

Assessing sustainability in smallholder vegetable farms in Benin Republic: A matrix approach

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ABSTRACT

This study aims to assess the level of sustainability in vegetable-based agrifood production systems in Benin and to propose actions to enhance sustainability, food safety, and year-round production in the vegetable production systems. Semi-structured interviews were conducted with 200 vegetable farmers in contrasting agroecological areas (with areas of extensive production of staples and intensive production of vegetables), using the “Indicateur de Durabilité des Exploitations Agricoles” (IDEA) framework (an on-farm sustainability index). Most of the surveyed vegetable farmers produced a wide range of crops, including leafy vegetables (amaranth, African eggplant, and African basil) and peppers, grown by more than 50% of the farmers. The average scores achieved by the vegetable farms regarding three dimensions of sustainability—ecological, social, and economic—were 35, 41, and 63, respectively, out of a maximum score of 100. All three sustainability dimensions of the vegetable farms were, on average, at a low level and improvements were needed for them to reach an acceptable standard. The vegetable farms located in the south of Benin had, on average, a higher sustainability score than those in the north: around 50% of vegetable farms in the south had a medium score, while the sustainability level of almost 75% of vegetable farms in the north was low. Interventions seeking to improve the sustainability of vegetable farms in Benin should focus on the promotion and adoption of eco-responsible practices that improve on-farm biodiversity, water conservation, and the effective allocation and management of land and labor, to mitigate the environmental impacts of vegetable production.

1. Introduction

Fruit and vegetables are important in human diets, and their inadequate consumption is estimated to be responsible for approximately 14% of gastrointestinal cancer deaths worldwide and around 11% of deaths attributed to heart disease (Afshin et al., 2019). A shift to healthier diets requires sufficient foods, including fruit and vegetables, to be available and affordable for the low-income population (Darmon and Drewnowski, 2015). However, the availability of fruit and vegetables has historically been insufficient to meet recommended consumption levels (FAO, 2020; Mason-D’Croz et al., 2019). In low-and-middle-income countries, there is a need to align production policies to address the quality and quantity of fruit and vegetables produced with the

expectations of consumers that include affordability, desirability, and safety. At the same time, there is increasing consumer demand for more sustainable products (or products from sustainable production lines) with high quality and a low environmental footprint (Craheix et al., 2015).

Sustainability is a complex and multidimensional concept. Ikerd (1993) defined sustainability in agriculture as the ability to achieve simultaneously several objectives, such as food production, environmental protection, economic viability, and social acceptance, while maintaining this ability in the long term. Sustainable agriculture is perceived as being low-input and regenerative, with a focus on the incorporation of natural processes into agricultural production and the greater use of improved knowledge and practices (Rasul and Thapa,

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2004). Sustainable agriculture relies on external and non-renewable inputs only to the extent that these are deficient in the natural environment. These conditions are highly congruent with the multidimensional attributes inherent in the concept of sustainable development, highlighting ecological stability, economic viability, and socially fair agricultural systems (Roy and Chan, 2012).

In many sub-Saharan countries like Benin, vegetable value chains contribute to nutritional security and are important sources of income and jobs. However, current knowledge about the sustainability of vegetable production systems is very limited. Only one study, reported by Ahouangninou (2013), explored the sustainability of vegetable farms in southern Benin. It showed that the limiting factor in the sustainability of vegetable farms was the ecological dimension: vegetable farms had little diversity, together with fertilization and pest control practices that presented high risks to ecosystems and human health. During the last ten years, interventions in the vegetable sector in Benin have focused on the promotion of good agronomic practices along with the consumption of vegetables (Fassinou Hotegni et al., 2022), with very little focus on how to sustain vegetable farms in the long term. The aim of this study is to assess the level of sustainability of vegetable farms in Benin and to propose actions toward production practices that will strengthen the sustainability of these farms. A first step toward planning interventions to improve the sustainability of vegetable farms should focus on understanding which agronomic practices are used and how sustainable vegetable farms are currently in Benin. Three research questions were addressed in the current study: What are the main characteristics of vegetable farms in Benin in relation to sustainable agriculture practices? (2) What are the average scores for the three components of sustainability, i.e., social, economic and ecological, in the Beninese context? (3) what are the main characteristics of farmers and vegetable farms that have a significant impact on the overall sustainability score of vegetable farms in Benin? Considering previous studies in Benin, the main hypothesis of this research is that vegetable production in Benin is currently profitable; however, current agronomic practices would not support this profitability in the coming years. This study's findings will pave the way to context-specific interventions for long-term healthier and sustainable vegetable production.

2. Conceptual framework

Sustainability is a holistic, complex, and multidimensional concept that encompasses three main axes: economy, society and environment. A realistic assessment of sustainability requires (1) the integration of various economic, social, and environmental issues and (2) the consideration of conflicting objectives among the stakeholders involved in the process (Sadok et al., 2009). There are several methodological approaches to assess the sustainability of production systems at the farm level. More than 100 sustainability assessment methods have been developed in recent years, which makes the selection of a method difficult (Bockstaller et al., 2009). Iakovidis et al. (2022) argued that the selection of a method should be based on specific criteria that depend on the nature and the objectives of the research project. This includes the use of matrix-based questionnaires with indicators that consider the economic, environmental, and social dimensions of sustainability, facilitating a comprehensive assessment.

The "Indicateur de Durabilité des Exploitations Agricoles" (IDEA) framework was specifically developed for on-farm sustainability assessment (Boisset et al., 2008; Schindler et al., 2015; Zahm et al., 2008). IDEA proposes indicators close to on-farm situations, making it easier to adapt to specific contexts, and is more applicable in the context of small-scale farming systems as its indicators can be collected on-farm and are easy to measure (Torres-Lemus et al., 2021). In addition, the graphical and numerical results from IDEA can be discussed with farmers and also allow for monitoring and benchmarking across regions (Talukder and Blay-Palmer, 2017).

