Internet of Things (IoT) Application in Smart Farming to Optimize Tomato Growth

1st Dodi Yudo Setyawan
Faculty of Computer
Institut Informatika dan Bisnis Darmajaya
Bandar Lampung, Indonesia
dodi@darmajaya.ac.id

2nd Rahmalia Syahputri
Faculty of Computer
Institut Informatika dan Bisnis Darmajaya
Bandar Lampung, Indonesia
rahmalia@darmajaya.ac.id

3rd Nurfiana
Faculty of Computer
Institut Informatika dan Bisnis Darmajaya
Bandar Lampung, Indonesia
nurfiana@darmajaya.ac.id

4th Nurjoko
Faculty of Computer
Institut Informatika dan Bisnis Darmajaya
Bandar Lampung, Indonesia
nurjoko@darmajaya.ac.id

***Abstract*—Food is a vital need in human life and has become a significant commodity. In this sector, FAO Food and Agriculture Organization predicted in 2050 it will meet the food needs of 9.6 billion people. In addition, the reduction of agricultural land and climate change also contribute to the list of challenges in this sector. These challenges may trigger, for instance, a decline in the volume of agriculture yield, an increase in disease, and shifting cultivation periods. Therefore, it is a concern for all countries whose population growth rates keep increasing, including Indonesia. The fundamental thing in the Indonesian agricultural sector is the need for mass production of agricultural products to improve food security for its 275 million people. We can take advantage of cutting-edge Information and Communication Technology in the form of IoT to manage agricultural land and equip farmers in planning, monitoring, and managing agricultural land. This research aimed to compare the production of tomatoes that plant integrated by the IoT system with convention in a greenhouse situated in Cibodas, Lembang, West Java. The IoT system applied to smart farming uses the Message Queuing Telemetry Transport (MQTT) protocol. We found the productivity of integrated tomatoes increased by about 19% compared to conventional plants. Moreover, the Grade A-B of tomatoes increased by 9,8% while off-grade decreased by 9,6 %. Thus, IoT can optimize the yield of limited plant media.**

Keyword—Food; Agriculture; IoT; Greenhouse; Tomatoes

1 INTRODUCTION

Food is one of the issues faced by all countries whose population is rapidly growing. The immense challenge in Agriculture is to encounter the food needs of 9.6 billion people in the world by 2050 predicted by the FAO (Food and Agriculture Organization) [1],[2]. However, some obstacles appear, such as agricultural land and climate change. In Indonesia, the major problem is the need for intensification in agricultural production to increase Indonesia's food safety and security. Historically, Indonesia is an agrarian and maritime country and thus is wealthy in natural resources that are important as a source of public prosperity.

Nevertheless, there are many problems, particularly in agriculture and plantation, related to the quality of crops and the number of harvests. One of the solutions that could be employed is introducing and adopting precision agriculture techniques. It is required to use Information and Communication Technology to manage agricultural land to equip farmers in planning, monitoring, and managing agricultural land.

The Habibi Gardens, as an industrial company, and Darmajaya Institute, as an educational institution, created and produced an Internet of Things (IoT) system for the Smart Farming program operated in Cibodas, Lembang, West Java. This paper tries to explore IoT technology deployed on those projects. The problem of this work is how to improve the quality as well as quantity of agriculture production on greenhouse smart farming Fig. 1 .

Figure 1. Green House

The Habibi Gardens, as an industrial company, and Darmajaya Institute as an educational institution created and produced an Internet of Things (IoT) system for Smart Farming. This paper tries to explore IoT technology deployed on those projects. The problem of this work is how to improve the quality as well as quantity of agriculture production on greenhouse smart farming Fig. 1. According to [3]–[6], IoT is an emerging paradigm that enables the communication between electronic devices and sensors through the internet to facilitate our lives. IoT incorporates smart devices and the internet to provide innovative solutions to various challenges and issues related to business, governmental, and public or private industries globally. IoT is progressively becoming a substantial aspect of human life that could be sensed everywhere around us. Overall, IoT is an innovation that puts together intelligence systems, frameworks, intelligent devices, and sensors. Moreover, it takes advantage of nanotechnology in terms of storage data, sensing, and processing speeds which were not conceivable before [7], [8].

Whilst [9]–[11]mentioned that IoT has shown its importance and potential in the economic and industrial growth of a developing region. Also, in the trade and stock exchange market, it is considered a revolutionary step. However, the security of data and information is an important concern and highly desirable, which is a major challenging issue to deal with. The Internet is the largest source of security threats and cyberattacks have opened various doors for hackers and thus made the data and information. IoT has a multidisciplinary vision to provide its benefit to several domains such as environmental, industrial, public or private, medical, transportation, agriculture, etc [12]–[15]. Different researchers have explained the IoT differently concerning specific interests and aspects, [16]–[18] potential and power of IoT can be seen in several application domains. Fig. 2 illustrates a few of the application domains of IoT potentials. Various important IoT projects have taken charge of the market in the last few years.

Figure 2. Potential application domains of IoT

The application of IoT in the agriculture sector experienced considerable rapid development from 2010 to 2016 as shown by a paper published in Scopus with the theme IoT in Agriculture Fig. 3.

