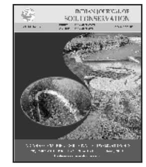
Vol. 44, No. 3, pp 343-349, 2016
Indian Journal of Soil Conservation
Online URL:http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home



Soil quality assessment of two cotton growing agroecological subregions of Vidarbha, Maharashtra

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ARTICLE INFO

Article history :
Received : March, 2015
Revised : March, 2016
Accepted : April, 2016

Key words:
Agroecological subregion,
Cotton,
Soil quality

ABSTRACT

The study was undertaken in soils of two major cotton growing Agroecological Subregions (AESRs) of Vidarbha namely, AESR 6.3 and AESR 10.2. For the same, Akola district has been selected from AESR 6.3, which is characterized by hot, moist semi-arid ecosubregion and Nagpur district is selected from AESR 10.2, which is characterized by hot, dry sub-humid ecosubregion for the study. Twelve profiles were identified for determining physical, chemical and biological indicators of soils. A minimum dataset was developed using expert knowledge for identifying soil quality indicators. Soil quality was determined using concept of Relative Soil Quality Index (RSQI). The RSQI was computed for each pedon based on the five soil attributes, which are known to exert influence on crop productivity. The RSQI was found to be the highest in pedon 3 from AESR 6.3 and pedon 12 from AESR 10.2 and was found to be good quality soil. The RSQI values of both the AESRs were significantly correlated with average cotton yield.

1. INTRODUCTION

Soil resources are precious and are directly linked to food security (quality and quantity), environmental quality and biodiversity. The concept of Soil Quality (SQ) and its significance have been recognised since ancient times. Soil quality has been defined as the capacity of soil to function within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality and promote plant, animal and human health (Carter *et al.,* 1997; Karlen *et al.,* 1998). Bouma *et al.* (1998) also lent support to the definition of Karlen *et al.* (1997) by stating that SQ cannot be seen in isolation and must be linked to certain types of land use and the associated management. In context of agriculture, SQ is a measure of soil's fitness to support crop growth without becoming degraded or otherwise harming the environment (Acton and Gregorich, 1995).

Cotton is one of the most important fibre crops of great commercial value. It is usually referred as white gold and plays a pivotal role in economic, political and social affairs of the world. It is cultivated in tropical and sub tropical regions of more than seventy countries in world over. India, during 2012-13, was the second largest producer of cotton in the world after China, accounting for about 18% of the world cotton production. The yield ha^{-1} during 2011-12, in the country (482 kg ha^{-1}) is however, much lower than the world average (754 kg ha^{-1}). By way of exports, foreign exchange earnings of cotton amount to about ₹ 760 billion which is one-third of the total foreign exchange earnings of our country. Cotton is cultivated in three distinct agro-ecological regions (north, central and south) of the country. The northern zone is almost totally irrigated, whereas the percentage of irrigated area is much lower in the central and southern zones. The central zone has nearly 60% of cotton area of our country.

The major states growing cotton in 2013 in order of hectarage were Maharashtra (4.13 m ha or 40% of the total cotton growing area in the country) representing almost half of the total area growing cotton in India in 2012, followed by Gujarat (2.36 m ha or 20%) and Andhra Pradesh (2.14 m ha or 16%) (CCI, 2013). The production and productivity of cotton in Maharashtra, during 2012-13 was 80.0 lakh bales and 329 kg ha^{-1}, respectively (CCI, 2013). Vidarbha is an important cotton growing region in Maharashtra where a continuous increase in area under cotton crop was recorded, from 15.66 lakh ha (1991-92) to 33.76 lakh ha (2009-10) (Anonymous, 2010).

An Agroecological Region (AER) that comprises homogenous set of natural physical environments, such as climate, soils and physiography (landform) often becomes a regional planning unit. The entire state of Maharashtra is categorized into four AERs, namely, AERs 6, 10, 12 and 19 (NBSS&LUP, 1992) that exhibit contrasting climate, soil and land use. Of these agro-ecological regions, 6 and 10 are the major cotton growing regions together accounting for 33.21 lakh ha (95.68%) of the cotton area in Maharashtra (Anonymous, 2010). AESR 6.3, a finer subdivision of AER 6 is the dominant cotton growing sub-region and similarly AESR 10.2, a finer subdivision of AER 10 is the dominant cotton growing sub-region.

