

Article

Impact of Flooding on Lands with Emerging Contaminants on the Quality of Receiving Water Bodies

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Abstract: Among crucial factors that control flooding events are extreme climate, urban growth, and mismanagement. Islands in the Nile River have experienced successive cycles of flooding and drying due to recent rainy years in the Nile Basin countries. This paper focuses on the impact of floods on the amounts of ammonium-N released, total concentrations of heavy metals, enzyme activities, and microbial biomass (C and N) in flood soils of 11 Nile River islands. Field moist soils and their airdried counterparts were collected from the outskirts of the island and incubated for 15 days at 30 °C to be analyzed. Results reflected that the amounts of released $\text{NH}_4\text{-N}$ were higher in airdried than in wet soils. The average hydrolysis rates of the studied six enzyme substrates were correlated significantly with organic C, organic N, microbial bio-mass C and N in the field moist soils. The highest correlation coefficients (r) were with rates of hydrolysis of substrates of asparaginase, amidase, and β -glycosaminidase. A significant intercorrelation between rates of hydrolysis of the six studied enzyme substrates and r values which range from 0.81 to 0.98. At 10 mmol kg^{-1} soil, Co^{+2} , Cd^{+2} , Pb^{+2} , Cu^{+2} , Cr^{+3} , and Ni^{+2} inhibited the release of $\text{NH}_4\text{-N}$. Arginine hydrolysis was inhibited by the six heavy metals at 5 mmol kg^{-1} soil; the most effective inhibitors were Pb^{+2} , Ni^{+2} , and Cr^{+3} . Due to the complex soil enzymatic and organic nitrogen hydrolase activities that occur during floods, fertile fields on the Nile River islands should not be fertilized before the summer flood seasons, which will prevent contamination of the Nile River water and loss of its island soil fertility.

Keywords: Nile River; flooding; enzyme activity; heavy metals; arginine; soil fertility



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1. Introduction

Among the several factors which participate in increasing the dangers of flood disasters are climate change and urbanization that handicap the existing and future management strategies for flood in urban areas [1–4]. Floods which take place in urban cities commonly lead to destructive results for both human lives and properties [5]. United Nations reports [6] indicated that about 43% of naturally born disasters which happened from 1995 to 2015 were associated with water scourges, impacting more than 56% of people around the world. Urban spread is related to an extent of both social and environmental problems that

comprise social isolation, flooding, erosion, small farms death, wildlife extinction, health issues, and lessening of natural balance [7]. It is possible for lands in urban areas exposed to both flood and drought to rise above 250% [8].

The Nile River serves as the main source of freshwater for Egyptians, with over 90% of the population living next to or directly dependent on it. Although the High Aswan Dam regulates the Nile River throughout the year, the hydrological data set indicates a slight increase in water flow from the High Aswan Dam through the period between 1995 and 2008 [9]. There is a remarkable variation in flow discharge that extends between August and July throughout the water year. During the period of the highest flow rate, water discharge can increase up to 4.5 times the lowest flow rate [9]. About 144 islands lie between Aswan and the Delta region, which are dispersed along the master channel of the Nile River. In Egypt, Nile River islands are known as the extreme fecund grounds, many of them have individual characteristics of land surfaces characterized by a high diversity of animal and vegetation, which is scarce in other environments, while others are rest stops for migratory birds. Migratory birds use some of these islands as resting grounds, while other islands are prominent for the existence of a wide extent of animals and flora and for their distinctive topographies [10]. These islands are suffering currently from the fierce impacts of human effects and are exposed continuously to exaggerated anthropogenic activity, like agriculture of Nile River islands which might lower water quality [11]. These islands are divided into four primary categories: tourist islands, residential islands, abandoned islands, and agricultural islands [12]. However, because of their high soil fertility, a lot of these islands in the Nile River have been populated and cultivated, making them particularly vulnerable to the destructive consequences of human activities [13].

During summer months, many farming islands along the Nile River, including those very productive soils frequently experience periods of flooding that last from a few weeks to several months. These conditions cause alterations in the soil's chemical and biochemical properties [14,15]. Among the processes involved, especially under arid conditions, manufacturing of $\text{NH}_4\text{-N}$ in soils under flooding is one of the worthiest, as considerable quantities of organic nitrogen are transformed into $\text{NH}_4\text{-N}$, which may produce impurity of surface and groundwater or volatilization into the atmosphere around the area. After drying, the produced $\text{NH}_4\text{-N}$ is nitrified, and the produced $\text{NO}_3\text{-N}$ may be transported with shallow water to the Nile mainstream or proceed to resources of groundwater contaminating water supplies [15].

Many research papers have been managed on the chemistry of production of $\text{NH}_4\text{-N}$ [16–18], but few data are obtainable on the biochemical factors impacting soil organic N mineralization under flood circumstances. Similarly, many research papers have been carried out on the influences of trace elements on N nitrification and mineralization in soils beneath aerobic conditions [19,20], but data on the role of heavy metals in the ammonification process are few. It is important to mention that the islands of the Nile River did not extradite suitable studies to recognize the effect of heavy metal pollutants associated with anthropogenic activity on human risk and aquatic animals. Recently, The Nile islands suffered from a significant growth in population which has been accompanied by slope increases in urbanization, as well as agricultural and industrial land use [12]. Heavy metals may be introduced with sprays of pesticide into soil such as copper fungicides, or through sewage sludge or compost application. Moreover, some soils may have huge concentrations of one or more heavy metals because of the geology of the soil or through the application of mining wastes [12,21]. Other research papers have exhibited that extra heavy metals concentration in soil has a considerable impact on microbial diversity and functionality, and also on many biochemical processes in soils involving the enzymes included in N, C, S, and P cycling [21–23].

The soil's organic nitrogen complexes are supplied from numerous sources, related to various chemical classes, and exist in various microenvironments [24]. Moreover, the status of enzymes in soils is very complicated [22,23]; however, through the diversity of enzyme proteins in soils, it seems that the most important enzymes in ammonification

are hydrolases. Studies of the composition of amino acids in soil organic matter exhibited that the 15 studied amino acids were mostly symmetric among soils [25] (apart from asparagine plus aspartic acids, expressed as a percentage of overall amino acids). The highest percentages of ten surface soils were attributed to aspartic acid plus asparagine (avg. = 18.6%) and glutamic acid plus glutamine (avg. = 15.7%), which are hydrolyzed by specific enzymes [25]. As $\text{NH}_4\text{-N}$ release from soil organic matter is biochemical in nature, mediated by specific hydrolases, estimation of the soils' hydrolase activities should furnish data on the state of key reactions that collaborate in rate-restricting steps of the decomposition of organic N.

Because of the agricultural and environmental significance of $\text{NH}_4\text{-N}$ manufacturing in soils under flooding circumstances, and due to limited available information on biochemical's number of reactions in the operations involved procuring to the release of NH_4 , this research was established with the following aims: (i) to determine the impact of flooding on soil fertility through characterizing some soil properties of some alluvial river Nile islands, (ii) to determine the quantities of $\text{NH}_4\text{-N}$ released in soil under flooding circumstances, (iii) to assess the relation between the quantities of $\text{NH}_4\text{-N}$ released and substrates hydrolysis rates of six organic N hydrolases, (iv) to assess the interrelationships among hydrolysis of the enzyme substrates, (v) to estimate the impacts of selected heavy metals on release of $\text{NH}_4\text{-N}$ and on arginine hydrolysis in soils and their similarity to those of other hydrolases available in the literature, and (vi) to determine the suitable time for Nile River islands fertilization.

2. Materials and Methods

2.1. Nile River Islands Study Area and Properties of Island's Soil

Nile River islands under investigation are located in El-Minia Governorate within Upper Egypt which is approximately 247 km away from Cairo, and it extends between longitude and latitudes of $28^\circ 6' 35.57''$ N, $30^\circ 45' 1.08''$ E (Figure 1) and (Table 1).

