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Evaluation of Nutrient Leaching Losses in Red Onion Grown on Sandy Regosols in Kalpitiya under Intensive Farming Systems

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Abstract

Background: Red onion is a short-term crop cultivated in Kalpitiya with excessive use of fertilizer, leading to contamination of groundwater. Therefore, the current study aimed to evaluate the leaching potential of plant nutrients from red onion cultivations managed under grower managed fertilizer practices, compared to Department of Agriculture (DoA) recommendations.

Methods: This study was carried out in Kandakuliya, where lysimeters were installed below the soil surface of separated plots. The variety Jaffna Local was used in the experiment. Growers' fertilizer practice was considered as the treatment 1 (T1). The DoA recommendation was used as treatment 2 (T2). The available P, total N, exchangeable K^+, Ca^{+2}, F^-, NO_3^- and NH_4^+ concentrations in the initial soil samples and leachate were analyzed using standard methods. The two-sample t test was used for statistical analysis.

Results: The mean cumulative Ca^{+2}, NO_3^- and P denoted significant differences, among the leachate collected from the two treatments. The concentration of NO_3^- in both treatments ranged from 35.1 mg/l to 160 mg/l. which was higher than the WHO permissible level of NO_3^- (50 mg/l) for drinking water. However, the mean values of cumulative leached NH_4^+ and K^+ did not indicate significant differences between the treatments. The highest mean cumulative values of Ca^{+2} (659.6 kg/ha), F^- (4.9 kg/ha) and P (26.4 kg/ha) were observed in the leachate collected from T1.

Conclusions: Among all the tested substances, NO_3^- was found to be the critical element in terms of leaching and contamination of groundwater. This emphasizes the pressing need for an improved nitrogen management strategy for the sustainable production of red onion grown in Kalpitiya.

Keywords: Fertilizer, Groundwater Contamination, Nutrient Leaching, Sandy Regosols

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INTRODUCTION

Fertilizer plays a significant role in increasing crop production while supporting to ensure food security in the world [1]. However, improper management and over usage of commercial fertilizers often lead to lower nutrient use efficiency, accumulation, and losses of nutrients from the soil. Leaching is the result of releasing ions in the soluble form and moving with percolating water. The magnitude of leaching loss is proportional to the element concentration in the soil and the amount of drained water. Nutrient leaching is becoming critically important due to the movement of nutrients out of the root zone, leading to an immediate loss of nutrients to crops and an economic loss to farmer. The nutrients applied to soil undergo a series of transformations by various physical, chemical, and biological processes within the soil, which make them available to crops as well as vulnerable to leaching losses [2].

Soil nutrient leaching is governed by various factors like soil type, available nutrient content, amount and intensity of rainfall, frequency of irrigation and the nature of the crop. Leaching of nutrients like nitrogen, potassium and phosphorus are a major environmental concern and cause potential risks to human health [2]. Overuse of fertilizers and consequent health and environmental issues have long been identified as major agriculture related environmental issues in many parts of the world, including Sri Lanka. The chemical fertilizer application rate has ranged from zero to 830% of the recommended level in different cropping systems in Sri Lanka [3]. Therefore, to fulfil the fertilizer requirement, Sri Lanka imports about 800 million kg of chemical fertilizers annually [4]. The usage of inorganic fertilizers has increased because of increased cropping intensity with high yielding varieties. Widespread and intensive use of inorganic fertilizers are common mainly in vegetable cultivation [5].

Kalpitiya is one of the highly productive agricultural areas of the country, situated in North-Western Province of Sri Lanka, which contributes to a high percentage of vegetable and fruit production in the country [6]. Intensive agricultural practices and human settlements have already imposed a high demand for groundwater utilization in the Kalpitiya peninsula. Groundwater usage of the Kalpitiya peninsula is about 100% as there are no surface water resources available [6]. It is reported that the farmers devote around 35% of their cost of production for irrigation [7].

Sandy regosols is the dominant soil type in the peninsula, which is extremely permeable, consisting of 90-98% sand. Hence, drainage and water logging conditions are not major concerns in Kalpitiya. Farmers in Kalpitiya struggle with issues related to less water and nutrient retention, and low organic matter content in sandy soil. Due to this infertile nature of the soil, farmers apply excessive amounts of commercial fertilizer expecting better yields throughout the year. The agrochemicals which are used may not perform to their maximum potential in terms of crop development, since sandy Regosols are unable to retain more of them. Therefore, fertilizers leach into shallow groundwater sources due to the excess irrigation and causing a severe groundwater contamination level [8]. Therefore, attention of the responsible authorities should be placed on ways to improve the nutrient utilization efficiency and decrease nutrient leaching losses. For this, characterizing the exact nutrient leaching losses from different crops, which are widely cultivated in Kalpitiya, is essential. Hence, this study was conducted to quantify the nutrient leaching losses from red onion cultivation in Kalpitiya under grower-managed fertilizer practices compared to the Department of Agriculture (DoA) recommended practices.