However, no systematic study has been undertaken on SQ assessment ever before in the two AESRs. It would, therefore, be important as well as interesting to study SQ parameters in these AESRs that are dissimilar in terms of basic soils properties, weather parameters and land use.

Soil quality assessment typically includes development of Minimum Dataset (MDS) of SQ indicators and their quantification (Saybold *et al.,* 1998) which reflects the capacity of any soil to function and is derived from educational studies or general quantitative observations of soil. A minimum dataset identifies locally relevant and mutually exclusive soil indicators and evaluates the link between selected indicators and significant soil and plant properties. This dataset should consist of a number of indicators describing the quality health of the soil. Conventionally, a MDS of SQ indicator is developed based on expert knowledge of local soil conditions and soil-crop response.

Keeping this in view, the present investigation has been undertaken with the objectives, to develop RSQI using minimum datasets and to apply the index for assessing performance of cotton crop in the two AESRs.

2. MATERIALS AND METHODS

Study Area

The study area constitutes cotton growing soils of two AESRs of Vidarbha region of Maharashtra, India namely, AESR 6.3 which is characterized by hot, moist semi-arid ecosubregion with dry summers and mild winters and AESR 10.2 which is characterized by hot, dry sub-humid ecosubregion with dry summers and mild winters. Districts Akola and Nagpur were selected from AESR 6.3 and 10.2, respectively for the study. Akola district (AESR 6.3) is situated at Deccan Plateau in between 20° 42' 11"N latitude and 76° 59' 58" E longitude at an altitude of 285 m above msl and has been classified under hot, moist semi-arid ecosubregion. Nagpur district is situated at Central Highlands (Malwa, Bundelkhand and Eastern Satpura Range) in between 21°09'24" N latitude and 79°05' 17" E longitude at an altitude of 339 m above msl and has been classified under hot, dry sub-humid ecosubregion.

Site Location

Twelve cotton-growing sites, six in each district were selected for soil profile studies. In Maharashtra, cotton is grown in both shallow and deep soils, to accommodate the existing conditions selection of soil profile based on variation in soil depth. The site location details of all the pedons are given in Table 1. Information was collected from farmers on crop yield data during 2011-2013 and a relationship was developed between SQI and average cotton yield of three years (2011, 2012 and 2013). Soil samples were collected at the time of flowering for determining physical, chemical and biological properties. For biological properties, surface samples (0-30 cm) were taken freshly at the time of flowering. For physical and chemical properties, horizon-wise soil samples were collected and after analyzing them profile weighted mean (PWM) (0-150 cm) has been determined using formula:

Table: 1
Site location of selected pedons

Pedon no.	Village	Site location	Elevation (m above msl)	Soil depth
AESR 6.3 (Akola district) - hot, moist semi-arid subregion				
Pedon 1	Dongargaon	20°42'13"N 76°56'55" E	296	Very deep (150 + cm)
Pedon 2	Sonori	20°43'23"N 76°20'25" E	315	Shallow (43 cm)
Pedon 3	Mana	20°46'20"N 76°28'30" E	307	Very deep (150 + cm)
Pedon 4	Vallabhnagar	20°50'17"N 76°59'18" E	273	Deep (143 cm)
Pedon 5	Rohana	20°52'26"N 76°45'21" E	276	Deep (120 cm)
Pedon 6	Popatkhed	21°11'59"N 76°59'57" E	417	Moderately deep (91 cm)
AESR 10.2 (Nagpur District) - hot, dry sub-humid subregion				
Pedon 7	Paradi	21°27'00" N 78°32'16"E	409	Very deep (150 + cm)
Pedon 8	Mangali	21°04'04" N 78°55'17" E	312	Deep (140 cm)
Pedon 9	Waroda	21°15'43" N 78°54'36" E	339	Shallow (50 cm)
Pedon 10	Pevatha	21°02'25" N 79°05'14" E	299	Deep (108 cm)
Pedon 11	Sawangi	21°52'09" N 78°54'08" E	297	Shallow (15 cm)
Pedon 12	Shiva	21°07'22" N 78°44'40" E	393	Very deep (150 + cm)

$$PWM - X = \frac{\sum DX}{\sum Dp}$$

Where, *PWM* value was determined as the ratio of summation of depth of an individual horizon (*D*) multiplied by any parameter of soil (*X*) and total depth of the profile (*Dp*).

