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Quinoa (Chenopodium Quinoa Willd) cultivation in Semi-Arid Regions of Telangana

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Abstract:

The article's objective is to evaluate the Quinoa (Chenopodium Quinoa Willd) at different dates of sowing intervals and water management using a smart sensor in semi-arid regions of Telegana. The field experiment was conducted at Ghapur village, during Rabi 2018-19 with different spacings implemented. The research was designed according to a randomized complete block design. Water management is very important for quinoa cultivation in the initial 4 weeks of the crop. It is better to give irrigation by drip method by using smart sensors, which recorded the higher yield and extremely very low water utilization. The obtained data showed that the application of drip irrigation led to an improvement in the physical properties of the soil. The treatment T1 (Irrigation by drip method using smart agriculture sensors) was superior and gave the highest panicle weight, panicle length, and seed yield compared with the flatbed treatments. Two sowing dates were used that is 1st October 19 and 1st November 19. Quinoa showed greater growth, yield, and yield qualities on 1st October 19 when it was sown with 15 cm × 10 cm spacing. However, the highest RGR absorbed at 30 kg N/ha at 15 cm × 10 cm was found to be significant. The performance of quinoa in all experiments was assessed by measuring total seed yield, seed size, harvest index (HI), panicle height, and volumetric moisture content respectively.

Keywords:

Quinoa (Chenopodium Quinoa Willd.), Sowing Dates, Drip Irrigation, Smart Agricultural Sensor, Harvesting, Semi-Arid Region, Telegana

1. INTRODUCTION

Quinoa (Chenopodium quinoa Willd.) is a plant belonging to the Amaranthaceous Chenopodiaceae family. Although it is known that quinoa has been cultured for 5000 years and is indigenous to South America, the cultivation of the plant is common globally [1]. Quinoa is highly resistant to adverse environmental and climatic factors (Jacobsen, 2003) such as drought, salinity, poor soil, and frost and could be grown from the sea level up to an altitude of 4000 m, between -8 C° and 38 C° ambient temperatures [2]. Quinoa is mainly cultivated in Bolivia and Peru, and these countries are major producers and exporters of quinoa. It is now grown in several European countries including France, England, Sweden, Denmark, Holland, and Italy, as well as in China, India, Pakistan, New Zealand, Australia, Canada, and the United States [3]. It is cultivated in the world with an area of 126 thousand hectares with a production of 103 thousand tonnes. Bolivia in South America is the biggest producer of quinoa with 46 per cent of world production followed by Peru with 42 per cent and the United States of America with 6.3 per cent [4]. It can be successfully grown where environmental conditions are similar to those of the Andean region. Quinoa has been observed to have high salt tolerance and frost tolerance and can grow under extremely dry conditions including in drought-prone areas of the world. Therefore, it can successfully be grown in the diverse climatic conditions of India [5].

Quinoa is a new crop in India and can be successfully grown in the Himalayas and the plains of Northern India with reasonably high yields (Bhargava *et al*., 2006). In India, quinoa was cultivated in an area of 440 hectares with an average yield of 1053 tons (Srinivasa Rao, 2015) [6]. Since its Independence, India experienced the green revolution (rice & wheat), and the white revolution (milk) and still India is tops in chronic malnutrition. Very high per cent of the population was suffering from diabetes due to over-dependence on a few cereal foods (rice or wheat) (APARD, 2013-14) [7]. Quinoa is a good source of food with high nutritional and medicinal values especially amino acids, high-quality protein content, vitamins, minerals etc. are twice the normally consumed cereals. Undoubtedly, the choice of variety, as well as knowledge of the appropriate sowing and harvesting periods, are of great importance for profitable production in cultivation, in terms of achieving high yield and quality performances from the unit area [8]. Quinoa is generally cultivated for its seeds which are utilized as human food. Thus, a great majority of agronomic studies conducted on the plant include evaluations of seed performance. In addition to high nutritive value, adaptive properties such as resistance to high temperatures, soil salinity, poor soil quality, and resistance to water stress are mentioned as beneficial traits [9]. In arid and semi-arid conditions, quinoa can be successfully cultivated in marginal soils, indicating that quinoa is an unpredictable plant. Today, agriculture needs to increase production per unit area, despite the limited water resources [10]. To achieve the best results from the cultivation of each crop, careful and calculated management is required. Irrigation intervals are one of the most critical strategies that can improve water use efficiency. This can play a major role in the future diversification of the agriculture system in India [11]. Despite its wide adaptability, nutritional superiority, and commercial potential have remained untapped. Hence, an experiment was conducted entitled “Evaluation of Quinoa (Chenopodium quinoa willd.) at different dates of sowing and optimize plant geometry to introduce irrigation treatments in semi-arid regions of Telegana” during the rabi season, 2018-19.

2. LITERATURE SURVEY

Raam Shaker Mahmood *et al* [12] field experiment was carried out at the College of Agricultural Engineering Sciences - University of Baghdad- Iraq, where the research station is located at latitude 33.27°N and longitude 44.38°E during the agricultural season 2019-2020. The study aimed to investigate the physiological behaviour of genotypes and sowing dates in the growth and yield of quinoa in a factorial experiment using a randomized complete block design (RCBD) with three replicates. The first factor included two quinoa genotypes; the first one is QW as the white seed and QR as the red seed. On the other hand, the second factor included four sowing dates, which are 1/10, 15/10, 1/11, and 15/11, symbolized by T1, T2, T3, and T4, respectively. The results showed the superiority of the white seeds genotype by giving the highest average leaves number, leaf area, and head weight was 131.70 leaves, Plant-1, 31.90 $cm^2$and 21.68 gm/ head respectively.

Qasim Badr Idress Al-Yasiry *et al* [13] study was conducted at the Agricultural Research Station, College of Agriculture and Marshes, Dhi-Qar University, during the 2020/2021 season. This work aimed to determine the best irrigation method (drip, surface) with NPK fertilizer at levels (0, 50, and 100 kg do^{-1}) in some physical soil properties and growth indicators of quinoa crop growth and root distribution. The obtained data showed that the application of drip irrigation led to an improvement in the physical properties of the soil, as the bulk density decreased by 58.34%, the total porosity increased by 45.29%, and the saturated water conductivity was 36.71% compared with the irrigation system, which was reflected in the vegetative growth characteristics of the quinoa crop if the treatment T3 (drip irrigation and 100 kg do^{-1} NPK fertilizer) was superior and gave the highest plant height, leaf area, number of branches and dry weight compared with the rest of the treatments, while the surface irrigation superiority in the distribution of roots in the soil and the treatment of adding manure and 100 kg do^{-1} NPK fertilizer.

Magda R. Abdrabou *et al* [14] study was conducted in pots and growth chambers to investigate the response of quinoa to water salinity at the germination and vegetative growth stages. The linear relationship was used to assess the threshold value of water salinity in germination and vegetative growth stages. The study evaluated the effects of eleven salinity levels of irrigation water (0.4, 2, 4, 8, 12, 16, 20, 24, 26, 30, and 34 dsm^{-1}) and organic matter application (farmyard manure) on rats of 20 t ha^{-1}. Quinoa seeds were able to resist the high levels of water salinity in the germination stage, however, the seed germination percentage shows that the increase in irrigation water salinity decreases the final germination percentage. Quinoa yield and its components were significantly affected by increasing the salinity level, on the other hand, the addition of organic manure mitigated the salt stress. Quinoa plants lost 50% of the relative yield at a water salinity of 18 dsm^{-1} when no organic amendment was added, while the addition of organic manure increased the threshold value of water salinity up to 34 dsm^{-1}.

Hamza Bouras *et al* [15] study was to determine the positive effects of P on growth and productivity and understand the major leaf mineral nutrient content of quinoa (Chenopodium quinoa Willd.) cv. “ICBA Q5” irrigated with saline water. A field experiment applying three salinity (Electrical Conductivity, EC) levels of irrigation water (ECw = 5, 12, and 17 $dS \cdot m^{-1}$) and three P fertilizer rates (0, 60, and 70 kg of P_2O_5 ha^{-1}) were evaluated in a split-plot design with three replications. The experiment was conducted in Foum El Oued, South of Morocco on sandy loam soil during the period of March-July 2020. The results showed that irrigation with saline water significantly reduced the final dry biomass, seed yield, harvest index, and crop water productivity of quinoa; however, P application under saline conditions minimized the effect of salinity and improved the yield. The leaf Na^+ and K^+ content and Na^+/K^+ ratio increased with irrigation water salinity. However, the leaf content of Mg, Ca, Zn, and Fe decreased under high salinity.

