Journal Homepage
www.ajas.uoanbar.edu.iq
Anbar Journal of Agricultural Sciences
(University of Anbar – College of Agriculture)

Evaluation Of Application Levels to Agricultural Extension Agents in Precision Agriculture Techniques to Improve the Efficiency of Agricultural Resource Usage in Salah Al-Din Governorate

W. S. Ayyed [1] **A. Z. Al–Hafidh [2]***

[1] Dept. Econ. And Agri. Ext. College of Agriculture, Tikrit University.
[2] Dept. Agri. Ext. and Tech. Trans., College of Agriculture and Forestry, Mosul University.

***Correspondence to:** Asmaa Zuhair Al–Hafidh, Dep. Agri. Ext. and Tech. Trans., College of Agriculture and Forestry, Mosul University, Iraq.
Email: asmaa_alhafidh@uomosul.edu.iq

Article info

Received: 2025-02-08
Accepted: 2025-07-14
Published: 2025-12-31

DOI-Crossref:
10.32649/ajas.2025.189369

Cite as:
Ayyed, W. S., and Al–Hafidh, A. Z. (2025). Evaluation Of Application Levels to Agricultural Extension Agents in Precision Agriculture Techniques to Improve the Efficiency of Agricultural Resource Usage in Salah Al-Din Governorate. Anbar Journal of Agricultural Sciences, 23(2): 1312-1324.

Abstract

This research evaluated the application levels for agricultural extension agents in precision agriculture techniques for improving agricultural resource usage in Salah Al-Din governorate. It examined their effectiveness, organizational planning, monitoring, implementation, and evaluating abilities and analysed differences based on specific variables. These included productivity gains from precision agriculture techniques, agricultural extension fields, qualifications, length of service, job grade, and participation in activities related to precision agriculture techniques. For this purpose, a questionnaire was prepared (with verified virtual and content validity) covering two areas, namely personal characteristics, and 30 norms comprising five measures that were developed after reviewing the literature and conducting interviews with specialists. Data was collected from 1/11/2024-28/1/2025. The research community represented 14.54% of the total 385 respondents, with the sample of 56 employees in Tikrit Governorate. Twenty employees were excluded from the final research sample. The statistical methods employed were the Kruskal-Wallis and Mann-Whitney U tests, and the Z-score. Key findings on the effectiveness of precision agriculture revealed a mixed picture, with two factors being particularly significant, i.e., agricultural extension and office qualifications. These had a substantial impact on how precision agriculture is evaluated. The main conclusions highlight the crucial role of specialists and senior staff in extension programs, who play a vital part in precision agriculture.

Keywords: Evaluation, Implementation, Monitoring, Organization, Planning.

تقويم مستوى تطبيق المرشدين الزراعيين لتقنيات الزراعة الدقيقة في تحسين كفاءة استخدام الموارد الزراعية في محافظة صلاح الدين

