



Strategic Optimization of Irrigation and Nitrogen Levels to Maximize Growth and Yield of Radish (*Raphanus sativus* L.)

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Abstract: A field experiment was conducted at the research farm of Gazipur Agricultural University, Salna, Gazipur, Bangladesh during the 2019-2020 rabi season to study the effects of irrigation and nitrogen level on the growth and yield of radish (*Raphanus sativus* L.). A split-plot design under three irrigation levels including I₁: one irrigation at 15 days after germination (DAG); I₂: two irrigations at 15 and 35 DAG; I₃: three irrigations at 15, 35 and 55 DAG, and four nitrogen rates (0, 100, 150, and 200 kg N/ha) to the subplots with three replications were applied. The radish variety 'Mino Early Long White' was used as the test crop. Results showed that both irrigation and nitrogen inputs influenced the vegetative growth, root yield and quality attributes of radish. The tallest plants (29.8 cm), greatest leaf area (400 cm²), and highest gross plant weight (920.5 g/plant) were obtained from I₃N₃. The maximum root yield (67.2 t/ha) was recorded in I₃N₃ with moderate pithiness and the next one is 56.7 t/ha under I₂N₂. The total water use ranged from 71.3 mm (I₁N₀) to 137.4 mm (I₃N₃), with higher nitrogen levels associated with increased water consumption. However, the combination of two irrigations with 100 kg N/ha (I₂N₁) showed most efficient, providing high yield with low pithiness and superior resource-use efficiency. Thus, moderate irrigation and nitrogen inputs were found the most effective for achieving optimal growth, yield, and sustainability of radish cultivation

Keywords: Irrigation frequency; Nitrogen levels; Root yield; Water-use efficiency; Nitrogen-use efficiency.

INTRODUCTION

Radish (*Raphanus sativus* L.) is a short-duration, fast-growing, and economically important root vegetable belonging to the family Brassicaceae. It is widely cultivated across tropical, subtropical, and temperate regions for its edible roots and leaves. Radish makes a substantial contribution to food and nutritional security, especially for smallholder farmers, because of its rich nutritional profile and capacity to adapt to a variety of agroclimatic situations. It is prized for its therapeutic and detoxifying qualities and is a good source of vitamin C, minerals, antioxidants, and dietary fiber (Islam *et al.*, 2019; Meena *et al.*, 2020). The increasing demand for fresh and processed vegetables has intensified the need to enhance radish productivity through

optimized agronomic management practices, particularly water and nutrient management.

Among the many variables affecting radish production, nitrogen (N) management and irrigation are thought to be the most important for attaining a good yield and quality. Physiological and metabolic functions like photosynthesis, nutrition transport, and cell division depend on the availability of water (Tiwari *et al.*, 2021). Likewise, nitrogen is essential for protein synthesis, chlorophyll production, and vegetative development (Kumar *et al.*, 2018). However, because of its quick growth cycle and thin root system, radish is especially vulnerable to changes in water and nutrients. While excessive irrigation can result in root cracking, deformation, and nutrient leaching, water stress at any stage

of growth can result in poor germination, decreased root expansion, and lower yields (Singh & Singh, 2017). However, poor nitrogen management can cause either too much vegetative growth at the expense of root development or a nutrient shortage that results in stunted growth and pale leaves (Shrestha & Thapa, 2018).

Consequently, the combined effects of nitrogen management and irrigation are essential for maximizing radish yield and growth. While appropriate nitrogen availability guarantees effective photosynthetic activity and balanced biomass allocation, enough irrigation improves nutrient uptake and root development (Rahman *et al.*, 2020). According to a number of research, radish roots with an ideal nitrogen dosage and moderate watering increase in length, diameter, and marketable yield (Ali *et al.*, 2021; Haque *et al.*, 2023). However, soil texture, climate, and cultivar traits all affect the ideal amounts of nitrogen and irrigation (Jat *et al.*, 2018). The requirement for site-specific irrigation and nitrogen regime adjustment to support sustainable radish growth is highlighted by this diversity.

In addition to affecting yield, the mismanagement of irrigation and nitrogen inputs can have serious environmental implications. Excess irrigation and nitrogen application can lead to nutrient leaching, groundwater contamination, soil salinity, and increased emissions of nitrous oxide, a potent greenhouse gas (Singh *et al.*, 2020; FAO, 2021). In order to increase productivity, water-use efficiency (WUE), nitrogen-use efficiency (NUE), and the general sustainability of production systems, it is crucial to strategically optimize these inputs. Reducing waste, lowering production costs, and minimizing environmental degradation are all possible with integrated management strategies that match nitrogen demand with water supply (Kumar & Yadav, 2020).

