# Integrated Nutrient Management and Salicylic acid Improves Grain Yield of Quinoa (*Chenopodium quinoa* Willd.) Subjected to Moisture Deficit Stress


## ABSTRACT

**Aims:**A field study was conducted to quantify the effect of moisture deficit stress at different critical stages of quinoa and different mitigation approaches were adopted in order to alleviate moisture deficit stress.

**Study design:**The experiment was designed in split plot design comprising of six main plots (water management) and four sub plots (stress mitigation approaches). The treatments in main plots viz., no irrigation at branching ($M_1$), at ear formation ($M_2$), flowering ($M_3$), grain filling ($M_4$) stages, irrigating at all four stages ($M_5$) and irrigating as and when required ($M_6$), and sub plot treatments viz., soil test-based fertilizer recommendation (STBFR) ($S_1$), STBFR+Salicylic acid spray at 100 ppm ($S_2$), STBFR+ rice straw mulching ($S_3$) and integrated nutrient management ($S_4$) were tested.

**Place and Duration of Study:**The experiment was conducted at the Instructional Farm, Odisha University of Agriculture and Technology, Bhubaneswar during *Rabi* 2021-22.

**Methodology:** Moisture deficit stress was imposed by withholding irrigation water and not irrigating in the defined period. The treatments in the subplots were imposed as per the schedule.

**Results:**Significantly taller plants, higher relative water content and grain yield were obtained when irrigation was given as and when required ($M_6$). In the other hand, the least grain yield was obtained in treatment where moisture deficit was imposed at branching stage of quinoa which was mainly attributed to greater reduction in relative water content and plant height. Among the different stress mitigation approaches, integrated nutrient management ($S_4$) was the best management practice followed by STBFR+Salicylic acid spray at 100 ppm ($S_2$).

**Conclusion:** The result indicated that branching stage is the most critical stage for irrigation in quinoa and integrated nutrient management could be the best approach under moisture deficit stress in quinoa among the other treatments.



**Keywords:** Quinoa, moisture deficit stress, salicylic acid, integrated nutrient management


## 1. INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) is a highly nutritious Andean seed crop which shows great potential to grow under a range of hostile environments. Quinoa is gaining popularity due to its high nutritional quality. It contains all the nine essential amino acids in well balanced amount. In India, it is cultivated in 440 hectares with an average yield of 1053 tonnes [1]. Climate change is leading to increased variability in weather patterns, including shifts in precipitation, temperature extremes, and prolonged drought periods. Moisture stress at critical stages of crop development is a significant challenge in agriculture, and its relevance has become even more pronounced in the context of climate change. These changes can disrupt the delicate balance required for optimal crop growth and development, often manifesting as moisture stress during critical growth stages. Moisture stress at critical stages, such as flowering and grain filling, can have devastating effects on crop yields. The losses due to moisture stress in quinoa is to a tune of 78.2% due to drought stress [2]. To mitigate the adverse impacts of moisture stress, several strategies have been developed. Salicylic acid, a naturally occurring plant hormone, has shown promise in enhancing crop tolerance to drought by triggering various stress-responsive mechanisms. Mulching, on the other hand, can reduce water evaporation from the soil, maintaining consistent moisture levels. Integrated nutrient management techniques, involving precise nutrient application at different growth stages, can enhance a crop's ability to withstand moisture stress and continue thriving. In this context, the combination of Salicylic acid application[3],mulching practices, and well-tailored integrated nutrient management (INM) offers a holistic approach to alleviating drought stress, improving crop resilience, and ensuring food security in an era marked by climate change-related challenges. This comprehensive strategy not only safeguards crop yields but also promotes sustainable agricultural practices in the face of an increasingly uncertain climate.

