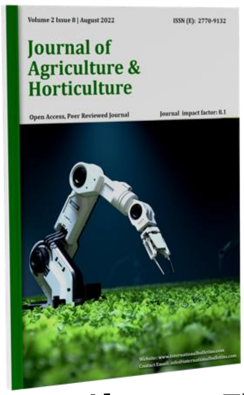

DEPENDENCE OF THE DURATION OF DEVELOPMENTAL PHASES OF WATERMELON VARIETIES ON IRRIGATION REGIMES AND MINERAL FERTILIZATION RATES

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Abstract: This study investigated the effect of irrigation regimes and mineral fertilization rates on the duration of developmental phases of watermelon (Citrullus lanatus) varieties under irrigated field conditions during the 2022–2024 growing seasons. The experiment was conducted using a two-factor design with four irrigation regimes based on limited field moisture capacity (60–70–65%, 65–75–70%, 70–80–75%, and 75–85–80% LFMC) and four mineral fertilization levels (control, $N_{100}P_{80}K_{40}$, $N_{120}P_{100}K_{50}$, and $N_{140}P_{120}K_{60}$ kg/ha). Two watermelon varieties, 'Shirin' and 'Sharq ne'mati', were evaluated. The results showed that the sowing–emergence phase was not affected by the tested factors, while the duration of later phenological stages varied significantly depending on irrigation and fertilization treatments. Optimal soil moisture combined with balanced mineral nutrition accelerated flowering and fruit formation while extending the active growth period. The irrigation regime of 70–80–75% LFMC combined with $N_{120}P_{100}K_{50}$ or $N_{140}P_{120}K_{60}$ ensured the most balanced phenological development. Varietal differences indicated higher growth potential of 'Shirin' and greater adaptability of 'Sharq ne'mati'. The findings highlight the importance of integrated water and nutrient management for regulating watermelon development and improving cultivation efficiency.

Keywords: watermelon, developmental phases, irrigation regime, mineral fertilization, phenology, limited field moisture capacity, varietal response.

1. Introduction

Watermelon (Citrullus lanatus) is one of the most important cucurbit crops cultivated widely in arid and semi-arid regions due to its high economic value and adaptability to warm climates. In recent years, increasing water scarcity and soil fertility degradation have necessitated the optimization of irrigation and mineral nutrition practices to ensure sustainable crop production.

The duration of developmental phases, including emergence, vegetative growth, flowering, fruit setting, and ripening, is strongly influenced by environmental and agronomic factors. Among these, irrigation regime and mineral fertilization play a decisive role in regulating plant growth rates, physiological processes, and phenological development.

Previous studies have demonstrated that maintaining optimal soil moisture levels within defined limits of field moisture capacity enhances root activity, nutrient uptake, and photosynthetic efficiency. Similarly, balanced application of nitrogen, phosphorus, and potassium accelerates vegetative growth and promotes timely transition to reproductive stages. However, deviations from optimal regimes may result in delayed flowering, uneven fruit development, and extended maturation periods.

Therefore, this study aims to evaluate the dependence of watermelon developmental phase duration on different irrigation regimes and mineral fertilization rates under field conditions.

2. Materials and Methods

2.1 Experimental Site and Climatic Conditions

The field experiment was conducted under irrigated agricultural conditions typical for arid and semi-arid regions. The soil of the experimental field was classified as light loam with moderate fertility and satisfactory water permeability. The climate of the study area is characterized by high air temperatures during the growing season and limited natural precipitation, making irrigation a decisive factor for watermelon cultivation.

2.2 Experimental Design and Treatments

The experiment was laid out as a two-factor field trial using a randomized block design with three replications. The experimental factors were as follows:

- Factor A – irrigation regimes based on limited field moisture capacity (LFMC), %
- Factor B – mineral fertilization rates, kg/ha

Two watermelon varieties were used as experimental material:

- 'Shirin'
- 'Sharq ne'mati'

Each experimental plot consisted of uniform plant density and standard agronomic practices, except for the tested irrigation and fertilization treatments.

