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METADATA ANALYSIS REVIEW OF INTEGRATED AGROECOSYSTEM COMPONENTS

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ABSTRACT

Explanation of the concepts related to integrated agroecosystems is discussed in different focus areas of agricultural science. The need for integration is important in terms of climate smart agriculture imperatives. The aim of this study is to understand how these areas are linked for the purpose of multidisciplinary research, which has become necessary due to the need to respond to climate change holistically. The objective of this study was to explain how three broad areas related to agroecosystem research can be linked based on available publications in the past ten years. For the purpose of this study, Soil-Plant-Atmosphere Continuum (SPAC), Water-energy-food nexus (WEF) and Sustainable Agriculture (SA) were selected as high-level domains in integrated agroecosystem research. The selection was informed by a review of literature published in the past decade and beyond. Identification of more specific research publication fields was performed using a binary indicator method based on two randomly selected key words to enhance reliability. The outcome was reduced to twenty-five research fields which were ranked as representative entities for the purpose of establishing the association of SPAC, WEF and SA with current literature. Reliability of research sources was established using the popular Source Normalised Impact per Paper (SNIP) guidelines. Regression analysis was used to relate the research domains and research fields. The conclusion of the study is that SPAC is the most highly integrated agroecosystem research area followed by SA. The WEF domain is ranked lowest. The visibility of research domains is confirmed by the impact of publications. This suggests that there is a need to escalate the value of the three research domains and create an integrated approach to integrated agroecosystem innovations. There is also a need to purposefully establish reasonable overlaps between SPAC, WEF and SA. This may be possible through multidisciplinary methods of data collection, which may create integration of information technology and indigenous knowledge systems.

Key words: agroecosystem, integrated agriculture, matrix, soil-plant-atmosphere, sustainable agriculture, water-energy-food

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INTRODUCTION

Human effect on the global landscape is aimed at influencing livelihoods. Food production occupies the primary position in this regard. Management of agroecosystems is directly linked to the primary objectives of expected outputs in terms of quantity and quality of produce [1]. Although there is a significant amount of literature on crop response to environment, there is less information about crop response to management practices. Management practices can enhance or impair the effect of environment on crop performance [2, 3, 4]. Understanding the soil and crop canopy relations has been the interest of integrated agriculture management research for decades. Notable in terms of consequential innovations was the development of the concept of Integrated Plant Management (IPM) and sustainable agriculture theories and practices [5, 6].

The challenge of integrating the different aspects of sustainable agriculture theories, practices and research is becoming more important in the context of climate change. Predictability of cropping seasons has been directly linked to water and solar radiation factors, rainfall, humidity, and temperature [7]. These factors are associated mainly with physiological, biochemical and genetic factors affecting metabolism and morphological traits. Below ground growth (tap root length and root density) responds to soil water availability as early as emergence stage which influence metabolic changes during crop development [8]. This can be associated with water use efficiency, drought tolerance, biomass accumulation and harvestable yield. Solar radiation influences both soil and canopy responses to environment. Soil temperature influences the biosphere activities, including soil life, health and composition, with respect to organic matter and nutrients [8]. In the canopy, solar radiation influences stomatal conductance, a major factor for evapotranspiration (ET). In the context of physics and chemistry, solar radiation can be explained using photosynthetically active radiation (PAR), net assimilation ratio (NAR) and Leaf area index (LAI), among others [9, 10]. Both soil and canopy environment conditions influence crop association with life in the microenvironment. This includes disease and pest occurrence as they affect crop performance at different stages of plant growth [11, 12].