METHODOLOGY

Study Location and Duration

The experiment was carried out in Kalpitiya peninsula as a field experiment within the period of 2021 to 2022.The experimental field was located at an elevation of 1 m above the mean sea level. The site was established with lysimeters previously installed. The monthly mean temperature at Kalpitiya during the study period was 30 °C, while the mean monthly rainfall was 83 mm.

Experimental Design

Leaching monitoring lysimeters each covering an area of 0.28 m^2 were installed at the experimental site, 90 cm below the soil surface. Jaffna local variety of red onion was taken as the planting material for the experiment. Six plots were prepared by 3 m*2.4 m (7.2 m^2 plot) with two treatments replicated three times.

Crop Establishment and Treatment Application

Prior to the planting of red onion bulbs, compost application was done at the rate of 10 t/ha for both treatments. Treatment 1 was applied with growers used rate of fertilizer, which was Urea- 100 kg/ha, TSP-250 kg/ha, Onion fertilizer (12:9:9-N: P: K)-125 kg/ha, Blue granules (12:12:7-N: P: K)-62 kg/ha and Calcium nitrate (N-15,5%, CaO-26%)-62 kg/ha applied at weekly intervals. Meanwhile, Treatment 2 was applied with the Department of Agriculture recommendation of fertilizer application (DoA) as shown in Table 1. According to the DoA recommendation, application of weedicides and the pesticides were done as needed. Irrigation was done two times per day, in the morning and evening using sprinklers.

Table 1: DoA Recommended Fertilizer Requirement of Red Onion in Kalpitiya

Fertilizer Application	Urea (kg/ha)	TSP (kg/ha)	MOP (kg/ha)
BD	68.5	100	50
TD 1 (3WAP)	65		
TD 2 (6WAP)	65		25

Note: BD- Basal Dressing, TD 1- First Top Dressing, TD 2- Second Top Dressing; TSP-Triple Super Phosphate, MOP- Muriate of Potash, WAP-Weeks after planting, DoA (Chemical fertilizer (100%) + Compost (10t/ha).

Collection of Leachate Samples and Irrigation Water

Prior to planting, initial leachate samples were collected from each plot. For this, leachate samples from individual outlets of lysimeters were collected continuously using an electric pump. The volumes extracted from the lysimeters of each plot were recorded. Leachate samples were obtained at weekly intervals for analysis, which represented composite samples of the leachate that had drained for 7 days. In addition, irrigation water was also sampled weekly from the well throughout the cropping season.

Analysis of Initial Soil Samples

Available phosphorus amount in soil was determined using the Sodium-bicarbonate extraction method [9]. The Kjeldhal method was used to detremine the total nitrogen content in soil [10]. The soil exchangeable potassium, calcium and fluoride content were analysed using the Ammonium-Acetate extraction approach [11]. Further, the Walkley and Black method [12] was used to analyse the organic carbon content in soil. Soil pH and Electrical Conductivity (EC) were measured electrometrically, using a 1:5 soil-water suspension [13].

Analysis of Leachate and Irrigation Water

NO_3^-, NH_4^+, F^- concentrations in the leachate as well as in the well water were determined using ion selective electrodes (CPI 505, Elmetron, Poland). K^+ and Ca^{+2} concentrations were determined using a flame photometer (BWB-XP, UK). Available P in leachate was determined using the Sodium-bicarbonate extraction method [9].

Statistical Analysis

For all the parameters, mean values ± Standard Deviation (SD) were calculated. The significance among the mean values of measured chemical parameters of two treatments were analyzed using the two-sample t-test. The R software package (version R 4.2.2) was used for the statistical analysis.

