Sensor-based Irrigation Management in Odisha (SIMO) – a pilot study on Tomato crop

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by

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Executive Summary

Water being a vital and increasingly scarce resource for all kind of human needs, it is highly important to develop methods and practices for its efficient use. In irrigated farming, appropriate timing and amount of irrigation is imperative for ensuring optimal crop productivity and sustainability. Scheduling of irrigation based on soil moisture sensors is advocated for its contribution to enhancing productivity and water use efficiency. There is limited information available on the deployment of this technology, particularly in the small holder context of global south.

This pilot study was undertaken to test the application of 'PlantAlarm' sensors developed by PlantCare AG in tomato crop in the Odisha state of India. A field trial was conducted at the Maa Mati campus of i-Concept Initiatives (iCi). Three different levels of plant available moisture (45%, 55% and 65%) at two soil depths (16cm and 31cm) were compared to the farmers' practice i.e., irrigation based on visual observation. In addition, Mini-loggers were deployed to collect soil moisture data in each treatment.

The results indicate that sensor-based irrigation has the potential of saving water and human resources without significantly compromising productivity. Unfortunately, the field trial suffered significant damage from pests and wilt disease, thereby hampering conclusive results based on robust statistical analysis. Nevertheless, the study provides many important insights and lessons. This report presents detailed account of the pilot study and summarizes the important learnings that could add significant value for conduct of future studies for more conclusive results and can benefit crop production.

Keywords*:* *irrigation, moisture sensor, soil moisture content, tomato, water requirement*

1. Introduction

Water and nutrients are two critical inputs for crop production. Per capita water availability is continuously declining due to increase in population and demand of water for other competing sectors like industry and urban usage. On the other hand, there is an increased demand for food production which in turn requires more water for crop production. Given the severity of the climate change scenario (IPCC, 2023), effective water management is of further critical importance. In humid tropics across most of Asia (south and eastern India in this particular case), the wet season beginning with the onset of monsoon rains, is generally hot and humid. This season is followed by a distinct dry season with cool humid condition (November to mid-February) and hot dry condition (mid-February to May). The evaporative demand is low (2 to 3 mm/d) in cool humid conditions while it increases under hot and dry conditions (4 to 8 mm/d) due to high wind velocity and intense solar radiation (Nag et al., 2014; Rautaray, 2021). Accordingly, the crops grown in these regions could broadly be grouped into two distinct groups. The first group is cold loving crops and these are sown in October-November, so that the vegetative growth period coincides with the cool period. The examples include tomato, potato, chick-pea, pea, lentil and mustard. The second group is warm loving crops and these are sown in February-March. The examples include okra, bottle gourd, sesamum, groundnut, sunflower and maize.

The dry season receives little or no rainfall. So, the water requirement is largely met from irrigation with little contribution from residual soil moisture and rainfall if any. In such situation, irrigation is vital to sustain/increase crop production. The limited water resource allocated for agriculture is at present mostly applied by surface irrigation method. Due to the increased scarcity of water, micro-irrigation methods such as drip irrigation and sprinkler irrigation are now being adopted, although only to a little extent yet. In India, about 12.9 M ha is under micro-irrigation out of the net sown area of ca. 140 M ha as of year 2021 (Deshmukh and Kumbhar, 2021). Irrigation water could potentially be further saved by adopting smart irrigation systems. Sensor based irrigation is one such approach to irrigate the field as per the crop demand. Such a system will avoid over-use and under-use of water and may produce more yield per unit of water applied. Also, the real time data from the field by using soil moisture sensors may reduce the human labour requirement in irrigating the fields and supervision.

Majority of the farmers in tropical regions are marginal and small. Most of the times due to wrong prediction of weather and incorrect method of irrigation, crops may suffer significant losses. Hence, there is a need to develop an intelligent irrigation scheduling system allowing an optimal use of water. Methods are being continuously developed to achieve precision in irrigation scheduling, those consider factors such as evapotranspiration, on-farm parameters, the climate, soil and crop, for example FAO CROPWAT (San and Thinzar 2019; Adamtie et al., 2022). Soil moisture sensors are good option for monitoring spatial variation of soil moisture and hence can be used as an effective tool for precisely managing water application to various crops. These sensors allow site specific crop management which is the most crucial part of precision agriculture (Badewa et al., 2018). Shaloo and colleagues (2021) suggest sensor-based irrigation system as viable, cost effective and water saving approach. The water saving potential of sensor-based irrigation as compared to conventional irrigation systems has been reported by some studies (Lawal and Shanono, 2022; Al-Ghobari et al., 2017; Geetha et al., 2019). Some recent studies have been conducted with a focus on optimizing sensor-based irrigation management in soilless crops (Millán et al., 2023; Tavan et al., 2021). However, the data from field conditions, particularly in the context of smallholder farming in Asia is still limited.

Vegetables are the second most important food commodity after food grains worldwide. Tomato (*Solanum lycopersicum* L.), is the world's most highly consumed vegetable due to its status as a basic ingredient in a large variety of raw, cooked or processed foods (Zakari et al., 2016). Tomato belongs to the Solanaceae family, which also includes two other commercially important species i.e., potato (*S. tuberosum* L.) and brinjal (*S. melongena* L.). Being one of the major vegetable crops grown globally, tomato accounted for about 16% of the world's vegetable production at 186.82 million metric tons in 2020 (FAOSTAT, 2020). China is the largest producer of tomato accounting for about 35% of the world's tomato production. India is the second largest tomato producer, followed by USA, Turkey and Egypt (FAOSTAT, 2020).

Considering the importance of this context, a project titled, "Sensor based Irrigation Management in Odisha (SIMO) – a case study on tomato crop" was taken up to study the irrigation scheduling at different soil moisture levels with the following objectives:

1. To evaluate the contribution of sensor-based irrigation scheduling towards improving crop productivity compared to farmers' practice

2. To evaluate the potential productivity under limited water availability conditions

3. To evaluate the effectiveness of PlantAlarm sensors under field conditions

2. Materials and methods

2.1 Location of the experiment

The field experiment was conducted in the fields of i-Concept Initiatives (iCi) at Maa Mati Campus, Kothabada, Pipli, Odisha, India. It is geographically situated at 20°04'33.0" N Latitude, 85°48'49.9" E Longitude, at an average altitude of 25m a.m.s.l. It is 36 kilometres from Puri and 18 kilometres from Bhubaneswar. The location of experimental site is presented in Photo 1.

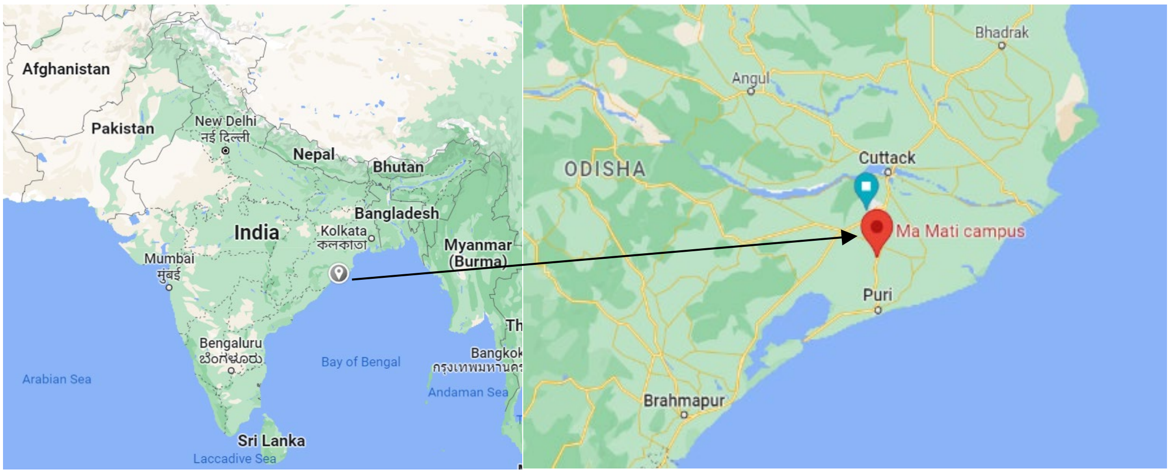

Photo 1: Location of the experiment (Source: Google Maps)