A Minimum Dataset (MDS) comprising physical parameters (depth, saturated hydraulic conductivity and clay), chemical (exchangeable sodium percent) and biological (soil microbial biomass carbon) parameters was developed for SQ assessment. Soil samples were analyzed for these physical, chemical and biological properties following standard procedures. Particle-size distribution (sand, silt and clay) was determined as per international pipette method (Jackson, 1979); Saturated Hydraulic Conductivity (SHC) was determined by constant head methods as per Richards (1954); Exchangeable Sodium Percentage (ESP) was determined by formula as the ratio of exchangeable Na with CEC by Jackson (1967); Soil Microbial Biomass Carbon (SMBC) was determined using the $CHCl_3$ fumigation-extraction method of Jenkinson and Powlson (1976).

Soil Quality Assessment

A number of methods are used to assess SQ namely, conventional techniques, statistical techniques such as, Principal Component Analysis (PCA), remote sensing techniques, modelling techniques to name a few are used to measure SQ. The present paper assesses SQ in AESRs 6.3 and 10.2 as per the procedure described by Karlen and Stott (1994).

Selection of the attributes for developing MDS comprising physical, chemical and biological properties of soils that best represent soil functions is made using expert knowledge (Sys, 1985; NBSS&LUP, 1994; Chatterji, 2000; Chatterji *et al.,* 2002; Kadu *et al.,* 2003; Naidu *et al.,* 2006; Venugopalan *et al*., 2009 and Chatterji *et al.,* 2014). For MDS, 5 soil attributes comprising 3 physical (depth, clay and SHC), 1 chemical (ESP) and 1 biological (SMBC) properties of soils were selected (Table 2). All these factors have been used to reflect the various aspects of SQ in relation to plant growth.

The MDS of attributes developed through expert knowledge were used for assessing SQ by using a conventional method through development of RSQI. The following steps were followed to assess soil quality:

a. Assignment of weightage: Weightage to each attribute was based on available knowledge about its relative role in influencing crop yield and also on the basis of soil conditions, cropping pattern and agro-climatic conditions of study area as also done by Davidson *et al.* (1994). Weightages are given (Table 3) on 0 to 100 scale and sum of all the weights was normalized to 100%. Depth is known to contribute more to influence cotton yield. It was, therefore, assigned the highest weight of 40, saturated hydraulic conductivity was next important property so it had a weight of 30, whereas clay, ESP and SMBC had a weight of 10 each. The sum of all the weights was normalized to 100%. These values were assigned based on expert (NBSS&LUP, 1994; Chatterji, 2000; Kadu *et al.,* 2003; Naidu *et al.,* 2006 Venugopalan *et al*., 2009) and based on personal expertise of two co-authors have long time study on cotton crop. It may also be noted that expert judgment is an experiencing criteria for assigning weight for different classes in Dhanashree *et al.,* 2014.

b. Scoring of attributes: The status of the each attribute was categorized according to four classes namely Class-I (very good), Class-II (good), Class-III (poor) and Class-IV (very poor) with assigned score of 4, 3, 2 and 1, respectively (Table 3).

c. Computation of SQI as per the method described by Larson and Pierce (1994).

$$SQI = \sum Wi\, Mi$$

Table: 2
Minimum datasets identified for assessing soil quality

MDSs Component	Justification
Depth	Cotton is a long duration deep rooted crop under conditions the tap root of cotton can grow upto 1.2 to 1.5 m depth. Soil quality was assessed under rainfed condition and being a long duration crop (6-7 months) the crop has to depend upon the moisture available in the soil profile during post monsoon period (Septeber-January). For providing adequate rooting depth and for supplying moisture depth becomes an important for MDS.
Clay	Clay by virtue of its high moisture holding capacity and their direct correlation between yield of cotton crop.
SHC	Saturated hydraulic conductivity is an important parameter which governs the moment of water in the soils.
ESP	High sodium percentage leads to structural decline e.g. dispersion of soil aggregates into individual soil particles leading to reduce water availability, low sHc, low permeability and reduced crop yield as a result of reduced availability of other nutrients.
SMBC	Soil microbial biomass carbon represents the fraction of soil responsible for energy and nutrient cycling and Regulation of organic matter transformation.