RESULTS AND DISCUSSION

Chemical Parameters of Soil

According to initial soil properties, the nutrient levels of the soil were very low, except for Ca^{+2}, indicating the need for an external supply (Table 2). Sandy Regosols in Kalpitiya contains a higher content of Ca^{+2} ions. This may be due to the deposition of tiny windblown shell fragments [14]. The mean pH of the initial soil was neutral, and the EC was 39.46±3.58 µS/cm. Soil exchangeable K^+ and F^- contents were 6.5±0.25 mg/kg and 0.84±0.21 mg/kg, respectively. Total N content of the soil was 0.04±0.03 mg/kg. Meanwhile, the mean soil available P level was as low as 0.35±0.01 mg/kg. It has been reported that most of the soils contain low concentrations of phosphorus in the soil solution, mainly due to poor solubility [15].

Table 2: Initial Soil Chemical Properties of the Experimental Site

Parameter	Mean ± SD
Soil pH (Soil : H_2O = 1:5)	7.17 ± 0.02
Electrical Conductivity (µS/cm)	39.46 ± 3.58
Available P (mg/kg)	0.35 ± 0.01
Exchangeable K (mg/kg)	6.5 ± 0.25
Exchangeable Ca (mg/kg)	608.7±64.7
Exchangeable F (mg/kg)	0.84±0.21
Organic Carbon %	0.135 ± 0.05
Total Nitrogen %	0.04±0.03

Analysis of Leached Nitrate and Ammonium (kg/ha)

The average nitrate and ammonium concentrations of irrigation water were 15.3 mg/l and 1.68 mg/l, respectively. There were significant differences (P<0.05) among the mean values of cumulative nitrate leaching between the two treatments, throughout the cropping season (Table 3). Hydrolysis, volatilization, nitrification and denitrification are the main processes that decide the fate of applied urea in soil. Once urea is applied to soil, it hydrolyses to form NH_4^+. Nitrification converts NH_4^+ into NO_2^- and subsequently, nitrite is transformed into NO_3^- [16]. Depending on the soil pH, moisture, and fertilizer application methods, urea undergoes chemical transformation to produce either NH_4^+ or NO_3^- [17]. Soils with high water infiltration rates and low water retention capacity are particularly conducive to nutrient leaching.

There were no significant differences (P<0.05) among the mean values of cumulative ammonium leaching between treatments, throughout the study period (Table 3). Because NH_4^+ is positively charged, it is held by the negative sites of soils. Therefore, NH_4^+ concentration in leachate was lesser than NO_3^- concentration in the leachate. The leaching loss of nitrogen through nitrogenous fertilizer can be reduced by minimizing the available amounts of NH_4^+ and NO_3^- in the soil in at a given time [18], while supplying enough nitrogen to crops.

Table 3: The Cumulative Leached Nitrate and Ammonium (kg/ha) throughout the Season

Treatment	Mean Nitrate (kg/ha)	Mean Ammonium (kg/ha)
T1	340.1^a±21.4	9.2^a±1.8
T2	311.4^b±3.5	8.1^a±0.9

Note: Means with the same superscript letter in each column are not significant at P=0.05 level

Concentration of Nitrate in the Leachate

The concentration of NO_3- in both leachates fluctuated over the growing season (Figure 1). Both treatments showed higher concentration of nitrate in the leachate than the WHO recommended NO_3- level for potable water (<50 mg/l), as shown by the dashed line in Figure 1, especially in the latter part of the growing period. The rapid increase in leaching losses of nitrogen in the form of nitrate (NO_3^--N) corresponded with the fertilizer application as shown in Figure 1, which was observed after a short duration from applying fertilizer (TD1 in 22 DAP). Furthermore, the T2 comparatively showed a higher concentration of nitrate (NO_3^--N) in leachate up to 14 days, after application of basal dressing

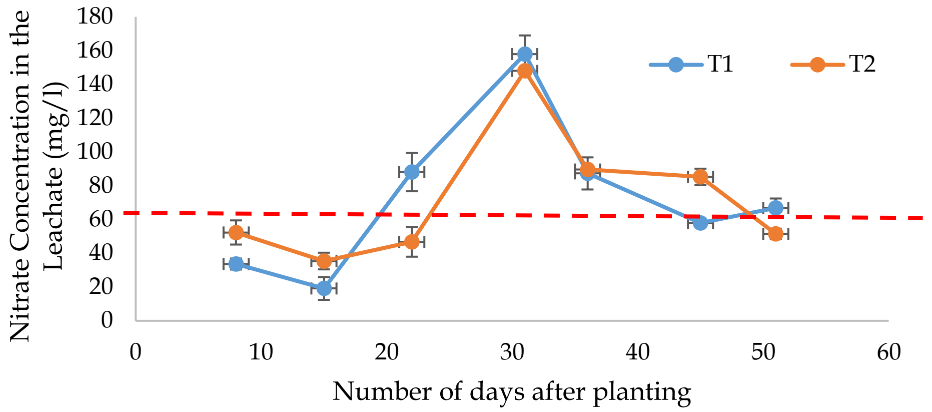

Figure 1: The Temporal Variation of NO_3^- Concentration in the Leachate throughout the Cropping Season

