Agricultural Landscapes of Costa Rica

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Abstract

Agricultural activities and introduction of new crops result in significant changes in society, culture, and most evident in short-term, the transformation of landscapes. For instance, the introduction of coffee (*Coffea arabica* L.) in Costa Rica and its further extension into the Central Valley during the 1800s led to substantial changes in socio-economic, geophysical, and infrastructural aspects of Costa Rican society. More recently, banana (*Musa* spp.), pineapple (*Ananas comosus* (L.) Merr.), sugarcane (*Saccharum officinarum* L.), rice (*Oryza sativa* L.), and oil palm (*Elaeis guineensis* Jacq.) plantations were established in specific regions of Costa Rica, where geomorphic features and agroecological conditions are considered suitable for their extensive production and economic revenue, affecting the evolution of demography and landscapes. The chapter summarizes essential information about landforms, soils, and climatic conditions in areas that have extensive agriculture as their main economic activity. This study highlights the regions and soils dedicated to cash crops and agricultural activities of Costa Rica. For instance, coffee, pineapple, and sugarcane production develop within highly weathered soils (Ultisols and Oxisols). Banana and oil palm production are mainly located in the coastal plains, where soil genesis is mostly associated with alluvial processes (Entisols and Inceptisols). Finally, horticultural crops like potatoes (*Solanum tuberosum* L.) and onions (*Allium cepa* L.) were mainly identified within the volcanic piedmonts, where volcanic ash soils (Andisols) are dominant.

Keywords

Costa Rica · Agriculture · Soils · Landforms · Tropical crops

11.1 Introduction

At around 2000 BC, the Pre-Columbian inhabitants of Costa Rica transitioned from hunting and gathering (10,000–2000 B.C.) to early agriculture (2000–300 B.C.), with "slash and burn" as the main system for cultivating tubbers, roots, and seeds (Corrales 2000). This transition transformed these early societies as they began to group into tribes and establish settlements scattered throughout the country, eventually leading to higher levels of organization and territorial expansion (Corrales 2000).

After the arrival of the Spaniards on the Caribbean coast of Costa Rica in 1502 A.D., several expeditions were conducted throughout the country, introducing cattle, swain, and basic grains such as barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.), and oats (*Avena sativa* L.), as well as bananas (*Musa paradisiaca*) and plantains (Sáenz 1960). Some of these expeditions led to the establishment of villages, cities, and regions where certain crops were predominantly developed such as corn (*Zea mays* L.).

Furthermore, the landscapes changed drastically, especially in the sector *Valle Central* with the introduction of coffee (*Coffea arabica* L.) around the year 1800 in Costa Rica. Coffee cultivation flourished since 1808 when the contemporaneous Costa Rican governor, Tomás de Acosta, imported seeds for its distribution and established coffee plantations as a source of job and economic activity, further

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supported by other leaders (Gutiérrez 1994). This last facilitated Costa Rica's coffee export to Panama in 1820, resulting from increased coffee cultivation and high production, leading to further exports to Europe and the United States of America.

Following this expansion of coffee cultivation, the need for a port on the Costa Rican Caribbean coast with a direct connection to the Central Valley to transport coffee and facilitate shipping to Europe led Minor C. Keith (a newcomer in railroad business), to move to Costa Rica in 1871 and further lead the construction of the "Atlantic Railroad," connecting the Reventazón valley with San José (Jones and Morrison 1952). Minor C. Keith was responsible for the introduction of some banana (*Musa* spp) varieties, starting this business in some tributary areas within central "Huetar Atlántica" Region in 1872 (Jones and Morrison 1952). After a slow start and some improvements in the cropping system (plant breeding, nutrient management, pest control, and fruit transportation systems), the banana crop expanded across the Caribbean lowlands of Costa Rica, covering a substantial portion of the Limón province (Soto-Ballestero 1994). This activity has been growing up to date, transforming the socio-economic conditions and, most evidently, the landscape, while promoting Costa Rica internationally due to the quality and the productivity of this crop.

Currently, pineapple (*Ananas comosus* (L.) Merrill) has become the main exported crop of Costa Rica. Pineapple plantations were first recorded in the 1930s when the Costa Rican Banana Company (Compañía Bananera de Costa Rica) introduced cultivars that were highly adapted to the conditions, displacing native cultivars (Castro 1994). After 1983, the company Pineapple Development Corporation of Costa Rica (PINDECO) intensified activities in the southern region and increased exporting fresh pineapple to the USA and Europe, leading to an exponential growth of the cultivated area with pineapple. For instance, in 1984, the total cultivated area with pineapple in Costa Rica was around 2,500 ha, whereas the reported area in 2020 was 44,000 ha (SEPSA 2023). This significant increase in cultivated land has caused dramatic changes in the landscapes of different regions of Costa Rica, transforming not only the socio-economic patterns and population dynamics within the corresponding communities, but also the biophysical environment.

The dynamics of landscapes is highly influenced by inner earth forces (e.g., tectonics and volcanism), other environmental factors (e.g., rainfall, winds, and temperature), and the living organisms developing within them. As mentioned before, agriculture is a powerful changing force acting on landforms, modifying their features and processes in a relatively short period. Therefore, assessing this activity and its diverse variants within the landscapes becomes fundamental to understand and address their evolution and potential fate.

The present chapter addresses the landscapes of Costa Rica where agricultural activities represent a considerable land extension of diverse cash crops under a diversity of climatic conditions and landforms. Socio-economic features, main soil orders, and productivity associated with these crops will also be described. Our findings will represent fundamental knowledge that could be transferred to other tropical landscapes with similar features and climate, where the same crops are currently expanding or have potential to do so.

11.2 Landscapes with Extensive Agricultural Crops in Costa Rica

The territory of Costa Rica can be subdivided into six socio-economic regions (hereafter planning regions): (1) Chorotega, (2) Pacífico Central, (3) Brunca, (4) Huetar Norte, (5) Huetar Caribe, and (6) Central (Fig. 11.1). Within each region, specific cash crops are extensively cultivated due to suitable climatic conditions, soils, and landforms, but some other crops are also observed in several regions. We will describe in detail the main agricultural activities within each of these six regions.

Additionally, and aiming to emphasize the role of the landscape within the current agricultural systems and commodity crops developing in each planning region, we are including the most recent soil orders map of Costa Rica at 1:200,000 scale (Fig. 11.2) as well as their distribution within the regions (Fig. 11.3).

11.2.1 Chorotega Region in the Northwestern Costa Rica

The Chorotega Region extends to cover most of Península de Nicoya (Fig. 11.1), including the municipalities of La Cruz, Liberia, Cañas, Carrillo, Santa Cruz, Hojancha, Bagaces, Abangares, Tilarán, and Nadayure. This region presents contrasting landforms, including a volcanic range with four main volcanic structures outcropping from the southeast to northwest, along with an adjacent volcanic plateau (piedmont sector). Additionally, there is an extensive lowland dissected by several rivers (Bergoeing 2017), which are included into three main watersheds: (1) Ríos de la Península de Nicoya, (2) Río Tempisque, and (3) Río Bebedero (IMN 2011). Lithology is diverse, comprising both sedimentary and igneous rocks distributed throughout these landscapes. Basalts, basalt-agglomerates, gabbros, dolerites, cherts, diorites, and siliceous limestones are prevalent, covering most of the Peninsula (Denyer et al. 2014).

Climatic conditions within the Chorotega Region are predominantly described as rainy with monsoon influence along

Fig. 11.1 Territory of Costa Rica and its six planning regions

the coastal areas and dry within the inner Peninsula. The average total annual precipitation values are 2321 ± 181 mm and a drought period lasts for 245 ± 18 days. Air temperature average values of 26 ± 2 °C (Solano and Villalobos 2001). Nevertheless, the driest part of the region reports an annual precipitation of only 1800 mm and just 99 days with rainfall. These conditions limit the growth and development of most plants and vegetation, promoting the growth of adapted plants.

However, due to the variability in landforms and geologic materials, most of the vegetation covering this region can be classified according Holdridge's life zone system (Holdridge 1967) as Premontane moist forest basal transition (mf-P Basal), followed by Tropical moist forest (mf-T), Tropical dry forest (df-T), Tropical moist forest dry transition (mf-T d), and Premontane Tropical wet forest (wf-T P). In less extensive areas covering the volcanoes and hills associated, Premontane rain forest (rf-P) and Tropical wet forest Premontane belt transition (wf-T P) occur.

This diversity of landforms and geologic materials explains the main soil orders (Soil Survey Staff 1999) observed in this region, including Entisols, Alfisols, Andisols, Vertisols, Ultisols, Mollisols and Inceptisols, including their associations with other soil orders (Mata et al. 2022). Entisols represent approximately 25% of the total area in the Chorotega Region (Fig. 11.3), followed by Alfisols (19%) and Andisols (14%).

Within these soil orders, various forestry and agricultural activities take place, whereas their respective extents vary due to physical (landforms and climate) and human conditions (socio-economic and cultural aspects). For example, an important activity commonly found in Alfisols of the Chorotega Region is forestry involving quality tropical hardwood such as teak (*Tectona grandis* L.f.), which has been extensively planted in the piedmont and the hills of Guanacaste province due to its high productivity and economic value (Fernández-Moya et al. 2014). Another example of agricultural activities comes from the highlands of Hojancha (southwestern part of the region), where these lands are normally cultivated with coffee (*C. arabica* L.) and orange trees (*Citrus sinensis* L.).

Soils within these landforms are classified as Alfisols, characterized by reddish color, with fine-textured subsoil horizons, and high base status deep soils (Buol et al. 2011). As result of these agriculture and forestry activities, some of land-modifying processes observed like cattle-creeping

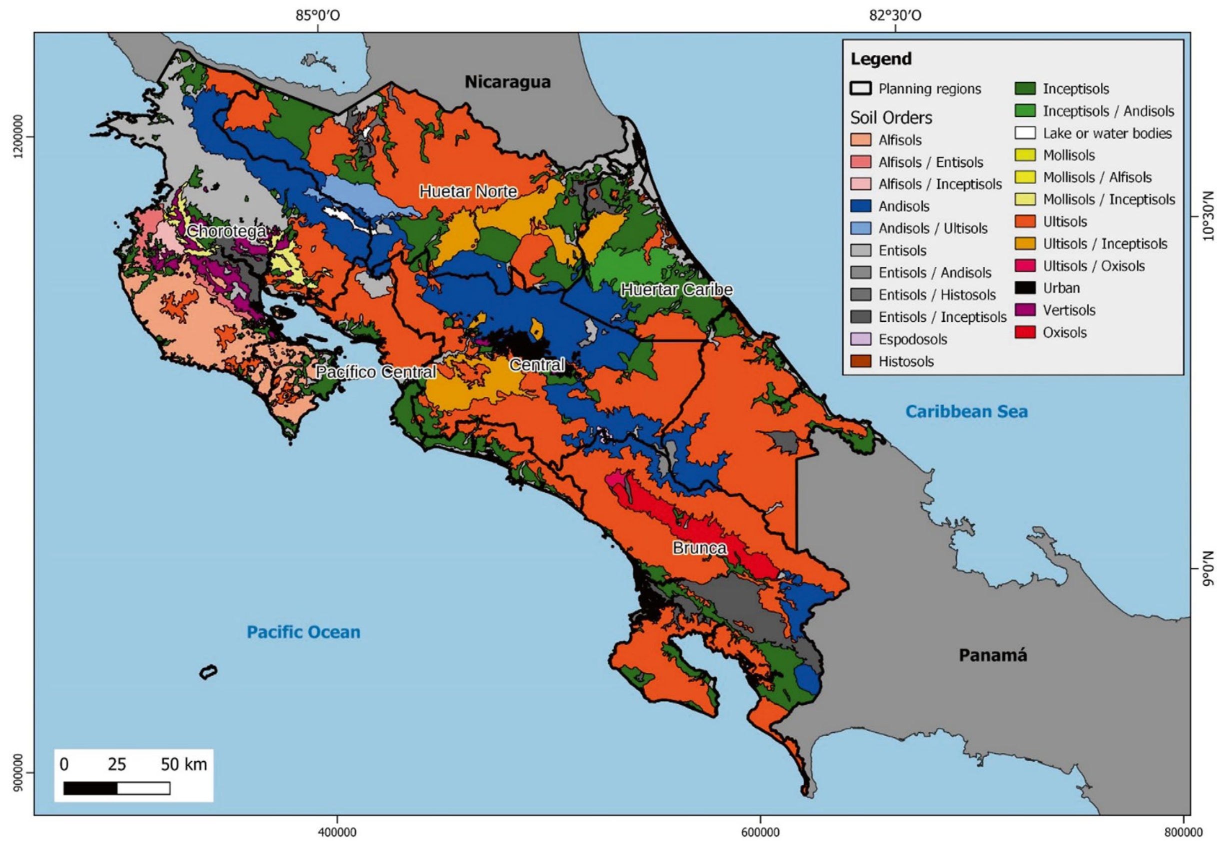

Fig. 11.2 Distribution of the primary soil orders within the six planning regions of Costa Rica. Adapted from Mata et al. (2022)

channels, or erosion processes and landslides, have modeled the landscapes (Fig. 11.4).

These soils are commonly found in regions with ancient geologic materials and landforms supplemented with sufficient nutrients within the parent materials (Buol et al. 2011), a characteristic that aligns with the basaltic materials present in this region (Denyer and Gazel 2009; Denyer et al. 2014). Coffee and orange typically cover a substantial portion of the areas within these hilly landscapes (Fig. 11.4). However, they are being surpassed by other land uses such as pastures, citrus plantations, and secondary forest (Fig. 11.4a–c). In fact, coffee plantations have experienced a decline in coverage, decreasing from 948 ha in 2012 to 791 ha in 2018 (ICAFE 2019). This trend is in favor of orange cultivation systems, despite some efforts to keep the coffee afloat as an economic and social-cultural activity within this sector (Fig. 11.5). Nonetheless, the variability of weather has made more challenging to maintain the land cover with this crop, allowing for other activities such as cattle production using drought-resistant grass species like *Brachiaria brizantha* (Fig. 11.4d).

Within the sector "La Bajura" (a term in Costa Rican Spanish used to describe a lowland), the common soil orders are Vertisols and Mollisols. Generally, Vertisols soils are dark and clayey with shrinking-swelling properties due to drying–wetting cycles (Buol et al. 2011), typically found in least elevated areas. On the other hand, Mollisols soils are deep and dark, friable, with relatively fertile surface horizons and excellent physical–chemical properties (Buol et al. 2011). They are commonly found in association with Alfisols and Inceptisols soils (Mata et al. 2022).

Despite their divergent pedogenesis and contrasting soil physical properties, both Vertisols and Mollisols are considered as fertile soils, with desirable chemical properties such as high base saturation and low acidity, making them suitable for certain agricultural activities. In fact, Vertisols and Mollisols soils assessed in the Chorotega Region are typically used for cultivating cash crops belonging to the *Poaceae* family (Fig. 11.6), including sugarcane (*Saccharum officinarum* L.) and rice (*Oryza sativa* L.).

The cultivation of both sugarcane and rice experienced an increase during the mid-nineteenth century, primarily propelled by new technologies in soil tillage, plant breeding, and government policies that incentivized farmers and landowners (Murillo 1994; Marchena-Sanabria 2015). These two crops play a pivotal role in the socio-economic activities of this region, with nearly 35,000 ha dedicated

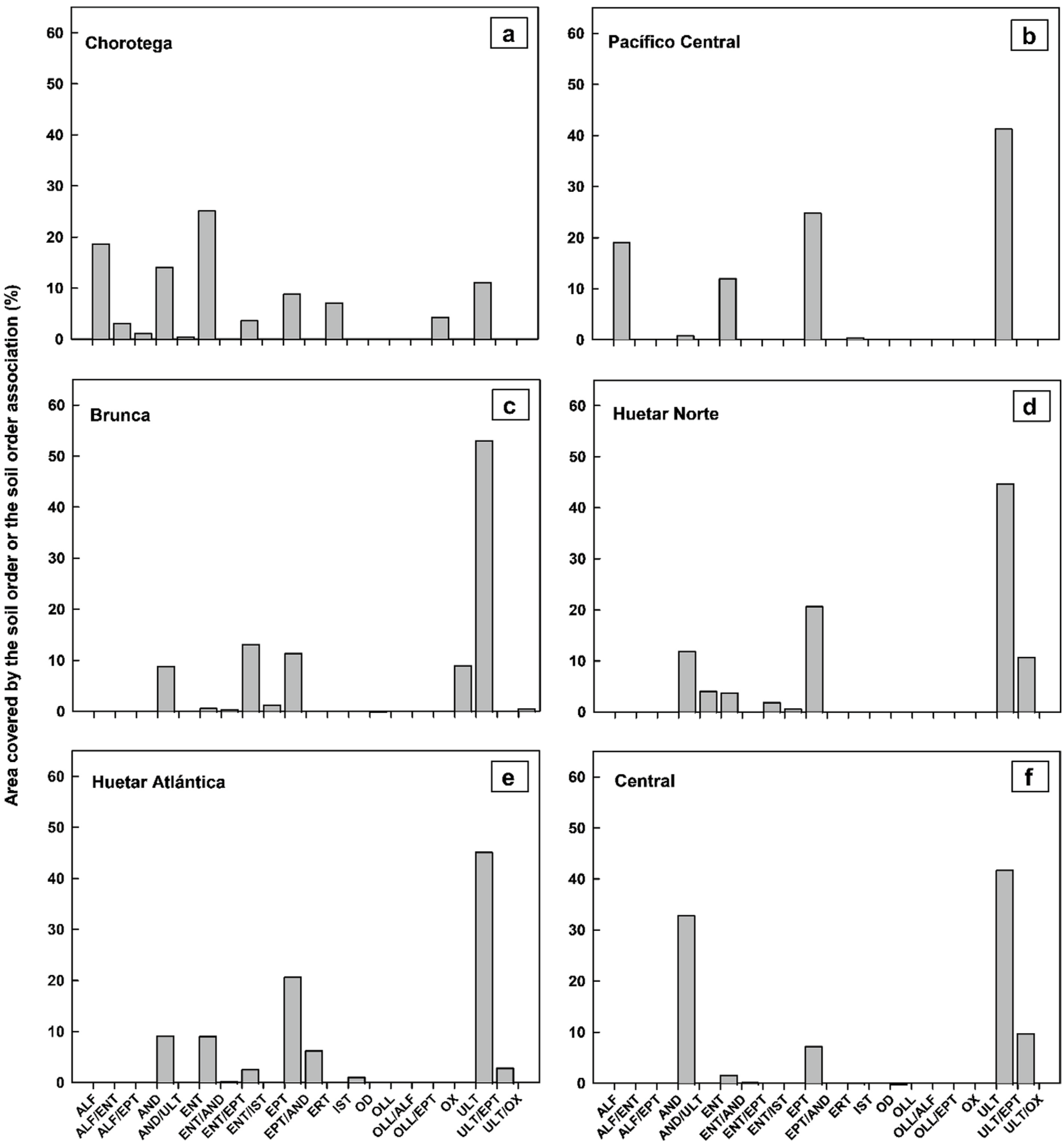

Fig. 11.3 Land coverage of the soil orders or soil associations within the six planning regions of Costa Rica: **a** Chorotega, **b** Pacífico Central, **c** Brunca, **d** Huetar Norte, **e** Huetar Caribe, and **f** Central. Adapted from data available in Mata et al. (2022). *ALF* Alfisols, *AND* Andisols, *ENT* Entisols, *EPT* Inceptisols, *ERT* Vertisols, *IST* Histosols, *OD* Spodosols, *OLL* Mollisols, *OX* Oxisols, *ULT* Ultisols (Soil Survey Staff 1999)

to sugarcane cultivation (Angulo et al. 2020), and an additional 18,206 ha allocated for rice cultivation (SEPSA 2023).