The IDEA framework employs an intuitive and user-friendly

framework of sustainability indicators (Nie et al., 2022). One of the major advantages of this method is its great comprehensibility for farmers. IDEA is an educational tool for explaining and measuring sustainability and is based on easily accessible indicators. Its objective is to guide farmers toward a more sustainable farming system. The IDEA method allows for a fairly precise reflection of the different management situations on the farm and an accurate estimation of a group of farmers from the same region (Zahm et al., 2008). The development of the IDEA method was based on identified objectives: coherence, autonomy, protection and management of biodiversity, soil protection, protection and management of water, protection of the atmosphere, economic management of non-renewable resources, animal welfare, product quality, ethics, human development, local development, quality of life, citizenship and eco-citizenship, adaptability and employment (Fig. 1; Boisset et al., 2008). This framework was updated several times and was developed as a self-assessment method for farmers (Gaviglio et al., 2016; Zahm et al., 2008). The IDEA framework basically covers indicators categorized into three dimensions or scales of sustainability: ecological (agronomy), social (territory), and economic, each subdivided into three or four, making a total of 10 components (Cruz et al., 2018; Ngo et al., 2021; Zahm et al., 2019). The IDEA matrix is constructed to check whether all the objectives are represented in a balanced manner by the indicators (Zahm et al., 2008). In the present study on vegetable farming systems in Benin, the IDEA framework was applied to assess the sustainability of vegetable farms. The adaptation of the IDEA method for the evaluation of the sustainability of vegetable farms in the current study is based on 43 indicators with 10 main components (Fig. 1).

3. Methodology

3.1. Sampling and data collection

Benin is divided into seven agricultural development poles (zones) that encompass specific regions. For this study, poles 1 (in the north) and 7 (in the south) were selected as they represented the primary vegetable-growing regions known by public agencies. Within each pole, major vegetable-production municipalities were selected. The survey was carried out in eight municipalities. Surveyed areas within each municipality were selected based on agroclimatic conditions and cropping systems. These cropping systems included planting after receding waters in the Ouémé Valley, rainfed cropping systems, and irrigation-based cropping systems.

A list of vegetable farmers was not available for random sampling, so a purposive sampling method was adopted. Preliminary meetings took place with local extension agents and heads of farmer-based organizations in the selected municipalities to identify vegetable farmers who would serve as entry points for individual interviews. In each selected municipality, 25 farmers were selected per municipality to represent the diversity of vegetable cropping systems in each municipality and to reach a total of 200 vegetable farmers. Individual interviews were conducted with vegetable farmers with a digitalized questionnaire on the KoboCollect App and administered by a team of trained enumerators using tablets. Collected data from respondents include socio-demographic data, experiences in vegetable production, access and use of inputs, vegetable farming systems, and additional data based on the IDEA framework for the computation of the sustainability scores.

The research protocol and questionnaire used were reviewed and approved by the CIMMYT Internal Research Ethics Committee. Prior to data collection, the written consent of the respondents was sought. Firstly, the purpose of the study was clearly explained to all the respondents. Secondly, respondents were given the opportunity to end their participation in the research at any time during the interview.

3.2. Data analysis

Data were analyzed using SPSS 26.0. The approach used to compute

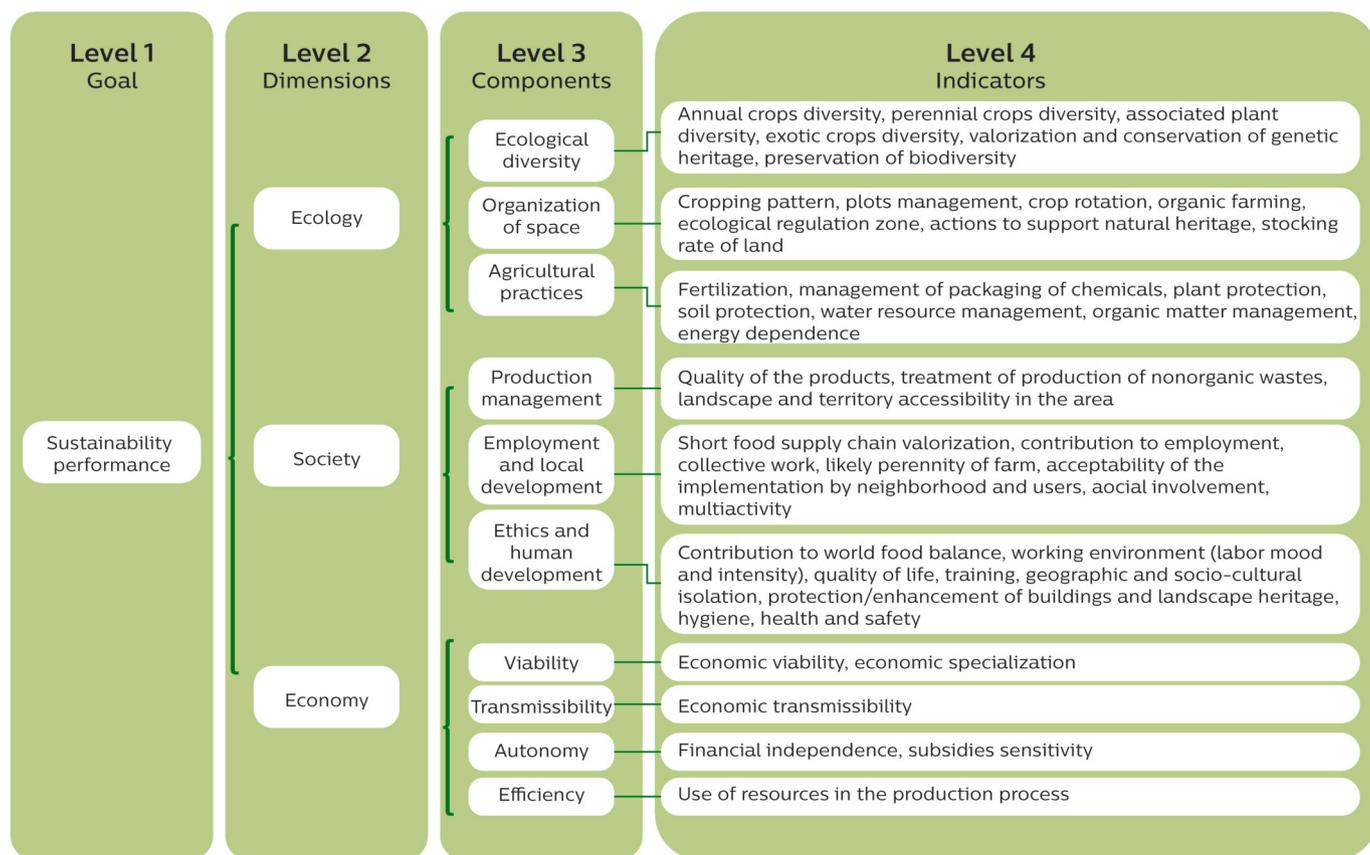


Fig. 1. The conceptual framework of farm sustainability (Adapted from Zahm et al. (2008) and Tzouramani et al. (2020)).

the scores of the sustainability indicators at the farm level was inspired by Ahouangninou (2013), who used the “Indicateurs de Durabilité de la Production Maraîchère” (IDPM) and Boisset et al. (2008), who used the IDEA approach for the assessment of vegetable farms. This approach is based on two principles: (1) the principle that the three dimensions of sustainability are equal; and (2) the limiting-factor principle, whereby the farm’s overall sustainability score is the lowest value recorded among the three dimensions. The procedure for weighting the indicators is guided by the existing literature and the study’s requirements (Thivierge et al., 2014). The dimensions, components, and indicators are presented in Table 1 with their determined weights.