Table 4: The Variation of Cumulative Leached Nutrients (kg/ha) from the Experimental Treatments throughout the Growing Season

Treatments	**Nutrient**			
	Ca^{+2}	**K^+**	**P**	**F^-**
T1	659.6^a±17.7	72.1^a±12.9	26.4^a ±1.7	4.9^a±0.9
T2	524.3^b±17.9	79.5^a ±12.1	11.9^b ±4.9	4.4^a ±0.9

Note: Means with the same superscript letter in each column are not significant at P=0.05 level

Variation of Cumulative Leached Nutrients (kg/ha)

No significant differences ($P<0.05$) were observed among the mean cumulative K^+ levels in the leachates between treatments (Table 4). Substantially a higher cumulative leached K^+ amount was observed in T2 (79.52±12.08 kg/ha), than T1 (72.06±12.96 kg/ha). This may be due to the application of muriate of potash as a potassium source for T2 at the basal dressing and top dressing 2. The K^+ is usually leached in much smaller quantities than Ca^{+2}, when applied as fertilizer. Intensive cultivation without balanced application of potassic fertilizers into the soil could lead into gradual declining trends of potassium in soils [15]. Moreover, a higher cumulative Ca^{+2} amount was observed in the leachate of T1 (659.61±17.67kg/ha) compared to the leachate of T2 (524.28±17.97 kg/ha). Even though Calcium nitrate was applied for growers' application (T1), Ca application was not recommended in Department of Agriculture recommendation (T2). Calcium is one of the elements that can be leached from agricultural soils in high amounts. The cation competition, especially between Ca^{+2} and K^+ ions, plays an important role in determining the Ca^{+2} availability in soil solution and consequently to its leaching potential [14].

Similar to Ca^{+2}, the accumulation of phosphate was also significant in the leachate. The fertilizer treatments indicated a significant difference ($P<0.05$) in the mean cumulative leached P levels, throughout the growing season. However, the highest cumulative leached P level was observed in T1 as 26.41±1.65kg/ha, while the leachate of T2 reported a P level of 11.94±4.93 kg/ha. Triple superphosphate was added as a P source for both T1 and T2 at the rates of 250 kg/ha and 100 kg/ha, respectively. Even though the agricultural lands in Kalpitiya have been fertilized for decades with phosphate fertilizers, the soil phosphate content of the study area remained low.

Phosphate is an immobile ion, and they react strongly with components on the surfaces of soil particles. Therefore, phosphate ions are very slow to move downward through the soil matrix with percolating water, thereby reducing the leaching losses [15].

Intense weathering of fluoride bearing rocks and minerals enhance the entry of fluoride into groundwater. When fluoride exceeds 1.5 mg/L in drinking water, it could cause dental fluorosis [19]. The average F^- concentration of both treatments ranged from 0.26 mg/l to 1.84 mg/l. Leachates of both T1 and T2 showed lower concentration of F^- than WHO recommended thresholds for potable water (<1.5 mg/l), except at few sampling points. The mean cumulative leached fluoride content of T1 and T2 were 4.95±0.86 kg/ha and 4.43±0.91 kg/ha, respectively. However, there was no significant difference in cumulative leached F^- content between T1 and T2.

CONCLUSIONS

Results revealed that, among all the tested elements, nitrogen remains as the critical element in terms of leaching and contamination of groundwater. The cumulative nitrate leached from grower's application was significantly higher, when comparing with the Department of Agriculture based fertilizer recommendation. Furthermore, the concentration of nitrate in leachate was above the accepted thresholds, irrespective of the treatments. Leaching of NO_3^- is economically and environmentally undesirable. Therefore, findings of this study emphasize the pressing need for an improved nitrogen management strategy to ensure sustainable production of red onion in Kalpitiya.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

AUTHORS' CONTRIBUTIONS

GS: Conducted the investigations, data collection, statistical analysis, and prepared the first draft of the manuscript; IH: Supervised the study and revised the manuscript; LU: Supervised the study and reviewed the manuscript; RG: supervised the study and coordinated the funding processes. All authors read and approved the manuscript.

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