Scientific Papers. Series B, Horticulture. Vol. LXIX, No. 1, 2025
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

PRECISION AGRICULTURE EXTENSION MODEL BASED ON INTERDISCIPLINARY COLLABORATION

Dragoș-Ioan SĂCĂLEANU[1], Adrian ASĂNICĂ[2], Abigail BORRON[3], Daniela FAUR[1], Horia-Nicolae CIOCAN[2], Gary L. HAWKINS[3], Ioan-Ștefan SACALĂ[1], Dan POPESCU[3], Mihai-Gabriel MATACHE[4]

[1]National University of Science and Technology Politehnica Bucharest, 313 Splaiul Unirii, District 6, 060042, Bucharest, Romania
[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăști Blvd, District 1, 011464, Bucharest, Romania
[3]University of Georgia, 147 Cedar St, 30602, Athens, GA, USA
[4]National Institute of Research–Development for Machines and Installations Designed for Agriculture and Food Industry Bucharest, 6 Ion Ionescu de la Brad Blvd, District 1, 013813, Bucharest, Romania

Corresponding author email: ciocan.horia@managusamv.ro

Abstract

This article presents the technical development of an autonomous irrigation system designed to optimize water delivery and support precision agriculture. Developed through a collaboration between the National University of Science and Technology Politehnica Bucharest and the National Institute of Research–Development for Machines and Installations Designed for Agriculture and Food Industry Bucharest and tested by the University of Agronomic Sciences and Veterinary Medicine of Bucharest, the system integrates advanced engineering principles and agronomic expertise to address challenges in modern agriculture. The system architecture includes an embedded control unit and wireless sensor nodes with microcontrollers, wireless communication transceivers, and soil-crop interaction sensors such as capacitive moisture probes. Real-time data acquisition enables adaptive irrigation management using predictive algorithms, ensuring precise water application aligned with crop phenological stages and environmental variability. The system's modularity ensures scalability across various farm sizes, from smallholders to large-scale operations. This initiative strengthens a cooperative agricultural extension framework, facilitating knowledge transfer between students and faculty from the involved universities. By bridging technical and agronomic expertise, the system represents a leap forward in integrating precision agriculture into sustainable farming practices.

Key words: *precision agriculture, cooperative extension, interdisciplinary collaboration, wireless sensors, irrigation.*

INTRODUCTION

The increasing demand for sustainable agricultural practices and the urgent need for climate-adaptive solutions have highlighted the importance of integrating precision technologies into modern farming systems. In this context, interdisciplinary collaboration among engineering, agronomic, and extension education institutions plays a crucial role in fostering innovation and ensuring the practical implementation of advanced technologies in the field (Teodorescu & Alexandrescu, 2007). This article presents a case study of such collaboration, developed between the National University of Science and Technology Politehnica Bucharest, the University of Agronomic Sciences and Veterinary Medicine of Bucharest, the National Institute of Research–Development for Machines and Installations Designed for Agriculture and Food Industry Bucharest, and the University of Georgia, USA. Building upon the century-old Cooperative Extension model from the United States, this initiative demonstrates how joint efforts among academic and research institutions can lead to impactful outcomes for rural communities and agricultural stakeholders (Borron et al., 2019).

The project focuses on the design, development, and testing of an autonomous irrigation system tailored for precision agriculture.

This c system integrates embedded technologies, wireless sensor networks (WSN), and adaptive control mechanisms to optimize water use based on real-time environmental data and crop-specific needs.

The principle of wireless technology applied to monitoring and control for environmental parameters started more than 20 years ago when multiple studies analyzed this possibility (Shen et al., 2001; Akylidiz et al., 2004). Many solutions are proposed these days due to the advantages that these systems bring. The challenges and opportunities offered to small-scale farmers by the latest technological advancements are reviewed by (Dhillon et al., 2023). To support them in enhancing productivity and sustainability (Ding et al., 2019) discuss the need for affordable technological solutions of monitoring and controlling. (Le Van et al., 2022) proposes a WSN with low-cost, low-power sensor nodes that operate using solar power. A controller was also developed to provide IoT connectivity. (Placidi et al., 2021) designed a low-power wireless sensor network based on the LoRaWAN protocol by using commercial components and free or open-source software libraries. A real-time, LoRaWAN-based sensor network is also proposed by (Kumar et al., 2020). Many solutions for WSN based systems for environmental parameters involves mainly the monitoring part (Rezvani et al., 2020; Săcăleanu et al., 2018). The solutions that include the control part usually use low cost and low reliability relays (Tatas et al., 2022; Kirci et al., 2022). The proposed solution contains both monitoring and control parts and, further, offers an independent operation based on an autonomous algorithm (Codeluppi et al., 2020).