Rice fields and sugarcane plantations dominate most of the "La Bajura" area, competing with cattle farms (pastures), water bodies, and an emerging trend in real estate project development (Fig. 11.7). Moreover, in 2021, the Chorotega Region harvested 96,841 t of rice grains, constituting 63% of national total rice production (SEPSA 2023). Additionally, the sugarcane yield reported for nearby farms during the 2019–2020 season was 2,355,412 t, representing 58% of the total production in Costa Rica (Angulo et al. 2020). Most of these aforementioned landforms have been modified by continuous cycles of agriculture, creating ground creep, raised beds, levees, and dikes due to the tillage and land preparing (Fig. 11.6).

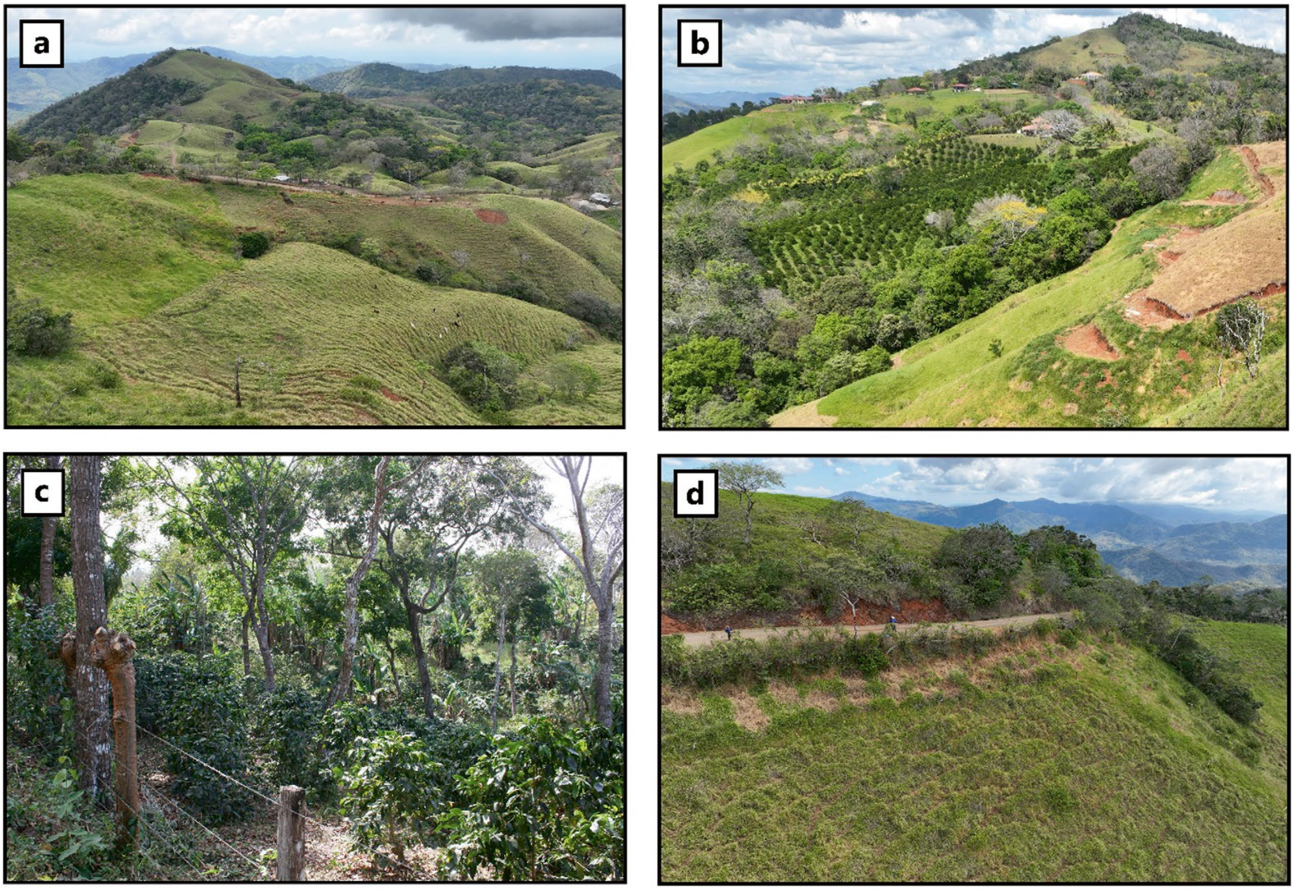

Fig. 11.4 Agricultural landscapes and crops within the hilly sector of the Chorotega Region: **a** Typical landscape with pastures, crops, and forest, **b** citrus (*Citrus* spp.), **c** coffee (*Coffea arabica* L) under shadow, and **d** pastures (*Brachiaria brizantha* (A.Rich))

11.2.2 Pacífico Central Region in the Central Western Coast of Costa Rica

The Pacífico Central Region extends from the southern side of Península de Nicoya and continues along the western central Pacific coast of Costa Rica. It includes piedmont areas with mountains and low elevations (<1500 m asl), comprising the municipalities of Puntarenas, Esparza, Montes de Oro, Quepos, Parrita, Garabito, San Mateo, and Orotina (Fig. 11.1). The geomorphology in this region presents contrasting landforms, including hills within two piedmont sections corresponding to divergent mountain ranges (Tilarán and Talamanca) that stretch in NW–SE direction, and coastal plains (lowlands) dissected by several rivers (Bergoeing 2017), included within the following watersheds: (1) Ríos de la Península de Nicoya (southern sector), (2) Río Abangares, (3) Río Barranca, (4) Río Jesús María, (5) Grande de Tárcoles, (6) Río Tusubres, (7) Río Parrita, (8) Río Damas, (9) Río Naranjo, (10) Río Savegre, and (11) Río Barú (IMN 2011).

Geologic materials observed within the region are diverse, consisting of rocks and soil parent materials of both sedimentary and igneous origins and with different ages (Bergoeing 2017). For instance, the Nicoya Complex (the main geologic unit aforementioned in Sect. 2.1) covers most of Península de Nicoya, but it can also be found in the highlands of Garabito (Herradura Terrain), associated with other pillow-type basaltic materials (Denyer and Gazel 2009), dated from the Maastrichtian to Lower Eocene (Arias 2003). In the northwestern sector (Barranca and Cerros del Aguacate), there mainly occur volcanic rocks from the Miocene-Pleistocene associated with sedimentary materials (alluvial terraces, alluvial deposits) from the Quaternary (Denyer et al. 2003). Additionally, coastline areas are constantly affected by intense erosion–deposition processes caused by both fluctuating tides, waves, or inland flows (Cárdenes and Obando 2005).

Climatic conditions within the Pacífico Central Region are generally described as rainy with monsoon influence, with total annual precipitation values of 3578 ± 237.8 mm

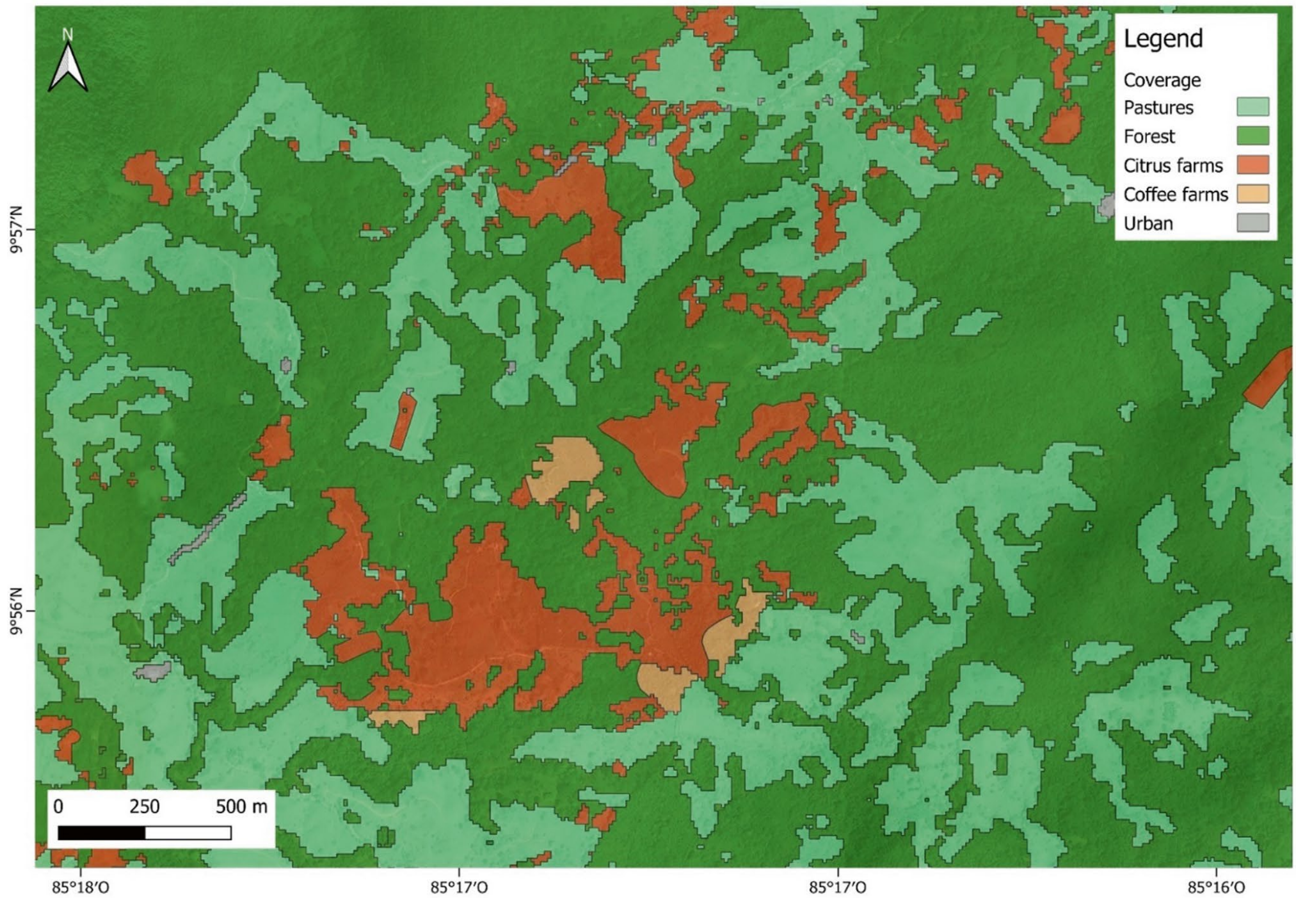

Fig. 11.5 Land coverage of a typical landscape within the hilly sector of the Chorotega Region. Land cover map generated using machine learning technics and supervised classification from PlanetScope Images (Planet Lab 2022)

and a dry period lasting 150 ± 7 days, with average air temperature values of 25 ± 2 °C (Solano and Villalobos 2001). These conditions facilitate the growth and development of vegetation classified according Holdridge's life zone system (Holdridge 1967) as Tropical moist forest (mf-T), Premontane wet forest basal transition (wf-P Basal), Tropical wet forest (wf-T), Tropical moist forest perhumid transition (mf-T perhum), Tropical moist forest dry transition (mf-T d), and Premontane wet forest (wf-T P).

The main soil orders mapped in this region (Mata et al. 2022), from the most to the least abundant, are Ultisols, Inceptisols, Alfisols, and lastly Entisols, including their associations with other soil orders. Ultisols represent around 42% of the total area of the Pacífico Central Region (Fig. 11.3), followed by Inceptisols (25%) and Alfisols (19%). Ultisols and Inceptisols dominate the Central Pacific region of Costa Rica, with Ultisols covering mostly the piedmont region, while Inceptisols extend along the coastal plains (Fig. 11.2). In this regard, Ultisols are described as clayey-reddish highly weathered soils, with low content of bases and desirable soil physical properties (West et al. 1997). These soils are commonly found in the highlands, hills, and piedmont areas, where landform stability prevents further soil-forming processes that would transform them into other soil orders (Buol et al. 2011). On the other hand, Inceptisols are described as weakly profile-developed soils, with some subsoil development and no diagnostic properties established (Skorupa et al. 2017). These last soils are typically found developing from materials accumulated through fluvial processes, including deposition within estuarine or delta rivers (Buol et al. 2011). Under proper soil management, both soil orders are considered suitable for agriculture development.

The Pacífico Central Region has a diversity of agricultural activities that have significantly influenced not only the idiosyncrasy of its habitants and the economy but also transformed the landscape and land cover. For instance, oil palm plantations were established in 1943 in Parrita municipality and extended to neighboring counties and planning regions of Costa Rica, becoming an intensive industrial activity aimed at meeting international demand for vegetable oil (Vargas et al. 2020). Currently, this crop covers a total of 75,700 ha of cultivated areas within the Costa Rican territory (SEPSA 2023).

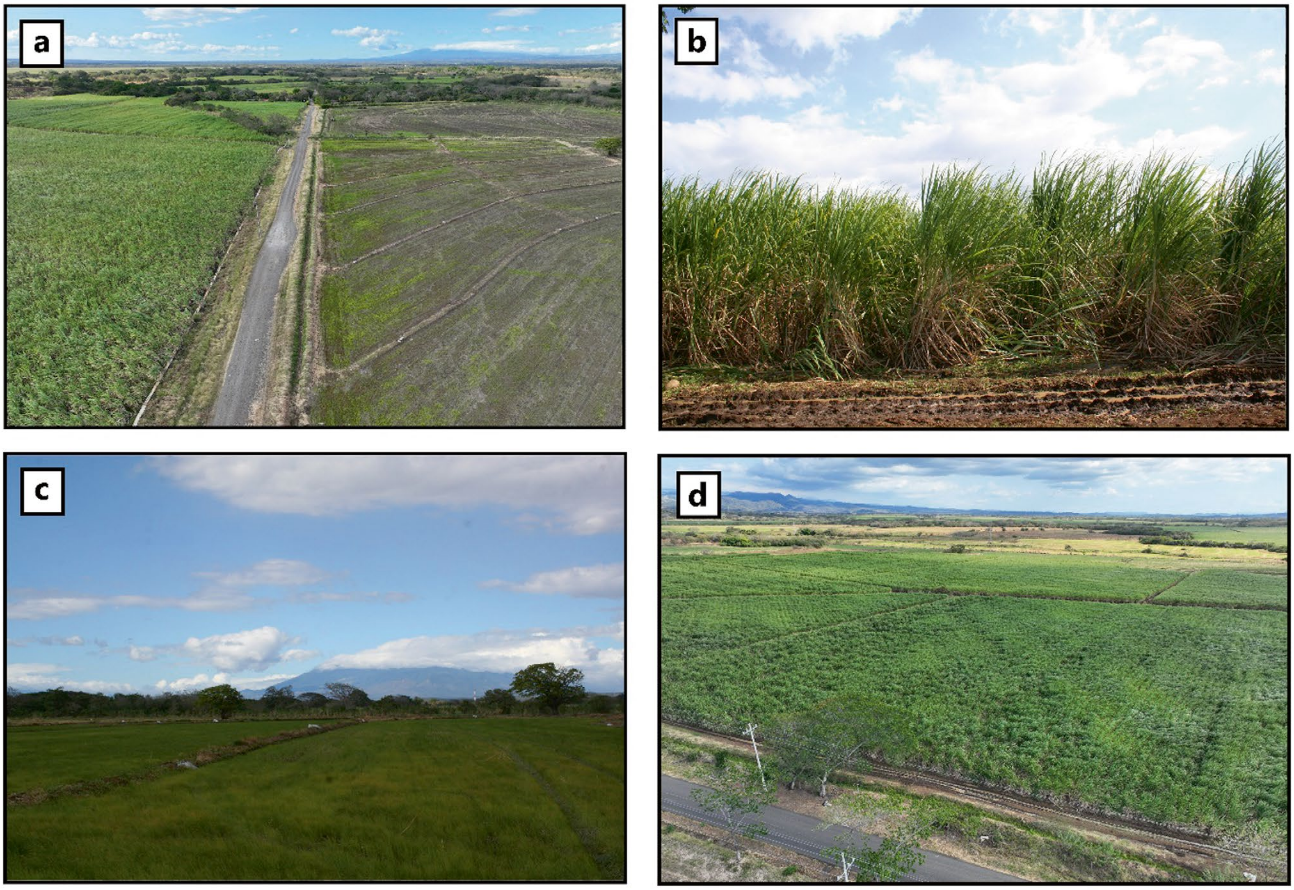

Fig. 11.6 Agricultural landscapes and primary crops within the lowland sector of the Chorotega Region: **a** Typical landscape with *Poaceae* crops, **b** sugarcane (*Saccharum officinarum* L.), **c** rice (*Oryza sativa* L.), **d** extensive sugarcane farms and pastures (*B. brizantha*)

In the Pacífico Central Region, 10,129.71 ha and 6121.10 ha have been planted in Quepos and Parrita municipalities, respectively, while a total of 227.18 ha are reported for Puntarenas and Garabito counties (MOCUPP 2021a). These oil palm plantations have become an integral part of the landscape in this planning region (Fig. 11.8), sharing soils, and landforms with other activities like pastures and cattle farms and the fruit crop papaya (*Carica papaya* L.) (Fig. 11.8). Another significant economic activity in the Pacífico Central Region is rice production. For instance, during the 2020–2021 season, a total of 5730 ha was cultivated with rice (CONARROZ 2021), resulting in a yield of 22,067 t of grain (SEPSA 2023).

These values were mainly taken from Parrita municipality, where 2746 ha were planted with rice, yielding a total of 11,030 t. This activity has been in decline over time and competing with emerging crops like papaya and banana (Fig. 11.9), which has significant implications for landscape transformation, management practices, and subsequent physical and social-economic consequences into the region (Fig. 11.9).

In this context, the cropping system selected will need specific practices that might be at odds with another system. For instance, within the same landform or landscape (the alluvial lowlands of Parrita), it is possible to find banana, oil palm, papaya, and rice fields (Fig. 11.10a) coexisting over the same soil order Inceptisols (Fig. 11.10b). However, the requirement for levees to retain ponded water (for rice cropping system) or drainages to remove the excess water and lower the water table (for banana, oil palm, or papaya cropping systems) will impact land water dynamics and other related processes such as erosion or sediment and solute transport, which in turn affects the shores and aquifers (Fig. 11.10c, d). These erosion processes have been enhanced by agricultural practices like plowing and leveling to create rice beds or drainages for oil palm production, modifying this landscape and its corresponding landforms (Fig. 11.10).