Moola Ram *et al* [16] field experiment was conducted during the rabi (winter) season of 2018-19 at Agricultural Research Station, Mandor, Jodhpur. The soil of the experimental field was loamy sand in texture, slightly alkaline in reaction, poor in organic carbon (0.12%), low in available nitrogen (172 kg ha^{-1}) and phosphorus (24.2kg ha^{-1}) but medium in available potassium (332 kg ha^{-1}). Among 8 dates of sowing, the performance of quinoa in terms of some branches, panicle length, test weight and seed yield were significantly better when quinoa was sown on 15th November and 25th November. Among plant geometry, seed yield per hectare was significantly higher under narrow spacing (30 cm x 30 cm and 45 cm x 30 cm) when averaged based on per hectare due to the higher number of plants in narrow spacing. The crop took on average 140 to mature on all the dates of sowing. The findings of the study would be helpful in crop planning for the introduction and development of the package of practices of quinoa for crop diversification in the State.

Ariba Asif *et al* [17] evaluated the appropriate sowing time of ten elite lines of quinoa, already screened from USDA germplasm. Seeds of each line were sown in the experimental area at Square No. 22, Block No. 5, Directorate of Farm, University of Agriculture, Faisalabad, Pakistan on 15 November, 30 November and 15 December during the quinoa cultivation season of 2019-2020. Sowing time significantly affected the emergence percentage, days taken to anthesis, chlorophyll contents, sodium and potassium concentrations in leaf, plant height, stem diameter, number of leaves and leaf area, panicle length, grain yield and 1000-grain weight. Lines; PIA-922, PIA-924, PIA-928 and PIA-929 performed better under first sowing and produced higher grain yield as compared to other lines. Similarly, PIA-921, PIA-922, PIA-925 and PIA-932 produced maximum biomass and grain yield under the second sowing date while in the case of the third sowing date, PIA-926, PIA-928, PIA-930 and PIA-931 were observed more responsive regarding the growth and yield attributes. A diversified pattern of agronomic, growth and yield contributing attributes of quinoa lines was observed when cultivated under varying sowing dates.

Zulkadir *et al* [18] determine the adequate sowing date and row spacing for the Q-52 quinoa variety, which is known to be suitable for Mediterranean climate conditions, in Kahramanmaras province. For this purpose, three different row spacing distances (Namely, 20, 40 and 60 cm) were adopted with four sowing dates at 15-day intervals between March 15 and May. The study findings demonstrated that the plant emergence period was 5.0-21.0 DAS, the budding period was 19.0-38.0 DAS, 50% of the flowering period was found as 44.7-67.3 DAS, the Grain-Filling period (GF) was fixed as 3.2-31.0 DAS, the growth period was realized as 88.0-131.7 DAS, the GY was calculated as 9.8-323.9 kg da^{-1}, and biological yield (BY) was determined as 70.8-528.5 kg da^{-1}. Considering the effects of the temperatures on the growth and development of plants, it was concluded that it would be adequate to sow the crops during early or late April. The analysis of the ideal row spacing demonstrated that the highest grain and plant yield was obtained at 20 cm spacing.

Abdullah Öktem *et al* [19] determine the forage value of quinoa at the different sowing dates under semi-arid conditions. The research was conducted according to a randomized complete blocks design with three replicates in Harran plain conditions in 2016, Sanliurfa, Turkey. Q-52 Quinoa (Chenopodium quinoa Willd.) variety was used as plant material. In the study 9 different sowing dates were used such as 15 February, 1 March, 15 March, 1 April, 15 April, 1 May, 15 May, 1 June and 15 June. In the research plant height, stem diameter, number of branches per plant, biomass yield, dry forage yield and harvest index were investigated. As a result of the research, statistically, significant differences were seen between sowing dates at tested characteristics ($P \leq 0.01$). As a result of the research, statistically, significant differences were seen between sowing dates at tested characteristics ($P \leq 0.01$). Plant height ranged from 81.8 cm to 109.4 cm, stem diameter from 9.0 mm to 12.6 mm, and number of branches per plant from 10.3 to 12.7 number. Dry matter yield values were between 415.8 (15 February) and 546.88 kg da-1 (1 April).

Paul Chaibva *et al* [20] presented the 4 x 3 factorial experiment arranged in a completely randomised design (CRD) was carried out to establish the effects of irrigation frequencies and different soil types on germination and early growth of quinoa. Three soil types (sand, loam, and clay) and four irrigation frequencies (after every 1, 2, 3, and 4 days) were used. Measurements taken included days to 50% emergence, germination percentage, mean germination time, germination rate index, the coefficient velocity of germination, seedling height, final crop stand, and root density. Analysis of variance (ANOVA) was done using GenStat 18th Edition and mean separation was done using the Least Significant Difference (LSD) at a 5% significance level. There was an interaction between irrigation frequency and soil type on days to 50% emergence ($p<0.05$), germination percentage ($p<0.05$), germination rate index ($p<0.05$), seedling height ($p<0.05$), root length density ($p<0.05$), seedling crop stand ($p<0.05$). Sandy soil irrigated at 1-day intervals recorded the highest germination percentage (96.7%), while clay irrigated at 3-day intervals recorded the lowest (41.7%) final germination percentage respectively.

Rachid Fghire *et al* [21] field experiment was conducted during two successive seasons to investigate the effect of deficit irrigation on agronomic performance. Four treatments of deficit irrigation (100%, 50%, 33% ETc and rainfed) were applied to one variety in the first season and four genotypes (two varieties and two lines). The results were evaluated by measuring biomass and seed quinoa yield, water-use efficiency, harvest index, seed size and

1000 seeds weight. Results show that the implementation of deficit irrigation is an appropriate strategy to reduce the use of agricultural water and maintain relatively high yields. On the other hand, the results of the economic quality reflected by the size and weight of seed yield indicate that quinoa can be considered well-adapted to the conditions of water scarcity culture. According to agronomic parameters, the L143 line followed by line L11 showed a high potential for adaptation under the different treatments of stress, while the "Puno" variety presented the best performance under the favourable conditions of irrigation (100% ETc).

3. RESEARCH PROBLEM DEFINITION AND MOTIVATION

Future food security is dependent on increasing edible grains by 2% annually (Sajjad *et al.*, 2014), which has been restricted by the lack of water resources. Environmental hazards, additionally, limited agricultural production growth. Therefore, planting crops with less vulnerability to environmental stresses, especially during drought in developing countries, can remarkably improve the Irrigation Water Use Efficiency (IWUE) of the crop. In this regard, crops like quinoa (Chenopodium quinoa wild) have received worldwide attention due to being well-adapted to adverse environmental conditions such as drought, frost, and salinity. This plant grows in the mountainous areas of the Andes and Bolivia, Peru, and Ecuador, and has recently become a source of income for the poor-dwelling parts of these countries through exports to European countries and the Middle East. Drought mitigation and the increase of water productivity can play a substantial role in drought-prone semiarid and arid regions (Smith, 2000). Conversely, the sustainability of these methods always needs to be addressed.

Various studies revealed that seed performances were significantly affected by sowing and harvesting periods and, as a consequence, sowing or harvesting should be carried out at an early or late period. However, to obtain the desired yield and quality performances in the quinoa plant grown, it is necessary to establish appropriate sowing and harvesting periods. Although it has been shown that the sowing and harvesting periods of quinoa differ according to the regions, it can be said that few studies conducted on the subject are inadequate, since sowing and harvesting periods may significantly vary as to the ecological conditions of the cultivation regions.Water conservation is an upcoming issue for the future in India due to increased demands from a growing population. One of the areas with the largest potential for reducing water consumption is agriculture. It is very essential to measure it, control it, and conserve it, with the application of soil moisture sensors in agriculture to develop smart irrigation systems. There is no research has yet been conducted to introduce quinoa (Chenopodium quinoa wild) into soil moisture sensors. Hence it is high time to introduce crops like quinoa in Telangana to supplement the malnutrition faced by the country'speople in semi-arid regions.

4. PROPOSED RESEARCH METHODOLOGY

The majority of the farmers still use the typical apparatus for farming (sowing, irrigating, thinning and harvesting). Minor and small farmers are using much individual effort, which outcome in the waste of human hard work, time-wasting and low yields per capita labour force. However flourishing efforts are made by the Indian government to promote, the farmers to adopt new technically sound agricultural equipment. Planting crops with less vulnerability to environmental stresses, especially drought in semi-arid areas, can remarkably improve irrigation water use efficiency (IWUE). Therefore, in this study, planting quinoa (Chenopodium quinoa wild.) crop yield estimation by different sowing dates and water management with drip irrigationunder semi-arid conditions was investigated.