Where, *Wi* is the weight of i^{th} indicator and *Mi* is marks of i^{th} indicator class.

The theoretical range of SQI was 100 to 400 *i.e.*, the minimum value of SQI was 100 and maximum value of SQI 400 (Wang and Gong, 1998).

In order to judge the SQI value of any site against theoretical maximum value of SQI (*i.e.* 400), used the concept enumerated by Karlen and Stott (1994) and Kundu *et al*. (2012) of RSQI which is given by,

d. $$RSQI = \frac{\text{SQI of the given site}}{\text{Maximum theoretical value of SQI}} \times 100$$

e. Categorisation of RSQI: Soils with RSQI values of less than 50% were identified as poor quality soil, those with RSQI values of 50-70% as medium quality soil and those with RSQI values of more than 70% were categorized as good quality soil.

f. Correlation study: Correlation of the values of RSQI with average yield for validation.

3. RESULTS AND DISCUSSION

Properties of MDS Parameters

For physical and chemical properties of the MDS, the weighted means of all the pedons were calculated (Table 4) and the final value of weighted means (0-150 cm) was taken for each pedon. The biological properties of the MDS of the studied soils were determined for 0-30 cm soil depth.

Data (Table 4) showed the variation in soil depth and were grouped under various categories *viz.,* shallow (< 50 cm), moderately shallow (50-75 cm), moderately deep (75-100 cm), deep (100-150 cm) and very deep (>150) as per Soil Survey Manual (Soil Survey Staff, 1998). In cotton growing soils of AESR 6.3, pedon 2 (43 cm) was shallow; pedon 6 (91 cm) was moderately deep; pedons 4 (143 cm) and 5 (120 cm) were deep; pedons 1 (150 + cm) and 3 (150+ cm) were very deep. In AESR 10.2, out of six cotton growing soils, pedon 11 (15 cm) and Pedon 9 (35 cm) were shallow; Pedons 10 (108 cm) and 8 (140 cm) were deep; pedons 7 (150 + cm) and 12 (150 + cm) were very deep.

In AESR 6.3, the pedons had fairly high clay content that ranged from 39.81 to 67.64% and in AESR 10.2 it ranged from 36.11 to 66.71%. Since all the pedons are derived from basaltic parent material, they had high clay content. It is advocated that as the immediate weathering product of basalt is smectite, hence more clay was observed in soils developed on basalt (Bhattacharyya *et al*., 1993).

In AESR 6.3, SHC was found to be low and it ranged from 0.67 to 3.23 mm hr^{-1} and in AESR 10.2 it ranged from 1.54 to 3.20 mm hr^{-1}. ESP in the pedons of AESR 6.3 (except P4) ranged from 1.2 to 4.5. In P4, it was 7.7 which may be due to accelerated rate of formation and accumulation of pedogenic calcium carbonate in arid climate. Similar results were observed by Kadu *et al*. (1993) in shrink-swell soils of the Purna Valley. In the pedons of AESR 10.2, ESP ranged from 0.8 to 2.5.

SMBC is one of the most promising indicators of soil quality because it responds promptly to environmental changes, often much earlier than physical and chemical parameters (Alvarez and Alvarez, 2000). Tabatabai (1994) suggest that maximum activities of soil microbial biomass occur at pH values of about 6.5. In AESR 6.3, among the six soils, the highest SMBC (157.55 μg g^{-1}) was recorded in P6 whereas the lowest SMBC was recorded in P3 (40.97 μg g^{-1}). In AESR 10.2, the highest SMBC was recorded in P12 (157.78 μg g^{-1}) and lowest in P7 (37.97 μg g^{-1}).