وليد صبار عايد [1] **اسماء زهير الحافظ** [2]*

[1] **قسم الاقتصاد والارشاد الزراعي، كلية الزراعة، جامعة تكريت.**

[2] **قسم الارشاد الزراعي ونقل التقنيات، كلية الزراعة والغابات، جامعة الموصل.**

***المراسلة الى:** اسماء زهير الحافظ، قسم الارشاد الزراعي ونقل التقنيات، كلية الزراعة والغابات، جامعة الموصل، العراق.

البريد الالكتروني: asmaa_alhafidh@uomosul.edu.iq

الخلاصة

استهدف البحث تقويم مستوى تطبيق المرشدين الزراعيين لتقنيات الزراعة الدقيقة في تحسين كفاءة استخدام الموارد الزراعية في محافظة صلاح الدين، بالإضافة إلى تقويم مستوى التطبيق من حيث التنظيم والتخطيط والتنفيذ والمتابعة والتقويم، مع تحليل الفروق في نتائج التقويم حسب متغيرات شخصية ووظيفية: الإنتاجية، التخصص في الإرشاد الزراعي، نوع الشهادة، مدة الخدمة، الدرجة الوظيفية، والمشاركة في نشاطات الزراعة الدقيقة. لتحقيق أهداف البحث، وُضعت استبانة ميدانية ذات صدق ظاهري ومحتوى، تكونت من جزئين: الأول للبيانات الشخصية، والثاني تضمن 30 معيارًا موزعة على خمسة مقاييس، صيغت بالاعتماد على مصادر علمية ومقابلات مع مختصين. لتحقيق أهداف البحث، وُضعت استبانة ميدانية ذات صدق ظاهري ومحتوى، تكونت من جزئين: الأول للبيانات الشخصية، والثاني تضمن 30 معيارًا موزعة على خمسة مقاييس، صيغت بالاعتماد على مصادر علمية ومقابلات مع مختصين. شمل مجتمع البحث 56 موظفًا زراعيًا، وشملت العينة الاستطلاعية 20 موظفًا من خارج عينة البحث. والتي تكونت من 56 موظفًا زراعيًا (14.54%) من المجتمع الكلي 385، اما العينة الاستطلاعية بلغت 20 موظفًا زراعيًا (خارج المجتمع البحثي). تم جمع بيانات البحث خلال الفترة (2024/11/1-2025/1/28) واهم الوسائل الاحصائية المستخدمة: مان وتني كروسكال والس والدرجة المعيارية. أما أهم نتائج البحث، فقد أظهرت أن تقويم فعالية تقنيات الزراعة الدقيقة في تحسين كفاءة استخدام الموارد الزراعية من وجهة

نظر المرشدين الزراعيين جاء بمستوى متوسط يميل إلى الضعيف. كما وُجدت فروق معنوية في متغيري التخصص الإرشادي والدرجة الوظيفية. وتؤكد الاستنتاجات ضرورة التركيز على تخصص الإرشاد الزراعي، ورفع كفاءة العاملين من ذوي الدرجات الوظيفية العليا، لدعم فاعلية الزراعة الدقيقة في المحافظة.

كلمات مفتاحية: تقويم، تنفيذ، متابعة، تنظيم، تخطيط.

Introduction

Agriculture remains the backbone of global food systems, supporting livelihoods, economic development, and food security, particularly in developing and transition economies (7).

Climate change and poor resource management contribute to declining agricultural yields, increasing production costs, and environmental stress.

Water scarcity significantly constrains agricultural productivity in arid and semi-arid regions, threatening long-term food security and necessitating improved water-use efficiency (21).

This challenge is particularly evident in Iraq, where water-dependent agriculture dominates production systems.

This highlights the urgent need for adaptive agricultural technologies like precision agriculture to improve resource use and sustainability, especially in water-scarce areas like Salah al-Din Governorate.

Climate change, land degradation, drought, and increasing resource scarcity are intensifying pressure on agricultural systems, making efficient resource management a global priority (22).

. These technologies boost productivity and promote sustainable resource management, especially in Salah al-Din.

In vulnerable areas like Salah al-Din, adaptive technologies are urgently needed. Precision agriculture can reduce these risks through better resource management and data-driven decisions.

As such, precision agriculture techniques have emerged as innovative solutions to enhance resource efficiency and achieve sustainability across various crops (8 and 11). These strategies improve productivity and optimize agricultural resource use in Salah al-Din. As agriculture is challenged by population growth and urbanization issues, precision agriculture offers a viable path to food security while conserving resources and addressing climate change.

Traditional agricultural practices struggle to meet current demands and offer limited sustainability. They are unable to support rapid population growth in the face of climate change, underscoring the need for modern technologies. Precision agriculture employs advanced technology to enhance efficiency and mitigate environmental impacts (15).

The agricultural response to urgent challenges diverges from traditional methods, recognizing environmental diversity and employing advanced technologies for improved production (15 and 17).

Therefore, precision agriculture technologies have been widely adopted due to their ability to support food security and mitigate the impacts of climate change (9 and 16). Forecasts indicate that the global population will reach approximately 9.7 billion by 2050, resulting in a significant increase in food demand and necessitating more effective and sustainable farming approaches. However, these conventional practices rely on the constant use of resources and inputs; thus, overconsumption cannot meet this demand without causing environmental damage. Review studies have shown that precision agriculture technologies enhance crop yields, improve soil conditions, and ultimately bolster the economic stability of rural communities by reducing production costs and increasing profits (10). One of the benefits of organic agriculture is its comprehensive approach to maximizing production, from soil preparation and planting to harvesting (13). Then, by utilizing farmers' data, it is possible to evaluate soil illnesses and moisture, as well as crop health, to enable precise livestock management, including the use of precision organic techniques, mechanical systems, programmed feeding, and monitoring implements, which have improved animal health and productivity (3).

