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Chemical properties of cotton growing soils and their rating in different talukas of South Gujarat

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Abstract
Chemical properties of some irrigated and rainfed cotton growing surface soils (0-22.5 cm) from 11 talukas of South Gujarat comprising Bharuch, Surat and Narmada districts were investigated. pH, EC, CEC, ESP, soil organic C and inorganic carbon were determined from total 110 nos. samples for proper management of these soils and achieving higher cotton yield. The results revealed that above parameters chronologically ranged from 6.5-8.8, 0.62-2.89 dS m^{-1}, 35.9-63.8 cmol (p+) kg^{-1}, 3.43-10.18, 2.70-9.41 g kg^{-1} and 0.95-14.40 g kg^{-1}, respectively in irrigated soils, while the corresponding values were 6.7-9.5, 0.21-2.59 dS m^{-1}, 35.9-55.7 cmol (p^+) kg^{-1}, 4.52-11.56, 2.85-7.90 g kg^{-1} and 1.58-19.40 g kg^{-1}, respectively, in rainfed soils. However, the mean values of the above parameters were 7.8, 1.70, 51.0, 6.55, 6.19 and 4.93, respectively in irrigated soils and 8.2, 1.41, 46.6, 7.94, 4.83 and 8.79 respectively in rainfed soils. Major irrigated soils (63.7%) belonged to 'neutral' to 'mild alkaline' in reaction while, major rainfed soils (67.4%) came under 'mild alkaline' to 'very strongly alkaline' in reaction. Salinity of both irrigated and rainfed soils were 'low'. For CEC > '40' cmol $(p)^+$ kg^{-1}, > 92.8 and > 85.5 per cent soils, for '5 to 15' ESP, 29.1 and 61.8 per cent soils, for 'low' organic carbon, 20 and 51 per cent soils and for 'high to very high' SIC, 20 and 51 per cent soils respectively were responsible in irrigated and rainfed situations, respectively.

Keywords: chemical properties, soils, irrigated, rainfed, cotton

1. Introduction
Cotton (*Gossypium* spp), the 'queen of fibres' or 'white gold' and one of the most important cash crops of Gujarat state and out of 99.66 lakh hectares cultivable land about 30 lakh hectares area is under cotton on various types of soils producing 125 lakh bales of lint, about 50 lakh tonnes of cotton seed and 60-65 lakh tonnes of stalks. However, the cotton crop in Gujarat is grown under variable annual rainfall situations ranging from 250 mm in the North West to more than 1500 mm in South Gujarat (*Annon*. 2016) [1]. Any research work towards enhancement of cotton crop productivity or soil quality on which it survives would be of paramount importance. A research topic, thus, was chosen on cotton growing soils of South Gujarat. Cotton is most important fiber crop which plays very important role in economic and social affairs of people, especially in India. Gujarat is situated at latitude of 20°01' 24.07"N and longitude of 68°04' 74.04"E with a total area of 196,077 km^2. The North-west region of Gujarat is desert, while the southern area of Gujarat is wet and moist due to heavy monsoon in the area. Gujarat has a tropical climate with the temperature in the range from 1-46°C. The annual rainfall is quite variable ranging from 250 mm in the North West to more than 1500 mm in South Gujarat. Gujarat is one of the main cotton producing states in India. It covers about 30 lakh hectares area under cotton, producing 125 lakh bales of lint, about 50 lakh tonnes of cotton seed and 60-65 lakh tonnes of stalks. Cotton cultivation in Gujarat is done on various soils right from sandy soil of Kutch, the alluvial soil of Ahmedabad and Kheda districts to the black and black cotton soils of Central, Southern and Saurashtra regions. As productivity of both rainfed and irrigated cotton crops largely depends on the soil areas characteristics under a specific set of climatic and ignorance of soil-site requirement of a particular crop leads to the sub-optimal yield or complete failure of the crop. Due to continuous cotton cultivation, soils under irrigated and rainfed system may differ/ or affect soil properties which may modify nutrients content and their availability to crops, so analysis of soil properties may have significant importance. Under these contexts, an attempt has been made to generate information on soil properties and status in irrigated and rainfed situations in

cotton growing areas of South Gujarat in order to future management of these soils for higher cotton yield.

Materials and Methods

Overview of study area: Cotton is an important cash crop of South Gujarat it is grown in about 100 lakh hectares cultivable land in South Gujarat in compassing 11 talukas namely, Bharuch, Jhagadia, Jambusar, Amod, Vagra, Hansot, Surat, Narmada, Dediapada, Tilakwada and Sagbara. These eleven talukas are distributed in three districts of South Gujarat namely Bharuch (21.3^0 to 22.0^0 N, 72.45^0 to 73.15^0 E), Surat (20° 10' 596" N, 072° 52' 638"E) and Narmada (21° 52' 028"N, 073° 30' 035"E). Major soils are clayey in texture. The area comes under subtropical climate with semi arid conditions. The annual rainfall varies in these talukas from 700 to 950 mm. However, Surat city receives little more rainfall *i.e.* about 1200 mm. Distribution of rainfall is not uniform. Moreover, soils fertility status is also medium to poor and a result, yield of cotton (desi or hybrid or *Bt*) crop is not optimum and varies widely from talukas to talukas. Thus, it is essential to analyze the soil samples chemically so as to have analytical results on parameters like pH, EC, SOC, SIC, ESP and CEC in order to take appropriate management practices for improving cotton yield.