Beyond its technical value, the system also brings clear economic benefits. By applying water only when and where it is needed, the technology reduces resource waste and operational costs. Moreover, by automating irrigation decisions and scheduling, the system significantly decreases the time spent by farmers on monitoring and manual intervention. This allows labor to be redirected toward higher-value tasks, increasing overall farm efficiency (Sofwan et al., 2020). In the long term, such innovations contribute to improved yield stability, better input management, and a higher return on investment (Săcăleanu et al., 2023).

The collaborative effort underpinning the development of the autonomous irrigation system also serves as a pilot for a broader extension strategy, in which students, faculty, and researchers engage directly in technology development, testing, and knowledge transfer (Ilvento, 1997). This academic-practical feedback loop strengthens both the educational experience and the responsiveness of scientific research to real-world agricultural challenges. By adopting an interdisciplinary and cross-institutional approach, the project not only addresses technical and agronomic needs, but also promotes economic sustainability, time efficiency, and scalable solutions for precision agriculture across diverse farming contexts (Ciocan et al., 2024b).

MATERIALS AND METHODS

Based on the Cooperative Extension model developed by the University of Georgia, this project demonstrates how interdisciplinary collaboration between engineering, agronomy, and extension sciences can yield scalable, affordable, and high-impact solutions for agriculture (Wang, 2014). The proposed autonomous irrigation system was developed not only as a technical prototype, but as a practical, user-oriented tool that can be deployed in real-world agricultural environments across Romania.

The technical architecture of the system supports the core goals of precision agriculture: real-time monitoring, data-driven decision-making, and resource optimization. Each wireless sensor node (WSn), built around the Arduino MKR WAN 1310 development board, integrates a suite of environmental sensors that monitor key parameters such as soil moisture, air temperature and humidity, light intensity, and atmospheric pressure. The use of LoRa communication protocol ensures low-power, long-range data transmission even in areas with limited network infrastructure, which is often the case in rural Romania.

Collected data are transmitted to a base station (BS) that also functions as a wireless actuator node (WAn), capable of controlling irrigation valves based on predefined thresholds and predictive algorithms. The modular structure of the system allows it to be adapted to different farm sizes and layouts, from a small greenhouse setup with two irrigation zones to a larger open-field system requiring multiple nodes and control points.

RESULTS AND DISCUSSIONS

To evaluate the practical implementation of the proposed system, a series of field tests were conducted using a modular setup that reflects the diversity of farm sizes and infrastructure commonly found in Romanian horticultural contexts. The following section presents the key technical results obtained during the deployment and testing phase, highlighting both the system's performance and its adaptability to real-world agricultural conditions. These findings are then discussed in relation to the broader goals of precision agriculture, sustainability, and rural innovation.

The system proposed in this paper is scalable, making it suitable for different scenarios. The tested implemented scenario includes four wireless sensor nodes (WSns) and a base station, serving also as a wireless actuator node. The scenario block diagram is presented in Figure 1.

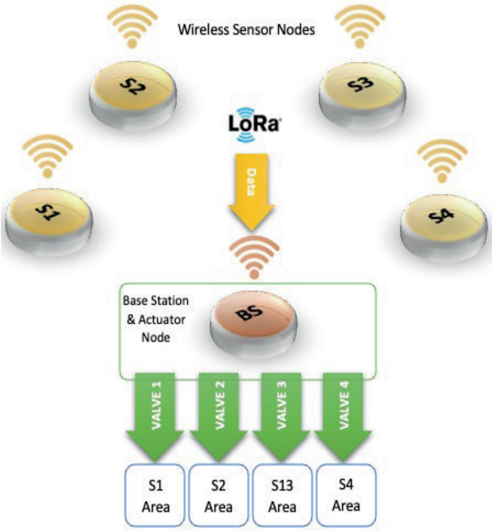

Figure 1. The architecture of the proposed system.

