



Effect of Organic Manure on Nitrogen Mineralization, Nitrogen Accumulation, Nitrogen Use Efficiency and Apparent Nitrogen Recovery of Cauliflower (*Brassica oleracea* L., var. Botrytis)

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Authors' contributions

This work was carried out in collaboration between all authors. Author AAB contributed in designing and conducting the experiment. Authors PEN and ARC contributed in designing, statistical analysis and report writing, authors JCS, EAL contributed in designing, monitoring the experiment. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The main aim of the study was to assess the effects of organic manure on nitrogen mineralization, uptake, use and recovery of cauliflower.

Methodology: Nitrogen is one of the major yield limiting nutrients in cauliflower production. However, organic manure is applied to supplement soil nitrogen supply to maximize dry-matter yield. A field experiment was conducted at the Droevendaal Certified Organic Research and Demonstration Site of Wageningen University, Netherlands during 2012. The experiment was laid out in a randomized complete block design with four replications. The treatments comprised of four

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rates (0, 75, 150 and 225kgN.ha⁻¹) each of lucerne pellets (LUP) and dry grass clover (DGC) organic manures.

Results: Results showed that LUP amended plots exhibited highest initial N-mineralization compared to DGC and control plots. Nitrogen uptake in plant organs increased with increasing organic manure application. Nitrogen accumulation was highest in cauliflower leaf (38.28mg.kg⁻¹), followed by the head (16.96mg.kg⁻¹) and lowest in the stem (3.01mg.kg⁻¹).

Conclusion: Results suggest that timely and adequate nitrogen release from organic manures is important for the success of conservation and sustainable farming systems. Findings in this study could be utilized in improving efficiency of N use in crop management rotation systems.

Keywords: Organic manure; mineralization; uptake; accumulation; cauliflower.

1. INTRODUCTION

Vegetable production is often associated with excessive use of nitrogen fertilizer resulting in large mineral N residues in the soil and crop [1]. The increasing use of nitrogen excites soil microbial metabolism and enzymes [2]. However, excessive N fertilization may result in adverse environmental and economic effects such as accelerated N₂O gas emission, NO₃⁻ leaching and higher cost of production [1].

Mineralization processes are significant, particularly in soils affected by long term cultivation and different cropping practices [3]. During mineralization of organic manures, additional mineral N is released into the soil, resulting in large nitrate residues in the soil. Mineralization contributes more to high nitrate leaching especially in autumn and winter [1]. Soil mineral N content is believed to increase following harvesting of vegetables [4]. Residues of cauliflower vegetables were observed to contain between 80 and 120kg N ha⁻¹ [5]. Soil tillage and crop residue management practices were reported to influence microbial population, activity, carbon and nitrogen mineralization dynamics, and plant biomass [6].

Nitrogen use efficiency consists of two main concepts including N uptake efficiency and N utilization efficiency. The N uptake efficiency is the ability of crops to take up N from the soil [7], while the utilization efficiency of the absorbed N, is the efficiency with which absorbed N are used to enhance growth and yield of crops [8]. Both efficiencies may vary within the same crop since they are dependent on different organs, mechanisms and environmental factors [8]. Several factors have been reported to cause low N use efficiency in the soil-plant systems [9]. These include volatilization of ammonia (NH₃), leaching of nitrate (NO₃⁻), denitrification and soil erosion [9]. Nitrogen use efficiency of crops can be improved through adoption of adequate

management practices. Use of adequate amount of nitrogen manures, forms and methods of application are important management strategies for good crop growth and development [10].

Crop nitrogen uptake from the soil is a function of two recovery factors including fertilizer-N and soil-N. Knowledge of these two recovery factors is needed since soil-N and fertilizer-N may not be available at the same time and space [7]. Moreover, knowledge of available nitrogen in organic manures is also imperative to improve nitrogen use efficiency and to reduce the pressure of agriculture on the environment [11]. Not all nitrogen taken up by crops ends up in harvestable produce. In cauliflower, for instance, about 50% of total N uptake is utilized to produce economic yield, while 50% remains in the field as crop residues [5]. The main objective of the study was to assess the effect of organic fertilization on nitrogen mineralization, nitrogen use efficiency and apparent nitrogen recovery of cauliflower.