An overall performance score is determined with the aggregation of the scores attributed to each of the three dimensions. A matrix is constructed to assess whether all the sustainability objectives are represented in a balanced manner by the indicators (Gaviglio et al., 2017). When all the indicators are computed, they provide the sustainability status of a farm. In our study, the scores of each vegetable farm were calculated for each dimension using the predetermined indicator scores. The main principle is that the higher the score, the more sustainable the farm. The scores ranged from 0 to 100, where 100 represents the optimal (fully sustainable), and 0 represents the worst situation (not at all sustainable). Three intervals were used, as suggested by Torres-Lemus et al. (2021), to assess sustainability levels: (1) 0 to 33, indicating low sustainability; (2) 34 to 66, indicating medium sustainability; and (3) 67 to 100, indicating positive sustainability.

The data collected and the scores computed were summarized using descriptive analyses. The Pearson chi-square test was used to evaluate the independence of the sustainability parameters computed and the categorical data collected.

4. Results

4.1. Characteristics of farmers and farms

Respondents’ ages ranged from 22 to 80 years, with an average age of 40 years; approximately 60% of the farmers were below the age of 40. Notably, vegetable farmers in pole 1 (northern Benin) tended to be older on average than those in pole 7 (southern Benin) (Table 2). There were more women involved in vegetable farming than men in the municipality of Akpro-Misséréte, located in pole 7, contrary to the other municipalities where the activity was male-dominated. Among the vegetable farmers, a significant majority (approximately 80%) were literate. Furthermore, nearly half of these literate farmers (45.5%) had completed at least secondary education. Primary and secondary school leavers were prevalent across all the municipalities.

The available land for vegetable farmers was generally around 1 ha, with the smallest farm plots found in the south (pole 7). Farmers in Sèmè-Kpodji had the least access to extension services across the surveyed municipalities. Despite these variations, over 50% of vegetable farmers had access to extension services across the surveyed areas. Family labor remained the most-used workforce, often supplemented by temporary paid workers. Most respondents reported farming as their primary source of income.

Vegetable farms were categorized into four groups (Table 3): (1) non-certified organic agriculture, referring to production systems that abstained from using chemical inputs, as indicated by the respondents; (2) certified organic agriculture denoting ecological farming practices that complied with established standards and received certification from a third-party; (3) conventional agriculture encompassing production systems where chemical inputs were applied; (4) mixed-model agriculture representing integrated farms that combined various agricultural production technologies, blending both conventional and ecological/

Table 1
IDEA adapted indicators and allocated weight (Ahouangninou, 2013; Boisset et al., 2008).

Dimension	Component	N°	Indicator	Weight
Ecological (100)	Ecological Diversity (30)	1	Annual crops diversity	8
		2	Perennial crops diversity	4
		3	Associated plants diversity	1
		4	Exotic crops diversity	7
		5	Valorization and conservation of genetic heritage	5
		6	Preservation of biodiversity	5
	Organization of space (35)	7	Cropping pattern	7
		8	Management of plots	7
		9	Crop rotation or succession	5
		10	Organic farming	5
		11	Ecological regulation zone	4
		12	Actions to support natural heritage	2
		13	Stocking rate of land	5
	Agricultural practices (35)	14	Fertilization	10
		15	Management of packaging of chemicals	4
		16	Plant protection/Pesticides	10
		17	Soil protection/Soil management	3
		18	Water resource management	3
		19	Organic matter management	3
		20	Energy dependence	2
Social (100)	Production management (26)	21	Quality of the products	15
		22	Treatment of production of non-organic waste	8
		23	Landscape and territory accessibility in the area	3
	Employment and local development (38)	24	Short food-supply chain valorization	5
		25	Contribution to employment	10
		26	Collective work	6
		27	Likely perennity of the farm	3
		28	Acceptability of implementation by neighborhood and users	3
		29	Social involvement	7
		30	Multiactivity	4
		31	Contribution to world food balance	7
	Ethics and human development (36)	32	Working environment (labor mood and intensity)	8
		33	Quality of life	4
34		Training	6	
35		Geographic and socio-cultural isolation	2	
36		Protection/enhancement of buildings and landscape heritage	2	
37		Hygiene, health and safety	7	
Economic (100)	Viability (30)	38	Economic viability	20
		39	Economic specialization	10

Table 1 (continued)

Dimension	Component	N°	Indicator	Weight
	Transmissibility (20)	40	Economic transmissibility	20
	Autonomy (25)	41	Financial independence	15
		42	Subsidies sensitivity	10
	Efficiency (25)	43	Use of resources in the production process	25

natural approaches. Nearly 90% of the vegetable farmers practiced mixed-model farming. However, less than 10% of them were engaged in either conventional systems alone or organic non-certified systems. Specifically, conventional farming was more common in pole 1, while organic non-certified farming was only reported in pole 7. None of the surveyed farms was involved in certified organic agriculture.

Almost all the vegetable farmers surveyed relied on agricultural inputs such as improved seeds, organic fertilizers, and agrochemicals (Table 3). Most farmers made use of improved seeds, but a little more intensively in pole 7. In pole 1, there was moderate use of organic fertilizer and high use of chemical fertilizer, while the opposite trend was observed in pole 7. The use of chemical pesticides was high in both poles. However, vegetable farmers in pole 7 used more biopesticides than those in pole 1. Regarding the irrigation system, surface irrigation (border irrigation with strips) was widely practiced in pole 1, while sprinkler methods predominated in pole 7, followed by the use of lay flat micro-perforated hoses.

4.2. Types of vegetables grown in the study areas

The surveyed farmers produced a wide diversity of vegetables (Fig. 2). Over 50% of the farmers produced amaranth (*Amaranthus* spp.), African eggplant (*Solanum macrocarpon*), tomatoes (*Solanum lycopersicum*), African basil (*Ocimum gratissimum*), and peppers (*Capsicum annuum*, *Capsicum chinense*). A considerable number of vegetable farmers (30%–50%) also cultivated species such as jute mallow (*Corchorus oleraceus*), vernonia (*Vernonia galamensis*), onion (*Allium cepa*), cucumber (*Cucumis sativus*), carrot (*Daucus carota* subsp. *Sativus*), and lettuce (*Lactuca sativa*). At least 10% of the respondents grew green beans (*Phaseolus vulgaris*), cabbages (*Brassica oleracea*), and okra (*Abelmoschus esculentus*).