Despite substantial research on irrigation and nitrogen effects independently, their interactive influence on radish growth and yield has received comparatively limited attention. The majority of research has concentrated on single-factor optimization rather than the combination or synergistic impacts of nitrogen and irrigation on yield performance and resource usage efficiency. Therefore, to create an effective and long-lasting management plan suited to the regional agro-ecological circumstances, a thorough assessment of the irrigation–nitrogen interaction is required. In this context, the present study was undertaken to evaluate the combined effects of different irrigation and nitrogen levels on radish growth, yield attributes, and resource-use efficiency. The objectives were: (i) to determine the optimal combination of irrigation and nitrogen for maximizing root yield and quality; (ii) to assess water- and nitrogen-use efficiencies under various management regimes; and (iii) to propose a strategic management framework for sustainable and profitable radish cultivation.

METHODOLOGY

Experimental Site and Climate

The experiment was conducted at the research farm of

the Gazipur Agricultural University, Salna, Gazipur, Bangladesh, during the period from 25th November 2019 to 4th February 2020. The experimental site is located within the Madhupur Tract, classified as Agro-Ecological Zone (AEZ) 28, at an elevation of 8.4 meters above sea level, with geographic coordinate's 24.09°N latitude and 90.26°E longitude. The area experiences a subtropical climate characterized by distinct wet and dry seasons. The monsoon period extends from May to September, receiving heavy rainfall, whereas the rabi season (November to March) is generally dry with low and erratic precipitation, resulting in soil moisture stress. Despite an average annual rainfall of approximately 2200 mm, which exceeds the potential evapotranspiration (PET), rainfall during the rabi season remains inadequate, necessitating supplemental irrigation for successful crop production. During the experimental period, air temperature ranged from 12°C to 31°C, conditions favorable for winter vegetables such as radish (*Raphanus sativus* L.).

Soil Characteristics

The experimental soil belongs to the Salna series of the Shallow Red-Brown Terrace Soils, which is nearly equivalent to the *Ochrept* suborder in the USDA soil taxonomy. The soil exhibited a clay loam to clay texture with moderate bulk density, porosity, and water-holding capacity. Detailed physical properties, including soil texture, bulk density, porosity, and field capacity, were determined at different soil depths. The infiltration rate was measured using a Double Ring Infiltrometer, and infiltration data were analyzed using the Kostikov equation:

$$Z=Kt^a$$

Where Z represents cumulative infiltration (cm), t is time (h), and K and a are empirical constants.

Experimental Design and Treatments

The experiment was laid out in a split-plot design with three replications. The main plots were assigned to irrigation treatments, while the subplots were assigned to nitrogen levels. The treatments were as follows:

- **Irrigation treatments:**
 - I_1 : One irrigation at 15 days after germination (DAG)
 - I_2 : Two irrigations at 15 and 35 DAG
 - I_3 : Three irrigations at 15, 35, and 55 DAG
- **Nitrogen levels:**
 - N_0 : 0 kg N/ha (control)
 - N_1 : 100 kg N/ha
 - N_2 : 150 kg N/ha
 - N_3 : 200 kg N/ha

Each plot measured 2.8 m × 3.0 m (8.4 m²), with 1.0 m spacing between plots and 1.5 m between blocks. Each plot consisted of seven rows, and each row contained twelve plants, maintaining a 40 cm × 25 cm spacing between plants.

Crop Variety and Cultural Management

The radish variety 'Mino Early Long White' was used for the experiment. This variety is characterized by long, cylindrical, snow-white roots (30–45 cm in length) with a mild flavor and is well adapted to cool, dry conditions typical of the rabi season. Standard cultural practices, including land

preparation, seed sowing, thinning, weeding, and pest management, were uniformly applied to all experimental plots according to local agronomic recommendations.

Water Use Efficiency Measurement

Water use efficiency (WUE) was estimated following the method described by Rahman and Ahmed (1980). Total WUE was calculated as the ratio of total yield (kg/ha) to the total water used (cm). Irrigation WUE was determined from the difference in yield between irrigated and non-irrigated plots, adjusted for soil water depletion during the crop growth period.

Data Collection and Observations

The crop was harvested on 4th February 2019. From each plot, ten plants were randomly selected (excluding border plants) for data collection. The parameters recorded included:

- Plant height (cm)
- Number of leaves per plant
- Total leaf weight (g/plant)
- Largest leaf area (cm²)
- Gross plant weight (g/plant)
- Root length (cm)
- Root diameter (cm)
- Pithiness (visual rating)
- Marketable yield (t/ha)

Statistical Analysis

All data were statistically analyzed using the Statistics 10 software package. Analysis of variance (ANOVA) was conducted to test the significance of treatment effects, and mean comparisons were performed using Duncan’s New Multiple Range Test (DMRT) at the 5% level of significance, following the procedure outlined by Gomez and Gomez (1983).

