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Balanced Fertiliser Use in Black Soils

Twenty five percent of worlds total area of Vertisols and Vertic inceptisols occur in India. Nearly 79% of sorghum, 60% of cotton, 45% of pigeonpea and 41% of groundnut are grown in these soils. Because of their high water holding capacity these soils were considered productive and were under cultivation since hundreds of years. Most of these soils are low in nitrogen and to a lesser extent deficient in phosphorus. Zinc is also becoming important in these soils. It has been shown both on farmers' fields as well as on research stations that most of the crops significantly respond to applied N. However, only cash crops like cotton, chillies, tobacco or irrigated crops like rice and sugarcane are well fertilised in these soils. Staple food crops like sorghum or millet hardly receive 18 kg/ha of nutrients. In order to achieve improved and sustained productivity a balanced nutrient management is a must. We suggest that after demarketing different agroclimatic zones in the Vertisol area, we have to calculate the nutrient requirement of suitable crops for these zones. Nutrient supplying capacity of these zones is estimated either through soil tests or using GIS and modelling approach. After taking into account the farm available nutrient sources, fertilizer application can be made to achieve balanced nutrient supply. Systems simulation modelling will help to avoid climatic risk in the investment of fertilizers especially under dryland conditions.

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The black soils of India, generally referred as "*Regur*" or black cotton soils comprise a group of clay- textured soils, which have been categorised as a major soil group in many international soil classifications i.e. (10) Soil Taxonomy (43, 44, 45, 46, 47), as Vertisol and FAO-UNESCO (12, 13, 14) as vertisols. They are synonymous with black earths, gray and brown soils, cracking clay soils of Australia (49, 18), Rendzinas and grumusols of Unites States (29), tirs in Morocco (9) and tropical black clays or dark clay soils of Africa (10). In India, black soils are considered a highly productiveand sustainable land resource as they have been cultivated for hundreds and even thousands of years and are still productive. They are characterized by their high clay content and intrinsic clay humus complex, which make them resilient soil systems. Shrink-swell behaviour of black soils upon dry-wet cycles favour the development of a fine granular mulch layer at the soil surface, hence some times referred to as self-mulching soils. Especially in drier regions, they often serve as the lifeline to subsistence agriculture where crops generally fail on more droughty soils.

Black soils in India, are extensively cultivated. Their contribution in terms of food grains, cotton and oil seeds production is of great significance to the national economy of India. Black soils contribute nearly 79% of sorghum, 60% of cotton, 45% of pigeonpea, and 41% of groundnut production in India. Improving productivity of these crops in black soils remains as a major challenge owing to inherent management problems, unreliable rainfall, higher retention of applied nutrients in clay complexes and failure to recognise nutrient limitations.

This review is aimed at summarising the recognised production potentialities and constraints with black soils in different agro-ecoregions; enlist specific nutrient imbalances associated with different cropping patterns, and suggest integrated and balanced use of fertilizer nutrients to improve productivity of these soils.

Distribution

India encompasses 25% of the worlds total area of vertisols and vertic intergrades currently estimated to be around 308 million hectars (11, 61). Tamhane (51) reported an earlier estimate of black soils occurring approximately in an area of 200,000 square miles in India. According to National Bureau of Soil Survey and Land use planning, black soils in Deccan Peninsular India occur mostly extending from 8°45' to 26°0' N latitude and 66°0' to 83°45' E longitude, covering an area of 73 million hectares, nearly 22.2% of the total geographical area of the country (27). Soil map of India (**Figure 1**), depicting vertisols distribution according to FAO-UNESCO classification. Black soils are mostly concentrated in the state of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh and

Karnataka which account for roughly 36, 23, 12, 10 and 9% respectively of India's total area under black soils (**Table 1**). Black soils occupy nearly 84% of Maharashtra, 48% of Madhya Pradesh and 44% of Gujarat in their total geographical area.

Formation of Black Soils

Parent material is the fore most important factor involved in the formation and distribution of any major soil group. These

