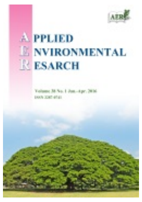
App. Envi. Res. 41(2) (2019): 27-40

Applied Environmental Research

Journal homepage : http://www.tci-thaijo.org/index.php/aer



Applying the New Theory to Assessment Criteria of Agricultural Water Management Schemes for Sustainable Rain-fed Agriculture in Thailand

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Article History

Submitted: 7 March 2018/ Received in revised form: 18 June 2018/ Accepted: 25 June2018/ Published online: 4 March 2019

Abstract

This paper describes the selection of assessment criteria to assess agricultural water management schemes for on-farm ponds to support sustainable rain-fed agriculture, guided by the New Theory of His Majesty King Bhumibol Adulyadej. The candidate set of criteria was obtained from several international and national sources related to sustainable rain-fed agriculture and the New Theory. The criteria were reviewed and modified by the expert team based on the goals of the New Theory in order to define an initial site-specific set of criteria that conform with the context of socio-topographical conditions of Thailand. The team screened, assessed, and prioritized the criteria using three multiple criteria decision-making (MCDM) techniques -ranking, rating and pairwise comparisons- in order to attain the final locality set of the assessment criteria. The process resulted in selection of a set of three criteria, with 15 sub-criteria. This final locality set of criteria was used to conduct a sustainability assessment of agricultural water management schemes of on-farm ponds. Criterion 1 (The pursuit of self-reliant agriculture based on limited agricultural land and water resources) was given the highest weighting, followed by Criterion 3 (The pursuit of sustainable rain-fed agriculture) and Criterion 2 (Self-sufficiency of household daily consumption and income generation). At the sub-criterion level, sub-criterion 1.1 (Land use efficiency) and sub-criterion 1.5 (Water use efficiency) of Criterion 1; sub-criterion 2.1 (Food self-sufficiency) of Criterion 2; and sub-criterion 3.1 (Mixed farming) of Criterion 3 were given the highest weightings. Further research is needed to examine the applicability and reliability of the assessment criteria in field situations.

Keywords: Criteria; Multiple criteria decision-making techniques; Sustainable rain-fed agriculture; The New Theory of His Majesty King Bhumibol Adulyadej

Introduction

Sustainable agriculture is defined by the Food and Agriculture Organization of the United Nations (FAO) as the successful management of resources for agriculture to satisfy changing human needs, while maintaining, or enhancing the quality of the environment and conserving natural resources [1]. In pursuing this objective in Thailand, the concept of the New Theory was initiated by His Majesty the late King Bhumibol Adulyadej based on the Sufficiency Economy Philosophy. It is a guideline for farmers to manage their limited agricultural land and water resources sufficiently, rationally, and flexibly in order to fulfill their social and economic needs [2]. This concept emphasizes self-reliance, self-sufficiency, and risk management, and has three goals: first, to enable farmers to pursue self-reliant agriculture by maximizing benefits from their limited agricultural land and water resources; secondly, to enable farmers to produce agricultural products sufficient for the household daily consumption and income generation for the purchase of non-farm produced food essentials and other necessities; and lastly, to enable farmers to pursue rain-fed agriculture sustainably [2-4].

To achieve these goals, the New Theory recommends that farmers divide their farmland into four parts. The first part is allocated to an on-farm pond to harvest rainwater in the rainy season, to allow irrigation during unseasonal dry spells and the dry season. This self-reliant small-scale water source is a prerequisite for sustainable agriculture in rain-fed areas where rainwater is the only water source due to lack of natural or man-made water sources or supplementary irrigation system [5]. The second part is dedicated to rice cultivation in the rainy season and for dryland crops in the dry season . The third part is allocated to production of horticultural crops and perennial trees. Together, these two parts can produce sufficient food to feed the household and generate a small cash surplus for the purchase of non-farm foods, farm inputs and other essentials throughout the year. Any year-end surplus remaining is to be saved. The fourth part is allocated to residential purposes. The proportion of land allocated to each use is flexible; however, the size of the pond must be sufficient to fully meet the needs of the farm throughout the year [2-4].

