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Mango-Growing Soils in Eastern India: West Bengal as Case Study

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Abstract: Mango-growing soils representing different agro-ecological sub-regions of West Bengal, India are very deep, well drained, and coarse-loamy to fine textural class in control section. They are moderately acid to slightly alkaline (pH 5.6 to 7.9), low to high in organic carbon (4.2 to 9.0 g kg^{-1}), low to medium in CEC [6.2 to 26.8 cmol (p^{+}) kg^{-1}] and high in base status (58 to 86 %). Soil texture, drainage congestion and soil fertility (especially pH and organic carbon content) are the major contributing factors towards the sustainable cultivation of mango in lower Indo-Gangetic plains. The type and nature of clay plays a crucial role for the good growth and yield of mango. These soils also help to increase the SOC stock and thereby improving soil health and mitigating the green house gases from the environment. The area for mango cultivation can be turned into highly productive zone through integrated nutrient management practices including leguminous intercrops or cover crops.

Keywords: *Mango soils, characteristics, agro-ecological sub region, INM, West Bengal*

Introduction

Ever increasing population of our country warrants more production of fruits to bridge the gap between per capita consumption and recommendation. This can be achieved by increasing the area under fruit crops and or by increasing the productivity per unit area. Fruit crops play an important role in the national food security of people around the world. They are generally delicious and highly nutritious, mainly of vitamins and minerals that can balance cereal based diets. Fruits supply raw materials for local industries and could be sources of foreign currency. Moreover, the development of fruit industry will create employment opportunities, particularly for farming communities. In general, Ethiopia has great potential and encouraging policy to expand fruit production for fresh market and processing both for domestic and export markets. Besides, fruit crops are friendly to nature, sustain the environment, provide shade and can easily be incorporated in any agro-forestry programs. Mango fruit appears to be one of the critical food sources for the consistently growing world population (UNCTAD 2016). It is the most popular and cultivated fruits of tropical and sub-tropical regions, ranked the second most cultivated tropical fruit and sixth major fruit crop worldwide (UNCTAD 2016).

Mango (*Mangifera indica* L.), a delicious fruit crop mostly grown in India for over 4000 years (Mukherjee 1967) and it has been originated from Indo-Burma (Myanmar) region (Pandey and Dinesh 2010; Ganguli *et al.* 2019; Bhattacharyya *et al.* 2018, 2019; Salvi *et al.* 2018). This fruit crop from tropical centre of origin is now gradually moved to sub-tropical land and largely cultivated; hence it is also termed as pan tropical

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fruit. It is grown at the equator and at latitude of 350-370 in southern Spain (Mukherjee and Litz 2009).

Besides delicious taste, excellent flavour and attractive fragrance, it is rich in vitamin A and C. It is high in beta-carotene, a precursor of vitamin A and is a rich source of vitamin B complex. The fruit contains nearly 81 per cent moisture, 0.4 per cent fat, 0.6 per cent proteins, 0.8 per cent of fibers. It also contains nearly 17 per cent of carbohydrate. The fruit is rich with important minerals like Potassium, Magnesium, Sodium, Phosphorus, and Sulphur. Mango contains over 20 different vitamins and minerals (Anonymous 2013).

Mango is the leading fruit crop of India and considered to be the king of fruits in the orient and the “National fruit of India". The tree is hardy in nature, can be grown in a variety of soil and requires comparatively low maintenance costs. Mango fruit is utilized at all stages of its development both in its immature and mature state. Raw fruits are used for making chutney, pickles and juices. The ripe fruits besides being used for desert are also utilized for preparing several products like squashes, syrups, nectars, jams and jellies. The mango kernel also contains 8-10 per cent good quality fat, which can be used for soap and also as a substitute for cocoa butter in confectionery.

Soil is the source of essential plant nutrients. So, its physical and chemical properties have fundamental importance for healthy growth of plants and productivity. The ability of soil to support plant's growth and productivity is positively related to its fertility status. Cropping pattern and farming system of any region is largely determined by the properties of soil. Thus the soils serve as reservoir of nutrients and water for crops and also provide mechanical anchorage and favourable tilth (Murthy and Hirekerur 2005). Most mango soils have imbalanced nutrient concentrations due to the exhaustive removal of nutrients by intercropped plants, augmented by partial or no soil replenishment, which results in long-term plant micronutrient deficiency.

Mango prefers very deep, well drained, red loamy, slightly acidic to neutral soils with water table below 6 ft. from the surface in every season of the year for its cultivation. The quality and taste of mango varies depending on the different varieties, agro-climate, balance between organic acids and soluble sugars which are predominantly represented in mango by citric and malic acids and sucrose, fructose and glucose, respectively (Medlicott and Thompson 1985).

Studies on soils in terms of its physical and chemical characteristics are essential to address different soil related issues pertaining to the quality, taste and production of mango. Soils play a very crucial role not only to increase the availability of soil moisture to the plants but also hold and release some of the essential nutrients to the plant and therefore information on physical and chemical makeup of the soil is important towards the management of natural resources. Therefore, basic information on soil resources has become imperative for scientific utilization of these natural resources for increasing productivity of the crops.

Mango grows well on wide variety of soils, such as lateritic, alluvial, sandy loam and sandy. Although it grows very well in high to medium fertility soils, its cultivation can be made successful even on low fertility soils by appropriate management especially during early stages of growth. The loamy, alluvial, well drained, aerated and deep soils rich in organic matter with a pH range of 5.5 to 7.5 are most favourable for mango cultivation. Extremely sandy, shallow, rocky, waterlogged, heavy textured and alkaline or calcareous soils are not suitable for mango cultivation.

Mango cultivation in the world

Mangos can be grown on a wide range of soil types, from light sandy loams to red clay soils. Soil pH of 5.5 to 7.5 is preferred. Deep and well- drained soils rich in organic matter give the best production and fruit quality. Moderately sloping sites are also recommended to prevent waterlogging. Deep soils without impermeable layers permit the development of deep taproots that aids in drought tolerance and wind resistance. Although mango cultivation on hard rock is not uncommon (Bhattacharyya *et al.* 2019). Mangoes grow from sea level to an elevation of about 1,500 feet in Hawaii, but mangos are most productive below 375-400 m above mean sea level. Mango is best adapted to hot, dry leeward areas that receive less than 1500 mm of rainfall annually, but supplemental irrigation is desirable for better performance. (Anonymous 2017).

Mango is one of the most consumed fruits worldwide, and it is still mostly appreciated in the fresh form. However, the consumption of mango processed products has grown due to the rising demand for practical foods, increases in products shelf life and in the awareness of the benefits of fruits on human health. The international trade of fresh mango has started in recent years where India and other Asian countries contribute the major share of global mango of which India alone produces an average of 19.69 million tonnes per year (Ganeshmurthy *et al*. 2018). The cultivation has now spread to more than 100 countries. There are more than 65 countries which produce more than 1,000 MT a year contributing to the total 40 MT global production of mangoes (FAO 2017). The demand for mango fruits, particularly from temperate countries, is increasing. European countries and the USA are the leading importers of fresh fruits. Though the main mango season is March to July, the mango season is expanding especially in the countries like Venezuela, Kenya, Columbia and Brazil, (Mitra 2016) due to the changes in the season. Presently, the mango is being cultivated commercially or in the backyard or as a mixed plantation in 89 countries of the world. The major mango-growing countries are India, Pakistan, Bangladesh, Myanmar, Sri Lanka, Florida and Hawaii of USA, Australia, Brazil, Thailand, the Philippines, Malaysia, Vietnam, Indonesia, Fiji Islands, Egypt, Israel, South Africa, Sudan, Somalia, Kenya, Uganda, Tanzania, Niger, Nigeria, Zaire, Madagascar, Mauritius, Venezuela, Mexico, West Indies Islands, Cambodia *etc.* The area, production and productivity in leading mango producing countries of the world are presented in table 1 and fig. 1.