Data is acquired by the WSn and transmitted via a LoRa radio to the base station. There, the data are processed, stored and, depending on the values, the actuators can be activated.

Depending on the amount of area that needs to be monitored, the number of sensors nodes can be increased or decreased, as the solution can be implemented from small-scale to large-scale scenarios. The WSn and Base Station architectures were developed to be compatible with the Arduino MKR developing boards family. For the presented scenario, the Arduino MKR WAN 1310 developing board was used with LoRa communication, but other communication protocol options can be implemented, like Wi-Fi (Arduino MKR1000).

Wireless Sensor Node development

The role of the wireless sensor nodes is to acquire data from sensors, process them, and transmit the information to the base station. In Figure 2 is presented the proposed block diagram of the node including the parameters acquired.

Figure 2. Wireless sensor node block diagram.

For signal conditioning and to facilitate the connection of multiple sensors with a variety of interface protocols, a flexible node interface was developed. The interface was designed as a two-layer PCB with dimensions of 85 × 66.5 mm. The central component of the node is the microcontroller-based development board Arduino MKR WAN 1310 from the Arduino MKR family that includes the high performance and low power SAMD21 Cortex®-M0 + 32-bit ARM MCU microcontroller, the Murata CMWX1ZZABZ module with LoRa® communication and support for power supply from Li-ion or Li-Po rechargeable batteries with an integrated recharge circuit. The Arduino MKR ENV Shield personalized shield with environmental sensors, and a microSD card slot is mounted on top of the Arduino MKR WAN 1310 (Arduino MKR ENV Shield).

Based on the parameters of interest tested in this paper, a set of sensors was selected. Table 1 presents the acquired parameters together with the used sensors.

Table 1. The WSn acquired parameters and sensors

No	Parameter	Sensor	Type
1	Light Intensity	VISHAY TEMT6000	Analog
2	Air Pressure	ST LPS22HB	SPI
3	Node Temperature	ST HTS221	SPI
4	Node Humidity		
5	Air Temperature	DHT22	OneWire
6	Air Humidity		
7	Soil Tension	Watermark Sensor	Analog

The battery voltage level is acquired using an analog pin, passed previously through a ½ voltage divider. Two Li-ion 18650 rechargeable batteries of 5000 mAh were used for power supply, and a 2 W photovoltaic panel was used for battery charging. A 3D printed custom covered case was developed to protect the circuits. Figure 3 shows the final version of the wireless sensor nodes.

Figure 3. The WSn installed in the prototype scenario

Each WSn had a basic data processing software routine. After the initial setup for the microcontroller, transceiver, and individual sensors, the node acquired data from the sensors, processed them, stored them on the microSD card, and sent them to the base station. Finally, the WSn enters in a sleep mode to reduce the power consumption. Considering the application, the sleep time can be adjusted, for this scenario the parameters are acquired, and the data packets are transmitted each 1 minute. When waking up, the WSn continued acquiring a new set of data.

Base Station development

The Base Station (BS) acts as a receiver for the messages transmitted by the WSn but, also, as a wireless actuator node (WAn) to control the activation and deactiviation of the irrigation valves. Figure 4 presents the proposed block diagram for the BS with WAn.

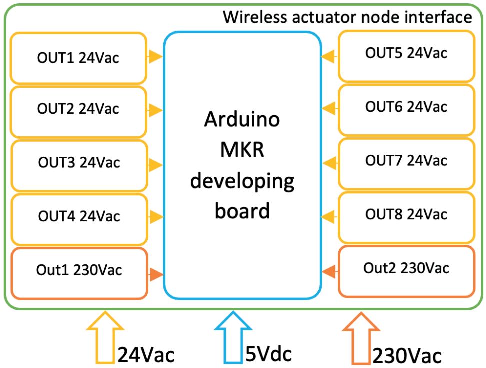

Figure 4. BS with WAn block diagram

Common equipment that can control environmental parameters (e.g., water, heat, ventilation, shadow) is powered by 24 Vac (e.g., solenoid valves for irrigation) or 230 Vac (e.g., fans and motors to control air temperature and humidity, CO2, and light intensity). The WAn was developed by considering eight channels to control 24 Vac, max. 0.5 A devices and two channels to control 230 Vac, max. 4 A devices. The Arduino MKR WAN 1310 was also used as central component for the WAn.