Soil sampling and analysis: In the above context, 110 numbers (55 irrigated and 55 rainfed) of representative surface soil samples (0-22.5 cm) encompassing eleven talukas of South Gujarat were collected by using GPS. *i.e.* Bharuch (21.3^0 to 22.0^0 N, 72.45^0 to 73.15^0 E), Surat (20° 10' 596" N, 072° 52' 638"E) and Narmada (21° 52' 028"N, 073° 30' 035"E) districts of South Gujarat, Gujarat state. The collected soil samples were processed and analyzed for pH, EC, organic carbon and inorganic carbon following standard methods (Jackson, 1973) [5]. pH and EC (1:2.5) were determined using glass electrode pH meter and digital EC meter, respectively (Sparks, 1965). Soil organic carbon (SOC) by Walkley and Black, (1934) [21], soil inorganic carbon (SIC) in the forms of $CaCO_3$ was determine as described by Piper, (1950) [12]. Soil inorganic carbon (SIC) forms mainly in carbonate minerals, such as calcium carbonate ($CaCO_3$) and dolomite (Ca Mg $(CO_3)_2$). However, for the purpose of determining soil inorganic carbon (SIC) in the present study the amount of $CaCO_3$ present in the soil has been considered as SIC. Cation exchange capacity (CEC) of soils was determined by summation of cationic ions (Black, 1965) [3] and exchangeable sodium percentage (ESP) was computed by dividing exchangeable Na^+ ions by CEC of soil and multiplying the same by 100. Results obtained from each and individual parameter was rated accordingly; pH as per SSSA (1962) [20], EC as per Seth (1967) [16], SOC content as per Walkley and Black (1934) [21], SIC as per Water Resources Department, Pune (2009). Results as well as ratings were interpreted and discussed.

Results and Discussion

Soil pH and EC: The pH and EC of surface soil from irrigated and rainfed area of 6 talukas of Bharuch district, 1 taluka of Surat district and 4 talukas of Narmada district are presented in Table 1. Irrigated soils of six talukas of Bharuch district revealed that pH varied wildly from 6.6-8.8 *i.e.* neutral to strongly alkaline, whereby out of 30 samples 23.3, 43.3, 16.7 and 16.7 per cent, in soils came under 'neutral', 'mild alkaline' 'moderate alkaline' and 'strongly alkaline', category. However, in case of individual taluka it was observed that only in Amod, Vagra and Hansot taluka few samples came under 'strongly alkaline' category and rest of the samples belonged to either 'neutral', 'mild alkaline' or 'moderate alkaline' category. In case of Surat city taluka pH range of irrigated soils was 7.2 - 8.1 *i.e.* 'neutral' to 'moderate alkaline' whereby major samples came under 'moderate alkaline' group. Coming to irrigated soils of four talukas of Narmada district, the result revealed that pH varied wildly from 6.7 - 8.8 *i.e.* 35, 35, 5 and 25 per cent soils came under 'neutral', 'mild alkaline' 'moderate alkaline' and 'strongly alkaline', category, respectively. When all the irrigated soils of 11 talukas were considered together, it was found that soil pH varied from 6.5 - 8.8 *i.e.* 'neutral' to 'strongly alkaline' showing 25.5, 38.2, 18.2 and 18.2 per cent soils under 'neutral', 'mild alkaline' 'moderate alkaline' and 'strongly alkaline' category, respectively. Rainfed soils of six talukas of Bharuch district revealed that pH varied wildly from 6.9-9.5 *i.e.* 'neutral' to 'very strongly alkaline', whereby out of 30 samples 2, 10, 12, 2 and 4 per cent, soils came under 'neutral', 'mild alkaline' 'moderate alkaline' 'strongly alkaline' and 'very strongly alkaline' category, respectively. However, in case of individual taluka, it was observed that only in Jhagadia, Jambusar, Amod and Vagra taluka few samples came under 'very strongly alkaline' category and rest of the samples belonged to either 'neutral' or 'mild alkaline' or 'moderate alkaline' category. In case of Surat city taluka, pH range of irrigated soils was 6.9 - 9.1 *i.e.* 'neutral' to 'very strongly alkaline' whereby major samples came under 'mild alkaline' group. Coming to rainfed soils of four talukas of Narmada district, the result revealed that pH varied wildly from 6.7 - 9.5 *i.e.* 5, 10, 5, 60 and 20 per cent soils came under 'neutral', 'mild alkaline' 'moderate alkaline', 'strongly alkaline' and 'very strongly alkaline', category, respectively. When all the rainfed soils of 11 talukas were considered together, it was found that soil pH varied from 6.7 - 9.5 *i.e.* 'neutral' to 'very strongly alkaline' showing 7.3, 25.5, 25.5, 25.5 and 16.4 per cent soils under 'neutral', 'mild alkaline' 'moderate alkaline' 'strongly alkaline' and 'very strongly alkaline' category, respectively. When all irrigated soils together were compared with all rainfed soils, the results indicated that mean pH of irrigated soils was lower (7.8) then that of rainfed soils (8.2). Further, about 42% per cent of rainfed soils came under 'strongly alkaline' to 'very strongly alkaline' category, while only about 18 per cent irrigated soils belong to 'strongly alkaline' group. The reason for higher percentage of rainfed soils with higher pH range ('strongly alkaline' to 'very strongly alkaline') was mainly due to higher surface evaporation under rainfed condition coupled with higher organic acids under irrigated condition arising from incorporation of higher quantum of organic matter by the farmers apart from higher foliage litter fall from hybrid as well as *Bt* variety of cotton including higher roots volume and their subsequent deposition. Rainfed soils mostly received low organic inputs along with low litter fall from mostly *Desi* cotton which ultimately results in higher soil pH. These facts indicated that amelioration (through organic/ inorganic amendments or biological means) of strongly to very strongly alkaline soils is of prime requirement in order to sustain soil quality and possible improvement in yield of cotton. The results on soil pH in surface (0-30 cm) obtained by Sağlam and Dengiz (2014) [14] ranged from 7.74 to 8.94 which strongly supported the present result of present study. Results were supported by Paramasivan and Jawahar (2014) [11] for cotton growing areas. In general, 'moderately to very strongly alkaline' soils might face nutritional imbalance especially N,

P and Zn deficiency in soils, which ultimately hampers the crop yield. Thus, for obtaining sustained crop yield and improvement in soil quality, amelioration of soil alkalinity as precautionary measure must be taken by farmers of those areas to overcome alkalinity problems and to create the favorable soil condition with increase in nutrients availability for enhancing the cotton crop yield.

