RESEARCH ARTICLE

Trend setting impacts of organic matter on soil physico-chemical properties in traditional vis -a- vis chemical-based amendment practices

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Abstract

Amongst the soil qualities that are taken into consideration while quantifying the fertility status of soil for agri-production, the properties of water holding capacity, bulk density, electrical conductivity and soil pH play crucially important roles, directly as well as indirectly. The role of organic matter content of soil in altering the aforesaid properties occurs through various complex interactions. In our study we attempted to understand the impact of amendments in traditional ecological knowledge (TEK)-based organic input agri-management systems (A1), versus conventional chemical-intensive agri-systems (A2) in altering/modifying the few important properties viz soil organic matter (SOM), pH, electrical conductivity (EC), bulk density, and water holding capacity of the soil in the three different crop phases viz. pre, mid and the post-harvest, spread over six cropping seasons in four years. The study area was a geo-ecologically unique terrain of Kachchh, Western India. Natural stressors as erratic rainfall, drought and salinity are a typical feature of this zone. Physico-chemical soil attributes have shown significant differences in the amendment systems. The application of organic manures and concoctions like *Jivamrit* from indigenous knowledge base of local farming community, certainly rendered better organic matter content that affect soil structure and stability, which in turn affected the maximum water holding capacity (MWHC), which was significantly higher in A1 (47.53%; (Standard Error [SE] = ±0.92%) across phases and seasons than A2 (37.99%; SE = ±0.74%). Probably, for the same reason, amendments with organic inputs had a lower bulk density (1.04 g/cm^3; SE = ±0.02 g/cm^3) as compared to amendments with no or very few organic inputs (1.31 g/cm^3; SE = ± 0.03 g/cm^3).The reduction in pH and electrical conductivity in A1 may be ascribed to increased amounts of SOM as a result of addition of green manures and organic concoctions. Even during the stressed period of drought in cropping seasons of season 2 (Kharif2012) and season 3 (Rabi 2012–2013) this trend was followed. This clearly shows that salinity endurance and drought resistance are remarkable features of organically amended soils and this resilience to drought is achieved over continual usage of organic manures. The arid and semi-arid tropics are highly prone to stressors like drought, highly erratic rainfall patterns, and salinity, and the present study advocates the supremacy of TEK-based agri-management systems in soil sustainability for maintaining the soil fertility in the long run.

1. Introduction

As per the FAO report 2009 [1], it is projected that the world's population will increase by 2.3 billion people by 2050, and most of this growth would be witnessed in developing countries. In a projection stated by World Population prospects of United Nations, 2019 [2], feeding the ever-growing world population of 9.7 billion in 2050 would require increasing the food production by almost 70% by the year 2050 [2].

Now, the biggest threat laid on the agricultural production system is the limitation of arable land, because expansion of this resource is limited by several criterions and hence all emphasis would be on increasing the production capacity of the present arable land. Hence, this increased impetus to increase production from the same available land resource is an important factor that leads to capacity enhancement through several external inputs.Amongst this pressing threat on arable land, the key element that promises to be the decisive factor is the soil. The inherent soil properties define the overall agriculture production and the carrying capacity of the soil to sustain the fertility that, in turn, decides the production capacity/yield. These soil properties encompass the physical, chemical, and microbiological properties that render this soil system its dynamism. The physico-chemical properties of different soils have varying values owing to the abiotic and biotic variables that include but are not confined to—topography of the place, parent rock material, climate, and vegetation cover.

In agricultural soils, the amendments that are added over a continued period of time are an important decisive factor in the soil fertility status. The chemical-based inputs have already raised several implications in terms of declining soil health [3]. Agri-management strategies that are based on traditional ecological knowledge (TEK) are gaining momentum owing to their better sustainability and adaptability [4]. The traditional inputs that are best suited to the local needs and are easily available are promising alternatives for chemical amendments and maintaining soil fertility to achieve the goal of environmental sustainability [4,5].

Soil properties such as soil organic matter (SOM), maximum water holding capacity (MWHC), electrical conductivity, bulk density, and pH play a decisive role in the fertility of soil. As an evidence of this, the availability of the important crop nutrient phosphorus in its bio-available form is highly dependent on variable pH, which determines the conversion of the fixed P into bio-available form [6]. Similarly, several complex reactions that occur in the rhizosphere of the plant are dependent on moisture availability and salt concentration in the rhizoplane.

Besides the factors that are inherent to the quality of soil, there are certain induced factors that alter the fate of soil properties. The amendments that are added into any soil enhance or alleviate any compositional or non-compositional elements that, in turn, affect the physico-chemical properties of soil.

Agricultural practices in stress-prone areas have their own challenges that include natural calamities and anthropogenic causes [7]. In conjunction with this the farming community, in order to sustain their profit margin and increase the input:output ratio, is compelled to find such alternative practices that can help them be sustainable in the long-run, from the point of view of economic benefits as well as the environmental implications. The sky-rocketing prices of chemical-based fertilizers and pesticides are an additional burden on their shoulders in conjunction with the natural disasters, in terms of drought and incessant rainfall that the farmers face.

Feeding the ever-growing population is a challenge that calls for cumulative efforts from governments, activists, the farming community, and academia [1]. Soil remains pivotal in deciding the production capacity of any agriculture management system. The physical, chemical, and microbiological properties render to any soil its true essence, in conjunction with the external inputs that are applied in the form of amendments. The present study is the first of its kind to attempt to assess the role that traditional farming amendments play in comparison to chemical-based fertilizers in enhancing the fertility of soil, in terms of organic matter and the physico-chemical properties that are in turn affected by it.