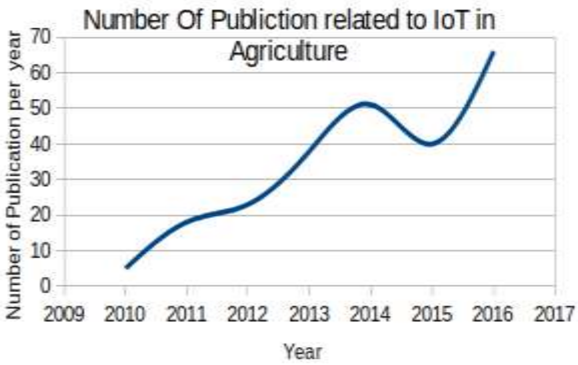

Figure 3. Research tema of IoT in Agriculture

2 METHOD

The Message Queuing Telemetry Transport (MQTT) protocol is one of the protocols that can be applied in smart farming. This protocol runs on top of the TCP/IP stack and for machine-to-machine communication that does not have a specific address while the MQTT work system implements Publish and Subscribe data. The devices will connect to MQTT Broker and have specific topics. We can see the MQTT protocol diagram in the following Fig. 4.

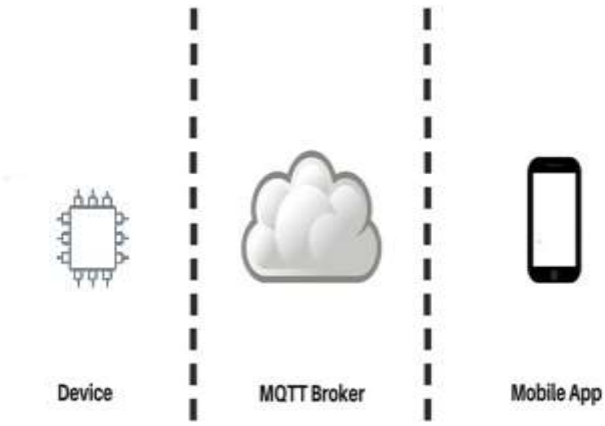

Figure 4 MQTT Protocol

The device consists of a soil PH sensor, a soil moisture sensor, an ESP32, a relay, and a water pump. Using the soil PH sensor to determine the level of soil acidity in a range from 1 to 14, the soil moisture sensor will be affected by fertilization and watering which is done either manually (pressing the button on the mobile app) or automatically (using the watering menu). This moisture and soil PH information is monitored via a mobile app. The connecting device to the Broker MQTT is the ESP32 node MCU. This device is widely used in smart farming [27], [28].

Fig.5 shows the device circuit where the soil PH sensor, soil moisture sensor, and relay are connected to esp32. The relay functions to turn on the water pump to activate this device to pump water or liquid fertilizer through the drip hose to each tomato plant, while the soil PH sensor and humidity sensor are located at the end of the tomato planting area. This device functions as a connector between Publishers (Sensors) and Subscribers (mobileApp).

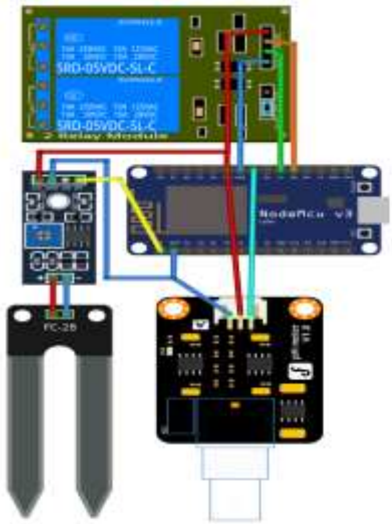

Figure 5. Device Diagram

The flow of data from soil PH and moisture sensor to ESP32, shown in Fig. 6 below. The soil PH library must be integrated to the ESP32. The data is still in analog and must be converted to digital data using ADC (Analog to Digital Converter) ESP32. The part of the program code, integrated the PH sensor library as follows:

```
#include "DFRobot_PH.h"
#include <OneWire.h>
#define sensor_ds18b20 2
OneWire oneWire(sensor_ds18b20);
DallasTemperature sensors(&oneWire);
int sensorPin = D5;
 DFRobot_PH ph;
```

The flow of data from soil PH and moisture sensor to ESP32 is shown in Fig. 6 below. The soil PH library must be integrated into the ESP32. The data is still analog and must be converted to digital data using ADC (Analog to Digital Converter) ESP32. The part of the program code, integrated the PH sensor library as follows:

```
#include "DFRobot_PH.h"
#include <OneWire.h>
#define sensor_ds18b20 2
OneWire one wire(sensor_ds18b20);
DallasTemperature sensors(&oneWire);
int sensor in = D5;
DFRobot_PH ph;
```

The soil moisture sensor did not need the library, only ADC ESP32, which has 10-bit data. the maximum value of moisture is 100 %, and the code to get 100 % is as follows :

```
float moisture = (analog read/1024)*100;
```

After reading the sensor's data and then the data is sent to the server by ESP32.