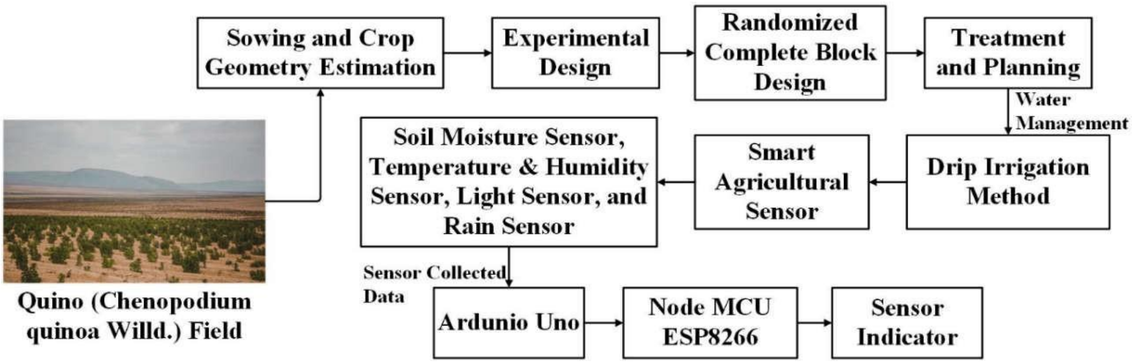

Figure 1: Flow Diagram of the Proposed Work

Figure 1 illustrates the flow diagram of the proposed work. A field experiment was conducted at Ghapur village during rabi 2018-19 to study the “Evaluation of Quinoa (Chenopodium quinoa Willd.) at different dates of sowing and varied crop geometry in semi-arid regions of Telangana.” Water management is very important for quinoa cultivation in the initial 4 weeks of the crop. It is better to give irrigation by drip method by using soil sensors. Consequently, the research was conducted on irrigation with different treatments and concluded that the drip method of irrigation with smart agriculture sensors recorded a higher yield and extremely very low water utilization. The performance of quinoa in all experiments was assessed by measuring total seed yield, seed size, harvest index (HI) and water use efficiency (WUE).

4.1 Materials and Methods

The field experiment was conducted at Ghapur village, during Rabi 2018-19 to evaluate Quinoa (Chenopodium quinoa Willd.) at different dates of sowing intervals at semi-arid regions of Telangana. The experiment was conducted under relatively more semi-arid conditions since lower precipitation was observed according to long-years averages in the cultivation period within which the research was conducted. Adequate amounts of soil samples (0-60 cm i.e. 96.2 mm.) were taken in both research years and according to the results of the analyses, it was found that soils were found to be non-saline, slightly alkaline, with mild lime content, low available phosphorus level and high potassium content. The soil is moderately blocky on the surface and sandy loam in texture slightly alkaline in reaction.

4.1.1 Experimental Design

The experiment was laid out according to a Randomized Complete Block Design (RCBD) in a split-plot arrangement with three replicates, and varieties assigned to the main plot and densities in the subplots. Each plot consisted of four rows with a length of 3 m and a width ranging from 1.20 to 2 m according to proposed densities. Quinoa seeds were sown by hand in rows of 35 cm on November 15, 2018, apart at a 2-3 cm of depth underground surface at a rate of 5 kg fed^{-1}. Seeds of quinoa were sown on one side of the drip-irrigated ridge in hills spaced 15 cm apart then thinned to two plants per hill. There were regular crop management practices to control pests, diseases, and weeds.

4.1.2 Soil Preparation

The experimental field was prepared as recommended in the experiment region and calcium super phosphate (50 kg P_2O_5) was applied during soil preparation at the rate of 100 fed-1. The preceding summer crop was millet during the rabi seasons. Well-drained soil particularly sandy loam is good to grow quinoa. It can thrive on alkaline soils (up to pH 9.0) and acid soils (up to pH 5.0) with a liberal application of lime. Soil should have high in organic matter with average nutrient contents.

Field preparation for the experiment consisted of deep pre-winter ploughing, followed by cultivation and harrowing in spring. Before sowing, the soil surface was carefully prepared and levelled to ensure uniform seed sowing to a depth of 0.5 cm and even plant emergence.

The methodology of the experiment did not provide fertilization before and during the cultivation. The experiments were established on soils rich in nutrients. In addition, the vegetation period of quinoa was a maximum of about 2 months and the expected biomass production was low; therefore, no fertilization was applied before the establishment of the experiment. Depending on moisture conditions, directly after sowing until emergence, the experiment was irrigated (especially on the summer sowing date), by sprinkling (2-3 times). No irrigation was applied after emergence. Depending on the necessity, weeds were removed mechanically and manually.

4.1.3 Treatment and Planning

The following treatment plan was followed to study the above-mentioned objectives:

- First sowing: 15 October 2019
- Second sowing: 30 October 2019
- Third sowing: 14November 2019
- Fourth sowing:29 November 2019

During the first sowing of quinoa on 15 November, the maximum, minimum and averagetemperatures were 20°C, 5℃ and 12.5℃ respectively. Relative humidity and rainfall were 68% and 0 mm respectively. On the second sowing date, the maximum, minimum and average temperatures were 16℃, 5.5℃ and 10.8℃, respectively, and relative humidity and rainfall were 89% and 0.4 mm respectively. In the case of the third sowing date, relative humidity and rainfall were recorded as 80% and 0 mm respectively while the maximum, minimum and average temperatures were observed as 20℃, 12℃ and 16℃ respectively. The number of seeds was counted at the time of sowing and the emerging seeds were counted daily for the final emergence percentage. The final emergence percentage was calculated according to the following formula;

□□□□□ □□□□□□□□□□ □□□□□□□□□□□ = (□□□□□ □□□□□□□ □□ □□□□□□□□ □□□□□) / (□□□□□ □□□□□□□ □□ □□□□□□ □□w□) × 100

To record the days taken to anthesis, five plants were tagged in each experimental unit and examined daily and data were recorded and averaged. Supplementary irrigation is found as the best field management strategy to combat water stress if there is access to irrigation water. On the other hand, Aqua-Crop model simulation results showed early sowing (sowing the crop 2-3 weeks earlier than the commonly sowing practice used by the farmers) as a good and easy strategy to combat the late season water stress with minimal cost and to increase the productivity of the crop in water-scarce areas.

4.2 Smart Agro System

Recent reports by the United Nations Food and Agriculture department estimated that in 2050 the world population will reach 9900 million. A major challenge will be to achieve the level of agricultural production necessary to meet the planned global demand for food and feed, fibre and fuel by 2050. This has faced major challenges in the past, but it must specifically target productivity. By 2050 address major barriers such as lack of resources, shortage of skilled labour, access to land and climate change. For 30 years location-based agricultural data collection has evolved rapidly with sensors and sensor devices, providing new examples of fact-based management decisions for accurate control. The sensor data collected from a single sensor does not provide relevant information that can be used to provide a fuller understandingof the situation. Consequently, sensor data collected from various sensors need to be added, and the collected data send through mobile applications to collect information related to environmental conditions.

4.2.1 Irrigation by Drip Method Using Smart Agriculture Sensors

Indian farming is mainly based on monsoon, which is doubtful, unpredictable and irregular which is why need for a suitable alternate irrigation system. Though India is 2nd leading irrigated nation in the world after China, only 1/3rd of the cropped region is under irrigation. Indian farmers still follow the traditional way of irrigation like surface level irrigation, and furrow irrigation. Determination of an appropriate location for monitoring soil water content (SWC) is a key factor in the efficient use of water in precision agriculture, however, the main challenge is the dynamic movement of water and root development in the soil profile. Overall, it is recommended to install smart soil sensors, at a horizontal and verticaldistance of 5~20 cm from the crop and a depth of 10~20 cm from the soil surface. This represents soil water condition in the root zone under a drip tape irrigation system.

Figure 2: Drip Irrigation System

The drip irrigation system can supply the required quantity of water to the crop on a daily or periodic basis. Drip irrigation delivers water near each plant through pipes (via flexible polyethene or 'black roll pipe') and a series of closely spaced emitters (drippers) (figure 2). Drip irrigation pipes or tubing are closed off with an end cap, allowing the water flow to pressurize through the length of the pipe. This creates the pressure that forces the water to drip (or spray) out from the emitter points. Depending on the crop, soil type, and production practices, drip irrigation lines may be laid inthe soil or buried. The flow rate of each dripper can be controlled from 1 to 4+ litres per hour. The use of drippers for the application of poor-quality water may give better crop yields due to an ability to maintain high soil moisture levels and replenish the water lost by ET daily. Drip irrigation is often preferred to sprinkler irrigation for species with a high sensitivity to leaf necrosis. However, because the diameters of the dripper openings are quite small, the evaporation of saline water at the end of the dripper opening can lead to clogging, which reduces (or completely stops) the discharge of irrigation water from individual drippers. Thus, drippers must be inspected periodically to prevent this problem. The sensors were installed at a distance of 0.10 m from the drip line. In the ET irrigation treatment, two of each type of sensor were installed to monitor soil water content. Results indicate that high-frequency irrigation events based on soil moisture sensor control can maintain crop yield and quality while reducing irrigation water applied. The drip Irrigation system saves nearly 40-80% of water compared to the traditional flood irrigation method.

