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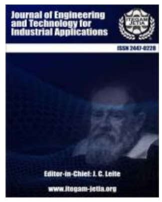

RESEARCH ARTICLE OPEN ACCESS

COST OF RAISING SOIL ORGANIC CARBON FOR A QUARTER-CENTURY IN A SEMI-ARID TURKISH PLAIN: HARRAN PLAIN

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ABSTRACT

For decades, scientists have been studying the role of soil organic carbon (SOC) in the environment. SOC in agricultural lands may rise if conditions such as adequate soil water retention, balanced nutrition, minimal tillage, crop rotation, added organic residues, and fertilizers are met. However, implementing all of these measures takes a long time, large expenditures, and enormous effort, particularly in semi-arid and arid lands where organic matter accumulation is difficult; such depletion can be attributed to oxidizing soil conditions. As a result, the long-term cost of increasing organic carbon is uncharted territory for policymakers and land users. In this context, the Harran Plain of SE Turkey, which borders the arid lands of Northern Syria, provides an opportunity to calculate the cost of a unit increase in organic carbon as a result of a drastic change in cultivation over 30 years of irrigation. We attempted to reveal the price of organic carbon increase in a semi-arid region that is far from sustainable agricultural practices after irrigation in this study. The organic carbon in the plain increased by 14,93 t. C/ha i.e., 0.28% on average which is well-below COP 21 initiative of 0.4% annual increase. When the irrigation network investment expenses, annual fertilizer use, and labor need for agricultural production were calculated for the entire Harran Plain from 1995 to 2018, it was calculated that one-ton C/ha in the Harran Plain costs US$491,19. We can estimate that the total SOC increase over 167.400 ha cost around $1,047,029,777. This revealed that increasing SOC in semi-arid climates is an expensive goal.

I. INTRODUCTION

Climate change, desertification/land degradation, and biodiversity loss in the ecosystem are posing serious risks to the planet, which humanity have never seen at such extreme levels [1], [2]. As of November 2019 (https://www.co2.earth), atmospheric CO_2 levels are above 417 ppm. Land degradation/desertification of the Earth's surface affects about half of the world's population (3.2 billion) [3], and more than one million living species are currently threatened with extinction [4]. Although the total impact of these problems will be felt more acutely in developing and low-income countries, migration from affected regions/countries to developed countries will magnify the problem's global impact. As a result, enhancing SOC is seen as the most important instrument in combating the aforementioned issues. Several successful strategies, including as crop rotation, raising soil moisture content, mulching, and green manuring, have been demonstrated to improve SOC; nevertheless, the precise computation of SOC increase cost as a result of these treatments is not well-defined, as this study attempts to demonstrate. However, financial cost of land degradation, in contrast to soil organic carbon loss, is well-studied, despite the fact that they are strongly linked.

Nkonya et al. (2016) reviewed 12 research on the costs of land degradation and found that values had risen from \$17.58 billion in 2007 to \$9.4 trillion in 2007. Due to reduced ecosystem functioning, land degradation alone costs \$6.3 trillion per year in ecosystem service value [5]. The social cost of an additional ton of carbon resulting from CO2 emissions or its equivalent carbon was assessed by Nordhaus (2017) at \$31. Since worldwide CO2 emissions hit 36 billion tons in 2018, this equates to \$36 billion [6]. Tol (2018) analyzed 27 studies from various parts of the world and concluded that a 2.5°C increase in global temperature would result in a 1.3 percent drop in global per capita income [7]. According to the Global Soil Partnership (2017), the erosion of the 75 billion tons (Pg) of arable soils around the world costs \$400 billion each year. If this volume of loss were spread as a 15-cm thick soil layer, it could cover 34 million ha of land, which is close to Germany's 37 million ha land size. Increasing harvest frequency to compensate for yield losses in degraded soils resulted in higher pesticide use, contributing to pollution [8]. In China, it is estimated that \$859 million will be required to clean the country's polluted soils [9]. Turkey is not an outlier in a globe beset by climate change, desertification, and loss of biodiversityr [10]. According to Akça and Çullu (2015), soil sealing is the major hazard to arable soils in all of the country's geographic regions, which is also corroborated by Kapur et al. (2019)'s study, which mentions soil sealing as a statewide land degradation driver [11], [12]. Turkey was rated 15th in the world in terms of CO^2 emissions, with 428 Mt. [6]. Using an analytical hierarchy process model, Türkeş et al. (2019) created a desertification vulnerability and risk assessment for Turkey, estimating that areas under moderate and high desertification risk account for well over 75% of the country's entire territory [13].

The global thresholds for preventing desertification, land degradation, drought, climate change, and biodiversity loss appear to have already been exceeded, and mitigation and adaptation appear to be the only options for securing humanity's future [14], [15]. Researchers proposed several techniques decades ago for mitigating and adapting to climate change, desertification, and land degradation. Researchers proposed several techniques decades ago for mitigating and adapting to climate change, desertification, and land degradation, such as water harvesting, water retention in a soil profile, conservation tillage, nutrient management, green manuring, crop residue management, afforestation, and terracing, when the threats were not extreme as today [16]–[19]. It is not surprising that organic carbon, due to its unique dynamics in soil ecosystems, is the main asset in the success and evaluation of many of these methods [20]. Orr et al. (2017) defined the scientific conceptual framework of the UN's land degradation neutrality (LDN) approach and recognized soil organic carbon (SOC) as one of the main indicators of LDN monitoring. Several SOC maps are produced at the local, regional, national, and global levels to assess the effects of land use, climate, and vegetation on soil carbon [21], [22].

Researchers are attempting to establish a SOC threshold level, such as Hiederer and Köchy (2012), who established 3 percent organic carbon as a baseline for calculating the bulk density of fertile soils. While Lal (2015) suggested increasing the SOC pool to above 10 to 15 g/kg to stimulate soil restoration activities, Johannes et al. (2017) suggest a SOC/clay ratio of 1:10 other than the mass of carbon for obtaining a good structure independent of soil management. Although a 0.4 percent/year increase in SOC was set as a global goal at the Paris COP21 meeting, there is still no fixed target value for SOC because numerous factors such as climate, soil properties, and land use practices control SOC dynamics [21], [23], [24].

Aside from these, the increase/sequestration of soil carbon is calculated as the gains from emissions reduction [8], and studies on the cost of raising/sequestering organic carbon in the soil are relatively few [25] because monitoring soil carbon, particularly in semi-arid regions, requires decades because increasing SOC requires long-term irrigation and nutrient inputs [26].

In this study, we attempted to assess each unit of carbon increase in the 167.400 ha Harran Plain (Şanlurfa, SE Turkey) from 1995 to 2018 by assessing infrastructure and ultrastructure investments, fertilizer, and labor costs, which we believe will improve current knowledge on the economics of land degradation rehabilitation even current land use in the Plain is unsustainable as a result of a yield-oriented production approach that ignores natural resource quality enhancement.

II. MATERIALS AND METHODS

The study relied on two data sources. The first is the organic matter values of 25 soil series defined in a soil survey conducted in 1998 before to the initiation of irrigation. The second set of data includes organic carbon data from 406 soil samples that will represent the entire plain in 2018, comprising resamples of 28 locations of the 1988 soil survey.