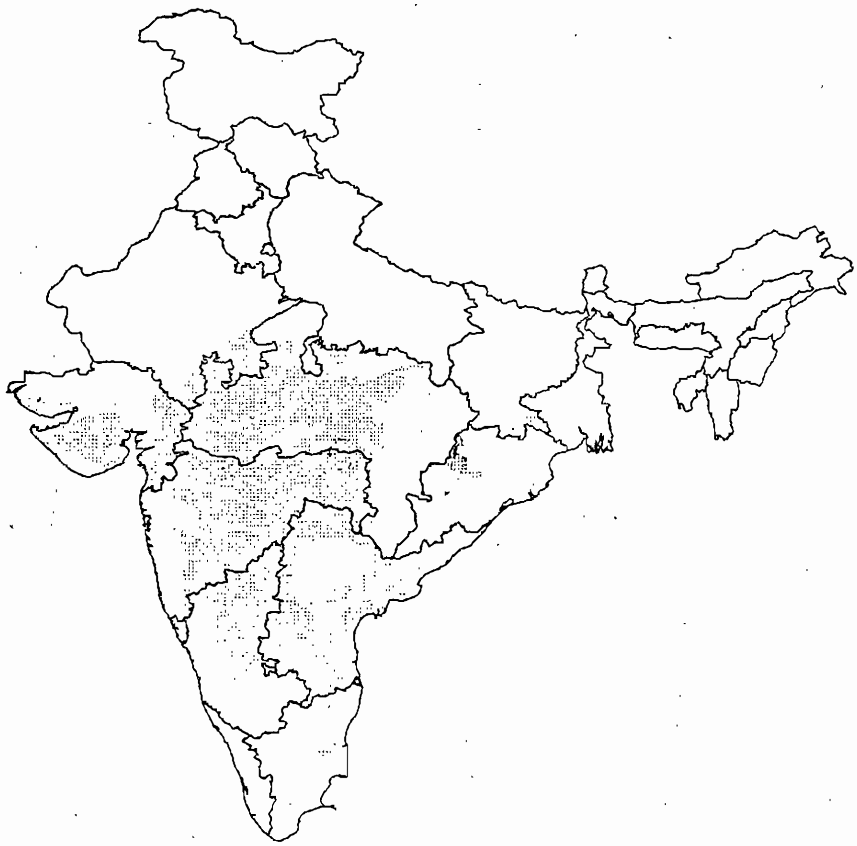

Figure 1 - Vertisols of India
Source : FAO Land and Water Development Division

soils have been formed mainly from Deccan trap, which is normal augite basalt of specific gravity 2.82. These soils range in texture from vitreous basalt to coarse grained dolerite (60).

In the extreme South black soils have also originated from granite and gneiss containing lime and soda lime feld-spars, and these soils are basic in character as distinguished from soils which contain potash feld-spar and are thus acidic.

It appears that these soils which originated from different parent materials have similar dark or black colour. It was believed that the black colour was due to organic carbon content in case of temperate humid region soils known as Chernozems, and the Indian regurs were considered tropical analogues of these chernozems, and dark clay soils of South Africa and Australia. However, Indian black soils are very low in organic carbon content (<1%) compared to chernozems (5-6%), attracted several explanations for black colour of these soils.

Climate is the second most important factor in formation and distribution of black soils. These soils must have undergone seasonal soil moisture stress which is a common phenomina in semi-arid tropical regions of the world and mean annual temperature vary from 0 to> 25°C (cryic to hyperthermic) are the two important factors responsible for the development of shrink-swell behaviour of these soils.

Characteristic Features of Black Soils

Physical properties

Clay content (<2µm) of these soils ranges from 40 to 80% and remains uniformly high (>35%) throughout the profile to a depth of at least 50 cm or more (35). They classified these soils into three groups based on soil depth. The depth varies from shallow to very deep, although the texture is generally fine in all cases. (1) Deep black soils (soil depth >90 cm) (2) Medium and

Table 1 - State-wise distribution of vertisols and associated soils of India

State	Total area under Vertisols and associated soils (million hectares)	Area under vertisols and associated soils expressed as	
		% of area to total vertisols area in India	% of area to total geographical area in India
Maharashtra	29.9	35.5	7.9
Madhya Pradesh	16.7	23.0	5.1
Gujarat	8.2	11.9	2.6
Andhra Pradesh	7.2	10.0	2.2
Karnataka	6.9	9.4	2.1
Tamil Nadu	3.2	4.2	1.0
Rajasthan	2.3	3.0	0.7
Orissa	1.3	2.0	0.4
Bihar	0.7	1.0	0.2
Uttar Pradesh	Negligible	-	-

Source : (26)

Table 2 - Length of growing season and cropping intensity in black soils at a rainfall probability of 75 per cent

Soil depth (cm)	Available water storage capacity (mm)	Rainfall (mm) season (weeks)	Effective cropping	Soil moisture availability period (weeks)	Cropping intensity
< 45	140	650	<20	21	Sole cropping
45 - 90	200	700	20 - 30	25	Inter-cropping
90	300	800	>30	31	Sequential cropping

Source : (58)

light black soils (soil depth 45-90 cm) (3) Shallow black soils (soil depth < 45 cm). The structure is blocky, may occasionally be granular and when soil is deep, the lower layer is often platy. They have high bulk density ranging between 1.5 - 1.8 mg/m^3 when clods are dry. These soils predominantly have montmorillonite type of clay in all most all the regions of the country except in some parts of Madhya Pradesh where illite and kaolinite were also reported (41). There is generally very little horizondifferentiation, the eluvial and illuvial layers being often indistinguishable. A very characteristic feature of these soils is the heavy swelling on wetting and contraction on drying. These soils are very hard when dry and very plastic, sticky when they are wet. The optimum soil moisture range is very narrow for tillage restricting land preparation period and demand high draught requirements. Black soils have a low terminal infiltration rate (about 0.2 mm/hr). During rainy season, water logging may affect standing crops due to low infiltration if proper drainage is not provided. These soils are usually very susceptible to erosion, in fact is very common even when the land is only gently slopy. These soils when severely eroded lime layer (Bca) is exposed to the surface and are often called as limey soils as in some parts of Karnataka.