2. Materials and method

2.1. Study area

Kachchh district (23˚13′48.00″ N, 69˚42′35.06″ E)inWestern India represents allied semi-arid and arid tropics that are prone to different natural calamities including but not limited to; salinity, rainfall pattern and drought (Fig 1). According to the National Bureau of Soil Survey (NBSSS) and Land Use Planning LUP), 2005 [8], soils of this zone aretypic-camborthids. The soils are typically calcareous sandy loams. The geological history of this area confirms origin

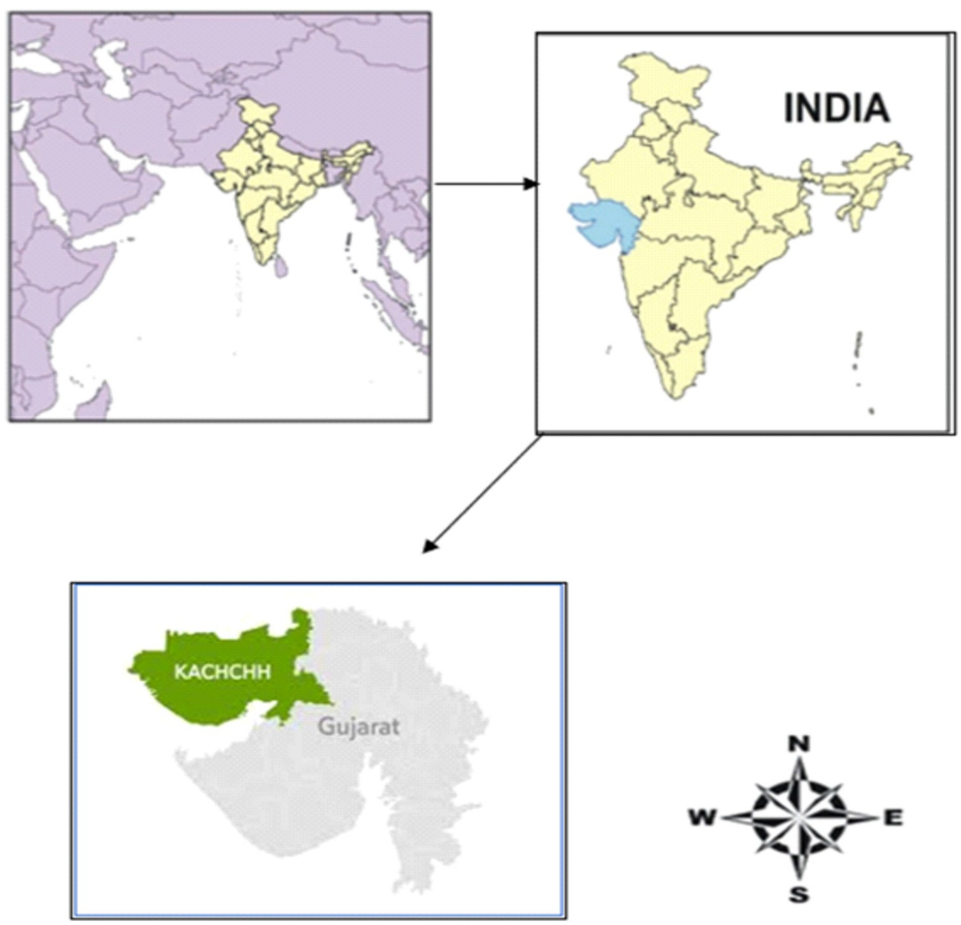

Fig 1. Study area location.

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from marine deposits of the Mesozoic and Cenozoic periods, that imparts the inherent salinity to the soil and hence the ground water [9]. With a reasonably high coefficient of variation (52%), the average yearly rainfall is 353 mm. Most of the agriculture in this zone is dependent on rains, however, after the setting-up of smaller dams under the Narmada Canal Project [10], irrigation facilities are changing the scenario from rainfall dependent to irrigation-based agriculture, but such agricultural activities are confined to some parts only.

For the present study, two types of amendment practices were chosen: traditional knowledge based organic(A1) and chemical-intensive integrated (A2). Finally, ten farms each of A1 and A2 were shortlisted. Organic manures of different types viz. farm yard compost (FYC), were used in A1, these were applied at a rate of 4 ton/hectare as a basal dose before sowing and *Jivamrit-S* [11], a concoction consisting of cow dung, cow urine, jaggery, gram flour, and soil; fermented for certain period, were also applied with watering twice, at a seven-day interval from sowing. This concoction/*jivamrit S* was prepared in composting pits [12]. The same fertilizer application was maintained for all seasons.

The integrated amended fields had a basal dose of farm yard manure (FYM) (applied at a rate of 1 ton/ha) and synthetic fertilizers as sources of Nitrogen and Phosphorus. Nitrogen based fertilizer urea (Brand Kisanmodified) was applied at a rate of 60 kg/ha as the top dressing at around 15–20 DAS (days after sowing) and Di ammonium phosphate (DAP) (Brand Kisan modified)as phosphorus source at the rate of 40–60 kg/ha was applied as the top dressing at around 15–20 DAS [12].

Collection of the samples was carried out from the rhizospheric soil of the crop upto the depth of 11 to 15 cm. The experiments were carried out at the farmers' fields (privately owned with prior permissions) and not experimental stations,hencethe crops were not restricted to one or two varieties. Only those farms were selected that followed same amendment practices for past 6 years. The sites for the experiment grew the crops wheat (*Triticum aestivum*) and castor (*Ricinus communis*) crops as Rabi (winter) and maize (*Zea mays*) and sorghum (*Sorghum bicolor)* as Kharif (summer); depending on the monsoon.Monoculture cropping pattern with minimal mechanization, where both types of fields used tractors only for ploughing purpose was adapted [12]. In all the three phases of crop, four different samples were collected per ha per field and were further pooled to form one composite sample. Analysis of these composite samples was carried out in triplicate. Soil samples were divided into two parts.First part of the sample was air dried in shade, sieved through a sieve size of 2 mm, and analyzed for physical and chemical characteristics, and the second part of this soil sample was stored at 4˚C for further microbiological analysis (12). For each crop season three phases were chosen: the initial, mid-, and post-harvest phases. In India, the cropping pattern follows two distinct seasons. From July to October is Kharif season and Rabi season is from October to March. For the present study, three Kharif (Summer crop; 2012, 2013 and 2014) and three Rabi (winter crop; 2011–2012, 2012–2013 and 2013–2014) were studied [12].

2.2. Soil analysis

The physico-chemical properties of soils were analyzed according to the standardized standard protocols, as mentioned by Alef and Nannipieri [13]. The samples were analyzed for electrical conductivity and pH in a soil suspension of ratio 1:2 (*w/v*) with a digital EC meter and glass electrode, respectively [14]; water holding capacity was determined using the gravimetric method [15]. The Keen's cup method [15] was applied for the determination of soil bulk density. The organic carbon in soil (SOC) was determined using the Walkely and Black, 1934 titrimetric determination method [16].