Hence, this diversity in cropping systems and the corresponding management has directly influenced not only the transformation and evolution of the landscape but also the socio-economic dynamics within the region. For instance, Fig. 11.11 illustrates the distribution of different soil uses

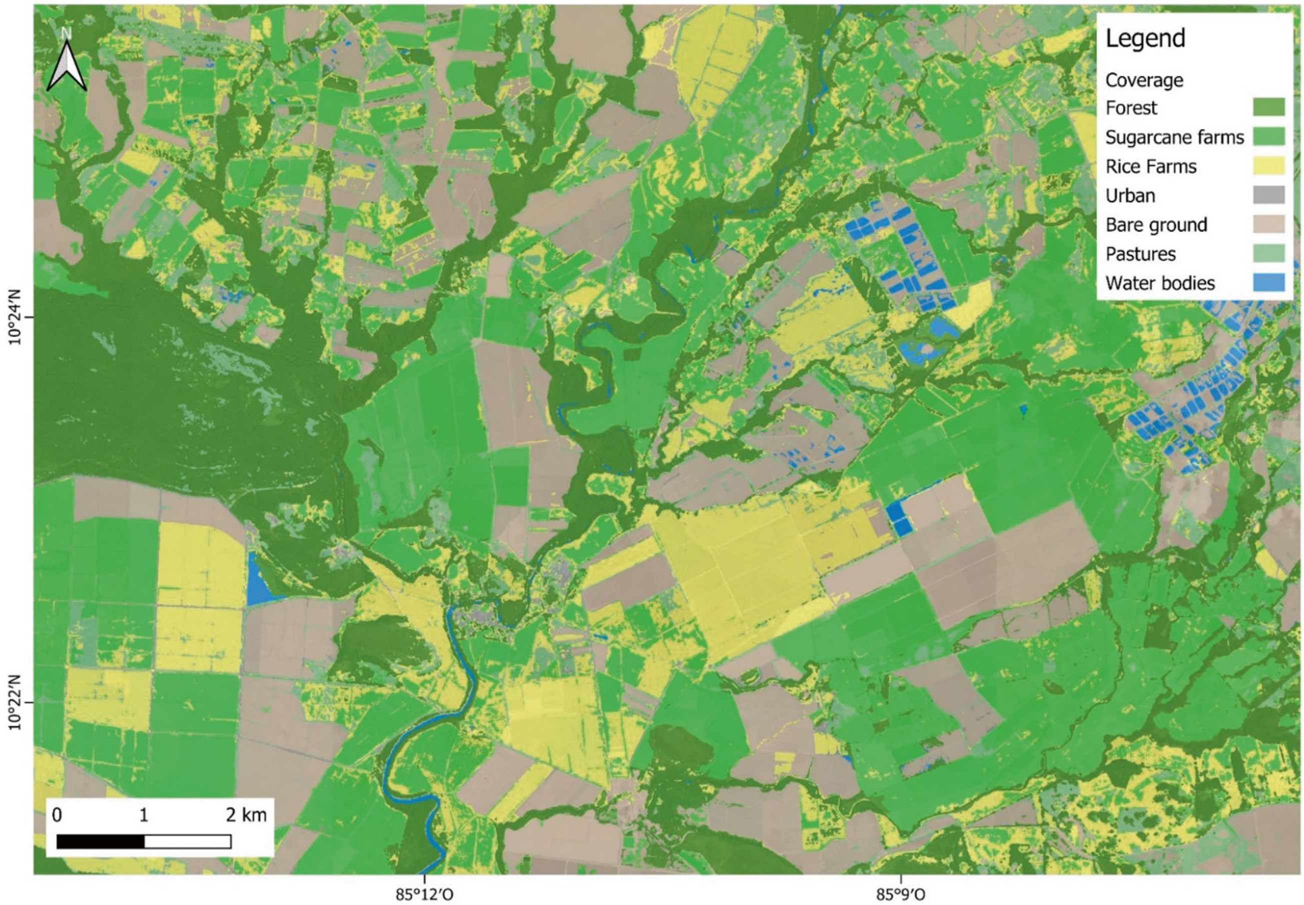

Fig. 11.7 Land coverage of a typical landscape within the lowland sector of the Chorotega Region. Land cover map generated using machine learning technics and supervised classification from PlanetScope Images (Planet Lab 2022)

within the same landscape in the lowlands of Parrita. It clearly highlights the dominant presence of oil palm plantations, followed by rice farms and mangrove forests. These land coverages are situated within an alluvial landscape that is actively shaped by the meanders and discharge of the Parrita River.

11.2.3 Brunca Region in the Southeastern Side of Costa Rica

This region extends from the southern side of Península de Burica (Burica Peninsula) and continues along the northwestern Pacific coast of Costa Rica. It encompasses diverse topography, including piedmont areas with ancient alluvial fans and the highest mountains of Costa Rica (> 3500 m asl), covering the municipalities of Pérez Zeledón, Buenos Aires, Osa, Golfito, Coto Brus, and Corredores (Fig. 11.1).

The geomorphology in this region presents a range of landforms, including Quaternary alluvial fans formed from sediments deposited after glacial periods correlated with the period MIS 6 (200,000–130,000 years ago) and the period MIS 1 (110,000–12,000 years ago) and forming those landforms (Quesada-Román and Zamorano-Orozco, 2019). These alluvial fans extend along the entire Pacific piedmont of Talamanca Mountain Range (Bergoeing 2011), covering a substantial area within the region. The Talamanca Mountain Range rises from southeast to northwest, housing the Costa Rica's highest peaks such as Cerro Chirripó (3819 m asl), Cerro de los Ventisqueros (3812 m asl), Cerro Pirámide (3807 m asl) and Cerro de las Lagunas (3761 m asl) (Bergoeing 2017).

These areas over 3000 m asl were molded by glacial and periglacial processes during the Last Glacial Maximum producing erosional and depositional glacial landforms such as aretes, glacial valleys, glacial lakes, and moraines (Quesada-Román et al. 2019, 2020, 2021). In addition to these diverse landforms, the Pacific Coast within the Brunca Region features the "Fila Brunqueña Costera," a mountain range composed of sedimentary materials from the Miocene, outcropping parallel to the shoreline (Bergoeing 2017). Two primary rivers, Río General and Río Coto Brus, dissect the lowlands of this region, eventually merging to form the Costa Rica's largest river and watershed, the Río

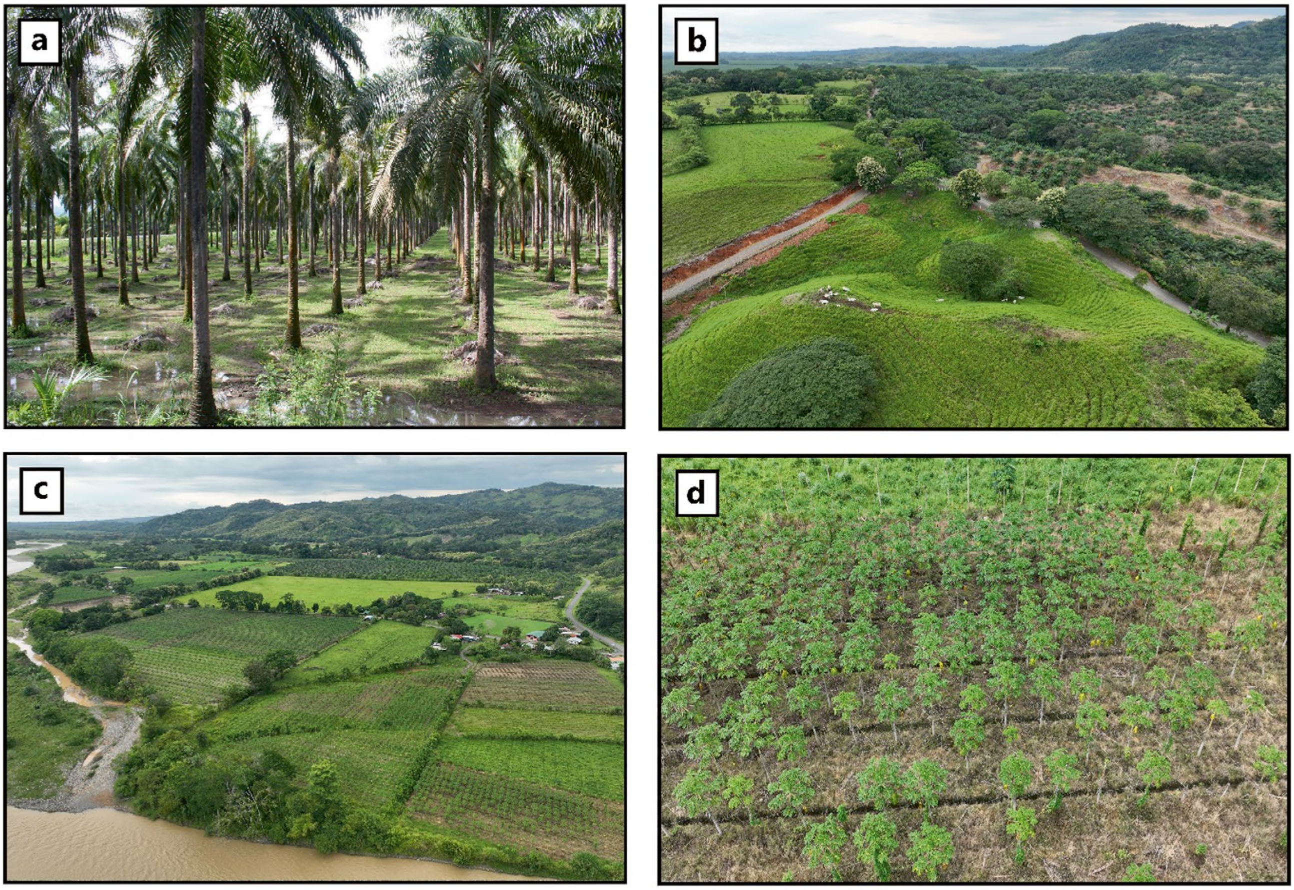

Fig. 11.8 Agricultural landscapes and crops along the Pacífico Central Region: **a** Typical landscape with oil palm (*Elaeis guineensis* Jacq.), **b** pastures (probably *B. brizantha*) and oil palm, **c, d** papaya (*Carica papaya* L.) cultivated within sedimentary terrains

Grande de Térraba. Four watersheds are included in this planning region: (1) Ríos de la Península de Osa, (2) Río Esquinas, (3) Río Coto Colorado, and (4) Río Corredor (IMN 2011).

Geologic materials observed in this extensive region of Costa Rica are remarkably diverse and likely the most intricate found in the country. For instance, the southern area encompasses the Península de Osa and Golfo Dulce (Dulce Gulf), which developed over the Rincón Block and the Golfito Terrane (formerly classified as Nicoya Complex). These two Miocene oceanic complexes are composed of basalts, dolerites, breccias, and interbedded pelagic sediments (Denyer and Gazel 2009). Adjacent to these ancient materials, sedimentary rocks (shales, sandstones, limestones, and conglomerates) emerged during the Miocene due to orogenetic processes (Bergoeing et al. 2010). Moving northwestward, Quaternary alluvial fans deposited along the piedmont region exhibit varying geologic ages and are primarily composed of conglomerates and igneous rock blocks immersed in a red-clayish matrix, highly weathered (Alvarado et al. 2009; Obando & Kussmaul 2009; Bergoeing 2011).

Finally, within the northern side of the Brunca Region, intrusive materials (classified as Comagmatic group Talamanca) predominantly consist of gabbro, monzonites, diorites, and granites. These intrusions cut through lava and other sedimentary strata, dating back to the Late Miocene (12–7.8 Myr.) (van Uffelen 1993; Alvarado et al. 2009; Alfaro et al. 2018). Climatic conditions within the Brunca Region are highly contrasting, described as rainy with monsoon influence, excessively rainy (with a reduction in rainfall from February to April), and characterized by low temperature and a very short drought period (Solano and Villalobos 2001). In general, the total annual precipitation reported for this region is 3836 ± 321 mm during a rainy period of 194 ± 9 days, with average air temperatures of 25 ± 1 °C (Solano and Villalobos 2001). However, the subregions of Valle del Coto Colorado and Península de Osa have reported total annual precipitation values exceeding 4200 mm, with over 190 days with rainfall (> 1 mm $day-^{1}$).

Vegetation within the Brunca Region can classified according Holdridge's life zone system (Holdridge 1967) as follows: Tropical wet forest (wf-T), Premontane wet forest

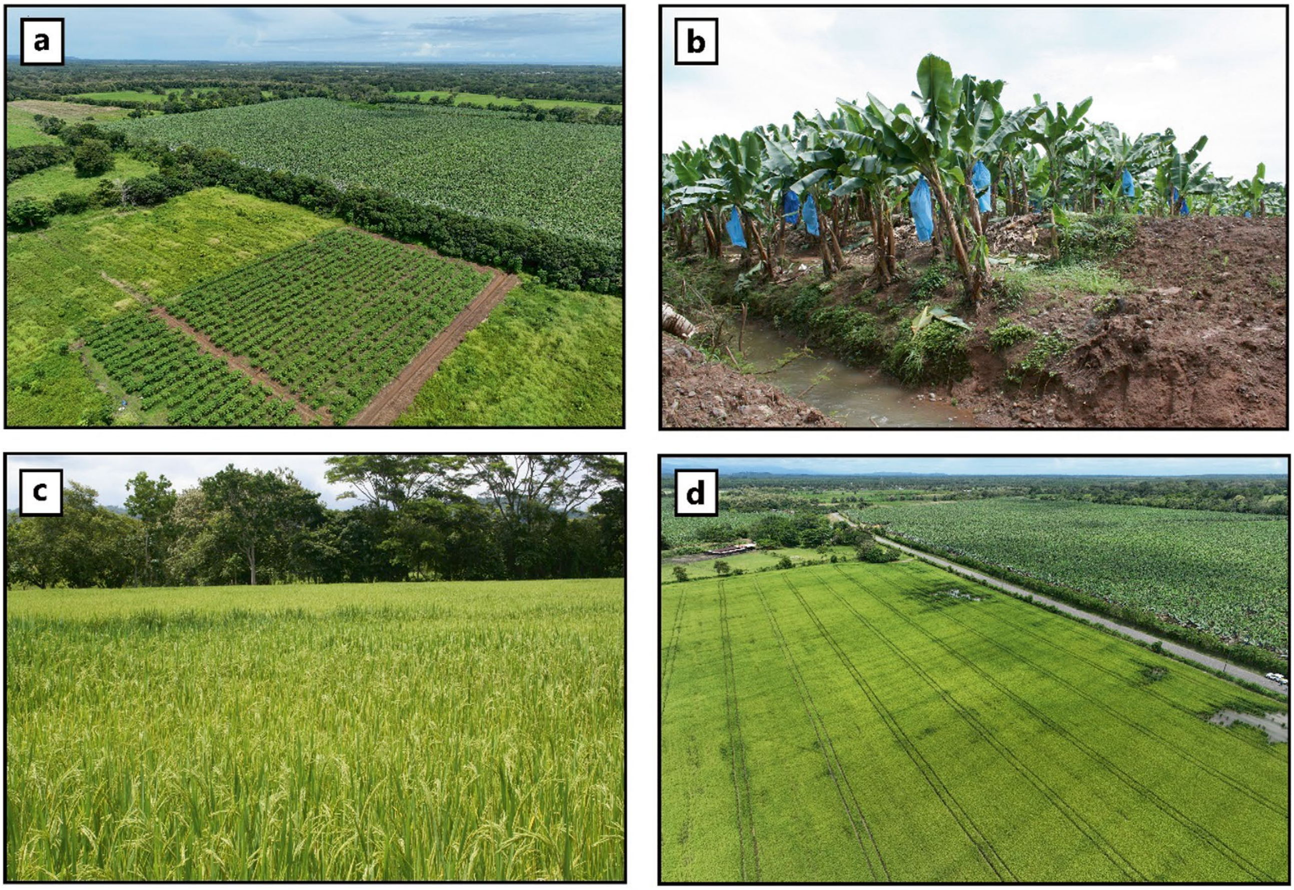

Fig. 11.9 Crop diversity within the lowlands of Pacífico Central Region: **a** Bananas (*Musa* AAA) and papaya, **b** banana farms with drainage, **c** rice fields, and **d** extensive crops such as rice and bananas within the same landform

basal belt transition (wf-P Basal), Premontane wet forest (wf-P), Premontane rain forest (rf-P), Lower montane rain forest (rf-LM), and Tropical moist forest (mf-T). The primary soil orders described and mapped in this region (Mata et al. 2022), from the most to the least abundant, are Ultisols, Inceptisols, Oxisols, Andisols, and Entisols, including some associations among them. Specifically for this landscape, Ultisols cover approximately 53% of the total area of the Brunca Region (Fig. 11.3c), followed by Inceptisols (12%) and Oxisols (10%). Despite Ultisols being reported as dominant in this region (Fig. 11.2), a revision of soil taxonomic orders assigned to specific geomorphic units within the piedmont (early and intermediate alluvial fans) has been proposed after performing a thorough determination of sand and clay mineralogy (Camacho et al. 2020).

This revision might lead to an increased coverage of Oxisols within this region, especially in landforms described as Quaternary alluvial fans (Camacho et al. 2020; 2021). Oxisols are characterized as highly weathered soils, with low-activity clays and desirable physical properties (Buol and Eswaran 2000). These soils are commonly found in stable landforms in the Tropics, where prolonged pedogenetic processes and limited weatherable minerals prevent further soil evolution. Despite their inherent low natural fertility, extensive crops like soybean, wheat, corn, and coffee can thrive with technified management practices (liming and fertilization) implemented by farmers and landowners (Buol et al. 2011). In fact, the Brunca Region's piedmont hosts extensive agricultural activities such as sugarcane and pineapple cultivation (Fig. 11.12). These activities not only serve as primary socio-economic drivers but also play a crucial role in shaping population dynamics, despite a significant number of people who emigrate due to limited economic opportunities and unemployment (Gatica-López 2017).

Historically, sugarcane cultivation has been a vital socio-economic activity within the region (Figs. 11.12 and 11.13), transitioning from low-input systems to extensive and technified cultivation that transformed the landscape and local society (Durán 2006). In this context, Miranda (1985), while studying the soil use change in the General Viejo community over six years, reported a substantial increase in sugarcane areal from 722 ha in 1973 to 1083 ha in 1979.