The EC of surface soil from irrigated and rainfed area of 6 talukas of Bharuch district, 1 taluka of Surat district and 4 talukas of Narmada district are presented in Table 1. Irrigated soils of six talukas of Bharuch district revealed that EC varied wildly from 0.62 - 2.85 dS m^{-1} and with mean value of 1.69 dS m^{-1} *i.e.* 90 and 10 per cent soils respectively came under 'medium' and 'low' salinity category. In case of Surat city taluka EC of irrigated soils, ranged from 0.69 - 2.01 dS m^{-1} and with mean value of 1.45 dS m^{-1} whereby, 60 and 40 per cent soils respectively belong to 'medium' and 'low' salinity category. Coming to irrigated soils of four talukas of Narmada district, the result revealed that EC varied wildly from 0.75 - 2.89 dS m^{-1} having mean value of 1.97 dS m^{-1} with 95 and 5 per cent soils under 'medium' and 'low' salinity category, respectively. When all the irrigated soils of 11 talukas were considered together, it was found that soil EC varied from 0.62 - 2.89 dS m^{-1} with mean value of 1.70 dS m^{-1} *i.e.* showing 89.1 and 10.9 per cent soils under 'medium' and 'low' salinity category, respectively. So far as soil salinity problem is concerned, > 89 % irrigated soils of these 11 talukas belonged to 'medium' salinity class and rest with 'low' salinity class. In case of rainfed soils, six talukas of Bharuch district revealed that EC varied wildly from 0.21 - 2.14 dS m^{-1} with mean value of 1.39 dS m^{-1} *i.e.* 73.3 and 26.7 per cent soils came under 'medium' and 'low' salinity category, respectively. In case of Surat city taluka, EC ranged from 0.59 - 2.12 dS m^{-1} with mean value of 1.23 dS m^{-1} showing 40 and 60 per cent soils under 'medium' and 'low' salinity category, respectively. Coming to four talukas of Narmada district, the result revealed that EC varied wildly from 0.59-2.59 dS m^{-1} with mean value of 1.61 dS m^{-1} *i.e.* 75 and 25 per cent soils came under 'medium' and 'low' salinity category, respectively. When all the rainfed soils of 11 talukas were considered together, it was found that soil EC varied from 0.21 - 2.59 dS m^{-1} and mean 1.41 dS m^{-1} *i.e.* showing 70.9 and 29.1 per cent soils under 'medium' and 'low' salinity category, respectively. So far as soil salinity problem is concerned, > 71 % rainfed soils of these 11 talukas belonged to 'medium' salinity class and rest with 'low' salinity class. Soils with 'medium' salinity class very likely to hamper the crop productivity to a certain extent due to higher osmotic pressure (OP) of soil solution as plant cannot extract available water properly at high OP. Thus, all the soils of 'medium' salinity both from irrigated and rainfed situations of 11 talukas most probably would face yield reduction of cotton due to low nutritional availability and microbial activity. Soils of 'medium' salinity are required to get rid of salts through leaching of soluble salt to improve and sustain the yield of cotton in these areas. However, according to Mehrad, (1968) [7] soils with EC < 2 dS m^{-1} (threshold limit), would not pose any adverse effect on cotton growth. Further, when irrigated soils as a whole were compared with rainfed soils, it was found that higher percentage of soils with 'medium' salinity came under irrigated soils possibly due to irrigation and higher evapotranspiration in irrigated soils as compared to rainfed soils which built up salinity. Another possibility of higher salinity in irrigated soils would be irrigation with poor quality of ground water. Under such situations, precautionary measure must be taken for irrigating cotton crop with good quality water. Under rainfed situations, farmers should make bunds surrounding their plots to store as much rain water as possible for good profile storage as well as leaching of salts from root zone depth for higher crop productivity.

CEC and ESP: The CEC (as summation of bases) of surface soils from irrigated and rainfed area of 11 talukas of Bharuch, Surat and Narmada district are presented in Table 2. Irrigated soils of six talukas of Bharuch district revealed that CEC varied widely from 42.0 - 63.80 cmol (p^+) kg^{-1} with mean value of 51.2 cmol (p^+) kg^{-1}. However, 46.7 per cent soils exhibited CEC between 41 and 50 cmol (p^+) kg^{-1} and the rest showed CEC '>50' cmol (p^+) kg^{-1}. In case of Surat city taluka, all the soils depicted CEC '>50' cmol (p^+) kg^{-1} showing a range from 54.4 - 59.8 cmol (p^+) kg^{-1} with a mean value of 56.3 cmol (p^+) kg^{-1}. Coming to Narmada district, CEC of soils of four talukas also varied widely from 35.9 - 59.0 cmol (p^+) kg^{-1} with a mean value of 45.5 cmol (p^+) kg^{-1} showing only 20 per cent soils having '>50' cmol (p^+) kg^{-1} CEC, 60 per cent soils came in the range of 41- 50 cmol (p^+) kg^{-1} and the rest of the soils showed CEC 31 – 40 cmol (p^+) kg^{-1}. When all the irrigated soils of 11 talukas were considered together, it was found that soil CEC varied widely from 35.9 to 63.8 cmol (p^+) kg^{-1} showing 7.3, 47.3 and 45.5 per cent soils having a range of CEC 31 – 40, 41 – 50 and > 50 cmol (p^+) kg^{-1} respectively. In case of rainfed soils, CEC varied widely soils of all the six talukas of Bharuch district, Surat city taluka of Surat district and four talukas of Narmada district. However, the ranged of CEC were 40.8 - 54.8, 46.6 - 55.7 and 35.9-54.0 cmol (p^+) kg^{-1} with mean values of 47.6, 50.7 and 41.6 cmol (p^+) kg^{-1} respectively in soils of six talukas of Bharuch district, Surat city taluka and four talukas of Narmada district. Only in four talukas of Narmada district, 40.0 per cent soils belonged to CEC between 31 and 40 cmol (p^+) kg^{-1} and for rest of the talukas not a single soil came in the range of CEC. However, 73.3, 60.0 and 55.0 per cent soils respectively from six talukas of Bharuch district, one taluka of Surat district and four talukas of Narmada district were in the range of 41-50 cmol (p+) kg^{-1}. Similarly, 26.7, 40 and 5.0 per cent soils respectively above chronological order showed CEC '>50' cmol (p^+) kg^{-1}. In case of all the rainfed soils CEC widely varied from 35.9 to 55.7 cmol (p^+) kg^{-1} showing 14.5, 65.5 and 20.0 per cent soils with '31 - 40', '41 - 50' and '>50' cmol (p^+) kg^{-1} CEC, respectively. The ranges of soil CEC for both the situations were indicative of presence of 2: 1 type expanding type clay in major soils. However, in some soils with 31 - 40 cmol (p^+) kg^{-1} CEC the presence of non-expanding illitic clay or degraded illitic clay cannot be ruled out along with 2: 1 type expanding clay. Higher the CEC value of soils, higher is the cation nutrient supplying capacity of these soils to the plant root. Overall mean CEC of irrigated soils was higher (51.0 cmol (p^+) kg^{-1}) as compared to those of rainfed (46.6 cmol (p^+) kg^{-1}) *i.e.* slightly higher nutrient supplying capacity than those of rainfed situation which might be due to higher content of silt+clay and organic matter content in irrigated soils. Within the same situations, the variation of CEC from place to place might be ascribed to presence of varying quantity and type of clay/ silt+clay and organic matters due to application difference of manures / biocomposts by the farmers and organic biomass/ litter - fall owing to varietal difference of cotton (hybrid/ *desi*/ *Bt*). These results were supported by Padekar *et al.* (2014) [9] and Paramasivan and Jawahar (2014) [11] for cotton growing areas. Results corroborated with the findings of Negash and

