Soil-physiographic relationship in a transect over basaltic trap

S.G. SAVALIA, B.P. TALAVIA, S.P. KACHHADIYA AND J.D. GUNDALIA

ABSTRACT
The relationship between physiography and the associated soils has been studied. Five physiography units, viz., hill slope, upper piedmont, lower piedmont, piedmont plain and coastal plain were identified in a transect over basaltic trap area. The soils over elevated topography (75-150m MSL) are shallow to moderately shallow excessively to well drained, dark yellowish brown to dark grayish brown, medium textured and exhibit poor profile development while those on lower topography (0-25m MSL), are deep to very deep, moderately well drained to poorly drained, dark brown to brown and fine textured and exhibit good profile development. The soils over moderately elevated topography (10-75m MSL) possess the intermediate characteristics between higher and lower elevated topography and moderate profile development. There was a gradual increase in EC, CaCO$_3$, CEC, exchangeable, water-soluble cations and SAR of soils with the decrease in topographic levels. Soils occurring at higher altitude lack diagnostic horizon and were classified as Entisols. While those occurring on depositional landscapes have well developed diagnostic horizons and were classified as Inceptisols.

Key words: Basaltic trap soils, Soil physiography, Altitude, Elevation, Piedmont

The nature of geographic features in conjunction with type of parent materials influences to a significant extent the type of soil formation under specific environmental features (Vink, 1975). Several attempts, to date, have been made to establish relationship between soil physiography and land use (Sharma and Roychowdhury, 1988; Deshmukh and Bapat, 1993; Singh et al., 1994 and Sharma and Bhaskar, 2003). Information on soils developed on different physiographic units over basaltic trap in Saurashtra region is scanty. Hence an attempt has been made to establish soil-physiographic relationship in a basaltic trap area for precise recognition and mapping of homogenous soil units in southern Saurashtra region of Gujarat.

MATERIALS AND METHODS
The majority of the soils of Saurashtra region is medium black in colour and has been derived from basaltic trap in semi-arid climate (Gundalia and Savalia, 2000).

The study area lies between 20°40' to 21°10' N latitude, 70°25' to 71°26' E longitude at an elevation between 4 to 162 m above MSL. The aridity index, moisture index and humidity index of study area varied from 61.97 to 67.76, -54.31 to -67.74 and 1.16 to 7.65, respectively. Hence, the area falls under semi-arid (dry) climate, which is characterized by hot summer, mild winter and dry non-rainy days with mean annual, summer and winter temperature of 27.6°C, 30.6°C and 22.4°C, respectively. The mean annual rainfall of area is 732 mm. The temperature regime of the study area is hyperthermic in hill slope, upper piedmont and lower piedmont, while isohyperthermic in piedmont plain and coastal area. The soil moisture control section meets the necessary criteria (Soil Taxonomy, 2003) to qualify for ustic soil moisture regime. The natural flora includes thorny and scrubby vegetation dominated by Prosopis juliflora, Zizyphus rotundifolia, Butea monosperma, Diopyros melanoxylon, Tectona grandis, Zizyphus mauritiana and Cassia auriculata. The ground flora comprises Cynodon dactylon, Cyperus rotundus L. Dichanthium annulatum and Chenopodium album. IRS 1A LISS Ï FCC imagery on 1:50,000 scale in conjunction with Survey of India topographical (SOI) map referred above on 1:50,000 scale were used to identify various land forms units such as hill slope, upper piedmont, lower piedmont piedmont plain and coastal plain.