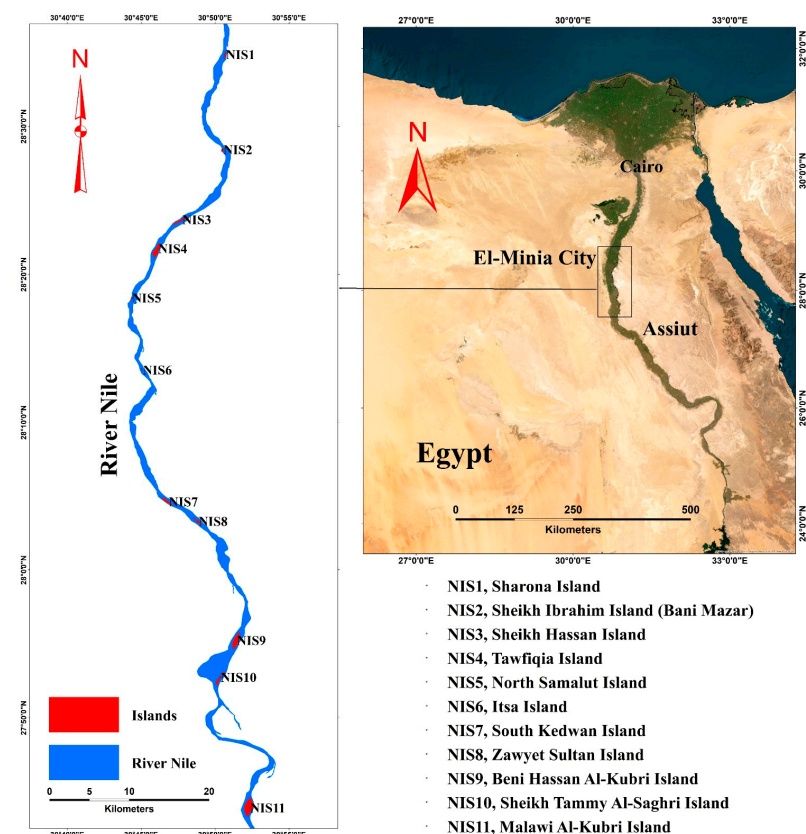
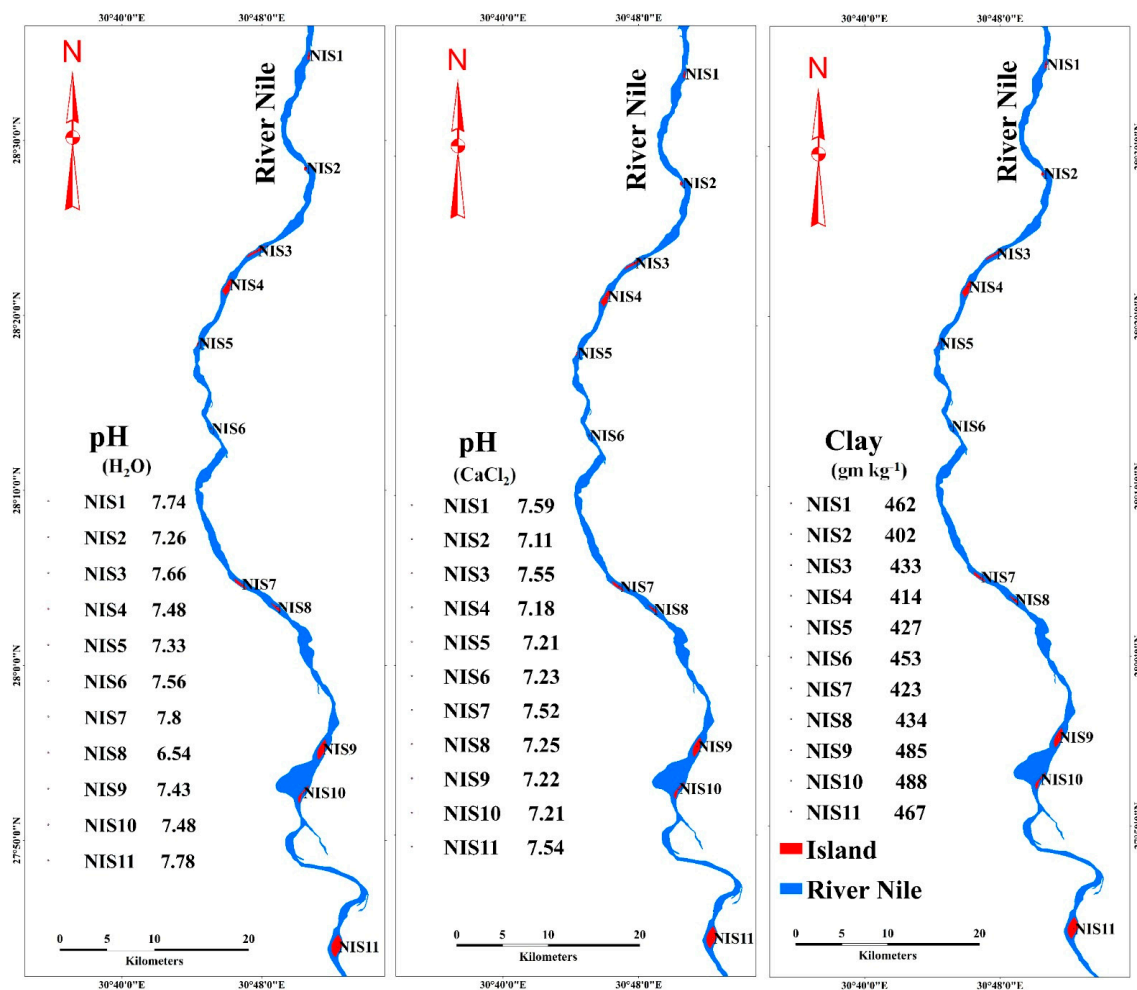


Figure 1. Map showing the location of the studied Nile River islands and distribution of soil samples.

Table 1. Some geographical locations and areas in a hectare of the investigated Nile River islands.

Island Series	Island Name	Latitudes	Longitude	Island Area (Hectare)
NIS ₁	Sharona Island	28.58076805	30.84492645	3.27
NIS ₂	Sheikh Ibrahim Island (Bani Mazar)	28.47372155	30.84203602	14.43
NIS ₃	Sheikh Hassan Island	28.39497501	30.79573226	9.36
NIS ₄	Tawfiqia Island	28.36232298	30.76862047	40.35
NIS ₅	North Samalut Island	28.30680639	30.73926231	71.28
NIS ₆	Itsa Island	28.2257438	30.75128266	5.88
NIS ₇	South Kedwan Island	28.07742444	30.78055002	31.16
NIS ₈	Zawyet Sultan Island	28.05535875	30.81410817	22.00
NIS ₉	Beni Hassan Al-Kubri Island	27.92039465	30.85721977	93.48
NIS ₁₀	Sheikh Tammy Al-Saghri Island	27.87898918	30.83898941	38.98
NIS ₁₁	Malawi Al-Kubri Island	27.7322974	30.87231104	149.51

These 11 islands are permanent sedimentary islands whose soil consists mainly of clay and silt along with a mixture of coarse and fine sand with a dominant clay texture (Figure 2). The main crop in most of these islands is bananas with little areas of vegetables for local fresh consumption. Island levels are close to the level of the flood plain where frequent floods are the main factor in building the islands and the plain. Apart from a summer flood season, these islands are naturally protected from being flooded by river waters all year round although they are encircled by Nile water on all sides.