Despite the proven benefits of precision agriculture, adoption remains uneven due to high investment costs, limited technical skills, and insufficient institutional support (20).

Iraq faces issues with land ownership and organization that impact technology implementation. However, increasing awareness and advanced agricultural technologies offer significant opportunities, particularly in Salah al-Din province. Embracing precision agriculture could enhance the sustainability and resilience of farm products.

This involves examining historical weather patterns, soil quality, and crop yields to enhance outputs and develop adaptive farming systems. Drone-enabled field monitoring and mechanical irrigation are essential for maximizing water efficiency, which is vital for Iraq’s arid environment (14). Agricultural extension services are critical in facilitating the adoption of modern technologies by improving farmers’ knowledge, skills, and confidence (4).

In precision agriculture, extension workers are crucial in bridging the gap between advanced technology and field applications, particularly in resource-scarce areas like Salah al-Din Governorate.

Effective extension systems must move beyond information delivery to provide hands-on technical support and continuous guidance for precision agriculture adoption (5).

Therefore, strengthening agricultural extension institutions and equipping workers with tools and knowledge are crucial for developing precision agriculture in areas like Salah al-Din, where environmental pressures and institutional gaps grow.

This study can benefit agricultural extension employees by facilitating the transfer of plants, programs, and extension activities to farmers. It highlights the increasing importance of precision agriculture as farming adjusts to the challenges of the modern world. As agriculture evolves, precision agriculture is crucial for enhancing yields, conserving resources, and minimizing environmental impact, making it a cornerstone of sustainability. In Iraq, adopting precision agriculture (PA) techniques in Salah Al-

Din can transform traditional farming into an efficient, data-driven system. Collaboration among policymakers, researchers, and farmers is crucial for overcoming challenges and promoting the adoption of PA in mainstream agriculture.

This study evaluates the effectiveness of PA technologies in the region, providing valuable insights for researchers and decision-makers. Evaluating PA in Salah Al-Din is crucial for sustainable food production and economic stability in Iraq.

This study evaluates precision agriculture techniques to improve risk management and mitigate climate change in Salah al-Din Province. It encompasses arrangement, planning, monitoring, and implementation, and is supported by sub-drives.

Research Objectives:

1. Evaluating the application level of agricultural extension agents in precision agriculture techniques for improving agricultural resource usage in Salah Al-Din Governorate in general.
2. Rearrangement of the evaluation levels in organization, planning, implementation, monitoring, and evaluation
3. Classifying the norms of measurements, which describe the evaluation of the role and effectiveness of precision agriculture technologies to improving agricultural resource usage.
4. Identifying differences in evaluating the application level of precision agriculture techniques according to productivity gains, agricultural extension, academic degree, service period, job grade, and participation in activities.

Materials and Methods

This research employed a descriptive approach as it is appropriate for describing data on evaluating the effectiveness of precision agriculture techniques in improving agricultural risk management and mitigating the effects of climate change. The analysis is based on the mean of its measures. To achieve these aims, a two-part questionnaire was developed to collect data. The first part included personal variables, such as productivity gains from precision agriculture in terms of small, medium range, and Large. The agriculture extension field is denoted (1) for agriculture extension specialists and (2) to non-specialists (that just to symbol). For Qualifications, 1 denotes preparatory certificate, 2 certificate from an institution, 3 college, high diploma, Master's certificate, and 4 PhD. Period of service was denoted by 1 (few years), 2 (median years), 3 (many years). Job grades and degrees in office work were denoted by 1 (assistant agricultural engineer), 2 (agricultural engineer), 3 (senior agricultural engineer), 4 (assistant to the president of engineering), 5 engineering president), 6 (senior engineering president), and 7 (experts).