Table 1. Soil physical properties of the experimental site

Properties	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Tex. Class	
Soil texture (%)	0-10	20.81	47.3	31.89	Clay loam	
	10-20	21.08	46.13	32.79	Clay loam	
	20-30	19.29	39.89	40.82	Clay	
Bulk density (g/cm³)	0-10	1.26 g/cm ³	(Mean value)			
	10-20	1.42 g/cm ³				1.36
	20-30	1.40 g/cm ³				
Particle density (g/cm³)	0-10	2.63 g/cm ³	2.64			
	10-20	2.63 g/cm ³				
	20-30	2.65 g/cm ³				
Porosity (%)	0-10	52.09%	48.42%			
	10-20	46.00%				
	20-30	47.17%				
Field capacity (%)	0-10	28.71%	28.5%			
	10-20	29.21%				
	20-30	27.58%				

Soil physical characteristics of the experimental site

The physical characteristics of the soil at the experimental site (Table 1) revealed that the topsoil (0–20 cm) had a clay loam texture, while the subsoil (20–30 cm)

transitioned into a clay texture. Such soils, with balanced proportions of sand, silt, and clay, are generally well-suited for radish cultivation due to their adequate water retention and aeration capacity. The bulk density ranged from 1.26 to 1.42 g/cm³, and the average porosity was 48.42%, indicating good soil structure for root development (Hillel, 2004). Field capacity values ranged between 27.58% and 29.21%, further confirming that the soil could effectively store and supply moisture during the radish growth period. These properties align with findings from Mandal *et al.*, (2020), who reported similar results in terrace soils under AEZ 28 conditions for winter vegetable production.

Table 2. Effects of nitrogen and irrigation regimes on plant growth characters of Radish plants

Treatment combinations	Plant height (cm)	Leaves number plant ⁻¹	Largest leaf size (cm ²)	Total leaf weight plant (g)	Plant gross weight (g)
I ₁ N ₀	16.4	17.8	143.6 d	53.6 c	297.5
I ₁ N ₁	19.9	17.1	174.4 bc	68.4 bc	405.1
I ₁ N ₂	20.2	16.8	187.0 bc	79.5 bc	473.0
I ₁ N ₃	22.8	18.1	201.6 cd	87.5 bc	479.4
I ₂ N ₀	19.4	18.3	173 cd	77.5 bc	409.4
I ₂ N ₁	23.7	19.8	257.9bc	113.6 bc	539.5
I ₂ N ₂	23.2	22.4	293.8 c	172.0 abc	638.1
I ₂ N ₃	25.7	22.2	331.3 ab	180.5 abc	721.5
I ₃ N ₀	20.4	16.1	187.1 cd	83.4 bc	429.3
I ₃ N ₁	24.5	20.8	261.1 bc	130.4 abc	6.23
I ₃ N ₂	24.9	22.6	312.0 ab	194.6 ab	746.9
I ₃ N ₃	29.8	24.2	400.0 a	248.4 a	920.5

[Note: I₁= Single irrigation at 15 days after seed germination, I₂ = Two irrigation at 15 and 35 days after seed germination, I₃ = Three irrigation at 15, 35 and 55 days after seed germination, N₀ = No nitrogen application, N₁ = Application of N at the rate of 100 kg/ha, N₂ = Application of N at the rate of 150 kg/ha, N₃ = Application of N at the rate of 200 kg/ha]

Effects of nitrogen and irrigation regimes on growth traits of Radish plants

Plant height increased with higher nitrogen levels and more frequent irrigation (Table 2). The tallest plants (29.8 cm) were observed under I₃N₃ (three irrigations + 200 kg N/ha). However, the number of leaves per plant did not significantly differ across treatments, indicating that nitrogen and water primarily influenced elongation rather than leaf production (Table 2). This observation is consistent with findings from Kumar *et al.*, (2014), who reported that nitrogen promotes vegetative growth through enhanced cell division and elongation, especially under favorable moisture conditions. Significant interaction effects were observed in total leaf weight and leaf size. The maximum total leaf weight (248.4 g) and the largest leaf size (400.0 cm²) were recorded in I₃N₃, suggesting that ample nitrogen and water availability boosted vegetative biomass (Table 2). These findings align with Patel *et al.*, (2015), who found that high nitrogen doses increase chlorophyll content and photosynthetic activity, leading to larger and heavier leaves. Plant gross weight was significantly influenced by both

irrigation and nitrogen. The maximum gross weight (920.5 g/plant) was noted in I₃N₃, followed by I₃N₂ (746.9 g). This pattern reflects cumulative gains in both foliage and root mass. The interaction is logical, as both water and nitrogen are critical for carbon assimilation and biomass allocation. Singh and Roy (2016) emphasized that nitrogen enhances carbohydrate production, which, when paired with adequate irrigation, results in greater translocation to the root zone.