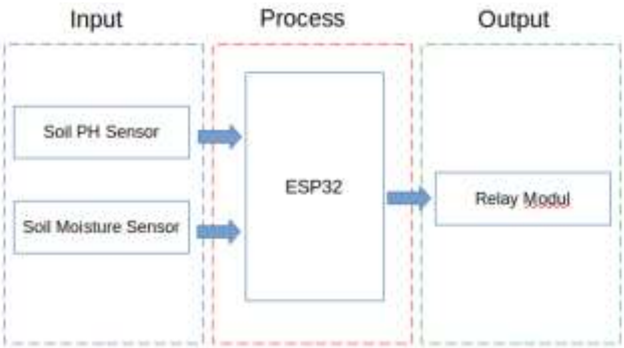

Figure 6 Process Diagram

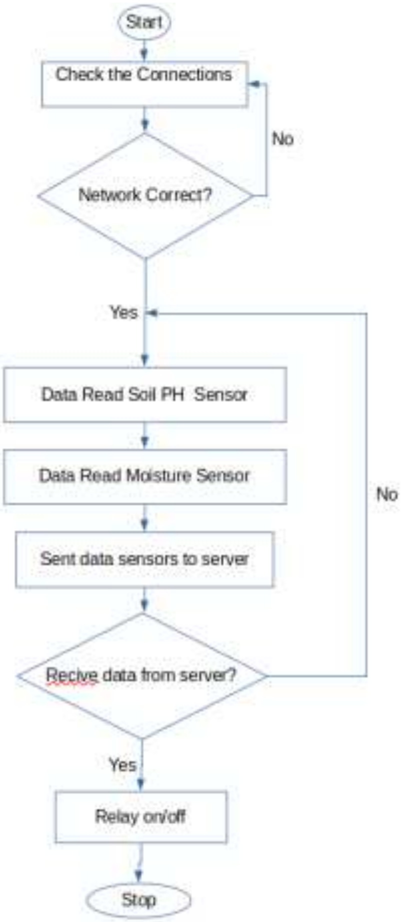

Figure 7 Flowchart hardware system

To control the relay can use automatic or manual mode. If automatic the relay is fully controlled by ESP32 and in manual mode the relay is controlled by the mobile app shown in fig. 7. Data from the mobile app is sent to the database in the server and then sent to the ESP32.

The program code to connect to the server ESP32 must integrate the ESP32 library and the name of the library is wifi. h. The part of the program code is as follows:

```
#ifndef WiFi_h
#define WiFi_h
const char* SSID = "BPP_SGH_LC";
const char* pass = "admin123";
String server = "http://tanicerdas.com/api/sensor";
```

BPP_SGH_LC is the name of SSID and admin123 is a password to connect to the wifi.
The sensors will publish a new message to intrusion detected topic on the MQTT broker immediately when an intrusion is detected then the Broker will add this message to the topic. Further, the mobile app will be a subscriber of this topic. This system is integrated into the tomato plant greenhouse. To examine the success of the integration of the IoT system in the smart farming of tomato plants, a comparison is made with other tomato plants that are not integrated, as shown in Fig. 8 below.

Figure 8. Conventional and integrated

Both conventional and integrated are located in one greenhouse. The number of plants both conventional and integrated is as many as 2000 tomato plants. The planting period for tomato plants is 308 days, and the integration of the IoT system is carried out from the beginning of planting until the harvest.

In the integrated area use a modern drip irrigation system. This system is not only used for water irrigation but also for fertilization. Drip irrigation is not only used in tomatoes but also for paddy cultivation. Drip irrigation can save 41,5% of water compared to conventional. the tools in the drip irrigation among other flush valves, sub-main line, dripper, polytube, and ball valve like figure 9

Figure 9 Drip irrigation

Monitoring and control of tomato plants with the help of a mobile app are easy to do, the mobile app shown in Fig. 10. The farmer can effortlessly monitor the temperature height, moisture content, nutrients or fertilizers, lighting, humidity, and air pressure in the greenhouse.

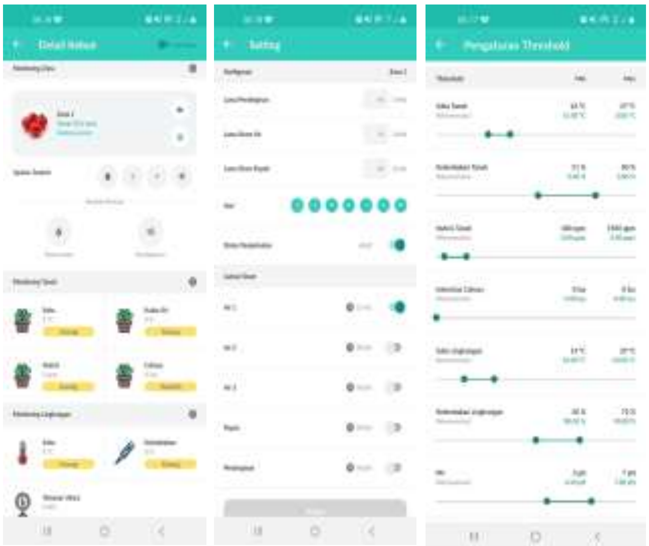

Figure 10. Mobile App menu

Watering and fertilization control can be done automatically by adjusting the watering time and time and fertilization in the settings menu from Saturday to Sunday. For tomato plants, the threshold for greenhouse conditions is in the temperature range of 26ºC to 37ºC, soil moisture is in the range of 51% to 80%, soil nutrition or fertilization is in the range of 400 ppm to 1500 ppm, light intensity is 0 lux, environmental temperature is in the range of 14ºC to 29ºC, environmental humidity in the range of 50% to 72% and soil acidity or power of Hydrogen (pH) 5 to 7.