Activity participation data was obtained by summing the days spent in each activity, then categorizing it into four groups. The following section prepares to evaluate the effectiveness of PA in improving agricultural risk management through five measures, each comprising five sub-measures that refer to the options for these applications (very greatly applying, greatly applying, appropriately applying, not greatly applying, not very greatly applying) and assigned weights as 5, 4, 3, 2, 5, 4, 3, 2, 1. The initial 45 norms were reduced to 30. Six paragraphs are allocated to each norm, except for the first and second, whilst norms 4 and 7 were frequently cancelled due to their invalidity.

Subsequently, a validity test was conducted on these types: apparent validity [in the pre-test sample], involving 20 agricultural employees (from the final society), while the research sample consisted of 56 agricultural employees selected randomly from a total population of 385, equating to 14.54%. data was collected from 1/11/2024-28/1/2025. The stability degree using Cronbach's alpha for all five scales was 0.76, indicating an acceptable reliability factor for all values. Statistical methods employed included the Kruskal-Wallis test, percentage, Mann-Whitney U test, Z-score, and frequency.

Results and Discussion

The application level evaluation of the agricultural extension agents in precision agriculture techniques for improving resource usage in Salah Al-Din governorate in general reached a theoretical range of 30-150 (Table 1), showing that the fewer than -1 class forming 7.14% of all staff. This indicates a significant need for increased evaluation of the effectiveness of precision agriculture techniques. The second rate is 14.28%, and the last, at 78.57%, constituted the largest group. This study aligns with (6), as many studies aim to limit efforts and consistently support extension work. These efforts should actively respond to agricultural tasks, which are considered national priorities necessary to move beyond traditional methods. This will not be a suitable option, as there are some differences in the use of information sources, indicating that all methods employed by staff were crucial.

Table 1: Distribution of agricultural engineers based on the standard score.

Classification	Standard score (Z)	Number	Ratio (%)
Little	Fewer than -1	8	14.28
Middle	(-1 , +1)	44	78.57
Great	Above +1	4	7.14

Mean = 58.02, S.D. = 8.16, Total = 56, Max = 80, Min = 4.

The data is divided by Z (Standard Score), that is, far away for measurement error, divided into three arrangements. The first arrangement (Great) which is above +1, the second (Middle) which is between -1 and +1, and the third (Little) representing less than -1. In addition, Figure 1 shows the Middle arrangement at high; therefore there is a huge gap in the evaluation of the effectiveness of precision agriculture techniques for improving and developing the skills and knowledge on precision agriculture to others.

