N Budgeting on Field and Landscape Scale with Intensive Agriculture under Monsoon Climate in a Heterogeneous Mountainous Area, South Korea

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Abstract: Excessive N fertilization and the heavy monsoon rains together with predominantly sandy soils in Haean Catchment (South Korea) are predestined for high N losses during the cropping season leading to environmental pollution. The purpose of this study was to relate the fertilizer N inputs into the soil under intensive agriculture to the outputs on field scale as well as on catchment scale. We measured the contribution of agricultural fields to the N export during the monsoon season by creating N budgets for the most important crops and soil types considering various landscape parameters. We identified typical amounts of N accumulation in soil and plants, N removal with harvest, and fertilizer N use efficiencies by crops. The field budgets were up-scaled to catchment level (64 km^2) and a general budget with amounts of N uptake, N retention and N loss was calculated. By using an ANCOVA, we determined parameters responsible for dissimilarities/similarities in fertilizer N use efficiency as well as in the N budgets on field scale. Finally, we aim to identify potential savings and give recommendation for a best practice and sustainable agriculture.
All N budgets were positive, with N inputs exceeding outputs for around 2.2 times. N net accumulation at field scale is found to be highest for rice paddies (240 kg N ha^{-1}) and lowest for soy bean (81 kg N ha^{-1}). At catchment level, rice and radish play the most important role for N export with 120 t and 80 t per cropping season, respectively. The highest N crop use efficiency shows bean (74%), whereas the NUE for rice is with 30% the lowest of all investigated crops. Radish (51%), cabbage (53%) and potato (46%) lie within the common range of 40-60% for upland crops.

Keywords: *catchment N budgeting, N surplus and leaching, N retention, sandy soils, summer monsoon, fertilizer N use efficiency, up-scaling*

1. Introduction

1.1 N Budgets of Korean Agriculture

Nitrogen cycles in intensively managed agricultural ecosystems have received more attention than those in natural ecosystems as it is one of the most challenging nutrient problems in agriculture (Liu et al. 2003). Nitrogen is removed in large parts from the system with harvest and the surpluses result in transportation to other environmental compartments through processes such as leaching, gaseous emissions and/or by runoff to surface water (Gliessmann 2000, Richter/Roelcke 2000).

Intensive agriculture in South Korea is characterized by excessive N fertilization on the background of a strong summer monsoon season. Korean soils are known to be poor in available nitrogen due to their low content of organic matter and the small amounts of organic fertilizer added annually. In Korea, the agricultural system shifted over the last 40 years towards an intensive agriculture, which heavily depends on high mineral fertilizer N inputs. In Gangwon Province, N application rates indicated by farmers of the Haean Catchment range between 150 and 450 kg N ha^{-1} yr^{-1}. However, such figures can be misleading since there are wide variations in the extent of N fertilizer application for individual crops and households. Still, heavy non-point agricultural pollution of surface and ground water as well as signs of soil degradation are becoming more and more evident and of growing concern because of its potential effect on water resources. Thus, N budgets and the fate of fertilizer N are becoming important issues and are receiving much attention. A good overview of general N budgets of N for agricultural systems in South Korea gives Bashkin et al. (2002). However, no measured data but only statistical data and literature data from 1994 to 1997 were used in this study. Even though 70% of South Korea belongs to mountainous regions (Bashkin et al. 2002), there is no detailed N budget approach at field level nor catchment level for mountainous regions in South Korea. Additionally, none of these budgets look at the influences of typical local management practices to N budgets in Korean mountainous areas.

Haean Catchment, our study site, shows typical characteristic for South Koreas intensive agriculture, such as the dominant use of ridge cultivation and plastic mulching as well as high N fertilization rates. Additionally, the local farmers show an interesting management practice of frequently adding sandy soil on the top layer of agricultural fields. We measured the contribution of agricultural fields in complex terrain to the N export during the monsoon season by creating N budgets for the most important crops and soil types considering different landscape parameters. We identified typical amounts of N uptake, N retention, and N loss as well as fertilizer N use efficiencies for the five important Korean crops: cabbage, rice, radish, potato, and soy bean.