## 2. MATERIAL AND METHODS

A field experiment was carried out to know the effect of moisture deficit stress on the plant height, relative water content and grain yield of quinoa at Instructional Farm, OUAT, Bhubaneswar during *Rabi* of 2021-2022. The experiment was conducted in split plot design comprising of six main plots and four subplots with 24 treatment combinations with three replications. Main plots were no irrigation at branching stage ($M_1$), no irrigation at ear formation ($M_2$), no irrigation at flowering stage ($M_3$), no irrigation at flowering ($M_4$), irrigation at all four stages ($M_5$), irrigation as and when required ($M_6$) and sub plots are STBFR ($S_1$), STBFR+Salicylic acid @ 100 ppm ($S_2$), STBFR+Rice straw mulching @ 5 tonnes ha$^{-1}$ ($S_3$), and INM ($S_4$). The soil of the experimental site was low in organic carbon (4.9 kg ha$^{-1}$), low in nitrogen (248 kg ha$^{-1}$), medium in available phosphorus (41.2 kg ha$^{-1}$), medium in available potassium (263 kg ha$^{-1}$). Recommended dose of fertilizers (60:30:30 kg of N: $P_2O_5$: $K_2O$) were supplied to the crop. Moisture deficit stress was imposed at respective treatments ($M_1$, $M_2$, $M_3$, $M_4$) by withholding irrigation at respective stages and irrigation was provided thereafter to relieve the crop fromstress. Similarly, irrigation was given as per schedule for $M_5$ and $M_6$. The sub plot treatments were imposed as per the schedule.

Observations on plant height, relative water content were recorded at 20, 35, 50, and 65 days after sowing (DAS), and at harvest. The plant height was measured from the base of the plant to the tip of the upper leaf and was expressed in cm. The relative water content was recorded according formula given by [4] and expressed in per cent. The grain yield (kg ha$^{-1}$) was recorded after harvest of crop. The collected data were statistically analysed by standard analysis of variance technique for randomized complete block design as suggested by [5].

## 3. RESULT AND DISCUSSION

The plant height recorded at different days of observations is provided in Table 1. There was significant difference in the plant height recorded at different days of observations due to moisture deficit stress and different mitigation approaches. The plant height recorded at harvest in $M_6$ (120.5 cm) was significantly higher among the different water management practices. The shortest plant height was recorded when irrigation was withheld at branching stage (67 cm) which was statistically par with $M_2$ (no irrigation at ear formation stage) with an average plant height of 69.5 cm. Similarly, plants under INM practices ($S_4$)were significantly taller (99.2 cm) which was statistically at par with $S_2$ (STFBR+ Salicylic acid spray) (95.5cm). The shortest (87.5 cm) plant height was recorded in $S_1$ (STBFR) when compared to all other stress mitigation approaches.

**Table 1. Effect of different water management and stress mitigation approaches on the plant height (cm) of quinoa**

| **Water management** | **20 DAS** | **35 DAS** | **50 DAS** | **65 DAS** | **At harvest** |
|---|---|---|---|---|---|
| $M_1$: No irrigation at branching | 17.2 | 34.9 | 47.2 | 59.5 | 67.0 |
| $M_2$: No irrigation at ear formation | 16.7 | 35.7 | 49.2 | 62.3 | 69.5 |
| $M_3$: No irrigation at flowering | 17.8 | 41.6 | 60.5 | 74.6 | 83.9 |
| $M_4$: No irrigation at grain filling | 18.4 | 43.6 | 78.5 | 85.9 | 99.8 |
| $M_5$: Irrigation at all above four stages | 18.3 | 43.0 | 81.0 | 105.0 | 116.3 |
| $M_6$: Irrigation as and when required | 18.7 | 44.5 | 80.5 | 105.3 | 120.5 |
| SEm(±) | 0.62 | 1.46 | 2.57 | 3.29 | 1.25 |
| CD (5%) | 2.0 | 4.6 | 8.1 | 10.4 | 3.9 |
| **Stress mitigation approaches** | | | | | |
| $S_1$: STBFR | 17.3 | 37.1 | 60.2 | 77.9 | 87.5 |
| $S_2$: STBFR + Salicylic acid | 17.0 | 40.3 | 68.1 | 84.6 | 95.5 |
| $S_3$: STBFR + Rice straw mulching | 17.5 | 40.0 | 64.0 | 78.0 | 89.1 |
| $S_4$: INM (75% Inorganic + 25% organic) | 19.6 | 44.9 | 72.4 | 87.8 | 99.2 |
| SEm(±) | 0.45 | 0.80 | 1.34 | 1.51 | 1.78 |
| CD (5%) | 1.3 | 2.3 | 3.8 | 4.3 | 5.1 |