This concept aims to help small semi-subsistence or part-commercial family farmers [6] who normally own little land, as well as farmers in rain-fed areas. Using this approach, farmers can become more self-reliant and economically active, and establish a foundation to enhance their livelihoods and well-being, leading to long-term sustainable development [3]. Nevertheless, the New Theory can also be applied by specialized family farms, commercial family farms and commercial estates [6] which typically use mono-cropping. Adoption can enhance the self-reliance, self-sufficiency, and sustainability in agricultural resource management . The approach also helps farmers cope with both internal and external risks as well as market volatility, resulting from extensive and rapid socio-economic and environmental changes [4].

Recognizing the benefits of the New Theory, government agencies in Thailand have provided on-farm ponds to farmers in rain-fed areas, which represents almost 80 %of the country's total agricultural land [7]. The initiative has been led by Land Development Department since 2005, benefiting at least 450,000 households in rain-fed agricultural areas throughout the country [8]. However, these on-farm ponds have only a small storage capacity and lack any alternative means to replenish capacity in the dry season [9-10]. Therefore, to ensure that sustainable rain-fed agriculture can be achieved in Thailand, it is necessary to define a set of criteria as a tool to assess the sustainability of agricultural water management via on-farm ponds, including not only water productivity, but also economic, social and environmental aspects as well.

The primary purpose of this study is therefore to select appropriate assessment criteria to fulfill this purpose. The study applied multiple criteria decision-making (MCDM) methods as decision support tools for screening, selecting, evaluating and prioritizing the final locality set of the assessment criteria.

Materials and methods

1) Multiple criteria decision-making (MCDM) methods

Multiple criteria decision-making (MCDM) techniques offer a decision-making tool for optimizing resource allocations among competing users, in a complex environment using multiple criteria in a systematic process. MCDM offers a rational, rules-based approach to optimizing resource allocation across the stakeholder community. The results are therefore accepted as objective, rational, participatory, and transparent, offering a traceable record based on a democratic and structured decision-making process [11-13]. Many researchers recommend MCDM techniques to develop recommendations that can be respected, embraced and adopted by all stakeholders [12-18].

This study applied three MCDM techniques for assessing and selecting criteria: ranking, rating, and pairwise comparisons. The ranking and rating methods offer a general filter for screening each selected decision element for inclusion or exclusion. The pairwise comparison method offers a finer filter for prioritizing decision elements to be applied for assessing the sustainability of the agricultural water management scheme of the on-farm pond.

1.1) Ranking

This method assigns each decision element a rank based on its perceived degree of importance relative to the decision being made, following a nine-point scale, defined as 1, weakly important; 3, less important; 5, moderately important; 7, more important; 9, extremely important. While, the even values 2, 4, 6, and 8 are intermediate values. The relative importance or weight can be calculated based on the ranks assigned to each element [13].

1.2) Rating

This method assigns each decision element a score between 0 and 100, based on its perceived degree of importance relative to the decision being made. The scores for all elements being compared must add up to 100 [13].

1.3) Pairwise comparisons

This method divides decision elements into a series of one-on-one judgements .The relative weight of decision elements is assigned by comparing between each pair of decision elements, following a nine-point scale where 1 = equally importance; 3 = moderately more important; 5 = strongly important; 7 = very strongly important; 9 = extremely more important . The even values 2, 4, 6, and 8 represent intermediate values [13].

This method also uses the Consistency Ratio (C.R.), for measuring consistency. In general, a consistency ratio of 0.10 or less is considered acceptable; otherwise, it is necessary to recheck and adjust the pairwise comparison matrix to ensure the preferred choice [12].

2) Criteria assessment and selection process

2.1) The candidate set of criteria

Criteria are offered as tangible proxies to assess achievement of a complex goal, supported by defined objectives [17]. Each goal must be supported by at least one criterion, while each criterion can be decomposed into sub-criteria defined by units of measure, in terms of indicators [11, 17]. The hierarchical structure of criteria is illustrated in Figure 1.