4.2.2 Smart Agricultural Sensor

The proposed irrigation system is based on a smart sensor which consists of an ARM microcontroller, sensor unit and motor control unit. The sensor unit comprises a temperature sensor, humidity sensor, light sensor, soil moisture sensor and rain sensor which is used to monitor the environmental conditions by collecting the physical parameters such as temperature, humidity, moisture content, light intensity and rainfall of the agricultural field. An irrigation application is developed for determining the wetness of the soil. The water level sensor includes a cable, which on one end has one prong pushed inside the soil.

Soil Sensor

For the detection of the humidity of the soil, the model used an HL-69 soil hygrometer moisture sensor. The basic purpose of using the HL-69 soil hygrometer moisture sensor (figure 3) is to provide better readings than other soil moisture sensors. This sensor is used for real-time monitoring of the soil moisture of plants in a tunnel farm. The voltages of the sensor output change accordingly to the water content in the soil. There are some key factors of the HL-69 soil hygrometer sensor. If soil moisture is greater, then the output voltage decreases, but if the soil is dry, then the output voltage increases. The hygrometer soil moisture sensor provides an analog signal as an output which has to be converted to digital by Arduino. This sensor includes two pieces: one is an electronic board and another one is two pads that detect the water content. LM393 comparator chip is located on the electronic board. The electronic board of the HL-69 soil hygrometer sensor has a fixed bolt-hole used for easy installation. It contains two lights: red and green; the red light shows the power indicator, and the green light shows the digital switching output indicator.

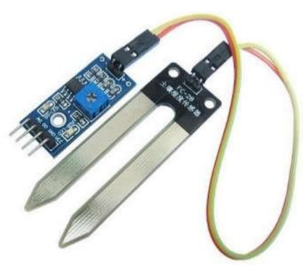

Figure 3: HL-69 Soil Hygrometer Moisture Sensor

Temperature Sensor

The temperature sensor is used to find the temperature of the atmosphere by converting the physical parameter into an electrical voltage. The output voltage produced by the temperature sensor is linearly proportional to the instantaneous temperature (in degrees Centigrade / Celsius). In the proposed irrigation system, The DHT22 sensor is a common temperature-humidity sensor that is used to determine temperature and humidity in the air. It operates between 4 V to 30 V and linearly produces an output voltage of 10 mV per. The DHT22 sensors are made up of two parts: a humidity sensor and a thermistor. DHT22 sensor (figure 4) is good for 0–50% temperature readings with 2–5% accuracy and a humidity range from 20 to 80% with 5% accuracy. The I/O voltage for the DHT22 sensor is between 3 V and 5 V. While requesting data, the maximum current used during conversion is 2.5 mA. DHT22 sensor contains 4 pins with 0.1 spacing between them. The body size of the DHT22 sensor is approximately 15.1 mm 25 mm 7.7 mm.

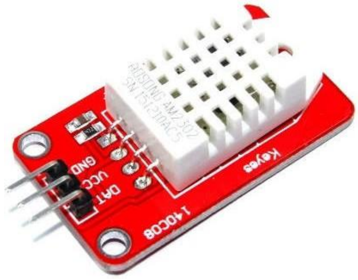

Figure 4: DHT22 Sensor

Light Sensor

BH1750 is a common digital light sensor that can determine the light intensity. BH1750 is a calibrated digital light sensor (figure 5), and it can measure even small traces of light and can convert it into a 16-digit numeric value. It is commonly used in mobile phones to exploit screen brightness based on environmental lighting. BH1750 measures the light intensity in the range of 0 to 65,535 lux (L). In the smart irrigation system for quinoa farming, the study used the H-resolution mode of the BH1750 sensor. The range of light intensity in the BH1750 sensor is 0 to 65,535 lux. The size (L*W) of the BH1750 sensor is approximately 3.2 cm*1.5 cm.

Figure 5: BH1750 Sensor

Rain Sensor

A rain sensor or rain switch is a switching device activated by rainfall. There are two main applications for rain sensors (figure 6). The first is a water conservation device connected to an automatic irrigation system that causes the system to shut down in the event of rainfall. The second is a device used to protect the interior of an automobile from rain and to support the automatic mode of windscreen wipers. Here PCB is used to collect the raindrops. When the rain falls on the board, then it creates a parallel resistance path to calculate through the operational amplifier. This sensor is a resistive dipole, and based on the moisture only it shows the resistance. This sensor module permits to gauge of moisture through analog output pins and it gives a digital output while the moisture threshold surpasses the rain sensor module.

Figure 6: PCB Sensor

All the data fetched by the flow sensor is transmitted to the Arduino Uno. Then Arduino Uno transmits this data for further process to the Node MCU ESP8266 using the serial communication pins of (RX, TX) of Arduino and node MCU. pH sensor connected to the Node MCU and pH values were determined. All sensor connected to the system fetches data and this data is then gathered at Node MCU from where it is transmitted to the server. As the irrigation process starts, data regarding the flow of water will be calculated say 1000ml and at the same time soil moisture content is also considered say 0%. This data will be sent to the sensor indicator. With these parameters, data received at the server will let the user know the status of the waterpump whether on or off. The threshold value is set for the water flow of 1000, if the value of the water flow is under the threshold value, the motor will be switched on. If the value exceeds a threshold value, the motor will be turned off automatically.

The physiological indices i.e., Crop Growth Rate (CGR), and Relative Growth Rate (RGR), were calculated at monthly intervals up to harvest, and yield attributes and yield were recorded. Growing degree days (GDD) were calculated based on the following formulae

$$\text{Growing degree days} = \sum_{i=1}^{n} \left(\frac{T_{max} + T_{min}}{2}\right) - T_b$$

Where, T_{max} is the daily maximum air temperature. T_{min} is the daily minimum air temperature, and T_b is the lowest temperature at which there is no growth (Base Temperature) n denotes the number of days between two stages of development. 15th October date of sowing showed optimum allocation of days to different phenological stages, i.e., vegetative (35 days), flowering (22 days), grain initiation to development (25 days) and grain maturity (13 days) and thus resulted in higher yield attributes and seed yield of quinoa with less vegetative growth (plant height, number of branches).

5. EXPERIMENTATION AND RESULTS DISCUSSION

Water management is very important for quinoa cultivation in the initial 20-30 days of the crop. If irrigation is not provided the crop will show wilting symptoms and result in lower yields. It is better to give irrigation by drip method if possible. The research was conducted on irrigation with different treatments and concluded that the drip method of irrigation recorded higher yield and yield attributes compared to other irrigation methods. To get optimum yield under irrigated conditions, 5-6 irrigations are sufficient, depending on the climatic conditions. If water is limited and available only for 4 irrigations; it may be applied at different growth stages.Panicle initiation, flowering, seed forming and seed hardening stages.

5.1 Statistical Analysis

Collected data regarding growth, yield and physiological and biochemical attributes were evaluated by using Analysis of Variance (ANOVA). Differences among years were tested by a two-sampled paired t-test, which indicated that the year effect was significant. Hence, data from both years were analyzed and interpreted separately. Two-way ANOVA was used to test the significance of the data. Data of dependent variables were tested for normality prior to ANOVA and variables with skewed distribution were normalized by the square root transformation technique. Treatments' means were compared by Tukey's honestly significant difference (HSD) post hoc test at a 95% confidence interval. Microsoft Excel was used for the graphical presentation of data.

5.1.1 Effect of Sowing Dates

Data in Table (1) presented the effect of sowing dates on all studied parameters i.e. plant height (cm), Sub: Spacing (cm), Number of panicles for the plant, Panicle length (cm), Panicle weight, Seed yield don't affect significantly by sowing dates in the growing seasons. The third planting date (1st October) had maximum values for all studied traits as compared with the rest dates during the growing seasons.

Table 1: Effects of Sowing Dates and Varied Crop Geometry

Sowing Dates	Sub: Spacing (cm)	Plant Height at Harvesting	Number Of Panicles for Plant	Panicle Length (cm)	Panicle Weight	Seed Yield (kg for ac)
1st October 19	15X10	112.0	11.0	19.5	670.0	809.37
1st October 19	30X10	120.0	12.0	21.2	500.0	728.43
1st November 19	15X10	121.0	14.0	22.7	480.0	651.54
1st November 19	30X10	119.0	12.0	23.3	420.0	590.84

The results showed that planting quinoa on the first of October was superior to other dates of sowing and met the environmental needs of the plant. It is worth concluding that planting quinoa on the first of October in various sun spacing is a good time to explore its yield potential under semi-arid conditions. In this study, there was a strong variation in panicle length and number of panicles under different sowing dates and among the lines. In general, among sowing dates, maximum panicle length was recorded as quinoa sown earlier as compared to other sowing dates. Additionally, lines also have a significant impact on panicle length. Meanwhile, a maximum number of panicles were reported for the first sowing. However, lowered panicle numbers were recorded under the third sowing date. In addition to sowing dates, lines also had a significant impact on some panicles. The maximum panicle length during the early growthof quinoa was mainly due to the optimal weather condition. The increase in temperature at lateral growth stages can cause a severe reduction in yield and yield attributes of quinoa.