Soil depth and rainfall often determines the length of growing season in these soils. Available soil water storage capacity depends on the above mentioned parameters is the ultimate deciding factor for crop growth. These soils have a high content of expansible layer silicates and therefore a high water storage capacity, ranging from 140 to 300 mm (220 mm in vertisols at ICRISAT centre). The stored moisture availability period ranges from 21 to 31 weeks (**Table 2**). Moisture storage capacity of these soils at different soil depths reported by (32) closely confirm to these values.

Medium and deep black soils provide an opportunity for double cropping with mean annual rainfall around 800 mm due to their capacity to store sufficient moisture for the second crop.

Chemical properties

Soil pH

Important chemical properties of Black soils from different parts of the country were studied (36) and more recently reviewed internationally (8). These soils consistently exhibit neutral or alkaline in reaction with a pH range between 7.3 to 9.5, as they are mostly derived from calcareous or base- rich parent materials as in case of Maharashtra (**Table 3**). pH values tend to increase with lower depths of the profile. Soils with higher pH values occur in some of the drier districts where exchangeable sodium tends to accumulate in deeper profiles of low-lying soils to make them more alkaline in reaction. The presence of Sodium Carbonate is an indication of alkaline condition (pH>8.3) which may destabilize structural peds and lead to very low permeability that is not congenial for crop production. Higher pH (8.5-9.5) promote increased silicon activity and dispersion of organic matter. These are signs of accelerated degradation of black soils.

Cation Exchange Capacity

Cation exchange capacity is high, ranging between 47 to 65 cmol/kg of soil and depends mainly on the clay type and content, in particular the smectite content and the organic matter content. Cations that occupy the exchange sites vary with soil environmental conditions. In Maharashtra, the medium black soils which occupy 65% of the state are base-saturated with calcium as the pre-dominant. exchangeable cation. They have high lime reserves. Deep black soils in this state have CEC higher than 60

Table 3 - Chemical properties, climate and soil fertility status of black soils reported from different Research Centres in India

Major soil order/climate	pH (1:2) Electrical conductivity (mmhos/cm)	Organic carbon (%)	Phosphate/potash (kg/ha)	Research Centre
1. Vertisol semi-arid (AWC18-40cm)	7.8 - 8.5 0.20 - 0.35	0.20 - 0.35	20 - 40 500 - 800	Akola, Solapur, Indore, Bijapur, Udaipur
2. Vertic Inceptisol	7.5-8.5 0.15-0.20	0.50-0.70	25-30 350-425	Rajkot
a. Arid (AWC9-11cm)				
b. Semi-arid (AWC10-22cm)	7.5-8.5 0.25-0.40	0.40-0.60	10-15 500-650	Jhansi Kovilpatti

Source : (59)

Table 4 - Phosphorus fixation and amount of P needed to obtain 0.2 mg/kg in soil solution of some vertisols of diverse origins

Parent material	Percent clay	Fixed P (mg/kg) Adsorption Maxima	Fixed P (mg/kg) At 0.2 mg in soil solution
Basalt	62	341	19
Granite	65	312	08
Granite gneiss	59	417	08
Limestone	72	304	22
Schist	44	356	16

Source : (2)

cmol/kg soil (30) as is the case in Andhra Pradesh also. In Gujarat, medium black soils have calcium as dominant exchangeable cation followed by magnesium, while deep black soils have dominant Ca, Mg and Na + K in that order, within the exchange complexes.

Organic carbon

Black soils in India are generally low in organic carbon content ranging between 0.7 to 1% of surface soils (27) compared to 0.5 to 2% in most of the African Vertisols and 2 to 4% in some vertisols of United States (10). Australian black earths are richer with organic matter as high as 6% of surface soil which also declined after prolonged cultivation. Organic carbon content in the soils of Maharashtra ranged between 0.21 to 0.4% in 4 districts, 0.41 to 0.60% in 18 districts and 0.61 to 0.8% in 8 districts, which suggest that they all contain OC less than 1%. Organic carbon as an index of available N showed medium in parts of Bijapur, Belgaum, Bellary, Chitradurga, Dharwad, Kolar, Raichur and Tumkur districts of Karnataka where black soils occupy large areas, while in AndhraPradesh the black soils are low to medium in organic carbon content. The organic carbon content of black soils is governed by natural vegetation, cropping history and temperature (10) besides rainfall of the area which has a positive bearing on the build up. Organic carbon content has been found to be more or less uniformly distributed upto a depth of 1 to 2m in some vertisols of Karnataka. Loss in organic carbon content is detrimental to soil structure and results in degradation of other physical attributes. Inappropriate, continuous cultivation practices for long period lead to loss of organic carbon in vertisols (42, 8).

Fertility Status of Black Soils

Nitrogen

Nitrogen, the vital plant nutrient is generally deficient in Indian soils evidenced by district level soil fertility maps during 1970's.