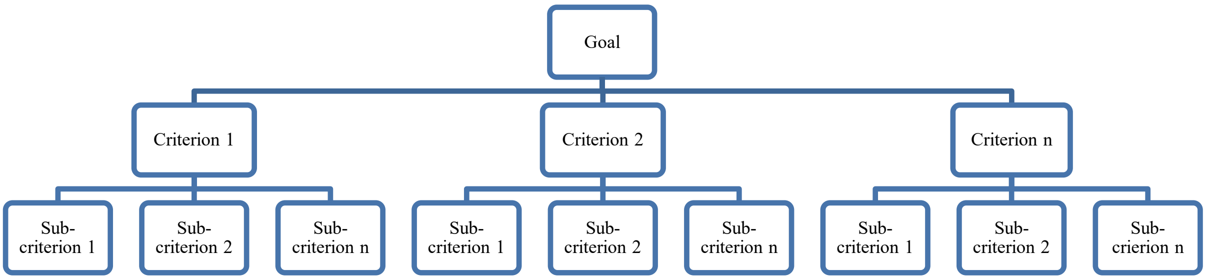

Figure 1 The hierarchical structure of criteria**.**

The criteria assessment and selection process generated a candidate set of criteria from which the expert team selected the final locality set of criteria as the agricultural water management scheme assessment tool. These criteria were derived from multiple sources, including UN-DESA, FAO, OECD, Office of the Royal Development Projects Board and the National Institute of Development Administration [4, 6, 19-13]. In covering economic, social, and environmental aspects of sustainability, together these criteria represented the global state of the art in the context of socio-topographical conditions of Thailand.

2.2) Composition of the assessment team

The 11-member assessment team included two agricultural experts and one water expert from the Chaipattana Foundation, one water expert from the Royal Irrigation Department, two officers from the Hydro and Agro Informatics Institute, three farmers from the farmer network of the Hydro and Agro Informatics Institute, and two project officers from the New Theory Demonstration Project of the Chaipattana Foundation. In spanning a range of different fields of endeavour, the composition represented multi-disciplinary experience and expertise in sustainable agriculture, water resource management, the New Theory, and Thailand's unique socio-topographical conditions. This broad range of perspectives leads to a highly informed and broad-based better selection of criteria [17].

2.3) Workshops for the expert judgement

Several workshops were conducted to undertake the expert judgement as a participatory assessment of candidate criteria. Key attributes for assessment included the relevance and logical association between each decision element and each decision hierarchy; a simple and unambiguous definition of criteria; a straightforward interpretation of the fulfillment of each criterion; the reliability and replicability of criteria; ease and cost-effectiveness of data collection; the acquisition of meaningful, high quality data; and the appeal of criteria in terms of their relevance and practicality for users. The most preferred criteria are those which can be simply measured, which can be verified by readily accessible data, and that can be directly detected, recorded and interpreted, by non-specialists [17]. The workshops resulted in an initial site-specific set of criteria which could serve as a platform for development of the final locality set of criteria.

As part of the voting process, three MCDM techniques- ranking, rating, and pairwise comparisons, were applied. Members of the assessment team independently gave their individual views on the relative importance of each criterion and sub-criterion in the initial site-specific set with respect to the New Theory. This process generated what became defined as the final locality set of criteria to be applied in measuring and comparing the sustainability of agricultural water management schemes of on-farm ponds.

The following section discusses the results of the final locality set of the assessment criteria of agricultural water management schemes of on-farm ponds, as derived from the workshops through application of the three MCDM techniques.

Results and discussion

The workshops used ranking and rating methods to screen candidate criteria and generate the initial site-specific set of criteria, which comprises three main criteria and 15 sub-criteria. All criteria and sub-criteria were then prioritized using the pairwise comparisons method. The result was consistent with those derived from the ranking and rating methods. However, it is noticeable that the range of the relative weights of each decision element from the pairwise comparisons method was typically much wider than those derived from the ranking and rating methods. This is because the pairwise comparisons method is able to differentiate the relative importance of decision elements more accurately than the other two methods [13].

Thus, the final locality set of the assessment criteria, comprising three criteria and 15 sub-criteria, is presented in the Supplementary Material, with relative weights assigned by the expert team according to the ranking method, the rating method, the combined weights of ranking and rating methods in terms of the average relative weights, and the pairwise comparison method, respectively.

Next, the result of each decision hierarchy, which are the criteria level and the sub-criteria level, respectively, will be discussed. Besides, their relative weights assigned by the expert team according to the ranking method, the rating method, the combined weights of ranking and rating methods in terms of the average relative weights, and the pairwise comparison method, respectively, will be presented.