Table: 4
Pedonwise weighted means of soil properties

Pedon No.	Depth (cm)	Clay (%)	SHC (mm hr^{-1})	ESP	SMBC* (μg g^{-1})
		AESR 6.3			
P1	150+	59.34	1.34	4.6	65.92
P2	43	39.81	1.69	2.5	46.76
P3	150+	60.84	3.23	1.4	40.97
P4	143	67.45	1.82	7.7	45.29
P5	120	65.98	2.40	1.9	58.22
P6	91	67.64	0.67	1.2	157.55
		AESR 10.2			
P7	150+	56.40	1.79	1.9	37.97
P8	152	60.37	1.54	1.1	62.90
P9	35	36.11	3.20	2.5	95.87
P10	108	64.81	1.80	0.8	41.86
P11	15	64.44	2.03	1.2	90.49
P12	150+	66.71	2.85	1.2	157.78

*Only surface samples were taken for SMBC

Table: 3
Soil quality indicators, their weights and classes

Soil quality indicator	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
Depth (cm)	40	> 100	100-60	60-30	<30
SH (mm hr^{-1})	30	>5.5	5.5-2.5	2.5-1.5	<1.5
Clay (%)	10	35-50	<35	50-60	>60
ESP	10	>1.5	1.5-2.5	2.5-4.5	>4.5
SMBC (μg g^{-1})	10	>90	90-65	65-45	<45

Seed Cotton Yield

Under identical set of management, crop yield can be an important indicator of soil quality, because it serves as a plant bioassay of the interacting soil characteristics. Otherwise also, the ultimate outcome of good soil quality is yield or economic produce.

Average of three years (2011, 2012 and 2013) yield information for cotton was collected from farmers' fields (Table 5). In AESR 6.3, pedon 3 had the highest average yield of 29 q ha^{-1} and the lowest average yield of 13.5 q ha^{-1} was recorded in pedon 2. In AESR 10.2, pedon 12 had the highest average yield of 35 q ha^{-1} and the lowest yield was observed in pedon 11 with an average yield of 12 q ha^{-1}.

Cotton is a deep rooted crop but pedons 2 and 6 in AESR 6.3 and pedons 11 and 9 in AESR 10.2 were shallow in depth. Ideally these soils are not recommended for cotton cultivation and alternative shallow rooted, short duration crops may be adopted. In case, the farmers wish to continue with cotton, then they may be advised to adopt High Density Planting System (HDPS) using early, semi compact varieties recommended for this purpose in order to improve yield on these soils (Venugopalan *et al.,* 2013).

Across AESRs, it is evident from Table 5 that seed cotton yield of P9 (35 cm) in AESR 6.3 a shallow soil was higher than the yield of P1 (150 cm) and P5 (120 cm) in AESR 6.3. It may be noted that the average rainfall in AESR 10.2 (1150 mm) is greater than the average rainfall in AESR 6.3 (750 mm). The higher rainfall is known to moderate the effect of soil depth by making additional quantity of water available to crop growth.

Soil Quality Assessment

The SQI and RSQI values of soils of both the AESRs were calculated (Table 6). The highest RSQI in AESR 6.3 was obtained for pedon 3 (72.5%), whereas the lowest was found for pedon 2 (52.5%). On the other hand, in case of soils of AESR 10.2, the highest RSQI was obtained for pedon 12 (87.5%) and the lowest for pedon 11 (47.5%).

Table: 5
Average yield (q ha^{-1}) of seed cotton

Pedon No.	Year-wise yield (q ha^{-1})			Average yield (q ha^{-1})
	2010-11	2011-12	2012-13	
		AESR 6.3		
P1	19.9	17.1	22.4	19.8
P2	14.4	10.5	15.6	13.5
P3	28.0	25.9	33.1	29.0
P4	17.1	12.5	23.0	17.5
P5	19.7	18.7	27.9	22.1
P6	16.2	13.2	17.3	15.6
		AESR 10.2		
P7	25.2	22	27.8	25.0
P8	26.3	26	28.7	27.0
P9	21.9	20.4	23.7	22.0
P10	30.2	28.4	35.9	31.5
P11	12.1	9.7	14.2	12.0
P12	36.8	29.8	38.4	35.0

The results (Table 6) indicate that the RSQI was positively correlated with average yield. The linear regression lines were also drawn using RSQI values (x) with average yield (y) and their mathematical expressions were y = 0.634 x - 20.62 (R^2 = 0.81) for the soils of AESR 6.3 and y = 0.58 x - 15.0 (R^2=0.89** *i.e.,* significant at 5% level) for the soils of AESR 10.2 (Fig. 1 and Fig. 2). It is observed from above discussion that the soils of AESR 10.2 had highest correlation of RSQI with average yield (R^2= 0.90** *i.e.* significant at 5% level) as compared to those of AESR 6.3 (R^2= 0.81).