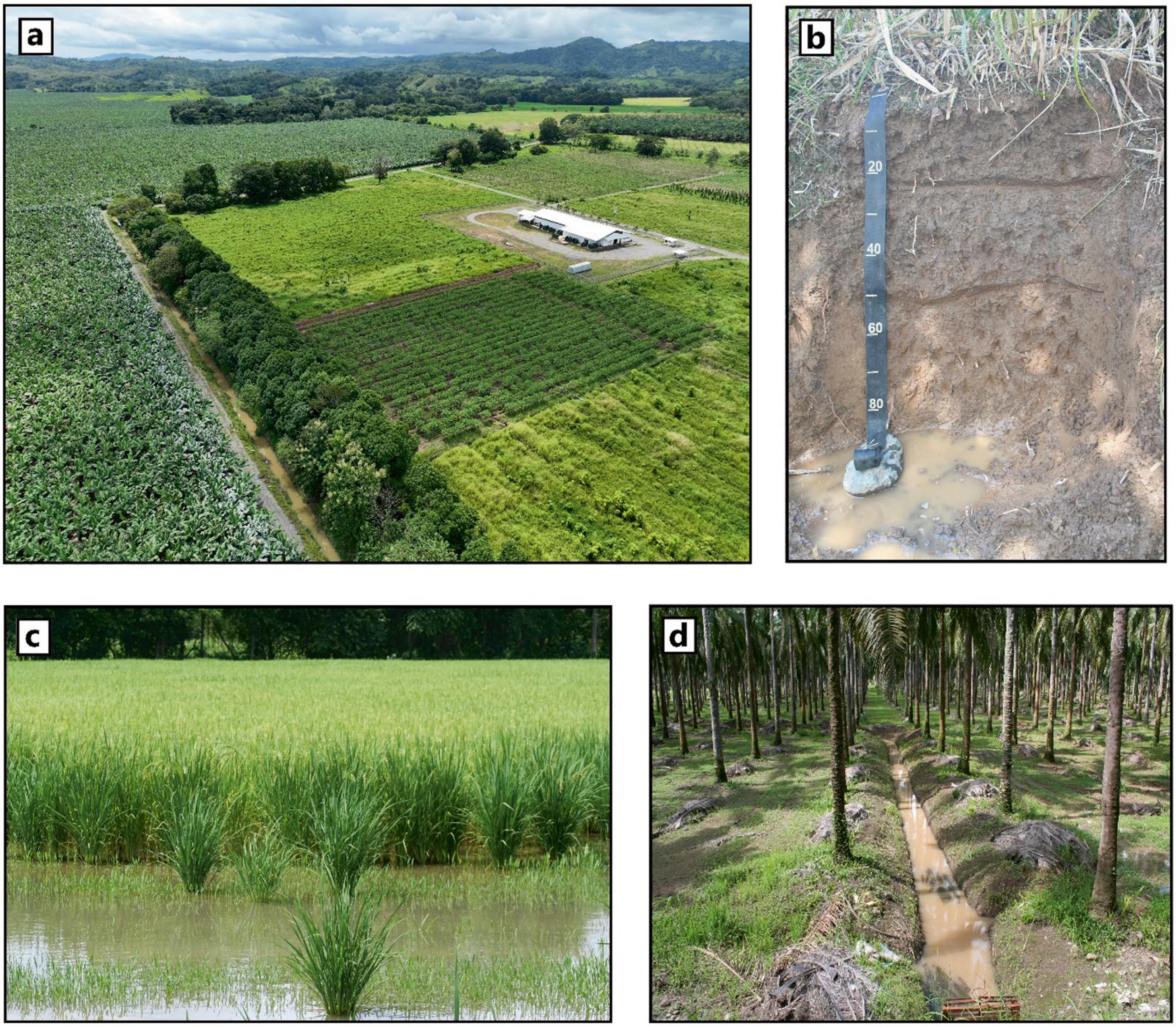

Fig. 11.10 Effect of cropping system and management practices on the agricultural landscape: **a** Distribution of banana, papaya, and rice within the same landform, **b** typical soil profile within this landscape in Parrita (*Aquic Haplustepts*), **c** waterlogged rice fields, and **d** drainage design for oil palm production

The coverage of this crop has continued to expand, reaching 4205 ha in 2019 for the entire region. Within this, 2910 ha is in Pérez Zeledón municipality, and 1295 ha in Buenos Aires municipality, contributing to a total yield of 295,167 t coming from 2312 producers, representing 43% of Costa Rica's sugarcane producers (Barrantes and Chaves 2020). Coffee production in the Brunca Region is primarily concentrated in Pérez Zeledón and Coto Brus municipalities (Fig. 11.13). Historically, coffee cultivation began in Pérez Zeledón when immigrant trailblazers from counties of Dota, Tarrazú, and Desamparados (Central Valley) arrived in the mid-nineteenth century, seeking improved socio-economic conditions (Miranda 1985). Similarly, in the 1940s pioneer families from the Central Valley moved to what is now Coto Brus municipality, establishing coffee farms due to optimal altitude and volcanic ash soils (Quesada-Román 2013).

Over time, coffee cultivation in both counties has expanded, with 8093 ha identified in Coto Brus municipality in 2012, increasing to 8727 ha in 2018. In Pérez Zeledón municipality, the coffee-planted area reached 13,116 ha in 2012 and expanded to 13,315 ha in 2018 (ICAFE 2019). In addition, a *fanega* represents 400 L of ripe coffee cherries, and the minimum volume to obtain 46 kg of coffee beans is considered as the official unit in Costa Rica. These extensions translated to total production of 159,767 *fanega* in Coto Brus and 212,759 *fanegas* in Pérez Zeledón in 2018 (ICAFE 2022). Interestingly, coffee cultivated areas in the

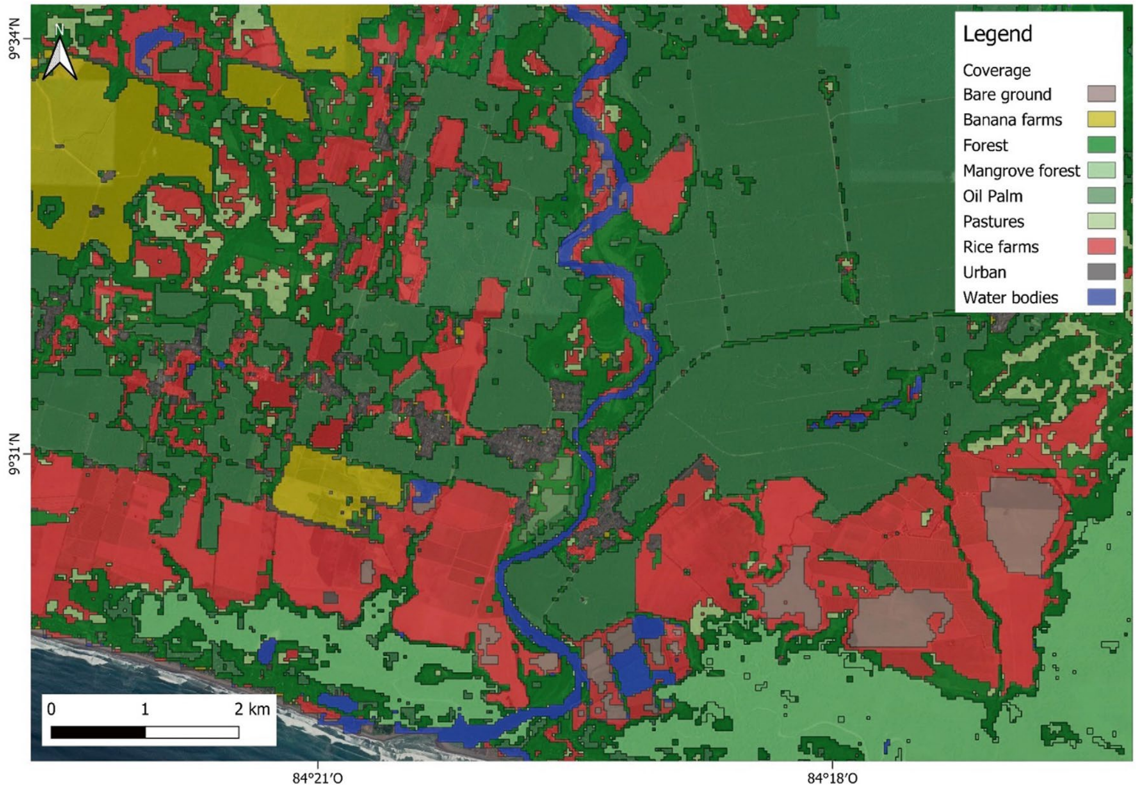

Fig. 11.11 Land coverage and soil use within the Pacífico Central Region. Land cover map generated using machine learning technics and supervised classification from PlanetScope Images (Planet Lab 2022)

last decades have grown in altitudes over even 1800 m asl and have been established on slopes above 40° (Quesada-Román et al. 2022). More recently, ICAFE (2022) reported a total production of 152,656 *fanegas* for Coto Brus municipality and 217,849 *fanegas* for Pérez Zeledón municipality. Coffee harvesting in the region is typically done by hand, requiring a significant labor force, often supplemented by immigrants from Panama (Quesada-Román and Díaz-Bolaños 2019).

Starting in 1983, pineapple cultivation surged in the Brunca Region to meet global demand for the tropical fruit (Castro 1994). This expansion of pineapple farming extended throughout Costa Rica, increasing from 1000 ha in 1984 to 37,660 ha in 2014 (Morales-Abarca 2018). By 2018, Buenos Aires municipality cultivated about 8700 ha with pineapple (Figs. 11.13 and 11.14), yielding a total 630,000 t of fruit. Meanwhile, Pérez Zeledón municipality contributed 2000 ha to produce 153,000 t (INFOAGRO 2023). However, pineapple planting areas decreased significantly in 2019, with only 6871 ha in Buenos Aires and 1200 ha in Pérez Zeledón municipalities (MOCUPP 2021b). Despite these fluctuations, pineapple has become a significant contributor to Costa Rica's economy, representing over 1 billion USD in fresh-fruit exports in 2021. The Brunca Region contributed 8800 ha to this industry (21% of the total pineapple-planted area in Costa Rica), supporting around 6160 direct employees (CANAPEP 2023).

These three crops—sugarcane, coffee, and pineapple—dominate the landscape of Pérez Zeledón and its surroundings (Fig. 11.15), particularly in the piedmont sector characterized by Quaternary alluvial fans. Pineapple is the most common element in the landscape, followed by sugarcane and coffee. As mentioned earlier, highly weathered soils (Ultisols and Oxisols) are commonly associated with these crops, subject to various soil management practices to maximize the yields, including liming, subsoiling, and organic addition (Molina 1998; Bertsch 1998; Camacho et al. 2015).

In the southeastern sector of the Brunca Region, abrupt variations in agricultural and socio-economic activities have resulted in landscape changes. For instance, in 1920, the current Osa and Golfito municipalities were areas where smallholders cultivated bananas, rice, and other grains (Royo 2004). Throughout its history, this region has been closely linked to extensive banana farming through "Compañía Bananera de Costa Rica," a subsidiary of the United Fruit Company, (UFC). Operations ceased in 1985 due to factors such as reduced farm productivity, market crises, and high operational costs that disadvantaged the region against other Central American areas

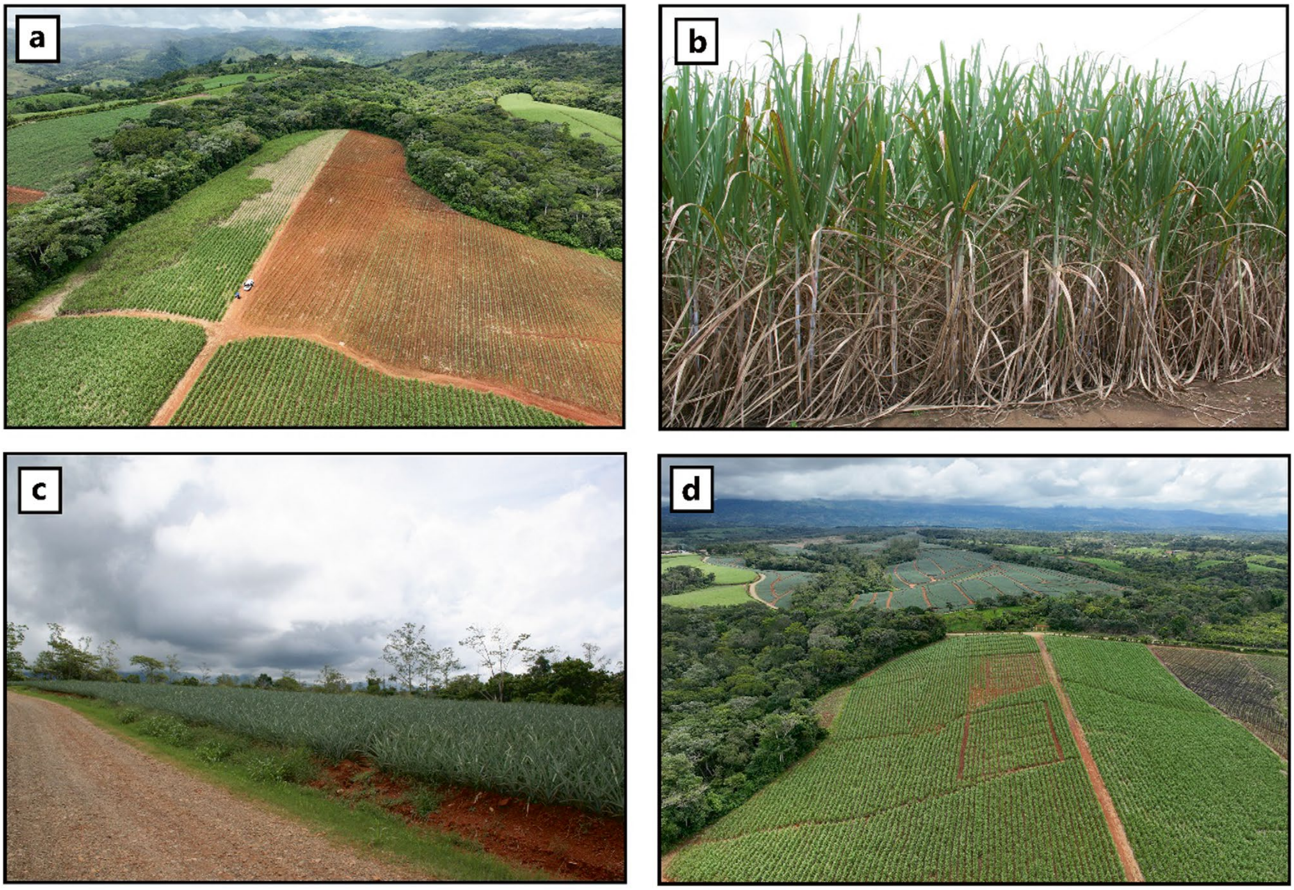

Fig. 11.12 Primary crops along the Talamanca piedmont sector within the Brunca Region: **a**, **b** Typical sugarcane fields, **c** pineapple (*Ananas comosus* (L.) Merr.), **d** sugarcane and pineapple fields within Quaternary alluvial fans

(Abarca-Jiménez 2015). Following this shutdown, banana farms gradually transitioned to oil palm under the United Fruit Company´s management, and subsequently, smallholders embraced oil palm production, forming associations and cooperative corporations (Fig. 11.16). However, these entities faced competition for land, resources, and operational power until the consolidation of major oil palm enterprises like Agricultural Services and Development (ASD) or “Palma Tica” (formerly UFC) established dominance within oil palm business (Clare 2012).

This activity continues to grow and expand the agricultural frontier in the Southern Brunca Region (Salas-González 2020). For instance, MOCUPP (2021a) reported that 48,160.77 ha were dedicated to oil palm in 2019, representing 5.25% of the Brunca Region’s total area. This area accounts for 68% of the total national oil palm cultivation area (MOCUPP 2021a). For instance, Corredores municipality possesses the largest oil palm-planted area, with 24,521.72 ha, followed by Golfito municipality with 12,480.2 ha, and Osa municipality with 10,969.97 ha.

Rice, another historically significant crop (Fig. 11.17), is also prominently cultivated within the Southern Brunca Region (Royo 2004). However, rice cultivation areas have fluctuated over the past decade and notably decreased over the last four years (Fig. 11.18).

For instance, the rice cultivation area was 6707 ha in the 2017–2018 growing season, dropping to 5650 ha in the 2020–2021 season (SEPSA 2023). This decline in cultivation areas led to reduced production, from 28,202 t of rice in 2017–2018 to 21,009 t of rice in 2020–2021. Similar trends of declining rice production and yields were observed in Costa Rica from 2003 to 2014, attributed to factors such as variation in climatic conditions, land conversion to more profitable activities like cattle production or oil palm (Sánchez and Vega 2018).

Land reconversion to oil palm (Fig. 11.19) was particularly notable in Corredores municipality, the primary political-administrative unit for oil palm cultivation. Here, rice cultivation area and total yield decreased by 16% and 32%, respectively, relative to 2019–2020 season (SEPSA 2023).

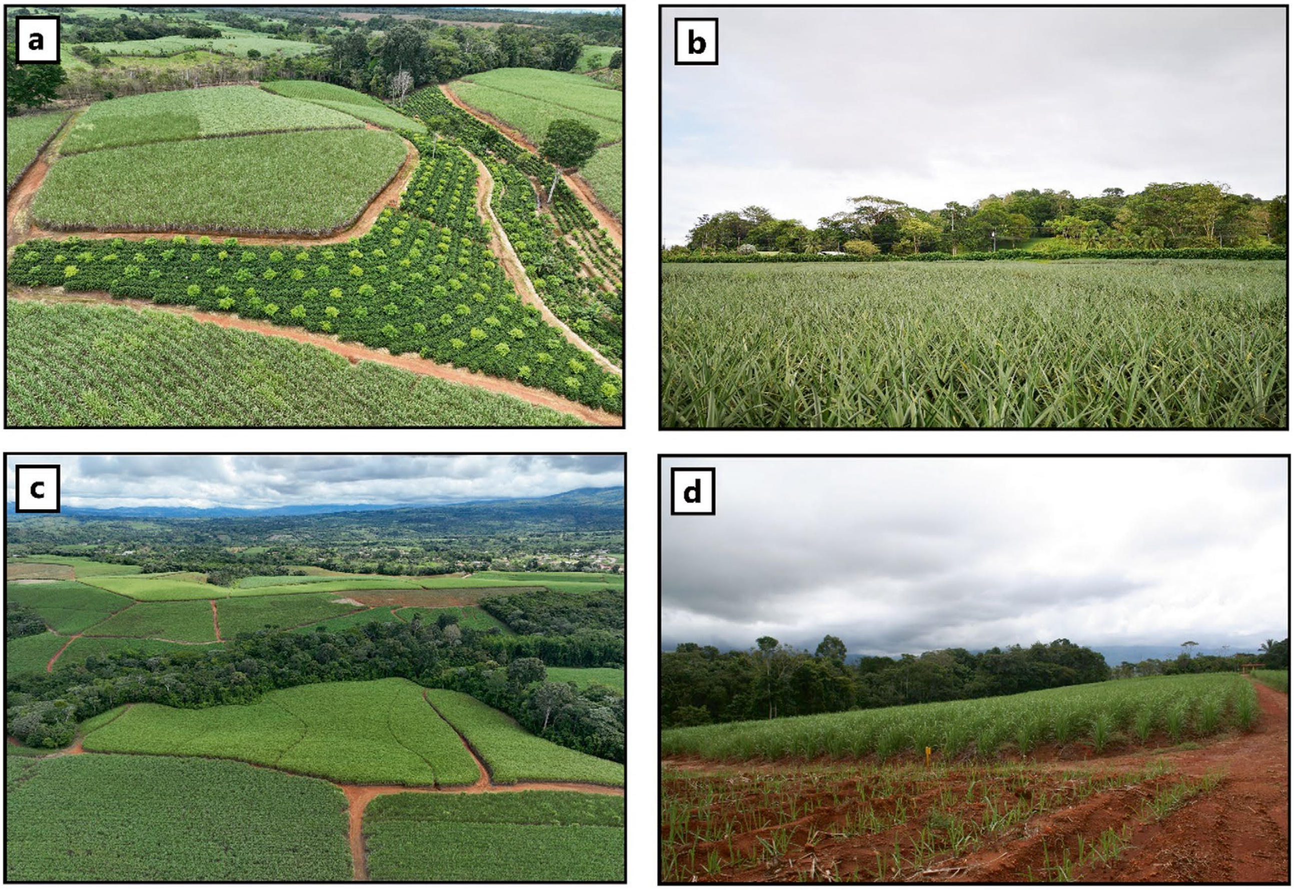

Fig. 11.13 Crop diversity along the Talamanca piedmont sector within the Brunca Region: **a** Intercropping system with sugarcane and coffee blocks, **b** typical pineapple fields (*Photo courtesy of S. Marín*), **c**, **d** extensive sugarcane cultivation within typical highly weathered soils

The predominant soils in this area are the Inceptisols, which are suitable for either or both crops under proper management practices (Fig. 11.19).

11.2.4 Huetar Norte Region in the Northern Side of Costa Rica

The Huetar Norte Region extends to cover the northern side of Costa Rica, bordering the San Juan River (the international boundary with the neighboring country of Nicaragua) and the Central Region of Costa Rica to its southern side. Its eastern sector includes the Guanacaste Volcanic Range, which encompasses five volcanoes (1659–2028 m asl), hills, and adventitious cones within the piedmont sector, as well as lowlands and plains that cover most of the entire planning region (Fig. 11.1).