Studies which focus on the soil-plant-environment nexus contribute knowledge to agroecosystem management in recent times [13, 14]. The scientific explanation of this nexus is known as soil-plant-atmosphere-continuum (SPAC) [15]. This has led to the recent focus on water-energy-food nexus (WEF) [16, 17]. Sustainable agriculture (SA) is a broad-based approach to integrated agroecosystem management and literature shows that it has multiple dimensions which include basic and applied sciences, social science and humanities (mainly economics and law) [18,19]. Explanation of how these three broad areas of integrated agricultural

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science research is a complex task. It requires different approaches, separately and in combination [20, 21]. The starting point should be a narrative of how they feature in our existing knowledge of integrated agroecosystem research, and how they interconnect in terms of broad-based agriculture and plant science. There is a need to generate theoretical match of the dominant domains of integrated agroecosystems and create opportunities to suggest relevance of the less known dimensions of current demands for sustainable agriculture, for example, regenerative climate smart agriculture for conservation and rural development. The hypothesis of this study is that an entity relationship approach can be used to confirm the major research domains of integrated agriculture systems. Hence, the objective of this study is to provide highlights of how the three research domains of integrated agroecosystems (SPAC, WF and SA) can be used to expand their meaning by identifying potential relevance to current research for future recommendations of new research. This is necessary for better understanding of agroecosystem management response to climate change in association with factors associated with indigenous knowledge systems and information and technology principles.

MATERIALS AND METHODS

Three research domains (i) Soil-Plant-Atmosphere Continuum (SPAC), (ii) Water-energy-food nexus (WEF), and (iii) Sustainable agriculture (SA) were identified for relevance to integrated agroecosystem management based on high visibility in literature in the past ten years [22,23]. Source Normalised Impact per Paper (SNIP) guideline was used to randomly select a combination of articles in quartiles one (Q1), two (Q2), three (Q3) and four (Q4) of peer-reviewed publications using the SCOPUS journal ranking (SJR: Scientific Journal Rankings) as a source [22, 23]. A bigram categorisation of research area by two randomly selected keywords was deemed suitable for the purpose of this study [24]. The bigram categorisation method is a technique commonly used in natural language processing (NLP) and text mining to analyse and classify text based on bigrams, which are pairs of consecutive words in a sentence or document [24, 25]. Consequently, twenty-five (25) research categories were generated based on the hypothesis that they are linked to all three research domains (SPAC, WEF, and SAC). This was achieved by using a framework-based selection, systematic literature review using defined inclusion/exclusion criteria [24]. Consequently, a binary matrix consisting of SPA, WEF and SA as attributes, the list of keywords for published research focus areas (25) as entities and journal quartiles as indicators to locate the priority rank of research domains and research focus areas was generated for pair similarity analysis (Table 1).

This study used a simplified modification of the previously published statistical model to calculate similarity and clustering [24] (Equation 1).

Q score = N_j/E_n ....Equation 1

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Where Q score refers to the value for each quartile; N refers to the number of journal articles matching the entity in the previous 10 years (2004 to 2023); E refers to the total number of selected binary entities (25). Hence, the binary scores were derived from dividing the total number of generated publications per quartile (N) by the total number of research fields (25). The mean values were used to generate new data to explain the integrated geosystem research attributes (SPAC, WEF, and SA) and research field entities.

Soil-plant-atmosphere continuum

Soil-plant-atmosphere continuum (SPAC) is a well-known method to explain the relationship between soil water availability, roots system activity and its influence on water movement through the vascular system to the atmosphere based on stomal activity [25, 26]. Linked to this approach, crop response to temperature and solar radiation have been explained. Consequently, SPAC is accepted as a reliable explanation of water relations in agronomy, plant physiology and agricultural management, including designing of irrigation systems [27]. Adaptation for descriptive factor-based equation for the purpose of this study is shown in equation 2. General illustration of SPAC components is shown in Figure 1.

SPAC indicators = $(S + P)M$ ....Equation 2

Where S refers to soil physics characterisation in terms of tension; P refers to plant physiological response characterisation of water in terms of diffusion and water deficit; and M refers to meteorological characterisation of atmospheric water in terms of vapour pressure or relative humidity.