1) Criteria level

As described above, criteria in the final locality set were developed based on existing ones related to the concept of sustainable agriculture, adapted to Thailand's socio-topographical context and reflecting the principles of the New Theory- self-reliance, self-sufficiency, and risk management. The relative weights assigned to each criterion are presented in Figure 2.

Criterion 1 (Pursuit of self-reliant agriculture based on limited agricultural land and water resources) was given the highest weighting using all three MCDM methods. Criterion 2 (Self-sufficiency of household daily consumption and income generation) and Criterion 3 (Pursuit of sustainable rain-fed agriculture) were assigned similar weightings according to all methods. The result was consistent with the objective of the New Theory, which is to enable farmers to manage the land independently and maximize benefits from their limited agricultural land and water resources [2]. Criterion 1 provides a foundation for farmers to fulfill the two remaining criteria. Self-reliant agriculture based on limited agricultural land and water resources can be achieved. Increasing resource use efficiency contributes to higher overall farm productivity, cash income and ultimately to improved livelihoods. Most importantly, this approach reduces internal and external risks and uncertainties through a diversified year-round approach to farming, leading to sustainable rain-fed agriculture.

2) Sub-criteria

Sub-criteria for each criterion in the final locality set were selected in the same way, based on existing ones related to the concept of sustainable agriculture and the New Theory . Though they still conformed and represented the global state of the art as well as international and national sources to which they belonged, units of measurement were changed.

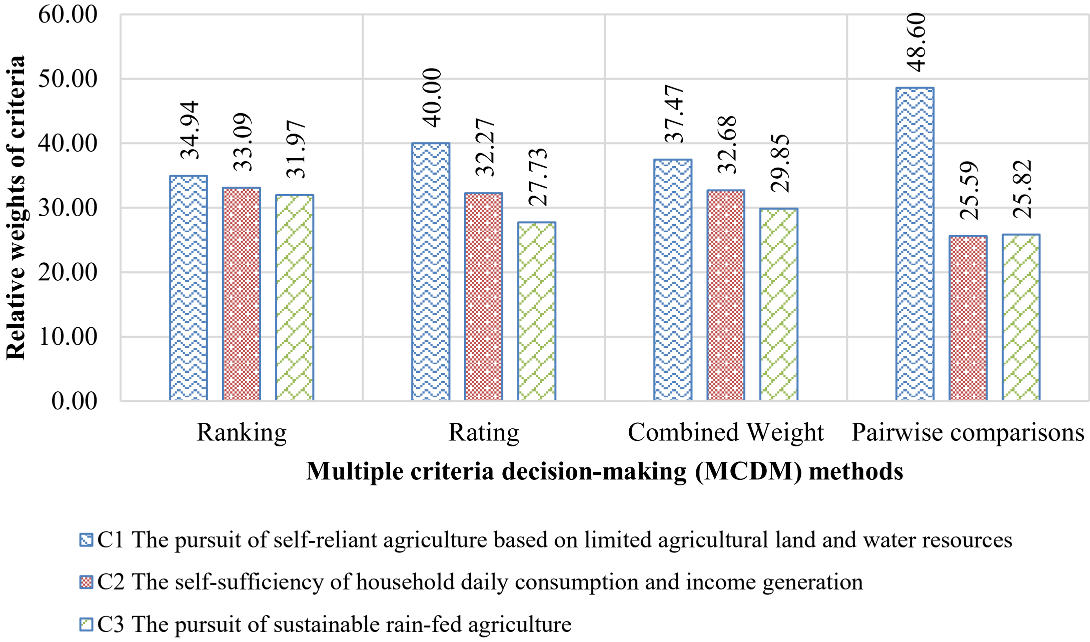

Figure 2 Relative weights of criteria calculated by ranking, rating and pairwise comparison methods.

Based on the workshop results, the relative weights assigned to each sub-criterion under Criterion 1 (Pursuit of self-reliant agriculture based on limited agricultural land and water resources) are shown in Figure 3. Sub-criterion 1.1 (Land use efficiency) and Sub-criterion 1.5 (Water use efficiency) were prioritized by all MCDM methods as the most important sub-criteria. Both measured resource use efficiency of the water management scheme of on-farm ponds in terms of the ratio of the cultivated area in dry and wet seasons and to the amount of rainwater harvested by the on-farm pond, respectively. This is because, in pursuing self-reliant agriculture based on limited agricultural land and water resources, it is necessary to initially use limited resources efficiently in order to fulfill social and economic needs of the household. The remaining sub-criteria are subsequently considered, once a decision has first been made on the most efficient use of agricultural land and water resources.

