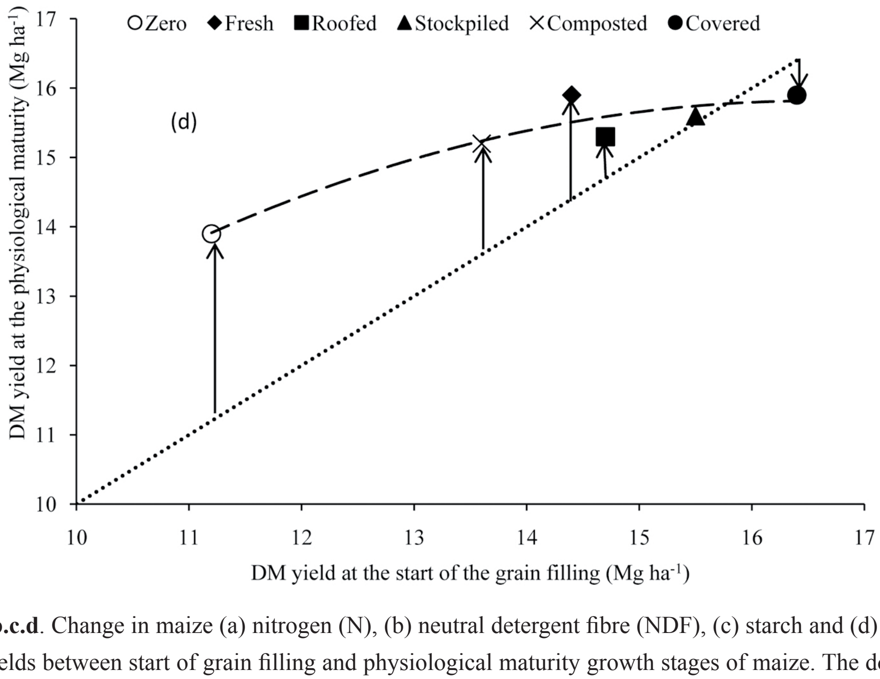


Figure 2a.b.c.d. Change in maize (a) nitrogen (N), (b) neutral detergent fibre (NDF), (c) starch and (d) dry matter (DM) yields between start of grain filling and physiological maturity growth stages of maize. The dotted and dashed lines represent 1:1 relationship and trend, respectively. Downward arrows indicate a decrease and upward arrow indicates an increase.

4. Conclusions

This study revealed that total N losses during storage of SCM can be reduced greatly by covering the heaps with an impermeable sheet. After field application, covered manure substantially increased maize crop N recovery and DM yield, especially with regard to composted manure. This all, resulted in relatively higher apparent recovery of the manure N taken from the barn, over one maize growing season. Calculated maize ANR decreased between the start of grain filling stage and physiological maturity due to increase in N losses through leaf death (senescence). This warrants keeping in mind the crop developmental stage when carrying out fertilisation experiments with maize. All these findings lead us to conclude that covered storage is a promising means for helping to retain as much of the animal excreted N as possible for plants uptake (if managed properly).

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