The average plant height (cm) was measured from ground level to the panicle tip on the main stem at physiological maturity. The panicles were counted on five tagged plants in the centre of each plot and then averaged as the number of panicles plant^{-1}. The length of the main panicle on five tagged plants was recorded and averaged as the main panicle length (cm). The biological yield was recorded by harvesting the whole plot. The harvested samples were dried in the sun for 7 days and the weight per plot was converted to kg ha^{-1}. A thousand grain's weight was recorded by counting 1000 quinoa seeds from each plot and then weighing (g). Grain yield was recorded by threshing the plants harvested for biomass yield and weighed and then converted into grain yield (kg ha^{-1}). The harvest index was determined as the ratio of grain yield to biological yield and expressed in percentage. Abdullah Öktem *et al.*, 2021 [19] determine the forage value of quinoa at the different sowing dates under semi-arid conditions. The highest biomass yield was obtained onthe 1 April sowing date with 1751.40 kg da^{-1} whereas the lowest biomass yield was seen on June 15 sowing date with 1295.28 kg da^{-1}. Amir Hamzaa *et al*., 2021 [22] revealed that quinoa sown on 14 November produced significantly higher panicle length (19.2 cm), 1000-grains weight (2.9 g) and grain yield (2063 kg ha^{-1}) compared with other sowing dates. Raam Shaker Mahmood *et al*., 2022 [12] showed that the second sowing date, 15/10, was exceeded by giving the highest plant height, several branches per plant, leaf area, chlorophyll content, and heads weight, which reached 95.50 cm and 17.79 branches.

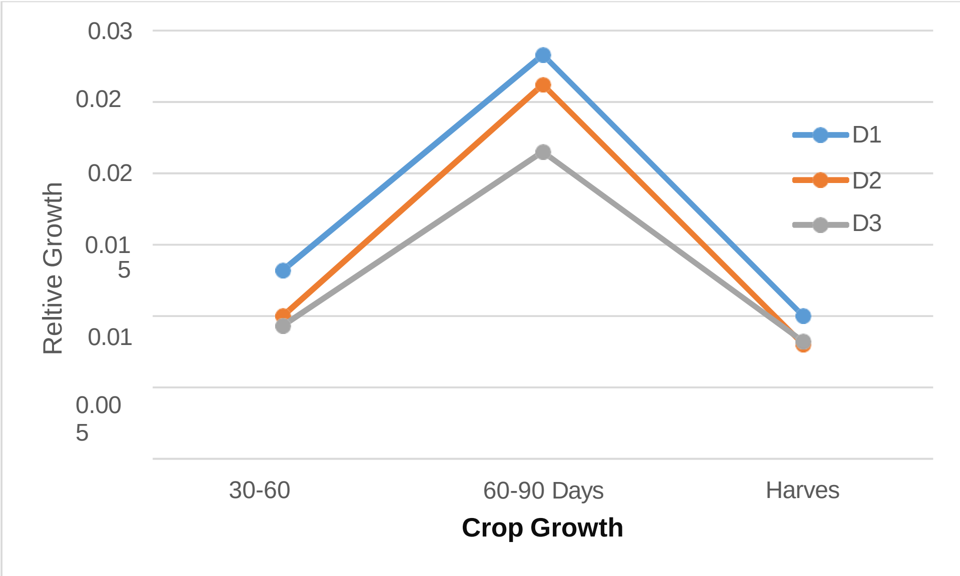

Figure 7: Relative Crop Growth Rate

The relative growth rate is a measure of the rate of dry matter increase per unit of time (figure 7). The RGR was low at the early phase of growth and increased between 30-60 DAS and again decreased maturity. October 15th date of sowing maintained higher RGR at 30-60 DAS, 60-90 DAS and 90 DAS-harvest growth stages and superior over the 1st November and 16th November dates of sowing. The relative growth rate was influenced by various levels of crop geometries at different growth periods. The higher RGR was achieved under wider 60 × 10 cm spacing compared to closer 15 × 10 cm spacing but the difference between the geometries was non-significant at 90 DAS- harvest period of the crop. However, the highest RGR was observed at 30-60 DAS under 15 × 10 cm and at 60-90 DAS under wider 60 × 10 cm spacing superior to other crop geometries. This might be due to the better performance of the individual plant in terms of dry matter production under wider spacing because of the utilization of available resources such as sunlight, water, nutrient and space which made a higher relative growth rate under wider spacing compared to narrow spacing.

Table 2: Irrigation Treatment with Drip with Sensor and Flatbed Methods

		Water Consumption Utilization	**Number Of Panicles**	**Panicle Length (cm)**	**Panicle Weight**	**Seed yield (kg for ac)**

			for Plant			
T1	Irrigation by drip method using smart agriculture sensors and need basis based on system sensor indication	Extremely Very low	12.0	19.5	680.0	820.80
T2	Irrigation by drip method weekly one through the crop growth	Low	11.0	21.2	505.0	728.43
T3	Irrigation by drip method once two weeks through the crop growth	Very low	10	20.2	550.0	740.00
T4	Irrigation by flatbed surface method weekly once through the crop growth	High	14.0	22.7	480.0	651.54
T5	Irrigation by flatbed surface method once two weeks through the crop growth	High	12.0	23.3	420.0	590.84

Yield attributes, water consumption utilization, number of panicles for the plant, panicle length, and grain and seed yield of quinoa were significantly influenced by different irrigation scheduling treatments (Table 2). Yield attributes like the number of panicle plants (12), length of panicle (19.5 cm) and 820.80 seed yield were higher in crops irrigated at drip method using a smart sensor (T1). Here the water consumption is extremely very low. Followed by drip irrigation in weekly one through the crop growth period (T2) seed yield was

728.43 kg for ac with low water consumption. Further, irrigation by drip method once in two weeks through the crop growth at grain filling stage (T3), the yield attributes like the number of panicle plants (10), length of panicles (20.2), panicle weight (550) and seed yield is of 740 kg for ac. For T3 the status of water consumption is very low when compared to T2. Irrigation by flatbed in flowering stage (T4) once through the crop growth water consumption utilization is high with seed yield of 651.54 kg. At flowering, T4 recorded a higher plant height (107.8 cm). Lower plant height was observed under surface irrigation. Finally, for T5, irrigation by flatbed once in two weeks yieldsa panicle height of 23.3 with a production of 590.84. The results indicated that the plant height of quinoa increased progressively with the advancement of crop age up to harvest, irrespective of the treatments. Stress-free conditions at the initial stages of the crop might be the cause for an increment in the plant height in superior treatments. Similar results were presented by Ramesh *et al*., (2017) [23]when the crop was at 90 days after sowing of quinoa in the Telangana regions of India. (Praveen Kadam *et al*., 2018) [24] declare the range of harvest index was higher among the treatments but was found insignificant. A lower harvest index was observed in continuous stress (0.5 IW: CPE) imposed in the surface method of irrigation in (T9) (38.5 %). Carlos Alberto Quiloango-Chimarro *et al*., 2022 [25] showed a similar variation trend under drought stress as water use efficiency, and its reduction was mainly associated with low filled grain percentage. Among the five irrigation treatments, both grain yield and WUE were the highest, the best cultivar recorded 9.3 Mg ha^{-1} and 1.62 kg m^{-3}, respectively. Agathos Filintas *et al*., 2022 [26] result in a substantial improvement in the cotton yield (up to +28.664%) and water savings (up to 24.941%), thus raising water productivity (+35.715% up to 42.659%).

Befikadu Belay Mamo *et al*., 2022 [27] study shows a highly significant difference ($P \leq 0.05$) among treatments for phenology, yield and yield components, and Water use efficiency. The highest fruit yield (64.65ton/ha) was obtained from the control treatment which was not significantly different from the treatment with 65%ETc applied at stage I (63.28 tons/ha). Gobena D. Bayisa *et al*., 2021 [28] study shows greatest water use efficiency of maize was obtained from alternate furrow irrigation under 75%ETc application and showed no significant difference with 100%ETc application. However, grain yield reduction under 75%ETc applications was very much higher than 100%ETc applications. Anbese Ambomsa *et al*., 2020 [29] increase crop water productivity are gaining importance in arid and semiarid regions. Saber Jamali *et al*., 2021 [30] study exposes that yield of quinoa increased by +62.5 and +70.8 percent. Generally, the use of variable alternative furrow irrigation + 200 Kg/ha nitrogen (VAFI200) decreased irrigation water consumption and increased water use efficiency, therefore with this treatment in Mashhad climatic conditions can be produced a reliable yield. Later he studies qunio in arid and semi-arid regions, here, the results showed the highest economic and physical water productivity in the treatment of variable alternate furrow irrigation + 200 kg/ha of nitrogen.

