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Integrating farmers' and experts' perspectives for soil health-informed decision-making in conservation agriculture systems

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Abstract

Soil health and conservation agriculture are two pivotal components of soil security that link agricultural and soil science to policy by integrating stakeholders, scales, functions, and assessment tools, going beyond crop production or other human profits (e.g., human health). The study employed the Analytical Hierarchy Process to integrate the perspectives of two key stakeholders, namely farmers and experts, in order to identify soil health indicators that could guide the selection of conservation tillage systems. The primary objective was to determine the priority assigned to different soil health indicators by these stakeholders. The results showed that farmers prioritized and assigned a higher weight to soil mineral nitrogen, soil organic carbon, and soil water content to enhance the soil health by means of the conservation tillage systems. Conversely, agricultural experts assigned the highest weight to soil organic carbon, soil water content, soil respiration, and soil microbial biomass when choosing the proper tillage systems to improve soil health. Further, the results indicated that farmers and agricultural experts prefer no-tillage and reduced tillage systems to enhance soil health. More so, farmers and experts together indicated that these criteria accounted for 59% of the selection of no-tillage, 34% for reduced tillage, and 19% for conventional tillage systems. The results showed the usefulness of our work as an analysis framework to inform policy makers for supporting No-Tillage crop management programs and other agroecological engineering practices. Our findings could be broadly used to offer insights into crafting soil health policy and soil security for transitions toward sustainable and healthy ecosystem.

Keywords Conservation agriculture · Tillage · Analytical hierarchy process · Soil health · Drylands

1 Introduction

The intensification of tillage-based agriculture poses a significant risk to soil health and associated ecosystem services, as the disruption of the soil structure caused by tillage leads to soil degradation (Dumanski et al. 2014; Kassam et al. 2018; Dumanski et al. 2014; Kassam et al. 2018). Soil health (soil functionality) and land suitability for agriculture in Iran are at risk due to tillage-based agriculture and its consequences, which include high soil sodium content, soil erosion, compaction, and low soil organic carbon in farming systems (Emadodin et al. 2012; Mesgaran et al. 2017). On average, Iran experiences a soil erosion rate of 15–20 tons/ha per year, which is among the highest levels of soil erosion and sediment production observed in developing countries. However, this rate significantly increases to 30 tons/ha in approximately 125 million hectares of land that are subject to accelerated soil erosion (Karamidehkordi 2010). When factoring the loss of soil fertility, sedimentation in dams, and the expense of fertilizer, the cost of soil erosion from arable land amounted to around $10.8 billion USD or almost 35% of the Gross Domestic Product (GDP) of the Iranian agricultural sector (Emadodin et al. 2012). That is, in Iranian agriculture, inadequate soil management has led to soil insecurity manifesting as reduced productivity, environmental harm, and potential future production declines (Mesgaran et al. 2017). Consequently, both the government and agricultural stakeholders have instituted a new policy and program to safeguard soil security and health (Mesgaran et al. 2017). It aimed at promoting the sustainable use and management of soil resources by refining soil health and implementing

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appropriate management practices (Evangelista et al. 2023). The goal of soil policy is to restore soil health via three main soil functions, i.e., carbon transformation, nutrient cycling, and structure maintenance (Pheap et al. 2019; FAO 2019). For instance, since 2002, Iran's Agriculture Administration has collaborated with the FAO to implement a National Soil Conservation Project, aiming to promote and encourage the adoption of conservation tillage systems. (FAO 2011; Ataei et al. 2021). Relatively an all-encompassing organization was established tasked with creating macroeconomic plans to assist CA's technology in interaction with intra- and inter-governmental sectors (Ataei et al. 2019). Conservation Agriculture (CA) is an agricultural system designed to reduce risks, improve resource utilization efficiency, and minimize reliance on external inputs through the integrated management of soil, water, and biological resources (Devkota et al. 2022). It is characterized by three interrelated principles, namely (i) minimizing mechanical soil disturbance throughout the entire crop rotation; (ii) maintaining continuous soil coverage; and (iii) implementing diverse crop rotations for annual crops or plant associations for perennial crops (FAO 2019). Engineers and scholars have developed various strategies, such as reduced tillage (RT), no-tillage (NT), residue retention, and appropriate crop rotations, to enhance biodiversity and biological processes both above and below ground (FAO 2011; Haddaway et al. 2017). Among these strategies, no-tillage (NT) and reduced tillage have garnered significant attention in agricultural research and development as a potential solution to address soil health challenges (Haddaway et al. 2017).

Accordingly, conservation agriculture (CA) started off in Khuzestan provinces and Kermanshah with the supply of several composite tillage machines and one direct sowing machine and then it was implemented across countries. For instance, in Khouzestan, Fars, Golestan, and Khorasan about 150 hectares in 2007 were planted using conservation agriculture (Latifi et al. 2017). In Kermanshah province, a main agricultural plain, CA began in 2016 with 2700 hectares of direct cultivation and 5000 hectares of reduced tillage.

Despite these efforts for CA, only 599,000 hectares of Iranian agricultural lands compared with over 160 million hectares in developing countries in 2015 (Aryal et al. 2016) was managed under conservation agriculture and its implantation is facing several challenges. Ataei et al. (2021) have articulated six challenges: institutional infrastructure, economic, education-investigation, environmental, modernization, and cognitive. To address these challenges, they recommended participatory planning for CA projects and programs to connect various related sectors (e.g., administration, policy makers [Ministry of Agriculture], education and research [Agricultural Research, Education and Extension Organization], and industry). A number of scholars acknowledged a participatory, multi-stakeholder method for approximates reaching the diverse interests and situations regarding CA (Reed et al. 2008; Singh et al. 2018; Marenya et al. 2021), such as no-tillage system participatory quality index (Telles et al. 2019) and participatory multi-criteria assessment (Kumar and Jhariy 2015; Xavier et al. 2020). UNEP (2012) specified a multidisciplinary evaluation of options and choice indicators to recognize the diversity of values among various actors (Hermans et al. 2021). Pradhan et al. (2018) indicated that AHP as the transdisciplinary approach embodies scientific knowledge produced by different disciplines and local knowledge from multiple stakeholders in co-design and implementation of field experiments of CA. De Marinis and Sali (2020) suggested AHP as a 'bottom-up' participatory and multi-stakeholder decision support system to enable stakeholders to comprehend each other's standpoint in iterative decision-making method. In these studies, AHP was used to explore the relationship between soil health indicators and tillage systems (Table 1) under different agricultural management practices (Ennaji et al. 2018; Kumar et al. 2019; Xue et al. 2019). AHP uses many indicators of soil health to provide a trustworthy baseline for decision-making when enacting an efficient soil management strategy for varied land-use systems (Fariabi and Matinfar 2017; Kumar et al. 2018) and even related fields (e.g., soil fertility (e.g., Sarmadian and Keshavarzi 2014)), crop production (ibid), soil erosion (Vulević et al. 2015), land-use changes, and land suitability analyses (Calegari et al. 2020; Hermans et al. 2021). To provide versatile and reliable indicators for measuring soil health, a multitude of soil health indicators were developed by the scientists (Jian et al. 2020; Lehmann et al. 2020; Banerjee et al. 2022). Broadly, they have clustered soil health indicators into three groups: physical, chemical, and biological (Bai et al. 2018; Lehmann et al. 2020). Considering several criteria, which include being relevant, functional, sensitive, practical, and informative for farming management (Rinot et al. 2019; Hermans et al. 2021),