**Figure 2.** Spatial distribution map of soil pH (CaCl₂), soil pH (H₂O), and clay content.

Surface (0–30 cm) samples of soils from several Nile River islands were utilized, and they were chosen after determining a variety of chemical, biological, and physical characteristics. Table 2 shows the texture composition of the selected islands. After the flood receded in September, eleven soil samples were collected from eleven consecutive islands along the Nile River in El-Minia Governorate; these soil samples are referred to in this study as NIS₁, NIS₂, NIS₃, NIS₄, NIS₅, NIS₆, NIS₇, NIS₈, NIS₉, NIS₁₀, and NIS₁₁. The samples of soil were collected from the outskirts of unfertilized islands directly after flooding, mixed, and then sieved to pass through a 2 mm mesh sieve and stored at 4 °C. A part of the field's moist soil was air-dried at room temperature (25 °C), while another portion of this was ground to pass through an 80-mesh (<180 µm) sieve. Determination of pH was by a combination electrode on soil/water or 0.01 M CaCl₂ ratio of 1:2.5 in air-dried soil samples, total N by Auto-Chemistry CS-1300 C and N analyzer, NH₄-N and NO₃-N by steam distillation [26], while organic N through subtracting inorganic N from the total-N values, organic C determined by Mebius method [27], and distribution of particle-size via a pipette method [28].

Table 2. Climatic data for the study area: monthly averages of five years (2018–2022), according to El-Minia meteorological station.

Month	Average Temperature °C			Rainfall mm	Relative Humidity %	Evaporation mm day ^{−1}	Wind Speed (kmh ^{−1})	Sunshine (hr/month)
	Mean Temp. °C	Min °C	Max °C					
Jan.	12.0	4.6	20.4	1.1	65	4	9.45	246
Feb.	13.9	5.6	22.4	1.7	58.8	5.4	10.74	273
Mar.	16.9	8.6	25.7	3.4	53.9	7.2	12.78	279
Apr.	21.9	12.8	31.0	0.5	44.9	10.9	14.63	300
May	26.3	17.2	35	1.4	39.1	13.8	15.74	333
Jun.	28.5	19.9	36.7	0	41.8	14.6	16.67	369
Jul.	29.2	21.1	36.9	0	48.4	12.6	13.70	375
Aug.	28.6	21	36.2	0	52.8	10.5	11.48	354
Sept.	26.9	19.4	34.7	0	53.1	9.9	13.15	318
Oct.	23.3	16.1	31.2	0	56.9	8.1	11.85	297
Nov.	17.7	10.7	26.2	3.5	63.4	5.2	10.56	267
Dec.	13.1	6.1	21.5	2.1	67.5	3.5	9.07	234

2.2. Climatic Data of the Investigated Area

Islands in the Nile River have experienced successive cycles of flooding and drying due to recent rainy years in the Nile Basin countries. The investigated area climate is classified as arid to semi-arid with a dry hot summer, while winter is temperate or rainless. The climatic data are presented in Table 2 according to El-Minia meteorological station. The summer months of June, July, and August have an average maximum temperature between 36.2 and 36.9 °C, and an average minimum temperature between 19.9 and 21.1 °C. In contrast to the hot summer, winter (December, January, and February) is temperate, with an average maximum temperature between 20.4 and 22.4 °C, while the average minimum temperature ranges between 4.6 and 6.1 °C. Additionally, the climate in the research area is dry to extremely dry all year round, with 0 mm as an average monthly rainfall in the summer months and up to 3.5 mm during the winter months. The relative humidity varies from 39.1 to 67.5% according to monthly averages, increasing in winter and decreasing in summer. The wind speed in the study varies from 9.07 to 16.67 km h^{−1} as a monthly average. Furthermore, evaporation rates are higher in the summer due to increased solar radiation and sunshine hours than in the winter. It varies from 3.5 to 14.6 mm day^{−1}.

2.3. The Released Ammonium

The released $\text{NH}_4\text{-N}$ was specified via steam distillation technique which was described by [29,30].

2.4. Total and Soluble Heavy Metals Concentrations in Soils

The total concentrations of Cd^{+2} , Co^{+2} , Cu^{+2} , Ni^{+2} , Cr^{+3} , and Pb^{+2} were determined in digests equipped by using the method of Akagi and Nishimura [31]. The digested mixture was analyzed to determine heavy metal concentrations using an inductively coupled plasma emission spectroscopy (ICP-AES, 1700) at the Central Laboratory, Faculty of Agriculture, Mansoura University, Egypt.

For soluble heavy metals in soils, 10 g of field moist soil was transferred into a 4 oz (125 mL) bottle and 100 mL of 0.01 M $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ was added, mixed on an end-to-end shaker for about 1 h, filtered using a Whatman No.42 filter paper and moved into a 100 mL volumetric flask, and the volume was adjusted with distilled water. The bottle was plugged and mixed thoroughly.

2.5. Microbial Biomass C and N

To determine both microbial biomass (C_{mic}) and N (N_{mic}), the fumigation extraction methods were described by Vance et al. [32], and Horwath and Paul [33], respectively.

2.6. Hydrolysis of Enzyme Substrates

2.6.1. Hydrolysis of Formamide

The method by Frankenberger and Tabatabai [34] was used to determine amidase activity, but without toluene or buffer, at 30 °C for 2 h. Controls were involved as the addition of substrate was after termination of the reaction.

2.6.2. Hydrolysis of Asparagine, Arginine, and Glutamine

The same steps were used for formamide, but 50 mM of L-asparagine, L-arginine, or L-glutamine, respectively, was utilized as a substrate for asparaginase, arginase, or glutaminase activity [35,36].

2.6.3. Hydrolysis of p-Nitrophenyl- β -D-glucopyranoside and p-Nitrophenyl-N-acetyl- β -D-glucosaminide

The hydrolysis of both enzymes was determined [22,37]. Controls were involved as the substrate was affixed immediately after the termination of the reaction. The released color of p-nitrophenol was determined.

Tests using various soils showed that the substrate hydrolysis rates characterized above did not shift when field wet soils were stored at 40 °C for 12 months. Duplicates and one control were included for all substrate hydrolyses using field moist soils, with results expressed on an oven-dried basis.

2.7. Inhibition of $\text{NH}_4\text{-N}$ Released and Enzymes Activities

Six heavy metals (Co^{+2} , Cd^{+2} , Cu^{+2} , Ni^{+2} , Cr^{+3} , and Pb^{+2}) of Fisher-certified reagent-grade chemicals were used. Impacts of heavy metals on $\text{NH}_4\text{-N}$ released were surveyed by comparing the amounts of $\text{NH}_4\text{-N}$ released in both soils of amended and unamended with heavy metals. The procedure was the same as that described in Section 2.2 for $\text{NH}_4\text{-N}$ released, but 10 mL of water was used together with 2 mL of the heavy metal solution containing 25 μmol of heavy metal, and 5 g of soil. The inhibition percentage of $\text{NH}_4\text{-N}$ released by each heavy metal was calculated from the equation:

$$[(A - B)/A] \times 100$$

where A is the amount of $\text{NH}_4\text{-N}$ produced in the control, and B is the amount of $\text{NH}_4\text{-N}$ produced in the soil sample amended with heavy metal.

For testing the impacts of heavy metals on arginine hydrolysis, a 5 g soil sample was added to 1 mL of a solution containing 25 μmol of heavy metal in a 50 mL volumetric flask. This solution was added dropwise to moisten the whole soil sample. After about 30 min of equilibration, arginine hydrolysis was determined described previously (Section 2.6.2), but here 8 mL deionized water was used because the soil sample was treated with 1 mL of heavy metal solution. The amount of $\text{NH}_4\text{-N}$ produced from arginine hydrolysis in heavy metal-treated soils was compared with those obtained with 5 g soil treated with 1 mL water. The percentage inhibition of arginine hydrolysis by each heavy metal was calculated as follows:

$$[(A - B)/A] \times 100$$

where A is the amount of $\text{NH}_4\text{-N}$ produced from arginine hydrolysis of the untreated soil, and B is the amount of $\text{NH}_4\text{-N}$ produced from arginine hydrolysis of heavy metal-treated soil. All results reported are averages of duplicate determinations calculated on an oven-dried basis. Tests using several soils reflected that the rates of released $\text{NH}_4\text{-N}$ were not changed with storing field moist soils at 40 °C for 12 months.