5.2 Smart Irrigation Analysis

More precisely, every 15 seconds, the IoT sensor device can provide 6 parameters such as moisture level, temperature, and humidity values. This information has been sent to the website server using the concept of channels in the publish/subscribe paradigm. Internet of Things for Research the PQ device publishes the above 6 parameters related to providing precise irrigation to crop fields.

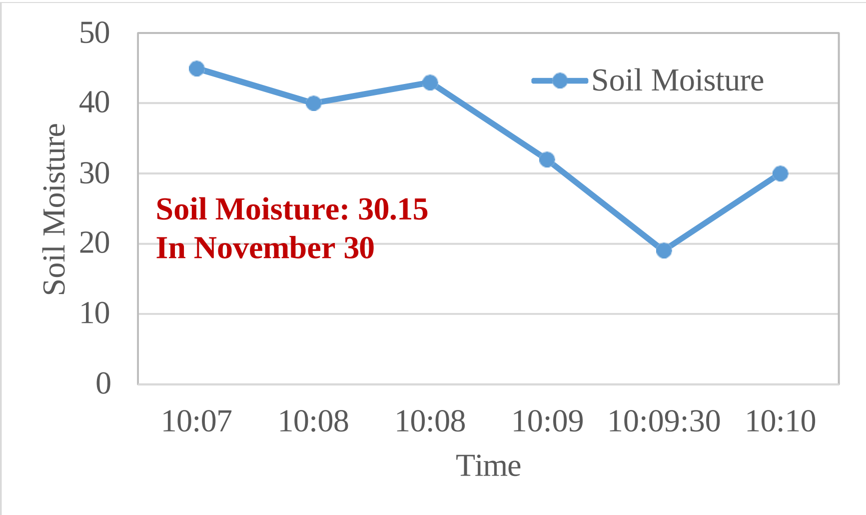

Figure 8: Soil Moisture in Smart Irrigation

Figure 8 depicts the soil moisture content measurement using sensorsfor various periods. Time series plot of soil-water content measured with HL-69 sensors at two depths in the root zone of a young Quinoa (Chenopodium quinoa Willd.) onNovember 30, 2019. The soil moisture content at the period of 10.00 AM was obtained with the senor indicator as 30.15 at the GMT +0530.

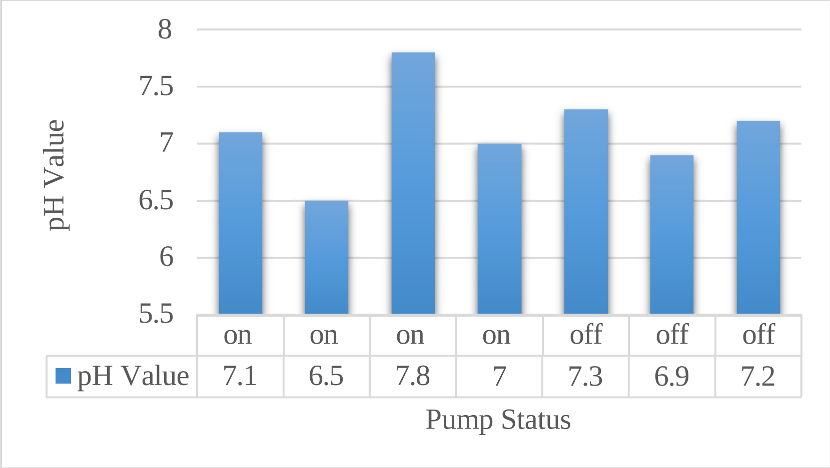

Figure 9: Effect of PH Value on Pump Status

Figure 9 represents the effect of pH value on the Quinoa (Chenopodium quinoa Willd.) The crop irrigation system and the performance of the proposed smart sensor drip irrigation are better because of the use of the IoT network for fast response to farmers. The pH value is measured in terms of the on and off status of the pump in drip irrigation. In on status, the pH value of soil is obtained as 7.8, and for the off status, it is predicted as 7.3.

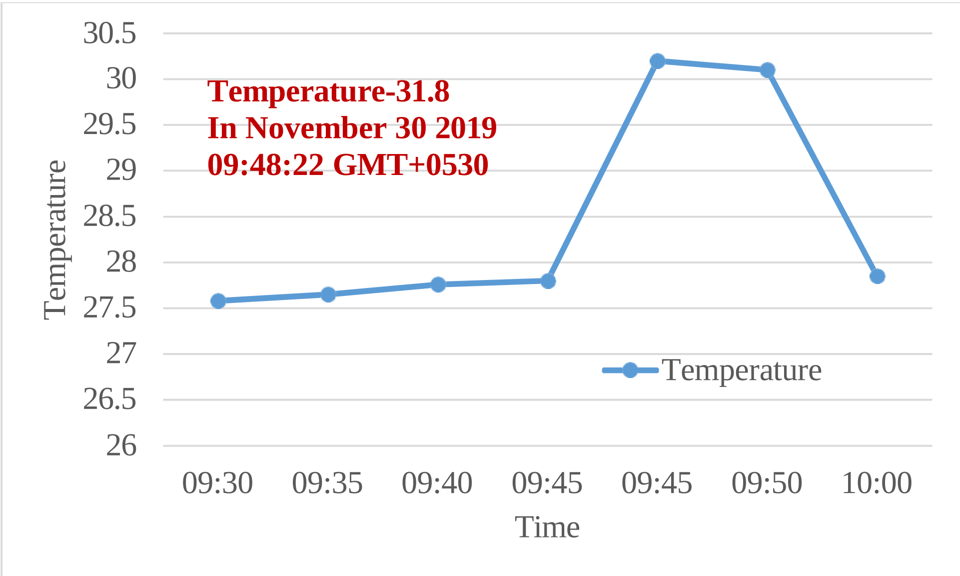

Figure 10: Temperature in Smart Irrigation

Figure 10 shows the energy information connected to the IoT device throughout the Temperature sensor. In the farming field, this information can be accessed from any device and from anywhere with an Internet connection. The interval measured in Figure 10temperature level contains an average value of 31.8 with various periods. The temperature was minimum around 9.30 to 9.35 am. The temperature remained high till 9.45, then decreased slowly with time and dropped after the time 9.50. The weather on 30 November 2019, was sunny and humid during the whole day except for some clouds in the morning hours (about 7-9 hrs LT) and at midday. The temperature difference (ΔT) was around 0.7°C for mostof the time of the day.

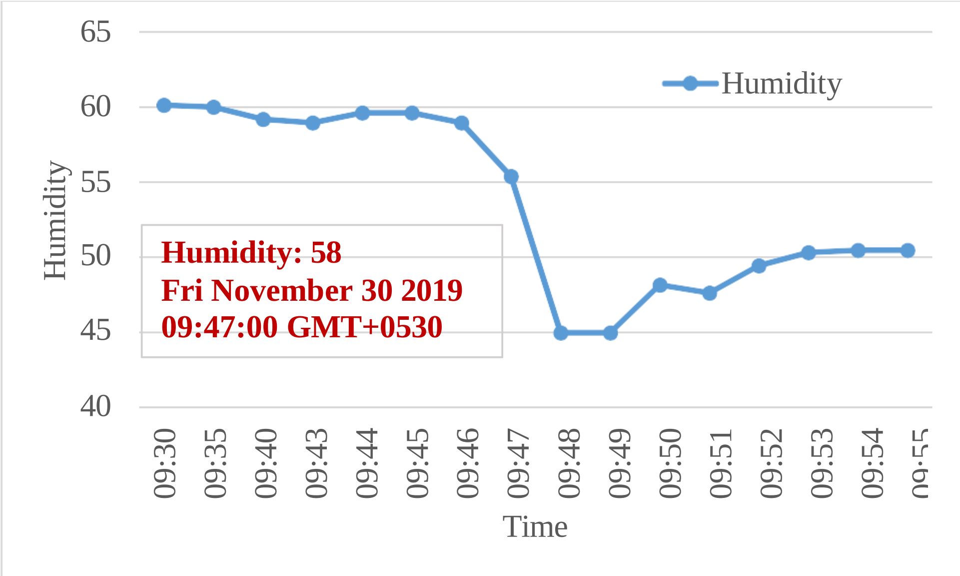

Figure 11: Humidity in Smart Irrigation

Figure 11 depicts thehumidity in smart irrigation with various periods on 30th November 2019. The humidity measurements of the DHT22 sensor are higher at observations of 58. The humidity was maximum duringmorning hours (about 62% H) and minimum in the 9.48 (about 45% H) and fairly constant at about 50% during 9.47 time.