Mohammed (2014) [8], whereby they found that CEC of the irrigated and rainfed soils, ranged from 44.5 - 52.3 and 28.7 - 35.7 cmol (p+) kg^{-1}, respectively.

The ESP of surface soils from irrigated and rainfed cotton growing area of 11 talukas are presented in Table 2. It was observed that ESP varied from 3.43 to 8.72 with a mean value of 6.37 in irrigated soils of six talukas of Bharuch district. However, in Surat city taluka the same ranged from 4.50 to 7.66 with a mean value of 6.15. In case of soils from four talukas of Narmada district, the same varied from 3.56 to 10.18 with mean value of 7.13. Soil ESP > 9.0 indicated the high possibility of alkalinity hazards as reported earlier by Savalia and Gundalia (2009) [15] especially for black soils of Gujarat. In this respect major soils samples of Narmada, Dadiapada, Tilakwada and Sagbara talukas were found highly prone to alkalinity hazards (> 9.0 ESP) as compared to soils of Bharuch, Jhagadia, Jambusar, Amod, Vagra, Hansot and Surat city taluka (< 9.0 ESP). The variation in ESP in soils of different talukas might be attributed to the variation in quality of irrigation water coupled with its reaction with exchange complex of soil (clay and organic matter) along with soil drainage. Under rainfed situation soil ESP varied from 4.52 to 11.56 with a mean value of 7.41 in six talukas of Bharuch district, whereas in Surat city taluka, soil ESP ranged from 5.91 to 10.11 with a mean value of 7.83 and in case of soils from four talukas of Narmada district ESP ranged from 6.21 to 10.91 with a mean value of 8.58. Major soils in rainfed areas were observed to have ESP > 9.0, and thus the soils with ESP > 9.0 both from irrigated or rainfed areas need special care for reduction of sodicity effects to avoid the adverse effect on cotton crop yield and soil health. Further, preventive and reclamation measures along with improvement of drainage facility in the above referred area would be utmost beneficial. In case of soils of Saurashtra region of Gujarat Savalia and Gundalia (2009) [15] also opined similar preventive measures. A wide range of ESP of irrigated (0.4 to 20.9, mean: 5.9) and rainfed soils (0.6 to 19.7, mean: 7.1) were also observed by Shrvan Kumar *et al.* (2016) [17] in cotton growing areas of Bharuch district. Mean ESP of rainfed soils was slightly higher (7.94) as compared to that of irrigated soils (6.55).

SOC and SIC: Irrigated soils of six talukas of Bharuch district revealed that SOC content varied wildly from 3.30-9.41 g kg^{-1} *i.e.* low to high.with mean value of 6.53 g kg^{-1} showing 30, 50 and 20 per cent soils under 'high', 'medium' and 'low' status of SOC, respectively (Table 3). SOC, SIC and total carbon (g kg^{-1}) content in irrigated and rainfed surface soils of cotton growing 11 talukas of Bharuch, Surat and Narmada districts are presented in fig, 1. Similarly, for Surat city taluka, the SOC content ranged from 5.41-8.55 g kg^{-1} exhibiting only 2 samples under 'high' status and rest belonged to 'medium' status of SOC. However, mean SOC of surface soils of Surat city was 6.82 g kg^{-1}. Coming to irrigated soils of four talukas of Narmada district, it revealed that SOC content ranged from 2.70-7.42 g kg^{-1} (50 per cent came under 'low' and rest belonged to 'medium' category of SOC) with mean value of 5.20 g kg^{-1}. When all the irrigated soils of 11 talukas were considered together, it was found that soil SOC varied from 2.70 to 9.41 g kg^{-1} *i.e.* 20.0, 50.9 and 29.1 per cent soils with 'high', 'medium' and 'low' category of SOC, respectively. In case of rainfed soils of Bharuch district (six talukas) result revealed that SOC content varied wildly from 3.15 - 7.90 g kg^{-1} *i.e.* 'very low' to 'high' with mean SOC value of 4.95 g kg^{-1}. With respect to status of SOC 50.0 per cent soils belonged to 'low' status, while 46.7 and 3.3 per cent soils came under 'medium' and 'high' 'category of SOC, respectively. Similarly, for Surat city taluka, 60 per cent soils came under 'low' SOC status and 40 per cent soils belonged to 'medium' status showing a range from 4.20 - 7.21 g kg^{-1} with mean value of 5.52 g kg^{-1}. Surface soils of Narmada talukas (four) revealed that SOC content ranged from 2.85 - 5.40 g kg^{-1} with mean value of 4.03 g kg^{-1}, whereby 85 per cent soils exhibited 'low' status of SOC and rest were 'medium'. When all the rainfed soils of 11 talukas were considered together, it was found that soil SOC varied from very low to high status *i.e.* from 2.85 - 7.90 g kg^{-1} showing about 62 per cent soils under low category followed by medium (about 36 per cent) and high (about 2 per cent) category of SOC. Low to medium content of SOC in rainfed as well as irrigated soils could be attributed mainly to the warmer climate inducing rapid mineralization coupled with less quantum of external addition of organic matter. Similar reason was also reported by Abayneh, (2005) [1]. As SOC affects physical, chemical and biological properties of the soil and plays a crucial role in sustaining soil quality, agricultural crop production and environmental quality (Zhang *et al.* 2003) [23], for obtaining sustained yield of cotton, soil and environmental quality, addition of more organic matter /manures would be of immense need, particularly in soils of low to medium carbon status. Conservation practices, crop rotation with legume crops and addition of plant residues might play an alternative role for achieving higher status of SOC. So far as low SOC is concerned in irrigated and rainfed soils in 11 talukas, presence of low soil carbon would reflect low productivity and pose constraints in relation to nutritional availability due to poor carbon status which might be low addition of organic matter/ manures/ bio-compost/ compost/vermi-compost/ wastes *etc.* in these soils or might be due to continuous mono cropping with cotton crop which could reduce SOC in these soils. Similar results along with almost same reasons for low carbon and low productivity was put forwarded by Jatav and Mishra (2012) [6] from Chattisgarh region. The variation in SOC content from place to place both irrigated and rainfed soils might be ascribed to addition of varying quantity of organic matters / manures / biocomposts *etc.* by farmers, variations in tillage operation/ cultivation by the farmers and difference in rate of decomposition of organic matter due to differences in temperature and precipitations. When mean SOC content of all irrigated soils was compared with that of rainfed soils, it was noticed that rainfed surface soils were quite inferior to irrigated counter parts showing poor productivity index as opined by Zhang *et al.* (2003) [23]. Soil organic carbon (SOC) is a good indicator of soil productivity potential. This was possibly due to higher addition of organic matter/ manures/ compost *etc.* in irrigated soils by the farmers, apart from higher biomass production, including root of crop under irrigation and balanced fertilization resulting in higher litter fall and subsequent deposition under irrigated condition (because of hybrid cotton variety) which ultimately improved the organic carbon content of soils under arable irrigated systems. Results were supported by Padekar *et al.* (2014) [9], Negash and Mohammed (2014) [8] and Paramasivan and Jawahar (2014) [11].