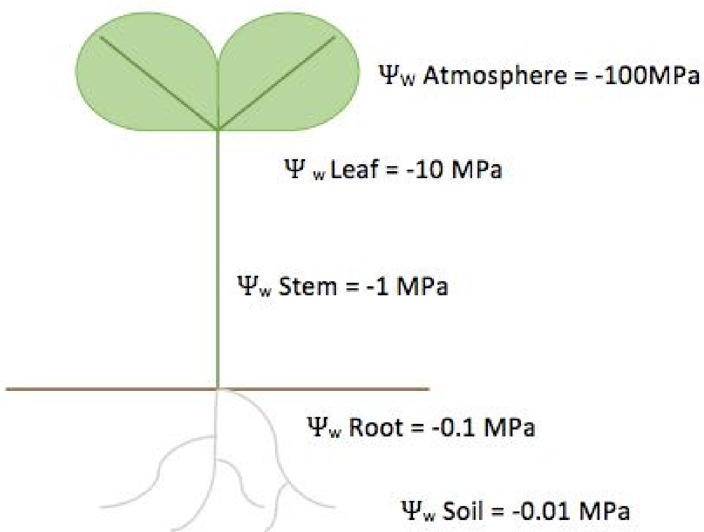

Figure 1: General illustration of SPAC components according to Taiz (2014)

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Water-energy-food nexus

The need to explain the interconnectedness of the major resources and inputs for food security was recognised by the Food and Agriculture Organisation of the United Nations in 2014. Potentially, this is a mandate for agricultural and food scientists to use a holistic interpretation of the agroecosystems research niche areas. It is important to design a system that links plant water use for crop productivity, energy utilisation in the agricultural management. The water-energy-food (WEF) nexus is a complex concept that is presented in different ways focusing of partial linkages of environmental crop science, food science and economics [28]. Metadata linkage refers to the process of connecting or integrating metadata from different sources or systems to create a unified, enriched, and more useful dataset. This is especially important in research fields like sustainable agriculture and water management, where data comes from diverse disciplines, formats, and institutions. The current study provides a simple explanation in the context of metadata linkage with the other two selected research domains based on previous description of WEF Nexus Index [29]) (Equation 3). Illustration of the relationship is explained in Figure 2.

WEF indicators = ($W + E$)/F…………………………………. Equation 3

Where W refers to water access by plants as defined by availability; E refers to energy access for plant growth and management practices; F refers to crop quantity and quality

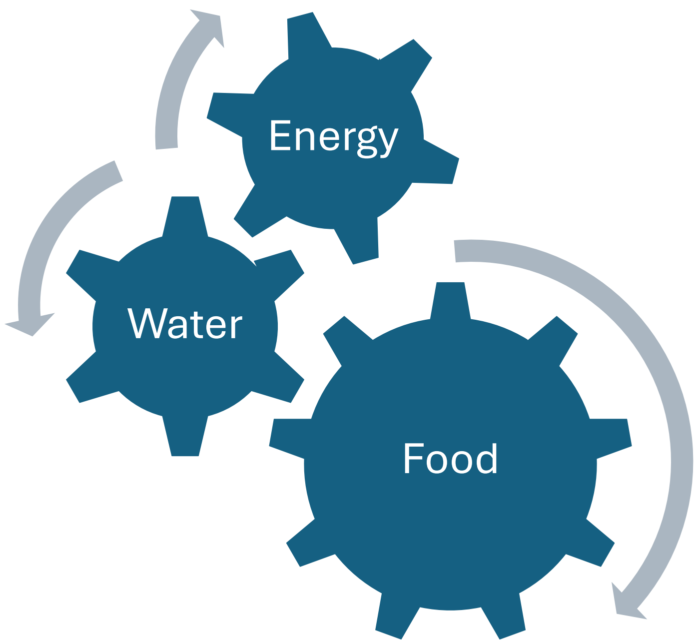

Figure 2: Proposed WEF nexus indicators to suggest the necessary combination of water and energy to produce high quantity and quality food produce

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Sustainable agriculture

The definition of sustainable agriculture (SA) is ambiguous [30]. It is necessary to identify the relevant dimensions that make SA fit in the global reflection of integrated agro-ecosystem management. An attempt to make this happen requires acceptance of a shift while simultaneously establishing a reliable probability. Despite its complex nature, for this study, SA is explained using three components which are deemed relevant to integrated agroecosystem management (Equation 4). An adapted illustration is also presented (Figure 3).