2.3. Statistical analysis

A general linear model (GLM) three-way analysis of variance model was adopted for analyzing the data sets for different soil physical and chemical parameters for six cropping cycles.The significant effects ($p<0.05$) were noted for running a further multiple Tukey's honestly significant difference (HSD) comparison for Least Square Means (LSM). In order to understand the magnitude and nature of the relationships between various soil parameters in different seasons and phases for both the amendments, correlation analyses were carried out. A probability level of 0.01 was considered to be statistically significant. Pearson's test of correlation (two tail) was performed. The following statistical software were used to carry out various analytical procedures: SPSS version 20 (IBM), SAS version 9.3, Microsoft Excel version 7 [12].

3. Results

3.1. Maximum Water Holding Capacity (MWHC)

Water holding capacity is an important soil parameter of great agronomic importance, which alters and affects the availability of various nutrients in solution form. The range of maximum water holding capacity (MWHC) for the six cropping seasons for amendment A1 and A2 was from 20%to 67%,with SE = ±0.64 and SD = ±12.23 (Table 1). The mean value for MWHC for the amendments was 42.76%. However, A1 had higher MWHC values (47.53%; SE = ±0.92) as compared to A2 (37.99%; SE = ±0.74) (Table 1). The mid-phase had a higher MWHC value (50.96% ± 1.18) than both the pre-sowing (39.67% ±0.91) and post-harvest phases (37.64% ± 0.82) across all the amendments and seasons. The highest MWHC value amongst the six seasons was observed in season 5 (50%).Across whole study, effect of seasons and phases on the MWHC in the two amendment systems is shown in Fig 2.

Table 1. Overall and amendment wise descriptive Statistics for different variables in agriculture systems A1 and A2.

OVERALL	Range	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
MWHC	67.00	20.00	87.00	42.7648	.64455	12.22944
BD	1.65	.15	1.80	1.1812	.02153	.40852
PH	3.35	5.78	9.13	7.7092	.03754	.71232
EC	.84	.15	.99	.6223	.00955	.18121
SOM	1.64	.04	1.72	.5934	.01853	.35161
A1	Range	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
MWHC	63.00	24.00	87.00	47.5379	.92283	12.38105
BD	1.35	.15	1.50	1.0477	.02474	.33190
PH	3.35	5.78	9.13	7.3583	.04757	.63828
EC	.81	.18	.99	.5547	.01227	.16464
SOM	1.50	.19	1.72	.7543	.02742	.36791
A2						
MWHC	48.17	20.00	68.17	37.9917	.74850	10.04212
BD	1.62	.18	1.80	1.3148	.03238	.43436
PH	2.52	6.60	9.12	8.0602	.04488	.60211
EC	.84	.15	.99	.6899	.01281	.17191
SOM	1.64	.04	1.69	.4624	.01926	.25837

A1 = Traditional Ecological Knowledge based amendment system; A2 = Chemical Intensive integrated system. (maximumwater holding capacity (MWHC), bulk density (BD), pH, electrical conductivity (EC), and soil organic matter (SOM)).

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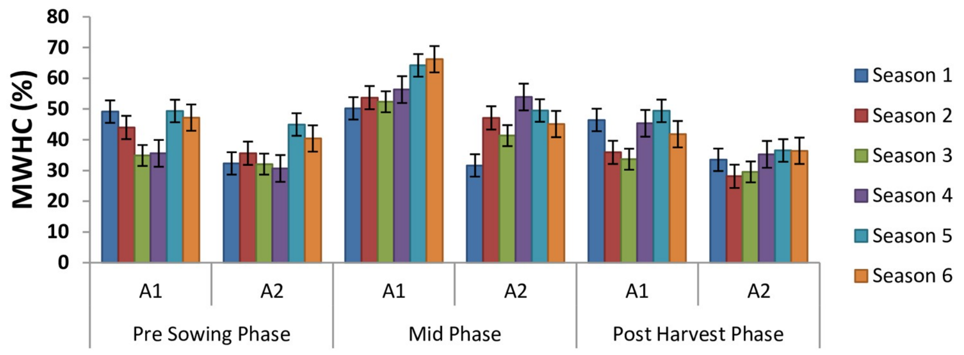

Fig 2. Seasonal variation in maximum water holding capacity (MWHC)in amendments A1 and A2 under different phases of crop growth.

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Furthermore, the GLM three-way ANOVA was applied and the F statistics (Table 2) show that there was a significant difference in the means of MWHC across the six cropping seasons (F (5324) = 16.28, $p< 0.05$). Similarly, the MWHC of soil was affected by the three phases of the crop growth (F (2324) = 93.92, $p< 0.05$), as well as the amendment practices in farm management (F (1324) = 124.70, $p< 0.05$). To further understand the interaction effect of these factors on the MWHC the interaction effects were statistically tested using F statistics. Moreover, there was a significant season by phase interaction effect on MWHC (F (10,324 = 5.79, $p< 0.05$)). Similarly, there was a significant season by amendment interaction effect (F (5324 = 3.54, $p<0.01$)) and phase by amendment interaction effect was also marginally significant (F (2324 = 3.05, $p = 0.049$)). However, the three-way interaction effect of season by phase by amendment was not statistically significant (F(10,324 = 1.67, $p = 0.08$)).

Furthermore, a Tukey's HSD test was applied to assess the pair-wise significance of the means of each of the factors and their interactions. The mean of MWHC during phase 2 (50.96%) was observed to be significantly higher than phase 1 (39.67%) and phase 3 (37.64%). However, the difference in MWHC during phase 1 and 3 was not statistically significant (Table A in S2 Text).

The means of MWHC in amendment 1 (47.53%) were significantly higher than Amendment 2 (37.99). Season 5 (48.98%) had the highest MWHC, but it was not significantly different from season 6 (46.18).The third season had the lowest MWHC (37.3%) and it was observed to be significantly lower than the rest of the seasons. The first, second, and fourth seasons did not differ significantly in their MWHC (Table A in S2 Text).

Table 2. The F statistics table for dependent variables using the general linear model(GLM)procedure.