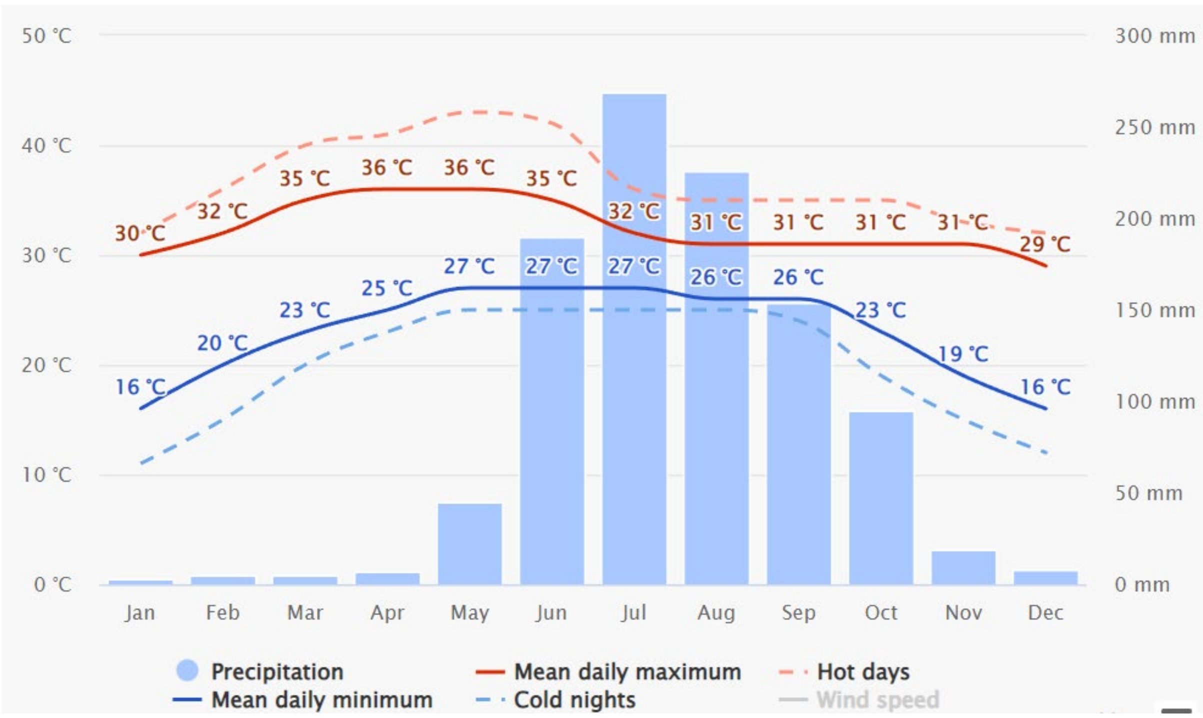

Figure 1: Long-term average temperature and precipitation of the study area (1971-2021). Source: Meteoblue, ERA5, the fifth generation ECMWF atmospheric reanalysis of the global climate.

2.2 Meteorological data

The project region is a coastal area with a climate generally described as 'tropical monsoon' type. Long-term mean monthly temperature and precipitation of the study area (1971-2021) is presented in Figure 1. The average annual maximum temperature for the location is 32.14°C and average annual minimum temperature is 22.91°C. The hottest months are April and May with mean monthly maximum temperature of 36°C followed by March and June. December and January are the coldest months with mean monthly minimum temperature of 16°C. July is the rainiest month with mean monthly precipitation of about 270 mm followed by August, June and October. The month receiving least precipitation is January followed by February, March and April. The field trial in SIMO project was conducted from mid-November 2022 till mid-February 2023.

2.3 Soil analysis

For soil chemical properties analysis, two composite representative soil samples were collected from the experimental field at the soil depths of 0-15 cm and 15-30 cm, corresponding to the two depths used for PlantAlarm sensor installation. The analysed soil properties were pH, electrical conductivity (EC), organic carbon (OC), available nitrogen, phosphorous, potassium, and micronutrients like sulphur, zinc, copper, iron, manganese, boron, exchangeable calcium and exchangeable magnesium. For determination of chemical properties such as soil pH and electrical conductivity, the mixture was prepared with 100 g of soil into 250 ml of distilled water by stirring well for 30 minutes at room temperature. The values of measured soil parameters are presented in Table 1 and Table 2.

Table 1: The pH, EC, OC and primary nutrient content in the soil at the beginning of the trial

Depth (cm)	pH	EC (dS/m)	OC (%)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
0-15	4.71	0.071	0.78	225	293.8	531.4
15-30	5.12	0.03	0.56	200	218.9	551.3

Table 2: The secondary and micronutrient status of soil at the beginning of the trial

Depth (cm)	Exch. Ca (meq/100g)	Exch. Mg. (meq/100g)	S (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	HWS-B (mg/kg)
0-15	7.0	6.5	10.20	241.23	60.39	10.44	3.60	0.82
15-30	6.4	7.0	8.20	225.03	47.43	8.56	3.28	0.67

2.4 Experimental design, treatments and layout

The experiment was conducted for irrigation scheduling with three levels of available soil moisture i.e., 45%, 55% and 65% at two different depths i.e., 16cm and 31cm (PlantAlarm sensors). This comprised of six treatment combinations, along with a seventh control treatment i.e., the farmers' practice. The sum-total of seven treatments were arranged in a randomised block design (RBD) (Gomez and Gomez, 1984) with three replications each, spread into a total of 21 experimental plots.

Treatments

T1: Irrigation at 65% available soil moisture at 31 cm depth

T2: Irrigation at 65% available soil moisture at 16 cm depth

T3: Irrigation at 55% available soil moisture at 31 cm depth

T4: Irrigation at 55% available soil moisture at 16 cm depth

T5: Irrigation at 45% available soil moisture at 31 cm depth

T6: Irrigation at 45% available soil moisture at 16 cm depth

T7: Farmers' practice

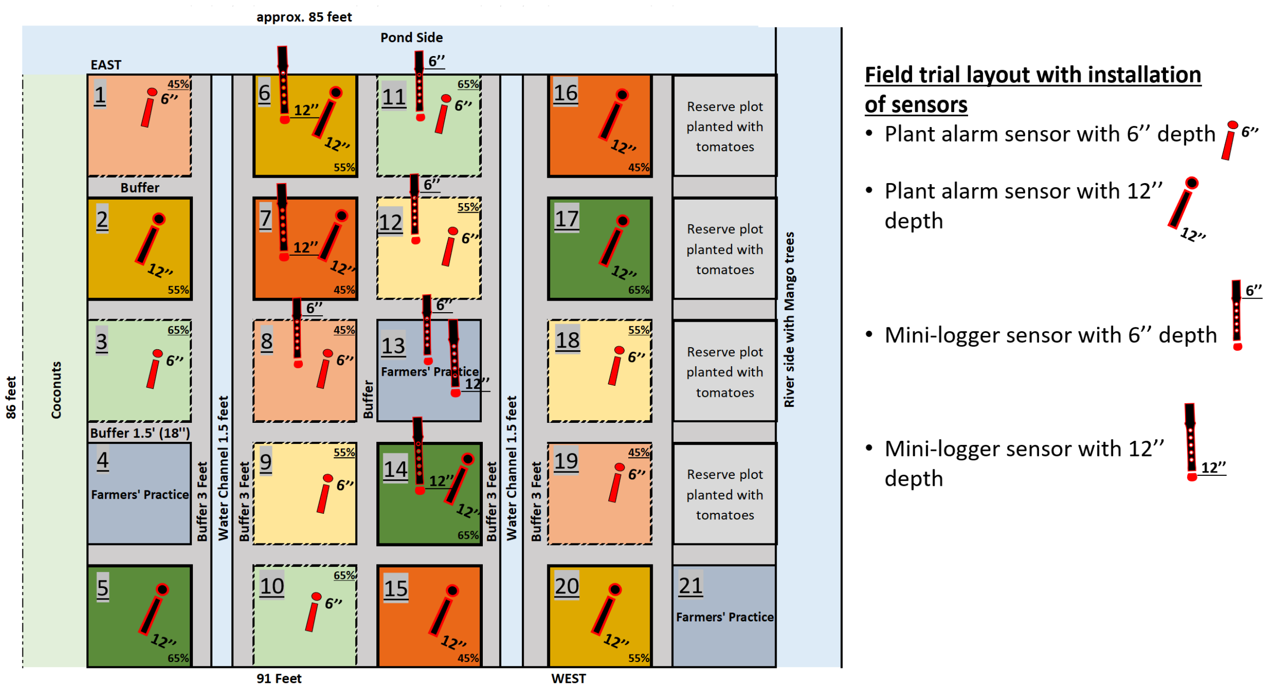

Figure 2: Layout of the experiment. Plot-wise positioning of sensors is indicated. The sensor depths are indicated in inches for convenience of iCi staff – 6" corresponds to 16cm and 12" corresponds to 31cm depth for PlantAlarm sensors.

The size of each treatment plot was 4.88m x 4.26m. The total experimental area was 27.73m x 26.21m (726.80 sq. m). The lay-out of the experimental field is presented in Figure 2. Each plot had 6 crop rows and each row had 8 plants. Tomato variety *Lakshya* was grown in the experiment. Nursery was sown on 28 October 2022. The planting on the main field was done on 19 November 2022 (Photo 2 and 3). During the crop growth, some of the plots got severely damaged (see section 2.8) and had to be substituted with replacement (reserve) plots, resulting into a changed layout – presented in Figure 3. Observations were taken from the central 24 plants excluding the plants in the outer rows to minimize the border effect (Figure 4).