Table 1. Area, production and productivity in leading mango producing countries of the world

Country	Area (ha.)	Share (%)	Production (million tons)	Share (%)	Productivity (t ha^{-1})
India.	2.52	46.0	19.69	41.6	6.92
China	0.48	8.8	4.62	10.7	9.6
Thailand	0.38	7.0	3.14	7.3	8.27
Indonesia	0.2	3.7	2.06	4.8	10.5
Mexico	0.2	3.7	1.9	4.4	9.56
Pakistan	0.17	3.1	1.66	3.8	9.68
Brazil	0.07	1.3	1.16	2.7	16.53
Bangla-desh	0.12	2.2	0.95	2.2	7.66
Nigeria	0.13	2.4	0.85	2.0	6.54
Egypt	0.09	1.7	0.83	1.9	9.09
Others	1.1	20.2	8.12	18.8	7.41
World	5.44	-	43.3	-	7.96

(Source: FAO 2017).

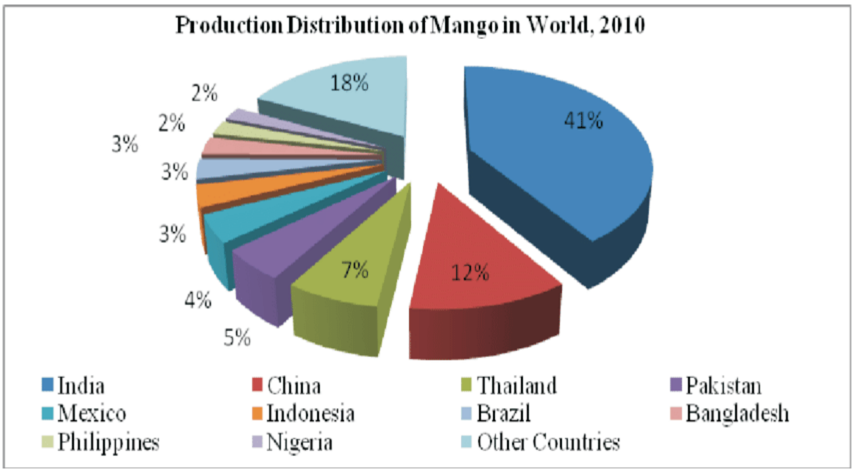


Fig. 1. Production distribution of mango in world, 2010

Mango cultivation in India

India ranks first among world's mango producing countries accounting for about 50 per cent of the world's mango production (Table 1). In India, the area under mango cultivation was recorded as 2262.8 thousand ha in 2016-17 with the production of 19686.9 thousand MT of mango with the productivity of 8.7 MT ha^{-1}, while that was recorded in West Bengal as 97.93 thousand hectare area with the production of 836.07 thousand MT giving rise to the productivity of 8.5 MT ha^{-1}. (Indian Horticulture Database 2009). In India, the important mango producing states are Andhra Pradesh, Uttar Pradesh, Karnataka, Bihar, Gujarat, Maharashtra, Tamil Nadu, West Bengal, Kerala, and Orissa (Fig. 2.). The state-wise area and production of mango in India for the year 2015-16, 2016-17 and 2017-18 is presented in table 2. The productivity of mango unfortunately declining over the years. The national average productivity is as low as 5.5 t ha^{-1} while Uttar Pradesh, which tops in the productivity produces 17.14 t ha^{-1} (Naik 2014). Poor plant population, growing of traditional low yielding varieties, poor nutrient and water management are the key factors of sustainable productivity of mango.

Table 2. State-wise area and production of mango in India

Sl. No.	States/Uts	2015-16		2016-17		2017-18	
		A	P	A	P	A	P
1	Andhra Pradesh	327.31	2803.66	336.96	4043.47	363.00	4373.61
2	Arunachal Pradesh	0.05	0.03				
3	Assam	4.62	46.15	4.66	47.15	4.68	48.44
4	Bihar	149.14	1464.93	149.96	1472.38	149.28	2443.47
5	Chattishgarh	71.52	420.61	74.17	434.32	77.03	461.73
6	Gujrat	153.18	1241.59	161.27	1424.87	162.77	1207.78
7	Haryana	9.26	89.97	9.34	96.79	9.35	98.60
8	Himachal Pradesh	41.52	37.63	41.77	48.24	41.99	31.35

9	Jammu & Kashmir	12.67	23.74	12.74	24.15	12.96	30.35
10	Jharkhand	50.41	393.67	50.56	438.54	54.53	435.86
11	Karnataka	181.70	1725.67	180.60	1719.73	183.23	1760.60
12	Kerala	70.13	382.52	70.41	388.14	83.12	439.20
13	Madhya Pradesh	27.89	371.48	43.42	586.24	45.52	654.79
14	Maharashtra	162.08	463.17	156.84	603.83	166.76	791.36
15	Mizoram	0.87	4.18	0.89	4.18	0.91	4.19
16	Nagaland	0.57	3.74	0.64	4.23	0.64	4.24
17	Odisha	199.29	778.72	199.42	817.91	199.08	805.77
18	Punjab	6.74	113.50	6.75	113.69	6.90	116.52
19	Rajasthan	5.00	82.27	5.16	154.79	4.97	87.37
20	Tamil Nadu	125.98	975.11	176.42	1282.44	152.57	1234.00
21	Telengana	194.05	1778.32	111.65	482.46	115.99	1080.14
22	Tripura	11.75	59.06	10.64	57.03	10.33	54.93
23	Uttar Pradesh	263.28	4512.71	264.94	4341.00	265.62	4551.83
24	Uttarakhand	35.91	149.73	36.42	150.14	36.48	152.71
25	West Bengal	96.74	693.39	99.22	736.90	103.25	918.35
	Others	6.91	27.00	7.40	33.58	7.17	35.14
	Total	**2208.56**	**18642.53**	**2212.24**	**19506.20**	**2258.13**	**21822.32**

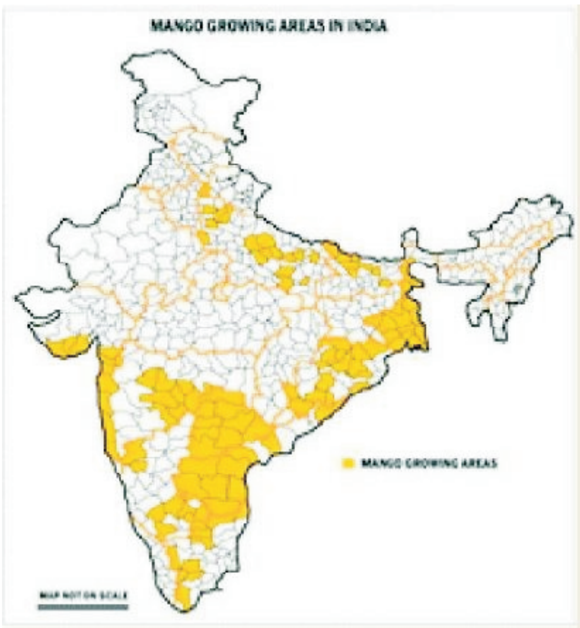


Fig.2. Mango-growing areas in India
Source: Ganeshamurthy *et al*. (2018)

In India, the area, production, productivity of mango during 2006-07 to 2016-17 is presented in fig. 3 and 4. However, the area and production of mango in different states in India during 2012-13 is presented in fig. 5 and 6. India ranks first in mango production in the world. But due to certain limitations, mango productivity is declining in the country. In the traditional low density cultivation (per ha plant population in mango orchard ranges from 75 -100 trees), mango trees become very big, which make it difficult to perform the needed cultural operations, like training, pruning, disease pests control *etc.* As a result, irregular bearing of fruits becomes the rule rather than an exception. Low yield or no yield is also common due to alternate bearing. Poor nutrient and water management are also very important factors to improve the needed productivity. The low productivity of mango is due to either soil related constraints or management of tree/orchards or climatic extremities or combination of all these factors. Again, within the soil related constraints, low yield to rainfed areas, nutritional deficiencies, soil constraints and biotic and abiotic stress are dominant (Ganeshmurthy *et al.* 2018). Of late, high-tech horticulture known as high density planting (HDP), has come into vogue, which is capable of removing the limitations of mango productivity in India. Poor plant population, growing of traditional low yielding varieties, poor nutrient and water management are the key factors of low productivity.