IRS 1A LISS II FCC imagery on 1:50,000 scale in conjunction with survey of India topographical (SOI) map referred above on 1:50,000 scales were used to identify various land forms units. Sixteen representative soils of five landforms viz., hill slope (LS-1), upper piedmont (LS-2), lower piedmont (LS-3), piedmont plain (LS-4) and coastal plain (LS-5) were selected for present study (Fig. 1). The morphological characteristics of sixteen pedons representing these landform units were studied. Physico-chemical characteristics of horizon samples were determined by standard methods. The soils were classified as per Soil Taxonomy (Soil Taxonomy,1998; 2003).
RESULTS AND DISCUSSION

Soil-physiographic relationship:

Hill slope:

These are usually covered with forest vegetation which is usually sparse with grass under cover and is mostly uncultivated land. Soils associated with the unit are shallow, excessively drained, fine loamy to silty clay loam (skeletal) occurring on 8 to 15% slope, severely eroded, have rapid runoff, severe erosion, exhibit dark yellowish brown (10YR 3/4M) colour on the surface and moderately alkaline in reaction. Lithic Ustorthents constitute the dominant sub group in this unit.

Upper piedmont:

This unit is characterized by very gently to gently sloping land. Soils associated with the unit are moderately shallow to shallow, well drained, undergo moderate erosion, are moderately to moderately slowly permeable, occasionally flooded, have weathered basalt parent material, exhibit dark brown (10YR 3/3M) to dark grayish brown (10 YR 4/2M), colour and silty clay to clay texture. On these soils groundnut, wheat, rainfed pearl millet, cotton, cumin, sugarcane, pigeonpea, black gram and banana are cultivated and some patches are under wasteland and grassland. Dominant sub group in this unit comprises association of Lithic Ustorthents and Typic Haplustepts.

Lower piedmont:

It is characterized by nearly to very gently sloping, depositional surface formed by the material brought down by the runoff and/or streams from the adjoining hills/ hummocks, ridges and upper piedmont surfaces. Soils associated with the unit are moderately shallow to moderately deep, well drained to imperfectly drained, undergo moderate to very slow erosion, moderately to slowly permeable, occasionally flooded, very dark grayish (10 YR 3/1M) to dark grayish brown (10 YR 4/2M) colour in the surface, silty loam to clay occurring on 0 to 3% slope, moderately alkaline in reaction, slight to highly calcareous in nature and have parent material which is basaltic or a mixture of basalt and limestone. On these soils groundnut, sorghum, cotton, sugarcane, wheat, pearl millet and sesame are cultivated with suitable management and irrigation. Dominant sub group in this unit comprises association of Vertic Haplustepts. Piedmont plain.

This unit has developed over nearly level plain area of alluvial deposits along the streams carried from the upper and lower piedmont surfaces. Soils associated with the unit are deep to very deep, moderately well drained to poorly drained, very slightly eroded, moderately rapid to slowly permeable, moderately to severely flooded, dark brown (10YR 3/3M) to dark grayish brown (10 YR 4/2 M) colour in the surface, clay loam to silty clay loam occurring on 0 to 1% slope, moderately alkaline in reaction and highly calcareous in nature. On these soils to groundnut, wheat, black gram, green gram, pearl millet, sugarcane and banana are cultivated with suitable management and irrigation. Fluventic Calciustepts, Fluventic and Typic Haplustepts constitute the dominantly associated sub groups in this unit.

Coastal plain:

This unit is characterized by nearly level plain area of alluvium deposits along the stream courses. Soils associated with the unit are deep to very deep, imperfectly to poorly drained, very slightly eroded, moderately slow to very slowly permeable, severely flooded, dark gray (10YR 4/1M) to brown (10YR 5/3M) colour in the surface and silty loam to silty clay loam occurring on 0 to 1% slope. These are mostly uncultivated and left as a cultivable wasteland while at places these are cultivated to cotton, wheat, groundnut, pearl millet and sorghum crops with suitable management and irrigation. Dominant sub groups in this unit comprise the association of Fluventic and Calcic Haplustepts.

Soil features associated with different physiography indicate that soil developed on different geomorphic situations differ widely in soil characteristics (Table 1 and Fig. 1). Major soil characteristics are discussed as below.