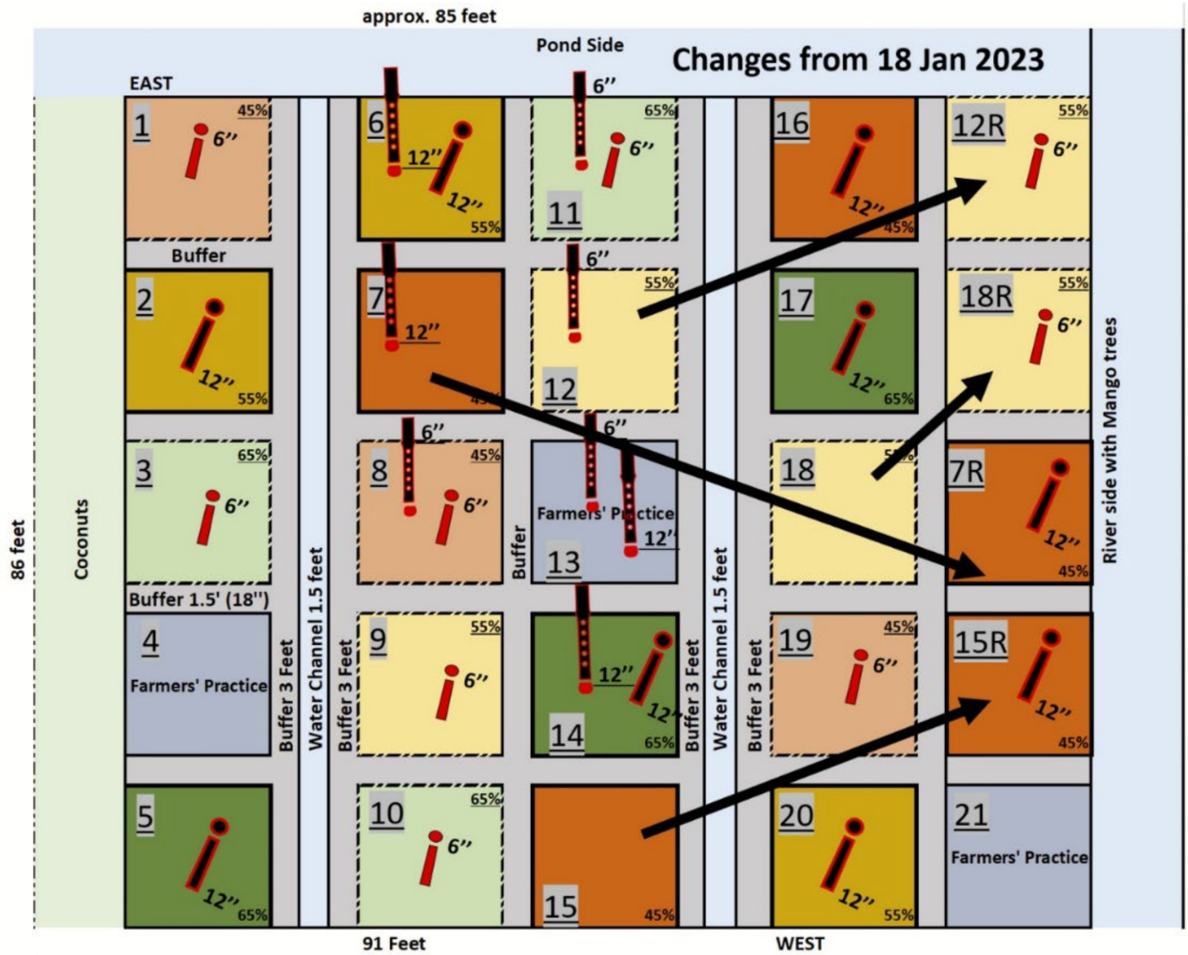

Figure 3: Changed layout after shifting of sensors on 18 January 2023. Reserve area was needed to be brought under experiment due to heavy crop damage owing to diseases and pests. The changes are marked with arrows. The sensors from plot numbers 7, 12, 15 and 18 were moved to the reserve plots, which were named as 7R, 12R, 15R and 18R for the remaining part of the study.

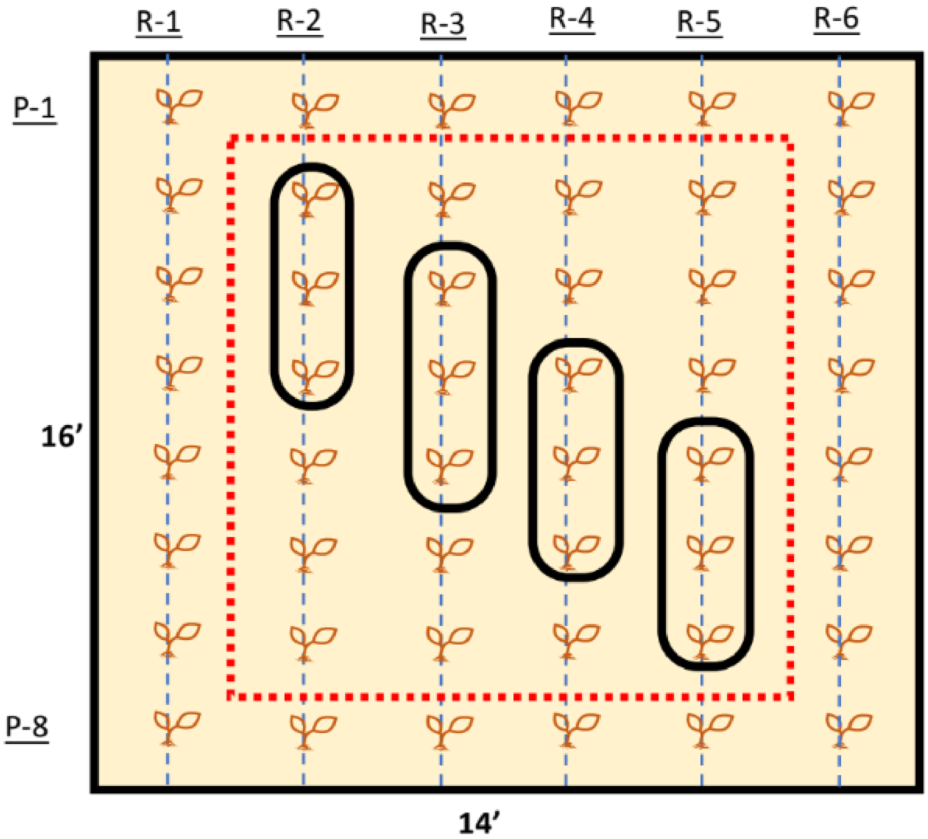

Figure 4: Plants marked for observation of plant growth parameters. In case of dying/damaged plants, observations were also considered from other plants from the central 24 plants indicating in the red dotted area.

Photo 2: Main field preparation. Measurement and layout being done by the research team together with the field staff

Photo 3: Main field preparation – measurement, layout and field preparation for planting

2.5 Sensor description and depth

The soil moisture sensors used in this experiment are PlantAlarm Sensor and PlantCare Mini-Logger developed by PlantCare AG, Switzerland.

PlantAlarm sensor can be set to three levels of volumetric soil moisture, which in this case were set to 45%, 55% and 65% for this experiment. Once the soil moisture reaches the set moisture level, the plant alarm sensor blinks giving an indication of the threshold soil moisture thereby suggesting requirement for irrigation. Daily observations were made to check the blinking status of the sensors and irrigation was provided accordingly. In this experiment 18 PlantAlarm sensors were used, which were set to different moisture thresholds as per the treatments (Figure 2 and 3). Depth of sensors provided by manufacturer for PlantAlarm were 16 cm and 31 cm, respectively.

Photo 4: Furrow making

PlantCare Mini-Logger measures soil moisture and temperature using Micro-Heat-Pulse measurement (MHP). It has a measuring range of 0 - 100% at 0° - 37°C soil temperature. The data stored in the device can be exported by an export cable and a USB stick. This data can be analysed by the PlantCare DataViewer software. In this experiment eight PlantCare Mini-Loggers were used, one for each treatment and two for farmers' practice. Depth of sensors provided by manufacturer for Mini-Logger were 17cm and 35cm.

Photo 5 (a,b): Installation of PlantAlarm Sensor and PlantCare Mini-Logger on 12 December 2022

After the plant establishment and making of furrows by earthing up (Photo 4), the PlantAlarm Sensor and PlantCare Mini-Logger were installed in the fields (Photo 5a and 5b). The sensors were installed on 12 December 2022 i.e., 23 days after transplanting (DAT) next to the plants on top of the ridge. Even after provision of full irrigation, the sensors kept on blinking, indicating that the soil moisture was never sufficiently reaching the sensor tip. Therefore, it was decided to move the sensors to a lower depth i.e., installation at the bottom part of the ridge on 29 December 2022 (Photo 6a and 6b). Thereafter, the sensor indications could be used reliably for the experiment. Except for local logistical challenges, the sensor-based irrigation was provided from January 2023.

Photo 6 (a,b): Shifting of sensors to the lower part of the ridge on 29 December 2022

2.6 Data collection

Plant height was measured using a meter scale from ground level to the tip of apical meristem of the main axis. The date of flowering initiation was recorded for each plot. The date of 50% flowering was recorded visually, when ca. 50% of the plants in a plot had produced inflorescence. Fruits were plucked at maturity stage in batches (i.e. as they matured). The summation of fruit yield in different batches for a plot was reported as total fruit yield. Photos 7 to 12 below, present crop growth at different stages in the field referred as number of days after transplanting (DAT).