2.8. Statistical Analysis

Statistical analysis was carried out by the general linear model procedure of the SAS system [38]. The asterisks, *, **, and ***, indicate significance at $p < 0.05$, 0.01, and 0.001, respectively. For all data points, the differences between the duplicate values obtained in the analyses or assays were smaller than the symbol size.

3. Results

Results were discussed under subheadings that correspond to the biochemical processes that were researched for the sake of convenience and clarity.

3.1. Physical and Chemical Properties of Selected Islands

The spatial distribution of pH (H_2O and CaCl_2) and clay content (g/kg) were demonstrated in Figure 2. The highest pH (H_2O) was in NIS_7 with a value of 7.8 and for pH (CaCl_2) was in NIS_1 with a value of 7.59. The lowest pH (H_2O) value was 6.54 in NIS_8 and for pH (CaCl_2) was 7.11 in NIS_2 . For clay content, clay content was in NIS_{10} which contained the highest organic N and C content with a value of 488 g kg^{-1} , while the lowest was 402 g kg^{-1} in NIS_2 .

Figure 3 shows the spatial distribution of organic C (g kg^{-1} soil), organic N (g kg^{-1} soil), and C/N ratio. For organic C, the highest contents were in NIS_{10} and NIS_{11} that exceeded 3 g/kg soil, while the lowest was in NIS_1 . For organic N, it followed the same trend as that of organic C. The highest content was 0.316 g/kg soil in NIS_{11} , while the lowest was in NIS_1 with a value of 0.098. C/N ratios were opposite to that of organic C and N, as the highest value was 12.8 in NIS_1 , while the lowest was 10.5 in NIS_{10} .

3.2. The Amount of $\text{NH}_4\text{-N}$ Released

The $\text{NH}_4\text{-N}$ released amounts in airdried soils were higher than their field-moist counterparts (Figure 4). The range of those in the field moist soils was from 15.3 to 31.6 mg kg^{-1} of soil in NIS_2 and NIS_{11} soils, respectively (avg. = 22 mg kg^{-1} soil), and in the airdried soils was from 34.7 to 169 mg kg^{-1} of soil in NIS_2 and NIS_{10} soils among eleven Nile River islands, respectively (avg. = 98 mg kg^{-1} soil). Rewetting airdried soils breaks the aggregates, resulting in more surface areas and soluble organic N in solution, which results in the release of greater amounts of $\text{NH}_4\text{-N}$.

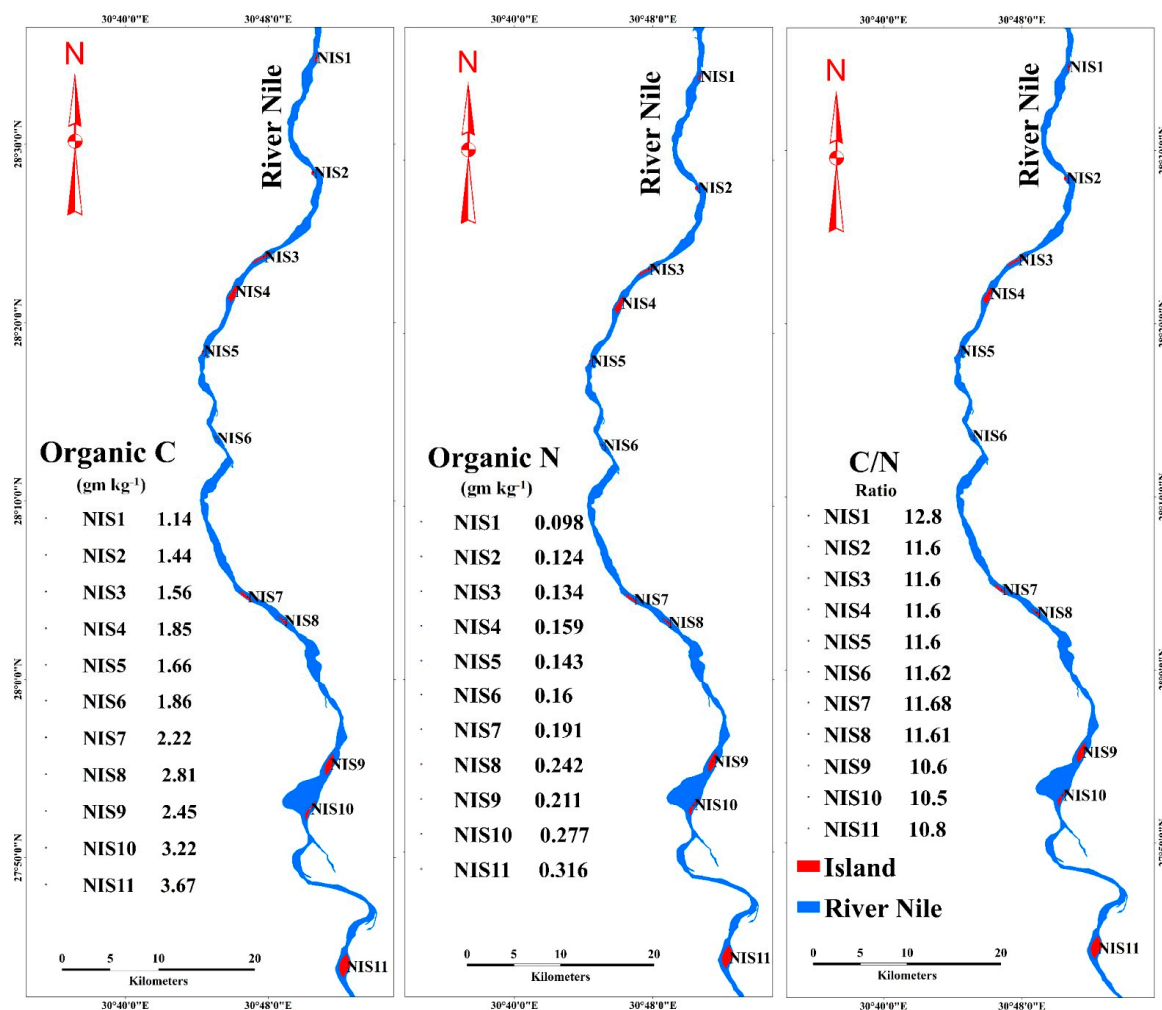


Figure 3. Spatial distribution map of soil Org. C, Org. N and C/N ratio.

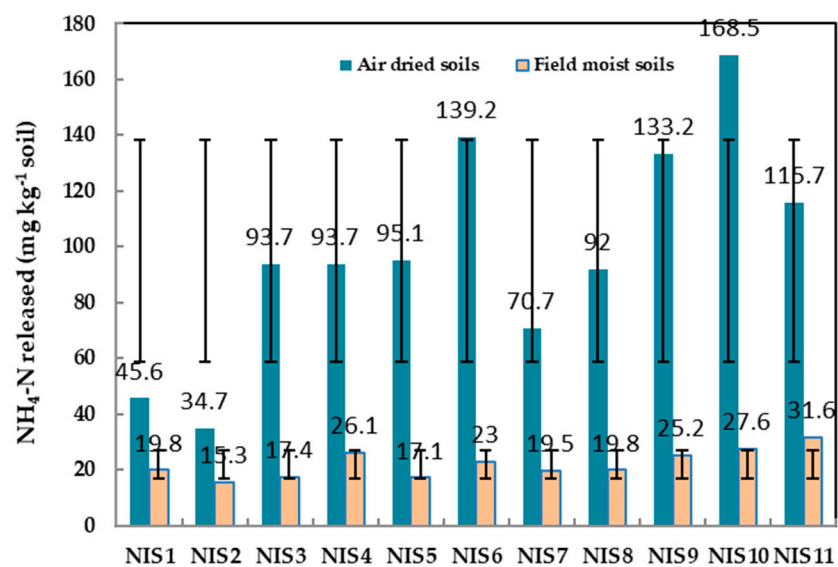


Figure 4. Amounts of NH₄-N released in soil samples (showing field-moist and air-dried samples) incubated at 30 °C under flooding conditions for 15 days.