The designed WAn signal conditioning interface has a two-layer PCB with dimensions of 217 × 131 mm. Solid State Relay are used to control the eight 24 Vac channels and the two 230 Vac channels, together with 1 A fuse and a 5 A fuse, respectively.

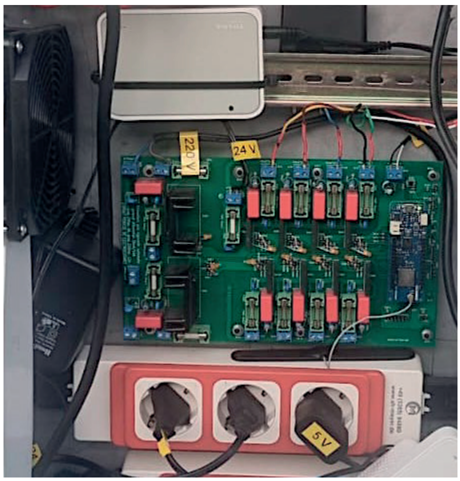

Figure 5. The installed Base Station

The BS receives the messages from the WSn and process them. The algorithm organigram can be observed in Figure 6. Each WSn has a unique ID implemented and transmitted with every message to distinguish the provenience of the data packet. Based on the value for the soil tension (Hum), compared with a defined threshold (THR), the correspondent valve is activated for 1 minute period or not. The BS is connected at the mains, and it is always in the listening state with no sleep periods.

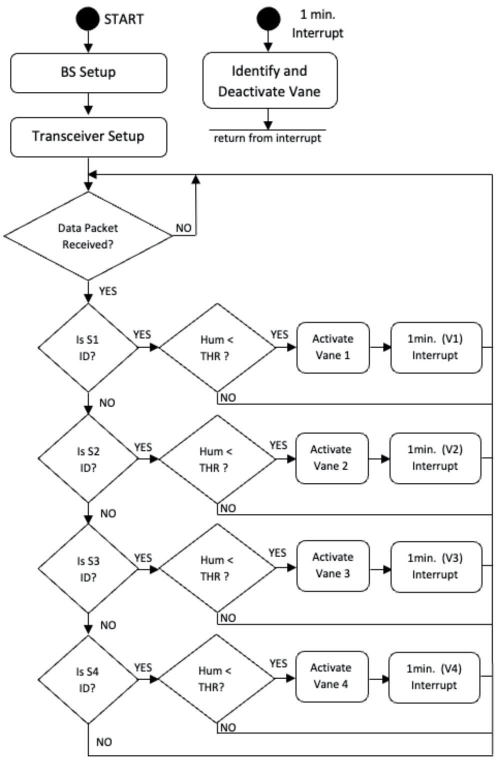

Figure 6. BS algorithm

The technical simplicity and low energy requirements (powered by photovoltaic panels and rechargeable batteries) make the system highly cost-effective and easy to maintain. This is particularly relevant in communities where farmers have limited access to high-end agricultural technology and technical support (Ciocan et al. 2024a,). In its current form, the system can be locally produced or assembled using affordable components, which opens the door for mass implementation through university-led extension programs or rural development grants (Stefanescu et al. 2013)).

From an applied perspective, the prototype addresses three fundamental challenges frequently reported by Romanian horticultural producers:

• lack of labor availability for daily irrigation tasks;

• poor water use efficiency, especially during dry seasons;

• lack of reliable data for making timely agronomic decisions.

The system was specifically designed to address the needs of small and medium-sized farmers, integrating direct input from growers regarding key aspects such as Matca (Galați County), Izbiceni (Olt County), Vidra (Ilfov County), Băleni (Dâmbovița County), and Lungulețu (Dâmbovița County). These localities represent some of the most active horticultural regions in Romania, characterized by intensive vegetable production both in greenhouses and in open fields. Farmers in these areas expressed interest in affordable, easy-to-use systems that can automate irrigation without requiring high levels of technical expertise. Discussions revealed common budget constraints (below €500 for a full system), irregular internet access, and a strong need for reliable solutions that could reduce water waste and manual labor (Teodorescu & Alexandrescu 2007).