2. MATERIALS AND METHODS

2.1 Experimental Site Description

This study was conducted at the Droeendaal Certified Organic Research and Demonstration Site of Wageningen University, Netherlands, to evaluate the effect of organic manure on nitrogen accumulation, nitrogen use efficiency and apparent nitrogen recovery of cauliflower from late June to early October 2012. The mean annual temperature and precipitation of the study area were 11 °C and 829mm, respectively.

2.2 Treatments, Experimental Design and Field Management

A total of eight treatments consisting of dried grass clover (DGC) applied at four rates (0, 75, 150 and 225kg N.ha⁻¹) were compared with the same rates of Lucerne pellets (LUP).

The grass clover was dried for two days before application. One white cauliflower variety, snowball, was used. The experiment was laid in a Randomized Complete Block Design (RCBD) with four replications. A plot size of 3 x 3m was used. The soil amendments were applied one day before transplanting at 50 x 60 cm apart giving a density of 30 plants per plot (33,333 plants ha⁻¹). Cauliflower seedlings were transplanted in late June and harvested in early October 2012. Weeding was done manually by hoeing when necessary. No pesticide was used.

2.3 Soil Sampling

A Jarret T-handle soil auger (100 mm head diameter) was used to collect soil samples prior to establishment of the experiment in late June 2012. Twenty samples were randomly collected per plot using repeated soil coring from 0-30 and 30-60 cm soil depth and composited for analysis. Fresh soil samples were first sieved using 8-mm grid size to remove plant residues, roots and stones, and dried in a forced-air oven at 75°C for 24h until consistent mass was attained. Dried soil samples were further sieved after cooling using 2-mm grid size for chemical analysis. Similar protocols were used for soil samples collected at 3, 5, 9 and 13 weeks after transplanting (WAT) from 0-30cm soil depth. Samples were collected at a 5-10cm radius from growing plants. At harvest, soil samples were collected from 0-30 and 30-60cm soil depths for the determination of residual soil mineral N. The later depth was done to determine the amount of nitrogen that leached beyond the rooting zone.

2.4 Nitrogen Mineralization

About 300mg of oven-dried soil taken at different sampling regimes for each organic treatment was used for total N (NH₄⁺ and NO₃⁻) determination as described by [12]. Each soil sample was heated to 100°C for 2 h after addition of H₂SO₄-Se. After cooling, 1M H₂O₂ was added drop-wise and the content heated again to 340°C for about 2h. The content was then diluted with distill water to 50ml, and analyzed for total N using the steam-distillation method in a spectrophotometer. Nitrogen mineralization was determined based on [13] as below:

$$N\text{-net mineralization} = \text{total plant N uptake} + N_{\text{min}} \text{ residue at harvest} - N_{\text{min}} \text{ at planting}$$

Where total plant N uptake = above-ground N accumulation in stems, leaves and heads calculated after determination of dry weight and

N content in the different plant organs excluding the roots [14]. Similarly, the recovery N efficiency was calculated based on the formula used by [14].

2.4.1 Nitrogen-use metrics

Nitrogen use in relation to dry matter yield was determined using nitrogen use efficiency (NUE) and apparent nitrogen recovery (ANR).

Nitrogen use efficiency (mass of biomass per mass of N) for each harvest was calculated as [15,16]:

$$NUE = (\text{yield at } N_x - \text{yield at } N_0) / \text{mass of N applied.}$$

Where N_x = x amount of N applied, and N₀ = no N applied.

Apparent nitrogen recovery (%) for each harvest was calculated using the N difference method [17]:

$$ANR (\%) = [(TNU_x - TNU_0) / TNA] \times 100.$$

Where TNU_x = the total plant N uptake from the manure treated plots, TNU₀ = total plant nitrogen uptake from the control plot and TNA = total manure N applied.

2.5 Manure Sample Analysis

Prior to application of dry grass clover and lucerne pellet, the manures were independently analyzed for dry matter content (DM), total N (N_{tot}), mineral N (N_{min}), P₂O₅ and K₂O as described in previous papers [18,19]. Manure samples were prepared and analyzed according to the procedures described by [12].