3.3. Relationships Between Rates of Enzyme Substrates Hydrolysis and Organic C and N

The hydrolysis rates of the enzyme substrates studied in the field moist soils were significantly correlated with organic C, with r values $> 0.63^*$. The highest correlation coefficients were with the substrates of amidase, asparaginase, and β -glucosaminidase, with an r value of 0.81^{**} , followed by glutaminase and arginase with r values of 0.78^{**} and 0.69^* , respectively, and the lowest value was in β -glucosidase with an r value of 0.63^* (Figure 5). The correlation coefficients of the relationships between soil organic N contents and the rates of enzyme substrates hydrolysis varied somewhat: β -glucosaminidase $>$ amidase $>$ asparaginase $>$ glutaminase $>$ arginase $>$ β -glucosidase, with r values of 0.89^{***} , 0.87^{***} , 0.85^{***} , 0.84^{**} , 0.77^{**} , and 0.75^{**} , respectively (Figure 6). Amidase activity was also significantly correlated with percentage N ($r = 0.74^{***}$).

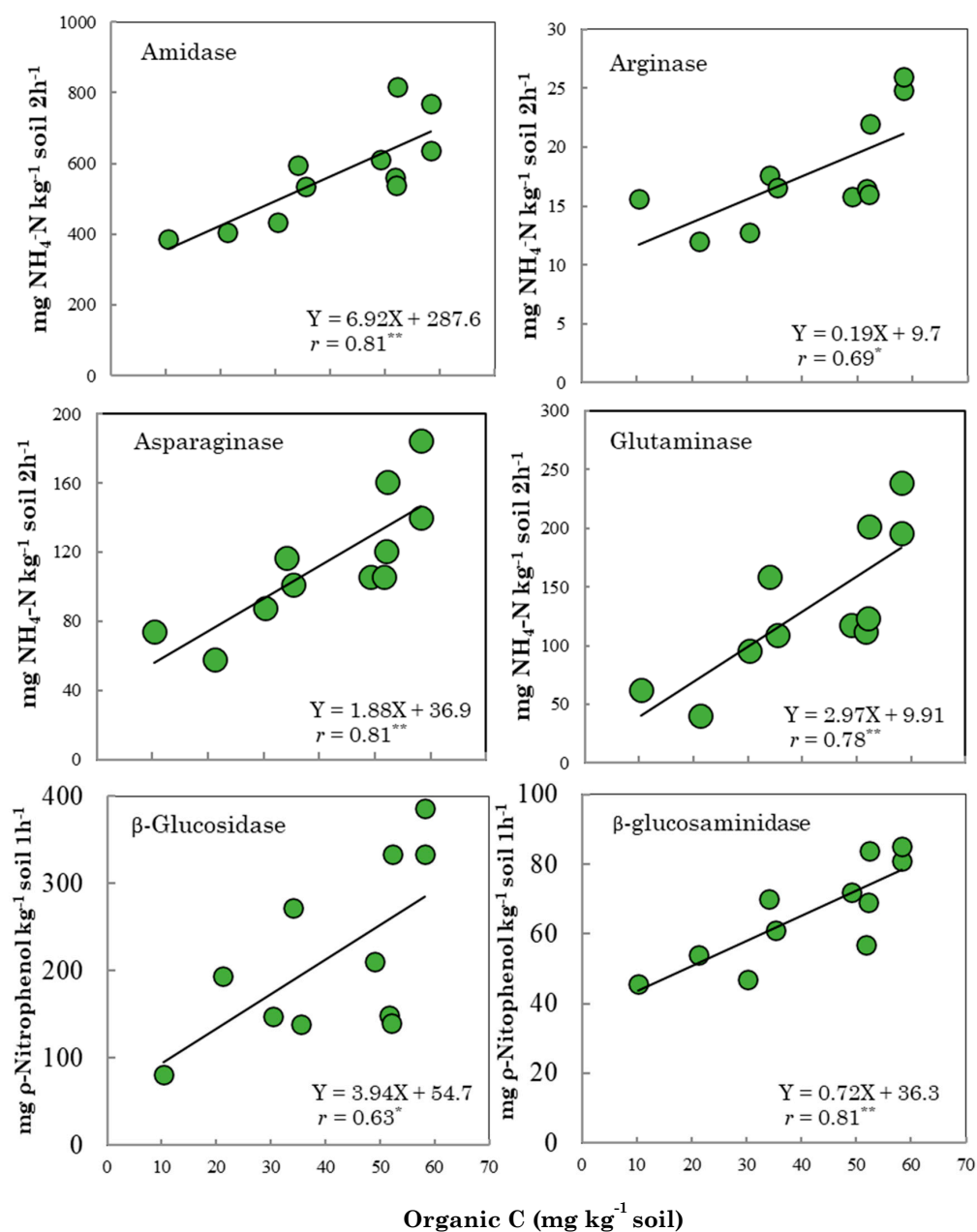


Figure 5. Relationships between selected enzyme substrate rates hydrolyzed in field-moist soils and organic C. Each point represents duplicate values. *, ** significant at $p < 0.01$ and 0.001 , respectively.