Soil colour:

Topography and drainage conditions have been reported to have direct influence on the soil colour (Thangasamy et al., 2005). Soils occurring on higher topography in Gir region have vegetative cover particularly on hill slope (Pedon P₁ and P₂); are excessively drained and have high organic matter content (0.95%) and exhibit dark yellowish brown (10YR 3/4 M) colour. The yellowish brown hue may possibly be attributed to oxidation of iron and manganese in high topography (Pedon P₁ and P₂) along with high organic matter content due to vegetation in hilly area of Gir region. The progressive dark gray to dark grayish brown colour in the soils of pedons P₁, P₂, P₆, P₁₀ and P₁₂ to P₁₆ (Fig. 1) reflect higher complexing and chelation of organic colloids on the surface of smectites (Dudal and Eswarn, 1988; Duchaufour, 1988 and Singh et al., 1994), under the influence of relative impeded drainage (Thangasamy et al., 2005) and stable landform, whereas decrease in organic matter and increase in calcareousness of the soils is mainly responsible for brown to pale brown colour in deeper horizons (Subbaiah and
The dark gray (10YR 4/1M) colour evidenced (higher value and lower chroma) in pedon P15 may be attributed to the presence of high amount of free CaCO3 and to the saturation and reduction coupled with mixing of organic matter and soil matrix with carbonate (Sharma et al., 2004) and/or transportation through the process of illuviation.

Soil depth:
Topography has been reported to influence the soil depth (Sharma et al., 1996). The increase in soil depth was witnessed from hill slope to the coastal plain. The soils of pedons P1 and P2 on the hill slope are shallow indicating the soils are less developed due to little chance of soil development (Deshmukh and Bapat, 1993) offered by this unstable landform. The soils of pedons P1 to P6 of upper piedmont are moderately shallow to shallow, while the pedons P7 to P10 of lower piedmont are moderately shallow to moderately deep. The soils of pedons P11 to P13 of piedmont plain and P14 to P16 of coastal plain (Fig.1) are deep to very deep (Singh et al., 1994; Velayutham et al., 1999 and Mandal et al., 2003) indicating thereby that depth of soil is also as a function of topography (Sharma and Roychowdhury, 1988 and Prasad et al., 1989). Wide variations in the soil depth in different geomorphic surfaces observed as above may be attributed to the variations in the erosional processes associated with slope and relief characteristics. The greater the degree of slope, (other conditions remaining constant), the greater would be the erosion due to increase velocity of water flow during rains. The high relief with strong slope accelerates the process of denudation, thus eliminating the possibility of deep soil.

Soil texture:
The soils occurring on hill slope and upper piedmont are medium textured while the soils occurring on lower piedmont, piedmont plain and coastal plain are fine textured (Table 1 and Fig.1). This may possibly be due to movement of finer soil particles along with runoff from higher topographic positions and their accumulation in the lower regions. In the present study, the higher elevated positions are mainly associated with high temperature, low rainfall and deep ground water table conditions all of which favour physical weathering and thus the process of rock disintegration is more pronounced leading to higher percentage of coarse sand fraction (coarser particles) in these soils (Shamra and Roychowdhury, 1988). The silt fraction also increase from higher topography to the lower topography (Table 1) indicating the migration of silt fraction as silt particles are highly vulnerable to water erosion (Sharma and Dev, 1985; Sharma and Roychowdhury, 1988; Prasad et al., 1989; Singh et al., 1991 and Nizeyimana and Bicks, 1992). There was no definite trend in distribution of clay fraction from upper topography to lower topography. This might be due to the process of differential weathering over different landforms as well as also due to differential deposition over different landforms.