The plant height varied significantly across different water management and stress mitigation approaches. The treatment $M_6$ resulted in the tallest plants at harvest which was due to continuous supply of water as and when required. But, plants under water stress i.e., $M_1$ to $M_4$, recorded relatively shorter plants compared to $M_6$. A reduction in height of44.3% and 42.3% was noticed in $M_1$ and $M_2$ i.e., moisture deficit stress at branching stage and ear formation stage, respectively. The reduction was mainly due to moisture deficit stress subjected at early stage of crop which would have inhibited the plants to grow taller. Besides, the relative water content also reduced due to stress. The taller plants under $M_5$ and $M_6$ were due to continuous supply of moisture. Similar results were obtained by another worker [6].

The final plant height was influenced by different stress mitigation approaches. Significantly taller plants were observed when plants were subjected to INM and STBFR + application of Salicylic acid. The increase in plant height was 13.3% and 9.1% in $S_4$ and $S_2$, respectively over $S_1$ (STBFR). The increase in plant height was due to integrated nutrient management and application of Salicylic acid with STBFR. In INM, the farm yard manure that applied along with inorganic fertilisers could have promoted better growth of crop by improving the soil physical and chemical characteristics. Similarly, the application of Salicylic acid would have increased the plant height by working as a growth regulator under controlled irrigation as well as under moisture deficit stress. Similar results were obtained byanother worker[6].

The relative water content recorded at different days of observation (Table 2) differed significantly due to different water management practices and stress mitigation approaches. At 20 DAS, the RWC of plants did not vary significantly due to different water management practices. At 35 DAS, $M_1$ (no irrigation at branching stage) had recorded significantly lower RWC (63.8%) which was statistically at par with $M_2$ (no irrigation at ear formation) with average RWC values (64.3%). At 50 DAS, significantly lower (66.6%) RWC was recorded with $M_3$i.e., irrigation was not provided at flowering stage. But it was statistically similar with $M_1$ and $M_2$ too. At 65 DAS, the lowest (71.6%) value of RWC was recorded with $M_4$ (no irrigation at grain filling stage). At harvest, almost similar trend was noticed but $M_2$ recorded significantly higher value (60.5%) of RWC. On the other hand, among the different stress mitigation approaches, the treatment with INM recorded the higher relative water contents at all the days of observations except 20 and 35 DAS, where STFBR+ Salicylic acid spray recorded higher RWC. Treatment $S_1$ (STBFR) recorded significantly lower values of RWC at all days of observations.

**Table 2. Effect of different water management and stress mitigation approaches on the relative water content (%) of quinoa**