Table 3. Effects of nitrogen and irrigation regimes on root yield and quality of Radish plants

Treatment combinations	Root Length (cm)	Root diameter (cm)	Root yield (t/ha)	Pithiness
I ₁ N ₀	29.2	12.2	24.3	Low
I ₁ N ₁	29.8	13.3	33.5	Medium
I ₁ N ₂	29.7	14.3	35.2	High
I ₁ N ₃	28.8	15.1	39.4	High
I ₂ N ₀	28.1	14.1	32.4	Low
I ₂ N ₁	30.4	16.0	42.9	Low
I ₂ N ₂	31.1	15.9	56.7	Medium
I ₂ N ₃	31.2	15.8	53.9	Medium
I ₃ N ₀	29.1	14.5	33.7	Low
I ₃ N ₁	32.6	16.6	49.6	Low
I ₃ N ₂	33.6	16.2	55.2	Medium
I ₃ N ₃	35.1	17.6	67.2	Medium

[Note: I₁ = Single irrigation at 15 days after seed germination, I₂ = Two irrigation at 15 and 35 days after seed germination, I₃ = Three irrigation at 15, 35 and 55 days after seed germination, N₀ = No nitrogen application, N₁ = Application of N at the rate of 100 kg/ha, N₂ = Application of N at the rate of 150 kg/ha, N₃ = Application of N at the rate of 200 kg/ha, ns=Non-significant]

Effects of nitrogen and irrigation regimes on root yield of Radish plants

Root length and diameter showed minor variations across treatments, with slightly higher values in the I₃ regime. The highest root length (33.6 cm) and diameter (17.6 cm) were observed in I₃N₂, suggesting that optimal water and moderate nitrogen enhanced root expansion (Table 3). Root size tends to plateau or slightly decrease at excessive nitrogen levels, as shown in Sharma *et al.*, (2017) likely due to imbalanced shoot-root growth ratios or excessive vegetative focus. The highest marketable root yield (67.2 t/ha) was recorded under I₃N₃, indicating that higher nitrogen and irrigation significantly improved root biomass (Table 3). Treatments with moderate irrigation and nitrogen, such as I₂N₁ (42.9 t/ha), also gave appreciable yields, reinforcing that moderate inputs can be efficient and sustainable were mentioned in Table 3. This trend supports Das *et al.*, (2013) who found that increasing nitrogen up to a threshold (often 150–200 kg/ha) improves root yields but beyond this can result in nutrient imbalance and quality loss.

Effects of nitrogen and irrigation regimes on root quality (pithiness) of Radish

Pithiness, a key quality concern in radish, was observed to be lowest under I₁ (single irrigation), increasing under higher

irrigation. Pithiness is associated with excessive vegetative growth and lignification, often resulting from over-irrigation and over-fertilization (Table 3). The I₃N₃ treatment, while high-yielding, showed medium pithiness, indicating a trade-off between quantity and quality (Table 3). Chhonkar *et al.*, (2007) emphasized that high water and nitrogen availability late in growth leads to spongy roots due to accelerated maturation and internal breakdown, reducing marketability. The interaction of irrigation and nitrogen significantly influences radish morphology, biomass, and yield. While I₃N₃ resulted in the highest yield and vegetative vigor, it also showed medium pithiness, indicating potential quality compromises. The I₂N₁ treatment, producing a balanced yield with low pithiness and efficient resource use, emerges as a practical and sustainable approach for radish cultivation in resource-limited environments was mentioned in Table 3.