Photo 7: Seedling stage (0 DAT)

Photo 8: Plant establishment stage (23 DAT)

Photo 9: Vegetative growth stage (30 DAT)

Photo 10: Crop at 45 DAT

Photo 11: Crop at flowering stage (60 DAT)

Photo 12: Maturity / Harvesting stage (77 DAT)

2.7 Cultural operations

On 19 November 2022, layout and transplanting was done in the field. After about 10 days of transplanting, insect pest attack was observed. Neem oil was sprayed four times, i.e., 10, 13, 15 and 17 DAT @ 40ml/15L water along with 20ml of *Metarhizium anisopliae*. *Trichoderma* was sprayed as a biocontrol against soil-borne diseases on 20 and 27 DAT. *Azotobacter*, MOP and Vermicompost were applied at 23 DAT. Earthing up was done at 23 DAT. Wilted plants were uprooted and bleaching powder was applied to reduce spread of wilt infection. Streptocyline (1.5g/10L) was applied to control the wilt. Copper oxychloride was applied along with the irrigation water. N:P: K (19:19:19) was applied as a foliar spray (100g/16L water). Flowering and fruiting hormone was sprayed on to the foliage to improve the growth of the wilt affected crop. Chlorpyriphos was sprayed against the caterpillars of *Spodoptera* at 59 DAT. Permethrin was applied along the irrigation water to kill the *Spodoptera* caterpillars in the soil. Seven fruit pickings were done on 71 DAT, 74 DAT, 77 DAT, 81 DAT, 84 DAT, 88 DAT and 92 DAT. Date wise cultural operations are provided in Annexure 1. Photo 13 shows surface irrigation in furrows (done manually during the establishment phase).

Photo 13: Furrow irrigation

2.8 Insect pest and disease incidence

Insect pests incidence was noted at 10 days after transplanting of tomato crop. The lower leaves were damaged due to scrapping and feeding by the grubs of *Epilachna* beetle. The other insects observed include aphids and jassids. About 2-3 *Epilachna* beetles, 10-15 Jassids, and 15-20 Aphids per plot were observed. Neem oil along with *Metarhizium anisopliae* was sprayed for the control of the pests on alternate days. Even after neem oil application, the pest population remained static. The aphid population had already reached the winged stage (non-destructive stage). *Trichoderma* was applied as a biocontrol measure at 60ml per 15L water. Aphid population was reduced by the application of debuttered curd after dilution (Dahi drabyana). In the meantime, whiteflies population increased severely, favoured by the foggy weather. Possibly due to the whiteflies, viral diseases were potentially transmitted to the plants. The plants seemingly affected by virus became stunted with yellowing of leaves and wrinkling of the foliage. Also, the top foliage gave a burnt appearance (Photo 14a, 14b).

Photo 14 (a, b): Some plants got affected by virus possibly due to the white fly attack (20 December 2022)

At 30 DAT, wilting (Photo 15) was first observed in the SIMO trial, which coincided with the whitefly infestation. The wilt was (falsely) attributed to improper transplanting by the local staff, and hence replacement with healthy plants was used as a measure. However, detailed visual analysis of the plants i.e., healthy root system (Photo 16), infected stem (Photo 17) and aerial root initiation (Photo 18) indicated the presence of disease. At 40 DAT, ooze test was conducted at a professional Plant Pathology laboratory and wilt disease was confirmed. Bacterial wilt is a widespread destructive disease caused by the pathogen *Ralstonia solanacearum* that induces rapid and fatal wilting symptoms (Yuliar and Toyota 2015). Disease control measures were applied as per expert recommendations (see cultural practices, Annexure Table 1).

Photo 15 (a,b): Wilting of leaves and succulent meristem

Photo 16: Even though roots seemed healthy and the plants had already established, the plants showed wilting (20 December 2022)

Photo 17: Dark colour inside the stem of wilt infected plant

Photo 18: Aerial roots due to blocked vascular bundles

Although the wilt was somewhat controlled with integrated disease management (Photo 19), significant loss occurred with some plots losing >50% of the plant population. Once the infection happens, bacterial wilt can be very difficult to manage as the chemical control offers only limited efficiency on suppression of the pathogen (Champoiseau and Momol 2008). The pathogen can affect a wide variety of hosts including tomato, tobacco, potato, eggplant, pepper, sunflower and other solanaceous plants (Meadows and Henson 2017). Initially the middle zone of the field seemed to be the most affected i.e., plots 11, 12, 13, 14 and 15. Gradually, the disease also spread to the nearby plots i.e., plots 6, 7, 8, 9 and 10 and also to the next patch i.e., 16, 17, 18, 19 and 20. The plots 1, 2, 3, 4 and 5 performed better. The adjacent non-experimental area (marked as reserve in the layout Figure 2) remain unaffected by wilt. The potential explanation for this is that the brinjal crop was not grown in the previous season in the adjacent non-experimental area (infection free area) and it was brought new into cultivation during field preparation for this study.

Photo 19: Soil drenching with Streptocycline

At 55 DAT, damage on fruits due to borers (Photo 20) was spotted. The insects, identified as *Spodoptera*, were big (larval stage in Photo 21). The larvae hibernated in the soil after the previous season crop and re-appeared with the favourable environment as well as enough food availability with the tomato plants at fruiting stage. At 63 DAT, six kg of damaged tomatoes were collected from plots 1 to 20, while the replacement plots 7R, 12R, 15R and 18R remained unaffected. This difference in the disease incidence between the area newly brought under cultivation and the rest of the field that was planted with brinjal in the previous cropping season further emphasises the importance of following proper crop rotation. Pest control measures as well as increasing temperatures in February brought the *Spodoptera* population somewhat under control.

Photo 20: Fruit Borer damage (18 January 2023)

Photo 21: Fruit Borer, larval stage of *Spodoptera* (18 January 2023)

Evidently, the trial faced heavy insect-pest and disease infestation (especially, wilt) throughout the period of the study. Wilt is the most serious problem in tomato, potato, brinjal and chillies belonging to *Solanaceae* family, especially in the coastal areas and was also a major damaging factor to the current study.

3. Results

Given the heavy damage to field trial, the results presented below need to be interpreted with precaution. Despite taking every care to process the data in a best possible way, it is impossible to avoid the significant influence of the heavy infestation of disease and pest damage. In particular, the study could not sufficiently address the objectives 1 and 2. As evidenced by the high variation among replicates (yield data below) arriving at conclusive results using a statistical model is neither advisable nor possible. Despite this unfortunate situation, this field study serves the purpose of a pilot trial with moisture sensors and yields valuable learning outcomes.

3.1 Plant height

Plant height measured at 20, 40 and 60 DAT are presented in Figure 5. In all the treatments, the plant height progressively increased with the advancement of crop growth stages. At 60 DAT, the average plant height ranged between 88.2 cm and 97.3 cm.

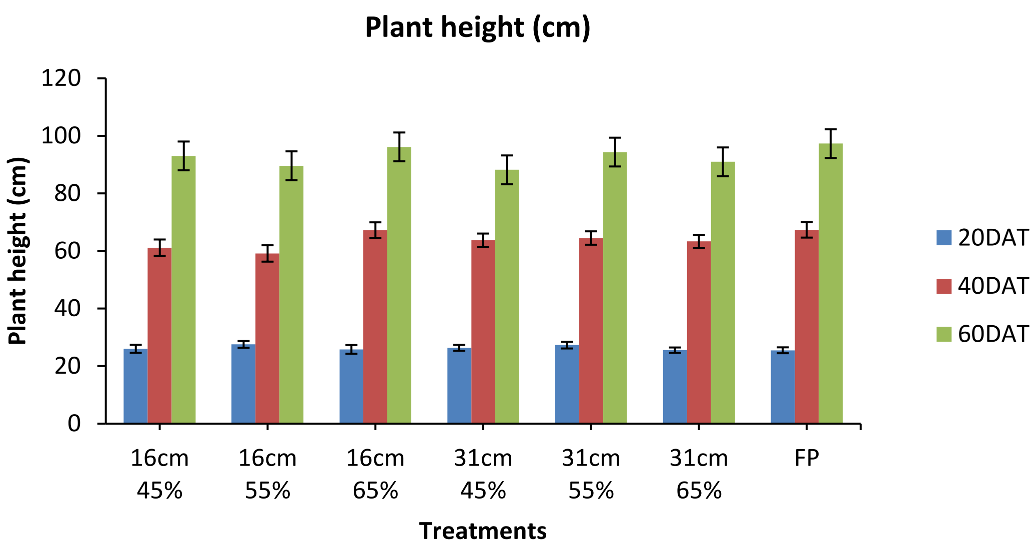

Figure 5: Plant height at 20, 40 and 60 DAT in different treatment plots

3.2 Days to flowering

Number of days taken to flowering after transplantation varied slightly among different replications (Figure 6). This variation might result from the replanting as replacement for dead plants. Nevertheless, tomato plants in all the plots exhibited 50% flowering between 52 and 59 days after transplanting (Figure 7).