There was a greater diversity of vegetable crops produced in pole 7 than in pole 1. In the south, the species cultivated most frequently were African eggplant, amaranth, African basil, pepper, vernonia, jute mallow, tomato, bell pepper, onion, green bean, cucumber, cabbage, carrot, and lettuce. Important crops in the north were peppers, onions, tomatoes, cabbages, and okra. Leafy vegetables were more prevalent among vegetables grown by farmers in the south, while those in the north focused more on fruit vegetables. Pepper was one of the most widely cultivated species in both poles, cultivated on over 50% of surveyed farms.

Farmers in both areas commonly employed crop rotation and intercropping to optimize land use and crop management, with these practices more prevalent among farmers with a small size of land (less than 0.5 ha). There was great variability in the crop rotation and intercropping patterns applied by the surveyed farmers. The most frequent crop rotation sequences were: African eggplant–amaranth; onion–pepper; onion–tomato; African basil–African eggplant–amaranth; and onion–pepper–tomato. Regarding intercropping, the most frequent associations on the same plot were: African eggplant–amaranth; African eggplant–pepper; amaranth–lettuce; amaranth–pepper; and jute mallow–pepper.

Mixed cropping was prevalent in the north, with more integration of livestock products with crop production. The most common animal species found on the farms were cattle (in the north especially), hens/

Table 2
Sociodemographic characteristics of farming units.

Surveyed farmers parameters		Pole 1		Pole 7					Total	
		Malanville	Allada	Ouidah	Grand-Popo	Athiémé	Sèmè-Kpodji	Akpro-Misséréké	Dangbo	n = 200
		n = 25	n = 25	n = 25	n = 25	n = 25	n = 25	n = 25	n = 25	n = 200
Gender	Female (%)	4	12	28	28	20	16	52	16	22
	Male (%)	96	88	72	72	80	84	48	84	78
Age	Average year	45.8	38.5	35.7	36.8	37.2	38.5	43.7	42.8	39.9
	Std. deviation	9.8	7.0	9.3	9.8	8.0	12.4	14.7	11.3	10.9
Education level	None (%)	32	4	16	12	8	12	52	28	20.5
	Primary (%)	28	44	32	36	36	40	12	44	34
	Secondary (%)	36	44	36	32	28	40	20	20	32
	University (%)	4	8	16	20	28	8	16	8	13.5
Total land holding	Average (ha)	2.34	0.91	1.00	0.42	2.14	0.67	0.35	1.25	1.13
	Std. deviation	0.64	1.36	0.57	0.46	3.11	0.43	0.54	1.06	1.48
Cultivated land	Average (ha)	2.18	0.6	1.0	0.4	1.0	0.6	0.2	1.2	0.9
	Std. deviation	0.64	0.47	0.57	0.46	0.58	0.45	0.19	1.07	0.83
Type of workforce	Use rate (%)	93	65	100	100	46	94	51	99	80
	Household	100	84	92	100	100	68	96	100	93
	Permanent paid (%)	40	32	76	68	24	72	16	0	41
	Temporary paid (%)	84	76	44	96	92	60	92	100	81
	Mutual aid (%)	76	52	0	8	0	0	0	40	22
Access to extension services	Yes (%)	60	72	84	72	84	36	92	52	69
	No (%)	40	28	16	28	16	64	8	48	29
Vegetable farming as main activity (%)		100	84	96	84	84	92	84	76	88

Table 3
Percentage of vegetable farmers making use of different agricultural inputs within each pole in Benin.

Parameters		Pole 1		Pole 7		Across the surveyed area	
		(Municipality = 1/n = 25)		(Municipality = 7/n = 175)		(Municipality = 8/n = 200)	
Farming model	Conventional	20.0		4.0		6.0	
	Organic certified	0		0		0	
	Uncertified organic	0		6.9		6.0	
Level of use of improved seeds	Mixed model	80.0		89.1		88.0	
	High (Intensive)	32.0		41.7		40.0	
	Moderate (Intensive)	48.0		34.3		36.0	
	Low (Extensive)	20.0		24.0		24.0	
Level of use of organic manure	No use	0		0		0	
	High (Intensive)	0		55.4		48.0	
	Moderate (Intensive)	72.0		33.1		38.0	
	Low (Extensive)	8.0		7.4		8.0	
Level of use of chemical fertilizers	No use	20.0		4.0		6.0	
	High (Intensive)	56.0		24.6		28.0	
	Moderate (Intensive)	44.0		46.3		46.0	
	Low (Extensive)	0		22.3		20.0	
Level of use of organic pesticides	No use	0		6.9		6.0	
	High (Intensive)	0		12.0		11.0	
	Moderate (Intensive)	40.0		34.3		35.0	
	Low (Extensive)	40.0		49.7		48.0	
Level of use of chemical pesticides	No use	20.0		4.0		6.0	
	High (Intensive)	36.0		48.0		46.0	
	Moderate (Intensive)	64.0		41.1		44.0	
	Low (Extensive)	0		4.0		4.0	
Mode of irrigation	No use	0		6.9		6.0	
	Automatic	0		6.9		6.0	
	Semiautomatic	88.0		62.9		66.0	
	Manual	12.0		29.7		27.0	
Type of irrigation	Rainfall	0		0.6		1.0	
	Drip	8.0		12.0		11.0	
	Sprinkler	4.0		79.0		69.0	
	Surface	96.0		27.0		36.0	
	Microperforated hoses	0		45.0		39.0	
Intercropping	Rainfall	0		0.6		1.0	
	No	8.0		49.7		45.0	
	Yes (<50% of surface)	16.0		19.4		19.0	
Crop rotation	Yes (≥50% of surface)	76.0		30.9		36.0	
	No	8.0		16.6		16.0	
	Yes (<50% of surface)	0		3.4		3.0	
On-farm animal breeding	Yes (≥50 of surface)	92.0		80.0		81.0	
		76.0		12.0		20.0	