About 81% of the yield variations in AESR 6.3 and 89% of yield variations in AESR 10.2 could be attributed

Table: 6
Relative soil quality index (RSQI) of different pedons

Pedon No.	SQI	RSQI	Pedon No.	SQI	RSQI
AESR 6.3			AESR 10.2		
P1	270	67.50	P7	280	70.0
P2	210	52.50	P8	290	72.5
P3	290	72.50	P9	260	65.0
P4	230	57.50	P10	280	70.0
P5	280	70.00	P11	190	47.5
P6	240	60.00	P12	350	87.5

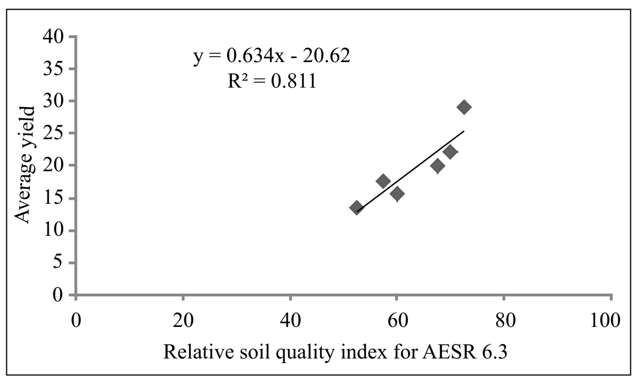

Fig. 1. Relation between RSQI and average yield of AESR 6.3

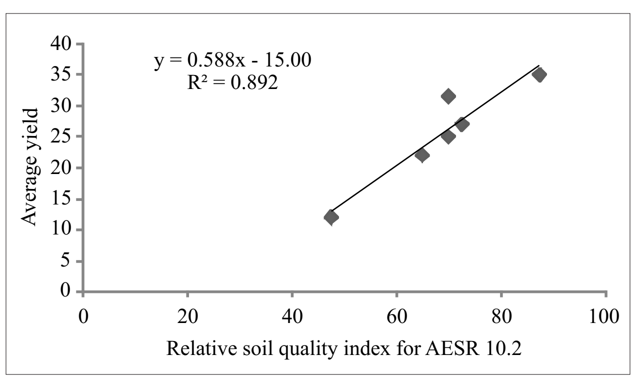

Fig. 2. Relation between RSQI and average yield of AESR 10.2

to the RSQIs. This is essential because the individual parameter selected for MDS *viz.,* depth, SHC, clay, ESP and SMBC have a strong influence in determining the yield of rainfed cotton in soils of study area. These properties regulate essential physical (infiltration, moisture availability), chemical (nutrient balance) and biological (nutrient mineralization) functions require for supporting optimum growth and yield of cotton crop.

Based on RSQI, pedons were categorized into quality ratings (Table 7). In AESR 6.3, pedons 1, 2, 4 and 6 were medium in soil quality, whereas pedons 3 and 5 were good in soil quality. In AESR 10.2, pedons 7, 8, 10 and 12 were good in soil quality; pedon 9 was medium in soil quality and pedon 11 was poor in soil quality.

4. CONCLUSIONS

Whenever we have such datasets (as used in the present investigation) for similar agro-ecological setups, we can compute soil quality indices by using this method for assessing and monitoring soil quality**.** Having mentioned this, more studies will, however, need to be conducted before this method could be recommended as a standard method of soil quality assessment in the respective similar agroecological setup. Once this is done, the soil quality indices could also be effectively used to determine the future course of action for sustaining and improving the quality of soils.

Table: 7
Grouping of soils into different categories based on RSQI

Pedon No.	RSQI	Quality rating	Pedon No.	RSQI	Quality rating
AESR 6.3			AESR 10.2		
P1	67.5	Medium	P7	70.0	Good
P2	52.5	Medium	P8	72.5	Good
P3	72.5	Good	P9	65.0	Medium
P4	57.5	Medium	P10	70.0	Good
P5	70.0	Good	P11	47.5	Poor
P6	60.0	Medium	P12	87.5	Good

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