The Huetar Norte Region includes the municipalities and districts of San Carlos, Upala, Los Chiles, Guatuso, Sarapiquí (Heredia), Peñas Blancas (San Ramón), Río Cuarto, Sarapiquí (Alajuela). This region presents contrasting landforms, including Quaternary volcanic cones and craters in the highlands, large alluvial fans formed from sediments deposited during the Pleistocene as part of the piedmont sector, extensive floodplains located in the northern part and crossed by several rivers (including Río Zapote, Río Frío, Río Pocosol, Río Peñas Blancas, and Río San Carlos), and lacustrine estuaries in the lowest areas (Bergoeing and Protti 2006; IMN 2011).

Floodplains belong to the Northern Plains of the Nicaraguan Graben which formed due to continental uplift and sediment deposition within this part of the tectonic depression of Nicaragua during the Quaternary, where sediments mainly originated from the Guanacaste and Central volcanic ranges (Bergoeing 2017).

On the other hand, geologic materials commonly found in this vast region are quite diverse. For instance, within the eastern sector of this region, diverse volcanic rocks are present: (1) dacitic porphyritic mounts, (2) quarzitic blocks, (3) blocks and ashes fluxes with pyroclastic-felsic materials, and (4) vitric welded-tuffs (Vargas and Alfaro 1992; Gazel et al. 2006). Much of these volcanic materials are dated to the Miocene. Porras et al. (2021) studied the San Carlos watershed, which is a significant area within the Huetar

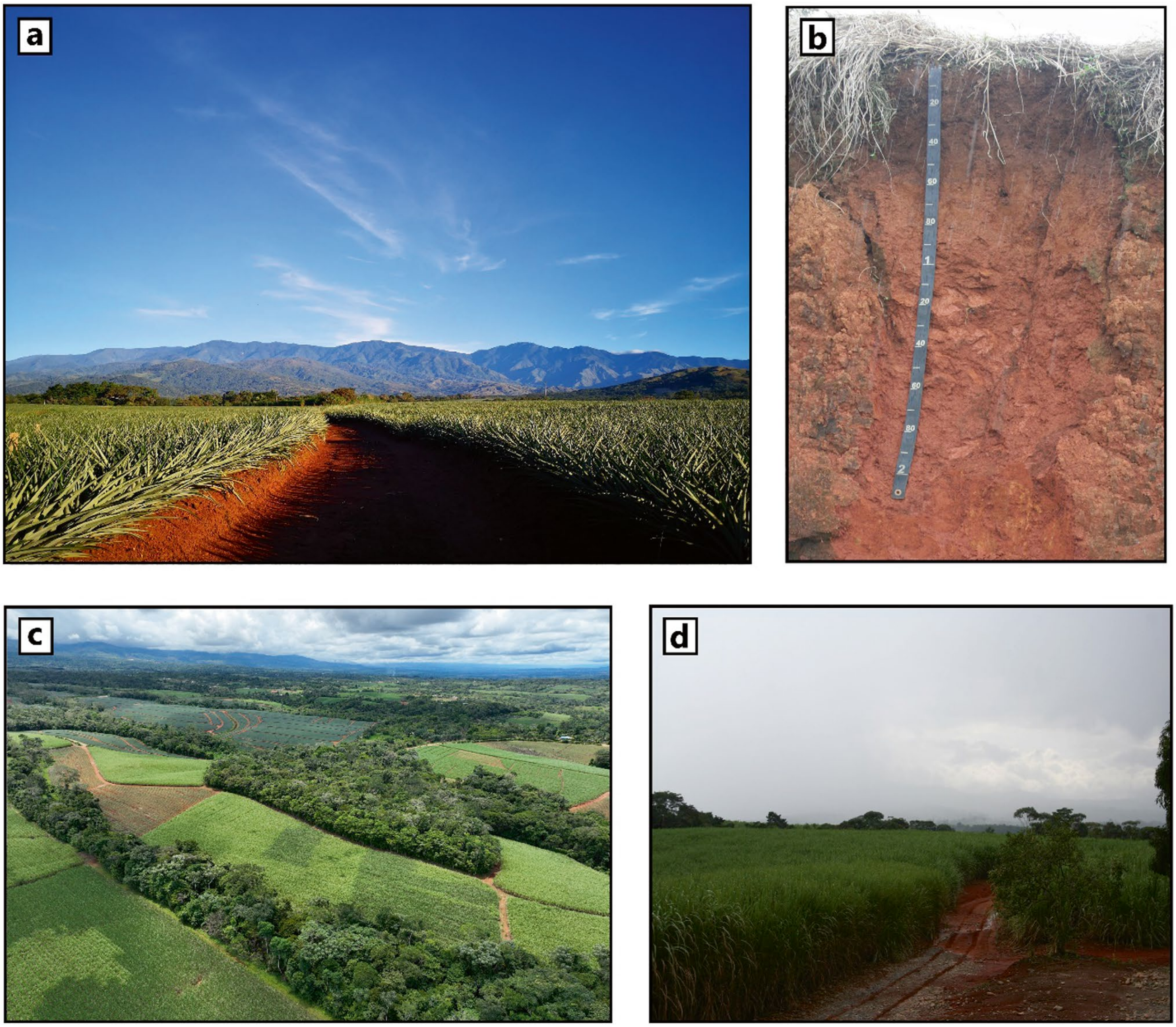

Fig. 11.14 Landscapes and landforms of the Talamanca piedmont sector within the Brunca Region: **a** Talamanca highlands in the background and pineapple fields within the piedmont (*Photo courtesy of S. Marín*), **b** typical soil profile within these old alluvial fans in Pérez Zeledón (*Anionic Acrustox*), **c** sugarcane and pineapple fields within Quaternary alluvial fans, and **d** typical view of sugarcane fields

Norte Region, and described the general stratigraphy, which includes: (1) peridotites and pelagic rocks as the basement (Cretaceous, Albian-Cenomanian), (2) intercalated sandstones, lutites, and limonites (Paleocene), (3) tholeiitic basalts and dacitic material, and rhyolites (Oligocene–Miocene), (4) sandstones and limestones with volcanic materials (Miocene-Pliocene), (5) alkaline volcanic materials (Pleistocene), and (6) andesites and basaltic rocks covered by fluvial and alluvial deposits (Pleistocene-Holocene).

Climatic conditions within the Huetar Norte Region are described as highly rainy, with a decrease in rainfall during February, March, and October, and temperature values not dropping below 22 °C (Solano and Villalobos 2001). In general, the total annual precipitation reported for this region is 3264 ± 204 mm during a rainy period of 206 ± 8 days, with average air temperature values of 24.6 ± 1 °C (Solano and Villalobos 2001). These climatic conditions account for the vegetation within the Huetar Norte Region, which can be classified according Holdridge's life zone system (Holdridge 1967) as Tropical wet forest (wf-T), Premontane wet forest basal transition (wf-P Basal), Tropical moist forest (mf-T), Tropical wet forest premontane transition (wf-T P), Premontane rain forest (rf-P), and Tropical moist forest perhumid transition (mf-T perhum).

The main soil orders described and mapped in this region (Mata et al. 2022), from the most to the least abundant, are Ultisols, Inceptisols, Andisols, and lastly Entisols,

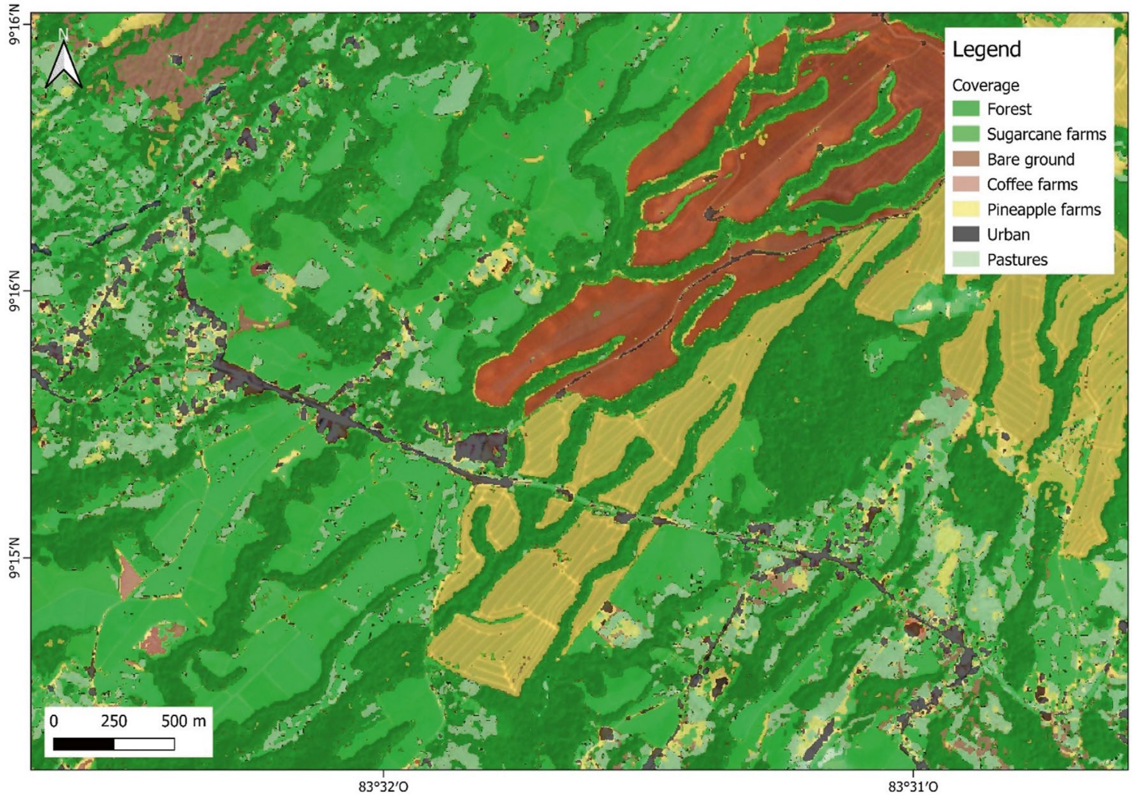

Fig. 11.15 Land coverage and crops observed within the Brunca Region. Land cover map generated using machine learning technics and supervised classification from PlanetScope Images (Planet Lab 2022)

including some associations among them. Specifically, Ultisols represent around 45% of the total area of the Huetar Norte Region (Fig. 11.3), followed by Inceptisols (21%) and Andisols (12%) (Fig. 11.2). Similar to what was reported for the Brunca Region, some Ultisols (dominant within the Huetar Norte) could be reclassified as Oxisols after determining sand and clay mineralogy accurately (Camacho et al. 2020). Indeed, these Oxisols have been reported in Crucitas de Cutris and San Rafael, both within San Carlos municipality (Camacho et al. 2021; NCSS 2023). Oxisols and Ultisols are highly weathered soils that normally have fertility limitations (low base status, low contents of phosphorus, high acidity) but they possess desirable physical properties like high drainage capacity, soil structure, and high porosity, which under proper management make them suitable for agriculture (West et al. 1997; Buol and Eswaran 2000).

Among the agricultural crops that are adapted to these weathered soils, pineapple, orange, sugarcane, and cassava (*Manihot esculenta* Crantz) stand out (Fig. 11.20). In addition to these crops, red and black beans (*Phaseolus vulgaris* L.), or other activities like grasslands and tree species like *Vochysia guatemalensis* Donn. Smith and *Gmelina arborea* Roxb (Moya 2004; Camacho et al. 2016) have been traditionally cultivated in this region, not only on Ultisols and Oxisols, but also Inceptisols. Black and red beans have been cultivated for decades in this sector of Costa Rica. In this regard, Faure and Samper (2004) described the colonization of northern Costa Rica during nineteenth century by trailblazing families and small producers, who initiated small farms with subsistence crops like beans, rice, corn, and roots vegetables. Despite the considerable decrease in planting areas for rice and beans due neoliberal policies established during the 1980s, they still occupy a significant area (Fig. 11.21).

Indeed, according to SEPSA (2023), the areas cultivated with beans reported for 2022–2023 corresponded to 4979 ha, with a total production of 4815 t within the Huetar Norte Region. These values are taken from the municipalities or districts of Upala, Guatuso, Los Chiles, Pocosol, and Santa Rosa, and constitute 33% of the total national production. Similar numbers have been reported for rice-crop areas, with 3666 ha and a total production of 14,520 t, accounting for 9.5% of total production in Costa Rica. Despite these last values of planted land being considerable, they were nearly three times higher during 1999–2000 (Faure and Samper 2004). This decrease is due to the conversion of land to more profitable crops like pineapple or citrus (Fig. 11.22), whose acreage has increased dramatically since the 1970s as industrialized activities (Arias et al.

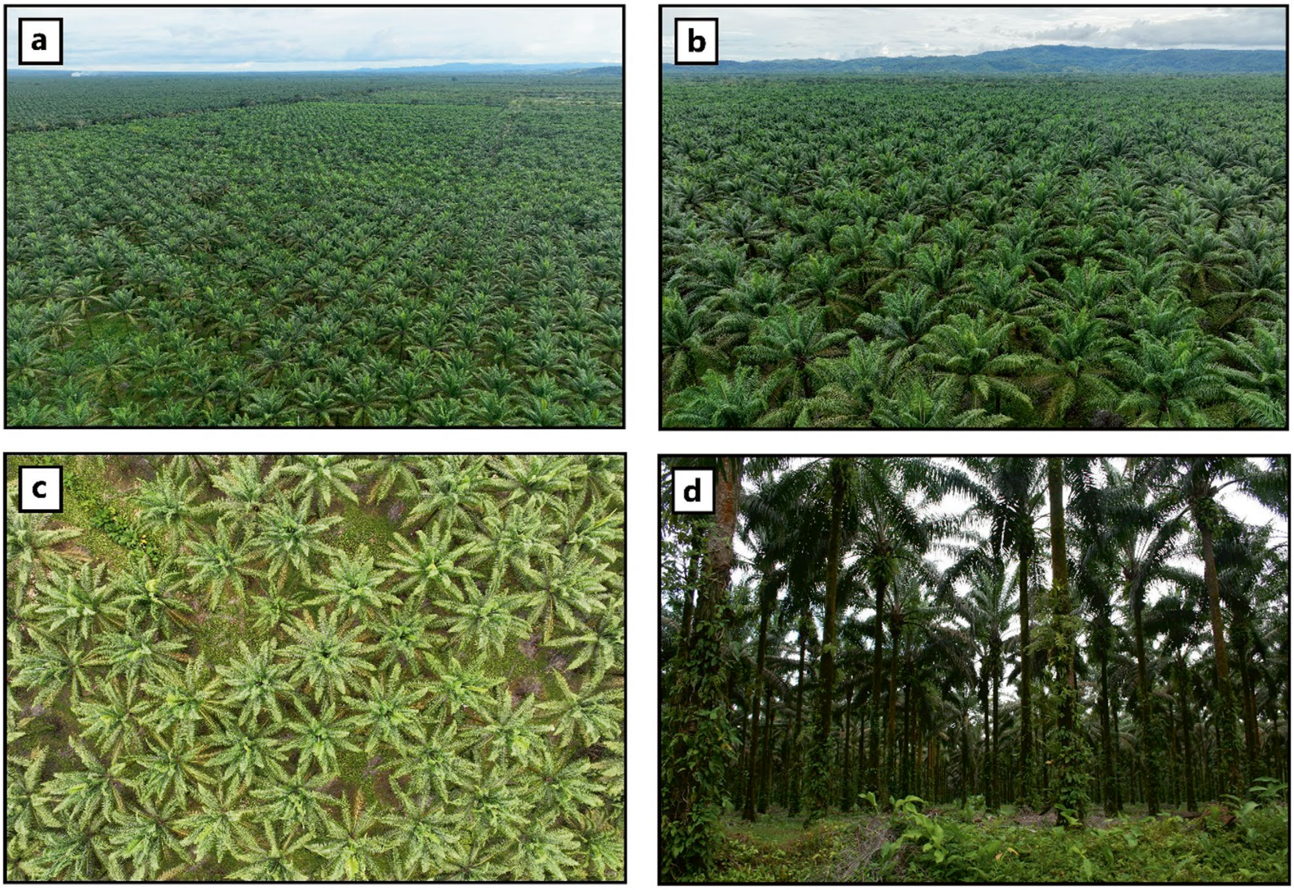

Fig. 11.16 Extensive oil palm fields observed in the southeastern sector of the Brunca Region: **a–c** Aerial pictures taken in Guaycará, Puntarenas, and **d** close-up of a plantation

2018; Obando 2020). For instance, in 2021, SEPSA (2023) reported that 9,626 ha was planted with oranges within the Huetar Norte Region (Fig. 11.23), with a total production of 144,390 t. These values are distributed within three municipalities: Los Chiles, Upala, and San Carlos.

In addition, pineapple has become the most planted crop within this region and represented 68% of total pineapple-covered land in Costa Rica in 2018 (MOCUPP 2021b), with a total of 44,138.52 ha. These extension values are mostly distributed within six counties: San Carlos (18,509.51 ha), Los Chiles (8742.74 ha), Sarapiquí (6199.70 ha), Río Cuarto (5665.27 ha), Upala (3383.16 ha), and Guatuso (1510.91 ha). Pineapple production as an industrial activity requires a considerable number of workers involved in the agronomic management, fruit harvest, post-harvest practices, and packing, which provide a crucial source of income for families living in these areas. Some communities, however, are striving to find alternative job sources to avoid dependence on this industry (Obando 2020).

11.2.5 Huetar Caribe Region in the Caribbean Coast of Costa Rica

Moving to the Caribbean coast of Costa Rica, the Huetar Caribe Region covers the entire eastern coast, bordering the San Juan River delta on the northern side and the Sixaola River in the southeastern sector (the international boundary with the neighboring country of Panama). The eastern sector of the Huetar Caribe Region borders the Caribbean Sea, while the western sector borders with the Talamanca and the Central Volcanic Range. In addition, the eastern sector encompasses the piedmont region of Irazú and Turrialba volcanoes (1200–2200 m asl), the eastern piedmont of Talamanca hills (600–1400 m asl), and lowlands and alluvial plains that cover most of the whole planning region (Fig. 11.1).