2. Materials and Methods

2.1 Study Site

The field experiment was conducted in Haean-myun Catchment (128° 5' E, 38° 13' N, 420 m asl) in Yanggu County, Gangwon Province, South Korea. The study area falls within the East-Asian monsoon area and has an 11-year average annual air temperature of 8.5°C and an annual precipitation of approximately 1577 mm, with 70% occurring as heavy rains in June, July and August and 90% within the cropping season from April to October. The growth season of 2009 was typical according to temperature and total precipitation over the year as well as over the cropping season. The agricultural soils of the catchment can be mainly characterized as Anthrosols (FAO 2006) because of the long-term addition of sandy material on the original soil surface. The texture of the top layers (0-30 cm) can generally be characterized as sandy loam or loamy sand. Other main characteristics of the topsoil are: pH 5.8, organic matter 11.7 g kg^{-1}, total N 0.064%, C_{org} 0.63%. About 27% of the catchment is counted to agriculture land use. Rice paddies cover 30% of the arable land, whereas the four most important dryland crops (radish, bean, potato, cabbage) account for approx. 52% of the cropped area (Yanggu County Office 2010). While rice is cultivated in the areas of flat land that are flooded annually during monsoon season (Kim et al. 2007), dry land crops are grown in ridge-cultivation systems with plastic mulching on slope lands, where irrigation is difficult.

2.2 Calculations and Estimates of N Budget and Fertilizer NUE

N budgets for the cropping season of 2009 were defined separately for each of the 30 field sites. Soil samples from 0-30 cm were used as most of the crop roots were distributed within this depth. For each field site, all major flows of N were either measured in the field or estimated using literature data, statistical data or simulation modeling. Finally, the N balance on field scale was calculated using the input-output approach of Korsaeth/Eltun (2008). The apparent N loss was attributed to the sum of NO_3-N leaching, denitrification and other N losses. The fertilizer N use efficiency was calculated as the amounts of harvested N divided by the amounts of applied fertilizer N (Nyamangara et al. 2003). It should be noted however that, with this method of calculating nutrient efficiency, the results may be strongly affected by other nutrient sinks and sources (Korsaeth/Eltun 2008). The determination of system boundaries in both space and time is a crucial step in the compilation of nutrient budgets (Watson et al. 2002). Within the horizontal dimension of the spatial system boundary, only the managed arable land was included in the field size. It was accepted that forest (covering 39% of the catchment) does not contribute to the N leaching and other N losses. Regarding the vertical dimension, the main crop rooting depth of 30 cm was used as the lower boundary. The budget considers a single growing season as the investigated processes do not play an important role during winter time due to cold temperatures and very less precipitation.

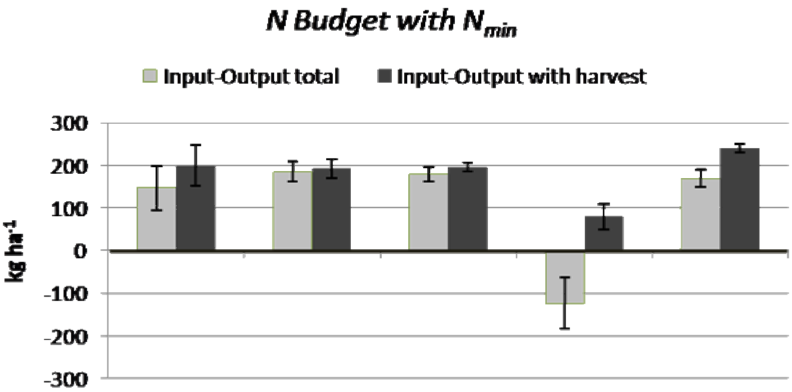
3. Preliminary results

3.1 Biomass Production and N Uptake of Crops at Field Scale

Results of mean biomass production (DM) differ considerably between the five crops (Figure 2). However, due to a low N content of rice and potato, these two crops show rather low amounts of total crop N at harvest time (< 200 kg N ha^{-1}). On the contrary, the large biomass production combined with a high crop N content shows a mean N uptake of 430 kg N ha^{-1} by beans. The differences between the crops in residue N remaining at the field sites after harvest are fairly high (Figure 2). For rice and bean, more than 50% of the crop commonly remains at the field site, whereas at potato as well as at radish fields only small amounts of root material and dead plant material are left after harvest. However, the local management methods after harvest for rice and bean can be fairly different. The percentage of residues left on different field sites depends to a great deal on the use of the crop residues. At field sites where the dried residues are sold as straw for cattle, the percentage of biomass remaining after harvest is close to zero.