The SIC content of surface soil from irrigated and rainfed area of 11 talukas of Bharuch, Surat and Narmada district are presented in Table 3. Irrigated soils of six talukas of Bharuch district revealed that SIC content ranged widely from 0.95-14.40 g kg^{-1} *i.e.* from low to high with mean value of 3.80 g

kg^{-1}. So far as categorization is concerned, 20, 70 and 10 per cent soils came respectively under 'high', 'medium' and 'low' category of SIC content. Similarly, for Surat city taluka, SIC content ranged from 5.14-6.91 g kg^{-1} with mean value of 5.94 g kg^{-1} showing 20 and 80 per cent soils under 'high' and 'medium' category of SIC content, respectively. In case of four talukas of Narmada district, SIC content widely varied from 1.68-12.10 g kg^{-1} with mean value of 5.06 g kg^{-1} showing 5, 15 and 80 per cent soils respectively with 'high', 'medium' and 'low' category of SIC content. When all the irrigated soils of 11 talukas were considered together, it was found that soil SIC widely varied from 0.95 to 14.40 g kg^{-1} exhibiting high percentage (74.5) of soils under medium SIC content followed by high (18.2 per cent), low (5.5 per cent) and very high (1.8 per cent) category of SIC content. In fact, more the content of SIC, more the chance of problems of crop root growth due to restrictions, soil salinity causing reduction of organic matters as reported earlier by Pal *et al.* (2000) [10]. Rainfed soils of six talukas of Bharuch district revealed that SIC content widely ranged from 1.58 - 11.64 g kg^{-1} with mean value of 4.91 g kg^{-1} exhibiting 23.3 and 76.7 per cent soils respectively with 'high' and 'medium' category of SIC content. However, in Surat city taluka, SIC content ranged from 9.45 - 19.40 g kg^{-1} with mean value of 13.45 g kg^{-1} showing 20 and 80 per cent soils respectively with 'very high' and 'high' category of SIC content. In case of four talukas of Narmada district, SIC content ranged from 2.27 - 10.32 g kg^{-1} with mean value of 10.72 g kg^{-1} showing 10, 70 and 20 per cent soils respectively with 'very high', 'high', and 'medium' category of SIC content. When all the rainfed soils of 11 talukas were considered together, it was found that soil SIC content widely varied from 1.58 to 19.40 g kg^{-1} exhibiting 49 per cent soils with 'medium', 45.5 per cent soils with 'high' and only 5.5 per cent with 'very high' SIC category. The results indicated that major soils of these talukas either irrigated or rainfed, contained moderate quantum of SIC. Overall mean SIC of rainfed soils was higher (8.79 g kg^{-1}) as compared to those of irrigated soils (4.93 g kg^{-1}). This might be due to the effect of dissolution process of $CaCO_3$ under irrigated condition, apart from low and erratic distribution of rainfed semi-arid climatic situation which favoured the formation of more $CaCO_3$. Similar result was observed by Shrvan Kumar (2017) [18] in cotton growing area of Bharuch. The black cotton soils / *Vertisols* from these districts (irrigated + rainfed soils) were developed over granite with patches of basaltic lava hills. The Deccan trap occurs widely in South Gujarat also. The Tapi valley and the South Gujarat plains are formed as a result of recent alluvium of trap origin which has developed black cotton soils containing higher clay content with accumulation of $CaCO_3$. For black cotton soils of Nagpur district, Maharashtra, Maji *et al.* (2005) found high amount of $CaCO_3$ (50 to 248 g kg^{-1}) due to their development from basaltic parent material. Results were also supported by Rajeshwar and Mani (2015) [13] and Ganorkar *et al.* (2015) [4].