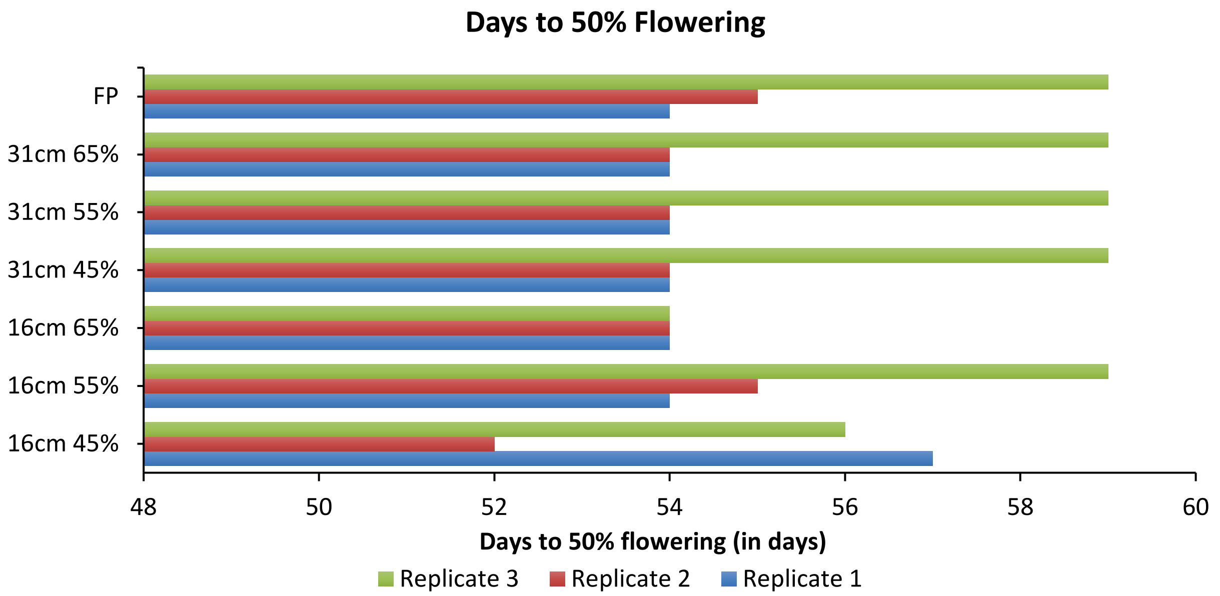

Figure 6: Days to 50% flowering after transplanting (replication wise)

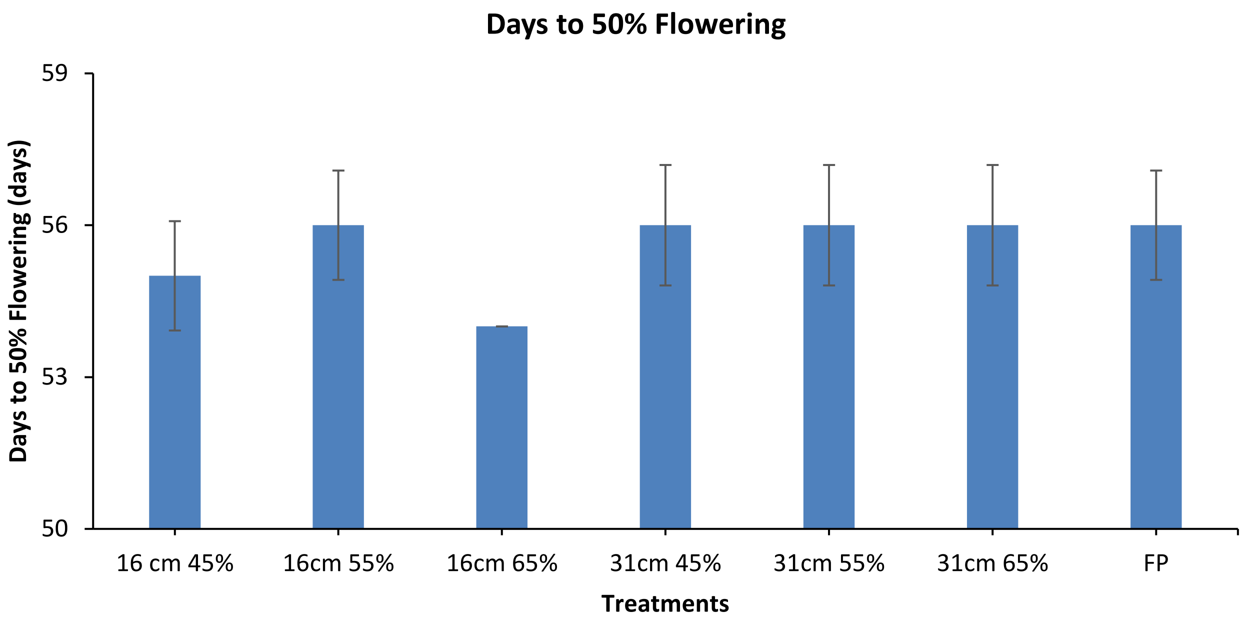

Figure 7: Days to 50% flowering (mean) after transplanting

3.3 Number of sensor-based irrigations and yield

During the establishment period, all the plots were irrigated regularly at the same time i.e. without any difference among treatments. The irrigation scheduling based on sensors started in January 2023. To coordinate the irrigation application for different treatments, as a rule, irrigation for a particular treatment was advised when PlantAlarm sensors blinked for at least two out of three replicates of that particular treatment. In the farmers' practice (FP) treatment, irrigation was provided based on visual observation by field staff, in a way similar to the usual practice of the farmers.

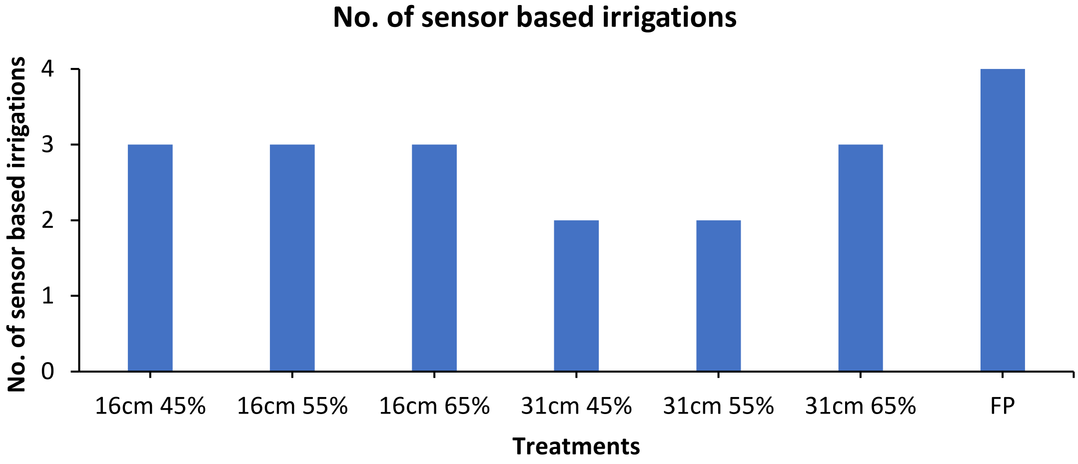

Figure 8: Number of sensor-based irrigations under different soil moisture sensor-based scheduling

In total, FP received the highest number of irrigations i.e., four irrigations (Figure 8) after the scheduling with sensors began in January 2023. In other treatments, the number of irrigations varied from 2 to 3. The blinking of PlantAlarm sensors upon reduction of available moisture in the soil was confirmed by the data retrieved from the Mini-loggers.