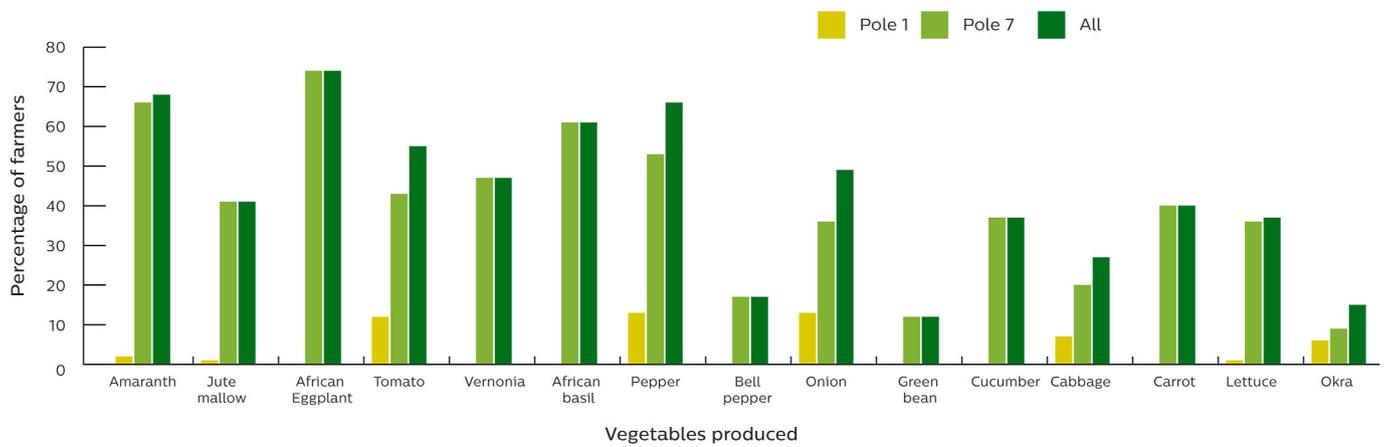


Fig. 2. Vegetables produced on the surveyed vegetable farms.

roosters, sheep, and pigs. Since animal husbandry was a complementary activity, the herds were quite small, with numbers ranging from 6 to a maximum of 72 for mammals (sheep, cattle, pigs, goats, and rabbits) and 5 to 46 for poultry (guinea fowl, ducks, turkeys, pigeons, and hens/roosters).

4.3. Sustainability of vegetable farms

The sustainability components with the highest average scores, which increased the overall sustainability of the farms, were ethics and human development, viability, and autonomy. Organization of space, agricultural practices, production management, employment, and local development had the lowest scores, hindering the farms' sustainability (Fig. 3). Scores were generally low for the agricultural practices and production management components, with more farms recording values below 50% in pole 1 (Fig. 3). Vegetable farms in the south (pole 7) scored very low for organization of space, employment, and local development. In contrast, most of the farms in the north (pole 1), scored above 50% for ethics and human development, viability, transmissibility, and autonomy components. In pole 7, most farms recorded above average scores for the efficiency component. Finally, scores for ecological diversity were generally high in pole 7 and low in pole 1 (Fig. 3).

The lowest average scores among all the farms surveyed were

observed for the ecological dimension, ranging from 15 to 64, with an average value of 35 ± 9 . The scores for the social dimension ranged from 22 to 58, with an average value of 41 ± 6 . The highest average score among all farms was for the economic dimension, with an average value of 63 ± 16 , ranging from 10 to 91 for individual farms (Fig. 4).

Since the surveyed farms had to meet the sustainability criteria, i.e., use the lowest score obtained among the three dimensions and be in the positive score range, the results indicated that none of the farms were found to be sustainable. There were more farms at the medium level (55% of the farms) than at the low level (45%). The sustainability levels that the majority of farms achieved for the social dimension (90%) and the ecological dimension (53%) were medium, and only 45% of the farms reached a positive sustainability level for the economic dimension.

Across the two poles, the situation regarding the sustainability of the surveyed farms was slightly different. A higher sustainability score was recorded in the south than in the north. Indeed, considering overall sustainability, around 50% of the vegetable farms in the south were in a medium sustainability situation, while in the north, almost 75% were in a low situation. With regard to ecological sustainability, more than 50% of vegetable farms were in a low situation in the north, while more than 50% were in a medium situation in the south. In terms of social sustainability, the situation was similar in both poles, with a concentration of farms in medium condition. Finally, in terms of economic

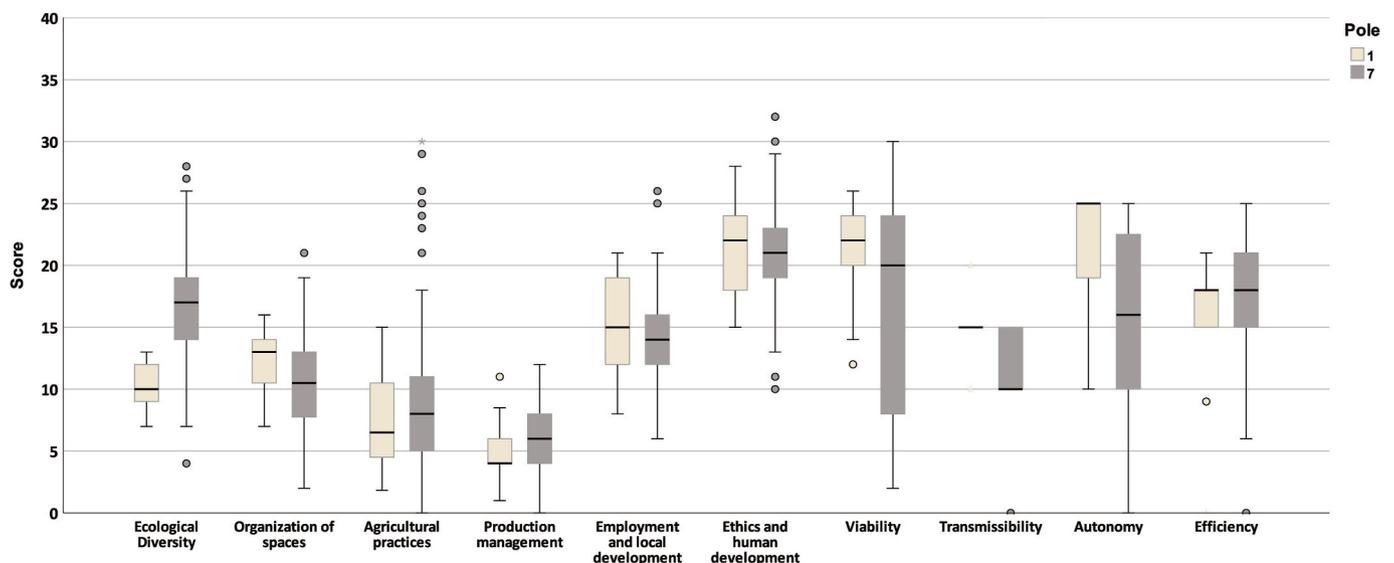


Fig. 3. Farms' average scores for the sustainability components in poles 1 and 7.