Chemical characteristics:
Soil pH is observed to gradually increase along the topography from hill slope to coastal plain (Table 1). This could be the result of continuous flow of bases from higher topography to lower topography (Tiwary et al., 1989 and Singh et al., 1991). The higher values of pH in piedmont plain and coastal plain might be due to calcareous parent material and accumulation of salts (Arnold and Venketeshwarlu, 1982). The ESP decreased as topography elevated indicating that appreciable amount of salts have moved down the slope alongwith flowing water (Tiwary et al., 1989). While traversing from hill slope to coastal plain a gradual decrease in the organic carbon content of the soils was observed. This may be attributed to a gradual decrease in the vegetative cover (Singh et al., 1991). The content of CaCO3 increased down the slope and it registered its maximum value in coastal plain (22.42 per cent). Gaikwad et al. (1974) have also found calcium carbonate content to increase down the slope. There was no definite trend in distribution of CEC, exchangeable cations and BSP from higher to lower topography. Sharma, 1995 also observed CEC, exchangeable, base saturation per cent not to be influenced by the physiographic position of soil. The ESP was influenced by topography, which increased with decreasing topography (Sharma, 1995). The ESP was greater than 10 in lower elevations. This might be due to greater mobility of Na ion and position of profile in transect. The total water-soluble cation content increased from hill slope to coastal plain, which may be attributed to the effect of hydraulic distribution of soluble ion in the soils from higher to lower altitude and soil depth. The low content of soluble salts in the upland soils may be attributed to the dissolution and removal of salts by rainwater whereas more quantity of soluble salts in low land soils can be attributed to their accumulation over these landforms.

Profile development:
Soils occurring at higher altitude lack diagnostic horizon other than ochric epipedon and have been classified as Entisols while those occurring on depositional land slopes have well developed surface and sub-surface diagnostic horizons such as Ochric epipedon, Cambic
### Table 1: Soil indicators, limitation levels and soil sustainability classes of studied soils of different landforms

