CHEMICAL ENGINEERING TRANSACTIONS
VOL. 97, 2022
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-96-9; **ISSN** 2283-9216
DOI: 10.3303/CET2297083

Analytical Hierarchy Process for Automated Fertigation Blending System in Reducing Nutrient and Water Losses

Dhiya' Hawina Che Aziz[a], Nurul Hanim Razak[a,*], Nur Izyan Zulkafli[a], Jiří Jaromír Klemeš[b]

[a]Faculty of Mechanical Engineering,Centre for Advanced Research on Energy (CARe), Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia,
[b]Sustainable Process Integration Laboratory - SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology- VUT Brno, Technická 2896/2, 616 69, Brno, Czech Republic
nurulhanim@utem.edu.my

Fertigation is one of the agricultural methods of farming techniques which is can produce high productivity crops and efficiency in using resources. This research attempt to design and select the best criteria for an Automated Fertigation Blending System (AFBS) for reducing the eutrophication problem. Eutrophication is caused by the excessive use of nutrients and water runoff into the fresh water. The criteria had been selected based on the customer requirements (CRs) from the survey. The CRs and ECs are the two criteria for the four best design alternatives using the House of Quality (HoQ) selection method. A new methodological framework that integrated the design optional consisting of an Analytical Hierarchy Process (AHP) was developed. The AHP was developed to evaluate the selection criteria in each design developed by using a pairwise-comparison matrix. Seven criteria were implied in selecting the best design, covering ease of installation, compact and portable, safety, low equipment maintenance cost, user friendly, durability, and reduce nutrient and water runoff. The best AFBS is Design 4 with the highest performance and higher score 73.7 % because of its safety, durability, user friendly, compact and portable, and reduces nutrient excess and water runoff. Conclusively, this proposed framework provides the decision to select criteria and ECs for future AFBS without an extensive experiment by saving time, and money, and reducing the negative impact on sustainability.

1. Introduction

Fertigation is a farming method of technology technique which is the best utilization methods due to its high productivity and resource utilization efficiency. This is because the old methods are not efficient at providing the nutrients plants need, as humans are not robots that do the jobs at the exact time every day. Humans also tend not to use the resources allocated to them accurately because of the limitations of manually calculating the number of resources to use. The problem with the current system is that it is not fully effective in delivering the right amount of fertilizer and water to the plants based on their optimal needs and cause excessive use of nutrients and water runoff into the fresh water. This led to eutrophication pollution (Saaid et al., 2021).

1.1 Analytical Hierarchy Process

AHP was developed by Prof. Thomas L. Saaty in the 1970s (Petrillo et al., 2016). The hierarchy of the AHP method usually consists of the goal, the alternatives for achieving the goal, and the criteria that apply to the individual alternatives of the goal. AHP belongs to that method with a cardinal level of information on criteria preferences based on a pairwise comparison (Siekelova et al., 2021). The AHP method was selected due to its simplicity and structure robustness, fast results, and low computational cost (Razak et al., 2022).
There are four main principles in AHP which is consists of a hierarchy framework, pairwise comparison, priority analysis, and logical consistency which is its consistency ratio must be less than 0.1 or 10 %. If the value is more than 0.1 or 10 %, then the measurement cannot accept and need to be reassessment (Razak et al., 2021).

Paper Received: 15 June 2022; Revised: 26 August 2022; Accepted: 1 September 2022
Please cite this article as: Aziz D.H.C., Razak N.H., Zulkafli N.I., Klemeš J.J., 2022, Analytical Hierarchy Process for Automated Fertigation Blending System in Reducing Nutrient and Water Losses, Chemical Engineering Transactions, 97, 493-498 DOI:10.3303/CET2297083

The pairwise comparison is carried out in pairs for each criterion and alternative to assess the best scale for expressing opinions as shown in Table 1.

Table 1: Scale for pairwise-comparison (Asep Anwar et al., 2021).

Score value	Definition
1	Two elements are equally important
3	One element is slightly more important than the other
5	One element is more important than the other
7	One element is more essential than the other
9	One element is more important than the other elements
2, 4, 6, 8	A value between adjacent considerations
1/3, 1/5, 1/7, 1/9	Reciprocal for inverse comparison

Sumaryanti et al. (2019) proposed a Self-Monitoring, Analysis, and Reporting Technology (SMART) and AHP methods to analyze criteria and alternatives of support systems for a specific location of fertilizer by comparison of this method which is proposed as the best option. Veisi et al. (2022) presented the AHP to choose the best irrigation system which interviewed with 42 questionnaires had measured the relative importance.