Total N status of black soils in particular has not been very different-ranging from low to medium in Maharashtra. In Madhya Pradesh, the soils in 38 districts tested low, 7 districts found to be medium in total N out of 45 districts, while the entire area of black soils in the state are found to be low except in Jabalpur where total N was rated medium (41). Decrease in concentration of total N is observed in lower layers of the profile and closely follows organic carbon content.

Nitrate nitrogen, ammonical nitrogen are the two ionic forms present in the soils and extracted by plants for their nitrogen requirements. Often these are subjected to losses in Vertisols, resulting in reduced availability to plants. Ammonia retention has been reported in Vertisols by several authors (3, 7). Ammonium, like potassium has similar charge, size and hydration energy. But polarization of ammonium is higher than potassium (48), hence preferred for retention on clay exchange complexes over potassium. Other ways of ammonium losses in these soils are (i) volatilization of ammonia species (ii) leaching or denitrification of nitrate after bacterial transformation. In calcareous black soils of India ammonium is also lost because of its inability to compete with calcium dominated exchange sites. In black soils, loss of nitrate nitrogen takes place when nitrate in solution phase movedown ward from top soil layer all along macro pores of structural interfaces and by pass solution in the meso-micro pores of soil matrix. Denitrification due to flooded condition in rainy season is another possible way of nitrate loss in these soils. Type of land use systems, for example growing crops like sorghum for many seasons may also decrease the nitrate in the soil profile.

Phosphorus

Phosphorus is one of the major elements that is essential for plant growth but is limiting in many soils because it is present in very low concentrations in the Earth's crust, and not readily available due to its being held in chemically stable forms. Total phosphorus content in vertisols is reported to be low in most parts of the world, for instance, total phosphorus varies between 0.012 and 0.11% (116- 1051μg P/g) in vertisols of Texas (23, 34), and low in regurs of India (38). Total phosphorus content is highly dependent on the type and origin of parent material and the amount of organic matter (8). In Madhya Pradesh, shallow and medium black soils of Seoni, Damoh and Sagar districts, soil test values were indicated low in phosphorus. In another 12 districts, phosphorus content in black soils were reported medium. Interestingly deep and medium black soils in Hoshangabad, Indore, Khandwa and Khargoue were found to be high in available phosphorus content (41). Black soils in Maharashtra were either low or medium in available phosphorus except in Nanded where it is found to be high ranging between 9.0 and 17.6 kg P/ha (30). In Andhra Pradesh

Table 5 - Forms and status of potassium in vertisols of India (in m mol /kg)

State	Water soluble	Exchangeable	1N HNO_3 soluble	HCl soluble	Total
Andhra Pradesh	0.1	5.5	19.7	-	-
Bihar	Trace	2.5	36.0	-	231.9
Gujarat	0.9	12.8	81.0	91.9	-
Karnataka	Trace	5.5	15.0	-	173.4
Madhya Pradesh	Trace	10.0	-	-	-
Maharashtra	0.1	4.1	19.9	62.6	139.1
Rajasthan	0.1	10.0	36.0	120.0	256.0
Tamil Nadu	0.3	5.1	21.0	7.2	230.0
U.P.	Trace	5.6	31.0	121.5	600

Source : (63)

black soils are generally deficient in available phosphorus. Mehta and Singh (25) reported that available P determined by Olsen's method in deep black soils of Gujarat varies from 2 to 34 kg/ha, and 4 to 27 kg P/ha^{-1} in the Marathawada region Maharashtra. Total phosphorus was highly correlated with available phosphorus but negatively correlated with $CaCO_3$ of vertisols (27). This phenomena exists due to surface adsorption of phosphorus on $CaCO_3$, thus resulting in low availability of P in calcareous black soils. In a significant proportion of Indian Vertisols, Olsen's method extracts only low amounts of P, even when crops are able to extract sufficient P (i.e. there is no response to added P). Clearly the bicarbonate extract is not strong enough (or the sorption is a little tighter than in other soils (even other Vertisols) (37). Availability of soil phosphorus is strongly influenced by soil pH, organic matter, clay content and phosphorus concentration among several other factors. Black soils have high P-fixation capacity ranging from 304 to 417 mg/kg of soil, and rarely contain more than 0.01 mg/L of P in soil solution (2), in contrast to 0.2 - 5 mg/L of P to produce maximum yields (4). Work done at Advance centre for Black Soil Research, Dharwad, India showed in **Table 4**. provide relationship between the amount of inorganic P to be added to the black soil to maintain a critical concentration of 0.2 mg/L P in solution desired for field crops. It ranged between 8 - 22 mg P per kilogram of soil.