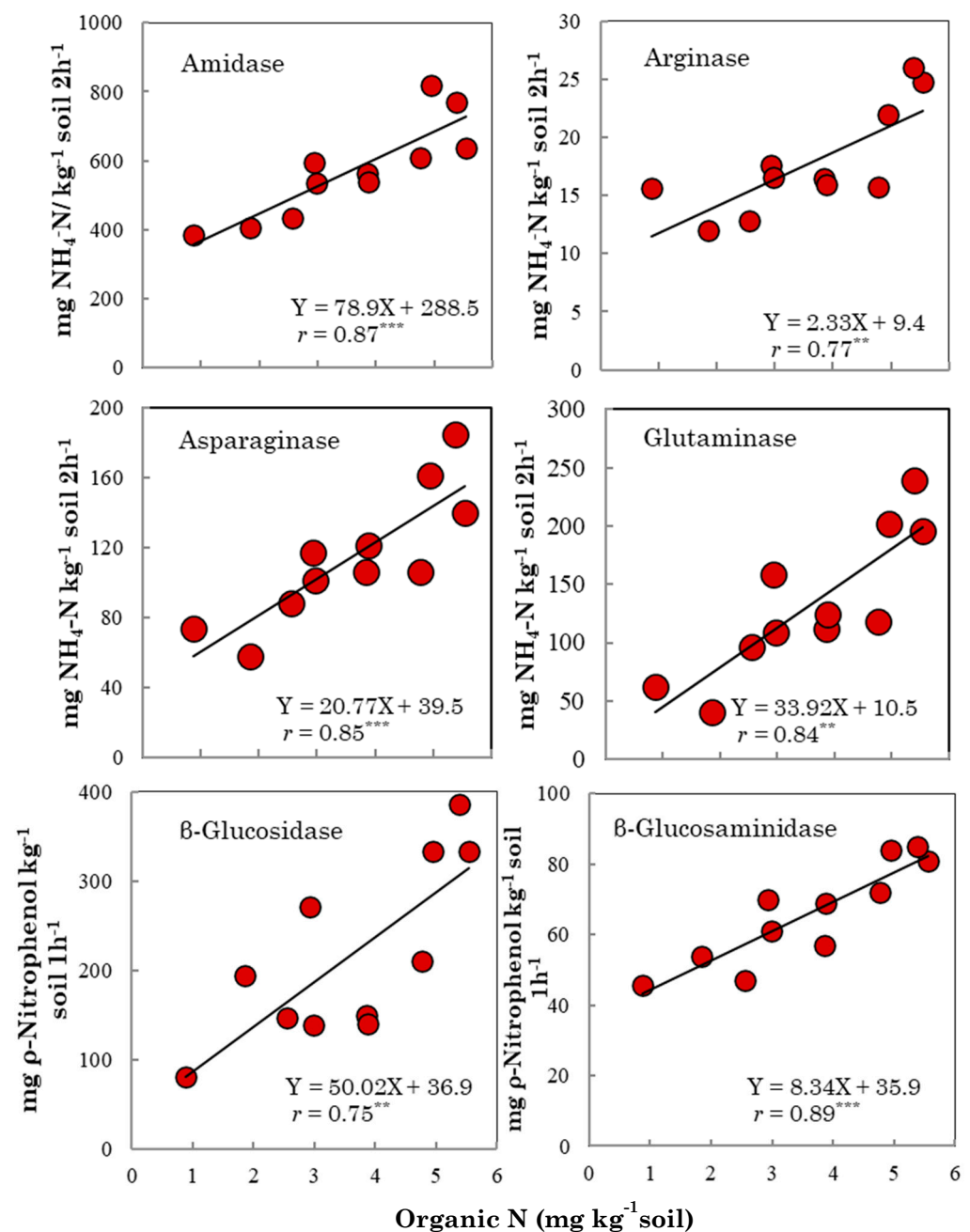


Figure 6. Relationships between selected enzyme substrate rates hydrolyzed in field-moist soils and organic N. Each point represents duplicate values. **, *** significant at $p < 0.01$ and 0.001 , respectively.

3.4. Relationships Between Rates of Hydrolysis of Enzyme Substrates and Microbial Biomass C and N

Results showed a strong correlation between the hydrolysis rates of enzyme substrates studied in the field moist soils and the microbial biomass C (C_{mic}) and microbial biomass N (N_{mic}) (Figures 7 and 8). The rates of enzyme-substrate hydrolysis in the field moist soils were significantly correlated with C_{mic} (Figure 7). The correlation coefficients (r) for those relationships for amidase, β-glucosaminidase, asparaginase, glutaminase, arginase, and β-glucosidase were 0.84^{***} , 0.82^{**} , 0.81^{**} , 0.79^{**} , 0.77^{**} , and 0.65^{*} , respectively. The corresponding r values for N_{mic} were 0.88^{***} , 0.84^{**} , 0.84^{**} , 0.82^{**} , 0.81^{**} , and 0.71^{*} , respectively (Figure 8).

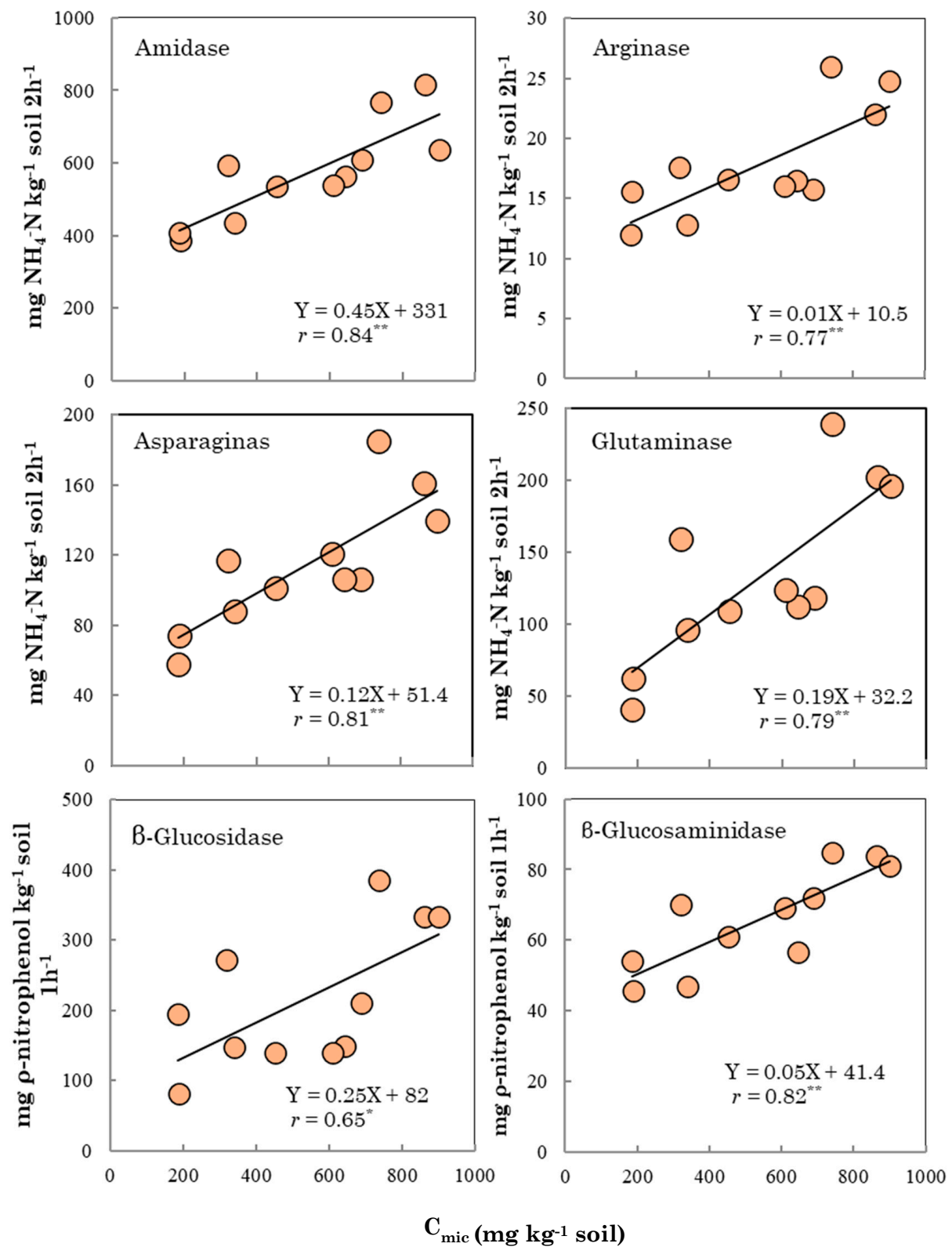


Figure 7. Relationships between selected enzyme substrate rates hydrolyzed in field-moist soils and microbial biomass C. Each point represents duplicate values. *, ** significant at $p < 0.01$ and 0.001, respectively.