1.2 Research novelty and objective

The research gap is limited knowledge or literature related to highlighting the benefits of the automated system, especially among farmers and agro practitioners (Aziz et al., 2021). This automated is newly penetrated in the agricultural industry and is not widely used in industry. Decisions on organic fertilizer selection and criteria for agricultural irrigation systems using AHP have received only a limited review in the literature. There are limited studies on eutrophication reduction based on fertigation performance, cost, and safety features of selection tools using HOQ and AHP. AHP was used to determine the selection criteria for variables in HOQ. AHP scores ECs based on customer demand paired selection criteria.

The main novelty is in the development of a new methodological framework to systematically evaluate the best selection criteria for AFBS design using AHP. The framework can help policymakers with a practical decision-making platform that integrates both quantitative and qualitative concerns. This study aims to propose a new and novel systematic methodological framework to design and select the best criteria of AFBS for reducing the eutrophication problem which is the HOQ integrates with AHP.

2. AHP Methodology

The method used in this research is an integrated quantitative and qualitative method. The target is to decide on AFBS design selection systematically, factual, and accurately of the problems faced by paired with the ECs. The framework of this research methodology is shown in Figure 1 which consists of three stepwise to obtain the best selection criteria for this AFBS design.

Phase 1 is the process of development by gathering the data regarding of fertigation system in the previous research to understand the system in agricultural use. Then, the specification of the system needed had been visualized and the market survey spread by obtaining the customer requirements (CRs) of this system. As the CRs selected, HOQ was created based on the market survey results, and four (4) designs had been proposed.

Phase 2, is the concept generation in the ranking and selection using the AHP method. AHP addresses the entire problem, arranging it in a hierarchical framework and identifying the elements of the problem by clarifying decisions (Asep Anwar et al., 2021).

Phase 3 the decision making for the best design was analyzed based on the specification selection from HOQ by AHP leads through the calculation of pairwise-comparison decision criteria for every level of hierarchy at a time. Then to provide an overview of solving the problem, a literature review is carried out as a comparison between the real problem and the theory-based method.

Compare the observations with the literature review and then identify the question of this research. The data obtained are those generated from questionnaires of different respondents, including housewives, students, farmers, the private sector, and the government sector. Multiple questionnaires revealed multiple criteria for selecting requirements for AFBS development in agriculture, including ease of installation, compact and portable, safety, low equipment cost, ease of use, durability, and reduced nutrient loss and water runoff.

AFBS criteria are available for selection. The next step is to identify alternatives to CRs and ECs. After conducting a market survey of the respondents, the results indicated that 4 designs emerged, namely Design 1, Design 2, Design 3, and Design 4.

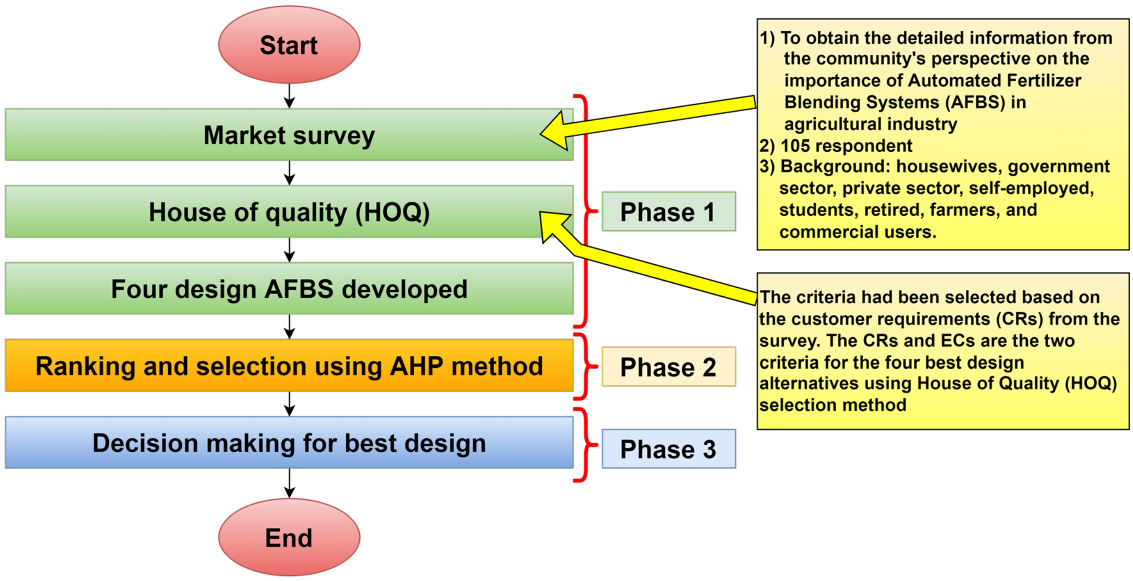

Figure 1: The systematic framework of automated fertigation blending system in design.