Even though India occupies the prime position in the production of mango fruits in the world, still mango cultivars of India are facing grave challenges including: very small land holding. mango transportation and marketing problem, maximum orchards are 35-40 years old, providing low yield, lack of proper training on fertilizer application, irrigation, pest and diseases management, non-availability of good quality saplings, drying of branches, Insect attack (mango hopper, mealy bug, fruit fly *etc.*), disease infestations (anthracnose, powdery mildew, mango malformation), middle man menace, lack of harvesting and post harvesting technology *etc*.

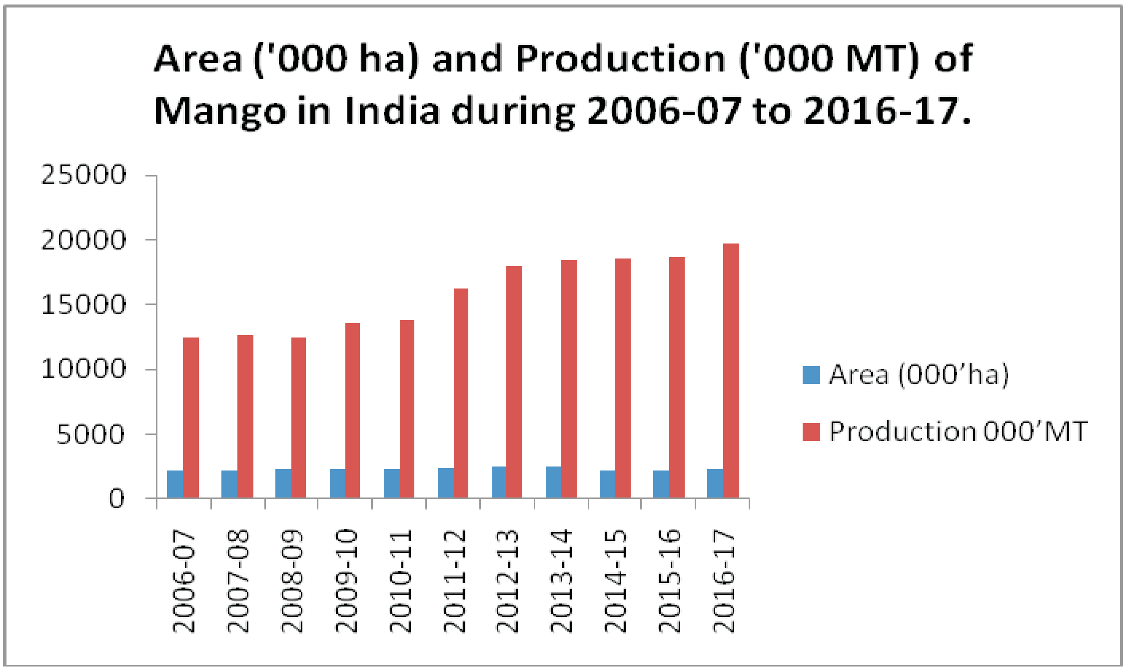


Fig. 3. Area ('000 ha) and Production '000 t) of mango in India during 2006-07 to 23016-17.

Source: Horticultural Statistics at a Glance, NHB (2018)

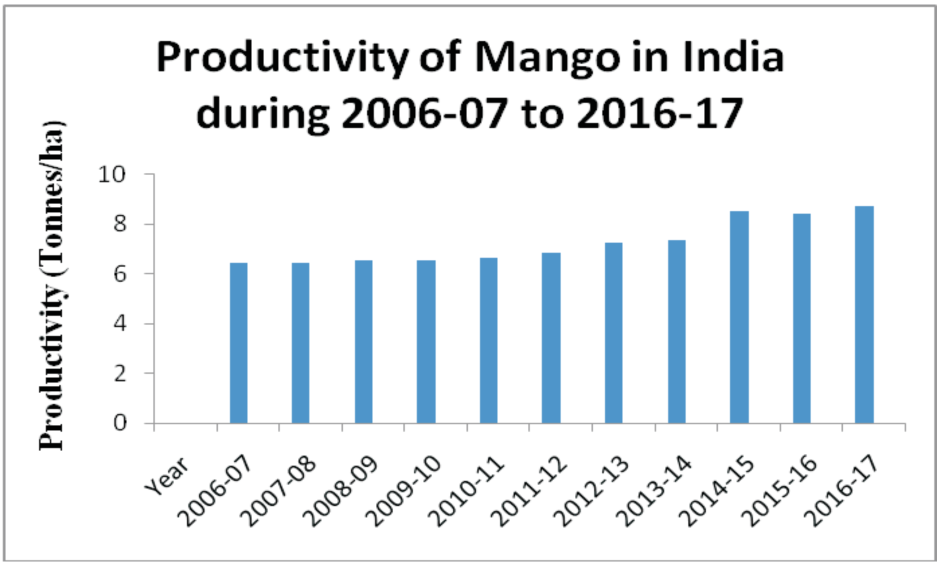


Fig. 4. Productivity of mango in India during 2006-07 to 2016-17

Source: Horticultural Statistics at a Glance, NHB (2018)

However, mango orchards face several problems like micronutrient deficiencies, physiological stresses, and fruit yield and quality challenges (Kumar and Kumar 2016) that ultimately decrease production and exports. Many of the mango-growing soils in Asia are calcareous, mostly intercropped, and received less than the optimum doses of fertilizers (Masroor *et al*. 2016). Additionally, soils are mainly deficient in zinc (Zn) and boron (B) (Alloway 2009). Boron, an essential micronutrient, plays a critical role in the growth and enlargement of reproductive cells, initiation of flowering, and translocation of sugars (Bariya *et al*. 2014). Prolonged lack of results in premature shedding of flower or fruit, suggesting a higher demand for Boron during floral or fruit development (Bariya *et al*. 2014). Zinc is also known to be essential for metabolic processes and enzymatic and redox reactions occurring in plant cells. Zinc is directly involved in many plant growth processes, like the synthesis of specific amino acids (Hegde and Venkatesh 2007). Its deficiency is prevalent in mango orchards due to the calcareous nature of soils that do not support the micronutrient uptake.