2.3 Irrigation Regimes (Factor A)

Irrigation regimes were established according to pre-irrigation soil moisture levels expressed as a percentage of limited field moisture capacity (LFMC). The following irrigation treatments were applied:

- 60–70–65% LFMC
- 65–75–70% LFMC
- 70–80–75% LFMC
- 75–85–80% LFMC

Soil moisture content was determined gravimetrically before irrigation. Irrigation timing and water application rates were adjusted according to the phenological development stages of watermelon plants.

2.4 Mineral Fertilization Rates (Factor B)

Mineral fertilizers were applied at four levels:

- Control (without fertilizers)
- $N_{100}P_{80}K_{40}$ kg/ha
- $N_{120}P_{100}K_{50}$ kg/ha
- $N_{140}P_{120}K_{60}$ kg/ha

Nitrogen, phosphorus, and potassium fertilizers were applied in split doses: phosphorus and potassium were applied as a basal treatment before sowing, while nitrogen was applied partly before sowing and partly as top dressing during vegetative growth and flowering stages.

2.5 Phenological Observations

Phenological observations were conducted according to standard agricultural methodologies. The duration of developmental phases was recorded in days for each treatment combination. The following growth phases were observed:

- Sowing to emergence

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- Emergence to vine formation
- Vine formation to flowering
- Flowering to fruiting
- Fruiting to ripening
- Total growing period

Observations were carried out regularly, and each phenological stage was considered completed when at least 50% of plants in a plot reached the corresponding phase.

2.6 Data Collection and Statistical Analysis

The duration of each developmental phase was calculated as the number of days between successive phenological stages. Mean values were determined for each treatment and variety. Experimental data were processed using standard statistical methods, including analysis of variance (ANOVA), to assess the significance of irrigation regimes, mineral fertilization rates, and their interaction effects on the duration of watermelon developmental phases.

3. Results and Discussion

The results presented in Table 3.1 demonstrate a clear dependence of the duration of developmental phases of watermelon varieties on irrigation regimes and mineral fertilization rates under the conditions of the 2022 growing season.

The duration of individual phenological phases varied considerably depending on soil moisture levels and nutrient supply. In both studied varieties ('Shirin' and 'Sharq ne'mati'), the sowing–emergence period remained stable at 25 days across all treatments, indicating that early germination was not significantly influenced by irrigation or fertilization conditions.

However, subsequent growth stages showed pronounced differences. Under the lowest irrigation regime (60–70–65% LFMC) and without mineral fertilization, the duration of the "vine formation–flowering" phase was relatively short (9.8 days in 'Shirin' and 8.8 days in 'Sharq ne'mati'), but this was followed by an extended flowering–fruiting period, resulting in a longer total growing season.

Increasing mineral fertilization under the same irrigation regime led to a gradual extension of vegetative and reproductive phases. In particular, application of $N_{140}P_{120}K_{60}$ prolonged the "vine formation–flowering" and "flowering–fruiting" stages, indicating enhanced vegetative growth and improved physiological activity of plants.

Table 1. Dependence of the duration of the development phases of watermelon varieties on irrigation regimes and mineral nutrition standards, 2022 year

Options		Interphase periods, in days				
Factor A, % LFMC	Factor B, kg/ha	seedling age	"vine formation–flowering"	"flowering–fruiting"	"fruiting - ripening"	vegetation period
Shirin						
60...70...65	Control	25	9,8	8,9	26,8	70
	$N_{100}P_{80}K_{40}$	25	10,7	9,8	30,7	76
	$N_{120}P_{100}K_{50}$	25	12,9	10,9	33,0	82
	$N_{140}P_{120}K_{60}$	25	13,8	11,7	34,2	84
65...75...70	Control	25	10,8	9,9	29,0	74
	$N_{100}P_{80}K_{40}$	25	11,7	10,7	32,1	80