II.1 MATERIALS

The Harran Plain, located in SE Anatolia at (38°47′–39°15′ E and 36°40′–37°21′N), is one of Turkey's largest irrigated plains, with an average temperature of 18.8°C and an annual rainfall of about 442 mm. Rainfall is irregular and mostly falls in the winter, with almost no rain falling between June and September (DM, 2011). It has a slope of 530 meters in the north and 358 meters in the south (Figure 1).

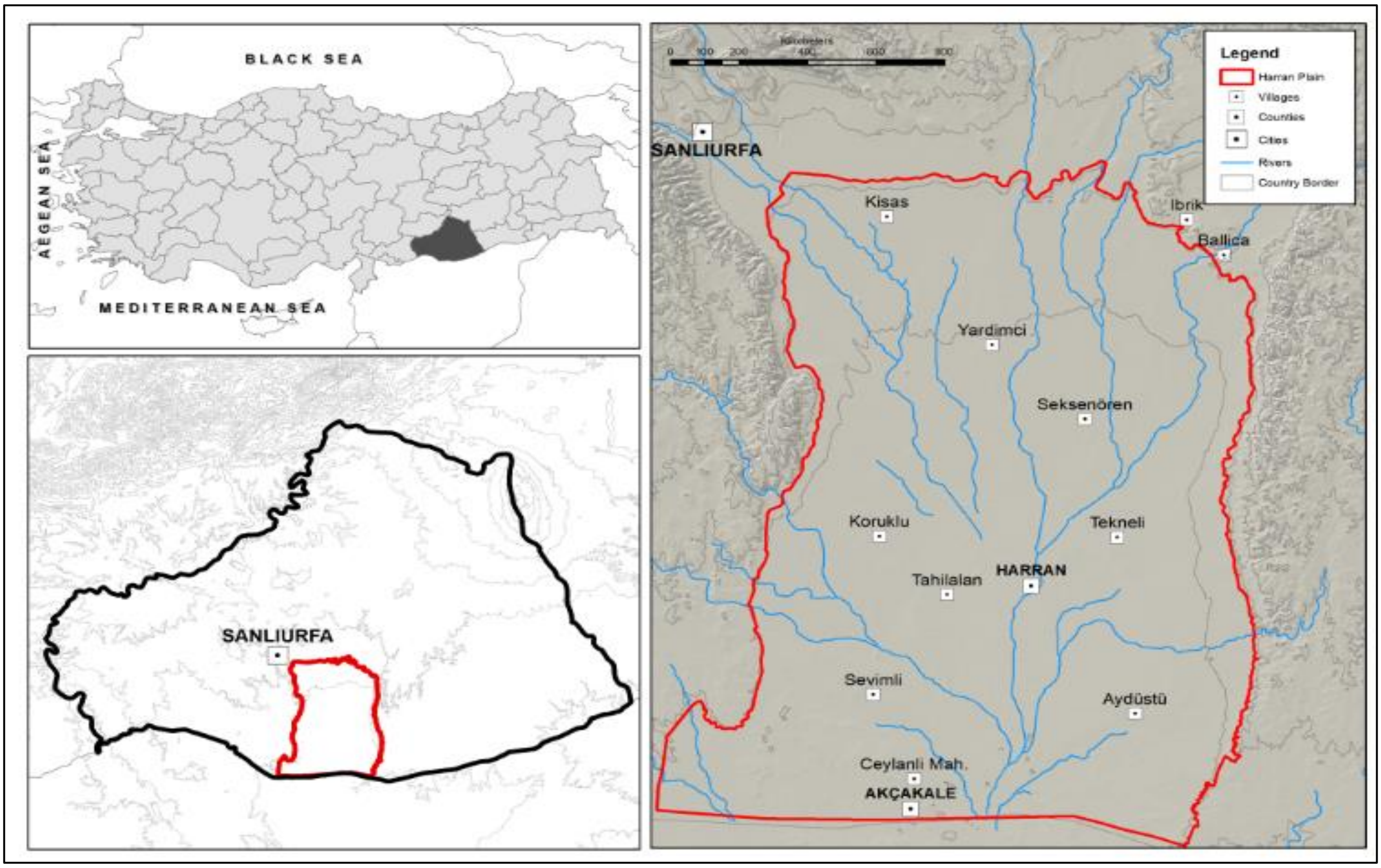

Figure 1: The location of Harran Plain.
Source: Authors, (2022).

The Turkish government initiated a detailed soil survey in 1988 prior to the construction of an irrigation network within the framework of GAP (Turkish acronym for Güneydoğu Anadolu Projesi-Southeastern Anatolia Project), with the goal of irrigating 1.8 million ha of land. The survey followed the 1975 Keys to Soil Taxonomy [27] and Soil Maps of the World [28]. Dinç et al. (1988) defined 25 soil series classified as Aridisols (now Inceptisols of Keys to Soil Taxonomy 12th edition due to revisions in soil moisture regime), Vertisols, and Entisols during the soil survey (Table 1) [29]. In addition to the 25 soil series, three varieties of the Harran, Sırrın, and Cepkenli series were defined, bringing the total number of 1988 soil series to 28. Soils of the plain are mainly clayey with high calcium carbonate (>%5) and pH above 7.5 [29].

Table 1: Soil series classification according to Soil Survey Staff (1975) and FAO-UNESCO (1974).

Soil Series	Soil Survey Staff (1975)	FAO-UNESCO (1974)
Fatik	Lithic Torriorthent	Lithosol
Gülveren	TypicPaleorthid	Calcic Xerosol
İkizce	VerticTorrifluvent	CalcaricFluvisol
Bellitaş	TypicTorrifluvent	CalcaricFluvisol
Kap	TypicPaleorthid	Calcic Xerosol
Akören	TypicCalciorthid	Calcic Xerosol
Gündaş	VerticCalciorthid	Calcic Xerosol
Karabayır	VerticCalciorthid	Calcic Xerosol
Harran I	VerticCalciorthid	Calcic Xerosol
Harran II	VerticCalciorthid	Calcic Xerosol
Sırrın I	VerticCamborthid	HaplicXerosol
Sırrın II	VerticCamborthid	HaplicXerosol
Beğdeş	TypicTorrert	Chromic Vertisol
Uğurlu	PaleoustollicTorrert	Chromic Vertisol
Gürgelen	TypicCalciorthid	Calcic Xerosol
İrice	TypicCalciorthid	Calcic Xerosol
Urfa	TypicTorrifluvent	CalcaricFluvisol
Konuklu	TypicCamborthid	HaplicXerosol
Kısas	TypicTorrert	Chromic Vertisol
Bozyazı	TypicTorrert	Chromic Vertisol
Çekçek	TypicTorrifluvent	CalcaricFluvisol
Sultantepe	VerticCalciorthid	Calcic Xerosol
Akçakale	TypicTorrert	Chromic Vertisol
Meydankapı	TypicCalciorthid	Calcic Xerosol
Ekinyazı	TypicCalciorthid	Calcic Xerosol
Hancığaz	TypicCalciorthid	Calcic Xerosol
Cepkenli I	TypicGtypsiorthid	GypsicXerosol
Cepkenli II	TypicGtypsiorthid	GypsicXerosol

Source: [29].