SA indicators = $(Ace + Pe)/Tte$.................................Equation 4

Where A refers to adaptation of cultural practices to environment; P refers to preservation of environment; T refers to technologies for the environment

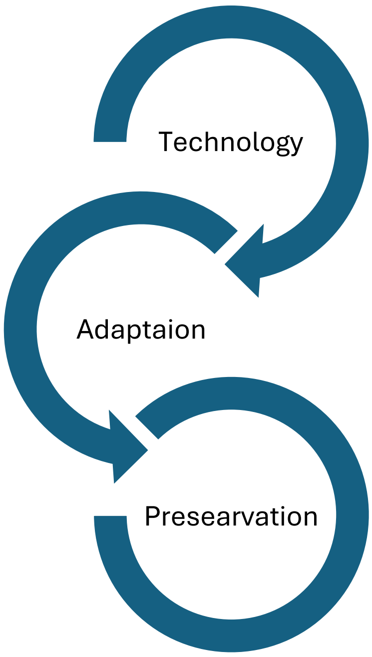

Figure 3: Proposed nexus for sustainable agriculture in an integrated agroecosystem

RESULTS AND DISCUSSION

Application of agricultural practices is a human response to innovation, science and technology [31]. This principle can be traced back to the era of hunter-gatherers which was associated with reliable organisation of agriculture as a management practice for food security. This human-centred response is influenced by the environment in terms of soil, landscape biodiversity and climate [31, 32]. A combination of these factors shows agricultural ecosystems with well-defined magnitudes, duration and resilience [33]. How the habitat is managed is also dependent upon the resource pulse of the habitat at a micro-(field), meso-(farm) and

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macro – (ecosystem) levels. Modern agriculture is a well-defined habitat that is characterised by spatial and temporal homogenisation [33, 34]. However, there is a wide range of agroecosystems.

Scientific research has established distinct factors and variables to explain plant-environment interactions at individual plant level, monocrop field, intercrop systems and ecosystems [35]. As the science develops, the need to emphasize the importance of interdisciplinary and multipurpose interpretations has been ignored until recently [7, 10]. Although it is based on ancient principles of physical and biological sciences, the concept of Soil-Plant-Atmosphere continuum (SPAC) is the most recent model of agroecosystem explanation compared with the water-energy-food nexus (WEF) [7, 10]. On the other hand, sustainable agriculture is a hybrid system that requires deliberate selection and careful combination of components for crop management systems versus socioeconomic dimensions.

Analysis of literature revealed a variable contribution of the major research areas that are relatable to SPAC, WEF and SA (Figure 4). Plant Science and Environmental Science dominate the 28% of the research fields across SPAC, WEF and SA systems occupying percentile rank ≥ 80%. However, this contribution represents only 8% of the total (25) research fields considered. Fifteen research fields (60%) occupy percentile ranking between 50% and 80%. The remainder of the research fields (12%), namely, Agricultural Development, Agricultural Ecology and Climate Change are located below 50% in percentile ranking. These findings may be an indication of research attention provided to the three agroecosystems focus areas [36, 37].