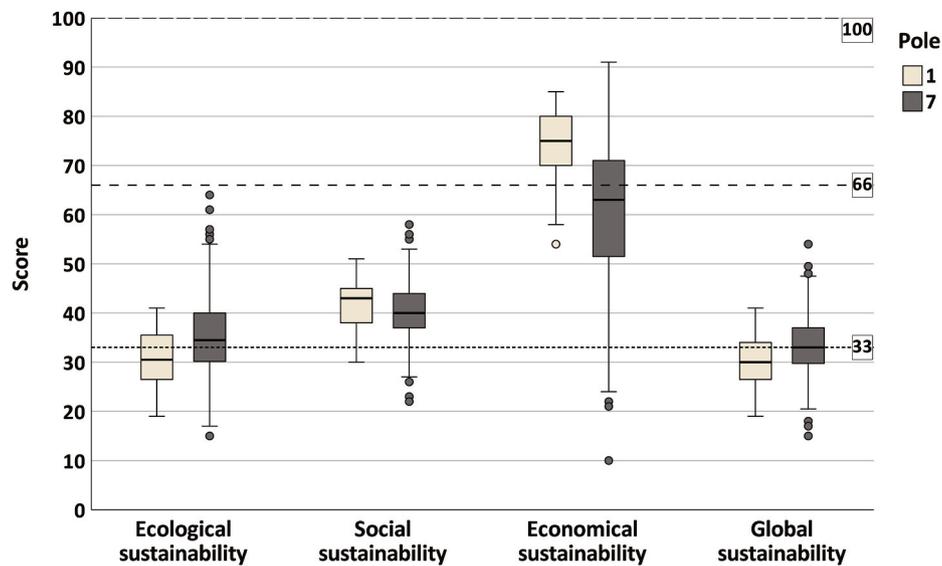


Fig. 4. Average scores of farms' sustainability dimensions in poles 1 and 7.

Table 4
Relationships between the sustainability scores and farm characteristics.

Parameters	Overall sustainability score			Ecological sustainability			Social sustainability			Economic sustainability		
	Value	df	Asymptotic significance (2-sided)	Value	df	Asymptotic significance (2-sided)	Value	df	Asymptotic significance (2-sided)	Value	df	Asymptotic significance (2-sided)
Sex	0.295	1	0.587	0.204	1	0.652	0.814	1	0.367	9.633	2	^a 0.008
Education level	1.921	3	0.589	0.895	3	0.827	0.744	3	0.863	3.666	6	0.722
Principal activity	1.530	1	0.216	0.562	1	0.453	0.190	1	0.663	4.416	2	0.110
Extension service access	0.016	1	0.900	2.479	1	0.115	22.402	1	^a < 0.001	0.885	2	0.643
Farmland tenure	4.920	6	0.554	9.885	6	0.130	5.305	6	0.505	10.175	12	0.601
Plot access difficulties	0.004	1	0.949	0.115	1	0.734	2.345	1	0.126	0.488	2	0.783
Family workforce	0.133	1	0.715	7.379	1	^a 0.007	15.017	1	^a < 0.001	6.071	2	^a 0.048
Permanent paid workforce	0.186	1	0.666	0.177	1	0.674	0.082	1	0.775	3826	2	0.148
Temporally paid workforce	0.902	1	0.342	0.226	1	0.634	1.488	1	0.223	1.278	2	0.528
Mutual aid workforce	0.691	1	0.406	2.562	1	0.109	5.948	1	^a 0.015	15.284	2	^a < 0.001
Farming model	20.433	2	^a < 0.001	24.185	2	^a < 0.001	0.136	2	0.934	2.480	4	0.648
Improved seed use level	2.308	2	0.315	4.018	2	0.134	7.152	2	^a 0.028	3.535	4	0.473
Organic manure use level	16.355	3	^a 0.001	17.907	3	^a < 0.001	8.318	3	^a 0.040	16.983	6	^a 0.009
Chemical fertilizer use level	33.321	3	^a < 0.001	39.102	3	^a < 0.001	4.172	3	0.244	13.518	6	^a 0.036
Organic pesticide use level	22.513	3	^a < 0.001	19.491	3	^a < 0.001	7.382	3	0.061	19.599	6	^a 0.003
Chemical pesticide use level	17.346	3	^a 0.001	15.479	3	^a 0.001	3.465	3	0.325	18.515	6	^a 0.005
Well water access	0.806	1	0.369	1.133	1	0.287	0.118	1	0.731	1.204	2	0.548
Drip water access	0.510	1	0.475	0.463	1	0.496	0.023	1	0.880	0.187	2	0.911
Surface water access	0.487	1	0.485	0.648	1	0.421	1.025	1	0.311	1.162	2	0.559
Rainwater access	0.101	1	0.751	1.793	1	0.181	5.252	1	^a 0.022	6.312	2	^a 0.040
Irrigation mode	1.550	3	0.671	1.783	3	0.619	2.011	3	0.570	9.716	6	0.137
Crop rotations (% of plot)	0.868	2	0.648	0.388	2	0.823	0.777	2	0.678	4.027	4	0.402
Crops associations (% of plot)	0.032	2	0.984	1.103	2	0.576	5.905	2	0.052	3.529	4	0.473
Animal breeding (on farm)	0.612	1	0.434	1.812	1	0.178	1.077	1	0.299	3.348	2	0.187
Pole	3.150	1	0.076	3.315	1	0.069	2.744	1	0.098	11.092	2	^a 0.004

^a Means significant at 5%.

sustainability, the majority of farms were in a positive situation in the north, while the vast majority were still below the positive threshold in the south.

4.4. Relationships between sustainability scores and dimensions and farm characteristics

The Pearson chi-square test carried out between sustainability status and variables such as socioeconomic characteristics and production practices revealed that the farming model, the level of organic and chemical fertilizer use, and the level of biological and chemical pesticide use affected overall sustainability (Table 4). The three sustainability dimensions were affected by slightly different factors. Ecological sustainability was influenced by use of family labor, farming model, level of organic and chemical fertilizer use, and level of biological and chemical pesticide use. The parameters that affected social sustainability were access to extension services, use of family and friends/neighbors (mutual aid society) for labor, and use of improved seed, organic fertilizer, and rainwater. The variables that influenced economic sustainability were gender, use of family or a mutual aid group for labor, level of organic and chemical fertilizer use, level of biological and chemical pesticide use, rainwater use, and the pole in which the farm was situated.