Most of the black soils in India have a higher pH range, while pH range of 6 to 7 is optimum for the soil solution to have maximum concentration of phosphate. Organic matter increases the phosphorus supply in soils through mineralisation of organic phosphorus. But, black soils in India are low in organic matter, resulting in low available phosphorus in these soils. High clay content in deep black soils and pore tortuosity decrease phosphorus diffusion rates (62). Out of inorganic forms of P i.e. Ca-P, Fe-P and Al-P, the latter two forms may be partially or totally dissolved under anaerobic condition. This form of P is most useful in puddled condition of black soils and best utilized in rice cultivation.

Potassium

Micaceous clay minerals and alkali feldspars are the main sources of potassium in soils. Chemically soil potassium is usually divided into three categories - water soluble, exchangeable and non- exchangeable. Exchangeable potassium in Black soils of Gujarat (24), Madhya Pradesh and Rajasthan is approximately twice that found in vertisols of Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu, Uttar Pradesh (**Table 5**) indicates that soils in Gujarat, M.P. and Rajasthan originated from mica clay minerals or feldspars.

Potassium removal by crops is either equal or higher than nitrogen in many cases. However, research needs like understanding potassium status and dynamics in soil, and crop responses were hitherto neglected with an impression that these soils are capable of supplying K adequately. Introduction of HYVs and Hybrids of crops the nutrient removal from the soil increased several times, thus requiring application of fertiliser potassium to replenish the soil supply so as to achieve nutrient balance along with N and P application.

Adsorption and release of potassium in soils is influenced by many factors (i) the amount and type of clay; (ii) site and amount of charge deficit of clay minerals; (iii) variation in moisture and temperature (iv) presence of other cations; and (v) electrolyte concentration (8). Based on physical and chemical properties of clay mineralogy, Tandon and Sekhon (55) provided some general guidelines on the likely needs of K fertiliser and hints for its managements (**Table 6**). Most of the black soils in India are montmorillonite clay soils which have marginally sufficient

Table 6 - General guidelines on the likely needs of K and its management

Dominant clay mineral	Soil texture	Likely K- availability	Remarks for efficient use of K
Illite	Coarse	Low-inadequate	Split application
Illite	Medium-fine	Adequate	Proper N P balance at high yield levels
Montmorillonite	Medium	Marginally sufficient	Crops may suffer at some peak stages and need K application
Montmorillonite	Fine	Adequate	Quick growing crops may experience K-deficiency
Kaolinite	Coarse	Very low and inadequate	Split application starting with a basal application
Kaolinite	Fine	Low-inadequate	Split application of K particularly at high rates of application

Source : (55)

Table 7 - Critical limits of sulphur in vertisols of India using soybean as test crop

Extractant	Critical limit (ppm)
(i) 0.5N NH_4OAc	8.0
(ii) NH_4OAc-HOAc	14.0
0.15% $CaCl_2$	
(iii) Morgan's reagent	9.0

Source : (17)

or adequate K- availability, still need K application as these soils are capable of producing two crops in a year either sequential or intercrops based on the length of growing season in a particular Agro eco-regions.

Secondary nutrients

Calcium

Black soils are generally alkaline in nature, have sufficient bases on their exchange complex and as such calcium deficiency is rarely encountered in these soils. But strongly alkaline soils are poor in total Ca, and their exchange complex is predominantly saturated with Na^+, hence Ca deficiency is invariably found in these soils. Deficiency of Calcium is expected where calcium saturation is lessthan 25% or less than 1.5 m.e. exchangeable Ca and pH are high. The magnitude of deficiency will vary according to degree of base saturation. Medium black soils occupying around 65% of area in the state of Maharashtra are base saturated with Ca^{++} as the dominant exchangeable cation (30). Total Ca content in black soils are generally sufficient around 4.7% of soil.

Magnesium

The condition that favour the occurance of Calcium deficiency bring about Mg deficiency. Soils with low exchangeable Mg and high in natural or applied K usually contain less exchangeable magnesium. Usually soils containing less than 1 m.e. exchangeable Mg/100g of soil or less than 4 to 15% of CEC occupied by Mg are considered deficient (6). Cotton growing areas of Andhra Pradesh are showing deficiency of Magnesium (53). We observed Mg deficiency in chillies when the black soils of Prakasam district, Andhra Pradesh were heavily fertilised with N, P, K in the absence of Mg application. The depressing effect of K on Mg has been attributed to leaching losses of Mg^{++} as a result of displacement from exchange sites by the applied K^+. This phenomena possibly exists in black soils with higher amount of K availability besides indiscriminate application of large quantities of K through fertilizers.

Sulphur

Sulphur is an essential nutrient for plants but is required in much lower amounts than nitrogen, phosphorus, potassium. Sources of sulfate anions are from (i) dissolution of minerals (ii) Acid rain (iii) oxidation of sulfides in acid black soils (iv) Fertiliser S application. Patil et al. (31) observed no evidence of sulfate retention in vertisols while Oxisols and Alfisols did demonstrate this phenomena. The content of anhydrous sesquioxides and organic matter was considered responsible for this difference. This may well suggest that vertisols that have relatively high organic matter content and/or derived from Iron-rich parent materials would limit movement of sulfate ions in the soil. As S is an important component of soil organic matter, the mineralization of O.M. releases the S in available from to the plants. Many industries also enrich the neighbouring soil with S.