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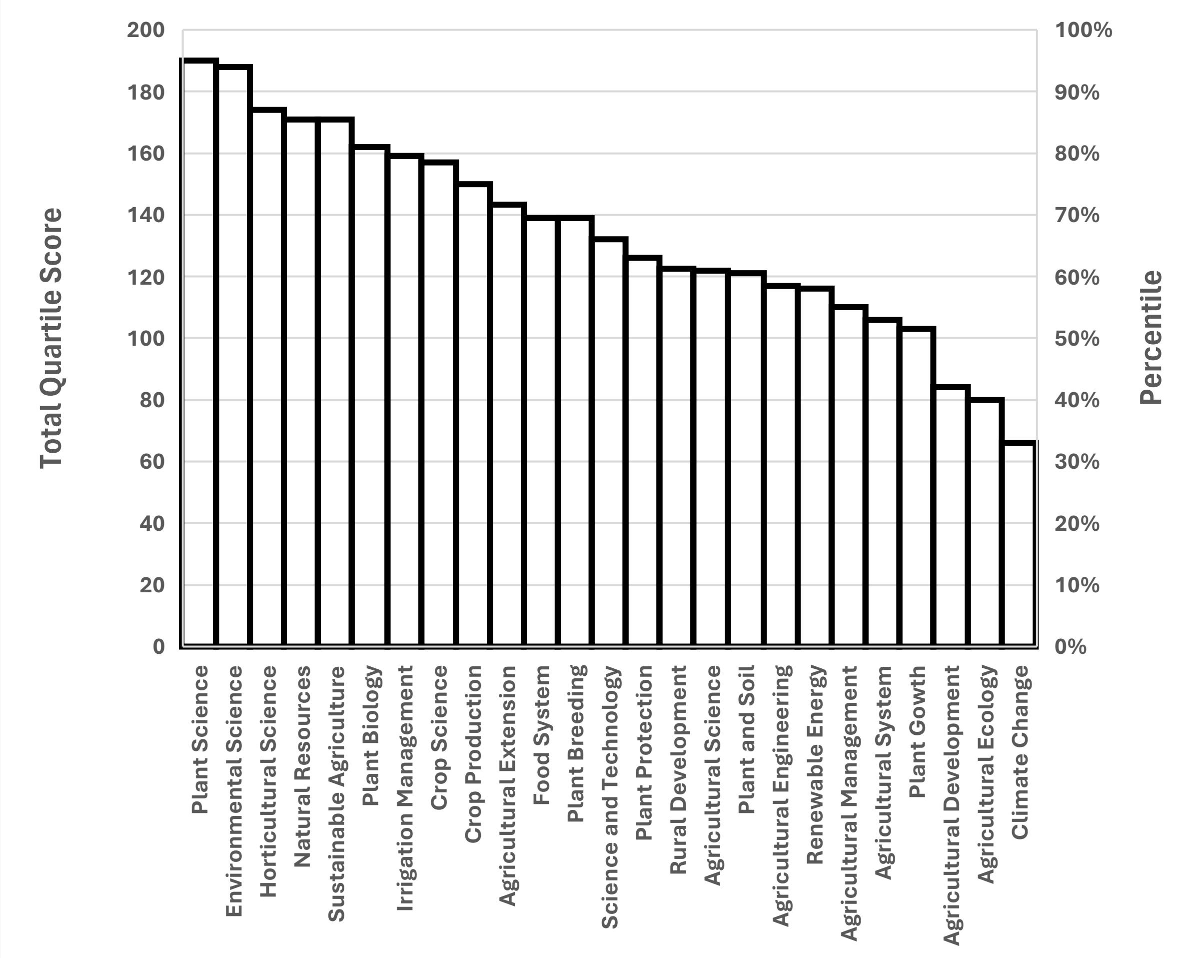

Figure 4: Comparison of selected research fields selected for relevance to the integrated systems of SPAC, WEF and SA

An attempt to confirm the validity of how research fields contribute to the integrated systems (SPAC, WEF and SA), it became necessary to use their correlation with the cluster evaluation of the research focus in terms of Source Normalised Impact per Paper (SNIP). Using the mean quartile score, results showed differentiation of integrated systems (Figure 5). The SPAC system dominates (53%), followed by SA (28%) and WEF (19%). These findings substantially indicate that the current focus of integrated agroecosystem research is Soil-Plant-Atmosphere Continuum. The SPAC area dominates consistently in low (Q4), medium (Q2; Q3) and high (Q1) impact sources of published research (quartiles). The explanation of SPAC dominance could be associated with the broad spectrum of research fields that include both applied, for example, agronomy, crop science, horticulture) and basic (biology) plant sciences, meteorology, hydrology and irrigation sciences [38, 39, 40].