The remaining sub-criteria were distributed within a narrow range of weightings. Two sub-criteria were given equal importance under Criterion 1: Sub-criterion 1.2 (Production cost) and Sub-criterion 1.6 (Production cost and benefits). The other sub-criteria shared similar weightings: Sub-criterion 1.7 (Diversification of farm production system), Sub-criterion 1.3 (Farm productivity) and Sub-criterion 1.4 (Water productivity).

Figure 4 shows the relative weighting assigned to each sub-criterion under Criterion 2 (Self-sufficiency of household daily consumption and income generation). All MCDM techniques assigned the highest weight to Sub-criterion 2.1 (Food self-sufficiency), followed by Sub-criterion 2.3 (Household self-sufficiency). Improvements in these sub-criteria will help farmers build a firm foundation to gradually raise their standard of living and quality of life through self-sufficient sustainable agriculture in rain-fed areas [4].

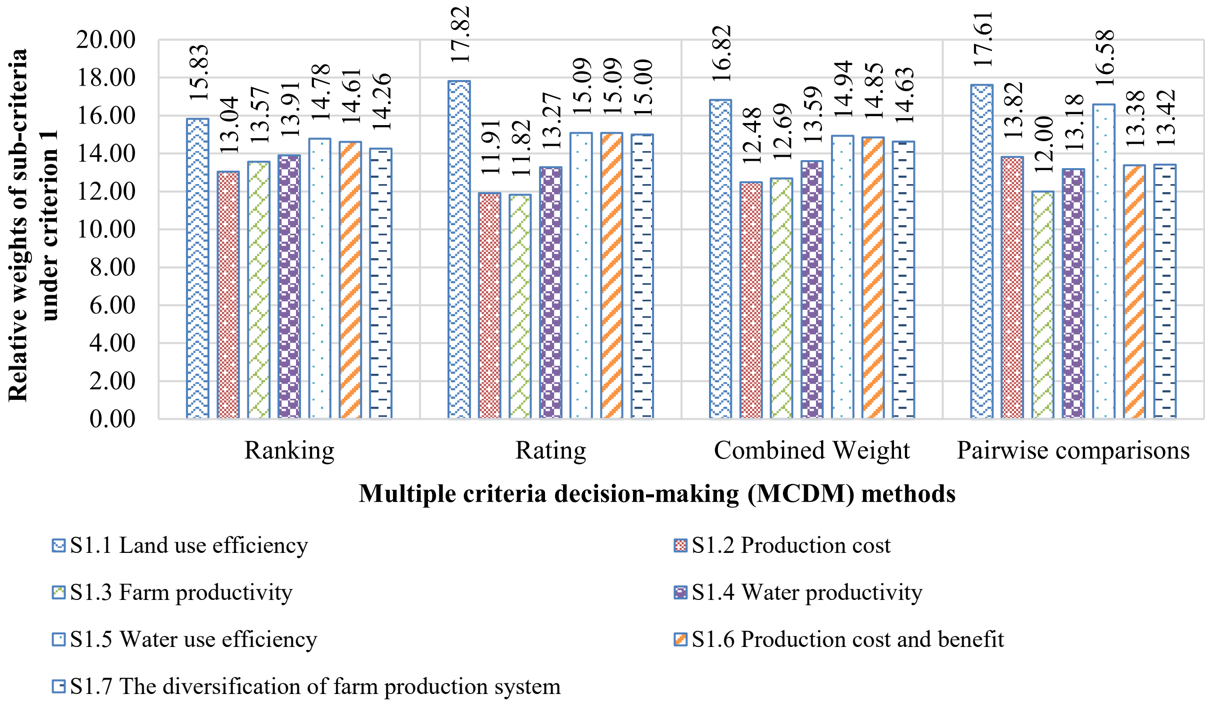

Figure 3 Relative weights of sub-criteria under criterion 1 calculated by ranking, rating, and pairwise comparison methods.