The Huetar Caribe Region includes the counties of Limón, Pococí, Siquirres, Talamanca, Matina, and Guácimo. This region presents two main sectors: (1) coastal plain mostly

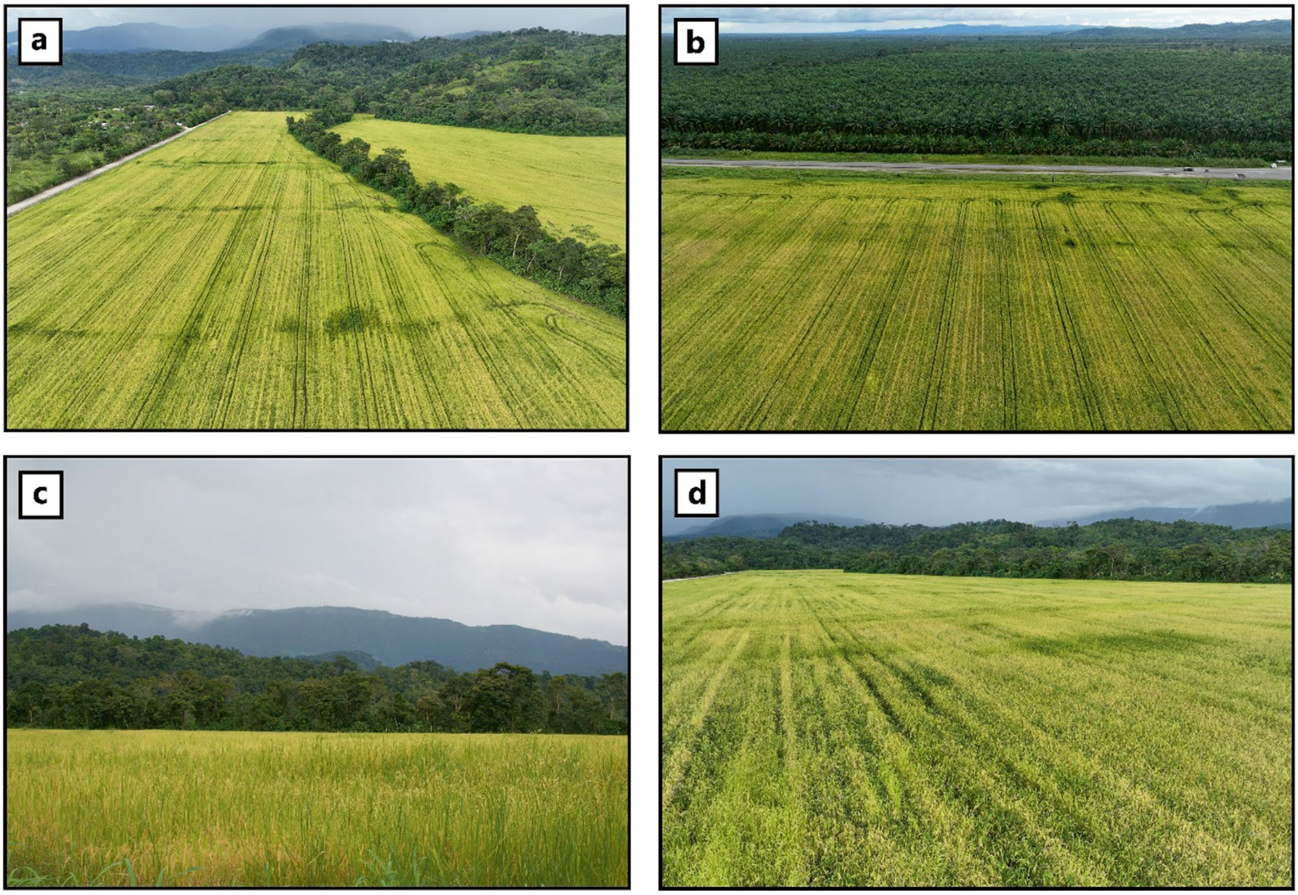

Fig. 11.17 Extensive rice fields observed in the southeastern sector of the Brunca Region: **a**, **b** Aerial pictures taken in Guaycará, Puntarenas, **c**, **d** aboveground biomass and panicles almost ready for harvest

composed of lowlands, and (2) piedmont with elevations and isolated hills, including volcanic cones of Quaternary ages (Bergoeing 2017; Quesada-Román and Pérez-Briceño 2019). Both sectors are dissected by several rivers, including Río Sixaola, Río La Estrella, Río Banano, Río Bananito, Río Moín, Río Matína, Río Madre de Dios, Río Pacuare, Río Reventazón, and Río Tortuguero (IMN 2011).

Geologic materials supporting these landforms are quite diverse, including volcanic and sedimentary materials from the Miocene to the Quaternary. For instance, within the northern sector of this region, volcanic materials crop out such as those building Miocene volcanic mounts (Lomas del Cerro Cocorí and Lomas de Sierpe). Moreover, alkaline basalts occur within dissected volcanic cones from the early Pleistocene (Cerro Coronel and Cerro Tortuguero). Other formations include sediments and materials deposited after the Holocene transgression and volcanic-sedimentary materials deposited as alluvial fans and lahars (Battistini and Bergoeing 1984; Bergoeing 2017).

Climatic conditions within the Huetar Caribe Region are mainly described as highly rainy (especially in the mountains) with no clear dry period throughout the year (Solano and Villalobos 2001). In general, the total average annual precipitation reported for the whole region is 3525 ± 494 mm with an average rainy period of 206 ± 14 days, along with average air temperature values of 23.0 ± 1 °C (Solano and Villalobos 2001). Similar to other planning regions, these climatic conditions can explain the vegetation within this region, which can be classified according Holdridge's life zone system (Holdridge 1967) as Tropical wet forest (wf-T), Premontane wet forest basal transition (wf-P Basal), Lower montane rain forest (rf-LM), Premontane rain forest (rf-P), Tropical wet forest premontane transition (wf-T P), and Tropical moist forest (mf-T).

The soils in this region (from most to the least abundant) are Ultisols, Inceptisols, Entisols, and Andisols, including some associations among them and other soil orders (Mata et al. 2022). Specifically, Ultisols represent around 45% of the total area of the Huetar Norte Region, followed by Inceptisols (21%) and Andisols (10%) (Fig. 11.3). Ultisols are mostly located in the southeastern sector (Talamanca Piedmont) and within the northern sector (hills and volcanic cones from the Quaternary) (Fig. 11.2). For instance, Ultisols are commonly found in Cerro Tortuguero, Lomas

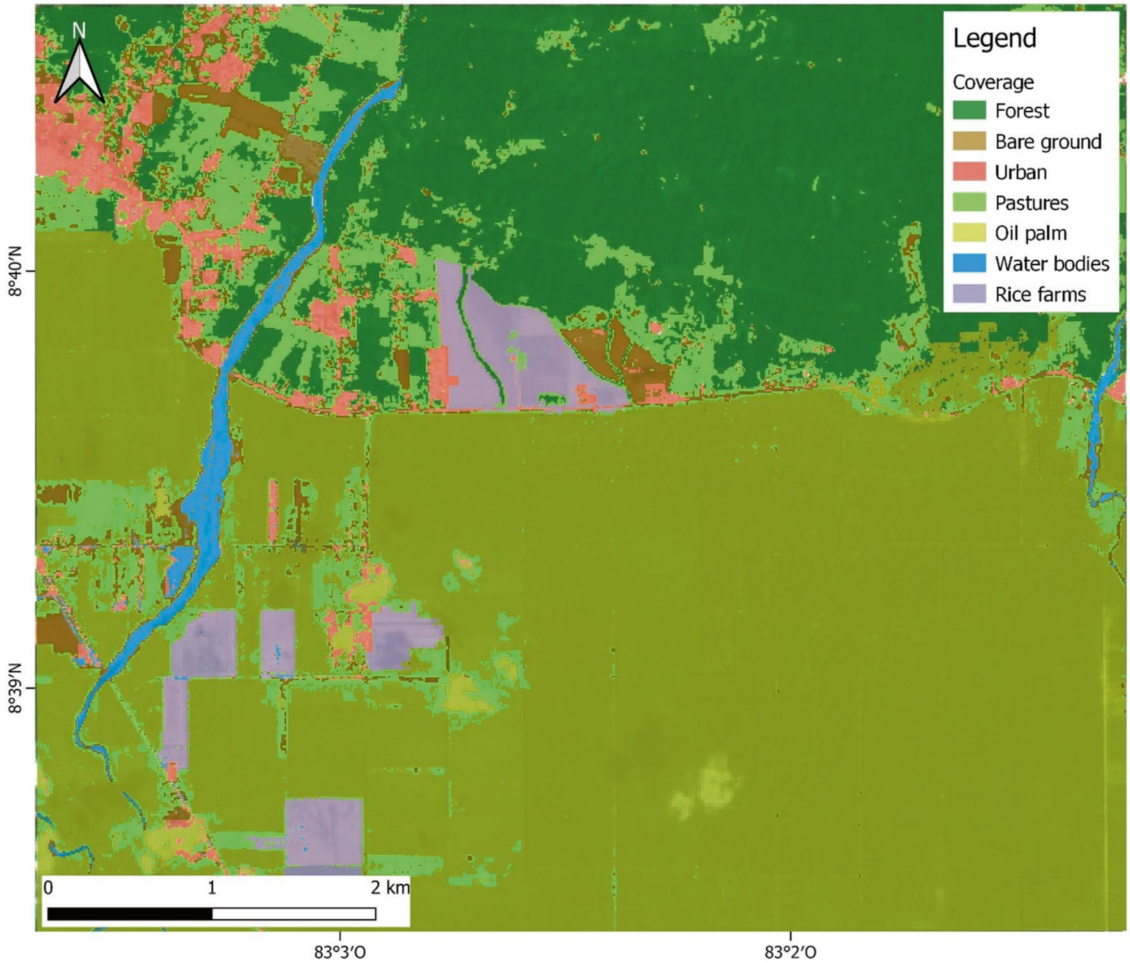

Fig. 11.18 Land coverage and soil use in the southeastern sector of the Brunca Region. Land cover map generated using machine learning technics and supervised classification from Sentinel-2 Images (ESA 2023)

de Sierpe, and Cerro Coronel, with soils in the latter being reclassified as Oxisols (Camacho et al. 2021). Inceptisols and Entisols are more abundant within the northern sector, commonly found within the areas of fluvial deposition as described by IMN (2011). Finally, volcanic ash-derived soils are mostly located within the northern side of Irazú and Turrialba volcanoes and adjacent piedmont region. As well, in some sectors, Andisols developed in association with Inceptisols (Mata et al. 2022).

In this regard, Arias et al. (2010) studied the genesis and mineralogy of soils planted with bananas within the eleven watersheds of the Caribbean side of Costa Rica. They mainly identified soil orders of Inceptisols, Andisols, and their associations, which were separated into two main zones according with their clay minerals and soil genetic pathways: (1) northeastern sector with volcanic ash-derived and medium fertility soils, and (2) southeastern sector with limestone-derived and fertile alluvial soils, physically separated by the rivers Vueltas-Silencio-Parismina. Due to this geomorphologic and pedologic diversity (and subsequent difference in fertility), several cash crops have been developing within the Huetar Caribe, with the most abundant being banana and pineapple extending across the region, as well as papaya and palm-heart (*Bactris gasipaes* Kunth) (Morales-Abarca 2018; Mora-Urpí 2002; Arias et al. 2010; Fallas-Corrales and van der Zee 2020).

Historically, the banana crop has been the main socioeconomic activity within the Huetar Caribe Region. In this regard, Minor C. Keith moved to Costa Rica in 1871 to join his brother's railroad construction business, aiming to connect the Costa Rican Central Valley with Puerto Limón (Limón Port). This project was as ambitious as challenging, where after 42 km of railroad already built, around 4000 lives (including Minor's three older brothers) were taken due to accidents or diseases (Jones and Morrison 1952).

Then, Mr. Keith took charge of this ambitious project, under several troublesome factors like tough climatic conditions and funding cuts that delayed and interrupted construction works several times. During these setbacks, the businessman found a new activity to keep getting profit

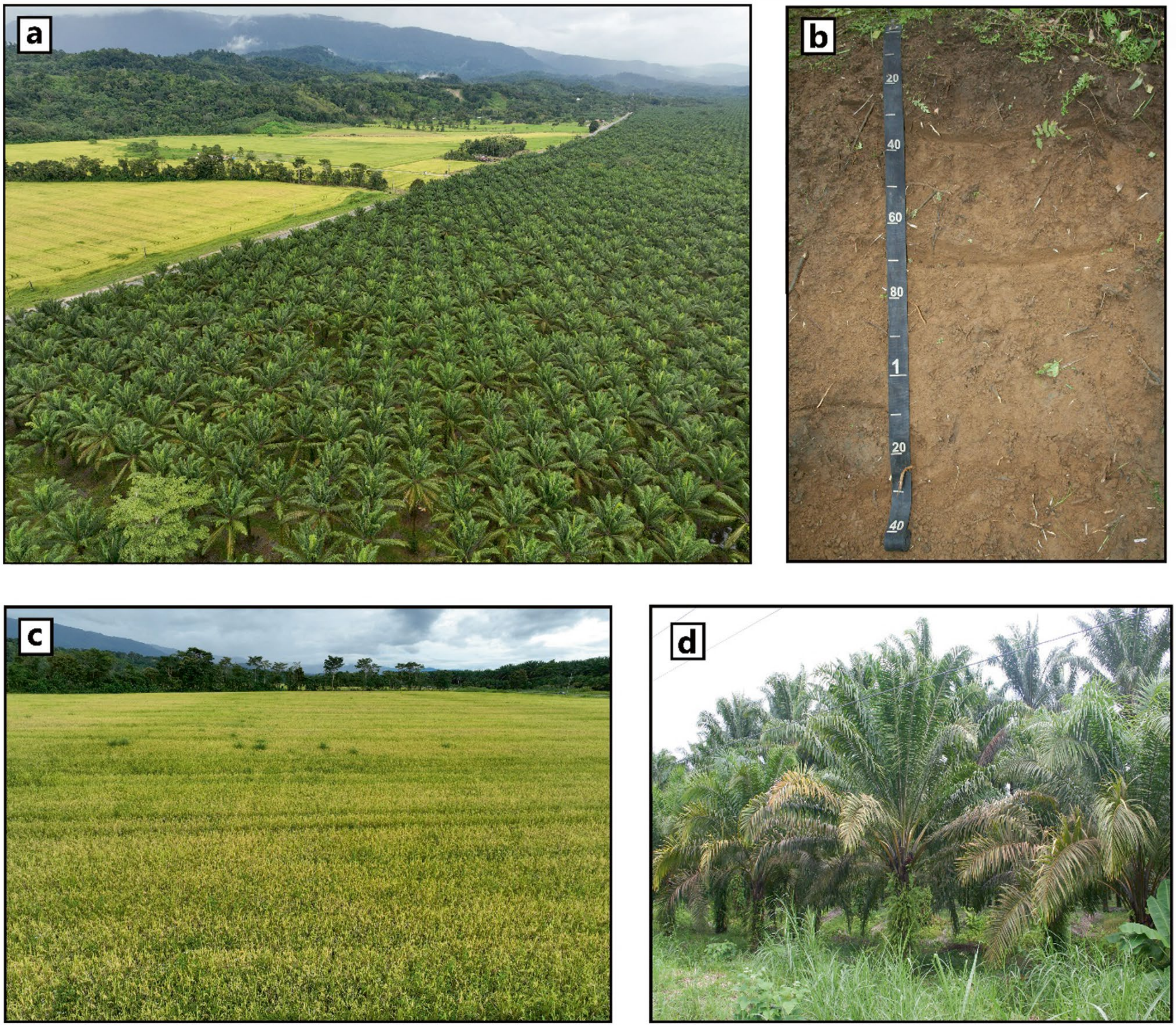

Fig. 11.19 Land reconversion in the southeastern sector of the Brunca Region: **a** Aerial picture of rice fields surrounded by oil palm in Guaycará, Puntarenas, **b** typical soil profile within an rice-palm agricultural landscape (*Andic Humudepts*), **c** rice field with plants near to be harvested, and **d** oil palm plants with oil seeds ready (plant is 3–4 years old)

within the agriculture, introducing banana rhizomes (variety "Gros Michel") from the region of Aspiwall, Panamá (currently named as Colón) (Jones and Morrison 1952). Initially, the banana plantations were set up in 1972 within the two valleys: (1) "Valle de Matina" and (2) "Valle de Zent all within the current Matina municipality, but this business further extended to other sectors of the Huetar Caribe Region (Montero and Viales 2014). The banana business and planted area grew dramatically until 1941 when yields started to decrease due soil exhaustion and the presence of two new plant diseases in the region: Panamá disease (*Fusarium cubense*) and Sigatoka (*Cercospora musae*) (Jones and Morrison 1952). Despite these last challenges, bananas have become the second most important cash crop in Costa Rica and currently appear among the first three most exported goods of Costa Rica (Fig. 11.24). During 2021, fresh banana export represented 1.03 billion USD (6.60% of total exported goods) and increased to $1.39 billion USD (7.78% of total exported goods) in 2022 (INEC 2022b, 2023).

According to SEPSA (2023), the areas planted with banana during 2022 corresponded to 41,059 ha and total production within the Huetar Caribe Region was 2,228,499 t. These values are taken from the municipalities Matina, Pococí, Siquirres, Sarapiquí, Limón, Guácimo, and Talamanca and represented 98% of the total national banana production. On the other hand, and despite the criticism about the crop's impact on soils, water pollution,

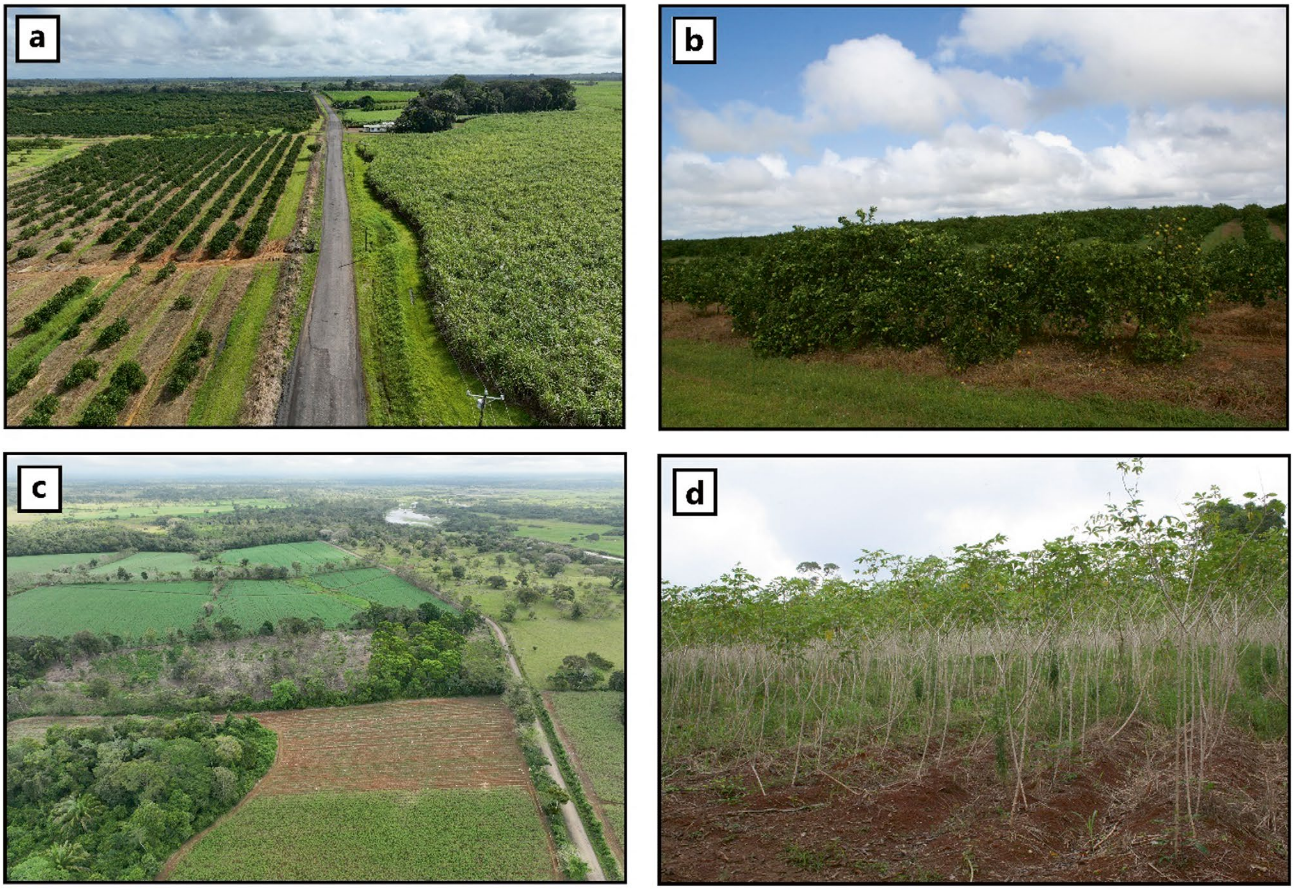

Fig. 11.20 Crop diversity within the landscapes of Huetar Norte Region: **a** Sugarcane and orange (*Citrus sinensis* L.) fields separated by the road, **b** typical orange field almost ready to harvest, **c** divergent cropping systems within the same landform such as cassava (*Manihot esculenta* Crantz) and beans (*Phaseolus vulgaris* L.), and **d** cassava plants

and sustainability, pineapple production, and land coverage grew dramatically between 2000 and 2017 (Blanco-Obando 2020) and currently represents the second most planted crop within this region (Fig. 11.24). In this regard, the Huetar Caribe Region represents 19% of total pineapple-covered land assessed in Costa Rica during 2018, with a total of 12,303.97 ha (MOCUPP 2021b). Pineapple plantations are mostly distributed within three main counties: Siquirres (2675.12 ha), Guácimo (3006.65 ha), and Pococí (6680.38 ha) (Fig. 11.25). Although the agriculture-covered land is dominated by banana and pineapple in this planning region (Fig. 11.25), there are other extensive crops with economic relevance like papaya and palm-heart (Fig. 11.26). For instance, the palm-heart which originally was extracted from the forests as a wild plant has been planted in monocultures within the Caribbean part of Costa Rica since 1978 (Mora-Urpí 2002).