3.2 Components of N Budget and N Use Efficiency

The calculation of the N budgets reveals that each crop shows N surpluses at the end of the cropping season. While cabbage, radish, potato and rice show N surpluses of around 200 kg N ha^{-1} yr^{-1}, bean only shows a surplus of 80 kg N ha^{-1} yr^{-1} (Figure 1). This relatively lower surplus can be explained by the low mineral fertilizer N inputs for bean due to its ability to biologically fix N. Hence, the mean N surplus of the five crops in the catchment amounts to 181 kg N ha^{-1}, resulting from a mean N input of 364 kg N ha^{-1} and a mean N ouput of 183 kg N ha^{-1} (Table 2). This leads to an average N crop uptake efficiency of 51%, soil N_{min} content and N mineralization of SOM not considered. The main N inputs (190-309 kg N ha^{-1}) for rice, radish, potato and cabbage with ~68% of N input were related to the application of mineral fertilizers (Table 1). The mineral fertilizer N input for bean only accounts to 33 kg N ha^{-1} which relates to 11% of N input. The main N input source for bean (~60%) is the biologically fixed N. N_{min} content from soil is up to now only estimated. This source often determines N crop response to N fertilizer. Atmospheric N deposition and non-symbiotic N fixation are responsible for the major rest of N input (~ 12%), not including bean. Finally, N output is defined as crop N removal with harvest. Total outputs were about 50% of the inputs, indicating other storage or loss of N in the landscape (Table 1). Regarding N crop uptake efficiency, our findings show the highest efficiency for bean (74%) and the lowest efficiency for rice (30%), averaging in 51% (Figure 1). Crop N uptake efficiency in Asia is typically 20 to 50% due to N losses from leaching, denitrification and other (Hossain/Singh 1995). Our findings are at the upper range of this estimation, but up to now soil N_{min} content and N mineralization of SOM are not considered and the actual response rate is therefore lower. However, the fertilizer N use efficiencies account for over 50% for each single crop type (Figure 1).



	Cabbage	Radish	Potato	Bean	Rice
Fertilizer NUE	74	70	66	-	54
Total NUE	53	51	46	74	30

Figure 1. Mean N budgets with measured and calculated inputs, including N_{min} content of soil. N loss or surplus was calculated as N input minus N output. The illustration compares differences between total crop removal and common crop removal with harvest. Fertilizer N use efficiency was calculated as amounts of harvested N divided by the amounts of applied fertilizer. Total N use efficiency was calculated as amounts of harvested N divided by total N inputs.

		Cabbage			Radish			Potato			Bean			Rice		
		Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
INPUT	Fertilizer N	309	44	282-362	284			256			33			190		
	Soil N_{min}	70			70			70			70			70		
	Deposition N	21.5			21.5			21.5			21.5			21.5		
	Fixation N	15			15			15			180			45		
	Irrigation N	0			0			0			0			15		
	Seed N	1.5			1.5			1.5			1.5			1.5		
	Sum Input	417			392			364			306			343		
OUTPUT	Harvest N	276	37	203-401	207	23	64-259	186	33	116-332	429	60	236-610	174	21	123-252
	Residue N at field site	53	11	28-92	7	2	0-20	19	7	6-42	204	28	89-284	70	11.6	46-119
	Sum Output	223	32	158-341	200	22	62-246	168	28	110-302	225	30	143-326	103	10	75-133
CALCULATIONS	Net N accumulation	199	48	-49-313	192	22	146-330	196	10	62-254	81	30	-20-163	240	10	210-268
	Output-Input-Ratio	0.53	0.10	0.34-0.87	0.51	0.06	0.16-0.63	0.46	0.08	0.30-0,83	0.74	0.10	0,47-1,06	0.30	0.03	0.22-0.39
	N uptake efficiency	53	10	34-87	51	6	16-63	46	8	30-83	74	10	47-106	30	3	22-39
	Fertilizer N use efficiency	74	14	44-121	70	8	22-86	66	11	43-118	683	90	433-987	54	5	39-70

Table 1. Overall N budgets with Net N accumulation, Output/Input-ratio, N uptake efficiency, and fertilizer N use efficiency for the five main crops in Haean catchment. Mean N input and N output values are shown with SE and range (mean n=5-8). All N flows are given in kg N ha^{-1}. Budgets were calculated for the top 30cm soil layer for cropping season 2009.