2.1 Developing a hierarchical framework

The next step is to create a hierarchy between the goals, criteria, and alternatives of the AFBS design as Figure 2. There are four designs, each with different criteria, such as Design 1 (easy to install, safety and low equipment cost), Design 2 (compact and portable, safety, low equipment cost and durability), Design 3 (compact and portable, safety, durability and reduced nutrient and water runoff) and Design 4 (compact and portable, safety, durability, user friendly, durability and reduced nutrient and water runoff). The process steps in the calculation using the application of Microsoft Excel are as follows. The assessment in the matrix used a scoring scale.

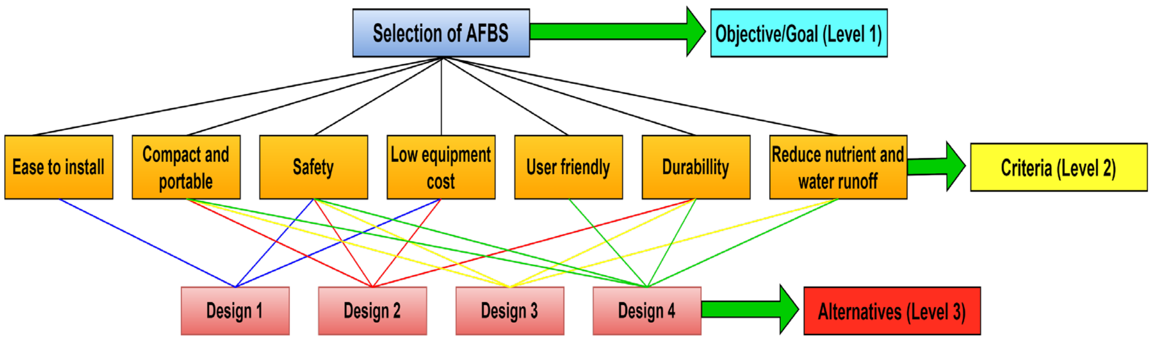

Figure 2: A hierarchy framework for selection of AFBS design

2.2 Construct a pairwise-comparison matrix

This pairwise-comparison matrix gives the relative importance of various attributes concerning the goal. Such as how important is ease to installation while developing AFBS or what is the importance of compact and portable when developing AFBS and similarly to other criteria. This pairwise-comparison matrix was created with the help of the scale of relative importance as tabulated in Table 1.

The length of the pairwise matrix is equivalent to the number of criteria used in the decision-making process with a 7x7 matrix as there are seven types of criteria easy to install, compact and portable, safety, low equipment cost, user friendly, durability, and reduce nutrient and water runoff. The value in the pairwise matrix depends upon the decision-maker or the person that develop this AFBS based on how important relationships between each criterion at column criteria to row criteria. Table 2 shows that the diagonal element takes a value of one because the same criteria will be of equal importance.

The functional value has been converted to a decimal value and the sum of each value was calculated as Eq(1), where A is the total score of each criteria in the comparison matrix and a_n is the score value of criteria at each column.

$$A = \sum_{n=1}^{7} \mathrm{a}_n \quad (1)$$

Table 2: The pairwise comparison matrix using Microsoft Excel.

	Ease to install, a1	Compact and portable, a2	Safety, a3	Low equipment cost, a4	User friendly, a5	Durability, a6	Reduce nutrient loss and water runoff, a7
Ease to install, b1	1	3/4	1 3/4	2	1 1/4	1 1/2	2 1/4
Compact and portable, b2	1 1/3	1	2 1/3	2 2/3	1 2/3	2	3
Safety, b3	4/7	3/7	1	1 1/7	5/7	6/7	1 2/7
Low equipment cost, b4	1/2	3/8	7/8	1	5/8	3/4	1 1/8
User friendly, b5	4/5	3/5	1 2/5	1 3/5	1	1 1/5	1 4/5
Durability, b6	2/3	1/2	1 1/6	1 1/3	1 1/3	1	1 1/2
Reduce nutrient loss and water runoff, b7	4/9	1/3	7/9	8/9	5/9	2/3	1
Total score value (A)	5.32	3.99	9.30	10.63	7.14	7.97	11.96

A normalized pairwise matrix was calculated all the elements of the column were divided by the sum of the column as results in Table 3. The criteria weight (*CW*) had been calculated by averaging all the elements in the row. By added all the row element values and dividing with several criteria (n) which is resulted in the *CW* as Eq(2), where b_n is the value of criteria at each row element.

$$CW = \frac{\sum_{n=1}^{7} \mathrm{b}_n}{n} \quad (2)$$

Table 3: Normalized pairwise-comparison matrix.