In 2018, 404 disturbed soil samples representing the entire plain were collected from 20 cm using global positioning system coordinates, 28 of which were resampled from 1988 soil survey points (Figure 2). 50 undisturbed soil samples were collected for bulk density analyses [30] and soil carbon mass analyses. Soil organic carbon (SOC) was calculated as tons per hectare (t.C.ha-1) for each point by calculating volume weights during laboratory analysis. The soil sample point values were integrated into a GIS environment using ArcGIS 10.1 to map the changes in SOC from 1988 to 2018 (Figure 2).

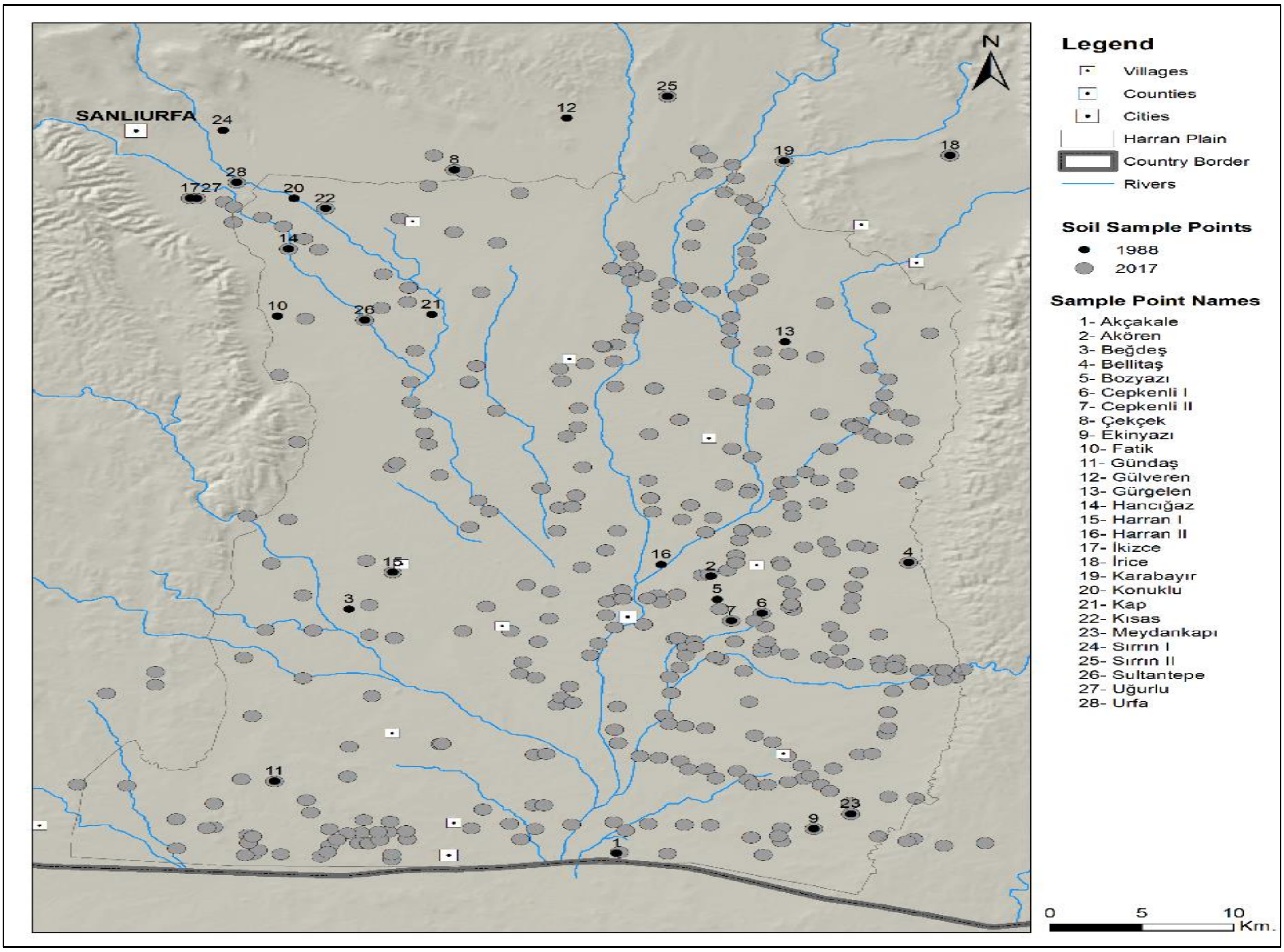

Figure 2: Soil sampling points.
Source: Authors, (2022).

II.2 METHODS

II.2.1 Soil Analyses

Soils were air-dried and sieved to a size of 2 mm. Shimadzu TOC-L CPN SSM 5000A/ASI was used to measure total organic carbon using 10 mg samples. A total of 28 samples collected in 2018 from the same points of the 1988 survey were analyzed by the Walkley-Black wet digestion method for calibration and comparison of soil organic matter with TOC results [30]. Furthermore, soil pH, EC, $CaCO^3$, and texture contents were analyzed using the Soil Survey Staff Laboratory Manual (2014) to assess any changes since 1988, as these properties affect SOC [31]. The SOC was estimated and integrated with the ESRI (2008) [32], [33] GIS software using time series analysis (1988 and 2018). Based on the distribution soil series given by Dinç et al., (1988) the georeferenced soil organic carbon levels were evaluated and mapped using geostatistical techniques [29], [34].

II.2.2 Soil Organic Carbon

SOC is calculated by comparing the organic matter and organic carbon of the 1988 and 2018 values as the percentage of organic matter because the 1988 data were expressed in percentage organic matter in soils (Table 2) but were converted to $t.C.ha^{-1}$ (area in ha x soil depth in m x bulk density in $gr.cm^{-3}$x %SOC) for a better understanding of the Harran Plain soil organic carbon. Although Pribly (2010) argued that using the value of 1,72 (assuming that 58 percent of organic matter is made up from carbon) when calculating organic carbon from organic matter in soils is a low value for most soils around the world, we chose to use this value in order to compare our study with other SOC studies. The equation used is as follows: Organic matter (%)=Total organic carbon (%) x 1.72 [35].

II.2.3 Economic Analyses

II.2.3.1 Infra and Ultrastructure Costs of Irrigation Project

This study attempts to demonstrate the cost of a unit of soil carbon increase in the Harran Plain following massive irrigation investments since 1995, i.e., when water from the Atatürk Dam was delivered to the Harran Plain via two parallel irrigation tunnels, each 26 km long with a diameter of 7.62 m and a construction cost of $585 million.

Irrigation investment calculations are complicated and can vary depending on the water source, whether the resource is used for other purposes, water transmission structures, and irrigation type [36], [37]. Thus, the share of irrigation was computed proportionally when calculating the irrigation investment expenses for the Harran Plain. In November 2019, the costs were calculated using the Central Bank's inflation calculation method [38], using pricing values obtained from the Ministry of Industry and Technology [39] and DSI (2017), as well as the General Directorate of Water Management [40], [41]. As of 2019, when this study was written, the exchange rate of 5.751[1] Turkish Lira (TL) to one US dollar was used as the base value for representing investment costs in US dollars.