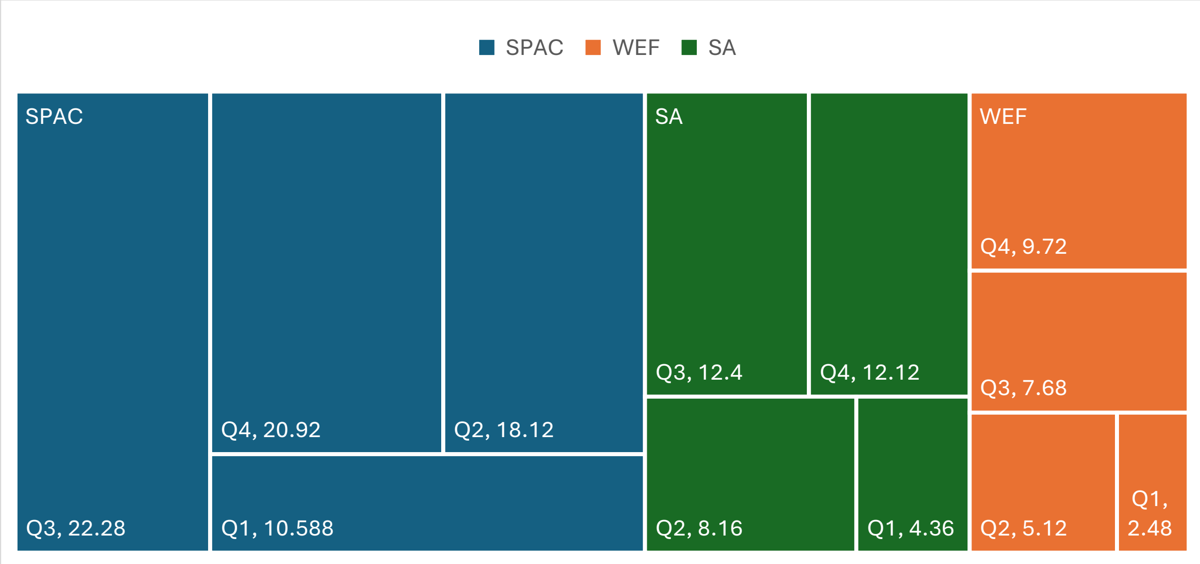

Figure 5: Comparison of three integrated research systems (SPAC, SA and WEF) based on distribution of research focus using mean quartile ranking scores (values) of published sources (Q1, Q2, Q3, Q4)

Regression analysis to relate each integrated system with visibility in the published literature revealed trends which confirm the data presented in Figure 5. Results are shown in Figure 6. These findings suggest that the majority of citations are in the low quartile research sources (Q4) across all fields of integrated agroecosystem areas. The highly signification correlation with respect to all the areas can also be interpreted to indicate greater interest and recognition of SPAC compared with SAC and WEF. The highest versus lowest quartile ranking for SPAC is 50% whereas it is 66% for SA and 70% for WEF.