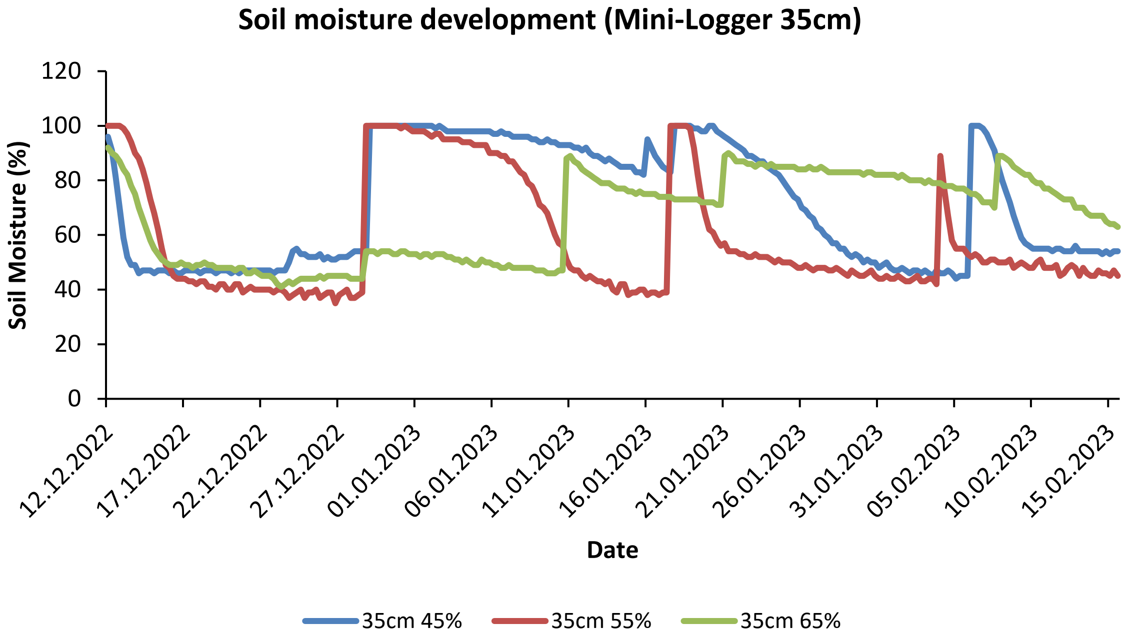

Figure 9: Soil moisture content when Mini-Logger was placed at 35 cm depth

Inclusion of Mini-Loggers in the trial proved to be valuable. Initially it helped in resolving the issue with placement-depth of PlantAlarm sensors. In a recent study, Pramanik et al (2022) also emphasized the importance of correct depth of placement of soil moisture sensors. The PlantCare Mini-Logger data helped to track the moisture changes in the soil and to cross-check the blinking status of PlantAlarm sensors in different treatments. Since the data could be retrieved easily without disturbing the sensor, it helps to know – in case of a PlantAlarm sensor not blinking – if it is due to sufficient moisture available in the soil or due to a technical issue. Furthermore, the Mini-Logger data provides useful insight on the moisture development with irrigation, time taken to depletion of moisture after irrigation and retention capacity of soil. The figures 9 to 14 present soil moisture development based on the data recorded by Mini-Loggers at different depths.

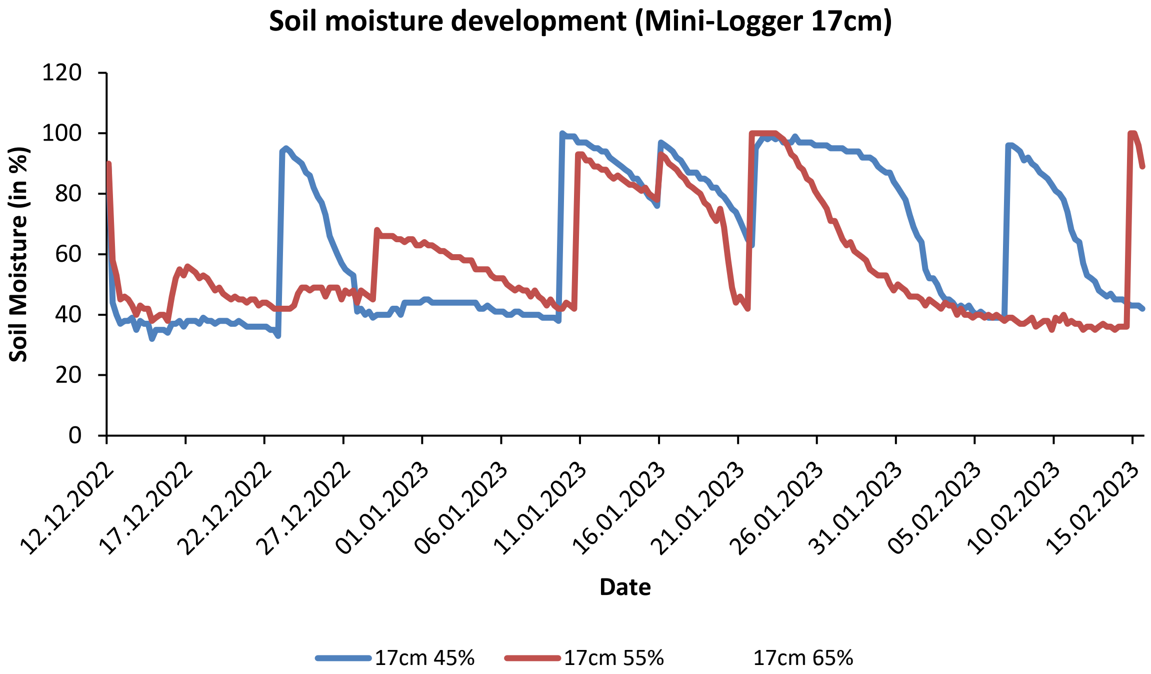

Figure 10: Soil moisture content when sensor was placed at 17 cm depth

The peaks of ca. 100% correspond to irrigation events. For example, in treatment 35cm 55% (Figure 9), the near saturation peaks (ca. 100%) on 12 December 2022 correspond to irrigation and on 29 December correspond to lower placement of sensors (watered at same time). It is evident that the moisture levels dropped below 55% on 11 January 2023. Due to local logistical constraints, timely irrigation was not available and hence the decrease in moisture continued till the moisture level reached below 40% on 17 January 2023. The PlantAlarm in plot 6 (treatment 35cm, 55%) showed consistency with this data and was blinking on 17 January 2023. On 18 January 2023, irrigation was provided, and moisture peak can be observed rising to 100%. In next 3 days, the moisture levels dropped to 55% on 21 January 2023. Similar rises and fall in moisture could be observed for other treatment plots.

With increase in day temperatures in January and February, the soil moisture decline was relatively faster and therefore the irrigation interval is consequently shortened.