Source	DF	WHC (%)		BD (g/cm^3)		pH		EC (dS/m)		SOM (%)	
		F Value	Sig.	F Value	Sig.	F Value	Sig.	F Value	Sig.	F Value	Sig.
Season	5	16.28	<0.0001	1.719	.130	6.68	<0.0001	10.01	<0.0001	14.349	.000
Phase	2	93.92	<0.0001	13.578	.000	34.12	<0.0001	87.65	<0.0001	198.30	.000
Amendment	1	124.70	<0.0001	54.805	.000	170.25	<0.0001	98.09	<0.0001	208.288	.000
Season × Phase	10	5.79	<0.0001	5.493	.000	3.47	0.0002	3.58	0.0002	1.96	.001
Season × Amendment	5	3.54	0.0040	4.466	.001	1.40	0.2236	0.80	0.5471	3.003	.002
Phase × Amendment	2	3.05	0.0488	.443	.643	17.27	<0.0001	1.19	0.3057	29.567	.001
Season × Phase × Amendment	10	1.67	0.0875	1.842	.053	2.73	0.0031	1.25	0.2575	2.12	.079

All the values are average of three replicates. Sig. = Significance; maximumwater holding capacity (MWHC), bulk density (BD), pH, electrical conductivity (EC), and soil organic matter (SOM).

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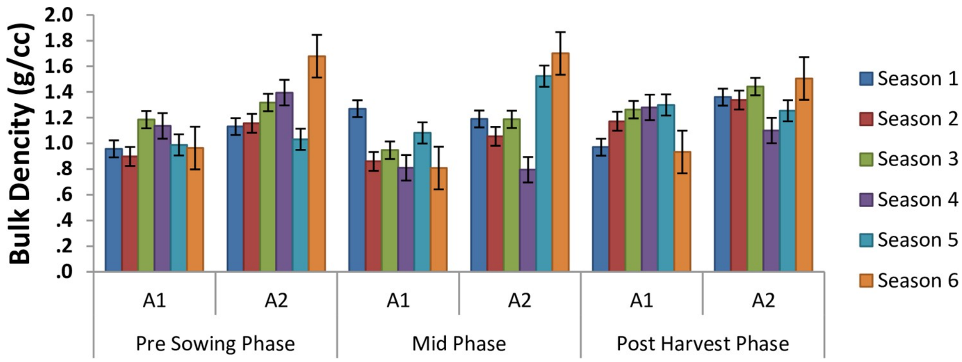

Fig 3. Seasonal variations in bulk density (BD) in amendments A1 and A2 under different phases of crop growth.

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3.2. Bulk Density (BD)

The bulk density of soil depends largely on the degree of compaction and mineral make-up of the soil. It affects rooting depth/restrictions, available water capacity, infiltration, plant nutrient availability, soil porosity, and soil microorganism activity, which in turn influence key soil processes and productivity.

The range of BD across the six cropping seasons for both the amendments A1 and A2 was from 0.15 g/cm^{3}to 1.80 g/cm^3, with SE = ±0.02 and SD = ±0.40. The mean value for BD for both the amendments was 1.18 ± 0.02 g/cm^3. It was observed that A1 had a lower value (1.04 g/cm^3; SE = ±0.02) as compared to A2 (1.31 g/cm^3; SE = ±0.03). The mid-phase had a lower BD value (1.08 ± 0.03 g/cm^3) than both the pre-sowing (1.15 ± 0.03 g/cm^3) and post-harvest phases (1.30 ± 0.04 g/cm^3) across all the amendments and seasons. The highest BD value amongst the six seasons was observed in season 6 (1.44 ± 0.05 g/cm^3) and the lowest in season 2 (1.07 ± 0.03 g/cm^3). The effect of phases and seasons on the BD in the two amendment systems is shown in Fig 3.

In the present study the statistical data show that there is no significant difference in the means of BD across the six cropping seasons ($F (5,324) = 1.72$, $p = 0.13$) (Table 2). However, the BD of the soil was affected by the three phases of the crop growth ($F (2,324) = 13.57$, $p <$ 0.05). Similarly, the amendment practices in farm affected the soil BD ($F (1,324) = 54.80$, $p <$ 0.05). In order to see the interaction effect of these factors on the BD, the interaction effects were statistically tested using F statistics which showed a significant season by phase interaction effect on BD (F (10,324 = 5.49, $p < 0.05$)). Similarly, there was a significant season by amendment interaction effect (F (5,324 = 4.46, $p < 0.01$)). However, the phase by amendment interaction effect was not significant (F (2,324 = 0.44, $p = 0.64$)). Similarly, the three-way interaction effect of season by phase by amendment was marginally statistically significant (F (10,324 = 1.84 $p = 0.05$)).

3.3. Soil pH

The soil pH is an important property which determines the microbial activity, availability of nutrients and physical conditions of soil. Many nutrients are present in an available form only at a certain pH range.

The range of pH across the six cropping seasons for amendment A1 and A2 was from 5.78 to 9.73 with SE = ±0.04 and SD = ±0.71. The mean value for pH for both the amendments was 7.71 ± 0.04. However A1 had a lower value (7.3; SE = ±0.05) as compared to A2 (8.1; SE = ±0.04). The post-harvest phase had a higher pH value (8.02 ± 0.05) than both the pre-sowing

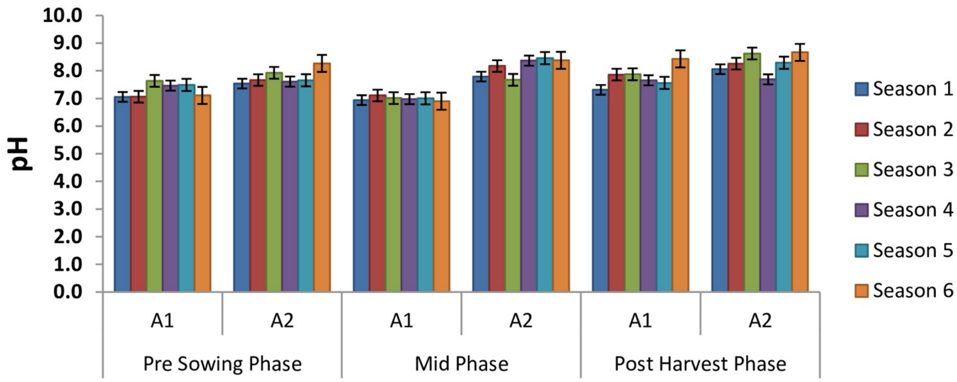

Fig 4. Seasonal variations in pH in amendments A1 and A2 under different phases of crop growth.