<table>
<thead>
<tr>
<th>Pedon No. and village (sub group)</th>
<th>Effective rooting depth (cm)</th>
<th>B.D. (Mg m$^{-3}$)</th>
<th>Texture</th>
<th>Structure</th>
<th>AWC/ profile (cm/m)</th>
<th>Sat. H.C. (cm hr$^{-1}$)</th>
<th>pH (1:2.5)</th>
<th>E.C. (dS/m$^{-1}$)</th>
<th>O.C. (%)</th>
<th>Surface horizon</th>
<th>SAR</th>
<th>Weighting factor total</th>
<th>SSC</th>
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<tbody>
<tr>
<td><strong>Hill slope, MSL 150-170 m</strong></td>
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<tr>
<td>P$_1$</td>
<td>Sasun (Gir) Lithic Ustorthents</td>
<td>35 (1)</td>
<td>1.28 (2)</td>
<td>silt (2)</td>
<td>soks (2)</td>
<td>23.4 (2)</td>
<td>0.22 (2)</td>
<td>7.70 (3)</td>
<td>0.18 (1)</td>
<td>1.25 (3)</td>
<td>0.88 (1)</td>
<td>22</td>
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<tr>
<td>P$_2$</td>
<td>Delan Lithic Ustorthents</td>
<td>15 (5)</td>
<td>1.37 (3)</td>
<td>silt (2)</td>
<td>soks (2)</td>
<td>22.6 (2)</td>
<td>0.30 (2)</td>
<td>7.87 (4)</td>
<td>0.18 (1)</td>
<td>0.65 (4)</td>
<td>1.86 (1)</td>
<td>26</td>
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<tr>
<td><strong>Upper piedmont, MSL 75-150 m</strong></td>
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<tr>
<td>P$_3$</td>
<td>Delan Lithic Ustorthents</td>
<td>33 (4)</td>
<td>1.40 (4)</td>
<td>silt (1)</td>
<td>soks (2)</td>
<td>27.3 (2)</td>
<td>0.06 (3)</td>
<td>8.13 (4)</td>
<td>0.23 (1)</td>
<td>0.38 (5)</td>
<td>2.53 (1)</td>
<td>30</td>
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<tr>
<td>P$_4$</td>
<td>Borvav (Gir) Lithic Ustorthents</td>
<td>30 (4)</td>
<td>1.34 (3)</td>
<td>silt (4)</td>
<td>soks (2)</td>
<td>21.5 (2)</td>
<td>0.14 (3)</td>
<td>8.08 (4)</td>
<td>0.19 (1)</td>
<td>0.87 (4)</td>
<td>1.24 (1)</td>
<td>28</td>
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<tr>
<td>P$_5$</td>
<td>Fakar Lithic Ustorthents</td>
<td>27 (4)</td>
<td>1.42 (4)</td>
<td>clay (5)</td>
<td>soks (2)</td>
<td>27.4 (2)</td>
<td>0.07 (3)</td>
<td>8.13 (4)</td>
<td>0.19 (1)</td>
<td>0.81 (1)</td>
<td>0.94 (1)</td>
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<tr>
<td>P$_6$</td>
<td>Jarnwala (Gir) Typic Haplustepts</td>
<td>55 (3)</td>
<td>1.32 (3)</td>
<td>silt (2)</td>
<td>soks (2)</td>
<td>19.6 (3)</td>
<td>0.12 (3)</td>
<td>8.13 (4)</td>
<td>0.24 (1)</td>
<td>0.84 (1)</td>
<td>1.43 (1)</td>
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<td><strong>Lower piedmont, MSL 25-75 m</strong></td>
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<tr>
<td>P$_7$</td>
<td>Jucavaldal Typic Haplustepts</td>
<td>45 (4)</td>
<td>1.36 (3)</td>
<td>silt (2)</td>
<td>soks (2)</td>
<td>22.1 (2)</td>
<td>0.08 (3)</td>
<td>8.16 (4)</td>
<td>0.22 (1)</td>
<td>1.00 (3)</td>
<td>2.17 (1)</td>
<td>25</td>
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<tr>
<td>P$_8$</td>
<td>Chotara Vertic Haplustepts</td>
<td>65 (3)</td>
<td>1.41 (4)</td>
<td>silt (1)</td>
<td>soks (2)</td>
<td>32.7 (1)</td>
<td>0.02 (4)</td>
<td>8.21 (5)</td>
<td>0.27 (1)</td>
<td>0.75 (4)</td>
<td>3.40 (1)</td>
<td>29</td>
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</tr>
<tr>
<td>P$_9$</td>
<td>Meljinavae Vertic Haplustepts</td>
<td>60 (3)</td>
<td>1.41 (4)</td>
<td>silt (1)</td>
<td>soks (2)</td>
<td>26.3 (2)</td>
<td>0.08 (3)</td>
<td>7.99 (4)</td>
<td>0.31 (1)</td>
<td>0.75 (4)</td>
<td>1.37 (1)</td>
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<td>P$_10$</td>
<td>Karedi Typic Ustorthents</td>
<td>40 (4)</td>
<td>1.57 (5)</td>
<td>silt (2)</td>
<td>soks (2)</td>
<td>19.0 (3)</td>
<td>0.14 (3)</td>
<td>8.15 (4)</td>
<td>0.25 (1)</td>
<td>0.42 (5)</td>
<td>3.43 (1)</td>
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<td><strong>Piedmont plain, MSL 10-25 m</strong></td>
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<td>P$_11$</td>
<td>Dewada Fluvic Haplustepts</td>
<td>85 (3)</td>
<td>1.40 (3)</td>
<td>silt (2)</td>
<td>sbk (2)</td>
<td>26.6 (2)</td>
<td>0.02 (4)</td>
<td>8.24 (5)</td>
<td>0.23 (1)</td>
<td>0.29 (5)</td>
<td>2.52 (1)</td>
<td>28</td>
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<tr>
<td>P$_12$</td>
<td>Devali Typic Haplustepts</td>
<td>85 (3)</td>
<td>1.43 (4)</td>
<td>silt (2)</td>
<td>sbk (2)</td>
<td>21.7 (2)</td>
<td>0.16 (3)</td>
<td>8.19 (4)</td>
<td>0.26 (1)</td>
<td>0.80 (4)</td>
<td>2.71 (1)</td>
<td>26</td>
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<td>P$_13$</td>
<td>Kajali Fluvic Calcustepts</td>
<td>200 (1)</td>
<td>1.44 (4)</td>
<td>silt (2)</td>
<td>sbk (2)</td>
<td>30.5 (1)</td>
<td>0.02 (4)</td>
<td>8.00 (4)</td>
<td>1.06 (1)</td>
<td>0.42 (5)</td>
<td>3.72 (1)</td>
<td>25</td>
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<td><strong>Coastal plain, MSL 0-10 m</strong></td>
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<tr>
<td>P$_14$</td>
<td>Rampara Fluvic Haplustepts</td>
<td>115 (2)</td>
<td>1.53 (5)</td>
<td>silt (2)</td>
<td>sbk (2)</td>
<td>26.0 (2)</td>
<td>0.10 (3)</td>
<td>8.39 (5)</td>
<td>0.24 (1)</td>
<td>0.20 (5)</td>
<td>2.16 (1)</td>
<td>28</td>
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<tr>
<td>P$_15$</td>
<td>Katiydi Calcic Haplustepts</td>
<td>70 (3)</td>
<td>1.47 (4)</td>
<td>silt (2)</td>
<td>sbk (2)</td>
<td>18.5 (3)</td>
<td>0.00 (5)</td>
<td>8.59 (5)</td>
<td>1.01 (1)</td>
<td>0.69 (4)</td>
<td>1.78 (4)</td>
<td>33</td>
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<tr>
<td>P$_16$</td>
<td>Chauhan Khan Fluvic Haplustepts</td>
<td>120 (2)</td>
<td>1.44 (4)</td>
<td>silt (2)</td>
<td>sbk (2)</td>
<td>29.6 (2)</td>
<td>0.01 (5)</td>
<td>8.05 (4)</td>
<td>0.67 (1)</td>
<td>0.59 (4)</td>
<td>4.89 (1)</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