	Ease to install, a1	Compact and portable, a2	Safety, a3	Low equipment cost, a4	User friendly, a5	Durability, a6	Reduce nutrient loss and water runoff, a7	Criteria weight (CW)
Ease to install, b1	0.1881	0.1881	0.1881	0.1881	0.1750	0.1881	0.1881	0.1862
Compact and portable, b2	0.2508	0.2508	0.2508	0.2508	0.2333	0.2508	0.2508	0.2483
Safety, b3	0.1075	0.1075	0.1075	0.1075	0.1000	0.1075	0.1075	0.1064
Low equipment cost, b4	0.0941	0.0941	0.0941	0.0941	0.0875	0.0941	0.0941	0.0931
User friendly, b5	0.1254	0.1254	0.1254	0.1254	0.1866	0.1254	0.1254	0.1342
Durability, b6	0.1254	0.1254	0.1254	0.1254	0.1866	0.1254	0.1254	0.1342
Reduce nutrient loss and water runoff, b7	0.0836	0.0836	0.0836	0.0836	0.0778	0.0836	0.0836	0.0828

2.3 Calculating the consistency

Next, calculated consistency was applied to check whether the calculated value was accepted or not. Table 4 shows the value taken from the same pairwise comparison matrix which is not normalized. Each value in the column element had multiplied by the *CW* value. The matrix of the weighted sum value (B) was calculated by taking the sum of each value in the row as Eq(3).

$$B = \sum_{n=1}^{7} b_n \quad (3)$$

The weighted sum value had been written next to the criteria weights. Next, calculate the ratio of weighted sum value and criteria weights for each row as Eq(4).

$$RI = \frac{\sum W}{CW} \quad (4)$$

Then, by using Eq(5), the $\boldsymbol{\lambda}_{max}$ calculated, where C_n is the ratio value at each column and n is the number of criteria.

$$\boldsymbol{\lambda}_{max} = \frac{\sum_{n=1}^{7} C_n}{n} \quad (5)$$

Next, calculate the consistency index (*CI*) as Eq(6), where n is 7 as there are seven criteria.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (6)$$

Finally, the consistency ratio (*CR*) was calculated as per Eq(7).

$$CR = \frac{CI}{RI} \quad (7)$$

Random index (RI) is the consistency index of the randomly generated pairwise matrix as tabulated in Table 5, which is up to ten criteria. As for this RI is equal to 7 criteria which are 1.35. The value of *CR* is 0.0109 for the proportion of inconsistency *CR* is less than 0.10 which is the standard that can assume that matrix is reasonably consistent. Thus, the weight was accepted and the process of decision-making continue in the next step.

Table 4: Calculating the consistency value.

	Ease to install, a1	Compact and portable, a2	Safety, a3	Low equipment cost, a4	User friendly, a5	Durability, a6	Reduce nutrient loss and water runoff, a7	Weighted sum value (B)	Criteria weight (CW)	The ratio of weighted sum value/criteria weight
Ease to install, b1	0.1862	0.1862	0.1862	0.1862	0.1677	0.2012	0.1862	1.3001	0.1862	6.9810
Compact and portable, b2	0.2483	0.2483	0.2483	0.2483	0.2236	0.2683	0.2483	1.7335	0.2483	6.9810
Safety, b3	0.1064	0.1064	0.1064	0.1064	0.0958	0.1150	0.1064	0.7429	0.1064	6.9810
Low equipment cost, b4	0.0931	0.0931	0.0931	0.0931	0.0838	0.1006	0.0931	0.6500	0.0931	6.9810
User friendly, b5	0.1490	0.1490	0.1490	0.1490	0.1342	0.1610	0.1490	1.0401	0.1342	7.7529
Durability, b6	0.1242	0.1242	0.1242	0.1242	0.1789	0.1342	0.1242	0.9338	0.1342	6.9607
Reduce nutrient loss and water runoff, b7	0.0828	0.0828	0.0828	0.0828	0.0745	0.0894	0.0828	0.5778	0.0828	6.9810

Table 5: Random index (RI) values for consistency check (Saaty, 1980).