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(7.53 ± 0.05) and mid-phase (7.56 ± 0.07) across all the amendments and seasons. The highest pH value amongst the six seasons was observed in season 6 (7.95 ± 0.11) and lowest in season 1 (7.4 ± 0.04). The effect of seasons and phases on the pH in the two amendment systems is shown in Fig 4.

The F statistics (Table 2) show that there was a highly significant difference in the means of soil pH across the six cropping seasons (F (5,324) = 6.68, $p < 0.0001$), with the lower range of 7.3 and upper limit of 8.0 across all six seasons (SE = ±0.06). Similarly, the soil pH was affected by the crop-phases (F (2,324) = 34.12, $p < 0.0001$), as well as the amendments (F (1,324) = 170.25 $p < 0.0001$). To further see the interaction effect of these factors on the pH, the interaction effects were statistically tested using F statistics. There was a significant season by phase interaction effect on pH (F (10,324) = 3.47, $p < 0.05$)). Similarly, there was a significant phase by amendment interaction effect (F (2,324) = 17.27, $p < 0.05$)). However, the phase by amendment interaction effect was not significant (F (5,324) = 1.40, $p = 0.22$)). Moreover, the three-way interaction effect of season by phase by amendment was statistically significant (F (10,324 = 2.73, $p = 0.08$)).

3.4. Electrical conductivity

Soil EC a measure of the salinity of soil i.e. the amount of salts in soil is an important soil health indicator. The range of EC for the six cropping seasons for amendment A1 and A2 was from 0.15 dS/m to 0.99 dS/m, with SE = ±0.01 dS/m and SD = ±0.18 dS/m. The mean value for EC for the amendments was 0.62 ± 0.01 dS/m. However, A1 had a lower value (0.55 dS/m; SE = ±0.01 dS/m) compared to A2 (0.69 dS/m; SE = ±0.01 dS/m). The post-harvest phase had a higher EC value (0.74 ± 0.01 dS/m) than both the pre-sowing (0.58 ± 0.01 dS/m) and mid-phases (0.53 ± 0.01 dS/m) across all the amendments and seasons. The highest EC value amongst the six seasons was observed in season 1 (0.69 ± 0.02 dS/m) and lowest in season 5 (0.56 ± 0.02 dS/m). The effect of phases and seasons on the EC in the two amendment systems is shown in Fig 5.

On further analyses of the interaction effects (Table 2), the season by phase interaction was significant (F (10,324) = 3.58, $p < 0.05$). In order to analyze where the difference in EC existed and its quantum, a post hoc Tukey's HSD table (Table D in S2 Text). was analyzed, which showedthatRabi 2013–2014 (season 5) had the lowest EC values (0.56 ± 0.02 dS/m). When crop phase was considered it could be observed that irrespective of the crop season, the mid-phase of the crop cycle had a lower EC (0.53 dS/m) than the pre sowing (0.58 dS/m) and post-harvest phases (0.74 dS/m), with SE values 0.01.

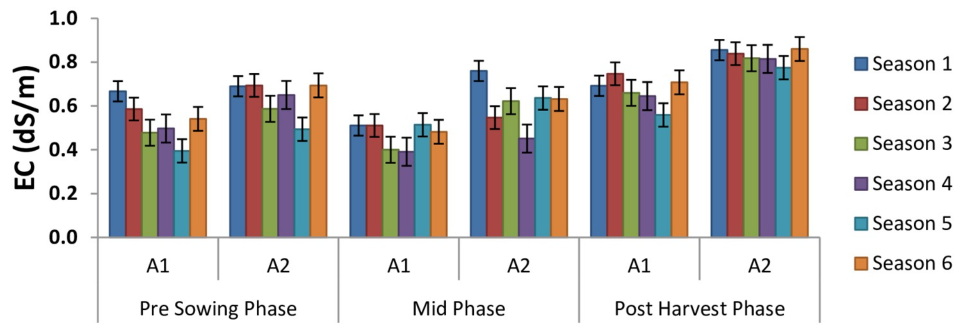

Fig 5. Seasonal variation in electrical conductivity (EC) in amendments A1 and A2 under different phases of crop growth.

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3.5. Soil Organic Matter (SOM)

Soil organic matter positively affects cation exchange capacity, structure aggregation, water holding capacity, and microbial activity. It is the major soil component that affects the availability and mobility of major and minor nutrients to plants. Soil organic carbon is a source of plant nutrients, forming the most important renewable source in soil [17].

The range of SOM for the six cropping seasons for amendment A1 and A2 was from 0.04% to 1.72%, with SE = ±0.01% and SD = ±0.25%. The mean value for SOM for the amendments was 0.59± 0.01%. Amendment A1 had a higher value (0.75%; SE = ±0.01%) compared to A2 (0.46%; SE = ±0.02%). The mid-phase, as expected, had a higher SOM value (0.91± 0.01%) than both the pre-sowing (0.52± 0.01%) and post-harvest phases (0.45± 0.02%) across all the amendments and seasons. The highest SOM value amongst the six seasons was observed in season 1 (0.81± 0.03%) and the lowest in season 5 (0.50 ± 0.04%). The effect of phases and seasons on the SOM in the two amendment systems is shown in Fig 6.

3.6. Corelation studies

A significant positive correlation ($p < 0.01$) of MWHC with SOM was observed; however, a significant negative Pearson's correlation coefficient ($p < 0.0I$) with pH, EC, and BD (Table 2) was observed. A significant positive correlation ($p < 0.01$) of BD with pH and EC was seen. However, BD had a significant negative correlation with SOM ($p < 0.01$). A significant positive correlation ($p < 0.01$) of pH was seen with EC. However, pH had a significant negative

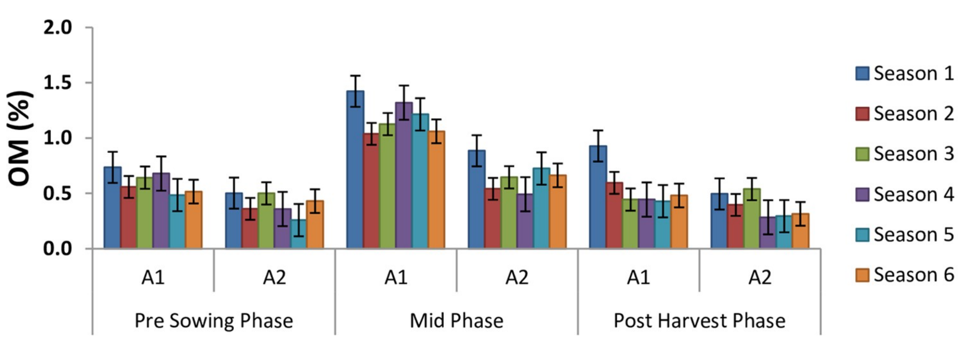

Fig 6. Seasonal variations in Organic Matter (OM) in amendment A1 and A2 under different phases of crop growth.