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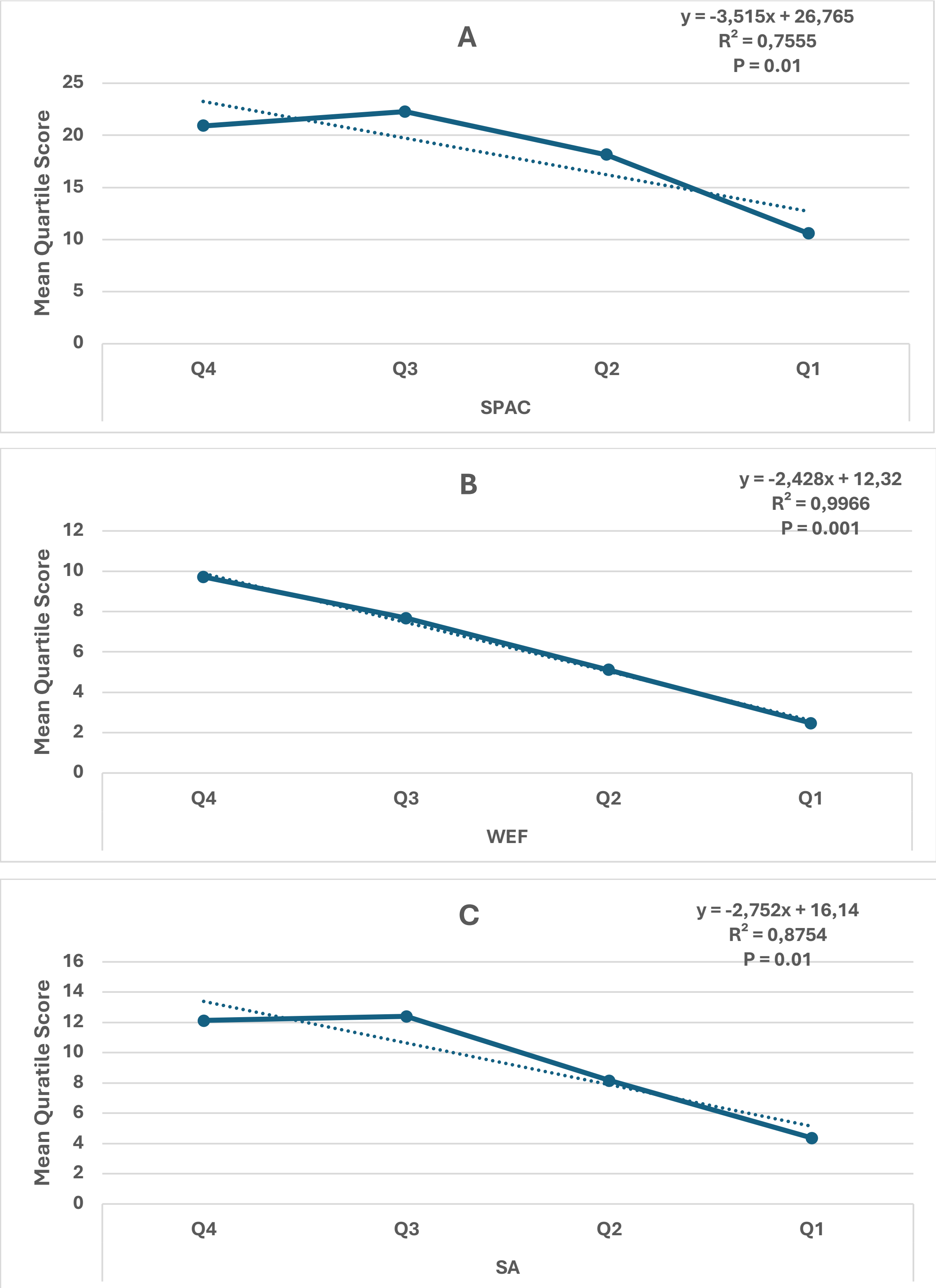

Figure 6: Correlation of SPAC (A), WEF (B) and SA (C) integrated agroecosystems research with research impact indicators shown by source quartile ranking (Q1, Q2, Q3, and Q4)

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

Developments in agricultural science research suggest that multidisciplinary approach is critical for understanding of integrated agricultural systems. It is for this reason that there is a shift towards integrated systems which permit data collection and analysis in the context of both basic and applied sciences. New research tools make the integrated approach possible. However, there is a need to show the relationship between integrated research fields in the context of complexity of agroecosystems as a habitat that is constantly responding to human influence. The need for climate smart agriculture requires an integrated approach to research. This study provides a simplified overview of the three areas which have a long history of integration of applied and basic sciences. Soil-Plant-Atmosphere Continuum is predominantly basic in its interpretation of how crops respond to environment based on predictive models of the obvious physical mechanisms in the soil, the plant and canopy milieu. The need for biological and management components to satisfy the models involved in SPAC may be the reasons why this area is most highly popular and relevant in integrated agroecosystem studies. The Water-energy-food nexus (WEF) theory is relatively new and interest in it may have grown with more interest in climate change. It is in this context that the indication of low visibility of WEF in the popular areas of agricultural science research selected for this study can be explained. Given its ambiguity in terms of location in agricultural science, the finding that Sustainable Agriculture is significantly more visible in published literature than WEF was a surprise. However, it is reasonable to assume that it is easy to directly or indirectly associate both SPAC and WEF research with Sustainable Agriculture. The study creates an opportunity to recommend future research questions. There is a need to enhance our understanding of the underrated fields: agricultural development, agro-ecology and climate change. It is likely that new opportunities for data collection using information technology could be combined with indigenous knowledge to enhance the quality of research in these areas. Possibly, more integrated approaches to study agroecosystems could be established. Entity-relationship methods are crucial in the natural sciences for extracting and understanding relationships between various entities within large datasets. This study recommends that future studies should focus on identifying and capturing entities and their relationships within texts, forming knowledge triples (head entity, relation, tail entity) for knowledge construction.