In subsequent years, there was a huge increment in heart-palm production. In 2002, around 12,000 ha were planted with this crop within the Huetar Caribe Region, becoming the second more extensive crop in this planning region (Ares et al. 2002). However, the planted area started to decrease due to the increment in demand of land for other uses or more profitable crops such as pineapple and banana (Figs. 11.24 and 11.25). In 2014, a total of 4618.0 ha was planted with heart-palm, where the counties Sarapiquí, Pococí, and Siquirres accounted for 2138.3, 974.4, and 492.9 ha, respectively (INEC 2015). Currently, only 3606.3 ha have been planted with heart-palm in the whole territory of Costa Rica (INEC 2022a).

Another important crop within the Huetar Caribe Region is papaya. In 2014, a total of 1393 ha was planted with this permanent crop in Costa Rica, where 515 ha corresponded to the counties of Pococí and Guácimo (INEC 2015). Most of papaya plantations have been established by smallholders and low-input farmers (Fig. 11.27), who struggle with plant diseases and poor nutrient management or fertilizers (Fallas et al. 2020). This could reinforce the increment trend of pineapple-covered land in detriment of other more reliable crops. Figure 11.27 shows the distribution of the area covered with papaya and heart-palm within the western sector of the region and highlights the small coverage

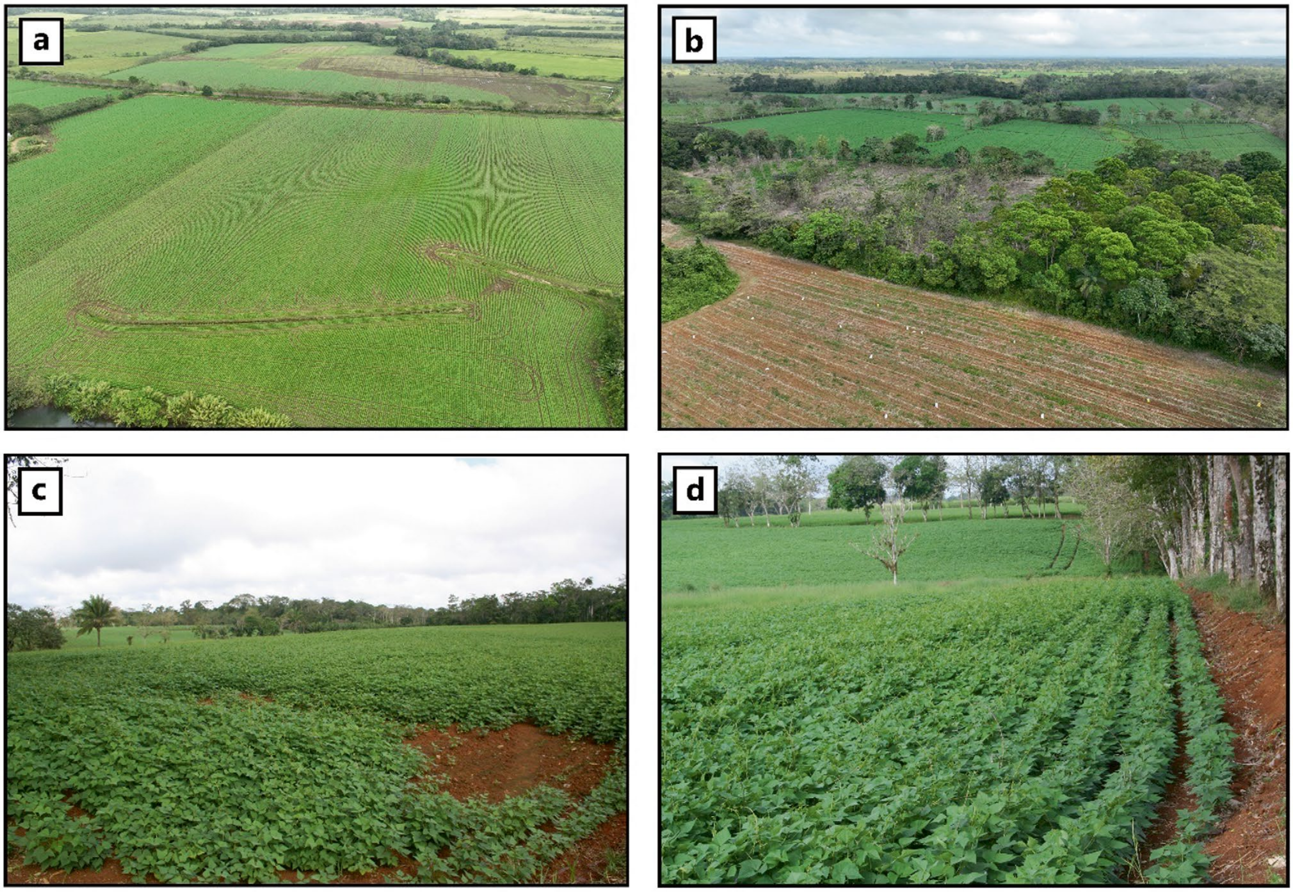

Fig. 11.21 Extensive black and red bean fields in Huetar Norte Region: **a**, **b** Aerial pictures taken, respectively, in Upala and San Antonio de Caño Negro, Alajuela; **c**, **d** aboveground biomass and phenological stages of beans

of papaya while comparing with other land uses such as banana, pastures, or heat-palm. All these activities have been modifying the landscapes within the Huetar Caribe Region along the time. For instance, drainage systems and raised beds designed for banana fields have impacted the surface water and sediment movement.

11.2.6 Región Central in the Central Sector of Costa Rica

The central sector of Costa Rica is known as Región Central (Central Region) and encompasses the central valley along with its surrounding mountains and volcanoes. This region is bordered by the Talamanca Mountain Range and its foothills in the southwestern to southeastern sector, and to the north by the Central Volcanic Range. Additionally, the northwestern sector borders the Tilarán Mountain Range. Notable features include the inner piedmont region of Poás, Barva, Irazú, and Turrialba volcanoes (with elevations ranging from 2500 to 1200 m asl), and the northern piedmont of Talamanca hills (with elevations ranging from 1800 to 900 m asl) that encircle this planning region (Fig. 11.1).

The Región Central comprises over 40 municipalities, with Turrialba covering the eastern part. The northern border is formed by the municipalities of Heredia, Alajuela, Poás, Sarchí, and Zarcero. The western border is defined by the municipalities of San Ramón, Atenas, and Turrubares, and the southern sectors are encompassed by Puriscal, Acosta, Aserrí, Tarrazú, and Dota. This region showcases two primary landform types: (1) the central tectonic depression that includes the cities of San José, Heredia, and Alajuela, also known as "Meseta Central" (Central Plateau), and (2) piedmont with foothills and isolated hills, encompassing the four volcanic cones mentioned above (Bergoeing 2017). Furthermore, several watersheds cover this region, including those of Río Grande de Tárcoles, Río Parrita, Río Naranjo, Río Savegre, Río Chirripó, Río Sarapiquí, Río Moín, and Río Matina (IMN 2011).

Geologic materials found within Región Central are both diverse and complex, consisting of igneous (plutonic or volcanic) and sedimentary materials from the Paleocene-Pliocene and Quaternary periods. For instance, Denyer and

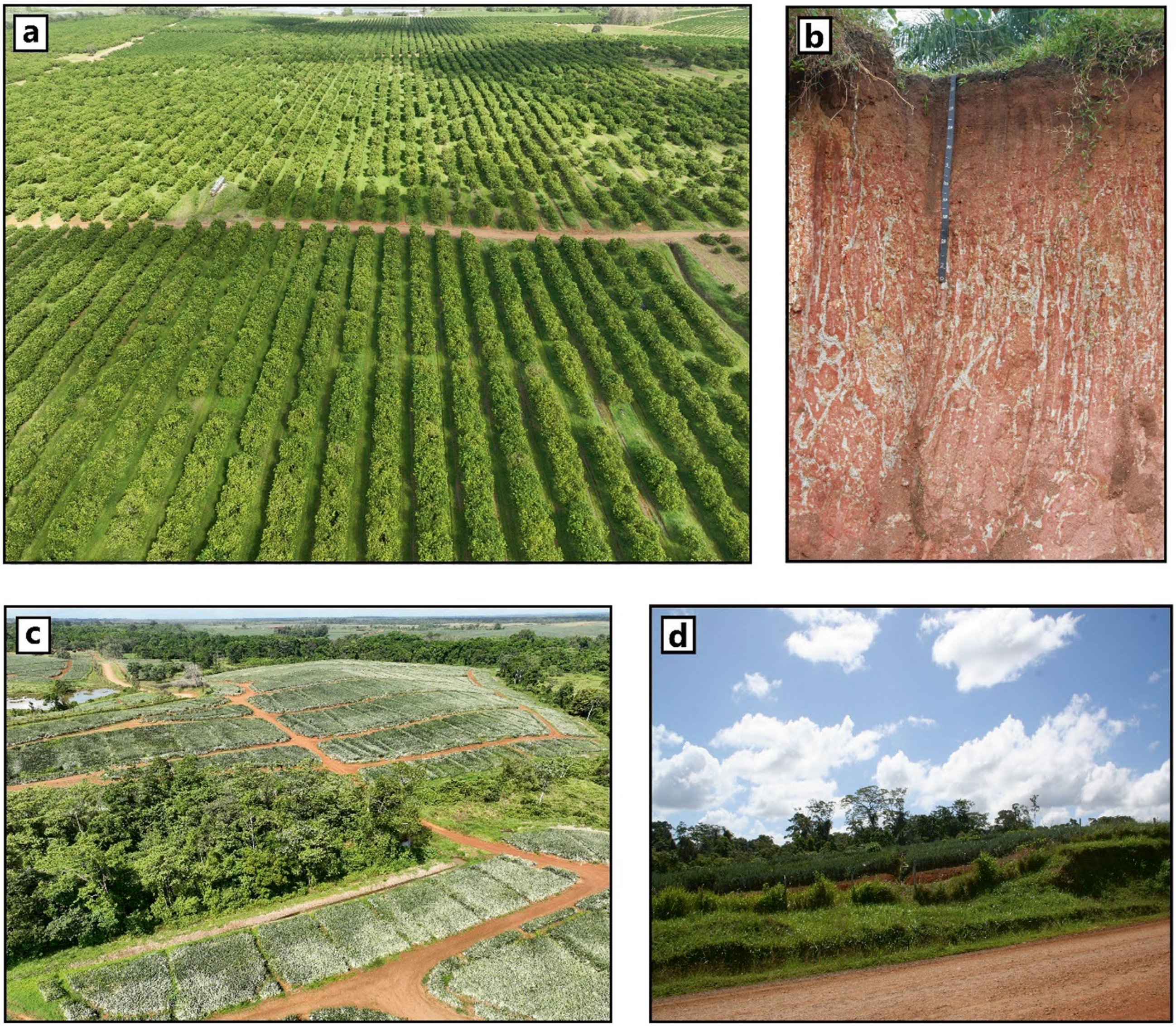

Fig. 11.22 Land reconversion and crops in Huetar Norte Region: **a** Aerial picture of extensive orange fields near of Finca Palmira, Alajuela, **b** highly weathered soil profile (*Plinthic Kandidults*) typically present in this planning region, **c** aerial picture of extensive pineapples fields near of El Concho de Cutris, Alajuela, and **d** pineapple plants at the same location

Arias (1991) examined the stratigraphy of the southeastern sector of the Región Central and described the basement as an ophiolitic oceanic complex (Complejo de Nicoya) overlain by Paleocene-Pliocene materials. These materials range from limestones (Parritilla Formation) and breccias (Caraigres Formation) to volcanoclastic rocks (Pacacua Formation), also including sedimentary materials like mudstones and sandstones associated with limestone (San Miguel and Peña Negra Formations). Further volcanic events, combined with deformation during the Miocene-Pliocene, contributed to additional geological materials. Later on, deposition of ashes and mud flow materials completed the filling of the central depression (Denyer and Arias 1991). Additionally, the volcanoes located within the Volcanic Central Range have significantly impacted the landscape due to their historical activity, producing volcanic ash, lava flows, extrusive rocks, and lahars (Casertano et al. 1983; Alvarado and Schmincke 2013; González et al. 2015).

Weather conditions across the Región Central vary among its sectors. The northern and northeastern sectors, especially in the mountains, are characterized as highly rainy throughout the year, while the south and southwestern sectors are drier, experiencing water deficits for at least five months (Solano and Villalobos 2001). In general, the average annual precipitation for the entire region is 2262 ± 280 mm, with a mean rainy period lasting 134.6 ± 6 days. The average air temperature is 19.0 ± 2 °C (Solano and Villalobos 2001). These climatic conditions

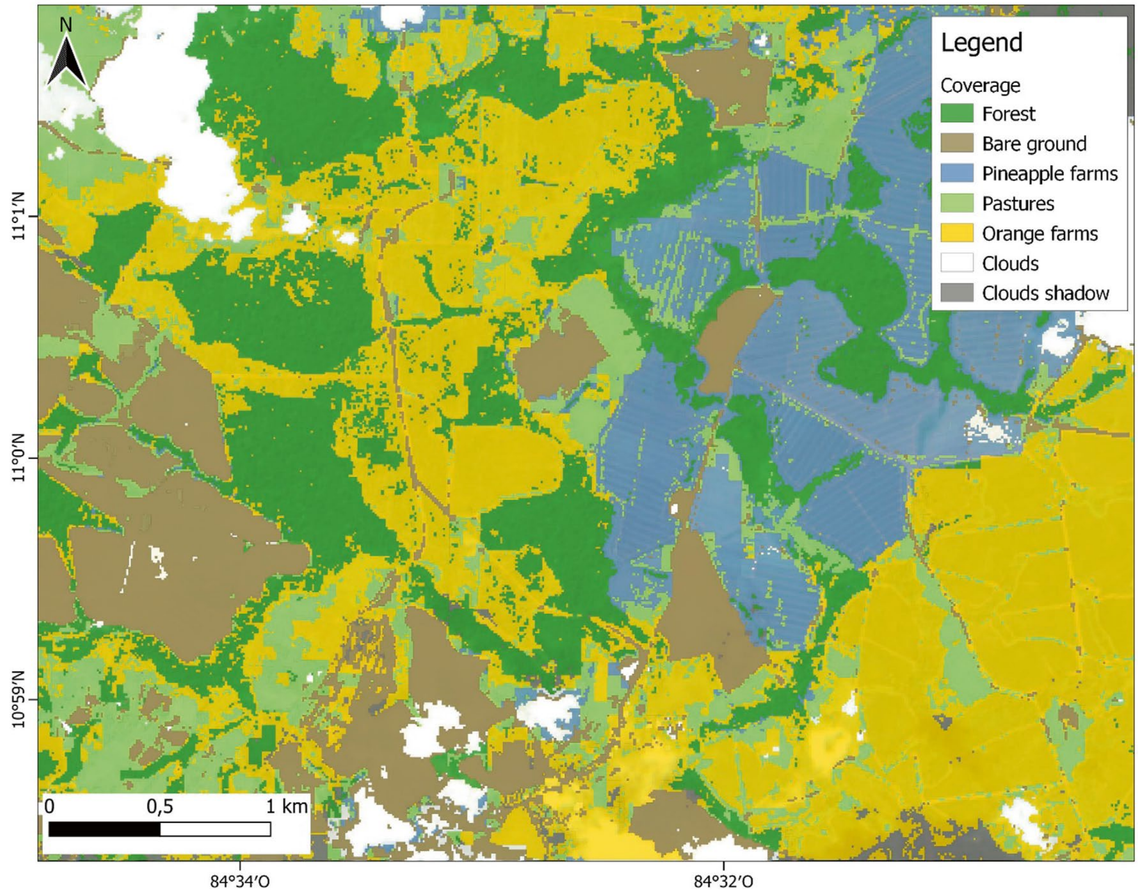

Fig. 11.23 Land coverage and soil use in the southeastern sector of the Huetar Norte Region. Land cover map generated using machine learning technics and supervised classification from Sentinel-2 Images (ESA 2023)

influence vegetation cover, which can be classified according to Holdridge's life zone system (Holdridge 1967) into Tropical wet forest (wf-T), Premontane wet forest (mf-P), Lower montane wet forest (wf-LM), Lower montane rain forest (rf-LM), Premontane rain forest (rf-P), and Tropical wet forest premontane transition (wf-T P).

Soils found in this region (from most to the least abundant), are Ultisols, Andisols, and Inceptisols, including some associations among them and other soil orders (Mata et al. 2022). Ultisols represent approximately 42% of the total area of the Región Central (Fig. 11.3), followed by Andisols (33%) and Inceptisols (8%) (Fig. 11.2). Ultisols are commonly found in the southeastern sector, in the hills and piedmont areas, while Andisols is prevalent around the volcanic piedmonts and foothill slopes.

Despite the pedological divergence and contrasting morphological, chemical, and physical properties of these soils (Buol et al. 2011), they have been found suitable for the development of agriculture with annual and perennial crops, adapted to local physiographic and climatic conditions. For instance, horticultural crops such as potatoes (*Solanum tuberosum* L.), onions (*Allium cepa* L.), carrots (*Daucus carota* Hoffm subsp. sativus), and crucifers (*Brassica* spp.) are primarily cultivated in the highlands and piedmont regions of volcanoes (mainly Irazú and Turrialba).