II.2.3.2 Land Management Costs

The amount of fertilizer and irrigation needed for cultivation, as well as the field labor costs, were obtained through face-to-face survey interviews with 52 Harran Plain farmers who kept a record of their annual expenses. The interviews were evaluated using the purposeful sampling methodology [42]. Field labor expenses are also included in the calculation because they are the monetary equivalent of the human labor required for agricultural production. In other words, it is a cost of production that has an indirect impact on the SOC level.

III. RESULTS AND DISCUSSIONS

In short, except in saline areas, increased biomass as a result of irrigation and fertilization in the Harran Plain causes soil organic carbon to rise.

III.1 LAND USE

The Harran Plain soils, mainly clayey with high $CaCO_3$ and pH above 7.5, have been cultivated for decades for wheat and cotton, and maize has been the major cultivated crop for the last 15 years. In comparison to wheat, cotton, and maize production, vegetable and horticultural production is negligible. Before irrigation, cotton received almost no chemical fertilizer in the plain, while wheat received 650 kg. ha^{-1} fertilizer containing diammonium phosphate—$(NH_4)_2HPO_4$ (18% N -46% P) and urea—CH_4N_2O-(46% N). Following irrigation in 1995, maize, which was given approximately 980 kg ha^{-1} fertilizer similar to cotton, was introduced to the Harran Plain. Irrigated cotton receives 917.5 kg.ha^{-1} of fertilizer, while irrigated wheat receives 650 kg.ha^{-1}, all raising groundwater nitrate content above 50 mg/L [43]–[46]. If you don't care about environmental costs, you can say that using nitrogen fertilizers in combination with irrigation increased crop biomass, which in turn would have a positive effect on soil organic matter in the Harran Plain.

III.2 SOIL ORGANIC CARBON

Harran Plain's SOC has risen steadily since 1988, however the maximum value of 54.91 t C ha^{-1} in 2018 is lower than the highest amount of 69.7 t C ha^{-1} in 1988. The lowest value of 11.01 t C ha^{-1} in 2018 was, however, significantly higher than the lowest value of 5.54 tCha^{-1} of 1988 (Table 2, Figure 3). In cultivated soils, the highest SOC increase is found at Harran I and Karabayır Series, with 27.45 t C ha^{-1} (1.12 percent increase) and 26.46 t C ha^{-1} (1.05 percent increase), respectively. In other soils, such as Akören, Ekinyaz, and Urlu, the increase was assumed to be entirely due to irrigation. The Urfa series (grazeland) had the highest SOC among all plain soils in 2018, at 54.91 t C ha^{-1} (2.08 percent SOM) even down from 69.70 t C ha^{-1} (2.64 percent SOM) in 1988 is attributed to low grazing pressure, i.e. locals abandoning animal breeding in favor of high-income irrigated agriculture opportunities. However, at places where grazing was still occurring such as the Fatik Series, the SOC value was as low as 38.75 t C ha^{-1}. This high SOC amount in grazelands is manifested elsewhere even in earlier studies of the century [47]. The salinity build-up caused SOC to decrease in areas around Akçakale (Figure 4). Çullu et al. (2010) and Bilgili et al. (2017) suggest that the capillary rise of the saline water table due to excess irrigation is the cause of the salinity build-up in these areas [45], [48].

Table 2: The soil organic matter change from 1988 to 2018.

Soil Series	1988	2018	Change
	%	%	%
Fatik	1,60	1,70	0,10
Gülveren	1,05	1,17	0,12
İkizce	0,61	0,76	0,15
Bellitaş	1,49	1,52	0,03
Kap	0,66	0,77	0,11
Akören	0,39	0,93	0,54
Gündaş	1,38	1,42	0,04
Karabayır	0,22	1,27	1,05
Harran I	0,50	1,62	1,12
Harran II	0,66	1,38	0,72
Sırrın I	0,44	0,86	0,42
Sırrın II	0,50	0,97	0,47
Beğdeş	1,32	1,60	0,28
Uğurlu	0,22	0,43	0,21
Gürgelen	0,88	1,59	0,71
İrice	0,66	0,98	0,32
Urfa	2,64	2,08	**-0,56**
Konuklu	1,49	1,67	0,18
Kısas	1,05	1,38	0,33
Bozyazı	0,72	0,93	0,21
Çekçek	0,72	1,08	0,36
Sultantepe	0,88	1,17	0,29
Akçakale	0,83	0,70	**-0,13**
Meydankapı	0,44	0,43	**-0,01**
Ekinyazı	0,44	0,76	0,32
Hancığaz	1,27	1,42	0,15
Cepkenli I	0,94	1,11	0,17
Cepkenli II	1,05	1,14	0,09
Average	**0,89**	**1,17**	**0,28**

Source: Authors, (2022).

The overall SOC increase in the Harran Plain (Figure 4) is calculated by assigning zero value to the SOC of the settlements and distributing soil series values by regression kriging as follows:

∑ [Soil organic carbon difference (ton C ha^{-1}) /soil series area (ha)] =ton C ha^{-1}

∑ [2,131,614.81 ton C/142,770.78 ha] = 14.93 ton C ha^{-1}

[1]www.tcmb.gov.tr/wps/wcm/connect/EN/TCMB+EN/Main+Menu/Statistics/Exchange+Rates/Indicative+Exchange+Rates

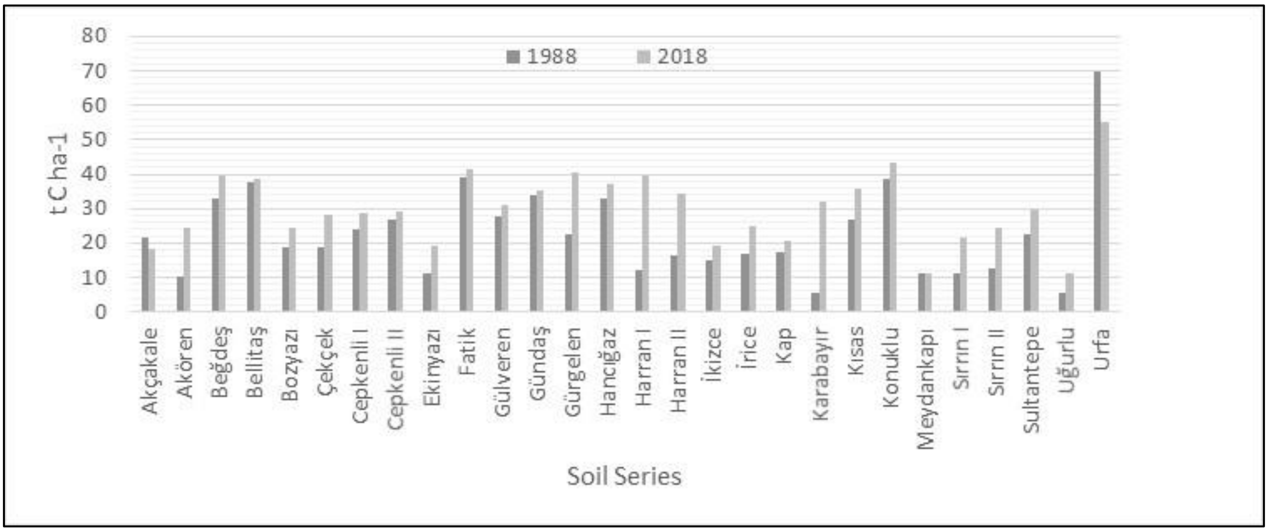

Figure 3: The soil organic carbon contents of the Harran Series in 1988 and 2018.
Source: Authors, (2022).