| **Water management** | **20 DAS** | **35 DAS** | **50 DAS** | **65 DAS** | **At harvest** |
|---|---|---|---|---|---|
| $M_1$: No irrigation at branching | 91.5 | 63.8 | 67.1 | 71.6 | 58.5 |
| $M_2$: No irrigation at ear formation | 91.9 | 64.3 | 67.7 | 72.0 | 60.5 |
| $M_3$: No irrigation at flowering | 93.2 | 94.4 | 66.6 | 71.8 | 55.8 |
| $M_4$: No irrigation at grain filling | 90.5 | 92.8 | 92.0 | 71.6 | 54.8 |
| $M_5$: Irrigation at all above four stages | 90.7 | 93.2 | 92.6 | 82.5 | 56.2 |
| $M_6$: Irrigation as and when required | 91.3 | 93.3 | 90.3 | 82.4 | 57.2 |
| SEm(±) | 1.60 | 1.74 | 1.20 | 1.12 | 0.84 |
| CD (5%) | NS | 5.5 | 3.8 | 3.5 | 2.7 |
| **Stress mitigation approaches** | | | | | |
| $S_1$: STBFR | 90.0 | 80.6 | 75.2 | 69.3 | 54.0 |
| $S_2$: STBFR + Salicylic acid | 91.8 | 85.9 | 82.1 | 79.6 | 58.3 |
| $S_3$: STBFR + Rice straw mulching | 91.5 | 83.3 | 77.9 | 72.0 | 55.6 |
| $S_4$: INM (75% Inorganic + 25% organic) | 92.7 | 84.7 | 82.4 | 80.4 | 60.8 |
| SEm(±) | 1.01 | 1.22 | 0.89 | 1.48 | 1.12 |
| CD (5%) | 0.03 | 3.5 | 2.5 | 4.2 | 3.2 |

The relative water content of quinoa leaves in different treatments was influenced by the supply of irrigation water. It is worthy to notice that, the moisture deficit stress at different crop growth stages had created loss of turgidity in plant leaves. As a result, there was decrement in the RWC. The reduction in the RWC was the maximum when stress was applied at branching and ear formation stage compared to flowering and grain filling stage. This might be due to susceptibility of those stages of crop to the moisture deficit stress condition which ultimately was reflected in terms of decrease in RWC of quinoa leaves. Susceptibility to moisture stress at early stage of crops is well documented by different workers [7,8].

Among the various mitigation approaches, the INM recorded higher values of RWC compared to other treatments. The integration of organic and inorganic form of nutrient would have reduced the susceptibility of crop during stress and increased tolerance to decrease in relative water content unlike other treatments except in $S_2$i.e., application of Salicylic acid along with STBFR during the crop period. Salicylic acid had a positive impact on the RWC of crop under water deficit stress. It could able to maintain the cellular turgidity by maintaining osmotic balance in the plant cell during drought stress. Similar results were obtained by various workers [3,9,10].

The grain yield significantly varied among the different water management and stress management approaches (Figure 1). The treatment with no irrigation at branching ($M_1$) recorded the lowest (589 kg $ha^{-1}$) grain yield and treatment $M_6$ recorded significantly higher grain yield (2631 kg $hs^{-1}$) among the various water management practices. Among the different stress mitigation tactics, $S_4$ (INM) could produce statistically higher (1663 kg $ha^{-1}$) grain yield which was followed by $S_2$ (STFBR+ Salicylic acid spray).