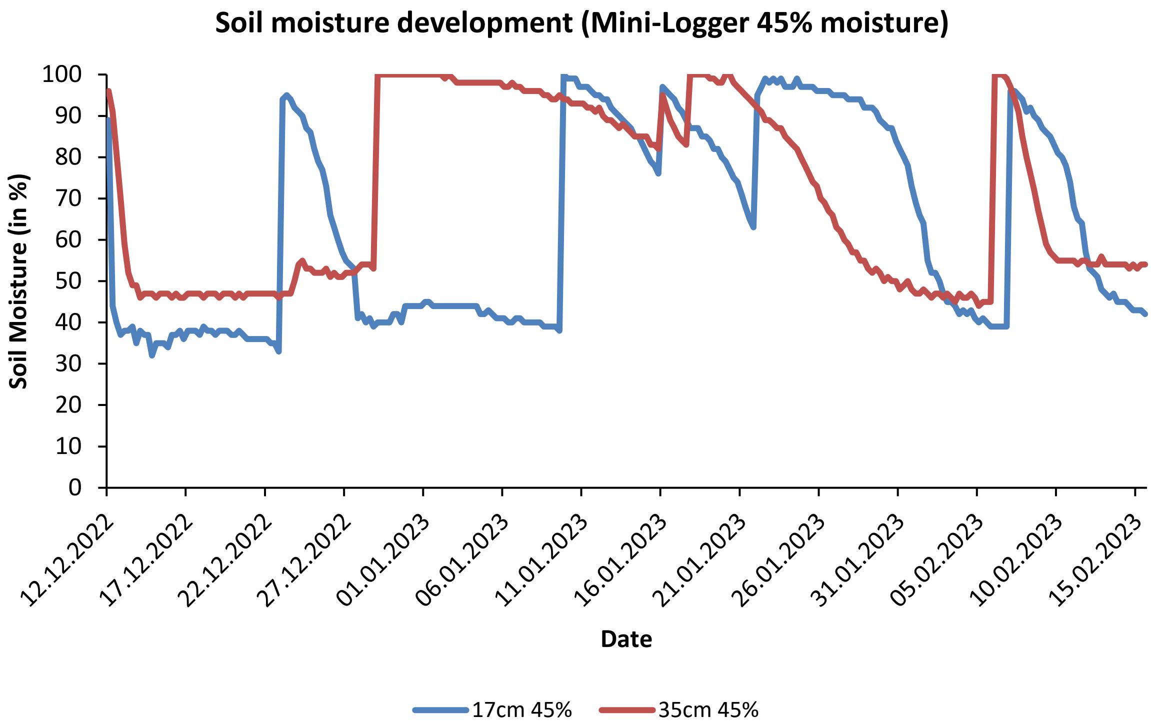

Figure 11: Soil moisture content at 17 cm and 35 cm depth with 45% setting

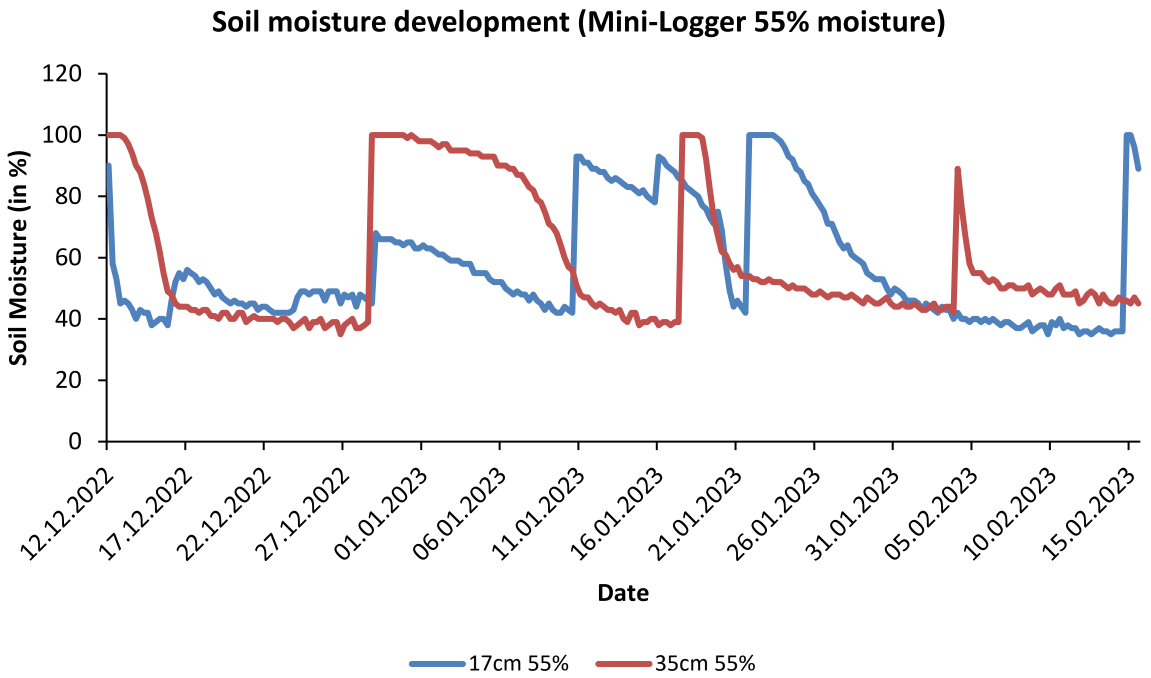

Figure 12: Soil moisture content at 17 cm and 35 cm depth with 55% setting

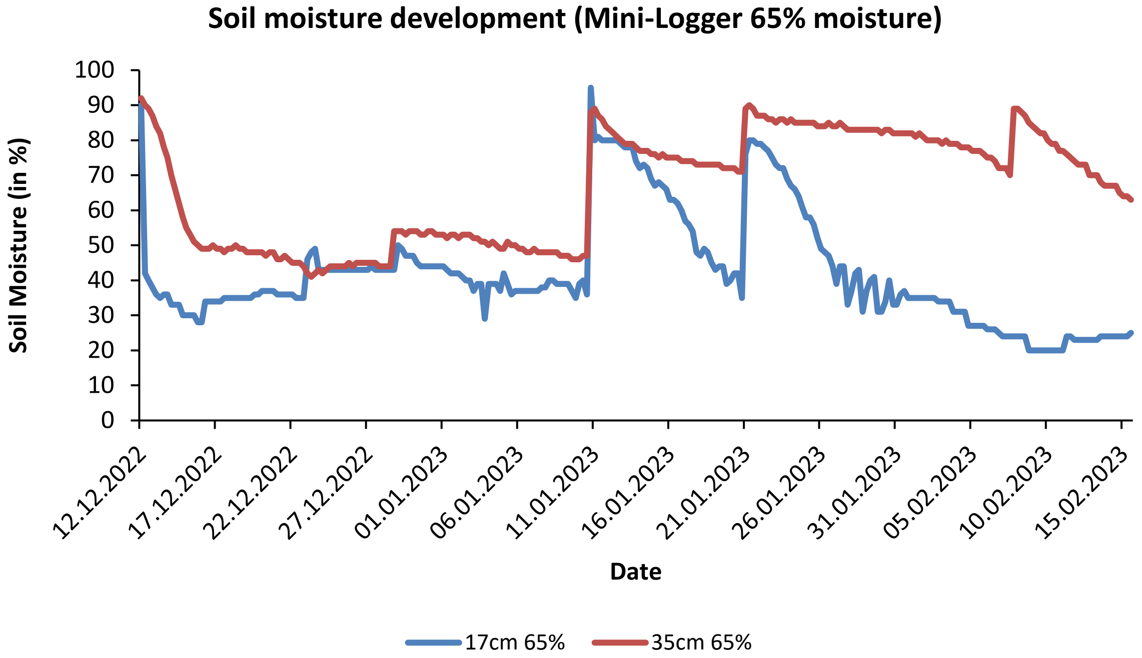

Figure 13: Soil moisture content at 17 cm and 35 cm depth with 65% setting

In farmers practice (Figure 14), the Mini-Logger placed at 35cm depth showed that the moisture was always above 65% and for the Mini-Logger placed at 17cm depth the moisture was always above 55%. This corresponds to more frequent irrigations based on visual observations by field staff. In figure 14, peaks for irrigation and the drop in moisture level between the two irrigation intervals can be clearly observed.

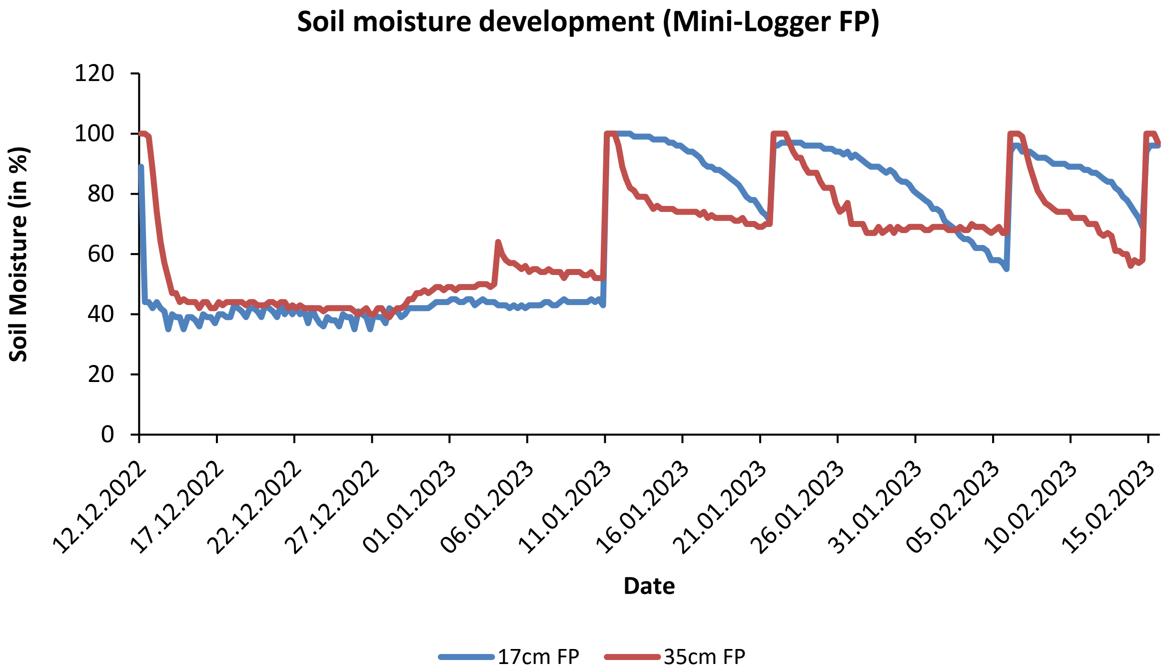

Figure 14: Soil moisture content in farmers' practice

Tomatoes were plucked manually as they matured based on visual observation of colour change from green to light yellow and then pinkish red. This stage of harvest was practised to meet the local market. They were sorted for quality and weighed per plot. In total, seven pickings were done - the first one on 29 January 2023 (71 DAT), followed by 6 pickings on 1 February (74 DAT), 4 February (77 DAT), 8 February (81 DAT), 12 February (85 DAT), 15 February (88 DAT) and 19 February (92 DAT), respectively. Replication wise yield for different irrigation treatments is presented in Figure 15.

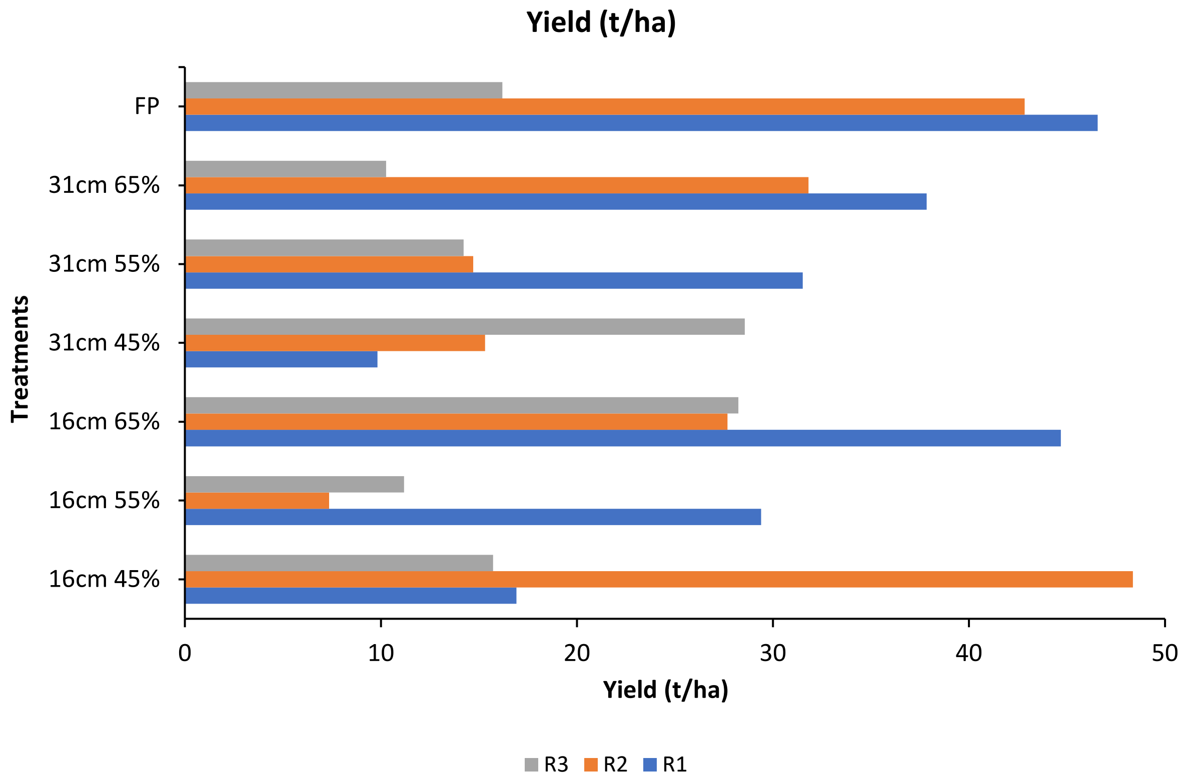

Figure 15: Yield (replication wise) of tomato under soil moisture sensor-based scheduling. Variation among three replicates of individual treatments can be observed. This high variation is primarily attributed to disease incidence in the trial field.