We reviewed the literature and selected nine indictors related to conservation tillage: bulk density (BD) and soil water content (SWC) as physical indicators; acidity (PH), electrical conductivity (EC), cation exchange capacity (CEC), soil mineral nitrogen content ($N_{\min}$), and carbon and nitrogen mineralizable potential in soil (CNMP) as chemical indicators; and soil organic carbon (SOC), soil microbial biomass (SMB), and soil respiration (SR) as biological indicators (Table 1). Each indicator impacts several vital agricultural system functions. For instance, production is significantly influenced by soil organic matter content, microbial abundance, and activity; soil nitrogen forms promote climate change mitigation; and water quality is influenced by microbial biomass and activity (Lehmann et al. 2020; Jayaraman et al. 2021). In conservation farming, conservation tillage potentially affects the

Table 1 Indicators and properties of soil health in farming systems

Indicators and properties of soil health	Explanation	Source
Soil organic matter	Refers to the amount of decomposed plant and animal materials in the soil. It enhances nutrient and water holding capacity and supports beneficial microbial activity	Allen et al. (2011), Lal (2015), Naresh et al. (2017)
Soil pH	Indicates the acidity or alkalinity of the soil. It affects nutrient availability to plants and influences the activity of soil microorganisms	Lal (2016), Moebius-Clune et al. (2016), Bai et al. (2018)
Soil texture	Describes the relative proportion of sand, silt, and clay particles in the soil. It influences soil drainage, water holding capacity, and nutrient availability	Rakhsh and Golchin (2017), Dendooven et al. (2012), Kumar et al. (2016)
Soil structure	Refers to the arrangement of soil particles into aggregates or clumps. Good soil structure promotes root penetration, aeration, water movement, and nutrient diffusion	Naresh et al. (2017), Xue et selection al. (2019), Allen et al. (2011)
Soil moisture	Represents the amount of water present in the soil. Adequate soil moisture is essential for crop growth and determines the availability of dissolved nutrients for uptake	Moradi et al. (2015), Renato et al. (2018), Moebius-Clune et al. (2016)
Soil nutrient content	Refers to the concentration of essential nutrients required for crop growth, such as nitrogen, phosphorus, potassium, and micronutrients. Optimal nutrient levels support crop growth, development, and overall health	Manzoni and Porporato (2009), Pasricha (2017), Kumar et al. (2018)
Soil microbial activity	Indicates the abundance and diversity of microorganisms in the soil, including bacteria, fungi, and other microbes. Microbes play a vital role in nutrient cycling, organic matter decomposition, disease suppression, and soil structure formation	Kumar et al. (2016), Lal (2015), Moebius-Clune et al. (2016)
Soil erosion	Represents the loss of topsoil by wind, water, or human activities. Erosion can result in reduced fertility, decreased water holding capacity, and ecological damage	Weintraub and Schimel (2003), Pradhan et al. (2018)
Soil compaction	Refers to the compression of soil particles, reducing pore space and restricting root growth and water infiltration. Compaction can lead to poor drainage, increased runoff, and decreased soil aeration	Kumar et al. (2016) and Moradi et al. (2015)

physical, chemical, and biological quality of soil (Bilibio et al. 2023). By reducing soil disturbance and maintaining soil coverage, conservation tillage systems (reduced tillage (RT), no-tillage (NT)) are a vital component of a sustainable agricultural system (USDA-NRCS 2020). They offered many benefits, including reductions in fuel consumption, costs, and the time and labor of operations, enhancement of soil organic matter, the improvement of soil structure, water-use efficiency, and water infiltration, and the enrichment of nutrient content, soil biological activity, and soil water holding capacity (Lamarca 1996; Six et al. 2002; Hobbs et al. 2008; FAO 2011; Pittelkow et al. 2015; Verhulst et al. 2018; Kassam et al. 2018). While conservation tillage practices were broadly accepted by farmers (Ashoori et al. 2017), the benefits they have for soil health, crops, environment, and public health are still in question, particularly in Iran's dryland farming. This study delves into the diverse engineering aspects of soil, encompassing its chemical, physical, and biological properties. It underscores their crucial role in fostering and preserving healthy soil and ecosystems, which is paramount for preserving water quality, mitigating climate change, and safeguarding human health. Specifically, we place emphasis on the significance of high soil organic carbon in improving soil health in dry farmlands. In such environments, elevated carbon levels can result in decreased reliance on fertilizers and soil-incorporated pesticides, subsequently reducing the risks posed to human health (Bennet et al. 2010; Brevik et al. 2019). To provide practical insights, this study aims to identify soil health indicators that could guide the selection of conservation tillage the Analytic Hierarchy Process (AHP) in Kermanshah's drylands. In the subsequent sections of this study, first, we introduce sampling method and AHP as a decision-making tool for selecting three tillage systems. Next, the AHP results are presented, and the final section encapsulates a comprehensive summary of the findings and discusses their implications for decision-making and policy (Fig. 1).

2 Methodology

2.1 Study area

This study was carried out in three districts in Kermanshah Province: Sarab Niloufar District, Badr District, and Palanganeh District in western Iran (Fig. 2). All districts are in a watershed, where their cultivation is often rainfed (dry farmland). The regions are in a latitude and longitude of 34° 42′ N, 46° 39′ E (Ravansar), 34° 48′ N, 46° 29′ E (Javanrud), and 34° 19′ N, 47° 04′ E (Kermanshah). The area has a Mediterranean climate with a 30-year average rainfall of 247.1 mm and an average temperature of 13.8 °C. These districts are significant in climate diversity, vast agricultural land, forest, and rangeland, particularly fertile soil, whose texture varied from sandy clay loam to sandy clay. The main crops grown are wheat, barley, maize, canola, and vegetables. Conventional agricultural methods (Tillage) in these districts expose a high potential for soil degradation (Haydari et al. 2022).