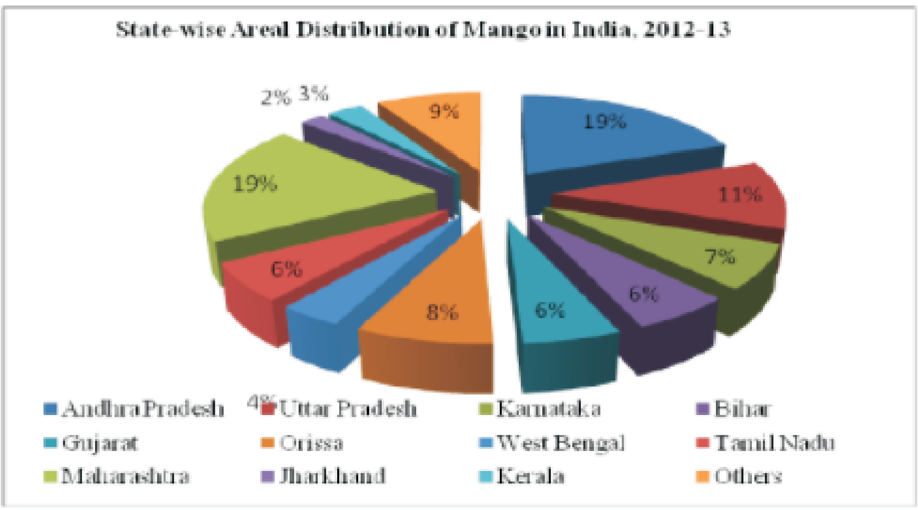


Fig. 5. State wise distribution of mango in India, 2012-13

Source: Indian Horticulture Database (2013)

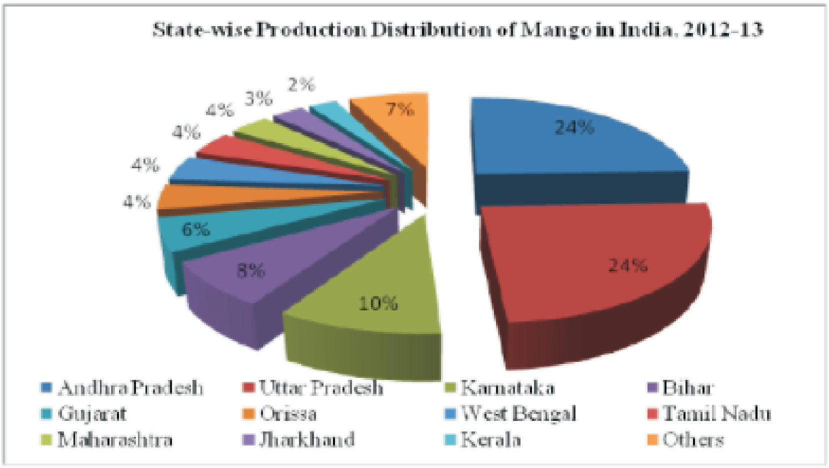


Fig. 6. State wise production of mango in India, 2012-13.
Source: Indian Horticulture Database (2013)

Mango cultivation in West Bengal

In West Bengal, mangoes are grown on many groups of soils under various agro-ecological sub-regions occupying about 80.90 thousand hectares which is more than 41 per cent of total area under fruits. As per Horticultural Statistics Division, Department of Agriculture, Cooperation and Farmers Welfare (2018), the production of mango in West Bengal during the period of 2015-16, 2016-17 and 2017-18 are presented in table 3.

Table 3. Major area and production of mango in west Bengal

Year	A	P
2015-16	96.74 (4.38)	693.39 (3.72)
2016-17	99.22 (4.48)	736.90 (3.77)
2017-18	103.25 (4.57)	918.35 (4.21)

A – Area in '000 ha; P – Production in '000 t
Source : Horticultural Statistics Division, Department of Agriculture, Cooperation & Farmers Welfare, 2018.

The figures in parenthesis indicate per cent of total area and production respectively.

Again, the area and production of mango in different districts of West Bengal (Table 4) indicates that the productivity of mango varies within the districts.

Table 4. Area and production of mango in different districts of West Bengal.

District	2015-16		2016-17		Productivity (t/ha)	
	A	P	A	P	2015-16	2016-17
Maldah	30.48	270.00	30.59	292.28	8.86	9.55
Murshidabad	18.04	146.08	19.79	162.42	8.09	8.20
24 Parganas North	7.62	65.42	7.15	65.82	8.58	7.67
Nadia	5.53	54.28	5.61	55.08	9.81	9.81

A – Area in '000 ha; P – Production in'000 t

Source : Horticultural Statistics Division, Department of Agriculture, Cooperation & Farmers Welfare (2018).

The data (Table 4) reveals that the production of mango is highest in the Maldah and Murshidabad district under lower Indo-Gangetic plain of West Bengal under agro-eclogical sub-region III, developed from old and young Indo-Gangetic alluvial plain.

Several workers *viz.* Yadav and Pande (2016), Murmu *et al*. (2017), Ganeshmurthy *et al*. (2019), Biswas and Kumar (2011), Singh *et al*. (2014), Bhattacharyya *et al*. (2018) and Bhattacharyya *et al.* (2019) have studied the different aspects of mango-growing soils. However, the knowledge and problems of soils supporting mango in the different agro-ecological sub-regions of West Bengal is meagre. The present study is an attempt to identify the characteristics of soils growing mango in different agro-ecological sub regions of West Bengal and the management needs for increasing productivity.

Materials and Methods

Study area

Six soil series ranging from Tista valey (Cooch Behar) through the Indo-Gangetic plain (Raigunj, Maldah, Murshidabad) upto undulating upland (Puruliya) supporting mango cultivation areas out of the soil series identified from entire West Bengal (Nayak *et al*. 2001) under different agro-ecological sub-regions, were studied for their morphological, physical and chemical characteristics. The location and environmental condition of the study area is presented in table 5. Mango is cultivated in all the geographical regions with significant variation in area, production and productivity. Thus, the study area represents the Tista valley developed from alluvium/colluviums, Indo-Gangetic plain from alluviums of river Ganges of different ages and undulating upland developed from granite gneiss with different physical and physiographic set up. As per Agro-climatic zones of West Bengal (Table 6), the study area falls under Agroclimatic zone II, Zone III and Zone VII (Banerjee *et al*. 2019). The climate of the study area changes from humid subtropical to sub-humid sub-tropical with annual precipitation ranges from 1100 to 3500 mm. The moisture and temperature regimes are 'Ustic' and 'Hyperthermic'. Paddy is the principal crop of this area. Besides this, pulses, oil seeds, vegetables and horticultural crops are grown in this area.

Table 5. Location, environmental conditions of soils in the study area.

Soil series	Location	Landform	Drainage	Land use	Agro-ecological Subregion*	Agro-ecological Region*
Nam-pur	Vill-Nampur, P.S.-Kaliachak. Maldah, W.B. (24˚54' N latitude and 88˚30' E longitude)	Nearly level (0-1 % slope) Active alluvial plain under Indo-Gangetic alluvial plain (Tista plain)	Imperfectly drained	Paddy, mango	Old alluvium	Gangetic Region under Zone III
Alina-gar	Vill.-Nampur, P.S.-Kaliachak, Maldah, W.B. (24˚52′ N latitude and 88˚03′ E longitude),	Very gently sloping (1 -3 % slope), Active alluvial plain under Indo -Gangetic alluvial plain (Tista plain)	Well drained	Paddy, mango	Old alluvium	Gangetic Region under zone III.
Durgapur	Vill-Durgapur, P.S.-Raigunj, North Dinajpur, W.B.(25˚32' N latitude and 88˚09' E longitude)	Nearly level (0 -1 % slope), Recent alluvial plain under Indo-Gangetic alluvial plain (Tista plain),	Imperfectly drained	Paddy, pulses, mango	Old alluvium	Gangetic Region under zone III
Jhunka	Vill-Jhunka, P.S. Beldanga, Murshidabad, W.B. (24˚0' N latitude and 88˚15' E longitude),	Nearly level (0 -1 % slope), meander alluvial plain under Indo-Gangetic alluvial plain (Bengal basin)	Well drained	Paddy, pulses, oilseeds, mango	New alluvium	Gangetic Region under zone III
Sirka-bad	P.S.-Arsha, Puruliya, W.B. (23˚16′ N latitude and 86˚13′ E longitude),	Very gently sloping (1 -3 % slope), Chhotanagpur plateau (Granite-gneiss landscape) undulating plain.	Well to moderately well drained	Paddy, mango	New alluvium	Gangetic Region under Zone IV
Matiarkuthi	Vill.-Matiarkuthi, P.S.-Cooch Bihar Sadar, W.B. (26˚20'N latitude and 80˚18' E longitude)	Very gently sloping (1 -3 % slope) Recent alluvial plain under Indo -Gangetic alluvial plain (Tista plain),	W#ell drained	Paddy, oilseed, mango, jackfruit	Terai	Eastern Himalayan region under Zone II.