Sulphur availability in black soils are generally sufficient. Total S content in Black soils of Maharashtra varied from 95 to 513 ppm, while organic S content and water soluble S content varied between 54-265 ppm, and from 6 to 54 ppm respectively (30). In a survey conducted on black soil regions of Madhya Pradesh indicated that 20 to 40% soils tested were found to be deficient in sulphur where a critical limit of 8 ppm of available sulphur (extracted by Morgan's reagent) was used (41). Available information on critical limits of available sulphur in vertisols with soybean as test crop are presented in **Table 7.** (17).

Sulphur deficiency is becoming more pronounced due to the use of sulphur free N-P-K fertilizers under intensive cropping.

Micronutrients

In the absence of replenishment of micronutrients into the soil, plant uptake of micro nutrients under intensive agriculture lead to the continuous depletion of these in the soil reserves. Black soils in India are fairly rich in total content of micronutrients like iron, manganese and zinc. Soils developed on basic rocks and situated in arid and semi-arid regions are generally enriched with total micronutrients (57). Total micronutrient contents are largely of geochemical interest as they hardly represent the availability of these micronutrients to plant growth. Plant usable micronutrients represent only a fraction of total micronutrient content (**Table 8**) known as available micronutrients were determined on 27 Bench mark sites (22).

Table 8 - Total micronutrient content and available micronutrient content of bench mark sites in India.

Soil order	No.of Soils	DTPA extractable				Total			
		Zn	Cu	Mn	Fe	Zn	Cu	Mn	Fe
		ppm				ppm			%
Inceptisols	15	0.60	2.54	29.5	24.9	62	35	489	3.1
Vertisols	12	0.41	1.49	12.4	9.1	63	63	731	4.0

Source : (22)

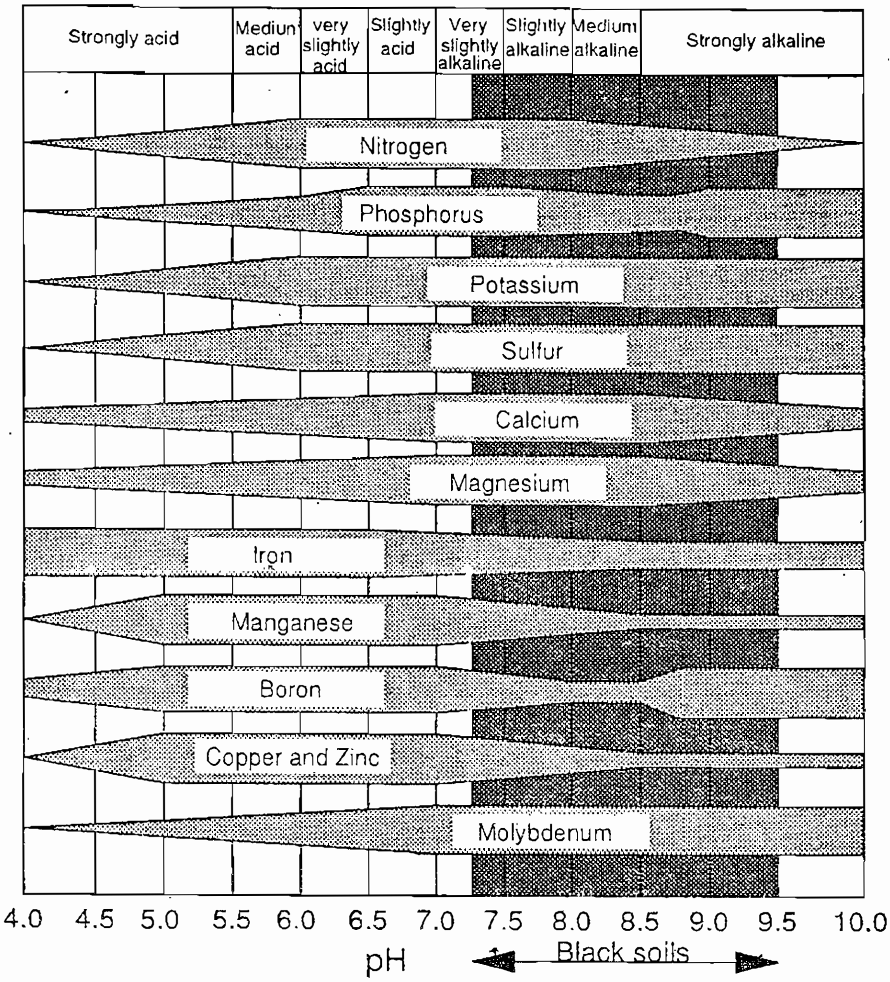

Figure 2 - Schematic diagram showing the effect of pH on the availability of nutrients
Source : (1)

Zinc

Total zinc content of black soils in Maharashtra varied between 72 to 284 mg/kg of soil and in Gujarat it varied between 59.6 to 72.2 mg/kg of soil. Takkar (50) reviewed the distribution of zinc in Indian soils and concluded that availability of zinc decreased with an increase in soil pH and lime content. Organic matter is the principal source of plant available Zn. Black soils are generally alkaline in reaction and low in organic matter, has low level of available zinc and needs zinc application to sustain productivity.