Table 1: pH and EC and their rating in surface soils of irrigated and rainfed cotton growing 11 talukas of Bharuch, Surat and Narmada district

	No of Samples	Soil pH		Soil reaction (pH status)					Soil EC (dS m^{-1})		Soil EC category		
		Range	Mean	Neutral (6.6-7.3)	Mild Alkaline (7.4-7.8)	Moderate Alkaline (7.9-8.4)	Strongly Alkaline (8.5-9.0)	Very Strongly Alkaline (> 9.0)	Range	Mean	Low (<1.0)	Medium (1.0-3.0)	High (>3.0)
Bharuch- Dist.													
Talukas	**Irrigated**												
Bharuch	5	7.3-8.0	7.6	1 (20)	3 (60)	1 (20)	0 (0)	0 (0)	1.03-1.97	1.65	0 (0)	5 (100)	0 (0)
Jhagadia	5	7.5-8.1	7.8	0 (0)	4 (80)	1 (20)	0 (0)	0 (0)	1.08-2.08	1.60	0 (0)	5 (100)	0 (0)
Jambusar	5	6.8-8.0	7.4	3 (60)	1 (20)	1 (20)	0 (0)	0 (0)	1.05-2.14	1.71	0 (0)	5 (100)	0 (0)
Amod	5	7.7-8.6	8.2	0 (0)	2 (40)	1 (20)	2 (40)	0 (0)	0.62-1.99	1.42	2 (40)	3 (60)	0 (0)
Vagra	5	7.3-8.6	7.9	1 (20)	2 (40)	1 (20)	1 (20)	0 (0)	0.67-2.10	1.52	1 (20)	4 (80)	0 (0)
Hansot	5	6.5-8.8	7.7	2 (40)	1 (20)	0 (0)	2 (40)	0 (0)	1.45-2.85	2.22	0 (0)	5 (100)	0 (0)
Overall	30	6.6-8.8	7.8	7 (23.3)	13 (43.3)	5 (16.7)	5 (16.7)	0 (0)	0.62-2.85	1.69	3 (10.0)	27 (90.0)	0 (0)
Surat- - Dist.													
Surat city	5	7.2-8.1	7.8	1 (20)	1 (20)	3 (60)	0 (0)	0 (0)	0.69-2.01	1.45	2 (40)	3 (60)	0 (0)
Narmada- Dist.													
Talukas													
Narmada	5	7.2-8.7	7.7	1 (20)	3 (60)	0 (0)	1 (20)	0 (0)	0.75-2.01	1.54	1 (20)	4 (80)	0 (0)
Dadiapada	5	6.7-8.7	7.6	2 (40)	1 (20)	1 (20)	1 (20)	0 (0)	1.49-2.65	2.23	0 (0)	5 (100)	0 (0)
Tilakwada	5	7.2-8.8	7.9	2 (40)	1 (20)	0 (0)	2 (40)	0 (0)	1.05-2.45	1.96	0 (0)	5 (100)	0 (0)
Sagbara	5	6.9-8.8	7.6	2 (20)	2(20)	0 (0)	1 (20)	0 (0)	1.49-2.89	2.14	0 (0)	5 (100)	0 (0)
Overall	20	6.7-8.8	7.6	7 (35.0)	7 (35.0)	1 (5.0)	5 (25.0)	0 (0)	0.75-2.89	1.97	1 (5.0)	19 (95.0)	0 (0)
Overall -11 talukas	55	6.5-8.8	7.8	14 (25.5)	21(38.2)	10 (18.2)	10 (18.2)	0 (0)	0.62-2.89	1.70	6 (10.9)	49 (89.1)	0 (0)
Bharuch-Dist.													
Talukas	Rainfed												
Bharuch	5	7.9-8.5	8.2	0 (0)	1 (20)	2 (40)	2 (40)	0 (0)	0.89-1.89	1.38	1 (20)	4 (80)	0 (0)
Jhagadia	5	7.2-9.1	7.9	1 (20)	3 (60)	0 (0)	0 (0)	1 (20)	0.21-1.94	1.10	2 (40)	3 (60)	0 (0)
Jambusar	5	7.5-9.1	8.0	0 (0)	2 (40)	2 (40)	0 (0)	1 (20)	0.54-2.10	1.40	2 (40)	3 (60)	0 (0)
Amod	5	6.9-9.0	8.0	1 (20)	1 (20)	2 (40)	0 (0)	1 (20)	0.68-1.78	1.24	1 (20)	4 (80)	0 (0)
Vagra	5	7.8-9.5	8.3	0 (0)	2 (40)	2(40)	0 (0)	1 (20)	0.58-1.85	1.19	2 (40)	3 (60)	0 (0)
Hansot	5	7.6-8.6	8.2	0 (0)	1 (20)	4 (60)	0 (0)	0 (0)	1.95-2.14	2.02	0 (0)	5 (100)	0 (0)
Overall	30	6.9-9.5	8.1	2 (6.7)	10 (33.3)	12 (40.0)	2 (6.7)	4 (13.3)	0.21-2.14	1.39	8 (26.7)	22 (73.3)	0 (0)
Surat- -Dist													
Surat city	5	6.9-9.1	7.9	1 (20)	2 (40)	1 (20)	0 (0)	1 (20)	0.59-2.12	1.23	3 (60)	2 (40)	0 (0)
Narmada-Dist													
Talukas													
Narmada	5	8.7-9.1	8.8	0 (0)	1 (20)	0 (0)	3 (60)	1 (20)	0.85-1.96	1.33	3 (60)	2 (40)	0 (0)
Dadiapada	5	8.1-9.3	8.7	0 (0)	0 (0)	1 (20)	3 (60)	1 (20)	1.02-2.59	1.69	0 (0)	5 (100)	0 (0)
Tilakwada	5	7.6-9.0	8.7	0 (0)	1 (20)	0 (0)	3 (60)	1 (20)	0.84-2.10	1.49	2 (40)	3 (60)	0 (0)
Sagbara	5	6.7-9.5	8.4	1 (20)	0 (0)	0 (0)	3 (60)	1 (20)	1.20-2.31	1.92	0 (0)	5 (100)	0 (0)
Overall	20	6.7-9.5	8.7	1 (5.0)	2 (10.0)	1 (5.0)	12 (60.0)	4 (20.0)	0.59-2.59	1.61	5 (25.0)	15 (75.0)	0 (0)
Overall -11 talukas	55	6.7-9.5	8.2	4 (7.3)	14 (25.5)	14 (25.5)	14 (25.5)	9 (16.4)	0.21-2.59	1.41	16 (29.1)	39 (70.9)	0 (0)

Values in bold are numbers of samples and values in parenthesis ( ) are per cent of samples.