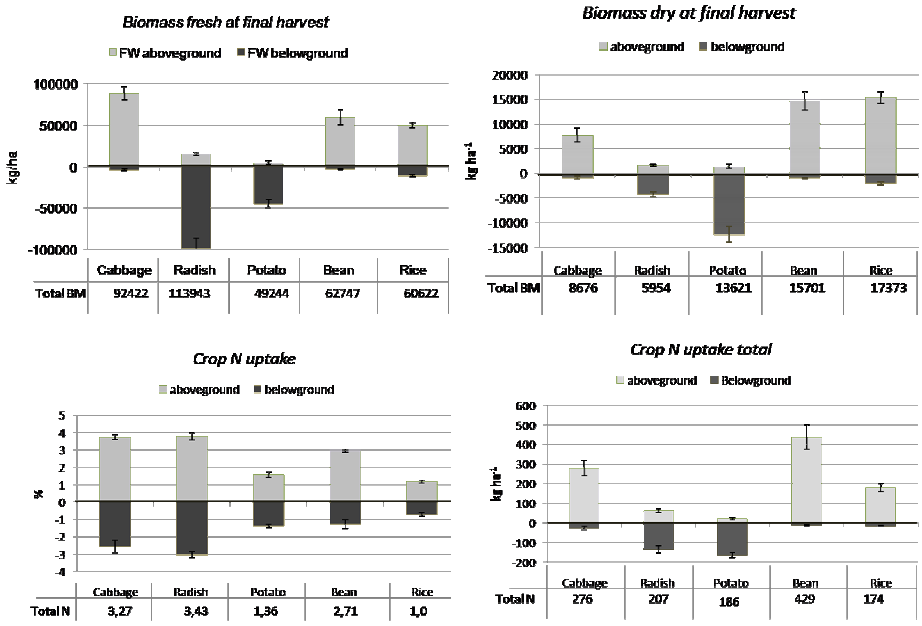


Figure 2. Measured mean biomass production (fresh and dry), mean N content and mean plant residue N of the five crops used in the study 2009

4. Discussion

The comparison of the local N budgets for Haean Catchment with the general N budget for agroecosystems in South Korea from Bashkin et al. (2002) shows somewhat higher N surpluses calculated by the latter. Bashkin (2002) calculates an average N surplus of 215 kg N ha^{-1}, resulting from a N input of 347 kg N ha^{-1} and a crop N output of 132 kg N ha^{-1}. This leads to an average N crop uptake efficiency of 38% for South Korean agroecosystems. While the N inputs are in both studies within the same dimensions, the composition of the N input differs. The most notable difference lies in the crop N uptake efficiency and the subsequent N output of the system with harvest. While Bashkin et al. (2002) found the Korean N crop uptake efficiency with 38% to be the lowest in Asia, our findings show a good accord with the one from China (51%) as well as Germany (59%). Figure 1 shows that each individual N crop uptake efficiency lies within the assumption of Cassmann et al. (1993), who stated that flooded rice generally recovers 20-40% of total applied N in field studies, depending on N source, management, and agroecological conditions, whereas upland crops usually recover about 40-60% (Vlek/Byrnes 1986). A possible explanation for the higher N crop uptake efficiencies in our study is the changing land use in South Korea. Paddy rice which shows usually low N crop uptake efficiencies is losing its dominant position, whereas bean with its high N crop uptake efficiency is gaining in importance.

Looking at the fertilizer N use efficiencies, it is conspicuous that it accounts for over 50% for each single crop type. Much lower results shows a ^{15}N field experiment for Haean catchment (Kettering 2011 in preparation), where fertilizer N use efficiency for summer radish calculated using ^{15}N amounts to ~30%. This study exposes the strong impact of other N sinks and sources on the calculation method used. For the calculations, agricultural recommendations of the Rural Development Agency for fertilizer N application were used. The results suggest that local farmers apply potentially more fertilizer N than is recommended. This could also influence the results of the total N crop uptake efficiency of the crop. Finally, the comparison of total crop removal and common crop removal with harvest emphasizes once more the important role of management after harvest for the N budgets. Especially for bean, the management after harvest is crucial factor which determines whether the N budget is positive or negative.

At catchment level, rice and radish play the most important role for N export with 120 t and 80 t per cropping season, respectively. The calculated N balances indicate that for the conventional treatments a high mineral N fertilization and the crop's fairly low N recovery causes high N surpluses after harvest. 75% up to > 94% of these N surpluses are assumed to be lost from the system by processes such as leaching, denitrification, and ammonia volatilization (Watson et al. 2002). In Haean Catchment, we assume that 90% of these losses are lost by leaching due to no significant storage in the sandy soil with little water and nutrient retention capacity. The large amount of surplus N in the budgets supports the fact that a considerable non-sustainability within the local agricultural takes place. Large potential to improve both findings show the factors fertilizer rate and timing as well as management after harvest. The fertilization relies almost exclusively on mineral fertilizer, which is applied in excessive rates. More than 50% of the mineral fertilizer N is applied before crop emergence, which makes it vulnerable to losses. A better adaptation of fertilizer rates and timing to crop needs seems the best way to improve both results. Additionally, a more adapted management of plant residues after harvest can play a relevant role in improving N budgets. Following Lehmann et al. (2006), crop residues from grain processing, such as rice husks, could be used for the production of biochar. Such obtained biochar could be applied to any cropping system (Lehmann/Rondon 2006) and would at the same time reduce the N surpluses at rice paddies. Finally, N losses are recorded to be much lower with incorporation of fertilizer into the soil, deep placement of fertilizers, use of enzyme inhibitors, coating of fertilizer granules and use of supplemental nitrogen sources, such as organic manures (Hossain/Singh 1995). An attempt to estimate the average N input-output balance under present conditions is presented, but several assumptions must be validated in future research. Most uncertain is the N input from biological N fixation, manure, and irrigation**.** Additionally, N balances must be monitored over periods of longer than a single crop or growing season.

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