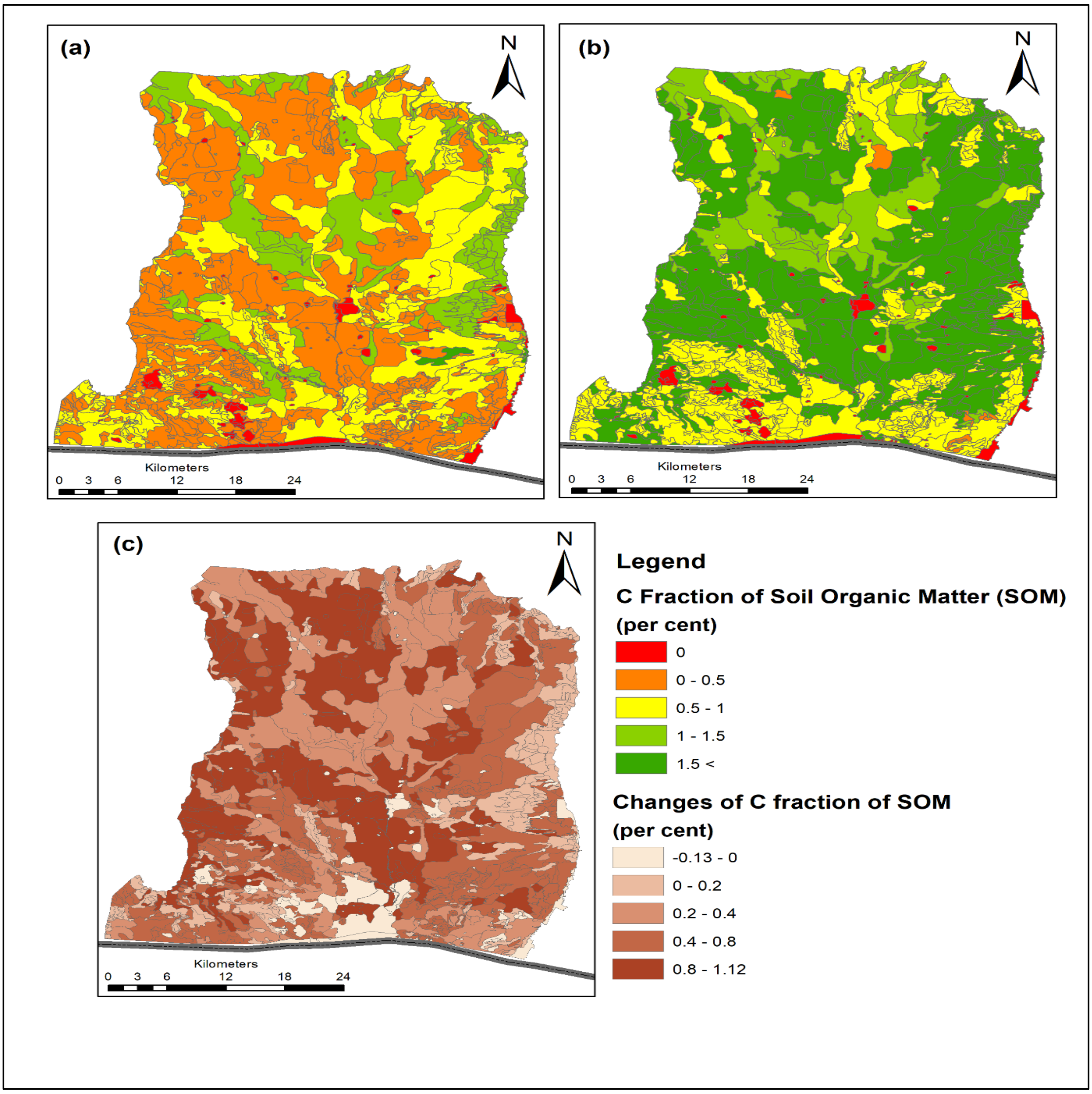

Figure 4: (a) SOC % in 1988, (b) SOC % in 2017; and (c) Changes of SOC between 1988 and 2018.
Source: Authors, (2022).

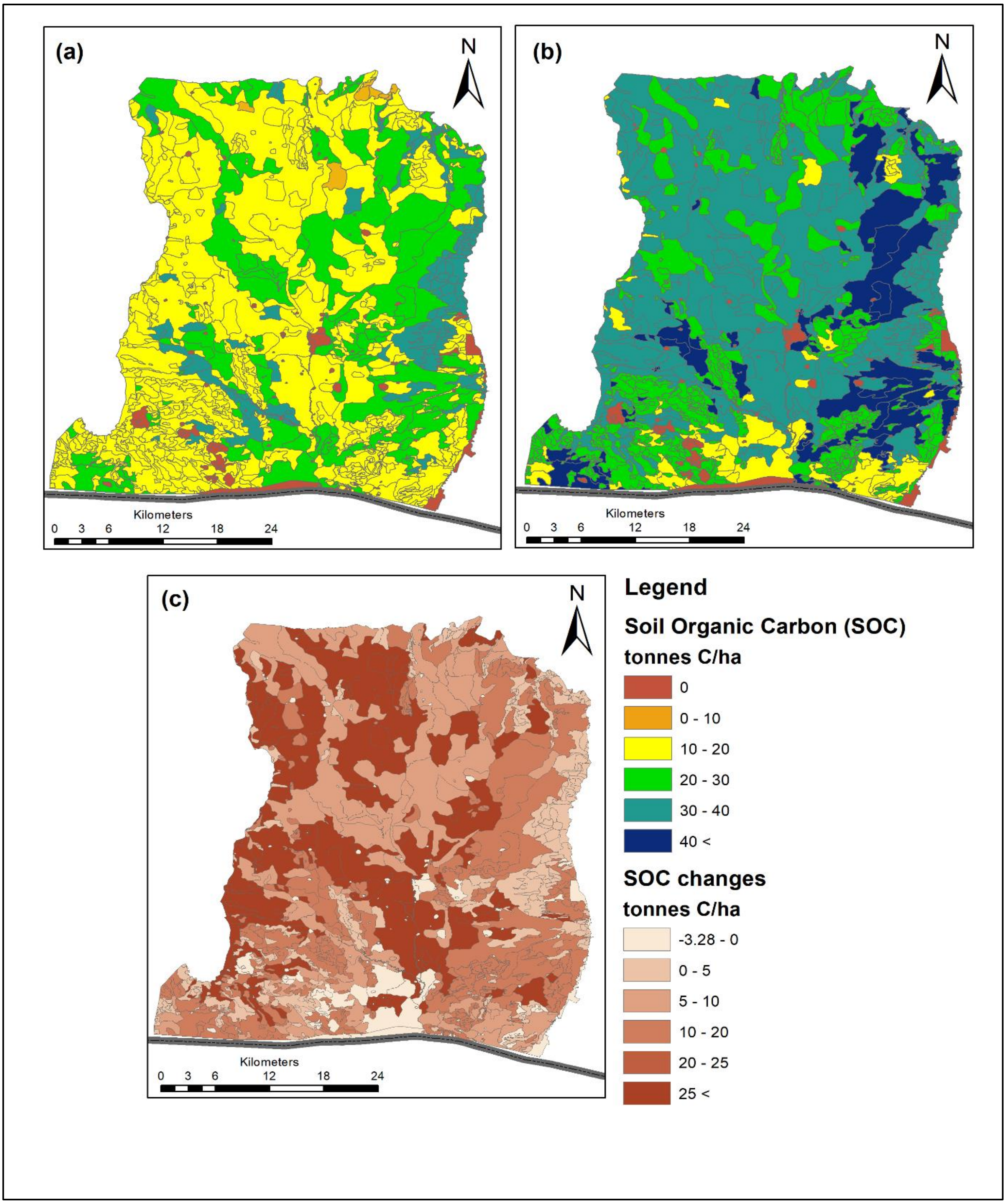

Figure 5. (a) SOC in 1988, (b) SOC in 2017; and (c) SOC changes between 1988 and 2018.
Source: Authors, (2022).