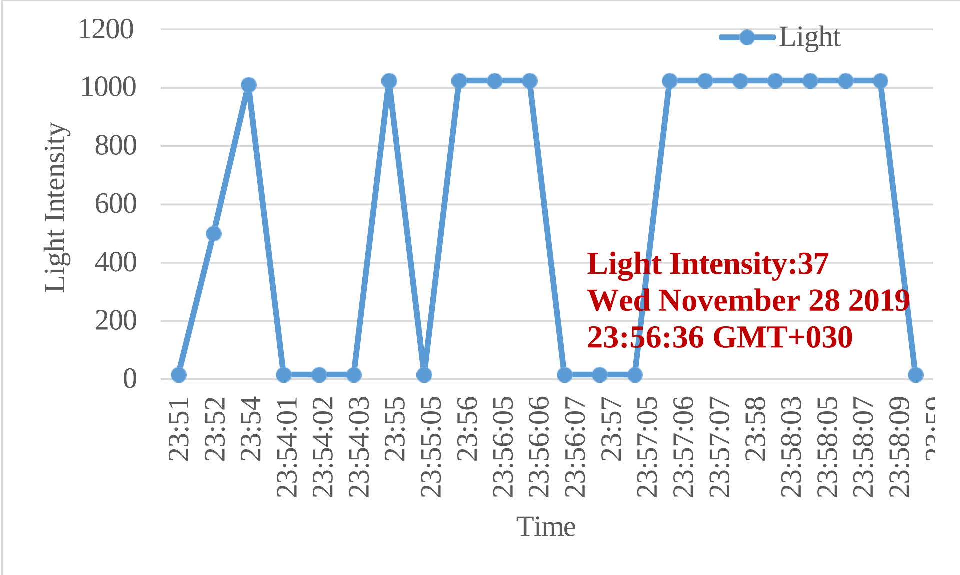

Figure 12: Light Intensity in Smart Irrigation

Figure 12depicts the smart irrigation light intensity measurement with various periods. Depends on the pest monitoring by the value of light intensity sensor values. It will display different hands from 0 to high value according to the random movement of pests.The LDR showed a more precise reading of 37 on November 28 2019. It showed that the luminous intensity was the maximum at 11am (1100 hrs. LT).

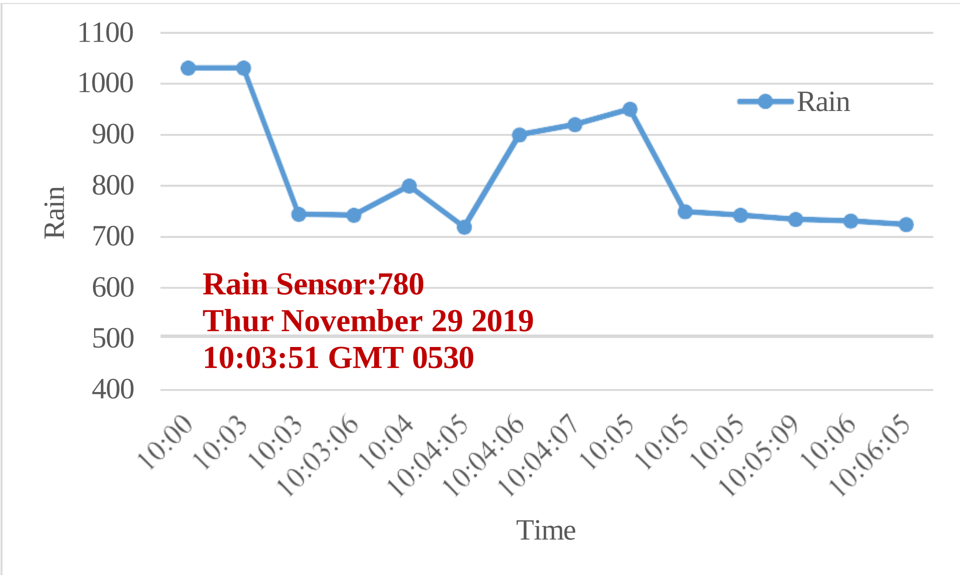

Figure 13: Rain Sensor in Smart Irrigation

Figure 13 depicts the rain sensor measure values with smart irrigation using the drip method with the sensor. It represents an average rain value in day/ week close depending on the motor for irrigation is on/off, such that if no rain with respect to time and it remains closed to zero. The sensor value was attained as 780 on the 29thof November 2019 in the rabi season at GMT 0530.

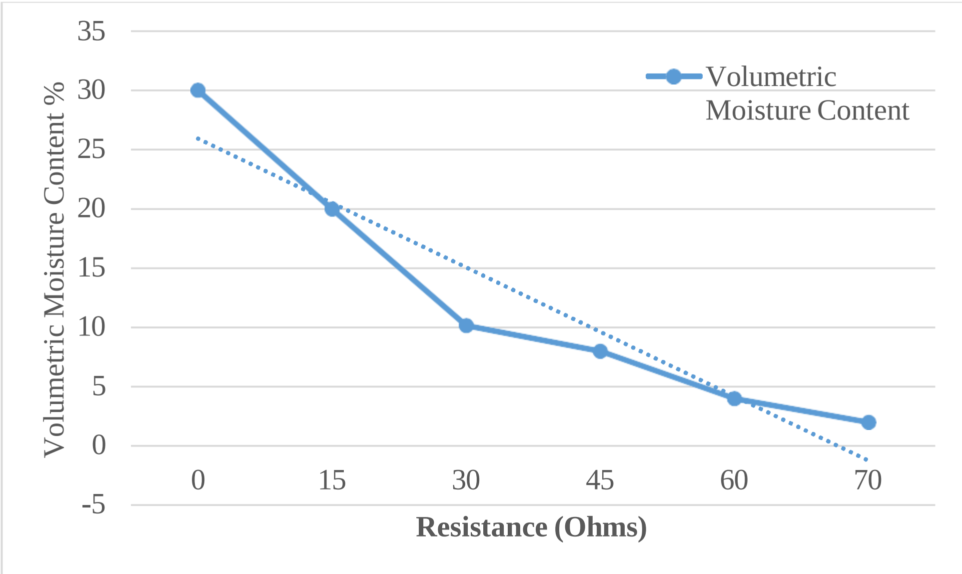

Figure 14: Volumetric Moisture Content

The soil volumetric water content in the upper 10 and 20-cm soil layers significantly decreased in the dry season (10.03%). This measurement was assumed to correspond to a nearly zero moisture content. Subsequently, a known amount of water was mixed uniformly throughout the entire soil volume and resistance was re-measured after each step (as depicted in Figure 14). The relative error of measured values remained nearly constant (at ~20% level of the measured resistance) within the range of 1-100 kΩ due to the fact that test values were adjusted automatically for each measurement.

6. RESEARCH CONCLUSION

Quinoa (Chenopodium quinoa Willd.), a member of the Amaranthaceae family, is a highly nutritious food product that has been cultivated for its seeds in South America for over 7000 years.In this study, quinoa was introduced as a new crop for Telangana and the cultivation possibilities of quinoa in semi-arid regions. The current study was conducted at the Ghapur village, during the 2018/19 rabi season. This work aimed to determine the evaluation Quinoa

(Chenopodium quinoa Willd.) at different dates of sowing intervals in semi-arid regions of Telangana, two sowing dates with different spacing were implemented. Further, analyses the best irrigation method (drip, surface) with RDF at levels (100 kg N, 50 kg P_2O_5, 50 kg K_2O ha^{-1}) in some physical soil properties and growth indicators of quinoa crop growth and root distribution. The rabi crops are sown around mid-November, preferably after the monsoon rains are over, and harvesting begins in April / May. The crops are grown either with rainwater that has percolated into the ground or using irrigation.The effects of irrigation and fertilization methods on the growth of quinoa, all vegetative growth characteristics increased by increasing the level of fertilizer and drip irrigation, due to the improvement of soil properties. Data were processed using Microsoft Excel and figures were developed using an excel sheet. Statistical software SPSS 8 were used to analyze the effects of the main factors (planting technique and quinoa accession) and their interactions on growth, biomass, and yield.The maximum seed, and stalk yield was obtained with the 1stOctober date of sowing along with narrow (15 × 10 cm) spacing and was followed by 30 ×10 cm. The higher number of grains in panicle-1 was recorded with 15 × 10 cm spacing.This study can be helpful to select the best irrigation method according to the soil type, climatic conditions, and mechanization. Further research is needed to explore the effect of fertilizer, irrigation, planting density, and sowing times under normal as well as stress conditions to make a better adjustment of quinoa in the cropping systems for irrigated land.

REFERENCES

[1] Kellogg, J.A., Reganold, J.P., Murphy, K.M. and Carpenter-Boggs, L.A., 2021. A plant-fungus bioassay supports the classification of quinoa (Chenopodium quinoa Willd.) as inconsistently mycorrhizal. Microbial ecology, 82(1), pp.135-144.