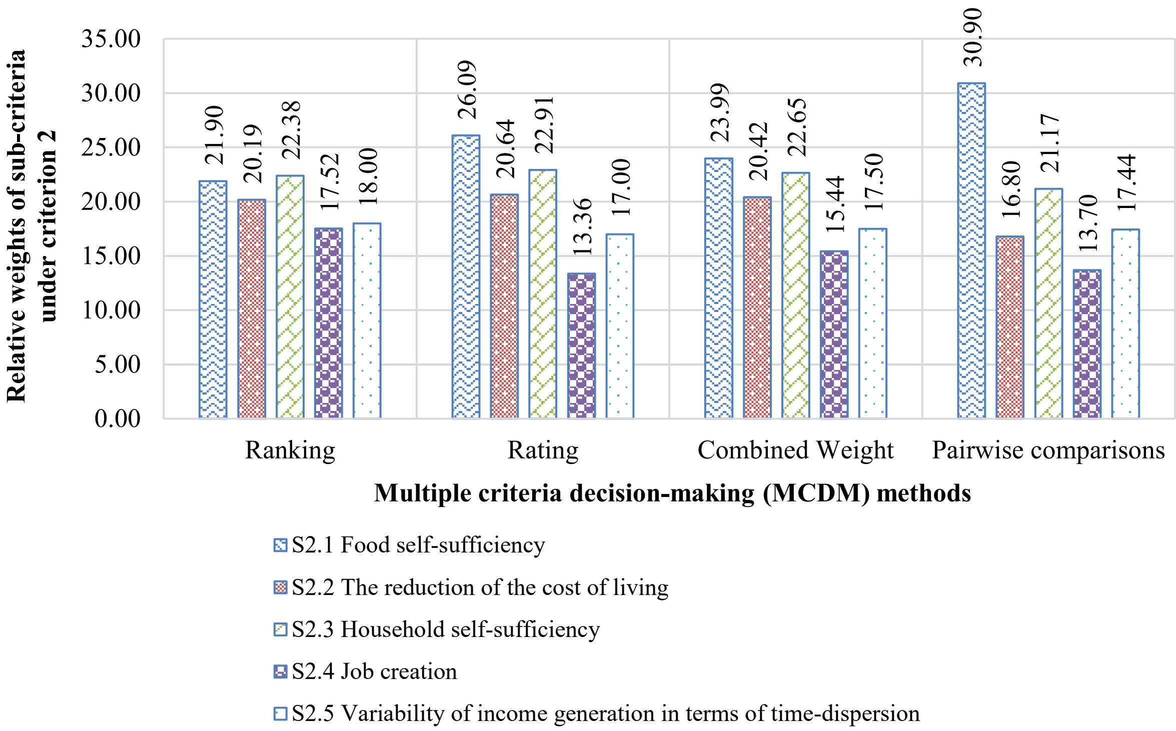

Figure 4 Relative weights of sub-criteria under criterion 2 calculated by ranking, rating, and pairwise comparison methods.

As rice is the staple crop, food self-sufficiency was measured in terms of the sufficiency of rice produced on the farm to cover the household's year-round consumption. One of the fundamental principles of the New Theory is that every household must produce enough rice to consume for the whole year, removing the need to buy their staple from the market, were prices can be volatile [2]. This also would contribute directly to improvements in Sub-criterion 2.2 (Reduction in cost of living).

Household self-sufficiency was defined as the ratio of the net profit received from the agricultural water management scheme of the on-farm pond to annual household expenditure. This is because every household needs to generate enough cash income from cash crops to purchase food, farm inputs and other essentials. Sustainability requires that the household should have some residual savings after these expenses [6]. To assess the household's progress towards self-sufficiency, Sub-criterion 2.5 (Variability of income generation in terms of time-dispersion) is used as an indicator, measured in terms of the number of months with income generation per year [3]. This criterion is thus linked to Sub-criterion 2.4 (Job creation) which is assessed in terms of the number of months during which household members were engaged in agricultural work. A water management scheme that provides year-round employment for household members will reduce seasonal unemployment and seasonal rural-to-urban migration, and enhance sustainable rural livelihoods [19-22].