5. Discussion

The present article reports on an exploratory study using the IDEA framework to assess the sustainability of vegetable farms in Benin. The objective was to characterize vegetable farming in two regions, estimate the scores of the three components of sustainability and analyze the relationship between these scores and the characteristics of the vegetable farms. The sustainability scores were computed using self-reported data from farmers, which represents a limitation of the current study. However, the data reported here can help design future studies to improve the sustainability level of vegetable farms in Benin.

5.1. Characteristics of vegetable farms

The vegetable farmers surveyed were predominantly literate, which is a key factor for the receiving and decoding of information and the adoption of new technologies to ultimately improve farm productivity (Reimers and Klasen, 2013). Among the respondents, 69% had access to extension services, which could be leveraged to disseminate information on sustainable vegetable production practices. However, in urban and suburban areas, farmers cultivated on small plots of land, often owned by third parties or part of the public domain, putting the farmers at risk of eviction. Insecure land tenure often leads to overexploitation of soils and low incentives for investing in sustainable practices (Eder et al., 2021; Ekpodessi and Nakamura, 2022). Improving vegetable farmers' access to secure land in peri-urban areas could be an incentive for them to invest in more sustainable practices and technologies. The study revealed that farmers grew a wide variety of both exotic and traditional vegetables and practiced crop rotation and intercropping. However, the current rotation and intercropping patterns currently practiced do not include nitrogen-fixing crops that could help in improving nutrient use efficiency and soil fertility. There is a lack of data on optimal crop rotations in Benin, and more short and long-term trials on this topic that consider species (including their economic importance), sequences, nutrient use, and local contexts are required. Crop rotation and intercropping are not only crucial to meeting market demand but also to increasing farm resilience (Bowles et al., 2020) and also help to reduce pest incidences. For example, the intercropping of tropical basil (*Ocimum gratissimum* L.) with cabbage significantly reduces the number of insect pests (Yarou et al., 2017).

Farmers used a combination of practices from both organic and conventional production systems. Most of the farmers surveyed in the

present study had moderate to high rates of chemical pesticide use for the management of pests. The overuse of chemicals is reported in Benin (Ahouangninou et al., 2013) and in several other parts of the world (Schreinemachers et al., 2020). Overuse of pesticides can affect the safety and quality of water resources and the biological activity of the soil and can pose risks to biodiversity and human health (Neufeld et al., 2023). Pazou et al. (2006) reported the presence of organochlorine and organophosphorus that exceeded the maximum safety level in the Ouémé river, whose water is used for irrigation in vegetable production. Furthermore, pesticides (organochlorines, DDT, endrin, heptachlor, aldrin and dieldrin, carbofuran, chlorpyrifos ethyl and endosulfan) residues of above the maximum residue limits were detected in vegetables (tomato, African eggplant, eggplant, cucumber, amaranth) across several vegetable production sites in Benin (Ahouangninou et al., 2012; Assogba-Komlan et al., 2007; Pazou et al., 2013; Sæthre et al., 2013). Many vegetable farmers in Benin are not able to decode instructions on chemical bottles and are not aware of the risks associated with the use of these pesticides. It is important to raise farmers' awareness of the handling and use of pesticides and to develop alternatives to the use of these pesticides in vegetable farming systems in Benin.

There is increased attention on the part of consumers to the safety of vegetables, and farmers said that there was a growing number of consumers willing to pay a premium for organically produced vegetables, as observed in other West African cities (Ahouangninou, 2013; Cobbinah et al., 2018). Consumers in Benin and Ghana were, for example, willing to pay a premium of over 50% and 180% for vegetables produced without chemical pesticides in Benin and Ghana, respectively (Cobbinah et al., 2018; Coulibaly et al., 2011). However, no farmers surveyed were certified for organic farming, and most farmers made little use of organic pesticides, accessibility being the main challenge. In the southern region, a small number of farmers said that they grew organic vegetables without third-party certification. It is worth noting that the use of organic products is not enough to ensure the safety of vegetables. For instance, Bankole et al. (2014) and Kouglbléou et al. (2019) reported the contamination of poultry manure used in vegetable production sites in Benin with fecal coliforms of *Escherichia coli*, which were ultimately found in vegetables (African eggplant, cabbage, tomato, carrot). While the intensification of vegetable production, especially in urban areas, has the potential to be sustainable, addressing and eliminating risks to human health and the environment associated with the use of organic and chemical pesticides is crucial to political and ethical acceptance (Nchanji et al., 2017).

More than 99% of the respondents used irrigation. In the south, farmers predominantly used sprinklers and flat micro-perforated hoses, while in the north, farmers used surface (furrow) irrigation. Vegetables are short-lived crops whose production is input-demanding and labor intensive. Vegetable farmers invest in the basic infrastructures to secure water for irrigation either as supplementary irrigation during dry spells in the rainy seasons or to enable them to produce in the off-season (dry season). However, many irrigation systems currently used are less efficient in water use, and furrow irrigation, for instance, was reported to cause nitrogen leaching (Lv et al., 2020) that can compromise the sustainability of vegetable farming systems. The requirement for watering is often twice a day, demanding a substantial volume of water and labor, depending on the area cultivated. Farmers were willing to invest in improved technologies, opting for semi-automatic or automatic irrigation systems to reduce labor requirements (Işik et al., 2017). While these systems positively impact production costs and outcomes and reduce the opportunity cost of time (Champness et al., 2023), they can also have adverse social and environmental consequences. A reduction in labor leads to short-term employment challenges, and fuel-powered motorized irrigation systems contribute to pollution through greenhouse gas emissions. Alternative systems for increasing water use efficiency may also require a high initial investment and may not be accessible to farmers. Consequently, the development and promotion of water conservation practices, such as cover crops and conservation tillage, must be

prioritized.

5.2. Sustainability status of the surveyed farms

None of the farms surveyed in the current study achieved a positive level of sustainability. This finding is similar to previous reports on urban vegetable production in Ghana (Nchanji et al., 2017), highlighting the urgency of promoting alternative production practices. Among all the farms, the dimension with the lowest score was the ecological dimension, while the economic dimension had the highest score. The social dimension scored hardly better than the ecological and remains a weak component. These results are similar to those reported by Ahouangninou (2013), who also reported that the ecological dimension of sustainability was lowest in southern Benin.

The low scores obtained in the social and ecological dimensions are indicative of low crop diversification, poor soil, lack of water, pests, and overall land management. In this context, farms with high ecological scores exhibited a diversity of crops and efficient spatial organization. These farmers appeared to be inclined toward ethical and human development values but prioritized farming practices and employment. Similarly, farmers with high social scores exhibited varying levels of interest in ethics and employment (Bir et al., 2019).