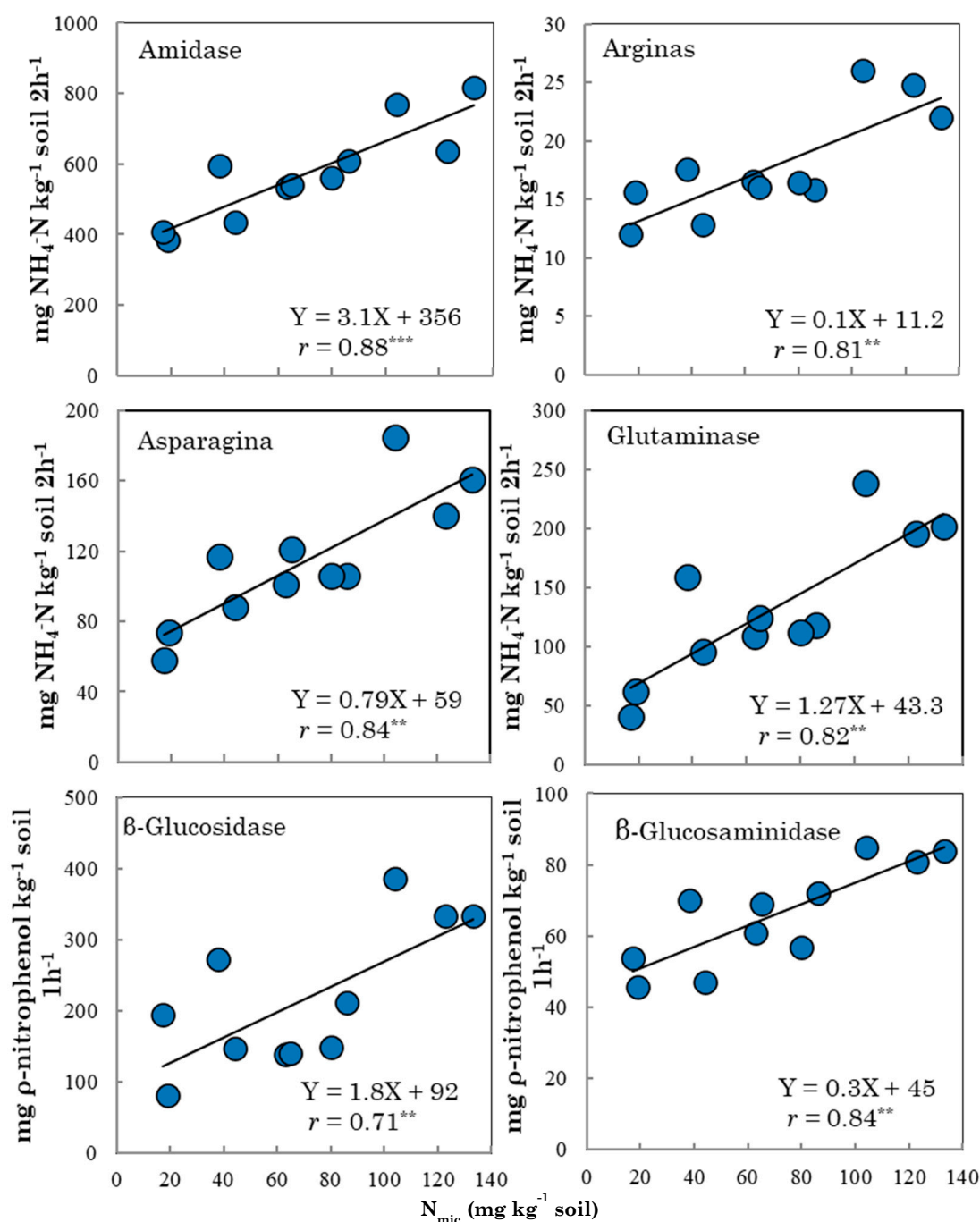


Figure 8. Relationships between selected enzyme substrate hydrolysis rates in field-moist soils and microbial biomass N. Each point represents duplicate values. **, *** significant at $p < 0.01$ and 0.001, respectively.

3.5. Interrelationships Between the Hydrolysis of Enzyme Substrates

There was a highly significant inter-correlation between the rates of substrate hydrolysis in the 11 island moist soils studied, with r value $> 0.81^{**}$ (Table 3). The highest correlation was between the hydrolysis of substrates of L-asparaginase and L-glutaminase with an r value of 0.98^{***} , followed by L-asparaginase and amidase with an r value of 0.94^{***} . Also, there was a highly significant correlation between L-glutaminase and amidase with r value of 0.92^{***} . Results also showed that there were highly significant correlations between L-asparaginase and L-glutaminase with β -glucosaminidase with an r value of 0.90^{***} . Arginase also showed a significant correlation with L-asparaginase with r value

of 0.92 ***. Generally, inter-correlation coefficients varied somewhat among the enzyme substrate hydrolyzed (Table 3).

Table 3. Interrelationship among hydrolysis of enzyme substrates.

Correlation Coefficient of the Linear Relationship of Hydrolysis of Substrate of the Enzyme Specified						
Enzymes	Amidase	Arginase	L-Asparaginase	L-Glutaminase	β -Glucosidase	β -Glucosaminidase
	r Value					
Amidase	1.00					
Arginase	0.81 **	1.00				
L-Asparaginase	0.94 ***	0.92 ***	1.00			
L-Glutaminase	0.92 ***	0.94 ***	0.98 ***	1.00		
β -Glucosidase	0.84 **	0.81 **	0.82 **	0.88 ***	1.00	
β -Glucosaminidase	0.93 ***	0.84 **	0.90 ***	0.90 ***	0.88 ***	1.00

Note: **, *** significant at $p < 0.01$ and 0.001 , respectively.

3.6. Heavy Metals Effects on Ammonium-N Released in Soils Under Flooding Condition

Studies to evaluate the effects of six heavy metals (Cu^{+2} , Cd^{+2} , Co^{+2} , Pb^{+2} , Ni^{+2} , and Cr^{+3}) on $\text{NH}_4\text{-N}$ released in island moist soils incubated for 10 days at 30°C under flooding conditions showed that all the studied heavy metals inhibited the amounts of $\text{NH}_4\text{-N}$ released; the relative effectiveness of the heavy metals in inhibition of $\text{NH}_4\text{-N}$ released depended on the properties of the island soil used. Tests reflected that the amounts of $\text{NH}_4\text{-N}$ release were linear with incubation time up to 15 days. When the heavy metals were compared at 10 mmol kg^{-1} soil, there was a much greater concentration than those of total or soluble heavy metals in soils (Table 4). Pb^{+2} was the most effective inhibitor in NIS_2 and NIS_{11} island soils with inhibition values of 82 and 30%, respectively, and Cd^{+2} for NIS_6 island soil with inhibition values of 70%; Co^{+2} , Cu^{+2} , and Cd^{+2} were the least effective inhibitors in NIS_2 , NIS_6 , and NIS_{11} island soils with inhibition values of 27, 10, and 7%, respectively (Table 4).

Table 4. Impacts of studied heavy metals on released ammonium-N in island soils under flooding circumstances.

Metal	Total Concentration ($\mu\text{mol kg}^{-1}$ Soil) ^a			Inhibition of $\text{NH}_4\text{-N}$ Released (%) ^b		
	NIS_2	NIS_6	NIS_{11}	NIS_2	NIS_6	NIS_{11}
Cd	3 (0) ^c	0 (0)	0 (0)	66	70	7
Co	163 (0.3)	127 (0.2)	18 (0.2)	27	69	22
Cr	800 (1.0)	520 (0.2)	699 (0.4)	50	63	32
Cu	294 (0.6)	390 (0.5)	409 (0.2)	43	10	14
Ni	182 (0)	210 (0)	200 (0)	71	43	21
Pb	109 (3)	128 (1)	143 (3)	82	55	30

Notes: ^a The soluble heavy metals in soils ($\mu\text{mol kg}^{-1}$ soil) are presented in parentheses; ^b at 10 mmol kg^{-1} soil; ^c not detectable.

3.7. Heavy Metals Effects on Activities of Hydrolases in Soils

In this research, the effect of six metal ions on the hydrolysis of arginine in soils was studied. Results demonstrated that arginine hydrolysis was hindered in soils by all heavy metals examined, with varying degrees of inhibition observed throughout the island soils tested. When the heavy metals were compared by using 5 mmol kg^{-1} soil, the averages of inhibition in island moist soils showed that Pb^{+2} , Ni^{+2} , and Cr^{+3} were the most effective inhibitors, with average inhibition values of 49, 45, and 49%, respectively. The least effective inhibitors were Co^{+2} and Cu^{+2} , with average inhibitions of 13% (Table 5).