Number of criteria (n)	3	4	5	6	7	8	9	10	11	12	13	14	15
Random index (RI) value	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51	1.54	1.56	1.57	1.58

3. Final AHP result: The best design for AFBS

The design was selected based on customer requirements from market research data to achieve customer satisfaction, giving it an edge over other designs. The results were also supported by constructing a hierarchical framework from AHP and pairwise comparison results and ranking the best design alternatives that meet the design goals. This ranking and selection were based on a priority vector value and pairwise match rates for seven judgment criteria. Although this new AFBS technology brings some benefits to farmers or the agricultural industry, the main benefits are the minimization of nutrient and water consumption which led to reduction of pollution such as eutrophication.

Table 6 shows the CW on ease to install 18.62 %, compact and portable 24.83 %, safety 10.64 %, low equipment cost 9.31 %, user friendly 13.42 %, corrosion-resistant 13.42 %, and reduce nutrient and water runoff 8.28 %. Each value in the column element is multiplied by CW and added to all the values to get the overall priority for each row element of criteria as tabulated in Table 7. Lastly, the rank of each criterion can be determined based on the overall priority value. Table 7 concluded that Design 4 is the best design selected for AFBS with the higher performance and the higher score of 73.7 %.

Table 6: Simple matrix for four best designs developed from HOQ data obtained and CW.

	Ease to install, a1	Compact and portable, a2	Safety, a3	Low equipment cost, a4	User friendly, a5	Durability, a6	Reduce nutrient loss and water runoff, a7
Design 1	9	3	5	9	3	3	1
Design 2	1	7	5	1	3	3	1
Design 3	1	7	5	1	5	7	7
Design 4	1	7	7	1	7	9	9
Criteria weight (CW)	0.18624	0.24831	0.10642	0.09312	0.13415	0.13415	0.08277

Table 7: Design selection based on the overall priority and ranking arrangement.

Alternative	Overall priority	Rank
Design 1	0.5732	3
Design 2	0.4668	4
Design 3	0.6199	2
Design 4	0.7369	1

4. Conclusions

This research work presents a systematic methodological framework for evaluating and selecting the optimal design by implementing an AHP tool. The CRs and ECs are the two key criteria in ranking and selection for the best design using the pairwise comparison matrix. The final AHP result concluded that Design 4 is the best design for AFBS with the higher performance and higher score value of 73.3 %. Design 4 was selected due to its compact and portable, safety, durability, user friendly, and reduced nutrient and water runoff. This study can be beneficial for policy makers, industrial players, and researchers to generate interdisciplinary perspectives to inform policies and development at a national level, especially from the mismanagement of nutrients and water consumption.

References

Asep Anwar, Rendiyatna Ferdian, D. D. R., 2021, Selection of organic fertilizer supplier using Analytical Hierarchy Process (AHP) method in Pt. Jmn Kabupaten Bandung, Turkish Journal of Computer and Mathematics Education, 12(8), 1044–1049.

Aziz D.H.C., Razak N.H., Zulkafli N.I., Saat S., Tumari M.Z.M., 2021, Automated fertilizer blending system to reduce nitrogen loss and water runoffs: A best evidence review, Chemical Engineering Transactions, 89, 367–372.

Siekelova A., Podhorska I., Imppola J.J., 2021, Analytic Hierarchy Process in Multiple–Criteria Decision–Making: A Model Example, SHS Web of Conferences, 90(01019), 1-10.

Petrillo A., Felice F. De, Saaty T.L., 2016, Applications and Theory of Analytic Hierarchy Process - Decision Making for Strategic Decisions.

Razak N.H., Hashim H., Yunus N.A., Klemeš J.J., 2021, Integrated GIS-AHP optimization for bioethanol from oil palm biomass supply chain network design, Chemical Engineering Transactions, 83, 571–576.

Razak N.H., Hashim H., Yunus N.A., Klemeš J.J., 2022, Integrated linear programming and analytical hierarchy process method for diesel/biodiesel/butanol in reducing diesel emissions, Journal of Cleaner Production, 337(130297), 1-21.

Saaid M.F., Nordin, M. K., Mohd Yassin, A. I., Md Tahir, N., 2021, Automated Fertilizer Mixer System for Fertigation Farming, Journal of Electrical & Electronic Systems Research, 18, 18–23.

Saaty T.L., 1980, The analytic hierarchy process: planning, In Priority Setting, Resource Allocation, MacGraw-Hill, New York International Book Company.

Sumaryanti L., Rahayu T.K., Prayitno A., Salju, 2019, Comparison study of SMART and AHP method for paddy fertilizer recommendation in decision support system, IOP Conference Series: Earth and Environmental Science, 343(1).

Veisi H., Deihimfard R., Shahmohammadi A., Hydarzadeh Y., 2022, Application of the analytic hierarchy process (AHP) in a multi-criteria selection of agricultural irrigation systems, Agricultural Water Management, 267, 107619.