The sustainability of farms within the surveyed areas was not homogeneous. The socioeconomic aspects of vegetable farming are better in the north than in the south. Unemployment and local development are still fairly low, while community solidarity is still strong, a little more so in the north than in the south. Most of the farms, especially in the north, were economically sustainable. However, considering overall sustainability, farms in the south recorded higher scores than those in the north. Despite high economic potential, the ecological dimension had a strong negative influence on overall sustainability. Many more farms in the south were in a better sustainability state than in the north due to their ecological sustainability component. In the north, a greater availability of resources, especially land, does little to encourage optimal agroecosystem management. Even though this availability of resources supported the economic dimension, the unsustainable management of these resources had a negative impact on overall sustainability. In the medium and long term, ecological aspects will condition economic results through declining agronomic performance (Navarrete et al., 2015).

5.3. Factors influencing the sustainability of vegetable farms

The use of family labor contributes to ecological sustainability. Many farmers who rely on this type of labor often manage small farms, making it easier for them to meet their fertilizer and pesticide needs using ecologically sound organic products. The results of this study highlight the fact that mixed-model approaches to farming and organic farming further enhance ecological sustainability. Organic inputs avoid harming the environment, but they also play a crucial role in preserving and sometimes restoring the ecology (Fess and Bénédicto, 2018). In the production process, prioritizing organic fertilizers and pesticides promotes ecological sustainability. In the same way, minimizing the use of chemical fertilizers and pesticides is essential for maintaining a favorable ecological balance.

Access to extension services significantly enhances social sustainability. These services, provided by training and advisory organizations, play a crucial role in supporting farms, facilitating relationships among stakeholders, and creating sustainable connections between farms and communities. Using family members and mutual aid groups for labor also contributes to social sustainability. Historically, these longstanding social connections have been essential for agricultural labor. They strengthen family ties, foster solidarity, reinforce individual growth, and collectively advance farmers' progress in their community. Furthermore, the adoption of improved seeds and organic fertilizers positively impacts social sustainability. The exchange framework for these

products benefits agricultural communities, promoting cooperation and shared progress. Using rainwater also enhances social sustainability—conflicts over the management of local water resources can hinder farmers' social development. Addressing this social issue, especially for seasonal production dependent on rainwater, can maintain social balance and peace.

Gender significantly influences economic sustainability, with farms run by men generally being more sustainable economically than farms run by women. This disparity reflects the financial power of men and their better access to resources and facilities. The level of use of agricultural inputs (whether chemical or organic) also contributes to economic sustainability. The cost difference between these types of input plays an economically decisive role. Generally, organic inputs are more expensive than chemical alternatives in the market, impacting profit margins for organic product users.

The use of family members and mutual aid groups for labor also plays an important role in enhancing economic sustainability by reducing the cost of labor. However, relying on this workforce may sometimes hide the true financial state of the farm. Rainwater utilization for vegetable production also reduces the cost of operations and potentially improves benefits, positively impacting economic sustainability. However, the unreliability of this resource introduces an instability factor that can significantly affect economic forecasts. Lastly, farms in the north of the country tended to achieve greater economic sustainability, while farms were more ecologically sustainable in the south. Farmers in the north specialized more in producing onions, peppers, and tomatoes, which are high-value crops. Farms in the south presented a good diversity of crops and followed farming practices that were beneficial in meeting land challenges. These differences between the two poles can be attributed to various factors, including land availability, agroecological conditions, types of support agencies/organizations and market opportunities.

Future studies should focus on evaluating better ways to minimize resource use and environmental degradation to produce vegetables, particularly crop rotations and intercropping schemes, which include the main food crops in Benin (maize, beans and cassava) and with the potential to increase the resilience of the agrifood system. Further studies should document pest and soil fertility management, water use efficiency and food safety challenges associated with the improper use of chemical pesticides and organic products. Besides, future investigations could adopt a longitudinal approach following an urban-rural continuum to account for potential seasonal and location effects on the sustainability of vegetable farming systems. Such a study could couple self-reported information with a quantitative assessment of sustainability. The emergence of and development of green artificial intelligence could help facilitate the design of these studies by analyzing results from elsewhere and provide insights into technologies and practices that could be tested and validated in the specific context of Benin (Ali, 2023; Bolón-Canedo et al., 2024).

6. Conclusion

The sustainability of vegetable farming in Benin is currently at a critical level. Indeed, none of the surveyed farms met the sustainability criteria, but more farms were at a medium level than a low level. Economic sustainability, the only dimension that was positive for some farms, was influenced by gender, types of inputs used, labor costs, and rainwater utilization. Farms in the north tended to achieve greater economic sustainability, while those in the south were more ecologically sustainable. Across the two zones, there were more farms at the medium level (55%) than at the low level (45%), showing that there are significant challenges to achieving sustainable vegetable farming in Benin. The majority of the farms achieved a medium sustainability level in the social and ecological dimensions, while only 45% reached a positive sustainability level in the economic dimension.

In Benin, the social and ecological dimensions primarily drive the overall sustainability of vegetable farms. Therefore, farmers should

prioritize efforts in these areas to demonstrate their consideration for the environment and their integration into society. Efforts in the future should focus on increasing the ecological dimensions of sustainability by developing and promoting practices adapted to the local context, including crop diversification oriented to the market but also promoting good agronomic practices that can help improve soil fertility as well as efficiency of water use. Efforts towards an integrated pest-management system should also help in preventing pest problems through a combination of cultural, biological, and chemical control methods. It is also important to provide training to farmers in these methods and in the responsible use of pesticides, with an emphasis on the correct use of label instructions and on using personal protective equipment.

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Ethical clearance

The research protocol used for the present study was approved by the CIMMYT Internal Research Ethics Committee (IREC.2023.15).

Data availability statement

The data used in this study are openly available in DataVerse: Odjo, Sylvanus; Fassinou Hotegni, Nicodeme V.; Guidimadjègbè, Alexandre Nouhougan; Ayenan, Mathieu Anatole Tele; Singh, Ravi Gopal, 2024, "Dataset of the assessment of on-farm sustainability of vegetable farms in Benin Republic using the IDEA framework" <https://hdl.handle.net/11529/10549080>, CIMMYT Research Data & Software Repository Network.

CRedit authorship contribution statement

Nicodeme V. Fassinou Hotegni: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Alexandre Nouhougan Guidimadjègbè:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Mathieu A.T. Ayenan:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Ravi Gopal Singh:** Writing – review & editing, Funding acquisition. **Sylvanus Odjo:** Writing – review & editing, Supervision, Project administration, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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