Table 6. Agro-climatic zones in West Bengal

Zone	Region	Sub-region	District covered	Characteristics	Major Horticultural Crops
Zone II	Eastern Himalayan Region	Hills	Darjeeling	Mainly brown forest soil,acidic in nature(pH 3.5-5.0), rainfall -2500-3500 mm.	Pine apple, Mandarine, Orange, Tomato.
		Terai	Jalpaiguri, Cooch Behar	Soils are mostly sandy to sandy loams, porous, low in base content, acidic in nature (pH 4.2-6.2), rainfall -2000-3200 mm.	Pine apple, Jackfruit, Orange, Banana, Guava, Tomato, Cashew, Turmeric
Zone III	Gangetic Region	Old alluvium	North and South Dinajpur and Malda	Soils are mildly acidic to neutral (pH 5.2-7.0), rainfall -1500-2000 mm.	Mango, Pine apple, Litchi, Tomato, Cabbage, Cauliflower
		New alluvium	Murshidabad, Nadia, Hooghly, Burdwan, North 24 Parganas	Soils are deep, neutral in reaction (pH 5.5-7.0) and fertile, rainfall -1350-1450 mm	Mango, Banana, Litchi, Guava, Onion, Tomato, Cabbage, Cauliflower, Cashew, Papaya, Turmeric
		Coastal saline	South 24 Parganas, Howrah, Purba Medinipur	Soils are mostly with heavy clay containing higher salts with pH 6.5-7.4, rainfall -1600-1800 mm	Mango, Sapota, Onion, Tomato, Betelvine, Chilli, Papaya, Litchi, Coconut, Cashewnut
		Red lateritic	Birbhum, Bankura, Paschim Medinipur	Soils are coarser in texture and erosion prone, pH 5.5-6.2, rainfall -1100-1400 mm	Mango, Guava, Onion, Tomato, Cashew
Zone VII	Eastern plateau and hill region		Purulia	Soils are gravelly, coarse textured, low water holding capacity, pH 5.5-6.2, rainfall -1100-1400 mm	Guava, Tomato

Source: Haldar and Das (2012)

Representative soil profiles were exposed up to 150 cm depth and the horizon-wise soils were studied morphologically (Soil Survey Division Staff 1995). The representative soil samples from all the horizons were collected and characterized for important physical and chemical properties following standard procedure (Jackson 1973; Black 1965).

Results and Discussion

Morphological properties

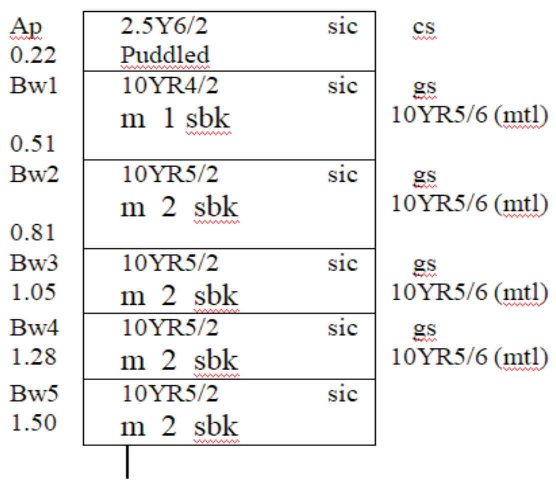
The morphological properties of the mango-growing soils under different agro-ecological sub regions of West Bengal are presented in fig 7. Soils are very deep, well to somewhat poorly drained, coarse-loamy to fine in control section, puddled in the surface and single grain (sg) to moderate medium sub-angular blocky (2m sbk) structure in the sub-surface to sub-soil and are slight to moderately eroded. The soils of Terai sub-region (pedon 6) from Cooch Behar are very deep, moderately well drained, gray (10YR 5/1) in the surface and gray (10YR5/1) to light gray (10YR7/1) in the sub-surface to sub-soil with redox depletion, coarse-loamy in control section with sandy loam texture at the surface and sandy loam to sand in the sub-surface to sub-soil leading to weak fine sub-angular blocky to single grain structure and thus the moist consistency is usually friable, slightly sticky and non-plastic to friable, non-sticky and non-plastic and slightly to moderately eroded.

Soils of old-alluvial sub-region under Indo-Gangetic Region (pedon 1, 2 and 3) from North Dinajpur and Maldah are very deep, moderately well to somewhat poorly drained, light brownish gray (10YR 6/2) to very dark grayish brown (10YR3/2) at the surface , dark yellowish brown (10YR 4/2) to very dark grayish brown (10YR 3/2) at the sub-surface to sub-soil with redox depletion, coarse-loamy to fine in soil control section with loam to silty clay surface texture and loamy sand to silty clay texture in the sub-surface to sub-soil, puddled at the surface and weak medium sub-angular blocky to massive in the sub-surface to sub-soil, friable, slightly sticky and slightly plastic moist consistency at the surface and friable, non-sticky, non-plastic to friable, sticky and plastic in the sub-surface to sub-soil and slightly to moderately eroded. This area is mostly represented by the Tal and Diara lands with Barind land in a few areas.

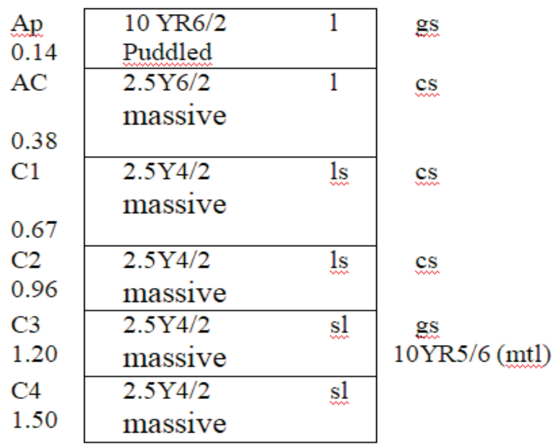
Soils of new alluvial sub-region under Indo-Gangetic Region (pedon 4) from Murshidabad, are very deep, moderately well drained, light brownish gray (2.5Y 6/2) at the surface, gray (2.5Y 5/1) to light gray (10YR 7/1) at the subsurface to subsoil with redox depletion, coarse-loamy in soil control section with silt loam surface texture and silt loam to sand in the sub-surface to sub-soil, weak, medium, sub-angular blocky at the surface and weak, medium, sub-angular blocky to massive in the sub-surface to sub-soil, friable, slightly sticky and slightly plastic moist and wet consistencies at the surface and friable, slightly sticky and slightly plastic to friable, non-sticky, non-plastic in the sub-surface to sub-soil and slightly to moderately eroded.

Soils of Eastern plateau and hill Region (pedon 5) from Purulia are very deep, well drained, yellowish brown (7.5Y 6/2) at the surface, gray (5Y 5/1) to light gray (10YR 7/1) at the sub-surface to sub-soil with redox depletion, coarse-loamy in soil control section with silt loam surface texture and silt loam to sand in the sub-surface to sub-soil, weak medium sub-angular blocky at the surface and weak medium sub-angular blocky to massive in the sub-surface to sub-soil, friable, slightly sticky and slightly plastic moist consistency at the surface and friable, slightly sticky and slightly plastic to friable, non-sticky, non-plastic in the sub-surface to subs-oil and slightly to moderately eroded.