2.2 Sampling, research instruments, and indicators

During any study, researchers must acquire appropriate knowledge from those with specialized expertise (Sajadian et al. 2017). First, experts and farmers were selected via reputational sampling by the academic research team and the three researchers involved in National Soil Conservation Project based on experience in CA in dryland cropping systems, contributions to the peer-reviewed literature (only for experts), and diversity with respect to geography (Kermanshah Province, Iran) and area of research (only for experts) (Brugha and Varvasovszky 2000; Jean DeFeo 2013). The reputational approach in sampling allows for the collection of valuable data from experts, ensuring that the study captures a diverse range of viewpoints and insights (Tansey 2009). As a result, the two target groups investigated in this study include (1) agricultural experts, working in Iran's Ministry of Agriculture and (2) farmers within the study regions who deal with dryland farming practices. In 2020 and 2021, a total of 20 individuals were chosen from each of these groups. Since AHP is not a statistical tool, there is no rule that defines the number of farmers or experts needed to complete the questionnaire (Agha et al. 2012). The characteristics of each group are shown in Table 2. The farmer interviewees were all men, while the expert group consisted of 50% men and 50% women. In this study, the farmers were introduced by experts working in agricultural centers. The average age of the farmers was 38.15, with an average of 15.2 years of agricultural experience. The experts had an average age of 42.9 with an average of 14.2 years of agricultural experience. On average, the farmer group was four years younger than the expert group and had two years more experience. In terms of work experience, most of the farmers had inherited their land and occupation, so most of them had known agricultural work and related activities since adolescence. Conversely, experts had generally turned to this occupation after completing a college education. The farmers in our sample were previously introduced by experts working in the Ministry of Jehad for Agriculture. Questionnaires were completed in individual face-to-face interviews with both farmers and experts. During the interview, each of the indicators (properties) in the questionnaire was explained. The scoring method of the indicators was also explained to all interviewees to inform about the AHP scoring rule. After collecting the questionnaires, answers from all interviewees were used to create a paired comparison matrix.

2.3 The analytic hierarchy process

AHP is a rigorous and adaptable decision-making tool that is deployed to find answers to complex multi-indicator puzzles, such as identifying the primacy of conservation activities (Vulević et al. 2015) and agricultural irrigation systems (Veisi et al. 2022). AHP is conducted in four steps: (1) the hierarchical structure, e.g., target, indicators, and alternatives, is created; (2) pairwise comparison matrices, $A=[aij]n\times n$, where n ascribes to matrix size and $a_{ij}\geq 0$ $a_{ij}\times a_{ji}=1$, and $a_{ij}=$significance of the ith decision components over the jth decision components are made; (3) the relative weights for each of the decision factors are estimated by means of a prioritization method, e.g., the eigenvalue (EV) method; and (4) the relative values for each alternative are synthesized on hierarchy levels (Vulević et al. 2015). All matrices must pass the consistency test, i.e., judgment matrices are conceded if the consistency ratio (CR) attained by means of the consistency index (CI) and random index (RI) is lower than 0.10 (Vulević et al. 2015). The underlying presumption in the Analytic Hierarchy Process (AHP) is that there is no inherent relationship or dependency between the criteria or factors being evaluated (Saaty 2004).

2.3.1 The analytic hierarchy process: model development

The AHP deployment begins with a problem being broken down into a hierarchy of indicators to be more easily analyzed and compared objectively (Viana Vargas 2010). Each level includes a few manageable indicators, and each indicator may be sequentially disintegrated into other sub-indicators. The process narrows to the most specific components of the problem, typically the alternatives considered, which appear at the lowest level of the hierarchy. For the first level of the model in the current study, tillage practices that refine soil health in the dry farmlands were identified as the top goal of stakeholders. Level two of the AHP contained soil health indicators. A total of 10 indicators were identified in Level 2 (Fig. 1). To promote soil health, a CA system is assumed to (1) enhance the physical indicators including bulk density (BD) and soil water content (SWC); (2) refine the chemical indicators of acidity (pH), electrical conductivity (EC), cation exchange capacity (CEC), soil mineral nitrogen content (N_{min}), and carbon and nitrogen mineralizable potential in soil (CNMP); and (3) improve the biological indicators for soil organic carbon (SOC), soil microbial biomass (SMB), and soil respiration (SR). At the lowest level of the hierarchy, the stakeholder's goal is structured such that the three alternative CA systems comprise the farmer's choice set (RT, NT, and CT) (Fig. 1). Obviously, farmers and experts can make different hierarchies indicating each one's unique understanding of the decision-making problem. Each farmer or expert may include more alternative choices and/or pursue additional objectives.

While the operation of conservation tillage enhances soil health and productivity (Fariabi and Matinfar 2017), it seems to have trivial effect on crop yields (e.g., Camarotto et al. 2018; Behnke et al. 2018; Liu et al. 2020). Considering these ambiguous results, yield was not considered an indicator for selecting tillage in the present study.

2.3.2 Prioritization: pairwise comparison of indicators

The second step in AHP is to gather survey data from respondents by asking them to commence the pairwise comparison of the different decision items in respect to alternatives in the hierarchy concerning the next higher level. We applied a numerical gauge of integers varying from 1 to 9 to convert qualitative (verbal) appraisals into quantitative data (Table 3).

According to Saaty (2004), this scale is validated using theoretical comparisons with other large scales. Table 3 shows the underlying scale of values that represent the judgment intensities. In the present research, the 10 indicators relating to soil were compared in pairs to evaluate their effects on the overall objective of improved soil health, and the three alternatives (NT, RT, and CT) were compared in pairs to weight their relative importance under each indicator. The obtained weights from the pairwise comparison, $aij = s_i/s_j$ for all decision items and their reciprocals, $a_{ji} = 1/a_{ij}$, were set into a reciprocal square matrix, $A = \{a_{ij}\}$.