Figure 5 shows the results of expert judgements assigning the relative weight of each sub-criterion under Criterion 3 (Pursuit of sustainable rain-fed agriculture). From all three MCDM techniques, the sub-criterion allocated the highest weighting was Sub-criterion 3.1 (Mixed farming), followed by Sub-criterion 3.2 (Multiple cropping) and Sub-criterion 3.3 (Environmental benefits and services of perennial plants), respectively.

Mixed farming combines various agricultural activities on the same farm unit, including crop and livestock production, poultry, fish farming, and possibly additional activities such as bee keeping, to sustain the farm family and diversify production and market risk [40]. Mixed farming is a central tenet of the New Theory [3], enabling the pursuit of sustainable rain-fed agriculture by maintaining the ecological balance and soil fertility over the long term [41].

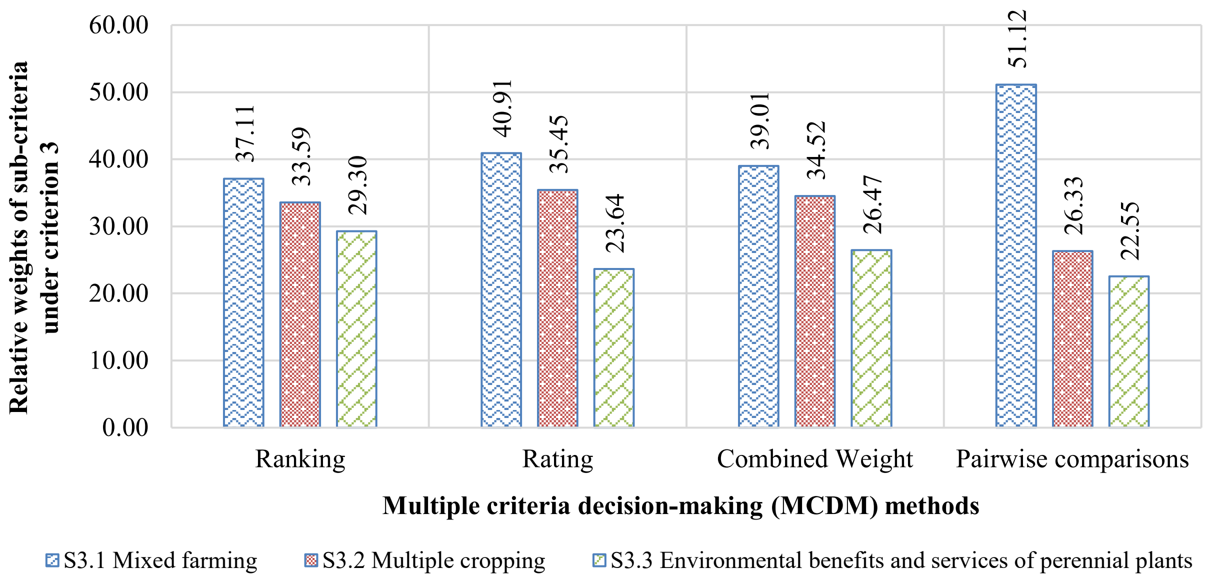

Figure 5 Relative weights of sub-criteria under Criterion 3 calculated by ranking, rating, and pairwise comparison methods.

Multiple cropping is the practice of growing different crops in succession on the same piece of land during the year. It is measured in terms of the number of crops in the same area in sequenced seasons [42-43]. Multiple cropping is essential to maximize the use of limited land area, but is only possible through on-farm water storage and appropriate water management to extend the growing period into the dry season and throughout the year. On-farm ponds thus provide some measure of resilience and adaptation to climate change in rain-fed agriculture [2]. As well as improving efficiency of land use, multiple cropping provides food, employment and cash income for the household throughout the year, which reduces internal and external risks .Moreover, multiple cropping accommodates the pursuit of sustainable rain-fed agriculture. It maintains the long-term productivity of the land by preventing soil erosion, improving the composition of the soil, as well as enhancing soil nutrient recycling and maintaining soil organic matter. By careful selection of crops, multiple cropping can reduce depletion of soil nutrients as well as pests and diseases often observed in mono-cropping [44].

The pursuit of sustainable rain-fed agriculture also generates environmental benefits and ecosystem services- for example, by maintaining perennial plants that maintain soil cover and preserve soil structure, nutrients and soil moisture through their root systems. They protect the soil against wind and water erosion, preserve the precious topsoil, and provide shade and cover as an animal habitat. In addition, this sub-criterion is directly related to the concept of the New Theory. Which stipulates that one part of the farmland should be dedicate to perennial trees that provide food and wood [4].