After the mobile app is on and then will display PH and moisture and read the database using manual or automatic mode. if use automatic mode mobile app will read PH and moisture threshold. The button control is not active. If using manual mode the button control will be active and the user can control the relay in the ESP32 to make a water pump or fertilizer pump, the length of time the relay is on is according to the schedule.

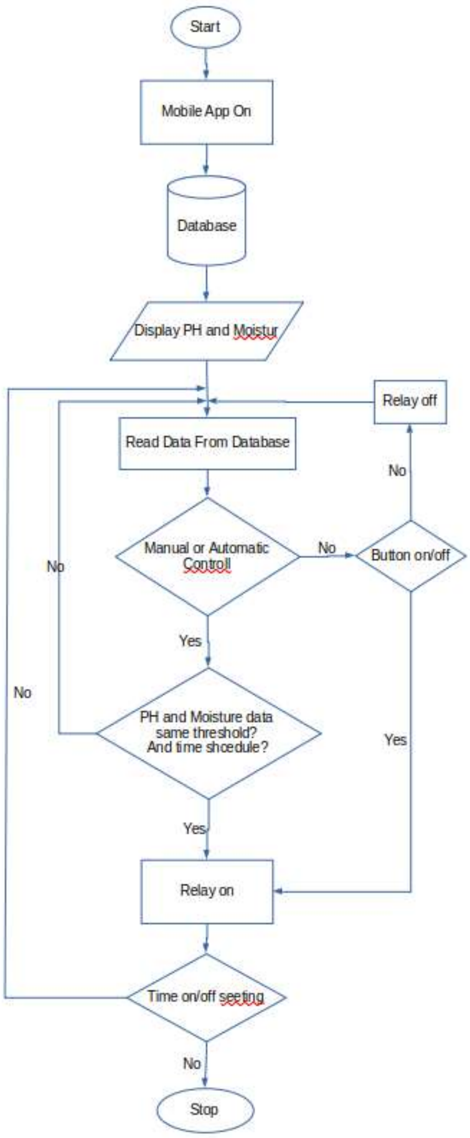

Figure 11. Flowchart mobile app

Beef tomato Used in this study as experiments carried out on Habibi Garden, Cibodas, Lembang, West-Java, Indonesia. Applied two systems, conventional which is without treatment (conventional), and integrated it means with some human intervention later such as applied fertilizer, plant distance, and maintenance. This research was carried out on Habibi Garden by using tomato beef plant two treatments were applied in this work specifically conventional and Maintenance. In maintenance, we apply 5 types of fertilizer, AB-Mix, Urea, KCL, MKP, Boron, and Organic fertilizer. Besides that, in this garden, deployed IoT tools systems (Habibi grow, Habibi dose, Habibi climate, Habibi link, and mechanical drip tape irrigation 1.6) shown in Fig. 11 to maintain that the normal environment is most likely natural. Several parameters were measured in this research such as root length, tomato size, tomato high, number of branches, number of stems, tomato fruits, and disease problems such as plant viruses, plant abnormality, and caterpillars. Experiment procedure; the Beef tomato was deployed using both conventional and integrated; Growth was computed fruit diameter, plant high, number of branches, number of stems, and length of root; Experiment was carried out from the 8th to 30th day of plant growth.

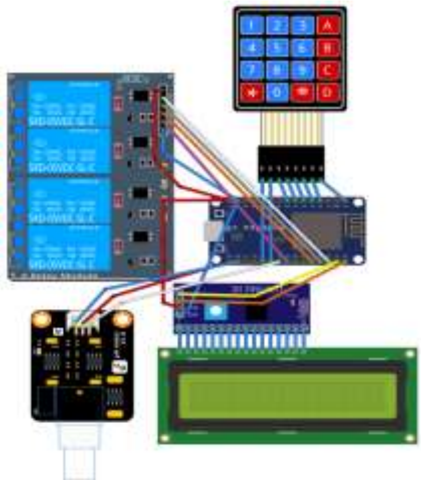

Figure 12 Device integrated tools

The integrated tools consist of ESP32, LCD 16x2, module relay, PH Sensor, and the keypad as shown in figure 12. It is used to control AB mix fertilizer. Modul relay used to control the water valve from a reservoir.

AB Mix fertilizer is a fertilizer consisting of a mixture of two fertilizers, namely A and B. The main elements in concentration A are calcium (Ca) and in concentration, Bare sulfate (S) and phosphate (P). Fertilizer concentration is 1120 ppm in the tank AB mix, shown Fig. 13. To get fertilizer concentration 1120 is mixing A and B fertilizer from tanks A and B. Make flow switch form tank A and B on or off using a relay from the integrated tool. A flow switch is a solenoid valve that is the valve with the movement of opening or closing the valve which is regulated by the system, how the solenoid valve work is shown in fig. 13.