In response to these constraints, the system was designed to be energy-independent, capable of operating offline, and structured around open-source hardware and software. It supports scalability, so it can grow with the farm's needs, and includes simple maintenance routines that can be learned quickly by end-users (Rezgui et al., 2007).

The benefits observed in the prototype phase include:

• up to 30% reduction in water usage compared to manual irrigation methods;

• potential reduction in fertilizer runoff through synchronized fertigation;

• labor savings by eliminating the need for constant field monitoring;

• consistent moisture control leading to healthier crops and potentially increased yields;

• extended equipment lifespan by optimizing valve cycles and reducing overuse.

These outcomes directly contribute to rural development goals by increasing farm profitability, lowering input costs, and improving resilience to environmental stress. Moreover, by embedding the system in a cooperative academic extension framework, it creates opportunities for local capacity building. Students and researchers become active participants in solving local agricultural problems, while farmers receive customized support and knowledge transfer based on scientific data and applied research (Ciocan et al., 2024b).

Finally, this initiative lays the foundation for a broader digital transformation of Romanian horticulture. The system can serve as a gateway for integrating other smart agriculture technologies such as remote diagnostics, weather forecasting, or crop health monitoring (Ding & Chandra, 2019). In time, such technologies can become central to national strategies aimed at increasing competitiveness, sustainability, and innovation in the agricultural sector.

CONCLUSIONS

The autonomous irrigation system presented in this study demonstrates the potential of interdisciplinary collaboration to generate practical, scalable solutions for precision agriculture. By combining engineering innovation with agronomic knowledge and cooperative extension principles, the cooperation initiative addresses both technological and economic challenges faced by small and medium-sized farms in Romania.

The system's modular design, low energy consumption, and compatibility with open-source platforms enhance its affordability and deployment, particularly in rural areas with limited infrastructure.

Engagement with farmers from major horticultural regions - including Matca, Izbiceni, Vidra, and Lungulețu - ensured that the proposed system is aligned with real-world requirements regarding cost-effectiveness, ease of use, and adaptability to field conditions.

Economically, this prototype reduces water use, labor input, and operational costs, contributing to more sustainable and efficient horticultural practices (Placidi et al., 2021). Strategically, this initiative reinforces the role of academic institutions in rural development through hands-on extension activities and digital innovation.

In the next stage, the system will be tested on a wide range of horticultural crops, and the data collected will be used to refine the irrigation algorithms and support further scientific research. This will strengthen the system's adaptive capacity and open new opportunities for integrating precision agriculture into broader digital farming strategies.

This initiative embodies not only a technical innovation, but also a scalable model of institutional collaboration aimed at promoting sustainable and digitally enabled agricultural development.

ACKNOWLEDGEMENTS

This research was carried out with the support of Ministry of Agriculture and Rural Development, and it was financed from Project ADER 6.1.3/18.07.2023.

The work of Dragoș-Ioan Săcăleanu was supported by a grant from the National Program for Research of the National Association of Technical Universities – GNAC ARUT 2023.

REFERENCES

Akyildiz, I. F., & Kasimoglu, I. H. (2004). Wireless sensor and actor networks: Research challenges. *Ad Hoc Networks*, 2(4), 351–367.

Borron, A., Lamm, K., Darbisi, C., & Randall, N. (2019). Social impact assessment in the cooperative extension system: Revitalizing the community capitals framework in measurement and approach. *Journal of International Agricultural and Extension Education*, 26(2), 75-88.

Ciocan, H. N., Batrina, S. L., Balta, I., Moraru, P. I., Săcăleanu, D. I., & Borron, A. (2024). A proposed agricultural extension model for Romania: Leveraging universities' resources to create a cost-efficient and impactful knowledge transfer system inspired by the U.S. model. *Scientific Papers. Series Management, Economic Engineering in Agriculture and Rural Development*, 24(4), 191–204. https://www.managementjournal.usamv.ro/index.php/scientific-papers/vol-24-issue-4

Ciocan, H. N., Popescu, A., Dinu, T. A., Stoian, E., & Moldoveanu, I. D. (2024). Filling the knowledge gap: How the absence of an agricultural extension system drives Romanian farmers to seek advice and informal consultancy on social media, increasing the misinformation risk. *Scientific Papers. Series Management, Economic Engineering in Agriculture and Rural Development*, 24(3), 213–228.

https://www.managementjournal.usamv.ro/index.php/scientific-papers/vol-24-issue-3

Codeluppi, G., Cilfone, A., Davoli, L., & Ferrari, G. (2020). LoRaFarM: A LoRaWAN-based smart farming modular IoT architecture. *Sensors*, 20(7), 2028.