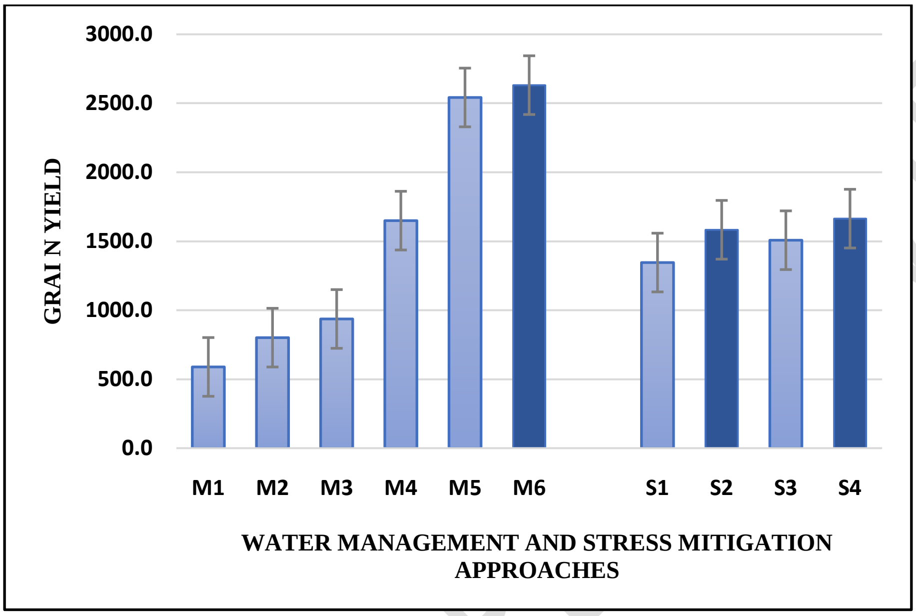


**Figure 1. Effect of different water management and stress mitigation approaches on the grain yield (kg $ha^{-1}$) of quinoa**

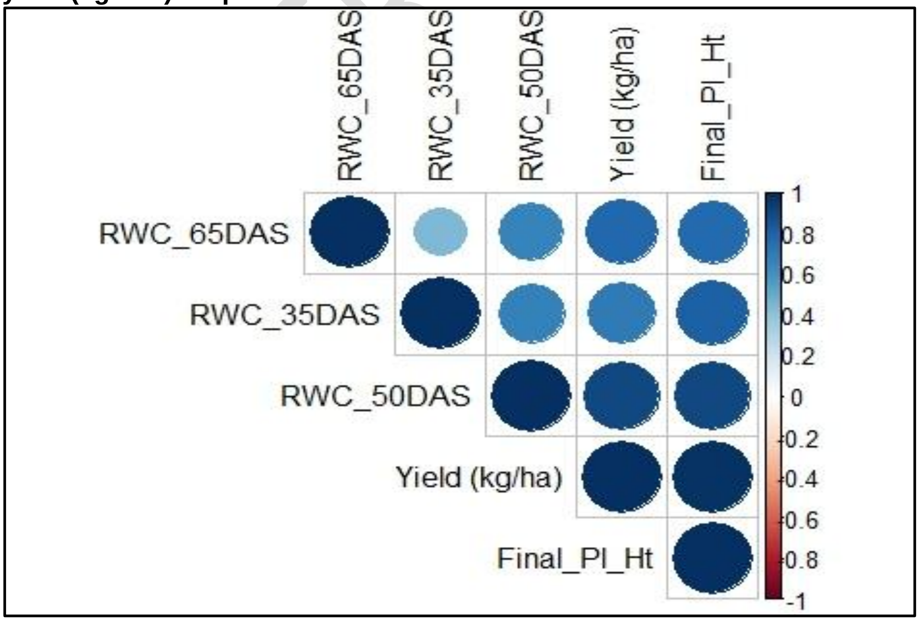


**Figure 2. Correlation heat matrix of different traits**

The grain yield is a function of growth attributes like plant height and cellular water content. The grain yield was decreased (77.6%, 69.5%, 64.3% and 37.3%, respectively) when drought stress was induced at different growth stages of crop i.e., branching, ear formation, flowering and grain filling stages, respectively. The decrease in grain yield was due to reduced plant height and reduced cell turgidity. Early stage of the crop is more susceptible to drought stress as no irrigation at early stage of growth could have reduced the sink formation capacity and ultimately leading to lesser grain yield [11,12]. There was a positive correlation between grain yield and plant height and relative water content at different stage of crop (Figure 2). In other hand, the increment in grain yield by following INM ($S_4$) and STBFR+ Salicylic acid ($S_2$) under drought stress and irrigated control was 23.6% and 17.6%, respectively over fully inorganic nutrient management ($S_1$). The beneficial aspect of Salicylic acid and INM on crop yield was reported by other researchers[13,14].

## 4. CONCLUSION

From the above experiment, it can be concluded that the effect of moisture deficit stress is detrimental with respect to plant height, relative water content and grain yield at different stages of growth in quinoa with more pronounced effect at branching and ear formation stage compared to other stages. Among the various stress mitigation approaches, following integrated nutrient management and application Salicylic acid with soil test-based fertilizer recommendation resulted in better yield influencing parameters over other two treatments.