2.6 Plant Organ Analysis

At harvest, the 6 tagged plants randomly selected in the experimental plots were cut at soil level for above plant organ analysis using secateurs. Fresh biomass from each plot was separated into leaves, stems and head organs. Samples were oven-dried at 105°C for 48h, weighed, ground and sieved using 1mm sieve. Total N in organs was measured after wet decomposition as described by [20]. Total N uptake for each plant organ was estimated by multiplying DM yield of plant organ with its N content.

2.7 Data Analysis

Data were subjected to analysis of variance (ANOVA) using the GENSTAT statistical programme (GENSTAT, 15th release, Rothampstead, UK). Mean separation was done using the Duncan's Multiple Range Test (DMRT). The residuals of data for the parameters used were first checked for normality and homogeneity using the Shapiro-Wilk test and Bartlett's test to ensure that data were normally distributed.

3. RESULTS AND DISCUSSION

3.1 Soil and Organic Manure Analyses

The LUP manure had higher dry matter and total N than DGC (Table 1). Dried grass clover exhibited longer decomposition time and higher C/N ratio compared to LUP). The P₂O₅ and K₂O contents were higher in DGC than in LUP.

Table 1. Mean dry matter (DM) content and chemical composition of plant-based fertilizers

Plant-based manures	DM (%)	C/N ¹	N _{tot} (%)	P ₂ O ₅ (%)	K ₂ O (%)
Dried grass-clover	55.6	23.2	1.9	0.4	2.4
Lucerne pellet	90.9	18.3	2.4	0.3	2.1

¹C/N ratio are based on a carbon content of 44%

3.2 Soil Mineral N Measured During the Growing Season

The effect of manure type and rate on N-mineralization during various sampling regimes is shown in Fig. 1. Generally, N-mineralization increased with increasing organic manure application. Lucerne pellet amended plots significantly (P<0.05) exhibited highest initial N-mineralization compared to DGC and control plots. At 3 WAT, LUP application at 150-225 N kg.ha⁻¹ produced higher total soil mineral N ranging from 42.02-44.88mg.kg⁻¹ compared to the remaining treatments. At 9 WAT, DGC plots produced significantly higher total soil mineral N ranging from 5.42-6.05mg.kg⁻¹ than the control (3.35mg.kg⁻¹). At 13 WAT, the non-amended plot had similar soil mineral N as most of the treatments, except for the 150 and 225kg.N.ha⁻¹ LUP amended plots. The lower soil mineral-N in DGC amended plots gives an indication of an initial increase in microbial N-immobilization.

Several authors also support this notion [21-23]. The slow growth of cauliflower in DGC amended plots may be attributed to the high C/N (23.2) ratio (Table 2), leading to lower soil N concentration as microbes competed with roots for N uptake [24]. Li et al. [25] noted that the cumulative mineralization of organic N and C increased as paddy soil fertility levels increased. Furthermore, [22] observed greater N mineralization in unfertilized winter wheat plots compared to the fertilized plots. This is partly consistent with soil mineral N content observed at 13 WAT.

The initial composition of the soil prior to planting is shown in Table 2.

Table 2. Composition of soil before planting

	0-30cm soil depth	30-60cm soil depth
N _{tot} (%)	0.1	*
N _{min} (kg ha ⁻¹)	48	32
pH (KCl)	5.4	5.6
Bulk density (kg dm ⁻¹)	1.5	1.5
SOC (%)	1.8	*

*= not determined, N_{tot}=total nitrogen, N_{min}=nitrogen mineralization, SOC=soil organic carbon

3.3 Nitrogen Accumulation and Nitrogen Use Efficiency (NUE)

Total N uptake of cauliflower plants increased with increasing organic manure application (Table 3; Fig. 2). Treatment LUP 225 exhibited significantly highest amount of total N uptake compared to DGC 75 and non-amended or control treatments. The early mineralization and higher uptake in LUP amended plots enhanced higher dry matter yield compared to other treatments as previous reported [19].

Both organic manure type and rate significantly (p<0.05) affected nitrogen accumulation in cauliflower leaf, stem and head organs (Table 3). Nitrogen accumulation in all organs increased with increasing organic manure application. Nitrogen accumulation was highest in cauliflower leaf (38.28mg.kg⁻¹), followed by the head (16.96mg.kg⁻¹) and lowest in the stem (3.01mg.kg⁻¹). The higher nitrogen intake in the various organs is indicative of the enhanced growth and increased yield in the organic amended plots compared with the non-amended plots [22,23].