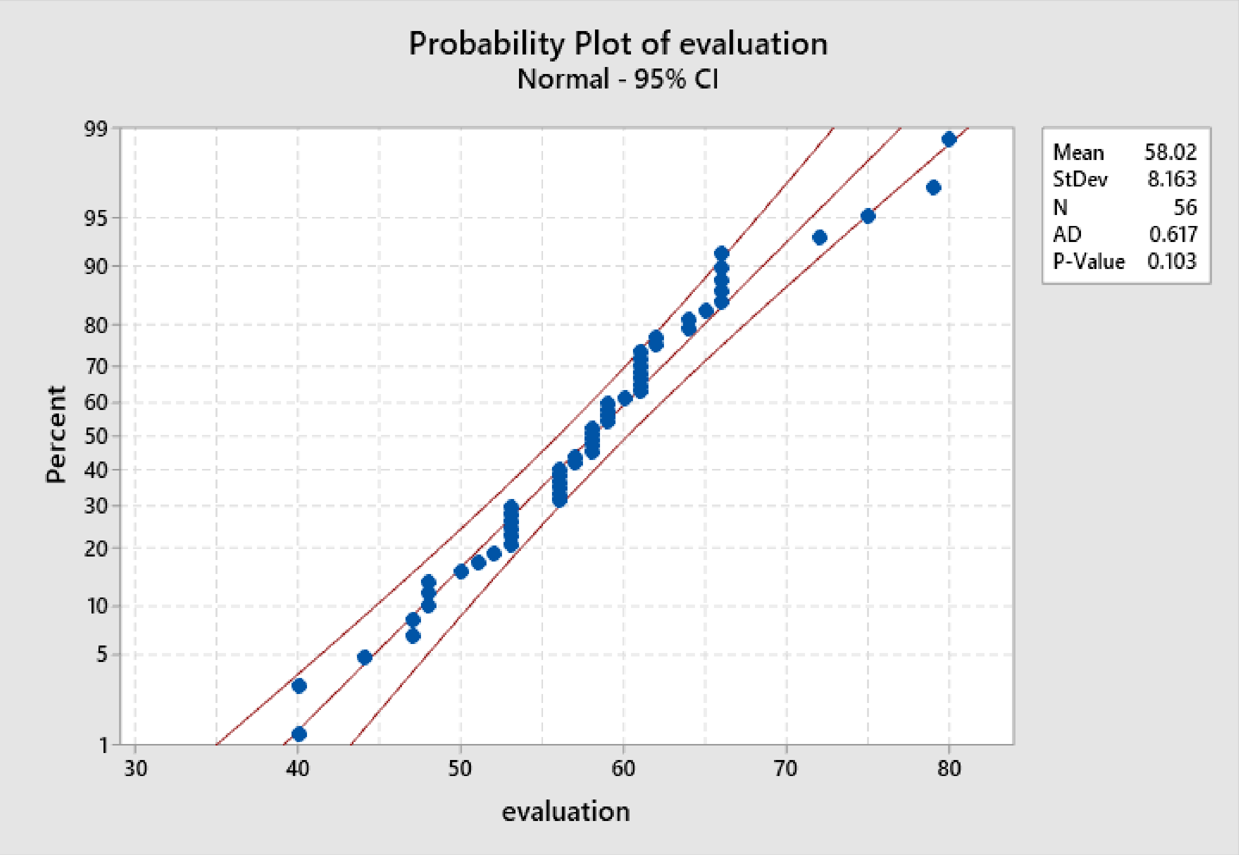

Figure 1: Ratio of the distribution of agricultural engineers for evaluating the role of effectiveness of precision agriculture techniques.

The second arrangement evaluation level for each organization, planning, implementation, monitoring, and evaluation, is shown in Table 2. The highest value in the evaluation of agricultural precision technologies reflects their effectiveness, with a mean of 19.00, taking the first rank, while the second rank has a mean of 12.55.

Table 2: Rearranging the scales of the main measure based on its mean.

Seq	Main measures	Mean	Rank of measures
A	Arrangement of effectiveness	19.00	1
D	Monitoring	12.55	2
E	Evaluation of effectiveness	12.33	3
B	Planning for effectiveness	8.48	4
C	Implementation	5.74	5

The third, classifying the norms of measurements, describe the evaluation of the role and effectiveness of PA technologies for improving agricultural resource usage. Table 3 shows the norms and their items according to measures based on their means, illustrating that the usefulness item is associated with the results of applying the effectiveness of PA at a mean of 12.33. This study agrees with (12) when comparing the norms and conducting a survey and judgment on it. which shows many domains related to the evaluation and development of precision technologies. This research concludes that most evaluation norms and their items are well-suited for the transfer of precision agriculture in Iraqi agricultural systems.

Table 3: Arrange the norms of measurements.

Seq.	Sub-measurements	Mean	Rank
5-4	Useful for evaluating the effectiveness of precision agriculture	12.33	1
1-3	Duties and tasks related to organisation	8.19	2
1-4	Duties and tasks related to implementation	7.80	3.5
4-3	Development of trainees tasks with regard to precision agriculture	7.80	3.5
5-1	Enough participation in the planning process	5.87	5
2-1	Assist to results evaluation as one of its types	5.0	6
1-1	Coordination of organisational personnel	3.0	7
3-2	Coordinating with other participating members	2.96	8.5
3-3	Concerned with material and financial allocations	2.96	8.5
3-1	Enough activities included in the diffusion implementation	2.94	10
2-2	Multiple activities are included in diffusion planning	2.88	11
4-1	Suitable period to complete the monitoring	2.66	12
2-3	Present all the requirements for planning	2.64	13
4-2	Present style of suitable monitoring	2.60	14
5-2	Concerning the quality and quantity of yields due to applying	1.82	15
5-3	Careful since the check evaluation is present	1.80	16

The fourth factor relates to finding the difference in evaluating the application level of PA techniques according to productivity gains, agricultural extension, academic degree, service period, job grade, and participation in activities

Productivity gains from PA techniques: Staff were distributed into three categories based on few (44.64%), median (19.64%), and big (35.71%). To determine the differences in evaluating the role of precision technologies, significant differences did not appear at the 5% level. Using the Kruskal-Wallis test, H (0.13) was calculated. This result differs from (18) and aligns with the hypothesis proposed in the research.