Considering average yield data, highest yield was obtained in farmers' practice (FP) i.e., 35.20 t/ha closely followed by treatment T2 (65%, 16cm) i.e., 33.53 t/ha (Figure 16). Notably, FP received highest number of irrigations i.e., four in comparison to T2 that received three irrigations based on PlantAlarm blinking sensors. The treatments with lower available moisture setting for PlantAlarm i.e., 55% or 45% received only two irrigations and correspondingly also resulted in lower yield. Our results indicate that at 65% plant available water settings, potential lies in saving of water and labour with sensor-based scheduling of irrigation, without significantly compromising productivity. However due to significant variation across replicates, as a result of crop damage, the yield outcome is not conclusive. Further studies are needed to quantify the yield per unit of water and to estimate the cropped area under limited availability of water resources for achieving an optimal production.

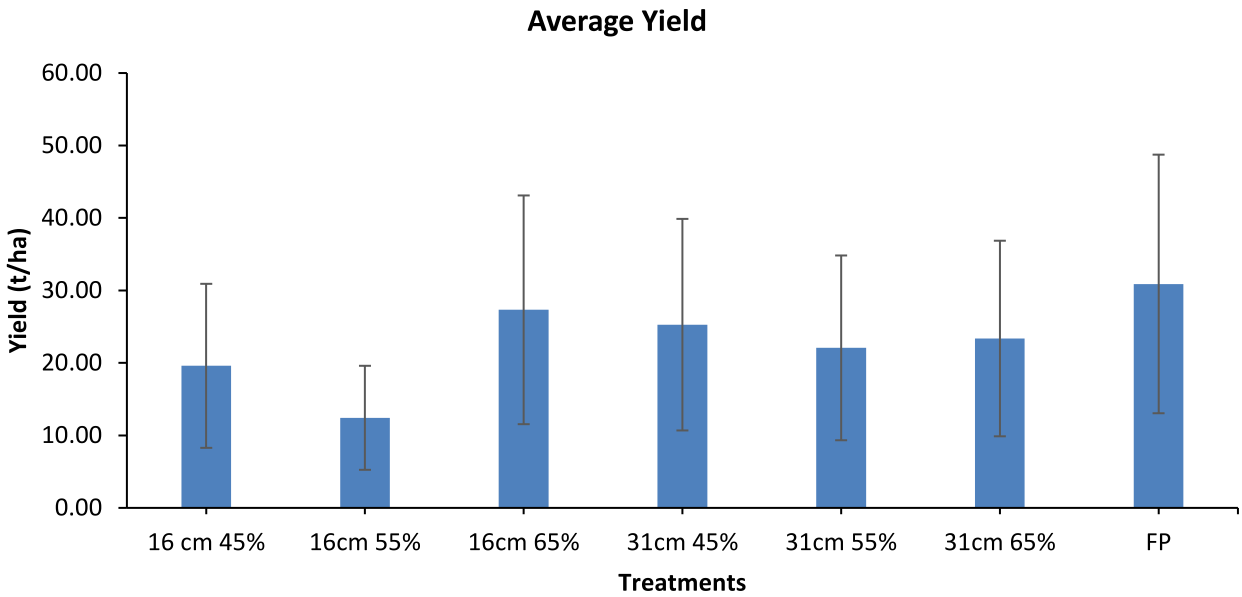

Figure 16: Mean yield of tomato under soil moisture sensor-based irrigation scheduling

4. Learning outcomes

Besides the results presented above, this first pilot study using moisture sensors provided a number of lessons that will be useful for future studies as well as for farming practices in the region. These learning outcomes are mentioned below:

1. Following appropriate crop rotation is an important practice for the sustainability and productivity of the farming system. *Solanaceae* - *Solanaceae* cropping sequence should be avoided to prevent pest build up. Soil borne disease of wilt and insect pest of *Spodotera* were very high in the present experiment due to adoption of *Solanaceae* (Brinjal) - *Solanaceae* (Tomato) cropping sequence. This information was not available at the commencement of the study. Other important vegetable crops in the Solanaceae family include potatoes, chillies and bell paper.

2. Wilt is an important disease that is either soil borne or transmitted through infected seedlings or infected equipment. Therefore, appropriate phytosanitary measures should be practiced and equipment used in the infected field should be thoroughly cleaned/sanitised before use in another field. Additionally, appropriate crop rotation and planting of cover crops (i.e., non-susceptible

plants) can reduce soilborne pathogen population. Further, cultivation of improved resistant tomato cultivars is highly recommended in coastal area to limit the incidence of wilt. An integrated management approach comprising of diverse control methods, i.e., cultural operations, host plant resistance and the use of chemical and/or biological control is the optimal way to control bacterial wilt of tomato in locations where the pathogen is established.

3. Soil solarisation should be done in the summer months to reduce the overall incidence of pests and diseases.

4. In case of ridge planted crops, the soil moisture sensor should be placed at the lower part of the ridge (not at the top of the ridge) in order to obtain optimal indication of soil moisture levels.

5. The depth of the soil moisture sensors and moisture settings need to be adapted to each crop and its agronomic practices i.e., planting strategy and irrigation method.

6. For a crop like tomatoes, staking support to the plant should be provided, so that the plant foliage or fruit do not come in contact with soil. Fruit damage by *Spodoptera* borers was high as the fruits were in contact with the soil. Another benefit of staking is uniform application of foliar spray on all parts of the plant.

7. To conduct an irrigation trial a site with sufficient and timely irrigation infrastructure needs to be selected. Unnecessary delay in irrigation or untimely irrigation may significantly influence the study results.

8. Communication channels and roles/responsibilities of different participants of the project need to be clarified in advance so as to ensure transparency and efficiency of communication and implementation.

5. Conclusions

Soil moisture sensor-based irrigation scheduling has potential for saving valuable water and human resources. This pilot study tested the 'PlantAlarm' sensor (developed by PlantCare AG) for the first time under Indian field conditions at Maa Mati campus in Odisha. The blinking status of PlantAlarm sensors was found to be sufficiently corresponding to the soil moisture data collected by Mini-Loggers. This shows that the PlantAlarm sensors are working well for irrigation scheduling. The depth of the sensor and moisture level settings need to be carefully adapted to the soil type, crop and its agronomic practices such as flat or ridge sown. To ensure optimal crop productivity and sustainability of the farming system, appropriate crop rotations and integrated disease and pest management are of crucial importance.

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Annexure 1: Details of date-wise cultural operations

Cultural Operations	**Date**
Date of nursery sowing	28.10.2022
Layout and transplanting	19.11.2022
Neem oil spray	29.11.22 2.12.22 4.12.22 6.12.22
Trichoderma	9.12.2022 16.12.22
Azotobacter (Crystal 8kg), MOP(4kg), Vermicompost (80kg) applied in all plots	10.12.22
Dahi drabyana applied 200ml in 15L water	11.12. 22 18.12.22
Earthing up done	12.12.22
Uprooting of wilted plants and application of bleaching powder there. Streptocycline soil drenching	30.12.22 02.1.23 04.1.23 06.1.23
Copper oxychloride alongwith irrigation water	11.1.23
N:P:K 19:19:19 applied @ 100g/ 16L	13.1.23
Spray of hormones @ 30ml/ 16 L water	15.1.23 06.2.23
Spray of insecticide Chlorpyriphos @30ml/16L	16.1.23
Chlorpyrifos sprayed	20.1.23
Permethrin along with irrigation water	21.1.23 06.2.23
Foliar spray of 19:19:19 N:P:K	05.2.23

Contributions

- **Intagris AG:** Project coordination and day-to-day supervision
- **BFH-HAFL:** Scientific back stopping and co-supervision
- **i-Concept Initiatives:** Provision of local infrastructure and field staff
- **Aqua Alimenta:** Financial support for the project
- **Swati Sucharita:** Researcher responsible for the conduct of experiment