Table 2: CEC and ESP and their rating in surface soils of irrigated and rainfed cotton growing 11 talukas of Bharuch, Surat and Narmada district

	No of Samples	CEC (cmol (p+) kg^{-1})		Range of CEC			ESP (%)		ESP status		
		Range	Mean	(31-40)	(41-50)	(>50)	Range	Mean	Low (<5)	Medium (5-15)	High (>15)
Bharuch District	**Irrigated**										
Talukas											
Bharuch	5	42.5-57.5	50.2	0 (0)	2 (40)	3 (60)	5.33-7.90	6.78	0 (0)	5 (100)	**0** (0)
Jhagadia	5	42.0-55.2	47.5	0 (0)	3 (60)	2 (40)	4.54-8.19	5.98	1 (20)	4 (80)	**0** (0)
Jambusar	5	48.2-59.2	51.8	0 (0)	3 (60)	2 (40)	5.05-8.72	6.95	0 (0)	5 (100)	**0** (0)
Amod	5	49.0-55.1	52.8	0 (0)	1 (20)	4 (80)	3.43-7.70	5.27	3 (60)	2 (40)	**0** (0)
Vagra	5	49.3-63.8	55.3	0 (0)	1 (20)	4 (80)	5.92-8.25	7.07	0 (0)	5 (100)	**0** (0)
Hansot	5	46.2-53.9	49.6	0 (0)	4 (80)	1 (20)	5.41-6.93	6.16	0 (0)	5 (100)	**0** (0)
Overall	30	42.0-63.8	51.2	0 (0)	14 (46.7)	16 (53.3)	3.43-8.72	6.37	4 (13.3)	26 (86.7)	**0** (0)
Surat District											
Surat city	5	54.4-59.8	56.3	0 (0)	0 (0)	5 (100)	4.50-7.66	6.15	1 (20)	4 (80)	**0** (0)
Narmada District											
Talukas											
Narmada	5	46.4-59.0	51.1	0 (0)	2 (40)	3 (60)	5.43-9.13	7.64	0 (0)	5 (100)	**0** (0)
Dadiapada	5	39.9-53.6	44.5	1 (20)	4 (80)	0 (0)	3.56-10.18	5.84	1 (20)	4 (80)	**0** (0)
Tilakwada	5	35.9-46.1	42.0	1 (20)	4 (80)	0 (0)	5.21-9.03	7.85	0 (0)	5 (100)	**0** (0)
Sagbara	5	36.1-52.3	44.3	2 (40)	2 (40)	1 (20)	4.93-9.87	7.20	1 (20)	4 (80)	**0** (0)
Overall	20	35.9-59.0	45.5	4 (20.0)	12 (60.0)	4 (20.0)	3.56-10.18	7.13	2 (20)	18 (80)	**0** (0)
Overall -11 talukas	55	35.9-63.8	51.0	4 (7.3)	26 (47.3)	25 (45.5)	3.43-10.18	6.55	7 (12.7)	48 (87.3)	**0** (0)
Bharuch District	Rainfed										
Talukas											
Bharuch	5	45.7-52.1	50.2	0 (0)	4 (80)	1 (20)	5.44-9.81	7.15	0 (0)	5 (100)	**0** (0)
Jhagadia	5	42.9-50.1	45.0	0 (0)	4 (80)	1 (20)	4.40-7.71	6.20	1 (20)	4 (80)	**0** (0)
Jambusar	5	40.8-47.8	44.6	0 (0)	5 (100)	0 (0)	6.22-8.77	7.36	0 (0)	5 (100)	**0** (0)
Amod	5	42.9-54.8	48.6	0 (0)	3 (60)	2 (40)	4.80-11.56	7.80	1 (20)	4 (80)	**0** (0)
Vagra	5	44.6-52.7	50.0	0 (0)	2 (40)	3 (60)	7.46-11.08	9.38	0 (0)	5 (100)	**0** (0)
Hansot	5	42.2-53.1	47.4	0 (0)	4 (80)	1 (20)	4.52-8.05	6.54	1 (20)	4 (80)	**0** (0)
Overall	30	40.8-54.8	47.6	0 (0)	22 (73.3)	8 (26.7)	4.52-11.56	7.41	3 (10)	27 (90)	**0** (0)
Surat District											
Surat city	5	46.6-55.7	50.7	0 (0)	3 (60)	2 (40)	5.91-10.01	7.83	0 (0)	5 (100)	**0** (0)
Narmada District											
Talukas											
Narmada	5	43.6-54.0	47.0	0 (0)	4 (80)	1 (20)	7.15-10.91	9.47	0 (0)	5 (100)	**0** (0)
Dadiapada	5	39.2-46.5	41.4	2 (40)	3 (60)	0 (0)	6.58-9.67	8.33	0 (0)	5 (100)	**0** (0)
Tilakwada	5	35.9-40.4	38.6	3 (60)	2 (40)	0 (0)	5.75-10.36	8.01	0 (0)	5 (100)	**0** (0)
Sagbara	5	37.5-42.3	39.3	3 (60)	2 (40)	0 (0)	6.21-9.60	8.51	0 (0)	5 (100)	**0** (0)
Overall	20	35.9-54.0	41.6	8 (40.0)	11 (55.0)	1 (5.0)	6.21-10.91	8.58	0 (0)	20 (100)	**0** (0)
Overall -11 talukas	55	35.9-55.7	46.6	8 (14.5)	36 (65.5)	11 (20.0)	4.52-11.56	7.94	3 (5.5)	52 (94.5)	**0** (0)

Values in bold are numbers of samples and values in parenthesis ( ) are per cent of samples.