	$N_{120}P_{100}K_{50}$	25	13,9	11,7	33,8	85
	$N_{140}P_{120}K_{60}$	25	13,6	12,8	35,0	87
70...80...75	Control	25	11,9	9,7	30,7	78
	$N_{100}P_{80}K_{40}$	25	13,9	11,9	32,2	84
	$N_{120}P_{100}K_{50}$	25	14,5	12,6	34,1	87
	$N_{140}P_{120}K_{60}$	25	14,7	13,9	35,8	90
75...85...80	Control	25	11,8	9,7	31,0	78
	$N_{100}P_{80}K_{40}$	25	14,9	11,8	33,3	86
	$N_{120}P_{100}K_{50}$	25	14,9	12,6	36,5	89
	$N_{140}P_{120}K_{60}$	25	14,9	13,7	38,1	88
Sharq ne'mati						
60...70...65	Control	25	8,8	9,9	28,0	72
	$N_{100}P_{80}K_{40}$	25	11,7	10,9	31,2	79
	$N_{120}P_{100}K_{50}$	25	12,9	10,7	32,8	81
	$N_{140}P_{120}K_{60}$	25	12,6	11,8	34,1	83
65...75...70	Control	25	10,8	10,9	28,7	75
	$N_{100}P_{80}K_{40}$	25	12,9	10,7	31,5	80
	$N_{120}P_{100}K_{50}$	25	13,7	11,9	32,6	83
	$N_{140}P_{120}K_{60}$	25	13,8	12,8	33,7	85
70...80...75	Control	25	12,9	11,8	28,6	78
	$N_{100}P_{80}K_{40}$	25	14,8	11,9	32,0	84
	$N_{120}P_{100}K_{50}$	25	14,6	12,6	33,3	85
	$N_{140}P_{120}K_{60}$	25	13,9	13,7	35,1	87
75...85...80	Control	25	12,8	11,8	30,3	80
	$N_{100}P_{80}K_{40}$	25	14,9	11,9	34,0	86
	$N_{120}P_{100}K_{50}$	25	14,7	12,8	35,2	88
	$N_{140}P_{120}K_{60}$	25	13,7	13,8	36,1	89

The most favorable phenological dynamics were observed under the 70–80–75% LFMC irrigation regime. In this treatment, both varieties exhibited balanced development with a clear acceleration of flowering and fruit formation stages when combined with optimal mineral nutrition. For 'Shirin', the total growing period reached 90 days under $N_{140}P_{120}K_{60}$, while 'Sharq ne'mati' showed a comparable duration of 87 days.

These results indicate that moderate soil moisture combined with sufficient mineral supply creates optimal conditions for photosynthesis, assimilate accumulation, and timely transition from vegetative to generative development. In contrast, excessive irrigation (75–85–80% LFMC) did not further shorten the growth phases and, in some cases, slightly prolonged the total growing period, particularly under higher fertilizer rates.

Distinct varietal differences were observed in response to irrigation and fertilization. The variety 'Shirin' generally exhibited a longer total growing period compared to 'Sharq ne'mati' under similar treatment combinations. This suggests that 'Shirin' has a higher growth potential and responds more actively to improved moisture and nutrient availability.

On the other hand, 'Sharq ne'mati' demonstrated relatively stable phenological development under varying conditions, indicating higher adaptability to changes in irrigation regimes.

The interaction between irrigation regimes and mineral fertilization played a decisive role in regulating the duration of developmental phases. Balanced fertilization significantly enhanced the positive effect of optimal irrigation, while insufficient nutrient supply limited the benefits of improved soil moisture.

Overall, the combination of 70–80–75% LFMC irrigation with $N_{120}P_{100}K_{50}$ or $N_{140}P_{120}K_{60}$ fertilization proved to be the most effective in optimizing phenological development and ensuring a harmonized growth cycle of watermelon plants.

The data presented in Table 3.2 indicate that in 2023 the duration of developmental phases of watermelon varieties was strongly influenced by irrigation regimes and mineral fertilization rates. Similar to the previous year, the sowing–emergence period remained constant at 25 days across all treatments and varieties, confirming that early plant establishment was not affected by the tested agronomic factors.