Pedon 1



Pedon 2



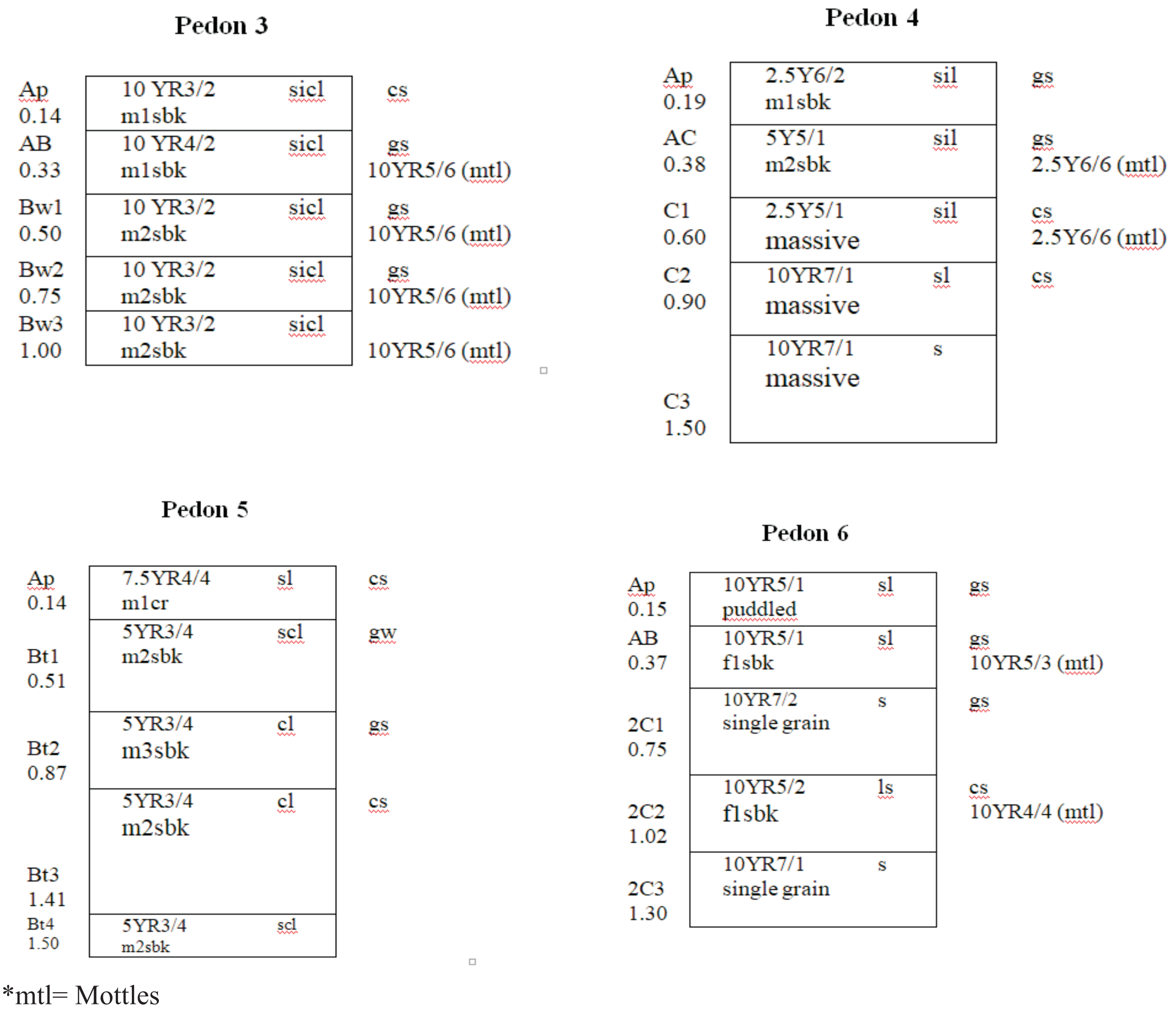


Fig. 7. Morphological properties of soils

Physical and chemical properties

The physical and chemical properties of the mango-growing soils under different agro-ecological sub-regions are presented in fig. 8a, -8b, 8c and 8d. Soils are variable in texture. Sand is the dominant constituent in Alinagar, Sirkabad and Matiarkuthi soil series (pedon 2, 5 and 6) while silt is dominant in Durgapur and Jhumka soil series (pedon 3 and 4) and clay is dominant in Nampur soil series (pedon 1). However, in all the cases, the soil constituents generally increase with the increase in soil depth. The irregular distribution of clay is observed in pedon 2, 4 and 6 indicating the deposition of different cycles of alluvium over a period of time. The soil control section varies from coarse-loamy to fine. Among the pedons, the soils of pedon 1 and 3 of silty clay loam to silty clay texture mostly represent the portion of Barind region, where larger proportion of clay and clay loam soil are found. The loamy soils are abundantly found both in Diara and Tal land areas and silt loam soils also follow the same suit of loamy soils. Sandy and sandy loam soils occur mainly in the Diara strips and also occur in the Tal region (Saadat and Gupta 2016). The distribution of clay within the pedons of the study area is represented in Fig. 8a. They also observed that the relationship of loamy, silt loam, sandy and sandy loam soil texture with mango productivity is fairly positive. This clearly indicates that the soils which have larger areal expansion of loamy, silt loam, sandy and sandy loam moderately increase the productivity of mango except the soils of pedon 5, the irregular distributions of organic carbon in all the soils indicate that the fluvial activity is more pronounced in the formation of these soils.

Soil pH is one of the most important soil chemical properties and affects nutrient bioavailability and microbial activity. Mango can be grown on a wide range of soils from alluvial to laterite soils provided they are deep (minimum 6 ft) and well drained. It prefers slightly acidic soils (pH 5.5 to 7.5). Studied soils are moderately acid (pH 5.6) to slightly alkaline (pH 7.9) at the surface and the pH of the soil increases with the increase in soil depth (Fig. 8b). When pH is greater than 7.5, the bioavailability of calcium or magnesium can be more than sufficient, but that of iron or manganese may not be satisfactory to feed crops. Similarly, active calcium and magnesium ions can precipitate phosphate out and may cause phosphorus deficiency of crops grown on the high pH soil (Liu *et al.* 2017).

Surface soils of Matiarkuthi series (pedon 6), Sirkabad series (pedon 5) and Jhumka series (pedon 4) are moderately acid (pH 5.6-6.0) while that of Durgapur series (pedon 3) is neutral (pH 6.8) and Maldah (pedon 1 and 2) are slightly alkaline (pH 7.6-7.9). However, the sub-surface to sub-soils are very strongly acidic to neutral (pH 4.6-7.1) in the soils of Matiarkuthi series (pedon 6), slightly acid to neutral (pH 6.3-6.7) for the soils of Sirkabad series (pedon 5), slightly acid (pH 6.2-6.5) for the soils of Jhumka series (pedon 4), neutral to slightly alkaline (pH 7.2-7.7) for the soils of North Durgapur series (pedon 3) and slightly alkaline (pH 7.5-7.9) for the soils of Nampur and Alinagar series (pedon 1 and 2). Based on soil pH, the soils of Matiarkuthi series (Pedon 6), Jhumka series (Pedon 4) and Sirkabad series (Pedon 5) are found to be moderately productive for mango and are problematic in the soils of Nampur and Alinagar series (Pedon 1 and 2). Again, the productivity of mango also depends on the variety of mango used. Most of the southern states and Western states have calcifuge mangos like Alphonso, Badami, Totapuri, Bernishan, Kesar, Raspuri, Neelam, Sindhura etc., which do not tolerate alkaline (basic) soil. All north Indian mangos like Dasheri, Langra, Chausa, Amrapali, Safeda *etc.* are calcicole mangos, which do not tolerate acidic soils. Though we find intermixing of these varieties these days, the productivity is affected by the respective soil constraints in their region (Ganeshmurthy *et al.* 2018).