Table 3: SOC and SIC and their rating in surface soils of irrigated and rainfed cotton growing 11 talukas of Bharuch, Surat and Narmada district

	No of Samples	SOC (g kg^{-1})		SOC category			SIC (g kg^{-1})*		SIC category			
		Range	Mean	Low (<5.0)	Medium (5.0-7.5)	High (>7.5)	Range	Mean	Low (<1.2)	Medium (1.2-6.0)	High (6.0-12.0)	Very high (12.0-18.0)
Bharuch District	Irrigated											
Talukas												
Bharuch	5	5.50-9.41	6.80	0 (0)	4 (80)	1 (20)	0.95-5.40	2.17	1 (20)	4 (80)	0 (0)	**0** (0)
Jhagadia	5	3.30-8.10	5.31	3 (60)	1 (20)	1 (20)	1.22-2.41	1.97	0 (0)	5 (100)	0 (0)	**0** (0)
Jambusar	5	4.70-8.40	6.30	1 (20)	3 (60)	1 (20)	1.50-9.40	4.62	0 (0)	4 (80)	1 (20)	**0** (0)
Amod	5	5.85-9.00	7.14	0 (0)	3 (60)	2 (40)	2.58-6.40	3.76	0 (0)	4 (80)	1 (20)	**0** (0)
Vagra	5	5.40-8.94	7.02	1 (20)	2 (40)	2 (40)	4.56-14.40	8.81	0 (0)	1 (20)	4 (80)	**0** (0)
Hansot	5	4.60-8.50	6.58	1 (20)	2 (40)	2 (40)	0.96-2.48	1.45	2 (40)	3 (60)	0 (0)	**0** (0)
Overall	30	3.30-9.41	6.53	6 (20.0)	15 (50.0)	9 (30.0)	0.95-14.40	3.80	3 (10.0)	21 (70.0)	6 (20.0)	**0** (0)
Surat District												
Surat city	5	5.41-8.55	6.82	0 (0)	3 (60)	2 (40)	5.14-6.91	5.94	0 (0)	4 (80)	1 (20)	**0** (0)
Narmada District												
Talukas												
Narmada	5	5.50-7.42	6.42	0 (0)	5 (100)	0 (0)	1.85-4.25	2.97	0 (0)	5 (100)	0 (0)	**0** (0)
Dadiapada	5	2.70-7.10	5.12	3 (60)	2 (40)	0 (0)	4.68-12.10	7.07	0 (0)	2 (40)	2 (40)	**1** (20)
Tilakwada	5	4.05-6.10	5.07	3 (60)	2 (40)	0 (0)	1.68-7.20	3.98	0 (0)	5 (100)	0 (0)	**0** (0)
Sagbara	5	3.00-6.70	4.18	4 (80)	1 (20)	0 (0)	3.18-9.40	6.23	0 (0)	4 (80)	1 (20)	**0** (0)
Overall	20	2.70-7.42	5.20	10 (50.0)	10 (50.0)	0 (0)	1.68-12.10	5.06	0 (0)	16 (80.0)	3 (15.0)	**1** (5.0)
Overall -11 talukas	55	2.70-9.41	6.19	16 (29.1)	28 (50.9)	11 (20.0)	0.95-14.40	4.93	3 (5.5)	41 (74.5)	10 (18.2)	**1** (1.8)
Bharuch District	Rainfed											
Talukas												
Bharuch	5	3.60-7.90	5.71	1 (20)	3 (60)	1 (20)	1.58-5.50	3.04	0 (0)	5 (100)	0 (0)	**0** (0)
Jhagadia	5	3.30-6.45	4.92	2 (40)	3 (60)	0 (0)	2.41-5.05	3.44	0 (0)	5 (100)	0 (0)	**0** (0)
Jambusar	5	3.70-6.50	4.59	4 (80)	1 (20)	0 (0)	3.58-6.58	4.94	0 (0)	4 (80)	1 (20)	**0** (0)
Amod	5	3.15-6.15	5.15	1 (20)	4 (80)	0 (0)	2.83-6.57	4.30	0 (0)	4 (80)	1 (20)	**0** (0)
Vagra	5	4.05-6.40	4.25	4 (80)	1 (20)	0 (0)	10.10-11.64	10.85	0 (0)	0 (0)	5 (100)	**0** (0)
Hansot	5	3.17-5.85	4.99	3 (60)	2 (40)	0 (0)	1.98-4.54	2.88	0 (0)	5 (100)	0 (0)	**0** (0)
Overall	30	3.15-7.90	4.95	15 (50.0)	14 (46.7)	1 (3.3)	1.58-11.64	4.91	0 (0)	23 (76.7)	7 (23.3)	**0** (0)
Surat District												
Surat city	5	4.20-7.21	5.52	2 (40)	3 (60)	0 (0)	9.45-19.40	13.45	0 (0)	0 (20)	4 (80)	**1** (20)
Narmada District												
Talukas												
Narmada	5	4.10-5.40	4.78	3 (60)	2 (40)	0 (0)	4.25-8.82	6.24	0 (0)	2 (40)	3 (60)	**0** (0)
Dadiapada	5	2.85-4.94	4.14	5 (100)	0 (0)	0 (0)	6.84-10.32	9.54	0 (0)	0 (0)	5 (100)	**0** (0)
Tilakwada	5	3.40-4.95	4.33	5 (100)	0 (0)	0 (0)	2.41-8.18	5.48	0 (0)	2 (40)	3 (60)	**0** (0)
Sagbara	5	3.00-5.35	2.88	4 (80)	1 (20)	0 (0)	6.72-18.76	10.72	0 (0)	0 (0)	3 (60)	**2** (40)
Overall	20	2.85-5.40	4.03	17 (85.0)	3 (15.0)	0 (0)	2.27-10.32	8.00	0 (0)	4 (20.0)	14 (70.0)	**2** (10.0)
Overall -11 talukas	55	2.85-7.90	4.83	34 (61.8)	20 (36.4)	1 (1.8)	1.58-19.40	8.79	0 (0)	27 (49.1)	25 (45.5)	**3** (5.5)

Values in bold are numbers of samples and values in parenthesis ( ) are per cent of samples.

Note: * g of $CaCO_3$ kg^{-1} of soil is expressed as SIC. Hence, categorization of SIC is based on category of g of $CaCO_3$ kg^{-1} of soil.

Conclusion

High soil pH and ESP in major soils beyond threshold limit and also medium to high salinity level of cotton soils necessitate adoption of sodicity or salinity tolerant crop varieties, besides addition of gypsum in requisite quantity in soil with appropriate low-cost drainage facility in sodic soils would be beneficial for sustain soil health as well as crop yield. Thus, for obtaining sustained yield of cotton, addition of more organic matter /manures would be of immense need, particularly in low to medium carbon containing soils of these talukas. Conservation practices also might play an alternative role for achieving higher status of SOC.

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