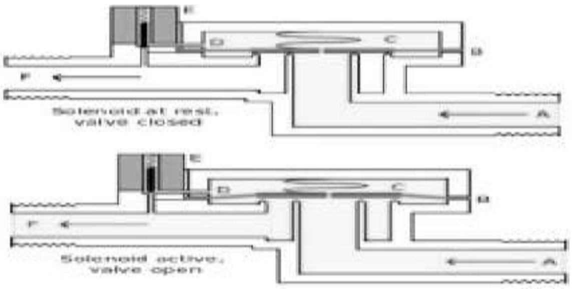

Figure 13. Selenoid Valve

The solenoid valve will work when the coil gets a current-voltage power according to the working voltage(mostly solenoid working voltage valve is 100/200VAC and most of the working voltage on DC is 12/24VDC). And a pin will be attracted by the strong magnetic force generated from the solenoid coil. And when the pin is pulled up then the fluid will flow from room C to section D quickly. So the pressure in room C decreases and the incoming fluid pressure raises the diaphragm. So the main valve opens and fluid flows directly from A to F.

The concentration value sensing by PH Sensor. Besides the mobile app the fertilizer concentration can show in Liquid Crystal Display (LCD). The flowchart integrated tools are shown in Fig. 15.

Figure 14. AB mix fertilizer

The system must hold fertilizer concentration in 1120 ppm sensing by a PH sensor placed in AB mix tank.

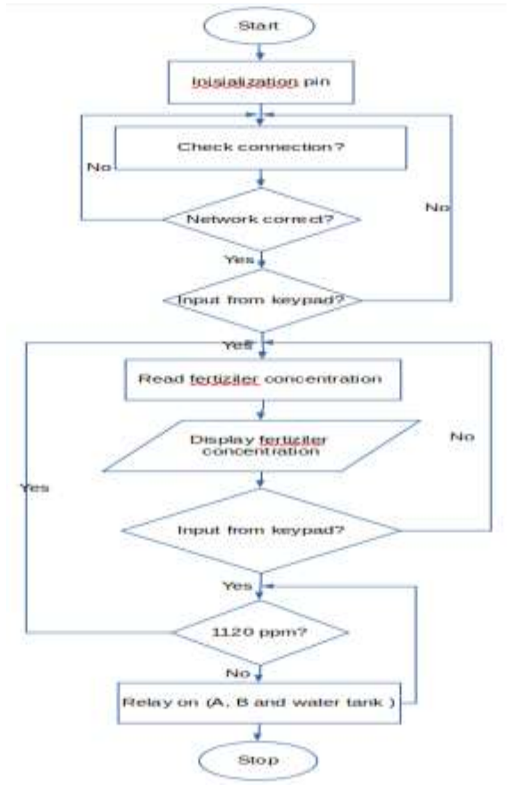

Figure. 15 Flowchart Integrated Tools

If using the other plant, fertilizer concentration can be set using a keypad and if the concentration was so high the flow switch from the water tank will be on. AB mix fertilizer contains all the essential nutrients Plants need nutrients in the form of Macro and microelements. The macro element contains Nitrogen (N), Calcium (Ca) Fosfor (P), Magnesium (Mg), and Sulfur (S). The microelement contains Ferit (Fe), Baron (B) Mangan (Mn) Copper (Cu) Molybdenum (NaMo), and H, C, and O from the air. AB mix fertilizer Not only uses water as a media plant, but the Hydroponic can also use soil. The value of fertilizer and PH in the other plant is shown in Table 1.

Table 1. Value of fertilizer

Vegetables	PH	PPM
Turnip	6.0-7.0	840-1540
Lettuce	6.0-7.0	560-840
Cauliflower	6.5-7.0	106-1400
Pakcoy	7	1050-1400
Cucumber	5.5	1190-1750
Eggplant	6	1750-2450
Tomatoes	6.0-6.5	1120-3500
Bitter Mustard	6.0-6.5	840-1680
Strawberry	6	1260-1540
Spinach	5.5-6.5	1050-1400
Mustard	5.5-6.5	1050-1400
Celery	6.0	1260-1680
Chili	6.0-6.5	1260-1540
Carrot	6.3	1120-1400
Marjoram	6	1120-1400
Peterseli	5.5-6.5	560-1260
Peas	6.0-7.0	980-1260
Sweet Corn	6.0	840-1680
Potato	5.0-6.0	1400-1750

To use an integrated tool for the other plant or vegetables just set the value Part Per Million (PPM) using the keypad.

3 RESULT AND DISCUSSION

Based on experiments, general plants with treatment show better growth in fruit diameter, plant height, number of branches, number of stems, and length of the root. Based on the experiment, beef tomato applied with fertilizer treatment shows more number plants compared to those without treatment (conventional). The comparison of maintenance fertilizer is shown in Table 2.