## REFERENCES


1. Srinivasa Rao K. Sarikothapanta quinoa, Sakhi News, 10 on 11.08.2015.
2. Telahigue DC, Yahia LB, Aljane F, Belhouchett K, Toumi L. Grain yield, biomass productivity and water use efficiency in quinoa (*Chenopodium quinoa* Willd.) under drought stress. J of Scientific Agric. 2017;1:222-32.
3. Najafabadi MY, Ehsanzadeh P. Salicylic acid effects on osmoregulation and seed yield in drought-stressed sesame. Agron. J. 2017;109(4):1414-22. https://doi.org/10.2134/agronj2016.11.0655
4. Gomez KA and Gomez AA. Statistical procedures for agricultural research Vol. 2nd Ed. New Delhi, India: Wiley India Pvt Ltd. 2010.
5. Saddiq MS, Wang X, Iqbal S, Hafeez MB, Khan S, Raza A, Iqbal J, Maqbool MM, Fiaz S, Qazi MA, Bakhsh A. Effect of water stress on grain yield and physiological characters of quinoa genotypes. Agron. 2021;11(10):1934. https://doi.org/10.3390/agronomy11101934
6. Sun Y, Liu F, Bendevis M, Shabala S, Jacobsen SE. Sensitivity of two quinoa (*Chenopodium quinoa* Willd.) varieties to progressive drought stress. J. Agron. Crop Sci. 2014;200(1):12-23. https://doi.org/10.1111/jac.12042
7. Patnaik GP, Monisha V, Thavaprakaash N, Djanaguiraman M, Sachin S, Vikram K, Girwani T, Jeeva M, Monicaa M, Patnaik L, Behera B. Selenium Application Improves Drought Tolerance during Reproductive Phase of Rice. Sustainability. 2023; 15(3):2730.https://doi.org/10.3390/su15032730
8. Singh B, Usha K. Salicylic acid induced physiological and biochemical changes in wheat seedlings under water stress. Plant Growth Regul. 2003;39:137-41.https://doi.org/10.1023/A:1022556103536
9. Bandurska H, Stroi ski A. The effect of salicylic acid on barley response to water deficit. Acta Physiologiae Plantarum. 2005;27:379-86.https://doi.org/10.1007/s11738-005-0015-5
10. Salama AM, Seleem E, Abd El Salam R, Ghoniem A. Response of quinoa plant grown under drought stress to foliar application with salicylic acid, paclobutrazol and algae extract. J. Agric. Sci. 2021;3(2):87-104.https://doi.org/10.21608/sjas.2021.81529.1118
11. Patnaik GP, Thavaprakaash N, Djanaguiraman M. Effect of Period of Soil Moisture Stress at Panicle Initiation and Flowering Stages on Nutrient Uptake and Post-Harvest Soil Nutrient Status in Rice. Madras Agric. J. 2020 11;107(7-9):1-6.https://doi.org/10.29321/MAJ.2020.000377
12. Sachin S, Thavaprakaash N, Djanaguiraman M, Patnaik GP. Effect of induced moisture stress at critical stages on physiological traits and yield of rice (*Oryza sativa* L.). J. Agromet. 2023 25;25(2):268-73. https://doi.org/10.54386/jam.v25i2.2043

13. Patnaik, G.P., N. Thavaprakaash, M. Djanaguiraman. (2021). Effect of moisture stress at critical stages on growth and relative water content of rice (*Oryza sativa*). In Extended Summaries: 5th International Agronomy Congress, 2, 1037-1038.
14. Yang A, Akhtar SS, Amjad M, Iqbal S, Jacobsen SE. Growth and physiological responses of quinoa to drought and temperature stress. J. Agron. Crop Sci. 2016;202(6):445-53.https://doi.org/10.1111/jac.12167