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Conflict of interest

The authors declare that there is no conflict of interest associated with the study.

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Table 1: Binary matrix calculation of relationship between areas of research (Entity), research attributes (SPAC, WEF, SA) and indicators of research impact in terms of quartiles (Q1, Q2, Q3, Q4)

	SPAC				WEF				SA						
ENTITY	Q4	Q3	Q2	Q1	Q4	Q3	Q2	Q1	Q4	Q3	Q2	Q1	Total	Mean	Min
Agricultural Science	26	19	15	5	12	8	4	1	15	8	6	3	122	10,17	1
Agricultural System	9	14	4	3	9	6	4	1	17	21	11	7	106	8,83	1
Agricultural Ecology	8	12	3	2	7	4	2	1	12	13	10	6	80	6,67	1
Sustainable Agriculture	20	20	11	2	14	12	6	3	22	27	20	14	171	14,25	2
Environmental Science	22	25	28	15	13	9	6	3	16	18	21	12	188	15,67	3
Plant and Soil	17	19	18	7	10	8	5	2	12	13	6	4	121	10,08	2
Irrigation Management	23	25	27	12	13	15	8	4	11	14	5	2	159	13,25	2
Food System	26	29	17	10	11	8	9	5	8	7	5	4	139	11,58	4
Crop Science	30	26	12	8	17	12	7	5	16	12	7	5	157	13,08	5
Horticultural Science	32	24	20	17	12	11	8	5	14	18	9	4	174	14,50	4
Renewable Energy	17	22	13	10	4	12	14	8	5	7	3	1	116	9,67	1
Climate Change	12	11	8	6	5	6	4	2	4	4	3	1	66	5,50	1
Rural Development	18	23	28	4,5	8	5	4	2	12	8	6	4	123	10,21	2
Agricultural Extension	22	26	9	2,2	3	2	1	0	22	26	22	8	143	11,93	0
Natural Resources	25	32	30	28	12	7	5	4	12	9	5	2	171	14,25	2
Agricultural Management	16	18	12	2	7	5	3	0	15	17	8	7	110	9,17	0
Plant Biology	27	32	34	29	14	6	3	2	7	4	3	1	162	13,50	1
Plant Protection	17	22	25	5	6	4	2	0	12	19	10	4	126	10,50	0
Agricultural Developmen	16	18	12	2	4	2	1	0	11	10	6	2	84	7,00	0
Crop Production	25	17	14	8	8	6	3	1	18	22	20	8	150	12,50	1
Science and Technology	12	18	25	31	12	13	5	3	7	3	2	1	132	11,00	1
Agricultural Engineering	23	22	14	12	14	10	8	5	4	3	2	0	117	9,75	0
Plant Gowth	22	18	15	12	9	7	4	2	7	4	2	1	103	8,58	1
Plant Science	31	34	31	16	12	10	9	2	15	18	8	4	190	15,83	2
Plant Breeding	27	31	28	16	7	4	3	1	9	5	4	4	139	11,58	1
Mean	20,9	22,3	18,1	10,6	9,72	7,68	5,12	2,48	12,1	12,4	8,16	4,36	134	11,162	1,52

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