Soil organic carbon (SOC) plays an important role in soil fertility and productivity. It occurs in soil as labile and non-labile forms that help in maintaining soil health. Generally orchards do have a potential similar to the forests but on a lower scale. The indirect C emissions associated with orchard through conservation horticulture can attain C sequestration levels in mango orchards similar to forest ecosystem (Ganeshmurthy *et al.* 2016) .In the studied soils, organic carbon content ranges from 2.8 to 12.0 g kg^{-1} at the surface and 1.3 to 27.0 g kg^{-1} at the subsurface to subsoil and it is mostly high at the surface and gradually decreases with the increase in soil depth (Fig. 8c). The highest amount of organic carbon was noticed in the soils of pedon 6 under Terai region followed by pedon 4 from new alluvium under Gangetic plain, pedon3, pedon1, pedon 2 from old alluvium under Gangetic plain and pedon 5 from Eastern plateau and hill region. Soils of Sirkabad series (pedon 5) contain least amount of organic carbon due to break down of SOC by the increasing temperature in summer season. The depth wise SOC content at different mango growing soils is presented in fig. 8c.

CEC of soil varies from 3.0 to 26.8 cmol (p^+) kg^{-1} and it generally shows an increasing trend with the increase in soil depth except the soil of pedon 6 (Fig. 8d). The CEC of soil is comparatively high in the soils of Nampur and Alinagar seres (pedon 1 and 2) followed by the soils of Durgapur (pedom 3), Jhumka series (pedon 4), Sirkabad and Matiarkuthi series (pedon 5 & 6). The clay CEC value of pedon 1 and 2 is more than 50 suggesting the dominance of smectitic minerals (Soil Survey Staff 2014). Again, the high exchangeable Ca and Mg content of the soils and moderate alkaline pH value also confirms the dominance of smectitic in these soils. The clay CEC value between 18 to 45 in other soils indicate mixed mineralogy with more than 20 per cent smectitic along with chlorite, vermiculite, illite and kaolinite *etc.* (Soil Survey Staff 2014).

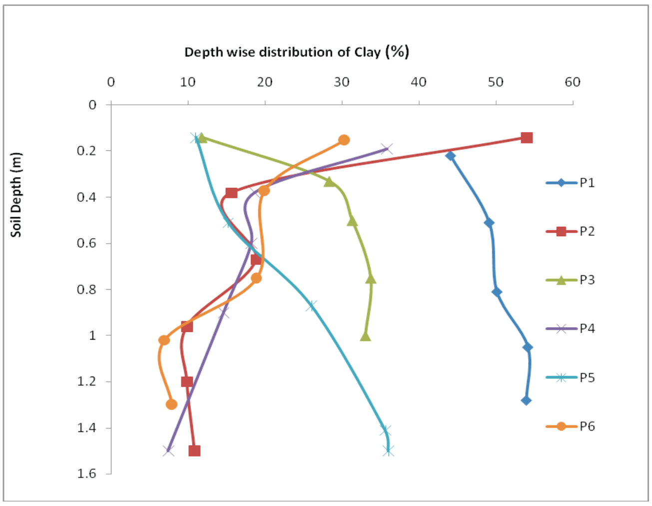


Fig.8a. Depth wise distribution of clay in mango-growing soils

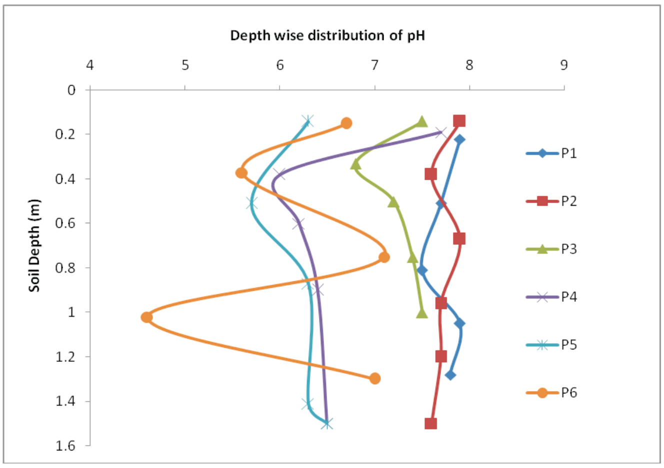


Fig. 8b. Depth wise distribution of pH in mango-growing soils

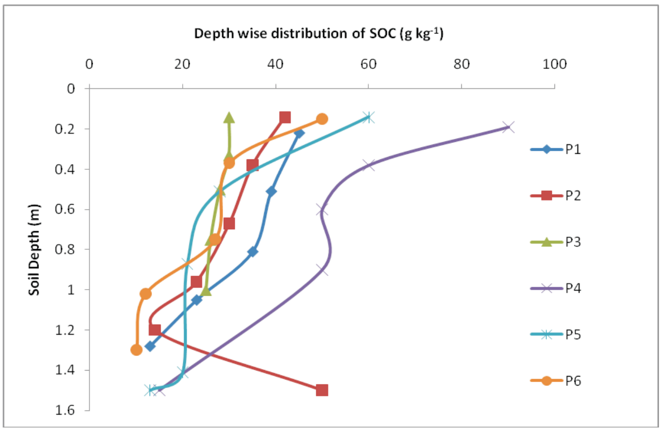


Fig. 8c. Depth wise distribution of organic carbon in mango-growing soils

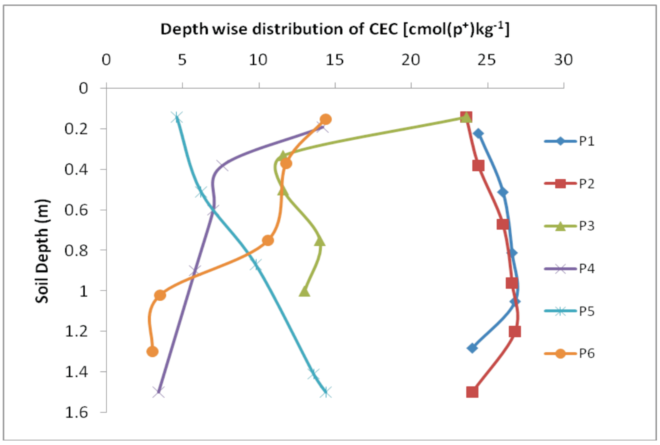


Fig. 8d. Depth wise distribution of CEC in mango-growing soils

Among the exchangeable bases, Ca^{2+} is the dominant cation followed by Mg^{2+}, Na^{+} and K^{+}. Exchangeable Ca^{2+} and Mg^{2+} content are high in pedon 1 and 2 due to the dominance of smectite. Again, it is low in pedon 4 and pedon 6 in comparison to the other pedons. Calcium deficiency symptoms in mango are rare and are expressed as initial cupping of young leaves with marginal necrosis. Since calcium is involved in mobility of boron in plants, deficiency of calcium and boron often overlap (Ganeshamurthy *et al.* 2016a). Again, low magnesium content is observed in pedon 3,4,5 and 6 in comparison to that of 1, 2. Relative to other major fruit crops, mango is a very magnesium demanding crop. An adequate magnesium supply ensures sufficient sugar production and translocation to the developing fruit. Due to deficiency of magnesium, tree growth becomes stunted and fruit yield and quality in terms of fruit colour, shape and size gets reduced. The magnesium deficiency is expressed as leaf bronzing starting from the edge of the leaf rounded margin between each pair of lateral veins exhibiting a green wedge down the central part (Ganeshamurthy *et al.* 2016a).

Exchangeable base content is high in the soils of Maldah (pedon 1 and 2) (B.S.-82-86 %) followed by the soils of North Dinajpur (pedon 3) (B.S. -73-81 %) , Purulia (pedon 5) (B.S.- 64-75 %), Cooch Behar (pedon 6) (B.S.- 49-75 %) and least in the soils of Murshidabad (pedon 4). (B.S.- 64-70 %). Soils are medium to highly base saturated and it varies from 49 to 86 per cent and shows an increasing trend with the increase in soil depth.