Iron

Availability of Fe in black soils is generally low due to higher pH and calcareous nature of most of these soils. Soil pH influence on the availability of plant nutrients was shown in schematic diagram (**Figure 2**) reveals manganese and copper availability is also very low. However, copper is currently not found deficient in black soils may be due to very low requirement of crops.

Role of fertilisers in nutrient supply

Chemical fertilisers have played a major role in raising production of food grains and other commercial crops in India since 1960.

According to the FAO recent estimate only 24% of the future food needs can be produced on new land and the remaining 76% must come from increased crop yields on existing cultivated lands. This would require an increase in average yield per hectare by at least 65%. Against this back drop, the importance of intensifying use of high yielding modern farming technologies and increasing use of chemical fertilisers cannot be over emphasised.

Steps in technology experiments conducted by ICRISAT on Vertisol indicated that fertilizers were responsible between 50-57% of total crop production in dryland cereals (20).

Nutrient Removal by Crops

Nutrient status of black soils has already been discussed, and indications are that soils generally low in N, P and Zn in most areas sulphur and iron in some soils as these soils have been in cultivation for hundreds of years. Some important food crops grown in these soils are sorghum, maize, pigeonpea, chickpea, soybean besides commercial crops like cotton, tobacco, sugarcane and groundnut. In cereal crops, bulk of N and P absorbed into the plant get deposited in grain while most of the K remains in the straw. In groundnut 41% of N, 52% of P and 28% of K absorbed ends up in kernel. Average nutrient uptake of these crops to produce one tonne of economic yield, gives an estimate of nutrients removed from the soil by each crop (**Table 9**).

Crop plants differ largely in their nutrient requirements and influenced by the nature and composition of soil (56). For example, virginia tobacco grown on clayey soil absorb 26% more nutrients than on a light soil per tonne of dry matter produced. Sorghum grain N concentration significantly varies from 120 kg N fertilized treatment to unfertilized treatment. Plants also have the tendency of luxurious consumption when the nutrient from the soil is in good supply. Hence it is difficult to calculate the exact crop requirement as different from crop uptake.

Table 9 - Average nutrient uptake removal by crops to produce one tonne of economic yield under field conditions in India

Crop	Produce	Nutrients removed N as (N)	P as (P_2O_5)	K as (K_2O)	S	Fe	Mn	B	Zn	Cu	Mo
		(kg/tonne)						(g/tonne)			
Sorghum	Grain	22.4	13.3	34.0	3-4	360	27	27	36	3	0.98*
Chickpea	Grain	46.5	8.4	49.6	8.5	-	-	-	-	-	-
Pigeonpea	Grain	63.8	7.7	48.3	7.5	-	-	-	-	-	-
Groundnut	Grain	58.1	19.6	30.1	12	499	39	44	9	5	1.32*
Soybean	Seed	66.8	17.7	44.4	8.8	-	-	-	-	-	-
Safflower	Seed	43.2	21.8	36.6	-	-	-	-	-	-	-
Cotton	Seed	44.5	28.3	74.7	-	106	14	15	16	8	0.77*
Tobacco	Leaves	17.0	5.0	26.0	-	692	132	96	21	11	0.60*

Sources : (55), (15)

Nutrient supply through organics and bio-fertilisers

Organic manures play a vital role in maintenance of physical and biological condition of soil and supply macro and micro nutrients to crops besides maintenance of humic substances in soil. FYM compost, sewage sludge, green manures, oil cakes and crop residues are the types of organic manures used for crop production, although they are low in major plant nutrients compared to fertilisers. Production of Rural compost (FYM), urban compost and green manured area annually in stateswhere black soils are in large areas and their total availability in India, is given in **Table 10**.

Organic manures vary widely in their nutrient contents, the macro and the micro-nutrients present in them, as the condition, and raw-material used to produce them also differ. There is a huge potential for crop residues/straw of some of the major cereals and pulses which yield approximately 141.2 million tonnes of straw which can contribute 0.7, 0.84 and 2.1 million tonnes of N, P_2O_5 and K_2O respectively (16). Sewage sludge amounting to 4 million tonnes/annum contains about 3% N, 2% P and 0.3% K (5). An estimated annul production of non-edible oil cakes is of the order of 3.8 m.t. which can provide 0.087, 0.025 and 0.057 m. tonnes of N, P_2O_5 and K_2O respectively (39).