In contrast, subsequent phenological stages showed clear variability. Under the lowest irrigation regime (60–70–65% LFMC) without mineral fertilization, both varieties exhibited relatively shorter vine development but longer fruit ripening periods, resulting in an overall extension of the growing season. This trend suggests that moisture and nutrient limitations slowed physiological processes during later growth stages.

The application of mineral fertilizers significantly influenced the duration of developmental phases. With increasing fertilizer rates from $N_{100}P_{80}K_{40}$ to $N_{140}P_{120}K_{60}$, the duration of the “vine formation–flowering” and “flowering–fruting” phases gradually increased in both varieties.

For the ‘Shirin’ variety, under the 70–80–75% LFMC irrigation regime, the total growing period increased from 79 days in the unfertilized control to 91 days under $N_{140}P_{120}K_{60}$. A similar pattern was observed in ‘Sharq ne’mati’, where the growing season extended from 80 to 89 days under the same treatment. This indicates that enhanced mineral nutrition promoted more intensive vegetative and generative development, prolonging the active growth period.

Among the tested irrigation regimes, 70–80–75% LFMC proved to be the most favorable for regulating phenological development in 2023. Under this regime, both varieties showed harmonized growth, timely flowering, and extended fruit development phases, which are essential for yield formation and fruit quality improvement.

Further increases in irrigation intensity (75–85–80% LFMC) did not result in a proportional acceleration of development. In some cases, excessive moisture slightly prolonged the total growing period, particularly when combined with high fertilizer rates, indicating reduced efficiency of water use.

Distinct varietal differences were observed in response to irrigation and fertilization. The ‘Shirin’ variety consistently exhibited a longer growing period than ‘Sharq ne’mati’ across most treatment combinations. In 2023, the maximum growing period of ‘Shirin’ reached 93 days under 75–85–80% LFMC combined with $N_{140}P_{120}K_{60}$, while ‘Sharq ne’mati’ reached 90 days under the same conditions.

These results suggest that ‘Shirin’ has a higher growth potential and stronger responsiveness to improved moisture and nutrient availability, whereas ‘Sharq ne’mati’ demonstrates relatively greater stability under varying environmental conditions.

Compared with 2022, the 2023 growing season showed a general tendency toward slightly longer phenological phases in both varieties. This may be attributed to interannual climatic variability, particularly temperature and moisture conditions, which influenced plant growth dynamics. Nevertheless, the overall trends in response to irrigation regimes and mineral fertilization remained consistent across years.

Table 2. Dependence of the duration of the development phases of watermelon varieties on irrigation regimes and mineral nutrition standards, 2023 year.

Options		Interphase periods, in days				
Factor A, % LFMC	Factor B, kg/ha	Seedling age	"vine formation–flowering"	"flowering–fruiting"	"fruiting - ripening"	Vegetation period
Shirin						
60...70...65	Control	25	10	9	28	72
	$N_{100}P_{80}K_{40}$	25	11	10	32	78
	$N_{120}P_{100}K_{50}$	25	13	11	34	83
	$N_{140}P_{120}K_{60}$	25	14	12	35	86
65...75...70	Control	25	11	10	30	76
	$N_{100}P_{80}K_{40}$	25	12	11	33	81
	$N_{120}P_{100}K_{50}$	25	14	12	35	86
	$N_{140}P_{120}K_{60}$	25	14	13	36	88
70...80...75	Control	25	12	10	32	79
	$N_{100}P_{80}K_{40}$	25	14	12	34	85
	$N_{120}P_{100}K_{50}$	25	15	13	35	88
	$N_{140}P_{120}K_{60}$	25	15	14	37	91
75...85...80	Control	25	12	10	33	80
	$N_{100}P_{80}K_{40}$	25	15	12	35	87
	$N_{120}P_{100}K_{50}$	25	15	13	37	90
	$N_{140}P_{120}K_{60}$	25	15	14	39	93
Sharq ne'mati						
60...70...65	Control	25	9	10	29	73
	$N_{100}P_{80}K_{40}$	25	12	11	33	81
	$N_{120}P_{100}K_{50}$	25	13	11	34	83
	$N_{140}P_{120}K_{60}$	25	13	12	35	85
65...75...70	Control	25	11	11	30	77
	$N_{100}P_{80}K_{40}$	25	13	11	33	82
	$N_{120}P_{100}K_{50}$	25	14	12	34	85
	$N_{140}P_{120}K_{60}$	25	14	13	35	87
70...80...75	Control	25	13	12	30	80
	$N_{100}P_{80}K_{40}$	25	15	12	33	85
	$N_{120}P_{100}K_{50}$	25	15	13	34	87
	$N_{140}P_{120}K_{60}$	25	14	14	36	89
75...85...80	Control	25	13	12	32	82
	$N_{100}P_{80}K_{40}$	25	15	12	35	87
	$N_{120}P_{100}K_{50}$	25	15	13	36	89
	$N_{140}P_{120}K_{60}$	25	14	14	37	90