Soil-site suitability of mango

Soil-site suitability evaluation for mango cultivation (Naidu *et al*. 2006) in different agro-ecological sub-region of West Bengal indicates that most of the studied soils are highly to moderately suitable for mango based on the suitability criteria and in most of the cases soil texture and soil fertility (pH, organic carbon, exchangeable bases) plays the key role for their suitability except the soils of pedon 2 and 4. Except the soils of pedon 5 (Sirkabad series), all the soils are climatically highly suitable for mango. In case of the soils of pedon 5, the mean temperature in the growing season is very high and the ground water level is low that makes the soil moderately to marginally suitable for mango.

SOC content and SOC stock of mango-growing soils

SOC is a unique indicator which exerts major influence on a number of soil physical, chemical and biological attributes. Soils in tropical regions like India are low in SOC as they fall under the influence of arid, semiarid and sub-humid climates and this is a major contributing factor towards the poor productivity (Katyal *et al*. 2001). Soil organic carbon (SOC) provides energy to soil biota. It acts as the primary driving agents of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emission. It modifies soil physical structure and water regimes, enhances the amount and efficiency of nutrient acquisition by the vegetation and improves plant health (Benbi 2015). Soils of mango orchard possesses greater amount of total soil organic carbon, active and passive pool of carbon in comparison to other orchards which is considered as the best orchard production system to sequester carbon (Naik *et al*. 2017).

The estimation of soil carbon sequestration potential of mango orchards in India (Ganeshmurthy *et al*. 2019) indicated that total carbon sequestration of mango orchards in India is about 285.005 mt.

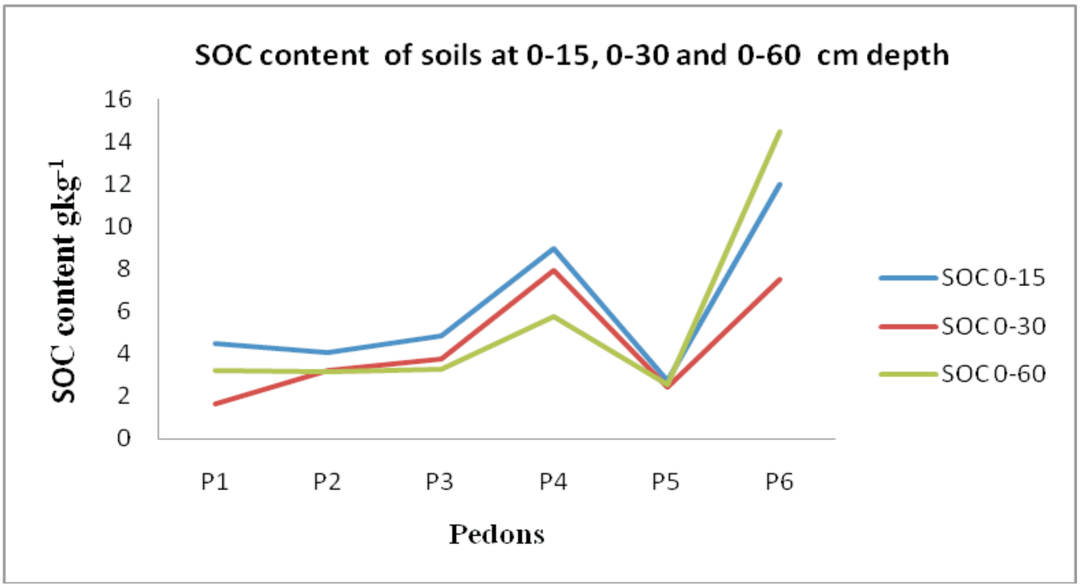


Fig. 9. Distribution of soil organic carbon content of soil at 0-15, 0-30 and 0-60 cm depth.

From the curve (Fig. 9) it is clear that the soils of pedon 6 and pedon 4 contain high organic carbon reflecting higher fertility status in comparison to the other soils. However, in soils of pedon 5, the undulating landform along with rainfed situation, lead to the water deficit and subsequently the nutrient deficit resulting reduction in fruit yield. However, the low soil organic carbon content in pedon 1, 2 and 3 under different soil depth (0-15, 0-30 & 0-60 cm) mainly due to drainage congestion, water logging/ flooding *etc.*

The SOC stock of the studied soils (Fig.10) revealed that soils of pedon 4 of Indo-Gangetic plain shows highest SOC stock at 0-30 cm and 0-60 cm soil depth, while the soils of pedon 6 of Tarai area shows highest SOC stock at 0-15 cm soil depth. Soils of pedon 5 of extension of Chhotanagpur plateau show least SOC stock in all the soil depths.

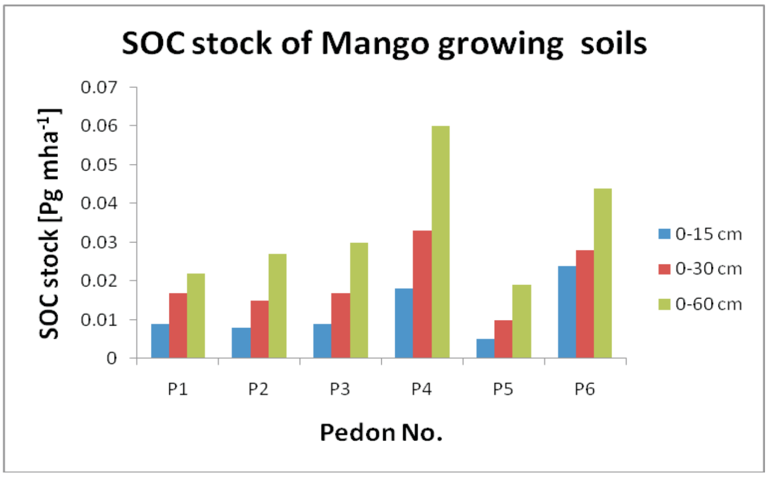


Fig. 10. SOC stock in mango-growing soils of West Bengal.

The decline in productivity of mango has been attributed to various management factors. Most of the problems are due to faulty management *i.e.* poor land use planning for orchard establishment (unsuitable site and climate), cultivation of intercrops by removing the entire crop residues, inadequate nutrition, improper planning, undesirable planting materials, incidence of insect pest and disease and other biotic and abiotic stresses.

In West Bengal, Himsagar orchards above 40 years age display very low productivity. About 30-40 per cent of the orchards in traditional areas are believed to have gone less productive. Apart from yield, the fruits borne on ageing trees may also be poor in bioactive compounds. For example the fruits from enhancing mango productivity through sustainable resource management 30-years old Amrapali trees had less total phenols, ascorbic acid and antioxidants (Meena and Asrey 2018). This is attributed mainly due to poor exposure to sunlight. Only sun-exposed areas produce good quality fruit.

Conclusion

Soils of Indo-Gangetic plain contribute significantly for mango cultivation which mostly depends on soil texture, pH, soil fertility, type of clay and the agro-ecology of the area. As mango grows well in the Indo-Gangetic Plains with increasing productivity, it may be assumed that the soil and climatic characteristics are also favourable for the growth of mango orchard. However, soil texture, alkaline pH and low fertility in some areas possess low productivity of mango. Hence, cultivation of mango in these soils with integrated nutrient management *vis-à-vis* the practice of 'intercropping' by planting turmeric, groundnut, various legumes may increases the fertility as well as moisture content. Besides, these soils also enhance the SOC stock by improving soil health and mitigating the green house gases from the environment. Hence, the cultivation of mango may be extended in some other areas of similar landform and agro-climatic situation to increase the productivity of mango and to earn increasing foreign money through export of the same.

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