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Table 3. Pearson's Correlation matrix (two-tail) for the variables.

	WHC	BD	Ph	EC	SOM
WHC	1	−0.247**	−0.303**	−0.412**	0.416**
BD	−0.247**	1	0.234**	0.279**	−0.178**
pH	−0.303**	0.234**	1	0.285**	−0.347**
EC	−0.412**	0.279**	0.285**	1	−0.310**
SOM	0.416**	−0.178**	−0.347**	−0.310**	1

** Correlation is significant at the 0.01 level (two-tailed); water holding capacity (WHC), Bulk Density (BD), pH, Electrical Conductivity (EC), andSoil Organic Matter (SOM).

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correlation with SOM ($p < 0.01$). EC had a significant negative correlation with all parameters (Table 3). The impact of SOC on various parameters mentioned in study is depicted in Fig 7A–7F.

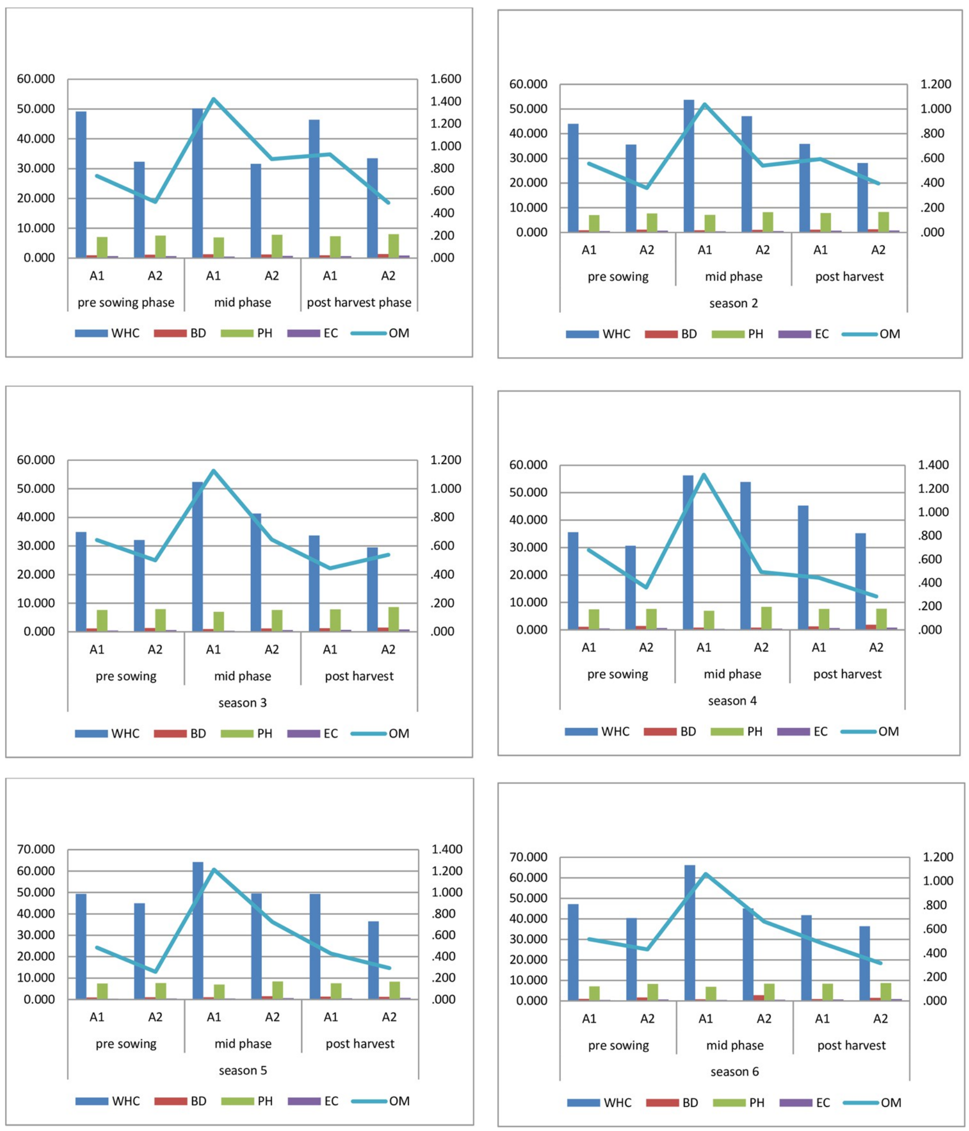

Fig 7. A-F: Trendline of Soil organic matter with respect to WHC, BD, pH and EC for season 1–6

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4. Discussion

The physico-chemical soil parameters are the building blocks that impart to any soil system its true essence. In that respect, the comparative analysis of the various soil parameters of water holding capacity, salinity, pH, and bulk density indicate that the organic amendment practices are competent in maintaining these parameters on a positive scale as compared to the chemical input-based systems—this was fortified on the basis of the results of the three crop phases of pre sowing, mid-phase, and post-harvest for the six cropping seasons studied. This was in agreement with similar studies in other areas [18].

The water holding capacity of a soil is an important agronomic property. Soils that hold higher amounts of water are found to be least subjected to losses of nutrients due to leaching. Soil water provides a soluble micro environment of dissolved nutrients that are available easily for plant uptake and acts as a medium through which the exchange of dissolved nutrients occurs. It is primarily dependent on soil texture and the organic matter content of the soil. The results demonstrated that the cropping phase, season, and the amendment practices, combinedly affected the MWHC of the soil, and the interaction statistics show that the effect of amendment on the MWHC depended on the cropping season and phase, and vice versa held true. Similarly, the effect of season on MWHC was determined by the phase of the cropping cycle.