Table 2. Fertilizer

Fertilizer	Conventional	Integrated
AB-MIX	150 Kg	115 Kg
Urea (ZA)	20 Kg	0 Kg
KNO-White	20 Kg	0 Kg
KCL	20 Kg	15,2 Kg
MPK	20 Kg	8 Kg
Boron	40 Kg	0 Kg
Organic Fertilizer	0 Kg	6 Kg

Integrated system liquid fertilizer has flowed through Drip Tape Irrigation on every tomato plant. Of the total fertilization between conventional and integrated is 2:1 produced. Fig 16 illustrated the number of branches, the number of branches integrated is more than conventional from day 5 to day 10.

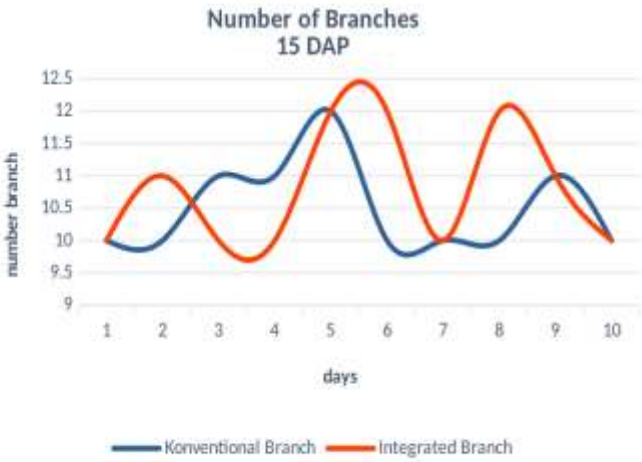

Figure 16. Number of beef tomato

Basics fertilizer was deployed on 1.000 m2 shows that the average number of used fertilizers is better compared to those without fertilizer, 1.684,08 and 1.462 plants.

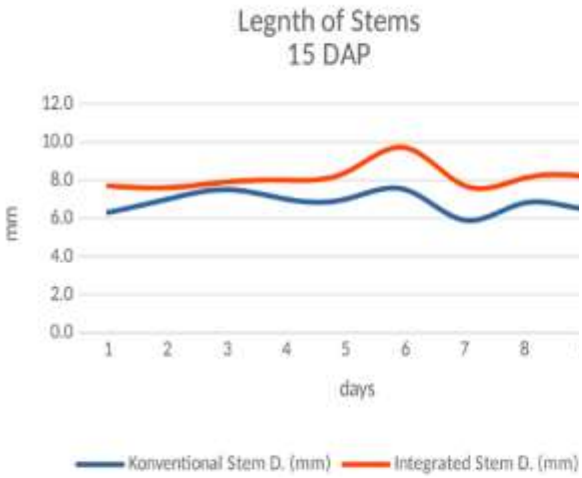

Figure 17. Length of Stems

Figure 17 showed the stems on integration were longer than conventional from day 1 to day 10 of observation.

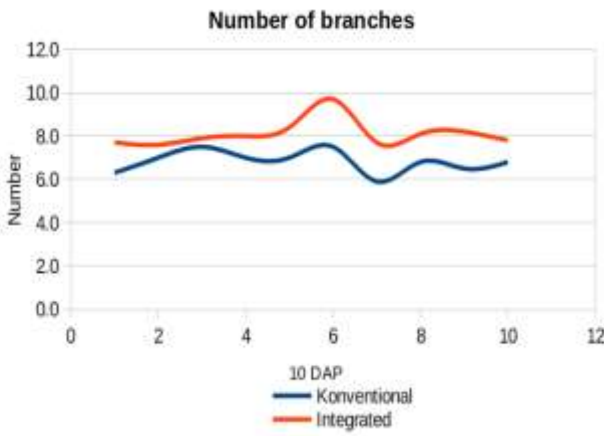

Figure 18. Number Branches

Figure 18 shown The number of branches in integrated is more than conventional

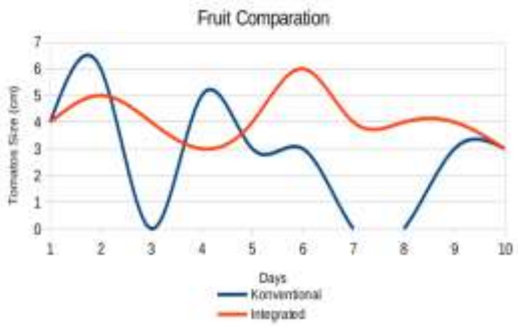

Figure 19. Fruits Comparation

Figure 19 shown the tomatos size in integrated is more than conventional.