Field in agricultural extension: Agricultural staff were distributed according to the field of agricultural extension. It revealed that 57.14% of staff were professionals in agricultural extension, and the rest (42.85%) were not. Additionally, there is a significant difference in the effectiveness of PA techniques of agricultural staff according to this factor, with the calculated Mann-Whitney test showing 43.0 at the 5% level. This matches a study by researchers in Greece on livestock farmers, which found that expertise influences the PA training needs of farmers (14).

While they used “area of expertise” instead of academic specialisation, the findings suggest that a person's background shapes their understanding of PA — a point further examined in this study in the Salah Al-Din governorate (19). This also differs from (1) as field specialisation influences the expertise of extension staff in crop management. The study indicates that academic specialisation impacts the effectiveness of PA techniques, particularly in input optimisation and decision-making, which are essential to such agriculture. This result is consistent with the research hypothesis.

Qualification: Data distribution according to the type of certificate showed a high percentage for the institute education certificates (17.85%), followed by college certificate and PhDs (both 14.28%), and high diploma and master's certificate (both at 8.92%). The Kruskal-Wallis test value was 6.99, which was not significant at the 5% level, differing from (18) but aligning with the research hypothesis.

Service period: Employees were distributed according to median office service years (29%), few (19%), and big (8%). The differences in evaluation of the precision technologies indicated that significant differences had not appeared at the 5% level. For the Kruskal-Wallis test, H was calculated at 3.27, indicating no significant differences. This result is consistent with the hypothesis proposed in this research.

Job grade: Here, Agricultural Engineer Assistants formed 12.5%, Agricultural Engineers 21.42%, Senior Agricultural Engineers 25%, Engineer President Assistants 30.35%, Engineer Presidents 8.92%, and Senior Engineer Presidents 1.78%. According to job grades, there were significant differences in the evaluation of the effectiveness of PA techniques based on the degree of office work. The value of the calculated Kruskal-Wallis test was 13.42, at the 5% significance level. This result is similar to (6) and to the proposed research hypothesis.

Participation in precision agriculture technique activities revealed that agricultural employees, categorised according to their farming activities, evaluated the effectiveness of PA techniques as follows: 21.42% have minor activities, 55.35% have medium activities, and 23.21% have major activities. There was no significant difference in the evaluation of the effectiveness of PA techniques based on participation activities for cultivation using these techniques. The calculated value of H was 1.57 at the 5% significance level as tested using Kruskal-Wallis. This is in contrast to studies by (1 and 13) conducted at Razi University, which assessed the educational needs of student cooperative members in PA. Regression analysis revealed that training participation and access to information accounted for 71% of the variance in these needs. The results underscore the importance of training activities, aligning with the study’s aim of evaluating in-service training for extension workers in Salah al-Din, which corresponds to the research hypotheses.

Table 4: Differences in the evaluation role of the effectiveness of precision agriculture techniques and technologies according to some factors.

Factors	N.	R.	Med.	Av. Rank	Ca. H	Ca. W	P Val.
Productivity Gains In Precision Agriculture Techniques							
*Few Kg/D	25	44.64%	59	29.4	0.13	---	0.93 N.S
*Median Kg/D	11	19.64%	56	27.9			
*Big Kg/D	20	35.71%	58	27.8			
Field Of Agriculture Extension							
*Professional Extension	32	57.14%	58	58.96	---	43	0.03 *
*Non-Professional Extension	24	42.85%	18	24.61			
Qualification							
*Preparatory	10	17.85%	59	33.1	6.99	---	0.32 N.S
*Institute	8	14.28%	56	24.3			
*College	5	8.92%	58.5	27.3			
*High Diploma	5	8.92%	58	27.1			
*Master Certificate	20	35.71%	58.5	16.2			
*Phd	8	14.28%	61	25.8			
Service Period (Years)							
*Few (2-13)	19	%	58	27.8	3.27	---	0.195 N.S
*Median (14-25)	29	%	56	24.9			
*Big (26 and More)	8	%	58	28.8			
Job Grade							
*Agricultural Engineer Assistant	7	12.5%	61	39.7	13.42	---	0.04 *
*Agricultural Engineer	12	21.42%	56	19.3			
*Senior Agricultural Engineer	14	25%	61	32.5			
*Engineer President's Assistant	17	30.35%	59	42.3			
*Engineer President	5	8.92%	62.5	19.3			
*Senior Engineer President	1	1.78%	53	48.0			
Participation Activities							
*Small (0-2) Degree	12	21.42%	56.5	22.1	1.57	0.45 N.S	
*Medium Range (3-5) Degree	31	55.35%	59.0	30.0			
*Large (6-And More) Degree	13	23.21%	57.0	28.3			