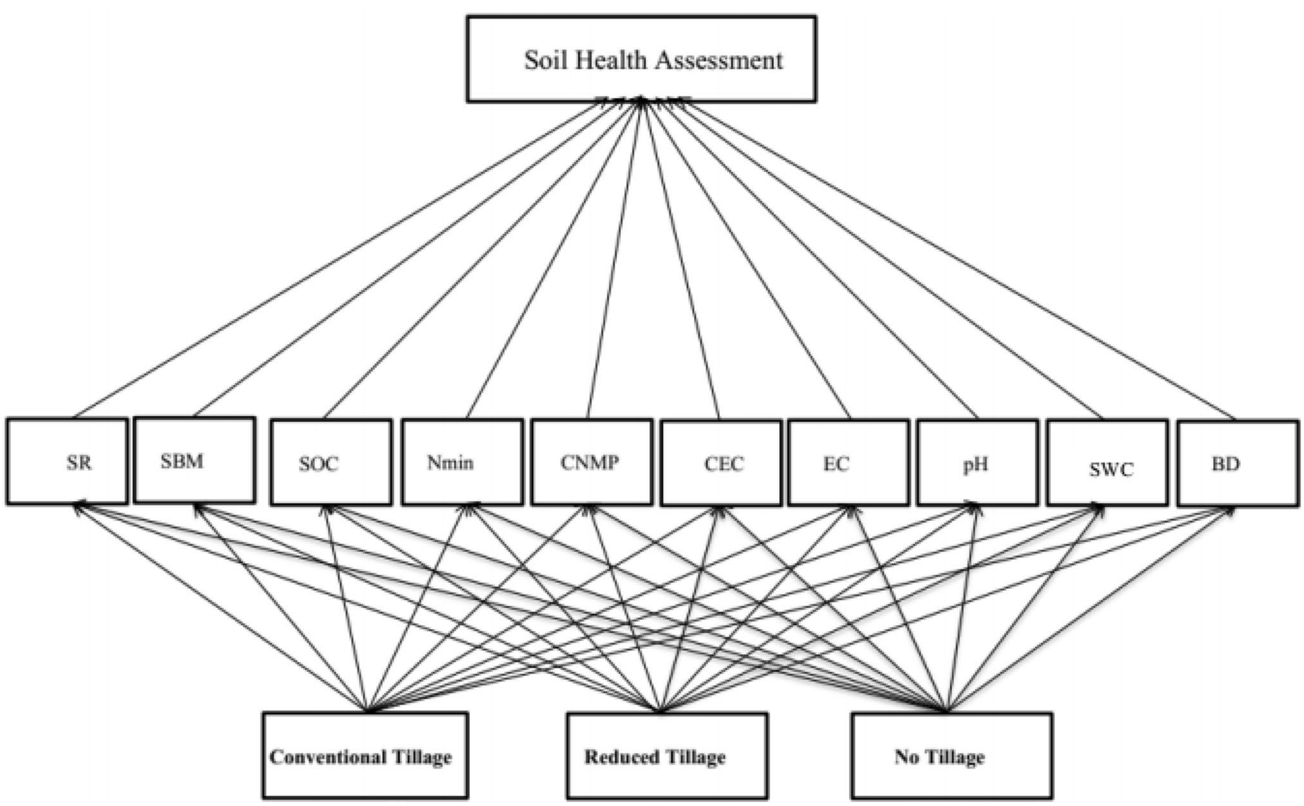

Fig. 1 Hierarchical model for the selection of tillage practice

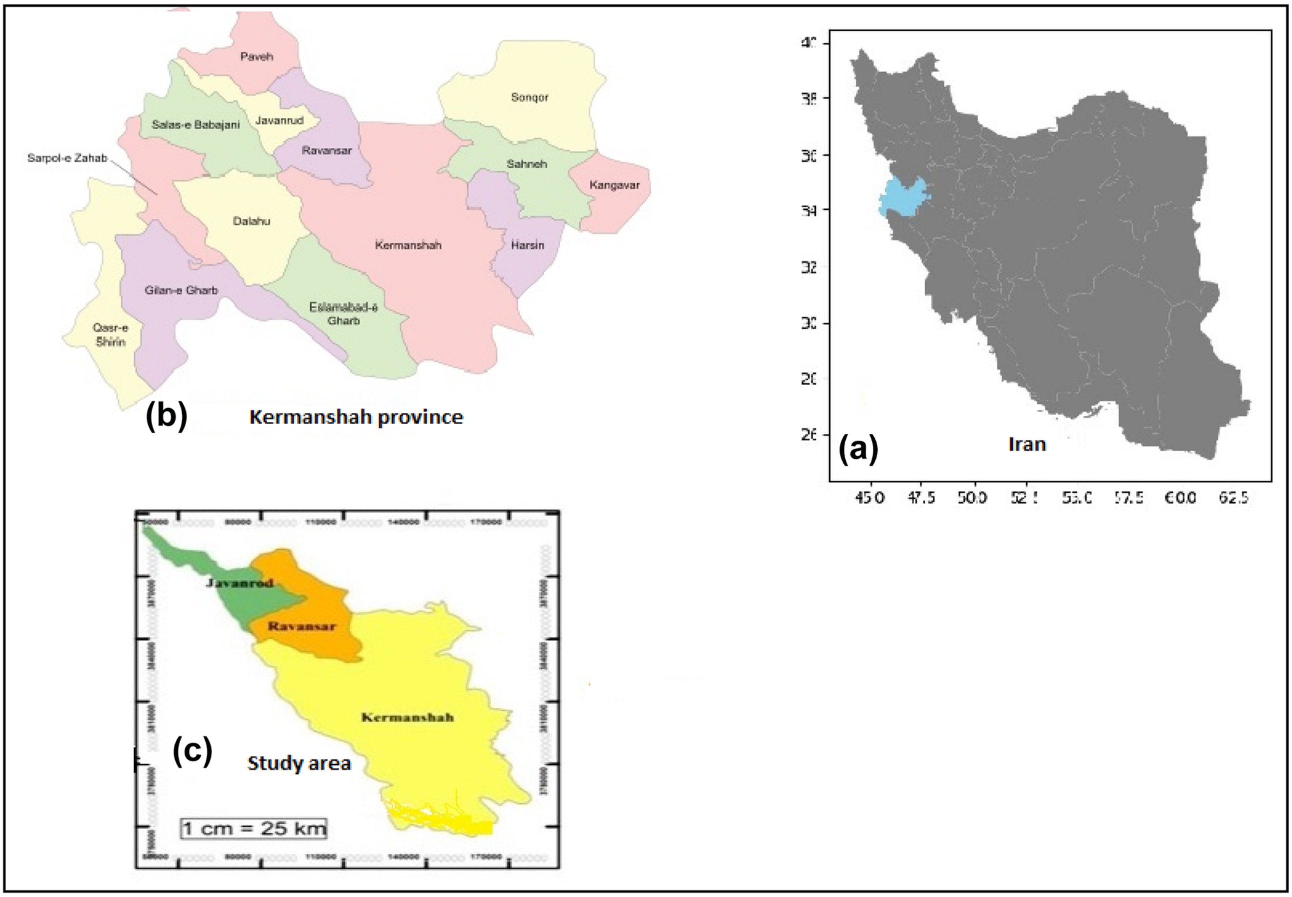

Fig. 2 Map of the study area

$$A = \left| a_{11} a_{12.....} a_{1n} a_{21} a_{22} a_{2n} a_{n1} C_y a_{nn} \right| \quad (1)$$

Matrix A would be consistent if all judgments were done properly, i.e., if $a_{ik} = a_{ij} a_{jk}$ for all i, j, and k. For a consistent matrix, exact measurements are used for the judgments, i.e., the weights $s_1, \ldots, s_n$. For the real case, the judgment (a_{ij}) was derived from the subjective judgments rather than the exact measurements, where the a_{ij} drifted from the ideal proportions s_i/s_j and Eq. (1) no longer held. To attain the priority vector (vector w), the matrix of pairwise comparison values must be satiated by Eq. (2), where

$$Aw = nw, Aw = \lambda_{\max} w \quad (2)$$

Saaty (2004) introduced an approximation mode where the weights were computed by normalizing the eigenvector related to the maximum eigenvalue ($\lambda_{\max}$) of the reciprocal matrix; the greatest eigenvalue is presented in Eq. (5), where

$$W_i = \sum_{j=1}^{n} a_{ij}^{*}/n \quad (3)$$

$$a_{ij}^{*} = a_{ij} / \sum_{i=1}^{n} a_{ij} \quad (4)$$

$$\lambda_{\max} = \frac{\sum_{i=1}^{n} \left[\left(\sum_{j=1}^{n} a_{ij} w_j \right) / w_i \right]}{n} \quad (5)$$

The inconsistency degree was calculated in the square matrix using a consistency index (CI) where

$$CI = \left(\lambda_{\max} - n \right) / (n - 1) \quad (6)$$

Saaty (2004) compared the computed CI with the same index taken from a Random Consistency Index (R.I) (Table 4) (Sajadian et al. 2017).