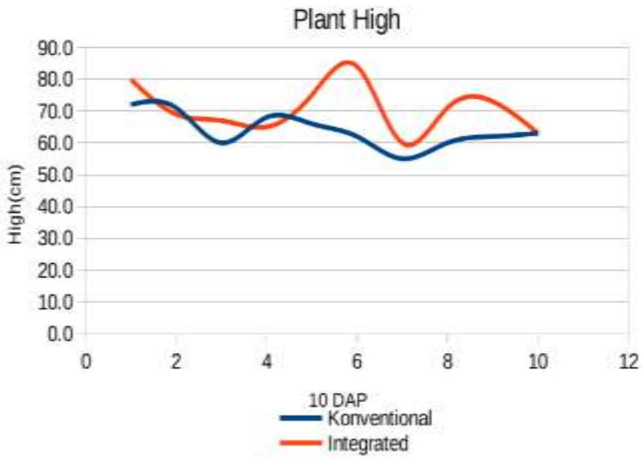

Figure 20. Plant high comparation

Figure 20 shown the high plant in integrated is more than conventional

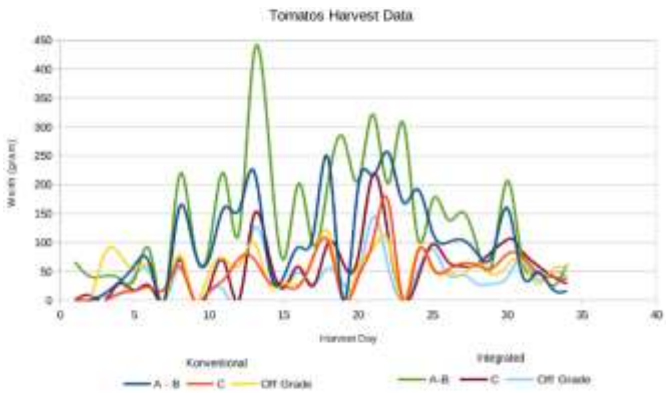

Figure 21. Tomatoes Harvest Data

The weight of tomato grade A-B is 150 to 400 grams/fruit, grade C in the range of 110-150 grams/fruit, and off-grade less than 110 grams/fruit. Off-grade tomatoes showed the size was not normal and the fruit skin was damaged. The problem of fruit damage and caterpillar attack before harvest resulted in lower integrated plot yields than conventional plots. Precaution has been taken to prevent further fruit damage by adding boron and calcinate to the integrated plot and reducing the application of protecting F and humic acid to suppress vegetatively

4 CONCLUSION

The integration of the IoT system in tomato plants produces better tomato products than tomato products without the integration of the IoT (conventional) system. In addition, the same area and number of plants can save fertilizer by 49% (referring to table 1). IoT system integration and data collection on growth and tomato fruit products from March 22 to August 4, 2020.

The integrated plot area was faster than the conventional plot. The height and number of branches of tomato plants on the integrated plot were higher and more numerous than the conventional one by comparison of 8.1 to 6.8. the yield productivity increased by 19%. The Grade A-B of tomatoes increased 9.8%, and the off-grade decreased 9.6%.

AUTHOR'S CONTRIBUTION

As the first author, Dodi Yudo Setyawan contributed technically and wrote to this research. He did the research under the supervision of the second and the third author namely Rahmalia Syahputri and Nurfiana for ideas and technical aspects. Last, the research got theoretical supervision from the third author Nurjoko.

COMPETING INTERESTS

Comply with the publication ethics of this journal, Dodi Yudo Setyawan, Rahmalia Syahputri, Nurfiana, and Nurjoko the authors of this article declare that this article is free from conflict of interest (COI) or competing interest (CI).

REFERENCES

[1] A. A. R. Madushanki, M. N, W. A., en A. Syed, "Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming towards Urban Greening: A Review", *IJACSA*, vol 10, no 4, 2019, doi: 10.14569/IJACSA.2019.0100402.

[2] K. Foughali, K. Fathallah, en A. Frihida, "A Cloud-IOT Based Decision Support System for Potato Pest Prevention", *Procedia Computer Science*, vol 160, bll 616–623, 2019, doi: 10.1016/j.procs.2019.11.038.

[3] R. Gorli, "Future of Smart Farming with Internet of Things", vol 1, no 1, bl 13.

[4] S. Lhazmir, O. A. Oualhaj, A. Kobbane, en L. Mokdad, "A decision-making analysis in UAV-enabled wireless power transfer for IoT networks", *Simulation Modelling Practice and Theory*, vol 103, bl 102102, Sep 2020, doi: 10.1016/j.simpat.2020.102102.

[5] N. Gulati en P. D. Kaur, "An argumentation enabled decision making approach for Fall Activity Recognition in Social IoT based Ambient Assisted Living systems", *Future Generation Computer Systems*, vol 122, bll 82–97, Sep 2021, doi: 10.1016/j.future.2021.04.005.

[6] S. Kamalakkannan, A. K. Kulatunga, en L. A. D. A. D. Bandara, "The conceptual framework of IoT based decision support system for life cycle management", *Procedia Manufacturing*, vol 43, bll 423–430, 2020, doi: 10.1016/j.promfg.2020.02.192.

[7] M. Bacco, P. Barsocchi, E. Ferro, A. Gotta, en M. Ruggeri, "The Digitisation of Agriculture: a Survey of Research Activities on Smart Farming", *Array*, vol 3–4, bl 100009, Sep 2019, doi: 10.1016/j.array.2019.100009.

[8] A. Ilmudeen, "Chapter 16 - Design and development of IoT-based decision support system for dengue analysis and prediction: case study on Sri Lankan context", in *Healthcare Paradigms in the Internet of Things Ecosystem*, V. E. Balas en S. Pal, Reds Academic Press, 2021, bll 363–380. doi: 10.1016/B978-0-12-819664-9.00016-8.

[9] K. N. Sivabalan, V. Anandkumar, en S. Balakrishnan, "IOT Based Smart Farming for Effective Utilization of Water and Energy", *International Journal of Advanced Science and Technology*, vol 29, no 7, bl 6, 2020.