Table 4. Total water use (TWU) of radish under different irrigation and nitrogen levels

Treatments	Soil water depletion (mm)	Water required for seedling establishment (mm)	Irrigation required (mm)	Effective rainfall (mm)	Total water use (mm)	Yield/unit water use (kg/ha/mm)	Yield/unit nitrogen use (kg/ha/kg)
I ₁ N ₀	28.22	15	23.06	5	71.28	340.91	0
I ₁ N ₁	28.31	15	25.0	5	73.31	456.96	335.0
I ₁ N ₂	30.74	15	25.45	5	76.19	462.00	235.0
I ₁ N ₃	34.02	15	26.49	5	80.51	485.65	196.5
I ₂ N ₀	23.69	15	60.38	5	104.07	311.33	0
I ₂ N ₁	23.97	15	61.17	5	105.14	408.02	429.0
I ₂ N ₂	24.36	15	64.57	5	108.93	520.52	378.0
I ₂ N ₃	24.81	15	71.13	5	115.94	468.29	269.5
I ₃ N ₀	4.26	15	97.12	5	121.38	277.64	0
I ₃ N ₁	7.00	15	100.34	5	127.34	388.72	495.0
I ₃ N ₂	7.42	15	100.42	5	127.84	431.79	368.0
I ₃ N ₃	8.82	15	108.53	5	137.35	489.26	336.0

[Note: I₁ = Single irrigation at 15 days after seed germination, I₂ = Two irrigation at 15 and 35 days after seed germination, I₃ = Three irrigation at 15, 35 and 55 days after seed germination, N₀ = No nitrogen application, N₁ = Application of N at the rate of 100 kg/ha, N₂ = Application of N at the rate of 150 kg/ha, N₃ = Application of N at the rate of 200 kg/ha, ns=Non-significant]

Total Water Use under Different Treatments

The total water use (TWU) of radish under varying irrigation and nitrogen treatments. The TWU increased with both irrigation frequency and nitrogen level (Table 4). Among the treatments, I₃N₃ (three irrigations with 200 kg N/ha) recorded the highest TWU of 137.35 mm, while the lowest TWU (71.28 mm) was observed under I₁N₀ (single irrigation with no nitrogen application). These results indicate a direct relationship between nitrogen application and water uptake, likely due to increased vegetative growth and evapotranspiration in well-fertilized plants (Shaheen *et al.*, 2013; Ahmed *et al.*, 2022). Water requirement for seedling establishment remained constant at 15 mm across treatments, while irrigation water demand varied depending on the number of irrigation events and soil moisture depletion. The soil water depletion was notably higher in the I₁ (single irrigation) treatment, reaching up to 34.02 mm under the I₁N₃ combination, suggesting that limited irrigation failed to replenish the soil moisture sufficiently, leading to higher crop water stress. Conversely, in the I₃ treatment, soil water depletion was lower (7.00–8.82 mm), indicating better moisture conservation and utilization. This implies that increasing irrigation frequency helped maintain soil moisture closer to field capacity, thus reducing stress and improving

water use efficiency, as supported by earlier work (Singh *et al.*, 2016; FAO, 2021).

Effect of Irrigation and Nitrogen on Water Dynamics

The study revealed significant interactions between irrigation and nitrogen application on water use patterns (Table 4). For instance, with increasing nitrogen levels, irrigation demand also increased, likely due to enhanced metabolic and transpiration processes in nitrogen-fed plants. Similar trends were observed by Islam *et al.*, (2020), who noted increased water consumption in radish with increasing nitrogen rates under controlled irrigation regimes. Interestingly, the effective rainfall remained constant at 5 mm, reinforcing the importance of supplemental irrigation during the rabi season when rainfall is minimal and irregular. This finding supports Karim and Egashira (1995), who emphasized the unreliability of winter rainfall in AEZ 28, necessitating strategic irrigation planning for root crops like radish.

Implications for Water Use Efficiency and Resource Optimization

While I₃N₃ provided the maximum water use, the efficiency of resource utilization may not always correlate with higher inputs (Table 4). Previous findings from the same study show that I₂N₁ (two irrigations and 100 kg N/ha) provided optimal yield with superior water and nitrogen use efficiency, making it a more sustainable and economically viable option for farmers (Sultana, 1997). This supports the concept that beyond a certain threshold, additional irrigation and nitrogen do not proportionally increase yield but may instead lead to resource wastage or environmental degradation (Zhang *et al.*, 2018; Jalota *et al.*, 2021).

CONCLUSION

The study demonstrated that irrigation and nitrogen levels significantly influence the growth, yield, and quality of radish (*Raphanus sativus* L.). The combination of three irrigations (15, 35, and 55 DAG) with 200 kg N/ha (I₃N₃) produced the highest yield (67.2 t/ha), though with moderate pithiness. In contrast, two irrigations combined with 100 kg N/ha (I₂N₁) provided a balanced outcome with high yield, low pithiness, and superior water- and nitrogen-use efficiencies. Therefore, I₂N₁ is recommended as the most efficient and sustainable management regime for radish cultivation. Further research under varying seasonal conditions could refine these thresholds for broader application.

Conflict of Interest

The author declares no conflict of interest.

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