Table 5. Effects of heavy metals on activities of selected hydrolases in island soils.

Heavy Metal	Oxidation State	Percentage of Inhibition of Enzyme Specified					
		Amidase ^a	L-Asparaginase ^b	L-Glutaminase ^c	β-glucosaminidase ^d	β-glucosidase ^e	Arginase ^f
Cd	2+	5, 6, 6 (6)	19, 20, 24 (21)	16, 20, 33 (23)	9, 37, 40 (29)	15, 19 (17)	24, 29 (27)
Co		4, 5, 8 (6)	5, 6, 15 (9)	3, 5, 8 (5)	37, 56, 68 (54) ^g	4, 10 (7)	12, 14 (13)
Cu		2, 2, 4 (3)	19, 19, 20 (19)	11, 14, 18 (14)	6, 33, 34 (24)	6, 16 (11)	5, 20 (13)
Ni		2, 2, 6 (3)	18, 19, 23 (20)	6, 7, 12 (8)	12, 14, 18 (15)	5, 15 (10)	38, 51 (45)
Pb		2, 5, 5 (4)	18, 21, 38 (26)	8, 9, 15 (11)	5, 7, 16 (9)	3, 29 (16)	22, 75 (49)
Cr	3+	4, 4, 4 (4)	12, 13, 21 (15)	26, 39, 42 (36)	9, 12, 16 (12)	3, 17 (10)	49, 49 (49)

Notes: ^a Results of 3 soils (Figures in parentheses are the means) [39]. ^b Results of 3 soils (Figures in parentheses are the means) [35]. ^c Results of 3 soils (Figures in parentheses are the means) [36]. ^d Results of 3 soils (Figures in parentheses are the means) [40]. ^e Results of 2 soils (Figures in parentheses are the means) [41]. ^f This study (Figures in parentheses are the means of two island soils). ^g The effect of Co⁺² on β-glucosaminidase activity was activation and not inhibition.

4. Discussion

Global climate changes and differences in precipitation patterns in recent years have produced flooding or ponding of a large number of farmlands worldwide. In numerous areas, farmlands are often moderately flooded with water during the growing season [42]. Under flooding conditions, NH₄-N is produced in the soil with the contribution of biochemical reactions under the control enzymes which are accountable for hydrolyzing specific N bonds in the organic matter of the soil and the breaking down of relatively large aggregates of air-dry soil [42]. Our results reflected that the amounts of NH₄-N released in airdried soils were higher than their field-moist counterparts. Rewetting airdried soils breaks the aggregates, resulting in more surface areas and soluble organic N in solution, which results in the release of greater amounts of NH₄-N.

The rates of hydrolysis of the enzyme substrates in our study were correlated significantly with organic C in the field moist soils. These are consistent with the results reported by Frankenberger and Tabatabai [38], who studied the distribution of amidase in soils and reported that the vigor of this enzyme was correlated significantly with organic C in surface soils ($r = 0.74$ ***) and in soil profiles ($r = 0.89$ **). For amidase activity, it was correlated significantly with percentage N. Our results are in harmony with those by Ekenler and Tabatabai [40,43], who showed that N-Acetyl-β-D-glucosaminidase activity was correlated significantly with organic carbon C and N with r values of 0.56 *** and 0.60 ***, respectively.

Enzyme activities have been suggested as early indicators of changes in soil properties and soil health, because of their rapid response to changes in management practices or flood existence, their relationship to soil biology, and the ease and accuracy of the assay [44–46]. Our data showed a strong correlation between the hydrolysis rates of enzyme substrates studied in the field moist soils and the microbial biomass C (C_{mic}) and microbial biomass N (N_{mic}). This is consistent with results of other studies indicating that C_{mic} and N_{mic} were correlated strongly with activities of several enzymes [43,46–51], including those reported here for substrate hydrolysis in soils (i.e., without the addition of buffer). Work by Lin and Brooks [52] indicated that arginine ammonification can be used for the estimation of microbial biomass. The results reported here indicate that hydrolysis of several other substrates in soils can be used for the same purpose, as C_{mic} and N_{mic} values were correlated significantly with hydrolysis of six soil organic N hydrolases. Similarly, in addition to arginine hydrolysis, the rates of hydrolysis of the other substrates used in this study can be utilized as indexes of N mineralization under flooding conditions [53,54]. Growing evidence has been synthesized by Mori et al. [46] that the enzymatic stoichiometry methodology cannot infer soil microbial nutrient limitation; however, this is not a conclusive answer until improved methods of measuring and interpreting soil enzyme activity regarding C and N dynamics are established. The results revealed a highly significant inter-correlation between the rates of substrate hydrolysis in the 11 island moist soils studied. These results agreed with those obtained by Frankenberger and Tabatabai [35,36].

For heavy metal impacts on ammonium-N released under flooding conditions in soils, the results showed that all the studied heavy metals inhibited the amounts of NH₄-N

released. The chemistry and biochemistry of heavy metals added to soils are complex; they may form complexes with soil organic matter, precipitate under certain conditions, react with enzyme proteins, or inhibit microbial population and dynamics [20]. Those and other reactions involved are the reasons for observed differences in the impact of different heavy metals on $\text{NH}_4\text{-N}$ released under flooding conditions.

According to Zerrari et al. [55], soil enzymes are frequently present in soil and are important for maintaining its physicochemical qualities as well as its ecology and fertility. Because of their sensitivity to the presence of heavy metals and their direct relationship to soil nutrient cycles, enzyme activities are a useful indication of soil quality [56]. The C, N, P, and S cycles in soils are significantly influenced by the activities of enzymes [21,55].

The inhibition of arginine hydrolysis by heavy metals was compared with those of other hydrolases available in the literature. Several studies have been conducted on the effects of trace elements on enzyme activities [21,35,36,40,55,57] but little information is available on the effect of heavy metals on arginine hydrolysis in soils. Enzyme activity in soils is influenced by heavy metal pollutants and soil characteristics, and it may be an indication of low soil microbial activity and degraded soil health. Data on the effects of heavy metals on soil enzyme activities in agricultural soils were supplied by Zerrari et al. [55]. On average, they reported a high positive correlation pointing to the same origin source between the heavy metals Cu, Pb, and Zn and the soil enzyme activity. Among the enzymes, phosphatase activity was the most sensitive indication; however, heavy metals had no effect on urea activity. The relationship amongst enzyme activity, heavy metal concentrations, and soil properties is contingent upon the metal speciation, or chemical form, in addition to the concentration of the heavy metal [12,21,58].

5. Conclusions

The amounts of $\text{NH}_4\text{-N}$ released from the Nile River islands' soils differed among the 11 studied islands. The amounts released under flooding conditions were higher in air-dried than in field-moist soils. Organic C and N, microbial biomass C and N impacted the rates of hydrolysis of six specific enzyme substrates and there were significant inter-correlations among the hydrolysis of the enzyme substrates studied. From the results reported about the hydrolysis of six enzyme substrates, it is obvious that the related enzymes are included in the hydrolysis of soil organic matter and the release of $\text{NH}_4\text{-N}$ under flooding conditions. The addition of six heavy metals to soil inhibited the amounts of the released under flooding conditions. The extent of inhibition varied among the soils and the metals studied; heavy metals were particularly inhibitory in the hydrolysis of arginine in soils. Fertile fields on the Nile River islands should not be fertilized before the summer flood seasons due to complex soil enzymatic and organic nitrogen hydrolase activities happening during floods. This will prevent contamination of the Nile River water and loss of its island soil fertility.

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