Dhillon, R., & Moncur, Q. (2023). Small-scale farming: A review of challenges and potential opportunities offered by technological advancements. *Sustainability*, 15(18), 15478.

Ding, J., & Chandra, R. (2019, October 11). Towards low cost soil sensing using Wi-Fi. In *Proceedings of the 25th Annual International Conference on Mobile Computing and Networking* (pp. 1–16). Association for Computing Machinery. https://doi.org/10.1145/3300061.3345443

Ilvento, T. W. (1997). Expanding the role and function of the Cooperative Extension System in the university setting. *Agricultural and Resource Economics Review*, 26(2), 153-165.

Kirci, P., Ozturk, E., & Celik, Y. (2022). A novel approach for monitoring of smart greenhouse and flowerpot parameters and detection of plant growth with sensors. *Agriculture*, 12(11), 1705.

Kumar, A., Singh, V., Kumar, S., Jaiswal, S. P., & Bhadoria, V. S. (2022). IoT enabled system to monitor and control greenhouse. *Materials Today: Proceedings*, 49, 3137–3141.

Placidi, P., Morbidelli, R., Fortunati, D., Papini, N., Gobbi, F., & Scorzoni, A. (2021). Monitoring soil and ambient parameters in the IoT precision agriculture scenario: An original modeling approach dedicated to low-cost soil water content sensors. *Sensors*, 21(15), 5110.

Rezgui, A., & Eltoweissy, M. (2007). Service-oriented sensor–actuator networks: Promises, challenges, and the road ahead. *Computer Communications*, 30(13), 2627–2648.

Rezvani, S. M.-e., Abyaneh, H. Z., Shamshiri, R. R., Balasundram, S. K., Dworak, V., Goodarzi, M., Sultan, M., & Mahns, B. (2020). IoT-based sensor data fusion for determining optimality degrees of microclimate parameters in commercial greenhouse production of tomato. *Sensors*, 20(22), 6474.

Săcăleanu, D. I., & Kiss, I. K. (2018, October). Monitoring walnut orchards with LoRa technology. In 2018 IEEE 24th International Symposium for Design and *Technology in Electronic Packaging (SIITME)* (pp. 76–79). IEEE.

Săcăleanu, D. I., Manciu, I. P., Roşu, Ş. G., Perişoară, L. A., Tannouche, A., & Creţu, L. E. S. (2023, June). GSM wireless sensor node prototype for infield environmental parameters acquisition. In *15th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)* (pp. 1–6). IEEE.

Shen, C. C., Srisathapornphat, C., & Jaikaeo, C. (2001). Sensor information networking architecture and applications. *IEEE Personal Communications*, 8(4), 52–59.

Sofwan, A., Sumardi, S., Ahmada, A. I., Ibrahim, I., Budiraharjo, K., & Karno, K. (2020, March). Smart Greetthings: Smart greenhouse based on Internet of Things for environmental engineering. In 2020 *International Conference on Smart Technology and Applications (ICoSTA)* (pp. 1–5). IEEE.

Stefanescu, S. L., Steriu, S., & Dumitraşcu, M. (2013). Public and Private Players on the Market of Agricultural Advice and Extension in Romania. *Extension Education Worldwide*, 239.

Tatas, K., Al-Zoubi, A., Christofides, N., Zannettis, C., Chrysostomou, M., Panteli, S., & Antoniou, A. (2022). Reliable IoT-based monitoring and control of hydroponic systems. *Technologies*, 10(2), 26.

Teodorescu, G., & Alexandrescu, D. (2007). Improvement of fruit production and precision horticulture opportunities in Romania. *Scientific volume*, (50).

Van, T. L., Thi, P. N., Minh, P. V., Thi, L. D., Cong, H. L., & Phuong, T. N. T. (2022). Design and implementation of a wireless sensor network for smart greenhouse controller. *CommIT (Communication and Information Technology) Journal*, 16(1), 1–8.

Wang, S. L. (2014). Cooperative extension system: Trends and economic impacts on US agriculture. *Choices*, 29(1), 1-8.