Table 3. Dependence of the duration of the development phases of watermelon varieties on irrigation regimes and mineral nutrition standards, 2024 year.

Options		Interphase periods, in days				
Factor A, % LFMC	Factor B, kg/ha	Seedling age	"vine formation–flowering"	"flowering–fruiting"	"fruiting - ripening"	Vegetation period
Shirin						
60...70...65	Control	25	10,2	9,1	29,2	74
	$N_{100}P_{80}K_{40}$	25	11,3	10,2	33,3	80
	$N_{120}P_{100}K_{50}$	25	13,1	11,1	35,0	84
	$N_{140}P_{120}K_{60}$	25	14,2	12,3	35,8	87
65...75...70	Control	25	11,2	10,1	31,0	77
	$N_{100}P_{80}K_{40}$	25	12,3	11,1	33,9	82
	$N_{120}P_{100}K_{50}$	25	14,1	12,3	36,2	88
	$N_{140}P_{120}K_{60}$	25	14,4	13,2	37,0	90
70...80...75	Control	25	12,1	10,3	33,3	81
	$N_{100}P_{80}K_{40}$	25	14,1	12,1	35,8	87
	$N_{120}P_{100}K_{50}$	25	15,5	13,4	35,9	90
	$N_{140}P_{120}K_{60}$	25	15,3	14,1	38,2	93
75...85...80	Control	25	12,2	10,3	35,0	83
	$N_{100}P_{80}K_{40}$	25	15,1	12,2	36,7	89
	$N_{120}P_{100}K_{50}$	25	15,1	13,4	37,5	91
	$N_{140}P_{120}K_{60}$	25	15,1	14,3	39,9	94
Sharq ne'mati						
60...70...65	Control	25	9,2	10,1	30,0	74
	$N_{100}P_{80}K_{40}$	25	12,3	11,1	34,8	83
	$N_{120}P_{100}K_{50}$	25	13,1	11,3	35,2	85
	$N_{140}P_{120}K_{60}$	25	13,4	12,2	35,9	87
65...75...70	Control	25	11,2	11,1	31,3	79
	$N_{100}P_{80}K_{40}$	25	13,1	11,3	34,5	84
	$N_{120}P_{100}K_{50}$	25	14,3	12,1	35,4	87
	$N_{140}P_{120}K_{60}$	25	14,2	13,2	36,3	89
70...80...75	Control	25	13,1	12,2	31,4	82
	$N_{100}P_{80}K_{40}$	25	15,2	12,1	34,0	86
	$N_{120}P_{100}K_{50}$	25	15,4	13,4	34,7	88
	$N_{140}P_{120}K_{60}$	25	14,1	14,3	36,9	90
75...85...80	Control	25	13,2	12,2	33,7	84
	$N_{100}P_{80}K_{40}$	25	15,1	12,1	36,0	88
	$N_{120}P_{100}K_{50}$	25	15,3	13,2	36,8	90
	$N_{140}P_{120}K_{60}$	25	14,3	14,2	37,9	91

The results obtained in 2024 (Table 3) further confirm the strong influence of irrigation regimes and mineral fertilization rates on the duration of watermelon developmental phases. As in previous years, the sowing–emergence period remained unchanged at 25 days in all treatments and varieties, indicating uniform seed germination and stable early establishment under field conditions.