[2] González, J.A. and Sarmiento, F.O., 2020. Andean indigenous foodscapes: food security and food sovereignty in mountains' sustainability scenarios. In The Elgar Companion to Geography, Transdisciplinarity and Sustainability (pp. 378-389). Edward Elgar Publishing.

[3] Ram, M., Meena, R.C., Meena, D. and Parewa, H.P., Growth and yield of quinoa (Chenopodium quinoa L) as influenced by dates of sowing and plant geometry in semi arid region.

[4] Angeli, V., Miguel Silva, P., Crispim Massuela, D., Khan, M.W., Hamar, A., Khajehei, F., Graeff-Hönninger, S. and Piatti, C., 2020. Quinoa (Chenopodium quinoa Willd.): An

overview of the potentials of the “Golden Grain” and socio-economic and environmental aspects of its cultivation and marketization. Foods, 9(2), p.216.

[5] Prajapati, B., Singh, M., Sharma, A., Chouhan, D. and Pandre, B.P., 2022. Agro Techniques of Quinoa Crop for Enhancing Nutritional Security in India. Vigyan Varta, 3(2), pp.6-8.

[6] Reddy, K.R., Singh, R. and Singh, E., 2021. Effect of spacing and nitrogen management on yield and economics of quinoa (Chenopodium quinoa).

[7] Choudhary, M., Tetarwal, J.P., Ram, B., Kumar, R., Bijarnia, A. and Kumawat, R., 2022. Effect of land configuration and irrigation scheduling on productivity and water use of quinoa (Chenopodium quinoa) under south-eastern ecologies of Rajasthan. Indian Journal of Agronomy, 67(1), pp.108-112.

[8] Wali, A.M., Kenawey, M.K., Ibrahim, O.M. and Abd El Lateef, E.M., 2022. Productivity of Quinoa (Chenopodium quinoa L.) under new reclaimed soil conditionsatnorth-western coast of Egypt. Bulletin of the National Research Centre, 46(1), pp.1-8.

[9] Manaa, A., Goussi, R., Derbali, W., Cantamessa, S., Essemine, J. and Barbato, R., 2021. Photosynthetic performance of quinoa (Chenopodium quinoa Willd.) after exposure to a gradual drought stress followed by a recovery period. Biochimica et Biophysica Acta (BBA)-Bioenergetics, 1862(5), p.148383.

[10] Salim, S.A., Hadeethi, I.K.H. and Hadithi, R.A.G.M., 2020. Water stress on different growing stages for quinoa (Chenopodium quinoa willd) and its influence on water requiriments and yield. Iraqi journal of agriculture sciences, 51(3), pp.953-966.

[11] García-Parra, M., Zurita-Silva, A., Stechauner-Rohringer, R., Roa-Acosta, D. and Jacobsen, S.E., 2020. Quinoa (Chenopodium quinoa Willd.) and its relationship with agroclimatic characteristics: A Colombian perspective. Chilean journal of agricultural research, 80(2), pp.290-302.

[12] Mahmood, R.S. and AL-Taweel, S.K., 2022, July. Physiological Response of Genotypes and Sowing Dates in the Growth and Yield of Chenopodium Quinoa Willd. In IOP Conference Series: Earth and Environmental Science (Vol. 1060, No. 1, p. 012111). IOP Publishing.

[13] Al-Yasiry, Q.B.I., 2022. Effect of irrigation method and application of NPK fertilizer on some physical properties of soil, growth of quinoa (Chenopodium quinoa Willd) and distribution of roots in the soil. Texas Journal of Agriculture and Biological Sciences, 3, pp.51-58.

[14] Abdrabou, M.R., Gomah, H., Darweesh, A.E., Eissa, M.A. and Selmy, S.A.H., 2022. Response of saline irrigated quinoa (Chenopodium quinoa Wild) grown on coarse texture soils to organic manure. Egyptian Journal of Soil Science, 62(2), pp.169-178.

[15] Bouras, H., Choukr-Allah, R., Amouaouch, Y., Bouaziz, A., Devkota, K.P., El Mouttaqi, A., Bouazzama, B. and Hirich, A., 2022. How Does Quinoa (Chenopodium quinoa Willd.) Respond to Phosphorus Fertilization and Irrigation Water Salinity? Plants, 11(2), p.216.

[16] Ram, M., Meena, R.C., Meena, D. and Parewa, H.P., Growth and yield of quinoa (Chenopodium quinoa L) as influenced by dates of sowing and plant geometry in semi arid region.

[17] Asif, A., Khan, S., Asif, B., Ibrar, D., Hasnain, Z., Ismail, M.S., Rizwan, M., Ullah, S., Bashir, S., Rais, A. and Irshad, S., 2022. Preliminary Study on Growth and Yield Potential of Ten Elite Lines of Quinoa (Chenopodium quinoa) Cultivated under Varying Sowing Dates. Plants, 11(16), p.2116.

[18] Zulkadir, G., 2021. The agroecological impact of different sowing dates and row spacing applications in quinoa (chenopodium quinoa willd.). Applied Ecology and Environmental Research, 19, pp.751-762.

[19] Öktem, A., Öktem, A.G. and Birden, Ö.F., 2021. Impact of Sowing Dates on Forage Value of Quinoa (Chenopodium quinoa Willd.) Under Semi-arid Conditions. Uluslararası tarım araştırmalarında yenilikçi yaklaşımlar dergisi (Online), 5(2), pp.172-182.

[20] Chaibva, P., Mugala, C., Makuvaro, V., Muziri, T., Chagonda, I. and Ndau, B.M., 2021. Irrigation frequency and soil type influence germination and early growth of quinoa (Chenopodium quinoa Willd). AgriRxiv, (2021), p.20210302314.

[21] Fghire, R., Anaya, F., Issa Ali, O., Lamnai, K., Foughali, B., Faghire, M., Benlhabib, O. and Wahbi, S., 2022. Effects of deficit irrigation and fertilization on quinoa (Chenopodium quinoa Willd.) water status and yield productions. Gesunde Pflanzen, 74(1), pp.97-110.

[22] Hamza, A., Usman, K., Malik, M.W.I., Saad, M., Ghulam, S., Khan, Z. and Ullah, A., 2021. Response of quinoa genotypes to sowing dates and sowing methods under agroclimatic condition of Dera Ismail Khan, KP Pakistan. Archives of Agronomy and Soil Science, pp.1-11.

[23] Ramesh, K., Devi, K.S., Gopinath, K.A. and Devi, M.U., 2017. Physiological Indices, yield and yield attributes of quinoa (Chenopodium quinoa Willd.) as influenced by dates

of sowing and varied crop geometry. Int. J. Curr. Microbiol. App. Sci, 6(7), pp.1023-1034.

[24] Kadam, V.P., Devi, K.S., Hussain, S.A. and Devi, M.U., 2018. Growth, yield attributes, yield and economics of quinoa (Chenopodium quinoa Willd.) as influenced by variable irrigation water supply through drip and surface methods. Int. J. Curr. Microbiol. App. Sci, 7(7), pp.3428-3438.

[25] Quiloango-Chimarro, C.A., Coelho, R.D., Heinemann, A.B., Arrieta, R.G., da Silva Gundim, A. and França, A.C.F., 2022. Physiology, yield, and water use efficiency of drip-irrigated upland rice cultivars subjected to water stress at and after flowering. Experimental Agriculture, 58.

[26] Filintas, A., Nteskou, A., Kourgialas, N., Gougoulias, N. and Hatzichristou, E., 2022. A Comparison between Variable Deficit Irrigation and Farmers' Irrigation Practices under Three Fertilization Levels in Cotton Yield (Gossypium hirsutum L.) Using Precision Agriculture, Remote Sensing, Soil Analyses, and Crop Growth Modeling. Water, 14(17), p.2654.

[27] Mamo, B.B. and Affessa, G.M., 2022. Assessment of stage-wise deficit furrow irrigation on tomato crop production at Arba Minch, Ethiopia.

[28] Bayisa, G.D., Hordofa, T., Tezera, K., Tesfaye, A., Ashame, G. and Wondimu, T., 2021. Maize Yield and Water Use Efficiency under Different Irrigation Levels and Furrow Irrigation Methods in Semiarid, Tropical Region. Air, Soil and Water Research, 14, p.11786221211058177.

[29] Ambomsa, A., Role of Drip Irrigation System as Increasing Water Use Efficiency over Furrow Irrigation System.

[30] Jamali, S., Ansari, H. and Zeynodin, S.M., 2021. Evaluation of the effects of nitrogen and alternate furrow irrigation method on water use efficiency in cultivation of Quinoa plant. Water and Irrigation Management, 11(2), pp.99-112.