III.3 THE ECONOMIC ANALYSES OF IRRIGATION INVESTMENTS IN HARRAN PLAIN

The overall trend for SOC in the plain is an increase, which decision-makers may consider a successful achievement. The expense of increasing, on the other hand, necessitates a thorough examination of the strategies for raising soil organic carbon. The availability of water and crop pattern, according to this study, are the key determinants of soil organic carbon dynamics in Harran Plain, a semi-arid environment. Thus, we calculated the three major expenditure items since 1995, namely I. fixed investment, maintenance, and repair operating costs, II. fertilization costs, and III. irrigation and fertilization labor costs.

III.3.1 Fixed Investment, Maintenance, and Repair Operating Costs of Harran Irrigation

In the Harran Plain, where rain-fed farming was common, irrigation of soils began in 1995 in an area of 30 thousand hectares under the pretense of GAP and gradually spread to almost the entire Plain [49]. The Harran Irrigation Project is gravity-based, with 80.2 percent irrigated by gravity and 19.8 percent irrigated by pressurized systems as of 2019. Irrigation investment calculations are complex and may differ depending on the water source, whether this resource is used for purposes other than irrigation, the water transmission structures, and the irrigation type [50], [51]. As a result, the irrigation share was calculated proportionally in the irrigation investment costs. Harran Irrigation's fixed investment cost was determined to be $6170.78 (35,481.97 TL) ha^{-1} based on the calculations. Face-to-face interviews with field irrigation institutions (Irrigation Unions and Irrigation Cooperatives) and DSI reports were used to obtain annual maintenance-repair operating costs [41]. The annual maintenance-repair and operating cost for the Harran Plain is determined to be $246.45 (1,417.08 TL) ha^{-1} after separating gravity and pressurized irrigation costs. The total cost of the Harran Plain Irrigation facilities, fixed investments, and maintenance and repair operation costs were estimated to be $6417.23 (36,899.05 TL) ha^{-1}. The total cost of fixed investment, maintenance, and repair operating costs for the entire plain is $1,074,244,302 (Table 3).

Table 3: The 25 years of irrigation cost in Harran Plain (167400ha) (US$).

	Fixed Investments & Repairing	Fertilizer	Irrigation and Labor	Total
1 hectare	6417,23	799	117,25	7333,48
All Plain	1.074.244.302	3.343.815.000	490.691.250	4.908.750.552

Source: Authors, (2022).

III.3.2 Fertilizer Costs

The Harran Plain's land cover is made up of 99.37% field crops. The crop pattern is composed of 82.70% cotton, 15.83 percent wheat, and 1.47 percent other products and fallow. Maize, after wheat, has become a widely grown second crop in the Harran Plain in the last 20 years as Turkey's sugar and fodder needs have increased [42], [52]. The amount of fertilizer used was determined through face-to-face survey interviews with 52 Harran Plain record-keeping farmers chosen using the purposeful sampling method. The farmers reported that the total amount of fertilizer (base and top) used in cotton is 917.5 kg. ha^{-1}, with urea accounting for 81.25% and triple superphosphate accounting for 18.75%. This fertile amount is likewise valid for maize with a 960 kg.ha^{-1} application rate. It is stated that 650 kg of fertilizer is applied to a hectare of wheat, with 66.2 percent urea and 33.8 percent triple superphosphate. The fertilizer cost in the region has been calculated as $799 (4,597.05 TL) ha^{-1} based on valid 2019 prices [53]. A total of $3,343,815,000 is spent on fertilizing crops across the entire plain (Table 3).

III.3.3 Salinity Remediation Infrastructure Cost

III.3.3.1 Irrigation and fertilization labor costs

Interviews with farmers in several regions of the plain yielded data on the number of irrigation and fertilizer application. The irrigation figures vary depending on the amount of annual precipitation and the method of irrigation. Cotton is irrigated 10.94 times on average, according to farmers. In the Harran Plain, on the other hand, it was discovered that, on average, 6 irrigations are carried out for winter wheat, despite the fact that this ratio varies depending on precipitation. Fertilizations are usually done twice as often as a base and top fertilizer. The estimate was based on the agricultural products cost system (TAMSIS) and the statistics data network (IVA) of the Ministry of Agriculture and Forestry of the Republic of Turkey [54]. According to this, the Harran Plain's irrigation and fertilizer labor expenses are $167.38 (962.42 TL) ha^{-1} and $987 (56.77 TL) ha^{-1}, respectively, totaling $177.25. (1019.19 TL ha^{-1}). Over the course of 25 years, $490,691,250 was spent on irrigation and labor on the Harran Plain (Table 3).

III.4 THE COST OF SOIL ORGANIC CARBON IN HARRAN PLAIN

Irrigation of the Harran Plain began in 1995, and the use of chemical fertilizers improved biomass production after irrigation for farming. Following 25 years of irrigation, the SOC in the Harran Plain increased by 14.93 ton C ha^{-1}, or 0.28% SOC, except in a few locations (Figure 4). When the total expenses of $7333.48 are divided by 14.93 t C ha^{-1}, it can be said that one ton of soil organic carbon increase, i.e., 0.28% SOC (Table 1) accumulation costs $491.19 in the Harran Plain. Harran Plain's total SOC increase of 2,131,614.81 t C ha^{-1} can be estimated to cost $1,047,029,777. However, when COP 21 Paris initiative is taken into account the current 0.28% increase should be 2.66% (Over the course of 25 years, a 0.04 percent annual increase translates to a total accumulated increase of 2.66% C.). As a result, the current 0.28 percent increase, rather than the 2.66 percent increase, represents unsustainable land management in Harran Plain for SOC.