The ratio of CI to RI for the same order matrix was named a consistency ratio (CR).

$$\mathrm{CR} = \frac{\mathrm{C.I}}{\mathrm{R.I}} \quad (7)$$

If CR is less than or equal to 0.10, the degree of consistency is acceptable. If CR is higher than 0.10, the inconsistencies are

Table 2 Socio-demographics of the participants

Group name	Characteristics		Frequency	Percentage	Mean
Farmers	Gender	Man	20	100	–
		Woman	0	0	
	Age (years)	30 >	2	10	38.15
		40–30	11	55	
		50–41	6	30	
		60–51	1	5	
	Education	Diploma	9	45	–
		Baccalaureate	11	55	
		MA and Ph.D	0	0	
	Agricultural experience (years)	10 >	2	10	16.2
		10–20	10	50	
		30–21	7	36	
		30 <	1	5	
Experts	Gender	Man	10	50	–
		Woman	10	50	
	Age (years)	30 >	0	0	40.9
		40–30	9	45	
		50–41	11	55	
		60–51	0	0	
	Education	Bachelor	12	60	–
		MA and Ph.D	8	40	
	Agricultural experience (years)	10 >	1	5	14.2
		20–10	18	90	
		30–21	1	5	
		30 <	0	0	

Table 3 Saaty' nine scale for indicators pairwise comparison in AHP

Definition	Score
Equal importance	1
Moderate importance	3
Strong importance	5
Very strong importance	7
Absolute/extreme importance	9
Immediate values between above scale values	8,6,4,2

serious, in which case the AHP may not lead to meaningful results (Chakraborty and Banik 2006).

2.3.3 Calculation of weights

After completion of the matrices, the relative weight of each index was computed (Sajadian et al. 2017). There are many methods for doing this, such as eigenvector, logarithmic least square, least squares, and estimated methods, but the eigenvector method is the most popular (Zebardast 2001). When there are many matrices, calculating certain elements is time-consuming, so Expert Choice software was used in this study to compute the relative weight of each indicator. To calculate the relative weight of indicators, Saaty (2004) suggests using multiple methods such as sum in rows, sum in the column, math mean, or the most frequently used geometric mean method, in which the geometric mean of the matrix rows is computed and

Table 5 Pairwise comparison matrix of hypothesized indexes A, B, C, D

	A	B	C	D
A	1	*Pab*	*Pac*	*Pad*
B	*Pba* = 1/*Pab*	1	*Pbc*	*Pbd*
C	*Pca* = 1/*Pac*	*Pcb* = 1/*Pbc*	1	*Pcd*
D	*Pda* = 1/*Pad*	*Pdb* = 1/*Pbd*	*Pdc* = 1/*Pcd*	1

Table 4 Randomness Index (R.I)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	*n*
1.59	1.57	1.56	1.48	1.51	1.49	1.45	1.41	1.32	1.1	1.12	0.9	0.58	0.0	R.I

normalized. For example, to compare sub-factors of A, B, C, and D, a matrix akin to Table 5 is formed.

As shown in Table 5, by computing half the table cells, the other half can be calculated. This means that if A's priority to B is equal to *Pab*, then B's preference for A (*Pba*) is 1/*Pab* (Sajadian et al. 2017). Consistent with the values of the paired comparison matrix, the geometric mean for each indicator can be computed using Eq. (2) as follows:

$$\mathrm{GM}_X = \sqrt[n]{1 + P_{x1} + P_{x2} + \cdots + P_{xn}} \tag{8}$$

where GM_x is the geometric mean of the *x*-weight of the paired comparison matrix, 1 is the *x*'s priority to itself, P_{x1} to P_{xn} is the *x*-function compared with other factors, and $n+1$ is the number of studied indicators. Similarly, the geometric mean of the four hypothetical indicators (Table 5) can be calculated as follows:

$$\mathrm{GM}_\mathrm{A} = \sqrt[4]{1 + Pab + Pac + Pad} \tag{9}$$

$$\mathrm{GM}_\mathrm{B} = \sqrt[4]{1 + Pba + Pbc + Pbd} \tag{10}$$

$$\mathrm{GM}_\mathrm{C} = \sqrt[4]{1 + Pca + Pcb + Pcd} \tag{11}$$

$$\mathrm{GM}_\mathrm{D} = \sqrt[4]{1 + Pda + Pdb + Pdc} \tag{12}$$

In a paired comparison matrix, $\mathrm{GM_A}$, $\mathrm{GM_B}$, $\mathrm{GM_C}$, and $\mathrm{GM_D}$ values are equal to the geometric weight mean of A, B, C, and D, respectively (Table 5).

2.3.4 Synthesis: scoring and integration of the alternatives

After identifying the relative weight for indicators to the target, the final weight of the alternatives is identified. At this stage, the alternative options are pairwise compared against each of the indicators for preference. The comparisons are processed mathematically using Saaty's 9-point scale (Table 3), and each alternative option is prioritized. The results of these calculations are presented in pairwise matrices. The geometric means of rows in these matrices are normal. It is worth noting that options are compared in relation to the indicators, not in relation to the study target (Zebardast 2001).

Expert Choice software performs the combination process of weights in both distributive and ideal modes. Ideal mode is used when there are several alternatives equal in weight and/or the option choice has the highest priority rating. Distributive mode is used to select options that have different values for each target, and the prioritization of alternatives is considered. The weight of the indicators is divided according to the importance of the alternatives. Thus, the total weight of the alternatives for each indicator is equal to the relevant indicator weight (Sarmadian and Keshavarzi 2014). In the current study, the goal was to select the best tillage system with respect to soil health indicators through a rating of alternatives. To this end, the distributive mode was used to compare pairs of alternatives with respect to each indicator of the questionnaire with a 2×2 matrix.