Significant differences were observed in subsequent phenological phases. Under the lowest irrigation regime (60–70–65% LFMC) and without mineral fertilization, both 'Shirin' and 'Sharq ne'mati' varieties exhibited shortened vegetative development but extended fruit ripening periods, resulting in relatively shorter overall growth cycles compared to fertilized treatments.

An increase in mineral fertilization rates led to a consistent extension of vegetative and generative phases in both varieties. For 'Shirin', under the 70–80–75% LFMC regime, the duration of the "vine formation–flowering" phase increased from 12.1 days in the unfertilized control to 15.3 days under $N_{140}P_{120}K_{60}$. Simultaneously, the "flowering–fruit ripening" phase extended from 35.8 to 38.2 days, resulting in a total growing period of up to 93 days.

A similar trend was observed in 'Sharq ne'mati', where enhanced mineral nutrition under optimal irrigation increased the total growing period from 82 days (control) to 90–91 days under $N_{140}P_{120}K_{60}$. These results indicate that improved nutrient availability stimulated physiological activity, assimilate accumulation, and prolonged active growth.

Among the tested irrigation regimes, 70–80–75% LFMC again proved to be the most effective in ensuring balanced phenological development. Under this regime, both varieties demonstrated harmonized growth, timely flowering, and prolonged fruit development, which are essential for yield formation and fruit quality enhancement.

Further increases in irrigation intensity (75–85–80% LFMC) slightly prolonged the total growing period, particularly when combined with high fertilizer rates. This suggests that excessive moisture may reduce the efficiency of nutrient uptake and delay the completion of fruit ripening.

Clear varietal differences were observed in 2024. The 'Shirin' variety consistently showed a longer growing period and stronger responsiveness to increased irrigation and fertilization levels, reaching a maximum of 94 days under 75–85–80% LFMC combined with $N_{140}P_{120}K_{60}$.

In contrast, 'Sharq ne'mati' exhibited relatively shorter growth cycles and greater stability across treatments, indicating higher adaptability to varying soil moisture and nutrient conditions. This varietal behavior suggests different growth strategies and resource use efficiencies.

Compared with 2022 and 2023, the 2024 growing season was characterized by a general tendency toward slightly longer phenological phases, particularly under optimal and high-input treatments. This may be attributed to favorable climatic conditions, such as moderate temperatures and stable irrigation management, which supported prolonged plant activity and fruit development.

Nevertheless, the overall pattern of response to irrigation regimes and mineral fertilization remained consistent across all three years, confirming the reliability of the observed trends.

Conclusion

The three-year field study (2022–2024) clearly demonstrated that the duration of developmental phases of watermelon varieties is strongly dependent on irrigation regimes and mineral fertilization rates. The sowing–emergence phase remained constant across all treatments, indicating that early seedling establishment was not significantly influenced by variations in soil moisture or nutrient supply. In contrast, the subsequent phenological stages—vine development, flowering, fruit formation, and ripening—were highly responsive to the tested agronomic factors. Optimal irrigation regimes ensured favorable soil moisture conditions that enhanced physiological activity and promoted balanced plant development. Increased mineral fertilization rates contributed to prolonged vegetative and generative phases by improving nutrient availability and assimilate accumulation.

Among the tested irrigation regimes, maintaining soil moisture at 70–80–75% of limited field moisture capacity (LFMC) proved to be the most effective in regulating phenological development. This regime, combined with $N_{120}P_{100}K_{50}$ kg/ha, provided optimal conditions for harmonized growth, timely flowering, and extended fruit development.

Varietal differences were also evident. The 'Shirin' variety exhibited a longer growing period and higher responsiveness to improved moisture and nutrient supply, while 'Sharq ne'mati' showed greater stability and adaptability under varying irrigation conditions. Overall, the results confirm that scientifically justified irrigation and mineral nutrition management are key factors for optimizing watermelon growth dynamics and improving production efficiency under irrigated conditions.

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