[10] G. Balakrishna en N. R. Moparthi, "Study report on Indian agriculture with IoT", *IJECE*, vol 10, no 3, bl 2322, Jun 2020, doi: 10.11591/ijece.v10i3.pp2322-2328.

[11] N. Pappas, A. Caputo, M. M. Pellegrini, G. Marzi, en E. Michopoulou, "The complexity of decision-making processes and IoT adoption in accommodation SMEs", *Journal of Business Research*, vol 131, bll 573–583, Jul 2021, doi: 10.1016/j.jbusres.2021.01.010.

[12] A. Muneer, S. M. Fati, en S. Fuddah, "Smart health monitoring system using IoT based smart fitness mirror", *TELKOMNIKA*, vol 18, no 1, bl 317, Feb 2020, doi: 10.12928/telkomnika.v18i1.12434.

[13] K. Sekaran, M. N. Meqdad, P. Kumar, S. Rajan, en S. Kadry, "Smart agriculture management system using internet of things", *TELKOMNIKA*, vol 18, no 3, bl 1275, Jun 2020, doi: 10.12928/telkomnika.v18i3.14029.

[14] P. Periyadi, G. I. Hapsari, Z. Wakid, en S. Mudopar, "IoT-based guppy fish farming monitoring and controlling system", *TELKOMNIKA*, vol 18, no 3, bl 1538, Jun 2020, doi: 10.12928/telkomnika.v18i3.14850.

[15] R. Dagar, S. Som, en S. K. Khatri, "Smart Farming – IoT in Agriculture", in *2018 International Conference on Inventive Research in Computing Applications (ICIRCA)*, Jul 2018, bll 1052–1056. doi: 10.1109/ICIRCA.2018.8597264.

[16] Dept of AIML, BMSIT&M, Bangalore, India *et al.*, "Smart Farming: IoT Based Water Managing System", *IJITEE*, vol 9, no 4, bll 2383–2385, Feb 2020, doi: 10.35940/ijitee.D1796.029420.

[17] S. Kim, M. Lee, en C. Shin, "IoT-Based Strawberry Disease Prediction System for Smart Farming", *Sensors*, vol 18, no 11, bl 4051, Nov 2018, doi: 10.3390/s18114051.

[18] P. C. Siswipraptini, R. N. Aziza, I. Sangadji, en I. Indrianto, "The design of a smart home controller based on ADALINE", *TELKOMNIKA*, vol 18, no 4, bl 2177, Aug 2020, doi: 10.12928/telkomnika.v18i4.14893.

[19] J. Fan, Y. Zhang, W. Wen, S. Gu, X. Lu, en X. Guo, "The future of Internet of Things in agriculture: Plant high-throughput phenotypic platform", *Journal of Cleaner Production*, vol

280, bl 123651, Jan 2021, doi: 10.1016/j.jclepro.2020.123651.

[20] N. Gondchawar en D. R. S. Kawitkar, “IoT based Smart Agriculture”, vol 5, no 6, bl 5.

[21] G. W. W. En en H. Devanthran, “The Development Of Smart Farming Technologies And Its Application In Malaysia”, vol 9, no 08, bl 6, 2020.

[22] O. Friha, M. A. Ferrag, L. Shu, L. Maglaras, en X. Wang, “Internet of Things for the Future of Smart Agriculture: A Comprehensive Survey of Emerging Technologies”, *IEEE/CAA J. Autom. Sinica*, vol 8, no 4, bll 718–752, Apr 2021, doi: 10.1109/JAS.2021.1003925.

[23] J. Muangprathub, N. Boonnam, S. Kajornkasirat, N. Lekbangpong, A. Wanichsombat, en P. Nillaor, “IoT and agriculture data analysis for smart farm”, *Computers and Electronics in Agriculture*, vol 156, bll 467–474, Jan 2019, doi: 10.1016/j.compag.2018.12.011.

[24] S. Omar, “Internet of Things (IoT) for Smart Farming: A Systematic Review”, *IJCA*, vol 174, no 27, bll 47–54, Mrt 2021, doi: 10.5120/ijca2021921182.

[25] “Fraga-Lamas et al. - 2020 - Design and Empirical Validation of a LoRaWAN IoT S.pdf”. Toegang verkry: 06 Junie 2022. [Online]. Available at: https://mdpi-res.com/d_attachment/proceedings/proceedings-42-00062/article_deploy/proceedings-42-00062.pdf?version=1587443453

[26] J. Doshi, T. Patel, en S. kumar Bharti, “Smart Farming using IoT, a solution for optimally monitoring farming conditions”, *Procedia Computer Science*, vol 160, bll 746–751, 2019, doi: 10.1016/j.procs.2019.11.016.

[27] A. I. Abdulla *et al.*, “Internet of Things and Smart Home Security”, vol 62, no 05, bl 13, 2020.

[28] R. N. Athirah, C. Y. N. Norasma, en M. R. Ismail, “Development of an Android Application for Smart Farming in Crop Management”, *IOP Conf. Ser.: Earth Environ. Sci.*, vol 540, no 1, bl 012074, Jul 2020, doi: 10.1088/1755-1315/540/1/012074