IV. CONCLUSIONS

Several studies have shown that decreasing soil organic carbon has negative consequences for climate, land use, and biodiversity. In addition to academic studies, these issues have become increasingly visible in the socio-economic sphere as a result of declining income, health, and quality of life. Countries have begun to take steps to increase SOC for the safety of their citizens and natural resources through a variety of measures. Increasing SOC through various land-use practices is one of the mitigation strategies. Irrigating dry and semi-arid fields to raise biomass is a common method among them because it creates revenue for communities while also raising SOC, especially in impoverished nations. Governments, such as Turkey's Southeastern Anatolia Project, set aside large sums of money to build irrigation networks. After 25 years of irrigation, SOC increased by 14.93 ton C ha (0.28 percent) across the plain. However, this falls short of the COP-21 Paris goal of a 0.04 percent yearly rise, which should be 2.66% rather than the existing 0.28 percent which somewhat revealed the unsustainable land management in Harran Plain. The cost of the 0.28% increase i.e. per t C ha-1 is $491.19 in the Plain which sums up $1,047,029,777 for 167.400 ha. This figure showed that rising SOC within the COP 21 target of 0.04% per year in semi-arid regions will be a costly strategy unless management is not just focused on output but also on ecosystem services. SOC, land productivity, and land use are the parameters of Land Degradation Neutrality, which aims to support ecosystem functions and services while also improving land quality. We believe that economic considerations should be considered when designing LDN studies in semi-arid regions, particularly in low-income nations. In a semi-arid region like the Harran Plain, attaining the “4 per 1000 initiative of COP 21 Paris” might cost $7,017 per year for a hectare if only dependent on irrigation and fertilization. Nevertheless, while irrigation and fertilization increase SOC, they also cause salinity build-up and pollution, both of which have a negative impact on SOC, as seen in the Harran Plain, and may result in higher land management costs.

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VII. REFERENCES

[1] C. Mora *et al.*, "Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions," *Nat. Clim. Change*, vol. 8, Art. no. 12, 2018, doi: 10.1038/s41558-018-0315-6.

[2] C.-E. Park *et al.*, "Keeping global warming within 1.5 °C constrains emergence of aridification," *Nat. Clim. Change*, vol. 8, Art. no. 1, 2018, doi: 10.1038/s41558-017-0034-4.

[3] IPBES, *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Bonn, Germany: IPBES Secretariat, 2019.

[4] IPBES, *The IPBES assessment report on land degradation and restoration*. Bonn, Germany: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2018.

[5] E. Nkonya *et al.*, "Global cost of land degradation," in *Economics of land degradation and improvement – A global assessment for sustainable development*, E. Nkonya, A. Mirzabaev, and J. Von Braun, Eds. New York Dordrecht London: Springer, 2016, pp. 117–165.

[6] Global Carbon Atlas, "Global Carbon Project," 2019. http://www.globalcarbonatlas.org/en/content/welcome-carbon-atlas (accessed Feb. 12, 2022).

[7] R. S. J. Tol, "The economic impacts of climate change," *Rev. Environ. Econ. Policy*, vol. 12, no. 1, pp. 4–25, 2018.

[8] P. Smith *et al.*, "Global change pressures on soils from land use and management," *Glob. Change Biol.*, vol. 22, no. 3, pp. 1008–1028, 2016, doi: 10.1111/gcb.13068.

[9] C. Delang, "Soil pollution prevention and control measures in China," *Forum Geogr.*, vol. XVII, no. 1, pp. 5–13, 2018, doi: 10.5775/fg.2018.003.i.

[10] S. Kapur *et al.*, "Land degradation in Turkey," in *Land degradation: contributions to the international workshop*, Italy, 2003, pp. 303–317.

[11] E. Akça and M. A. Çullu, "Misuse of soils of Turkey: 7 regions 7 main issues," in *Soil Atlas Heinrich Böll Stiftung, Berlin and Institute for Advanced Sustainability Studies, Potsdam*, Germany: Atlas Manufaktur, 2015.

[12] S. Kapur, E. Akça, C. Zucca, S. Berberoğlu, and S. R. Miavaghi, "Anthroscapes: A robust basis for mapping land quality and sustainable land use patterns," in *Eastern Mediterranean Port Cities. The Urban Book Series.*, F. Yenişehirlioğlu, E. Özveren, and T. Selvi Ünlü, Eds. Cham: Springer International Publishing, 2019, pp. 63–77. doi: 10.1007/978-3-319-93662-8_5.

[13] M. Türkeş *et al.*, "Desertification vulnerability and risk assessment for Turkey via an analytical hierarchy process model," *Land Degrad. Dev.*, vol. 31, no. 2, pp. 205–214, 2020, doi: 10.1002/ldr.3441.

[14] R. McLeman, "Thresholds in climate migration," *Popul. Environ.*, vol. 39, no. 4, pp. 319–338, Jun. 2018, doi: 10.1007/s11111-017-0290-2.

[15] K. van der Geest *et al.*, "The impacts of climate change on ecosystem services and resulting losses and damages to people and society," in *Loss and Damage from Climate Change: Concepts, Methods and Policy Options*, R. Mechler, L. M. Bouwer, T. Schinko, S. Surminski, and J. Linnerooth-Bayer, Eds. Cham: Springer International Publishing, 2019, pp. 221–236. doi: 10.1007/978-3-319-72026-5_9.

[16] P. Blaikie and H. Brookfield, *Land degradation and society*. New York, USA: Routledge, 1987.

[17] M. Kassas, "Desertification versus potential for recovery in circum-Saharan territories," *Am. Assoc. Adv. Sci.*, vol. 90, pp. 123–142, 1970.

[18] G. Schwilch, F. Bachmann, and Hp. Liniger, "Appraising and selecting conservation measures to mitigate desertification and land degradation based on stakeholder participation and global best practices," *Land Degrad. Dev.*, vol. 20, no. 3, pp. 308–326, 2009, doi: 10.1002/ldr.920.

[19] B. T. Bestelmeyer *et al.*, "Desertification, land use, and the transformation of global drylands," *Front. Ecol. Environ.*, vol. 13, pp. 28–36, 2015, doi: 10.1890/140162.

[20] W. Kutsch, M. Bahn, and A. Heinemeyer, *Soil carbon dynamics: An integrated methodology*. Cambridge, United States of America: Cambridge University Press, 2010.

[21] R. Hiederer and M. Köchy, “Global soil organic carbon estimates and the harmonized world soil database,” EUR 25225 EN. Publications Office of the European Union, 2012.

[22] S. Wang, Q. Wang, K. Adhikari, S. Jia, X. Jin, and H. Liu, “Spatial-temporal changes of soil organic carbon content in Wafangdian, China,” *Sustainability*, vol. 8, no. 11, Art. no. 11, Nov. 2016, doi: 10.3390/su8111154.

[23] A. Johannes, A. Matter, R. Schulin, P. Weisskopf, P. C. Baveye, and P. Boivin, “Optimal organic carbon values for soil structure quality of arable soils. Does clay content matter?,” *Geoderma*, vol. 302, pp. 14–21, Sep. 2017, doi: 10.1016/j.geoderma.2017.04.021.

[24] R. Lal, “Biochar and soil carbon sequestration,” in *Agricultural and Environmental Applications of Biochar: Advances and Barriers*, M. Guo, Z. He, and S. M. Uchimiya, Eds. Madison, USA: John Wiley & Sons, Ltd, 2016, pp. 175–197. doi: 10.2136/sssaspecpub63.2014.0042.5.

[25] C. M. Swanepoel *et al.*, “The benefits of conservation agriculture on soil organic carbon and yield in southern Africa are site-specific,” *Soil Tillage Res.*, vol. 183, pp. 72–82, Nov. 2018, doi: 10.1016/j.still.2018.05.016.

[26] G. Gebeyehu, T. Soromessa, and D. Teketay, “Organic crbon stocks, dynamics and restoration in relation to soils of agroecosystems in Ethiopia: A review,” *Int. J. Environ.*, vol. 6, no. 1, Art. no. 1, Feb. 2017, doi: 10.3126/ije.v6i1.16864.