*Figures in parenthesis: Haplustepts indicate weighting factor.  
1 = None 2 = Slight 3 = Moderate 4 = Severe 5 = Extreme limitation  
sbk = Subangular blocky, sat. H.C. = Saturated hydraulic conductivity, silt = Silty clay loam, sic = Silty clay, c = clayey,  
ssc = Soil sustainability class*
**Table 2: General soil constraints and soil sustainability class in different landforms**

<table>
<thead>
<tr>
<th>Land forms</th>
<th>Sub groups</th>
<th>Soil constraints</th>
<th>Mean weight factors</th>
<th>Soil sustainability class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lithic Ustorthents (4)</td>
<td>pH, &amp; O.C. &amp; B.D.</td>
<td>28.5</td>
<td>S3</td>
</tr>
<tr>
<td></td>
<td>Typic Haplustepts (3)</td>
<td>B.D.</td>
<td>28.0</td>
<td>S3</td>
</tr>
<tr>
<td></td>
<td>Fluventic Haplustepts (2)</td>
<td>depth &amp; B.D. &amp; O.C.</td>
<td>26.3</td>
<td>S3</td>
</tr>
<tr>
<td></td>
<td>Calcic Haplustepts (1)</td>
<td>Sat. H.C., B.D., &amp; pH.</td>
<td>29.3</td>
<td>S3</td>
</tr>
</tbody>
</table>

**Fig. 1: Soil-physiographic relationship in a transect of Southern Saurashtra**

![Soil-physiographic relationship in a transect of Southern Saurashtra](image-url)
horizon and Calcic horizon and have been placed in Inceptisols sub order.

Thus from the above study it is observed that topography has a significant bearing on soil development and properties and from the topographic situation it is possible to have fair idea about the type soil that can be found.

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Authors' affiliations:

B.P. TALAVIA AND J.D. GUNDALIA, Department of Agricultural Chemistry, Junagadh Agricultural University, JUNAGADH (GUJARAT) INDIA

S.P. KACHHADIYA, Department of Research, Junagadh Agricultural University, JUNAGADH (GUJARAT)

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