Conclusion

This paper presents assessment criteria for agricultural water management schemes of on-farm ponds for sustainable rain-fed agriculture, referenced to the New Theory of His Majesty King Bhumibol Adulyadej. The study applied three multiple criteria decision-making (MCDM) techniques- ranking, rating and pairwise comparisons, as practical and effective approaches to screen, select and prioritize a final locality set of assessment criteria. These MCDM methods allowed involvement of various interest groups with different backgrounds and specialties to be involved in prioritizing the importance of all decision elements. Among the three MCDM methods, ranking and rating were found to be easier and more convenient to apply than the pairwise comparison method, but were not sufficiently refined to reflect the true importance of each decision element. The pairwise comparisons method was able to differentiate the relative importance of each decision element more precisely. The two first methods were thus deemed preferable as an initial screening tool.

The study generated a final locality set of the assessment criteria comprising three criteria and 15 sub-criteria, selected from a number of international and national sources related to sustainable rain-fed agriculture and the New Theory. These criteria were modified by the expert team in order to conform with the context of Thailand’s socio-topographical conditions. The final locality set will assist small rain-fed farmers assess the sustainability of their agricultural water management schemes and make changes as appropriate.

At the criterion level, Criterion 1 (Pursuit of self-reliant agriculture based on limited agricultural land and water resources) was given the highest importance by the expert team, followed closely by Criterion 3 (Pursuit of sustainable rain-fed agriculture) and Criterion 2 (Self-sufficiency of household daily consumption and income generation). The result was consistent with the objective of the New Theory, which is to enable farmers to independently manage and maximize benefits from their limited agricultural land and water resources [2]. Moreover, the achievement of self-reliant agriculture based on limited agricultural land and water resources will enable the self-sufficiency of household daily consumption and income generation and lead to sustainable rain-fed agriculture.

At the sub-criterion level, Sub-criterion 1.1 (Land use efficiency) and Sub-criterion 1.5 (Water use efficiency, under Criterion 1) were given the highest weighting, followed by Sub-criterion 2.1 (Food self-sufficiency, under Criterion 2), and Sub-criterion 3.1 (Mixed farming, under Criterion 3). The result was consistent with the concept of the New Theory. In order to pursue sustainable rain-fed agriculture, water management schemes for on-farm ponds need to use optimize use efficiency of agricultural land and water resources. Moreover, mixed farming diversifies farm activity, ensuring income is generated throughout the year. This contributes to household food security and a secure annual income, and reduces the many internal and external risks faced by the farm household, where there is generally no social safety net to protect them against the impacts of crop failure or natural disasters etc.

A well-managed water management scheme will enable farmers, especially small, resource-poor farmers in rain-fed areas to meet their food security and economic needs year round- this is the most important expected outcome of applying the New Theory. The approach will lay a foundation for farmers to gradually raise their household living standard and well-being in the long term [4]. Eventually, farmers will be more self-reliant, managing their limited agricultural land and water resources to fulfill their social and economic needs sufficiently and sustainably.

In conclusion, the study developed a set of selected criteria which are useful for assessing the sustainability of agricultural water management schemes of on-farm ponds as well as provide inputs for future research. However, this study carries several limitations. The assessment criteria were developed mainly for farmers in rain-fed agricultural areas (i.e. small, semi-subsistence or semi-commercial family farms). They may not be fully applicable to farmers in fully irrigated areas, for specialized family farms or for commercial family farms and commercial estates due to their different economic models and resource availability. Therefore, future research should test the criteria and broaden the final set to accommodate a wider range of farm types. A second limitation arises because the selected criteria focus primarily on social and economic aspects; future research should place much greater emphasis on inclusion of environmental criteria. As a third limitation, the criteria have not yet been tested for certain key attributes, including practicality and cost-effectiveness of data collection in the field. Thus, future research should also evaluate their real-word applicability and reliability in field situations.

Acknowledgements

This research project was financially supported by the Chaipattana Foundation. The authors would like to thank the Chaipattana Foundation, the Royal Irrigation Department, and the Hydro and Agro Informatics Institute for research support provided.

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