[27] USDA (United States Department of agriculture), *Soil Taxonomy*. Washington, DC, USA: United States Department of Agriculture Natural Resources Conservation Service, 1975.

[28] FAO-UNESCO, “Soil map of the world, 1:5,000,000, volume 1 Legend. united nations educational, scientific, and cultural organization,” 1974. https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/ (accessed Mar. 17, 2022).

[29] U. Dinç *et al.*, “The soils of Southeastern Anatolia Region (GAT) 1. Harran Plain,” TUBİTAK Agriculture and Forestry Group, Ankara,Turkey, Guided Research Project Final Result Report TOAG-534, 1988.

[30] M. L. Jackson, *Soil Chemical Analysis - Advanced Course*. Madison, USA: Wisconsin, 1969. Accessed: Jul. 22, 2022. [Online]. Available: https://www.cabdirect.org/cabdirect/abstract/19791945527

[31] Soil Survey Staff, “Soil survey field and laboratory methods manual,” U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Investigations Report No. 51, Version 2.0, 2014.

[32] M. Rudden and I. Mackenzie, “Introduction to ArcGIS desktop and ArcGIS engine development,” 2008. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://proceedings.esri.com/library/userconf/devsummit08/papers/introduction_to_arcgis_desktop_and_arcgis_engine_development.pdf (accessed Apr. 15, 2022).

[33] ESRI, “The global market leader in geographic information system (GIS) software, location intelligence, and mapping,” 2022. https://www.esri.com/en-us/home (accessed May 15, 2022).

[34] E. H. Isaaks and R. M. Srivastava, *An Introduction to Applied Geostatistics*. Oxford, UK: Oxford University Press, 1989. [Online]. Available: https://books.google.com.tr/books?id=t62mtgAACAAJ

[35] D. W. Pribyl, “A critical review of the conventional SOC to SOM conversion factor,” *Geoderma*, vol. 156, no. 3, pp. 75–83, May 2010, doi: 10.1016/j.geoderma.2010.02.003.

[36] M. H. Aydoğdu and A. Bilgiç, “An evaluation of farmers’ willingness to pay for efficient irrigation for sustainable usage of resources: the GAP-Harran Plain case, Turkey,” *J. Integr. Environ. Sci.*, vol. 13, no. 2–4, pp. 175–186, Oct. 2016, doi: 10.1080/1943815X.2016.1241808.

[37] M. H. Aydoğdu and K. Yenigün, “Farmers’ risk perception towards climate change: A case of the GAP-Şanlıurfa Region, Turkey,” *Sustainability*, vol. 8, no. 8, Art. no. 8, 2016, doi: 10.3390/su8080806.

[38] Central Bank of Turkey, “Inflation Calculation,” 2019. http://www3.tcmb.gov.tr/enflasyoncalc/enflasyon_anayeni.php (accessed Dec. 14, 2019).

[39] Ministry of Development, “State Investments at Town Level (1999-2017),” 2017. http://www2.kalkinma.gov.tr/kamuyat/il.html (accessed Jul. 15, 2018).

[40] GDWM (General Directorate of Water Management), “Gediz Basin River Basin Management Plan,” TÜBİTAK-GDWM, Ankara,Turkey, Economic Analysis Final Report, 2018.

[41] SHW (State Hydraulic Works), “Gediz Basin Master Plan,” Department of Survey, Planning and Allocations, State Hydraulic Works, Ankara,Turkey, Economic Analysis Final Report, 2017.

[42] M. Aydoğdu, B. Karlı, H. P. Doğan, G. Sevinç, M. Eren, and N. Küçük, “Economic analysis of agricultural water usage efficiency in the GAP-Harran Plain: Cotton production sampling, Şanlıurfa- Turkey,” *J. Adv. Agric.*, vol. 3, no. 12, pp. 12–19, 2018.

[43] I. Ortas, “Effect of selected mycorrhizal inoculation on phosphorus sustainability in sterile and non-sterile soils in the Harran Plain in South Anatolia,” *J. Plant Nutr.*, vol. 26, no. 1, pp. 1–17, 2003, doi: 10.1081/PLN-120016494.

[44] M. I. Yesilnacar, E. Sahinkaya, M. Naz, and B. Ozkaya, “Neural network prediction of nitrate in groundwater of Harran Plain, Turkey,” *Environ. Geol.*, vol. 56, no. 1, pp. 19–25, Nov. 2008, doi: 10.1007/s00254-007-1136-5.

[45] A. V. Bilgili, Ç. Küçük, and H. M. Van Es, “Assessment of the quality of the Harran Plain soils under long-term cultivation,” *Environ. Monit. Assess.*, vol. 189, no. 9, p. 460, Aug. 2017, doi: 10.1007/s10661-017-6177-y.

[46] T. Binici, C. R. Zulauf, O. O. Kacira, and B. Karli, “Assessing the efficiency of cotton production on the Harran Plain, Turkey,” *Outlook Agric.*, vol. 35, no. 3, pp. 227–232, 2006, doi: 10.5367/000000006778536729.

[47] M. Howard, S. Perez-Castro, F. Wang, and J. Tang, “Carbon and nitrogen stock comparisons of corn monocultures,” *Crop Sci.*, vol. 3, pp. 11–18, 1942.

[48] M. A. Çullu *et al.*, “Implication of groundwater fluctuation on the seasonal salt dynamic in the Harran Plain, south-eastern Turkey,” *Irrig. Drain.*, vol. 59, no. 4, pp. 465–476, 2010, doi: 10.1002/ird.507.

[49] M. H. Aydoğdu, K. Yenigun, and M. Aydoğdu, “Factors affecting farmers’ satisfaction from water users association in the Harran Plain-GAP Region, Turkey,” *J. Agric. Sci. Technol.*, vol. 17, no. 7, pp. 1669–1684, 2015.

[50] M. H. Aydoğdu and K. Yenigün, “Willingness to pay for sustainable water usage in Harran Plain-GAP Region, Turkey,” *Appl. Ecol. Environ. Res.*, vol. 14, no. 3, pp. 147–160, 2016, doi: 10.15666/aeer/1403_147160.

[51] R. Q. Grafton, J. Williams, and Q. Jiang, “Possible pathways and tensions in the food and water nexus,” *Earths Future*, vol. 5, no. 5, pp. 449–462, 2017, doi: 10.1002/2016EF000506.

[52] M. H. Aydoğdu, “Evaluation of willingness to pay for irrigation water: Harran Plain Sampling in GAP Region -Turkey,” *Appl. Ecol. Environ. Res.*, vol. 14, no. 1, pp. 349–365, 2016, doi: 10.15666/aeer/1401_349365.

[53] Anonymous, “Fertilizer Prices 2019,” 2019. https://www.gemlikmanset.com/2019/01/08/2019-yili-gubre-fiyatlari-ciftciden-tepki-cekti/ (accessed May 01, 2020).

[54] Republic of Turkey Ministry of Agriculture and Forestry, “Şanlıurfa Provincial Directorate IVA and TAMSİS data. Use of Agricultural Products Cost System,” 2018. https://www.tarimorman.gov.tr/ (accessed Dec. 16, 2019).