Significant at the 5% level. NS: non-significant.

Conclusions

Concerns over evaluating the effectiveness of precision agriculture technologies require stepping up efforts in this area through knowledge acquisition, new information, and modern technologies to address agricultural risk management and mitigate the effects of climate change in Salah Al Din governorate. Currently, there is a lack of utilisation and application of the scientific methods of precision agriculture. According to the research findings, agricultural specialists and employees in relevant job grades play an important role in developing agricultural precision, and they need to exercise greater precision. This study recommends the continuation of training courses to improve the effectiveness of precision agriculture techniques, as well as increasing the number of agricultural engineers. It also recommends disseminating innovative ideas to agricultural engineers through participation in development lectures and accessing websites that facilitate the application, use, and submission of these technologies and useful conducting practices.

Supplementary Materials:

No Supplementary Materials.

Author Contributions:

W. S. Ayyed: writing—original draft preparation; A. Z. Al-Hafidh: writing—review and editing. Both authors have read and agreed to the published version of the manuscript.

Funding:

This research received no external funding.

Institutional Review Board Statement:

The study was conducted according to the protocol approved by the Head of the Ethics Committee at the College of Agriculture, University of Tikrit, Iraq.

Informed Consent Statement:

Not applicable.

Data Availability Statement:

Data available upon request.

Conflicts of Interest:

The authors declare no conflict of interest.

Acknowledgments:

The authors of this research gratefully acknowledge the assistance of the Directorate of Agriculture of Salah al-Din province and the Agricultural Extension Centre in enhancing the quality of this effort.

Disclaimer/Journal's Note:

The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of AJAS and/or the editor(s). AJAS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

References

1. Allahyari, M. S., Mohammadzadeh, M., and Nastis, S. A. (2016). Agricultural experts' attitude towards precision agriculture: evidence from Guilan Agricultural Organization, Northern Iran. *Information Processing in Agriculture*, 3(3): 183-189. https://doi.org/10.1016/j.inpa.2016.07.001.
2. Amjath-Babu, T. S., Krupnik, T. J., Aravindakshan, S., Arshad, M., and Kaechele, H. (2016). Climate change and indicators of probable shifts in the consumption portfolios of dryland farmers in Sub-Saharan Africa: Implications for policy. *Ecological Indicators,* 67: 830-838. https://doi.org/10.1016/j.ecolind.2016.03.030.
3. Aquilani, C., Confessore, A., Bozzi, R., Sirtori, F., and Pugliese, C. (2022). Precision Livestock Farming technologies in pasture-based livestock systems. *Animal, 16*(1): 100429. https://doi.org/10.1016/j.animal.2021.100429.
4. Becerra-Encinales, J. F., Boulanger, P., and Bijttebier, J. (2024). Agricultural extension for adopting technological practices in developing countries: A scoping review. *Sustainability, 16*(9): 3555. https://doi.org/10.3390/su16093555.