3 Results

3.1 Consistency analysis of decision-makers

In the commence, the consistency consensus matrix was used to identify the 'core of consistency' of the farmers and experts participating in the decision-making process (Tables 6, 7, 8). These rates were 0.02 for farmers, 0.01 for experts, and two groups of participants together 0.00 which are less than the maximum acceptable inconsistency rate of 0.10 specified by Saaty, which means that farmer and expert views are reasonable and statistically acceptable, more so common hierarchy is acknowledged by both farmers and experts (Moreno-Jiménez et al. 2008).

Table 6 Pairwise comparison matrix of soil health indicators by farmers

	BD	SWC	pH	EC	CEC	CNMP	N_{min}	SOC	SMB	SR
BD	1	0.617	0.564	0.901	0.791	0.589	0.504	0.463	0.565	0.681
SWC		1	1.688	1.365	1.004	1.320	0.764	1.116	1.619	1.100
pH			1	0.888	0.803	0.477	0.331	0.544	0.924	1.206
EC				1	1.340	1.239	0.625	0.766	1.194	0.757
CEC					1	1.129	0.657	0.564	0.874	0.691
CNMP						1	0.756	0.572	1.019	1.156
N_{min}							1	1.259	1.558	1.772
SOC								1	2.061	2.303
SMB									1	1.27
SR	Incon: 0.02									1

3.2 Pairwise comparisons

For all three comparisons (group one: farmers, group two: experts, group three: a combination of the two), the relative weight of indicators associated with target was also calculated using Expert Choice (Table 9).

3.2.1 Farmers

Among farmers, the results indicated that indicator N_{min} had the highest weight of 0.150, followed by indicators SOC and SWC, which had relative weights of 0.144 and 0.118, respectively (Table 9). The lowest weight, however, belonged to BD (0.062). The selection of the N_{min} indicator by farmers can be attributed to its ability to increase crop yield in a short time, which consequently decreases the need for mineral fertilizers (Renato Nunes et al. 2018; Xue et al. 2019).

3.2.2 Experts

According to the experts, SOC with a weight of 0.144 and SWC with a weight of 0.137 were the two most important indicators (Table 9). As indicated in Table 8, the weights of SR (0.116) and SMB (0.112) were significant. N_{min} was less important for experts than farmers. The lowest weight for experts belonged to pH (0.069).

3.2.3 Overall participants

Soil health is a complex phenomenon. Thus, the aggregate views of the different stakeholders (farmer and expert groups) link the priorities of the indicators with alternative tillage systems. Table 9 displays the outcomes of the comprehensive comparisons, indicating that the most significant weights were assigned to SOC (149) and SWC (122)

Table 7 Pairwise comparison matrix of soil health indicators by experts

	BD	SWC	pH	EC	CEC	CNMP	N_{min}	SOC	SBM	SR
BD	1	0.516	1.226	0.919	1.206	1.204	1.177	0.568	0.687	0.941
SWC		1	1.764	1.211	2.058	1.975	1.304	0.941	1.214	1.257
pH			1	0.663	0.821	1.121	0.658	0.491	0.604	0.606
EC				1	1.004	1.105	1.020	0.520	0.762	0.801
CEC					1	1.169	0.773	0.455	0.747	0.732
CNMP						1	0.859	0.628	0.670	0.785
N_{min}							1	0.718	0.739	0.605
SOC								1	1.207	1.204
SMB									1	0.745
SR	Incon: 0.01									1

Table 8 Pairwise comparison matrix of soil health indicators by overall participants

	BD	SWC	pH	EC	CEC	CNMP	N_{min}	SOC	SBM	SR
BD	1	0.598	0.860	0.935	0.844	0.814	0.734	0.475	0.589	0.727
SWC		1	1.626	1.427	1.504	1.403	1.012	0.815	1.338	1.054
pH			1	0.805	0.794	0.818	0.558	0.487	0.651364	0.720
EC				1	1.061	0.942	0.715	0.527	0.795	0.709
CEC					1	1.002	0.648	0.479	0.764	0.680
CNMP						1	0.857	0.643	0.800	0.787
N_{min}							1	0.829	0.932	0.937
SOC								1	1.400	1.269
SMB									1	0.755
SR	Incon: 0.00									1

Table 9 The combined weight of indicators relative to goal in the groups of farmers, experts, and overall participants

Indicators participants	BD	SWC	pH	EC	CEC	CNMP	N_{min}	SOC	SMB	SR
Farmers' group	0.06	0.12	0.07	0.09	0.08	0.09	0.15	0.14	0.09	0.09
Experts' group	0.09	0.14	0.06	0.09	0.07	0.07	0.0	0.14	0.11	0.12
Overall participants	0.07	0.12	0.07	0.08	0.08	0.08	0.11	0.15	0.11	0.11

indicators, followed by SR, N_{min}, and SMB, with relative weights of 0.115, 0.113, and 0.106, respectively.

According to the assessment conducted by both experts and farmers, Soil Organic Carbon (SOC) was assigned the highest rank among the critical biological indicators that affect soil health. The experts gave it the first rank, indicating its significant importance, while the farmers ranked it as the second most crucial indicator. This consensus highlights the recognition of SOC as a vital component for assessing and maintaining soil health (Xue et al. 2019). The selection of SMB and SR indicators by the experts revealed a deep scientific understanding of the correlation between SMB and many other soil indicators, such as SR, SOC, and porosity. This means that soil with high SMB leads to higher rates of SR (Naresh et al. 2017; Naresh et al. 2017).

After comparing the associated indicators with respect to the target, a pairwise comparison of alternatives was performed by both farmers and experts. According to Tables 8 and 9, the no-tillage alternative was the best option with respect to all the indicators, followed by reduced and conventional tillage (Table 10). Calculating the weight of indicators applying AHP showed that SWC, SOC, SMB (MBC and MBN), SR, and N_{min} had higher weights than pH, CEC, EC, or BD. Thus, representative soil properties functioned as indicators in evaluating soil health according to AHP results.

3.3 Sensitivity analysis

Sensitivity analysis allowed us to verify the results of the decision. The results of the sensitivity analysis explored how each alternative (RT, NT, and CT) performs on each indicator by increasing or decreasing the importance of the indicators. Moreover, in pairwise comparisons of the alternatives with the main target and the final weighting of the three alternatives. Based on Fig. 3a–c, both groups identified NT as the optimal choice followed by RT as the second best option. An overall analysis of CT systems selected by both groups indicated that no-till (0.59) was the most suitable option for maintaining soil health in dry farmlands. Reduced tillage (0.34) and conventional tillage (0.19) were ranked as the second and third choices, respectively (as shown in Table 11). The findings further highlighted that SOC (0.149) had the greatest influence on soil health management decisions, while SWC (0.12) and SR (0.11) had the next highest weights in order (see Table 9). Conversely, PH (0.072), BD (0.072), and CEC (0.081) had the lowest weights.