The results show that across all seasons, A1 had higher MWHC than A2. Significantly higher values of MWHC, even during stressed conditions like drought (season 2 and 3), indicate that organic amendments might be responsible for maintainig soil health even during stressed conditions.Themid-phase of the crop cycle had a higher MWHC irrespective of the season and amendments, probably because the mid-phase of the crop cycle is irrigated more frequently than the pre- and post-phases, accounting for higher MWHC during the mid-phase. However, on analyzing the interaction effects, phase 2 of amendment 1 (A1) had the highest MWHC (57.16%), and it was significantly higher than phase 2 of amendment 2 (44.76%). The irrigation water during the mid-phase of the crop cycle was able to maintain MWHC at good levels in both the agricultural amendment practices, but during the post-harvest phase, i.e., phase 3, the organic amendments were able to retain their MWHC in spite of the lack of crop cover to prevent soil moisture evaporation. This could be attributed to humic substances in organic soils [19]. Phase 2 of season six in A1 had the highest MWHC (66.20%) amongst all possible three-way interactions of the season, phase, and amendment. A higher than average rainfall was observed in the year of 2013 (653 mm spread across 25 rainy days), but 90% of this total precipitation occured in the month of September, owing to which the Rabi 2013–2014 (season 5) had a better MWHC in both the amendments, and due to the same reason, phase 2 of A1 of season 6 (Kharif 2014) had the highest MWHC, probably owing to higher water retention by the organic compounds in soil.

Water has an important role in the soil and plant growth relationship. Organic matter in amendment A1 was able to impart better soil structure and aggregate stability, which potentially increased the soil water holding capacity. This is in affirmation with our correlation studies. Several studies reported improvement of water transmissionand soil structureproperties through manure application [20,21]. Prasad and Sinha (1980) [22] have shown in their study that increased application of farm yard manureimproved the MWHC of soil, whilst the higher dose of only chemical fertilizers decreased the MWHC compared to the control. In a similar studyby Sharma et al., (2000) [23] revealed that the water holding capacity of soil was significantly improved by the application of FYM residues due to the build-up of soil organic matter (SOM) and improvement in soil structure. A computer simulation model study by Leu et al. (2010) [24] recommended organic matter application for enhancing the soil MWHC in areas with low rainfall.

The bulk densityofsoilgives an appropriate estimation of the aeration and permeability of the soil. The lower the bulk density, higher is the permeability. Bulk density is dependent on the structural variabilities of the soil. The results of the present study show that the season had no effect on the BD of the soil; however, the amendment practices and phase affected the bulk density of the soil, and the interaction statistics show that the effect of season on the BD depended on the cropping phase and type of amendment system followed. For organic amendment all six seasons had no significant differences in the BD, but for amendment 2 the BD in seasons 1, 2, and 5 was significantly lower than seasons 3, 4, and 6 which indicates that the organic inputs helped the soils in buffering against the effects of season as compared to the significantly fluctuating bulk density values in chemical input soils. Our study has shown that amendments with organic inputs had a lower bulk density in comparison to amendments with no or very few organic inputs; this can perhaps be attributed to a better soil structure, as evidenced from the increase in the MWHC of soil in organically amended soils. Srikanthet al. (2000) [25] found a significant decrease in bulk density of soil after the harvest of the crop in the soil amended with compost, as compared to the soil with inorganic fertilizer. Similarly, Sharma et al. (2000) observed a significant BD reduction in FYM residue-incorporated soils. TheapplicationofFYMalong with composted coir pith reduced the bulk density appreciably over control [26]. In Vertisols, a significant reduction from 1.32 to 1.28 g/cm^3 in bulk density in one season itself was observed [27].

The effect ofthepH of soil is great on the solubility of nutrient or minerals. For a nutrient to be plant available, it must be dissolved in the soil solution. The soil pH can also influence plant growth by its effect on beneficial micro-organisms' activity [28]. It determines the availability of various nutrients,asanexample,phosphorus is never readily soluble in the soil but is found in its fixed forms [29]. The results show that the season, phase, and the amendment practices used all affected the pH of the soil and the interaction statistics show that the effect of amendment on the pH depended on the cropping phase, but it was independent of the cropping season, and vice versa held true. The mean pH range of the studied soils fell between 7.5 and 8.5; this shows that the Kachchh area in general has an alkaline soil pH, which may be attributed to the parent rock material and the tectonic activities prevalent in the past and present. The Rabi season of 2012–2013 (crop season 3) had the second highest cumulative pH values (7.79 ± 0.06), and this shows how drought modifies the soil salinity levels and henceforth the pH values as well. The year of 2012 had just 209 mm average annual rainfall distributed around 19 days, which affected Rabi 2012–2013. Season 1, with pH 7.44, had significantly lower values, which can be attributed to the above average annual precipitation in the preceding years 2010 (922 mm) and 2011 (703 mm). The post-harvest phase of the cropping cycle had the highest pH value (8.02± 0.05), irrespective of the amendment practice adopted or the prevalent season; this is because once the crop is harvested the lag phase of crops does not receive irrigation water, and coupled with exposed land without crop cover, the soil water evaporation rate is the highest during this phase, hence a high salt content and increased pH. Tisdale et al. (1993) [28] have also shown change in pH over long-term fertilization experiments. Changes in soil pH over a period of time occur by the addition of sources of acidity, like hydrogen and aluminium ions, or by the displacement of cations. In organic amendments, increases in soil Ph could be attributed to the organic products decomposition that results in the release of Ca and Mg nutrients, which could slightly increase the pH [30]. Organic manures can cause an increase in the buffering capacity of soils, preventing swings in pH values, arising due to seasonal variations [31]. In A1 over a period of time the pH increase was not as profound as compared to amendment A2, attributable to the alkaline nature of chemical fertilizers, which may have caused soil pH to increase in A2 over a period of time. A study to know the effect of FYM on soil pH showed that there was a decrease in pH, with increase of FYM significantly, perhaps due to organic acid production during its decomposition [27].