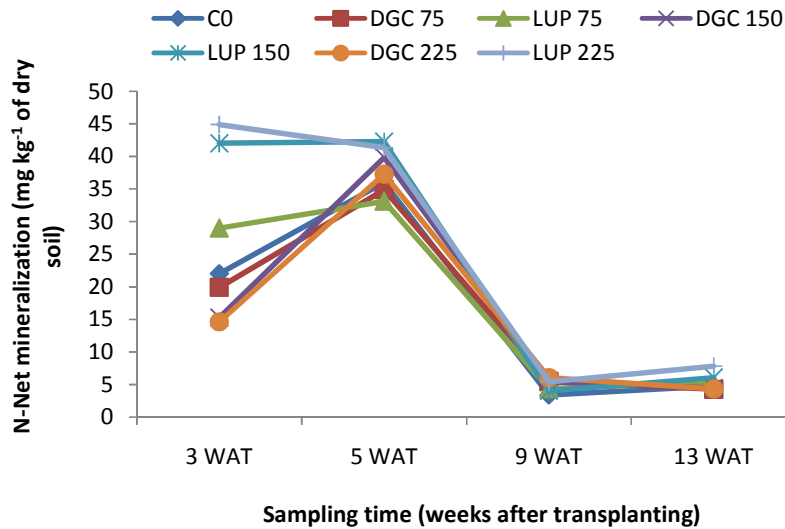


Fig. 1. Effect of manure application on N-mineralization across various sampling regimes
C0 = control plot with zero manure application, DGC=dry grass clover, LUP=lucerne pellet, each applied at 75, 150 and 225kg.N.ha⁻¹

Unlike total N uptake in various cauliflower organs, NUE decreased with increasing organic manure application (Table 3). Findings are in agreement with [26], who observed increased shoot N accumulation and decreased NUE with increasing N rate in pepper, tomato and lettuce. Quanbao et al. [27] also noted that nitrogen use efficiency of genotypes significantly decreased as N application increased. The decreasing NUE may be partly due to environmental influence on crop growth and development or the N availability from the soil through effects on mineralization of soil organic matter, organic manures and on nitrate leaching [28].

Total N in soil residue at harvest significantly increased with increasing organic application (Fig. 2). Nitrogen concentration in LUP residues was higher than DGC amended plants, resulting in lower C/N ratio. Application at 150-225.

kg.N.ha⁻¹ LUP left a considerable amount of mineral N in the soil at harvest compared to the remaining treatments. The high N release from LUP amended plots compared to non-amended.

plots was indicative of the residual effect of organic fertilization on the mineralization. Similarly, [1] also noted more nitrogen in artichoke residues with higher N application than lower application rates.

3.4 Apparent Nitrogen Recovery (ANR)

Apparent nitrogen recovery decreased linearly with a unit increase in N application rate (Fig. 3). Apparent nitrogen recovery was consistently higher in LUP than DGC treatments. The gap between the two manure types widens with increasing N rate.

Table 3. Effect of manure application on N accumulation in leaf, stem and head organs and NUE of cauliflower

N rate (kg.ha ⁻¹)	Leaf N uptake (mg.kg ⁻¹)		Stem N uptake (mg.kg ⁻¹)		Head N uptake (mg.kg ⁻¹)		Nitrogen use efficiency (kg N)	
	DGC	LUP	DGC	LUP	DGC	LUP	DGC	LUP
0	27.08 ^d	27.08 ^d	1.77 ^c	1.77 ^c	9.07 ^d	9.07 ^d	-	-
75	37.31 ^c	37.58 ^c	2.92 ^b	3.06 ^b	17.75 ^c	22.38 ^a	223.9 ^a	170.5 ^b
150	42.75 ^b	43.39 ^b	3.56 ^{ab}	3.44 ^{ab}	16.95 ^c	19.22 ^b	98.1 ^c	105.2 ^c
225	44.76 ^{ab}	46.27 ^a	3.91 ^a	3.68 ^a	18.59 ^{bc}	22.64 ^a	79.6 ^c	99.8 ^c
CV (%)	3.20		5.10		6.10		8.1	

Means within a column followed by the same letter are not significantly different (DMRT = 0.05); CV=coefficient of variation, DGC=dry grass clover, LUP=lucerne pellet, NUE=nitrogen use efficiency