Table 10 - Annual production of organic manures, India (1991-92)

State	Urban Compost (million tonnes)	Rural Compost (million tonnes)	Area green manured (million hectares)
A.P.	0.3	45.5	2.72
Gujarat	0.24	0.93	0.21
Karnataka	1.56	18.8	0.73
Madhya Pradesh	0.25	1.47	0.194
Maharashtra	0.85	0.89	0.025
Total (all India)	6.63	279.66	6.70

Source : (15)

Balanced use of plant nutrients in Black soils

Black soils are generally deficient in nitrogen, low to medium in phosphorus (P) and potassium (K). Crop intensification especially double cropping in medium and deep black soils with an annual rainfall approximately 700 mm, is already in practice for many years. High yielding fertiliser responsive crop varieties, tend to respond initially with application of excess quantities of nitrogen, helps to mine other plant nutrients like P, K, S and zinc from soil resources. Crop yields which are higher initially will not sustain due to deficiency of other nutrients. Singh and Brar (40) reported from their observations in long term fertilizer experiments of ICAR at different location, that production levels initially attained cannot be sustained without the balanced use of fertilisers. Data set from a long term experiments show that the use of N alone can led to accelerated depletion of soil P, upto 129% overa period of 8 to 11 years (28, 52). Similarly N + P application resulted in a quantum jump in the quantities of K removed by crops i.e. 78 kg K_2O/ha/year in unfertilized plots against 207.2 kg K_2O/ha/year when N + P were applied. The declining trend in productivity was noted even with adequate application N+P+K under intensive farming. This was due to emergence of secondary and micronutrient deficiencies like sulphur and zinc. It is evident from the available statistics, that any single source of nutrients, cannot achieve the yield sustainability under intensive farming systems. Integrated use of all the source of plant nutrients i.e. chemical fertilisers, organics and biofertilisers to supply all deficient nutrients in required quantities for crops to sustain yield at desired level is called balanced nutrient use has to be adopted. Low nutrient status of Vertisol has been recognised for several decades, but fertiliser use especially under rainfed condition is very low (54). Nitrogen, phosphorus and zinc are the main elements need to be added to soils to ensure satisfactory crop production. These

Table 11 - Summary of response of rainy season crops to fertiliser-N (Rao and Das 1982)

Crop	Reason of response (kg grain/kg N)
Sorghum	3.4-43.4
Pearl millet	2.1-24.8
Finger millet	5.0-42.4
Maize	4.1-67.4
Rice	4.5-33.9
Setaria	5.9-17.9
Sunflower	1.5-22.6
Castor	2.9-7.2
Groundnut	1.3-6.0
Linseed	1.2-11.5
Sesamum	1.3-5.0

Source : (33)

needs have been clearly demonstrated by thousands of agronomic experiments both at research centers and in farmers' fields. Supporting evidence has been provided by extensive surveys involving tissue analysis of crops and available nutrient status of soils. Nitrogen deficiency in the staple cereal crops is universal where as P fertiliser was needed on about 50% of soils. Zinc requirement is also becoming important in many soils.

The **Table 11** gives the significant response to applied N in different crops. Inspite of good responses to average fertilizer use in the dryland districts of the country was only 18.5 kg/ha/year (19). Again the average fertiliser application did not reflect the fertiliser applied to the staple food crops (sorghum, millet) of drylands. Of the total nutrients applied, most, some times all, was applied to either cash crops (i.e. groundnut, cotton, castor, chillies, tobacco) under rainfed agriculture or to small areas of irrigated land (i.e. rice, sugarcane) within the rainfed areas and in both these situations farmers may apply large amounts of fertilisers. The fertilisers applied to dryland staple food crops (sorghum and millet) is indeed very small. The reasons for the slow adoption of fertilizers in the cultivation of dryland cereals are not well understood although some factors are fairly obvious. Firstly dryland agriculture research emphasis is only in recent years because the earlier view that low and variable rainfall was a major constraint. Secondly, fertiliser inputs are most effective when several improved components are introduced concurrently i.e., improved cultivars, improved agronomy. Thirdly the most important in the view of Jha and Sarin (19) is the uncertainty of the responses ofcrops to fertiliser additions.

Future Research Need

We suggest the following approach to achieve balanced nutrient application:

* Demarkate uniform agroclimate zones in the Vertisol area may be based on soil depth, rainfall water holding capacity and length of growing season.
* Grow suitable crops in each zone without any constraints.
* Calculate the nutrient requirements for achieving potential yield.
* Estimate the nutrient supply of the soil.
* Estimate the nutrient supply in the farm from FYM, compost, green manure etc., with their efficiency factors.
* Supply the remaining nutrient requirements through appropriate fertilisers by taking into account their efficiencies.

In this way we can supply the nutrient requirements in the same proportion as the crop plant require to get the potential yield in a given agroclimatic situation.

In order to apply balance nutrition to crops in Vertisols especially under rainfed conditions, (a) nutrient requirements for different suitable crops/cropping systems in a given agro-ecological zone should be worked out (b) soil available nutrient status should be found out using soil testing (c) wherever soil testing is not feasible by using range of soil properties with the help of GIS and simulation modelling one should estimate the nutrient supply capacity of the given soil (d) systems simulation modelling which has the potential feature to provide advice on climatic risk associated with the investment on fertilisers in rainfed dryland conditions should be used.

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