4 Discussion

Soil health refers to the continuous ability of soil to function as a vital living ecosystem that supports the well-being of plants, animals, and humans (USDA 2021). This is achieved through the effective engineering of microbial communities, including bacteria, fungi, protists, viruses, and nematodes, using agricultural practices, such as crop rotation, cover crops, tillage techniques, and diversified cropping systems (Lal et al. 2021). These practices have a significant impact on the physicochemical properties of the soil (Bano et al. 2021). In this context, the improvement of soil health (properties) and the adoption of conservation practices such as reduced and no-tillage are two critical aspects that serve as the cornerstone of soil security (Xue et al. 2019; Rinot et al. 2019). In this study, we utilized the Analytic Hierarchy Process (AHP) to investigate the dynamic relationship between soil health and conservation agriculture practices, as perceived by farmers and experts (Hobbs et al. 2008) as perceived by farmers and experts. We specifically examined the indicators and properties used by farmers and experts to make informed decisions on the selection and implementation of conservation agriculture systems. The results indicated that both groups of participants, e.g., farmers and experts in the region, agree that NT performed the best to improve soil health in dry farmlands. They chose RT as the second best alternative. The indicators of SOC and SWC were ranked higher by both farmers and experts; for farmers N_{min}, SOC, and SWC had higher relative weight, while for the agricultural experts, properties of SOC, SWC, SMB, and

Table 10 Pairwise comparison of alternative with respect to each indicator in the groups of farmers, experts, and overall participants

Participants	Indicators alternatives	BD	SWC	pH	EC	CEC	CNMP	N_{min}	SOC	SMB	SR
Farmers' group	Conventional tillage	0.013	0.027	0.023	0.016	0.02	0.022	0.038	0.027	0.02	0.021
	Reduced tillage	0.022	0.039	0.026	0.029	0.032	0.032	0.046	0.048	0.03	0.03
	No-tillage	0.027	0.051	0.027	0.047	0.033	0.042	0.066	0.069	0.038	0.037
Experts' group	Conventional tillage	0.012	0.019	0.011	0.016	0.015	0.014	0.014	0.015	0.013	0.019
	Reduced tillage	0.034	0.046	0.026	0.033	0.03	0.028	0.033	0.045	0.036	0.039
	No-tillage	0.042	0.073	0.033	0.041	0.033	0.034	0.043	0.084	0.064	0.058
Overall participants	Conventional tillage	0.014	0.023	0.015	0.017	0.017	0.019	0.023	0.023	0.019	0.024
	Reduced tillage	0.025	0.042	0.027	0.030	0.031	0.030	0.038	0.049	0.035	0.39
	No-tillage	0.033	0.056	0.030	0.035	0.033	0.040	0.051	0.077	0.053	0.052

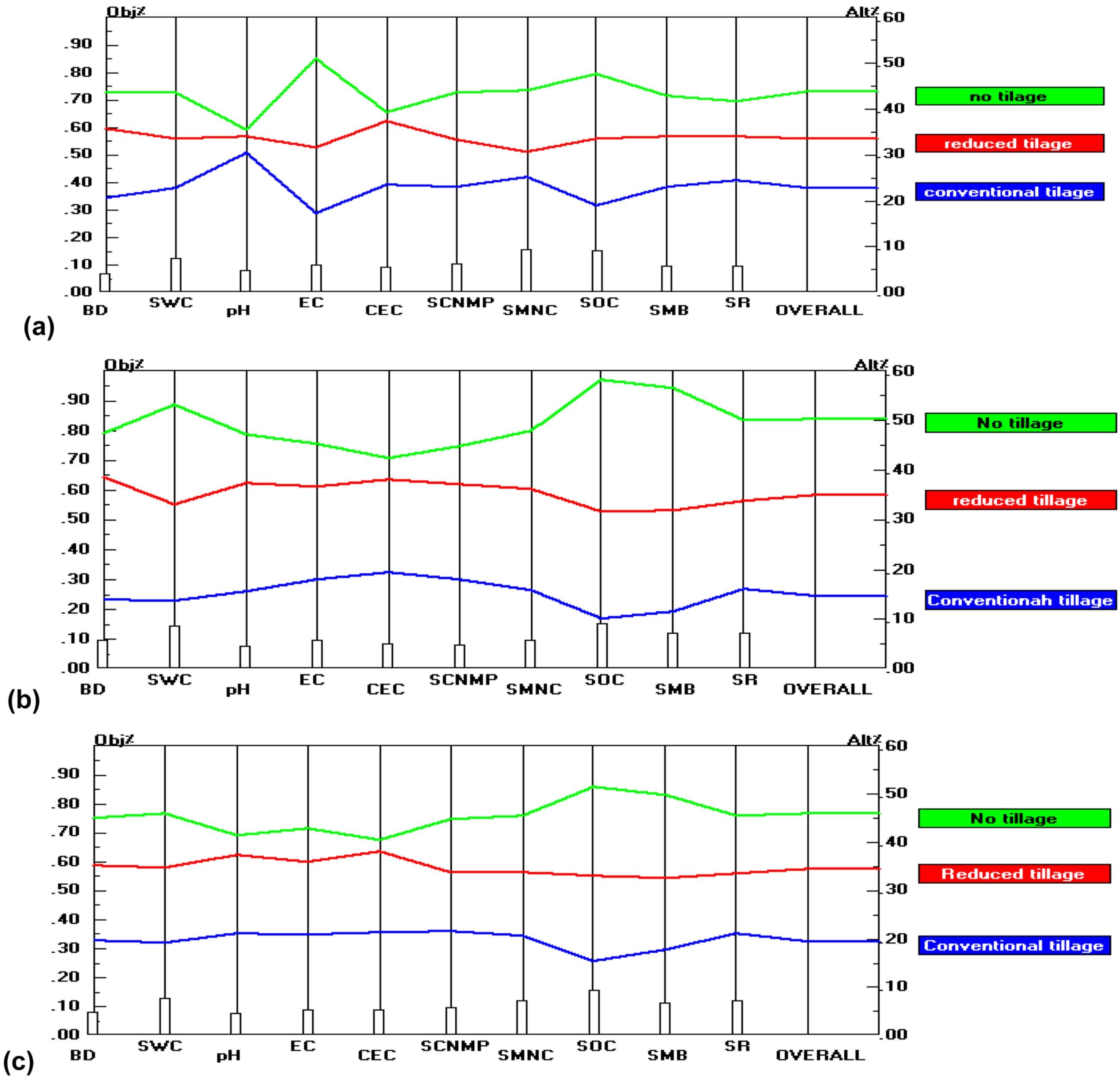

Fig. 3 Prioritization diagram of alternative with respect to the target for farmers (**a**), experts (**b**), and all participants (**c**). *Obj* objective, *Alt* alternatives, *BD* bulk density, *SWC* soil water content, *pH* acidity, *EC* electrical conductivity, *CEC* cation exchange capacity, *SCNMP* carbon and nitrogen mineralization potential, *SMNC* soil mineral nitrogen content, *SOC* soil organic carbon, *SMB* soil microbial biomass, *SR* soil respiration