5. Cerjak, M., Haas, R., and Brunner, F. (2025). Adoption of digital and mobile-based agricultural extension services. *Journal of Rural Studies*, *104*: 103121. https://doi.org/10.1016/j.jrurstud.2025.103121.
6. Erickson, B., Fausti, S., Clay, D., and Clay, S. (2018). Knowledge, skills, and abilities in the precision agriculture workforce: an industry survey. *Natural Sciences Education, 47*(1): 1–11. https://doi.org/10.4195/nse2018.04.0010.
7. FAO, IFAD, UNICEF, WFP, and WHO. (2024). *The State of Food Security and Nutrition in the World 2024*. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cd1254en.
8. Fróna, D., Szenderák, J., and Harangi-Rákos, M. (2019). The challenge of feeding the world. *Sustainability, 11*(20): 5816. https://doi.org/10.3390/su11205816.
9. Gebbers, R., and Adamchuk, V. I. (2010). Precision agriculture and food security. *Science*, *327*(5967): 828–831. https://doi.org/10.1126/science.1183899.
10. Grundy, M. J., Bryan, B. A., Nolan, M., Battaglia, M., Hatfield-Dodds, S., Connor, J. D., and Keating, B. A. (2016). Scenarios for Australian agricultural production and land use to 2050. *Agricultural Systems, 142*: 70–83. https://doi.org/10.1016/j.agsy.2015.11.008.
11. Halachmi, I., Guarino, M., Bewley, J., and Pastell, M. (2019). Smart animal agriculture: application of real-time sensors to improve animal well-being and production. *Annual Review of Animal Biosciences, 7*(1): 403–425. https://doi.org/10.1146/annurev-animal-020518-114851.
12. Kifle, T. (2021). Climate-Smart Agricultural (CSA) practices and its implications to food security in Siyadebrina Wayu District, Ethiopia. *African Journal of Agricultural Research, 17*(1): 92–103. https://doi.org/10.5897/AJAR2020.15100.
13. Loures, L., Chamizo, A., Ferreira, P., Loures, A., Castanho, R., and Panagopoulos, T. (2020). Assessing the effectiveness of precision agriculture management systems in mediterranean small farms. *Sustainability, 12*(9): 3765. https://doi.org/10.3390/su12093765.
14. Michailidis, A., Charatsari, C., Bournaris, T., Loizou, E., Paltaki, A., Lazaridou, D., and Lioutas, E. D. (2024). A first view on the competencies and training needs of farmers working with and researchers working on precision agriculture technologies. *Agriculture, 14*(1): 99. https://doi.org/10.3390/agriculture14010099.
15. Monteiro, A., Santos, S., and Gonçalves, P. (2021). Precision agriculture for crop and livestock farming—Brief review. *Animals, 11*(8): 2345. https://doi.org/10.3390/ani11082345.
16. Perakis, K., Lampathaki, F., Nikas, K., Georgiou, Y., Marko, O., and Maselyne, J. (2020). CYBELE–Fostering precision agriculture and livestock farming through secure access to large-scale HPC enabled virtual industrial experimentation environments fostering scalable big data analytics. *Computer Networks, 168*: 107035. https://doi.org/10.1016/j.comnet.2019.107035.
17. Petrović, B., Bumbálek, R., Zoubek, T., Kuneš, R., Smutný, L., and Bartoš, P. (2024). Application of precision agriculture technologies in Central Europe—review. *Journal of Agriculture and Food Research, 15*: 101048. https://doi.org/10.1016/j.jafr.2024.101048.

18. Sanyaolu, M., and Sadowski, A. (2024). The role of precision agriculture technologies in enhancing sustainable agriculture. *Sustainability*, *16*(15): 6668. https://doi.org/10.3390/su16156668.
19. Shehzad, K., and Haq, I. (2024). The mastery of extension field staff (EFS): Unveiling their expertise in crop management practices. *Sarhad Journal of Agriculture*, *40*(2): 562–569. https://dx.doi.org/10.17582/journal.sja/2024/40.2.562.569.
20. Vijayakumar, S., Reddy, P. R., and Kumar, A. (2025). Opportunities, challenges, and interventions for Agriculture 4.0 adoption. *Discover Food*, *5*(1): 32. https://doi.org/10.1007/s44187-025-00576-3.
21. Xing, Z., and Wang, J. (2024). Precision agriculture and water conservation strategies for sustainable crop production in arid regions. *Plants*, *13*(22): 3184. https://doi.org/10.3390/plants13223184.
22. Zhang, Y., Li, Z., and Chen, F. (2024). Climate-driven risks to agricultural sustainability and food security. *Agricultural Systems*, *228*: 103653. https://doi.org/10.1016/j.agsy.2024.103653.