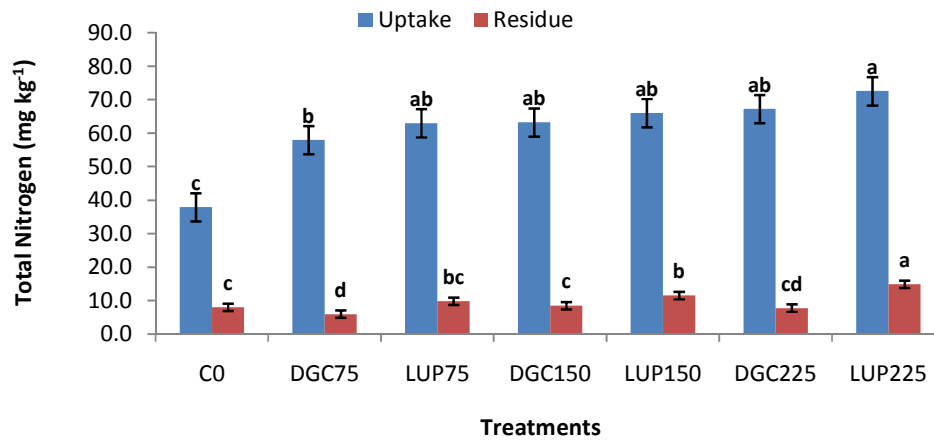


Fig. 2. Effect of nitrogen application on N total uptake and N in soil residue of dry grass clover, lucerne pellets and control plots

C0 = control plot with zero manure application, DGC=dry grass clover, LUP=lucerne pellet, each applied at 75, 150 and 225 kg.N.ha⁻¹

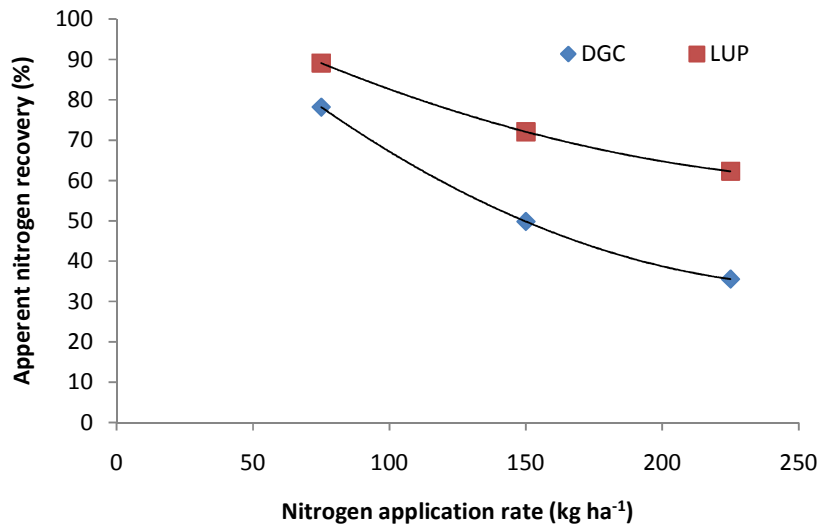


Fig. 3. Effect of organic fertilization on apparent nitrogen recovery of botrytis. LUP=lucerne pellets and DGC=dried grass clover

The decreasing ANR as N application rate increased implied high nutrient demand of the cauliflower crop. Similarly, apparent nitrogen recovery was noted to decrease as N application rate increased [27]. Findings are also supported by the fact that crops are more efficient at recovering N when the fertilizer-N rate is relatively low [7].

4. CONCLUSION

Timely and adequate nitrogen release from organic manures is important to N management and the success of conservation and sustainable

farming systems. Nitrogen immobilization in the initial period with high C/N ratio of DGC manure compared to LUP was observed in this study. Nitrogen mineralization from organic manures was dependent on the initial total N content in the plant and chemical composition of the organic manures. Nitrogen mineralization increased with increasing N application. Nitrogen accumulation in above ground organs increased as N rate increased with leaf organ possessing highest, followed by head and the stem; while NUE decreased with increasing N rate in cauliflower. The ANR was higher in plots with low organic fertilization than those with high N applications. Findings in this study could be utilized in

improving efficiency of N use in crop management rotation systems.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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