Table 11 Comparison of different tillage systems based on soil health indicators in selecting conservation tillage systems in drylands by studied groups

Alternatives	Groups studied		Overall participants
	Farmers' group	Experts' group	
Conventional tillage	0.228	0.147	0.196
Reduced tillage	0.335	0.349	0.345
No-tillage	0.437	0.504	0.595

SR received higher relative weight in choosing proper tillage systems to improve soil health. According to these results, it can be argued that

(i) NT was selected as a new paradigm for farming, because as Kassam et al. (2018) and Pittelkow et al. (2015) indicated, like other farmers in the world, stakeholders (farmers and experts) seek new innovations and paradigms for their critical problems. These include issues brought on by wind and water erosion as well as drought, which have been made worse by rising energy and production input costs. Relatively, Hemmat and Eskandari (2006) indicated that NT had higher grain yields (420 kg ha^{-1}) for dryland continuous winter wheat farming than those obtained with CT, in terms of higher water availability.

(ii) Indicators relating to three functions and services of soil (carbon transformations, nutrient cycles, and soil structure maintenance), such as SOC, SMB, and SWC, played a critical role in the selection of CA systems. Hence, farmers and experts selected NT and RT, because they think CT reduces SOC (Moshiri et al. 2018). NT contributes to soil health in the topsoil layer by improving the functions of soil structure, heightening soil biological activity and nutrient cycling, and decreasing soil bulk density (Haydari et al. 2022). They believe through causal chains that SOC refines soil water holding capacity, water infiltration, electrical conductance, and water-use efficiency (Pittelkow et al. 2015).

(iii) Farmers and experts demonstrated varying perceptions and perspectives regarding the assignment of weights to indicators. Farmers have significantly devoted higher weight to N_{min} compared to the experts. These gaps may stem from different experiences farmers and experts have had with the effects of conservation agriculture. In this regard, experts would consider the problems of reducing organic matter inputs and water scarcity as drivers when choosing CA options. In contrast, N drives farmer choice in addition to organic matter inputs for a higher yield (Cotrufo and Lavallee 2022). Organic matter input serves as valuable sources of nitrogen. By incorporating organic matter into the soil, farmers can enrich the nitrogen content, thus ensuring a sustained supply of this vital nutrient for crop growth.

While our study yielded promising results, its scope was limited to the perspectives of farmers and experts who participated in the research projects. Specifically, we only assessed how these individuals perceived the effects of Conservation Agriculture (CA) on soil health indicators. However, to comprehensively evaluate stakeholder perspectives, it is equally crucial to consider the views of scientists from various disciplines, as well as representatives from business, government, and civil society, and their perceptions of the impact of CA on soil health indicators. Despite this limitation, our findings have significant implications for designing and implementing a new soil security policy in developing countries, which we will outline below:

(i) In the context of soil security for sustainable agriculture, the use of the AHP can contribute to the co-production of knowledge (Evangelista et al. 2023). As a multi-attribute and multi-stakeholder tool, AHP enables fair and transparent decision-making for acute problems in sustainable agriculture. However, due to the imprecision and vagueness of decision-making information, scholars propose combining AHP with other tools, such as Quality Function Deployment (Scott et al. 2015), Life Cycle Assessment (LCA) (Dekamin and Barmaki 2018), and TOPSIS (Davarpanah et al. 2016). To address the limitations of AHP, Widianta et al. (2018) insinuate the use of a combination of AHP and TOPSIS to solve real-world decision-making issues, including the assessment of the relative performance of choice options. According to Widianta et al. (2018), these tools should be used together to create a participatory scenario aimed at improving soil health through CA.

(ii) CA adoption has been associated with certain issues, including increased weed growth, the retention of residues, and climate change that can serve as a stimulus for diseases and pests in response to increased moisture. Climate change indicators like elevated drought and temperature fluctuations provoke the distribution and interactions among microorganisms and pests (Meena and Jha 2018). As a result, the use of herbicides has increased in these systems. To address these challenges, we propose integrating CA into a comprehensive policy package that includes not only other innovations, such as water conservation, integrated pest management, and organic agriculture but the agency of climate change, all of which fall under the umbrella of adaptive agricultural management practices. This recommendation is in line with the findings of Bai et al. (2018), who advocate for a holistic approach to agricultural management that integrates multiple practices to address the challenges posed by CA. Such an approach would require the implementation of strategies such as "Agri-environment Initiative" and "Payment for Practice rather than Performance" (Jeffery and Verheijen 2020). For example, the agri-environment initiatives implemented in Europe have encouraged farmers to adopt practices that have a positive impact on the environment, even if they are not the most profitable option. This has created a legislative foundation for sustainable agriculture in Europe, highlighting the importance of policies that incentivize the adoption of sustainable practices. In conclusion, the integration of CA into a comprehensive policy package that incorporates other sustainable agricultural practices is essential for addressing the challenges such as climate change associated with soil security.

(iii) Taken together, the elucidation and recognition of the diverse impacts of CA alternatives, as assessed by farmers and experts on soil health, could pave the way for future researchers to formulate more comprehensive, longer-term research plans for on-farm experimental studies (Hermans et al. 2021). In line with Carlisle's (2016), we propose a supplementary methodology that combines empirical findings with mathematical and statistical techniques to incorporate a wider range of indicators, such as yield, and endeavors aimed at bridging farm practices and food system policies. This approach can provide more detailed and nuanced understandings of the possible impacts of CA alternatives on soil health and soil security.

5 Conclusion

Given the importance of soil health and CA for soil health, community well-being, and agricultural sustainability, it is essential to develop an inclusive agenda and framework to guide decision-making processes. This study utilized a suite of soil health-related indicators to explore a multi-criteria decision-making process for sustainable soil management, using AHP. We carried out a case study on the selection of conservation tillage systems by dryland farmers in Kermanshah Province, Iran, to highlight the implications of our approach in developing countries. Drawing from our findings, we have concluded that soil health and conservation agriculture (CA) practices can play a pivotal role in planning and ensuring soil security in dry farmlands, encompassing all three dimensions of soil quality for sustainable agriculture—physical, chemical, and biological—as identified by Lehmann et al. (2020). Farmers and experts indicated that these criteria accounted for 59% of the selection of no-tillage, 34% for reduced tillage, and 19% for conventional tillage systems. In order to ensure optimal decision-making, AHP can contribute to co-producing knowledge for optimal decision-making in efforts toward regenerative sustainable agriculture, where soil health and security are of utmost importance and more generally for crafting policies and strategies toward sustainable and healthy ecosystem. (Hermans et al. 2021).

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Data availability Data will be made available on request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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