The electrical conductivity of soil affects crop suitability, agriculture yield, plant nutrient availability, and the soil microorganisms activity [32]. It is affected by irrigation, land use, and the application of fertilizer and compost. In the present study it was found that the effect of season, phase, and the amendments on the electrical conductivity of the soil was very highly significant (p <0.0001). Interaction studies showed that the season by phase interaction was significant. However, the season by amendment and phase by amendment effect did not yield significant F values. This shows that EC of the soil is definitely affected by the prevalent management practices adopted by the farmers, irrespective of the seasonal conditions and crop phase. Rabi 2013–2014 (season 5) had the lowest EC values (0.56 ± 0.02 dS/m), and this is in affirmation with the fact that this cropping season had above average annual precipitation (541 mm). When crop phase was considered it could be observed that irrespective of the crop season, the mid-phase of the crop cycle had lower EC than the pre-sowing and post-harvest phases. This is due to the fact that duringthemid-phase, crop cover is sufficient enough to prevent soil evaporation rates and the land is adequately irrigated, which dilutes the concentration of the salts in the soil and consequently the soil EC values. The relatively low and stable EC levels in organic amendment indicate that the use of animal manures has not resulted in increased salinity. Inorganic chemical fertilizers increased the soil salinity in A2, specifically in areas as this, that face salinity issues [31,33]. Increased levels of salinity due to the input of chemical amendments in soils can pose a threat to the sustainability of the soil in the long run. Rathod etal. [34] reported that the EC reduced significantly by the application of FYM. Singh et al. [32] in theirstudy demonstrated the effect of the application of chemical fertilizers and farm yard manure on soil properties and found a substantial decreaseintheEC and pH of the soil, and related this to the decomposition and mineralization of organic matter. Similarly, Bajpai et al. [35] reporteda decrease in pH and EC at later stages of decomposition with the application of organic farm manures. Lower EC in organic amendments in our study is in affirmation with Gajda and Martyniuk [36] and Freitas et al. [37].

SOM is one of the most significant soil quality indicators; it has positive effects on soil physical properties and promotes water infiltration [19]. It is directly related to the, maintenance of soil structure, mineralization of organic matter, and nutrient availability. It could be discerned from the present study that the effect of season, phase, and the amendments on the SOM of the soil was very highly significant. Further analyses of the interaction effects for SOM revealed that all the interactions of season by phase, season by amendment, and phase by amendment were significant. The mid-phase of the crop cycle is irrigated more frequently than the pre- and post-phases, and also organic manures are added as a second batch just before the beginning of the mid-phase of the crop, so this could account for the higher SOM during the mid-phase. Organic amendments had substantially higher SOM as compared to chemical-based farming systems. This was quite an obvious observation, because higher inputs of the organic manures in A1 contribute to greater carbonaceous material, which tends to increase the SOM of soil. The irrigation water during the mid-phase of crop cycle is able to maintain soil moisture content to good levels, which in turn helps in the decaying process in both the agricultural amendment practices, but during the post-harvest phase, i.e., phase 3, the organic amendments were able to retain their MWHC in spite of the lack of crop cover to prevent soil moisture evaporation. This could be attributed to humic substances in organic soils.

It was evident that cropping seasons affected by drought—season 2 (Kharif 2012) and season 3 (Rabi 2012–2013)—had higher SOC levels in A1 than A2. This indicates that the organic inputs are an important precursor in preparing drought resistant soils; moreover, in ecoregions such as Kachchh, where droughts are a frequent phenomenon, organic-based farming systems hold a key to long-term goals of ecosystem sustainability.

The carbonaceous material in organic manures contributes to SOC after decomposition. Schjonninget al. [38] showed that after five–six years, different land management will influence SOM level. This is in accordance with the finding that microbial activities in soilarevital for nutrient turnover, and soil organic matter levels and thesoillong-term productivity of are significantly enhanced by the use of organic inputs [39]. Mastiholi [40] reported that post the harvest of sorghum, the organic carbon content of soil was higher due to the application of vermi-compostas an additive, than fertilizers alone. Studies conducted to determine the long-term implications of the continuous use of fertilizers and manures on the status of soil fertility have shown that organic matter of the soil was significantly higher over the years due to the application of organic manures [41]. Soil organic matter (SOM) is the important indicator of soil health, which is strongly connected to agricultural management [18, 42]. SOM is a major terrestrial pool for nutrients viz. N, P, C, and S, and the availability of these elements are constantly being changed by microbial mineralization and immobilization [43]. The importance of improved SOM or soil organic carbon (SOC) lies in the fact that it increases available nutrients, improves soil physical properties, and hence conserves water. These improvements should ultimately lead to an increase in crop yield due to the greater biomass [44,45,46].The climate change issues have raised several questions on present agriculture systems and it is high time that we developed climate smart agriculture systems [47, 48]

5. Summary and conclusions

Physico-chemical soil attributes, such as maximum water holding capacity, bulk density, electrical conductivity, and pH have shown significant differences in the amendment systems. The application of organic manures and concoctions like *Jivamrit* certainly had higher SOM, which rendered better soil structure and stability, which in turn affected the MWHC, which was significantly higher in A1 across phases and seasons than A2. Probably, for the same reason, amendments with organic inputs had a lower bulk density compared to amendments with no or very few organic inputs. Reduction in pH and electrical conductivity in A1 may be ascribed to increased amounts of organic matter as a result of the addition of green manures and organic concoctions. In the drought-affected season 2 (Kharif 2012) and season 3 (Rabi 2012–2013) this trend was followed. This clearly shows that salinity endurance and drought resistance are remarkable features of organically-amended soils, and this resilience to drought is achieved over continual usage of organic manures. In the present scenario—where chemical fertilizers had already shown detrimental effects in the form of long-term soil fertility depletion, health concerns occurring due to chemical inputs to both the growers and consumers, environmental deterioration—ecologically sustainable agri-management systems are not a choice but a necessity. This is a first of its kind study to assess the certain important physico-chemical properties in traditional versus chemical-based agri-management systems in natural fields of semi-arid tropics. Studies that incorporate yield data would be complimentary to this and are underway. The arid and semi-arid tropics are highly prone to stressors like drought, highly erratic rainfall patterns, and salinity, and the present study advocates the supremacy of TEK-based agri-management systems in soil sustainability for maintaining soil fertility in the long run.

Supporting information

S1 Text. Table A: F statistics table for dependent variable MWHC using the GLM procedure. Table B: F statistics table for dependent variable BD using the GLM procedure. Table C: F

statistics table for dependent variable pH using the GLM procedure. Table D: F statistics table for dependent variable EC using the GLM procedure. Table E: F statistics table for dependent variable SOM using the GLM procedure.
(DOCX)

S2 Text. Table A for MWHC (maximum water holding capacity). Table B for BD (bulk density). Table C for PH. Table D for EC (electrical conductivity). Table E for SOM (soil organic matter)
(DOCX)

S1 Data. Raw data for various parameters across the season, phase, and amendment.
(XLSX)

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