Extensive coffee plantations began in the "Central Plateau" of Costa Rica and expanded into other sectors within the Talamanca piedmont. Historically, coffee was a driving force for economic growth and social development within Región Central (Molina-Jiménez 1993; Gutiérrez 1994). The introduction of coffee to Costa Rica was first recorded in 1808 during the Tomás de Acosta's government, who imported *Typica* coffee seeds with the aim of establishing a profitable economic activity (Gutiérrez 1994). The expansion of coffee plantations encompassed the entire "Central Plateau" between 1830 and 1840. Subsequently, coffee spread to the western sector (Alajuela and San Ramón) in 1850–1860 and finally to the eastern sector (Reventazón Valley and Turrialba) in 1890 (Montero 2014). Immigrations to unexplored areas and land clearing facilitated the expansion of coffee plantations to southern sectors of this planning region such as "Los Santos" or "Valle del General" (Miranda 1985). Currently, coffee plantations play a pivotal role in several sectors of the Región Central's

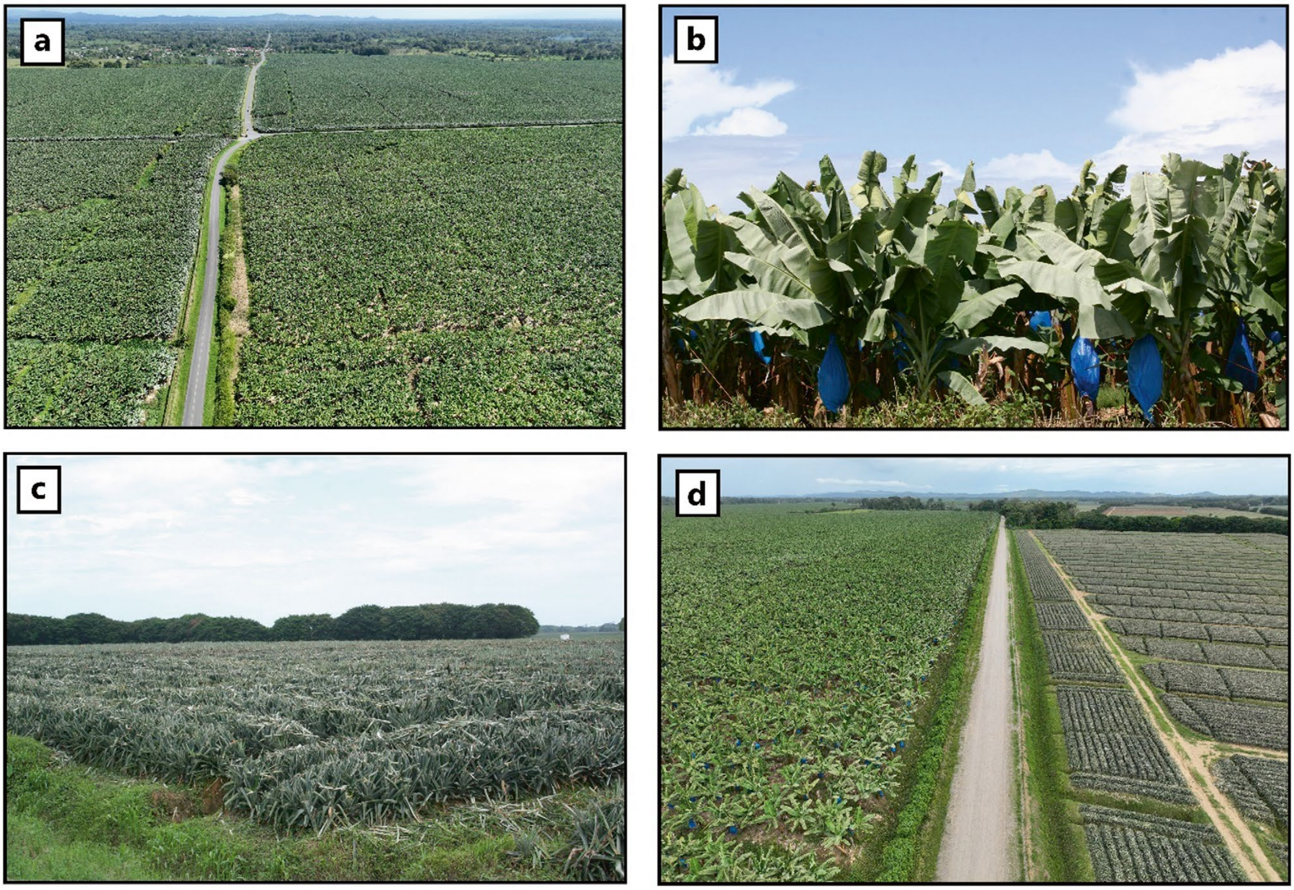

Fig. 11.24 Extensive crops observed in the northwestern sector of Huetar Caribe Region: **a** Aerial pictures of extensive banana fields taken in Los Angeles de Cariari, Pococí; **b** banana plantation; **c** pineapple plantation, **d** aerial picture of extensive banana and pineapple fields established within the same landscape

landscape (Fig. 11.28). In 2018, coffee plantations covered an area of 27,953 ha in sector "Los Santos" (Fig. 11.29), 21,992 ha in sector "Valle Occidente" (Western Central Plateau), and 13,321 ha in "Valle Central" (Central Plateau) according to ICAFE (2019). These three sectors reported yields of 732,608, 345,549, and 208,975 *fanegas* (a unit formerly explained), respectively, in 2018 (ICAFE 2022).

Furthermore, the northern sector of Región Central primarily features horticultural crops like potatoes and onions (Fig. 11.30), as well as crucifers, which provide a significant income and employment opportunities. Historically, indigenous varieties of potato were cultivated by the native people in the Cartago highlands during the colonial period. Later, in 1950, onions were introduced, diversifying regional production systems (Ramírez et al. 2008). In 2022, the Irazú and Turrialba piedmonts featured a total of 2155 ha planted with potatoes, predominantly distributed across the municipalities of Turrialba, Oreamuno, Alvarado, and Cartago (Fig. 11.31), with a reported yield of 58,693 t. In the same municipalities, onion-covered land encompassed a total area of 1015 ha (Fig. 11.31 and Fig. 11.32), which obtained a total production of 34,141 t (SEPSA 2023).

The same crops were observed in the northern sector of Región Central, notably in Zarcero municipality. Here, potato- and onion-covered areas amounted to 665 and 106 ha, respectively, with a production of 16,188 and 3592 t, respectively (SEPSA 2023). This consistency in crops across the volcanic piedmont region may arise from similarities in soils and climatic conditions (Solano and Villalobos 2001; Mata et al. 2022). Another significant crop within Región Central is sugarcane, predominantly planted in two main sectors of this planning region: (1) the northwestern Central Valley, covering municipalities such as San Ramón, Naranjo, Grecia, and Palmares, and (2) the eastern Central Valley, encompassing the municipalities of Jiménez and Turrialba (Fig. 11.33). Historically, the northwestern sector witnessed increased development in the nineteenth century due to immigration from the provinces of Alajuela, Heredia, and San José. This influx of people aimed to

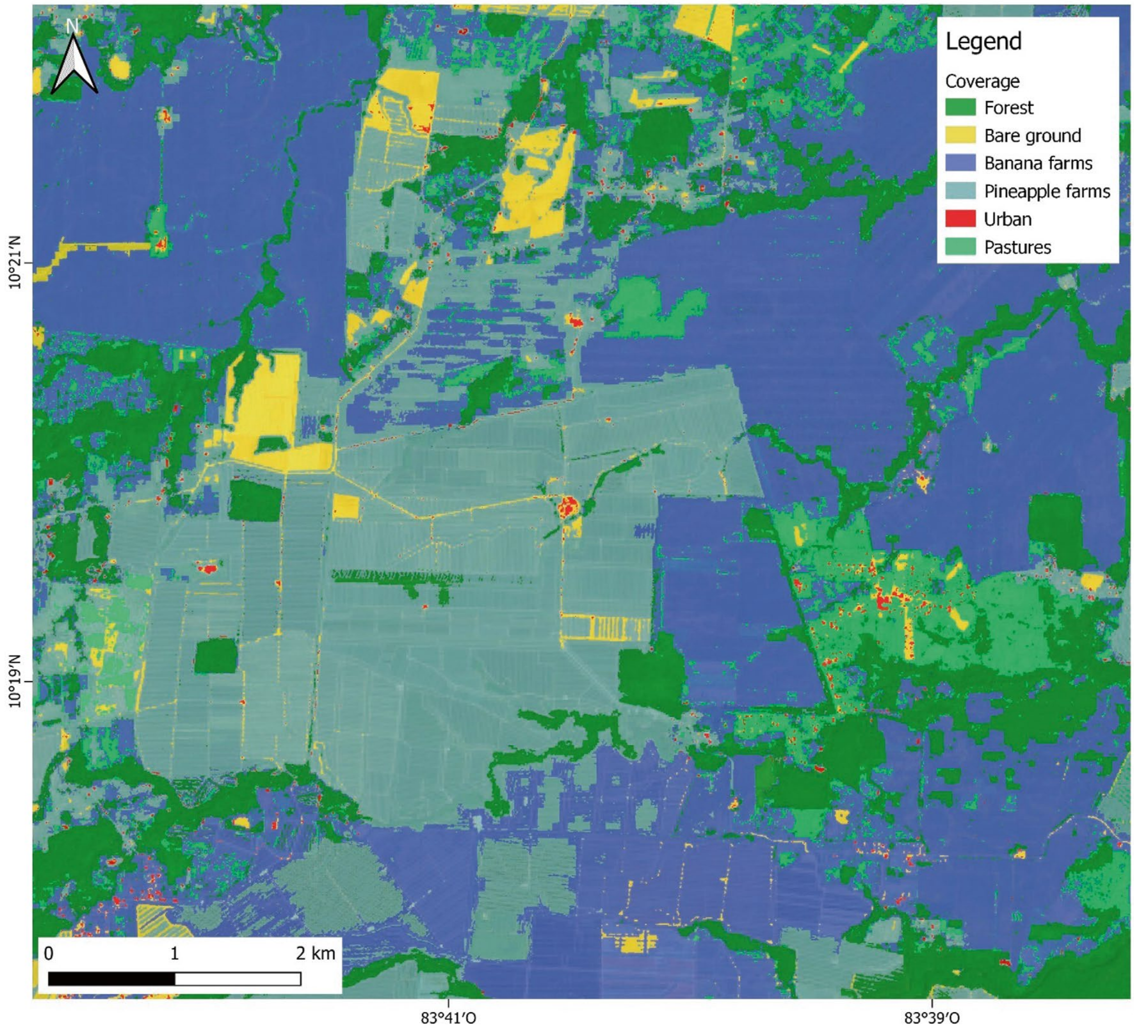

Fig. 11.25 Land coverage and soil use in the northwestern sector of Huetar Caribe Region. Land cover map generated using machine learning technics and supervised classification from PlanetScope Images (Planet Lab 2022)

expand agricultural endeavors, establish settlements, and cultivate these landscapes with the crops of coffee and sugarcane (Samper-Kutschbach 1986; Montero 2014).

Conversely, Turrialba and Jiménez municipalities have been traditionally known as “Campiña azucarera” (sugarcane countryside), with sugarcane production intensifying after 1890 when the railroad connected San José to Limón Port (Calderón and Chaves 2020). Currently, sugarcane occupies 4721 ha (Fig. 11.33), which represents a total yield a total of 225,438 t of fresh cane (Calderón and Chaves 2020). Within this same sector (municipalities of Jiménez and Paraíso), a non-traditional crop called “chayote” (*Sechium edule* (Jacq.) Sw.) is cultivated (Fig. 11.33). In 1999, chayote covered around 700 ha in Paraiso municipality (Saenz and Ruben 2004), which decreased to 407 ha in the same municipality by 2019 (INFOAGRO 2023).

11.3 Conclusions

Costa Rica exhibits diversity not only in its geologic, geomorphic, and climatic features, but also in agricultural crops and associated human activities that represent tradition and heritage within the regions assessed. For instance, coffee and sugarcane were staple crops in Región Central, while pineapple and oil palm dominated in different sectors of the Brunca Region, and banana farms are common along the Huetar Caribe.

Historically, the agricultural frontier underwent significant transformations due to substantial immigration from Región Central to colonize lands within the other five planning regions. These settlers initially planted subsistence crops (e.g., rice, beans, and tubers) and were involved in

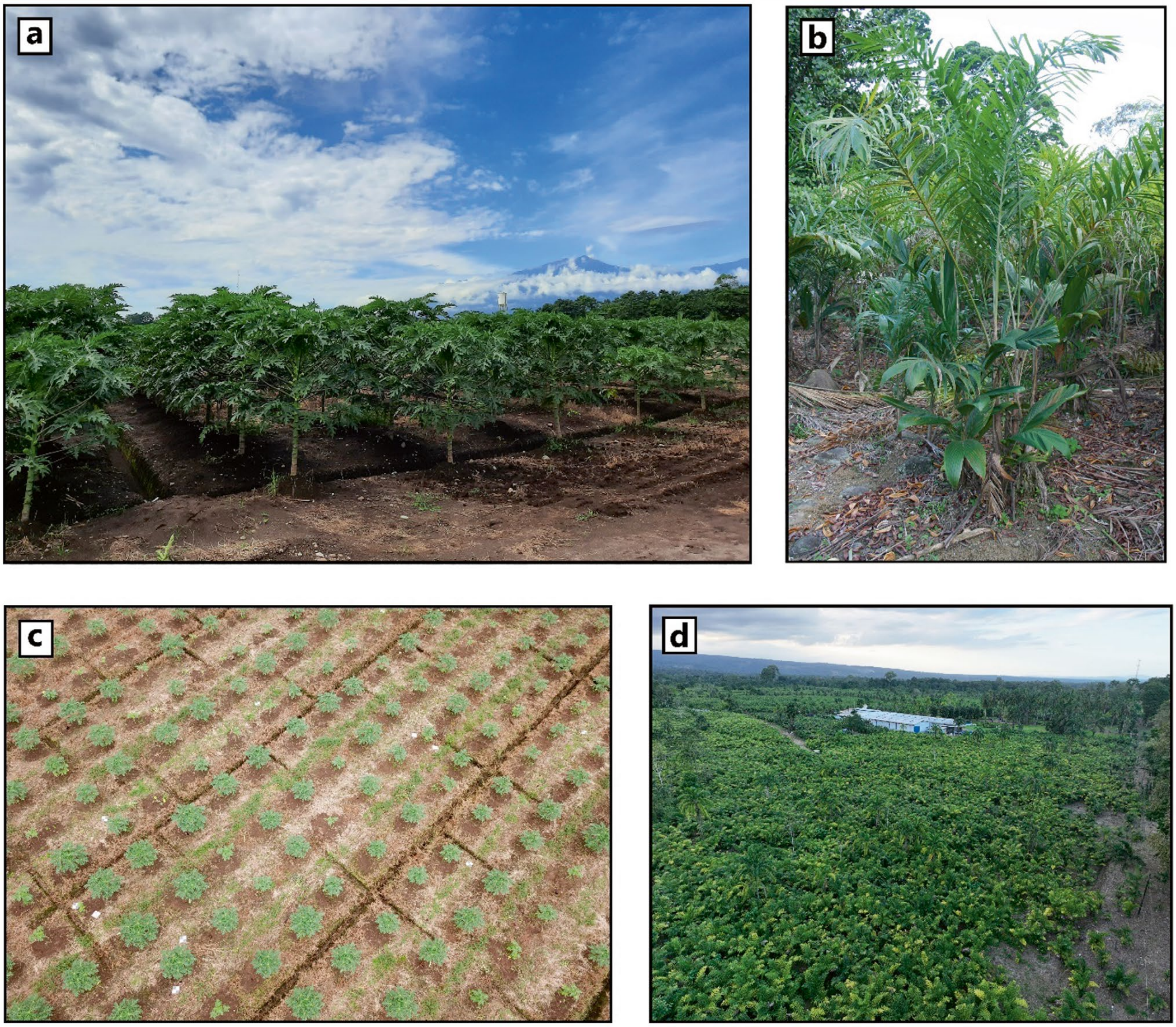

Fig. 11.26 Other extensive crops observed in the western sector of Huetar Caribe Region: **a** Papaya (*Carica papaya* L.); **b** palm-heart (*Bactris gasipaes* Kunth); **c** aerial picture of extensive papaya; **d** aerial picture of heart-palm plantations. *Photos A and C courtesy of. R. Fallas and B. Alemán*

cattle rearing. The landscapes and their agricultural systems have continuously evolved, influenced by changes in political, economic, and social factors over the last century such as land reconversion, immigration, government administration shifting, settlement, and environmental policies.

These activities have not only shaped the physical environment but also the social and economic dynamics throughout the country. They have contributed to forging distinct identities and idiosyncrasies within each planning region of Costa Rica.

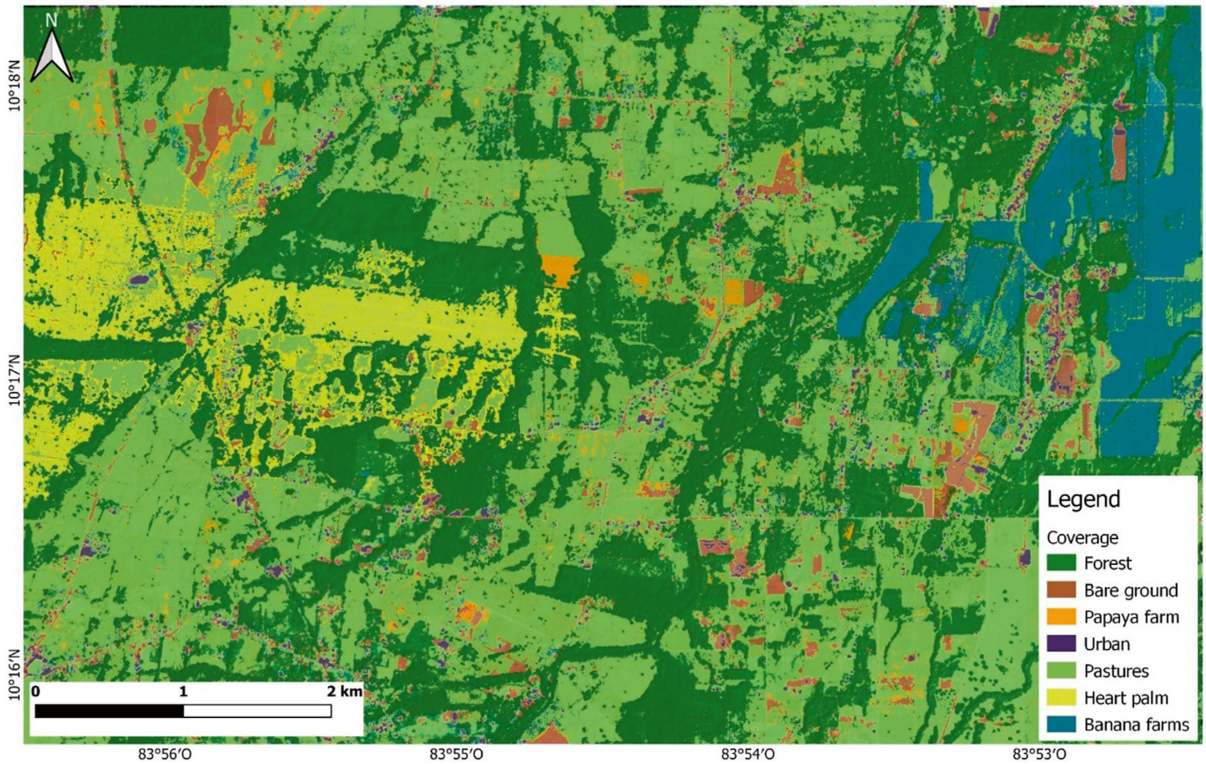

Fig. 11.27 Land coverage and soil use in the western sector of Huetar Caribe Region. Land cover map generated using machine learning techniques and supervised classification from PlanetScope Images (Planet Lab 2022)

Fig. 11.28 Coffee (*Coffea arabica* L.) as extensive crop within the southern sector of Región Central: **a** Aerial pictures of extensive coffee fields covering the mountains and sloped areas of Los Santos, **b** just-bloomed coffee plant, observed in La Legua de Aserrí, San José; **c** aerial picture of coffee plantations taken in León Cortés municipality, San José, **d** harvested coffee cherries and official measuring machine (known as "Guillotina"). *Photos B and D courtesy of. M.E. Camacho and A.M. Peavey, respectively*

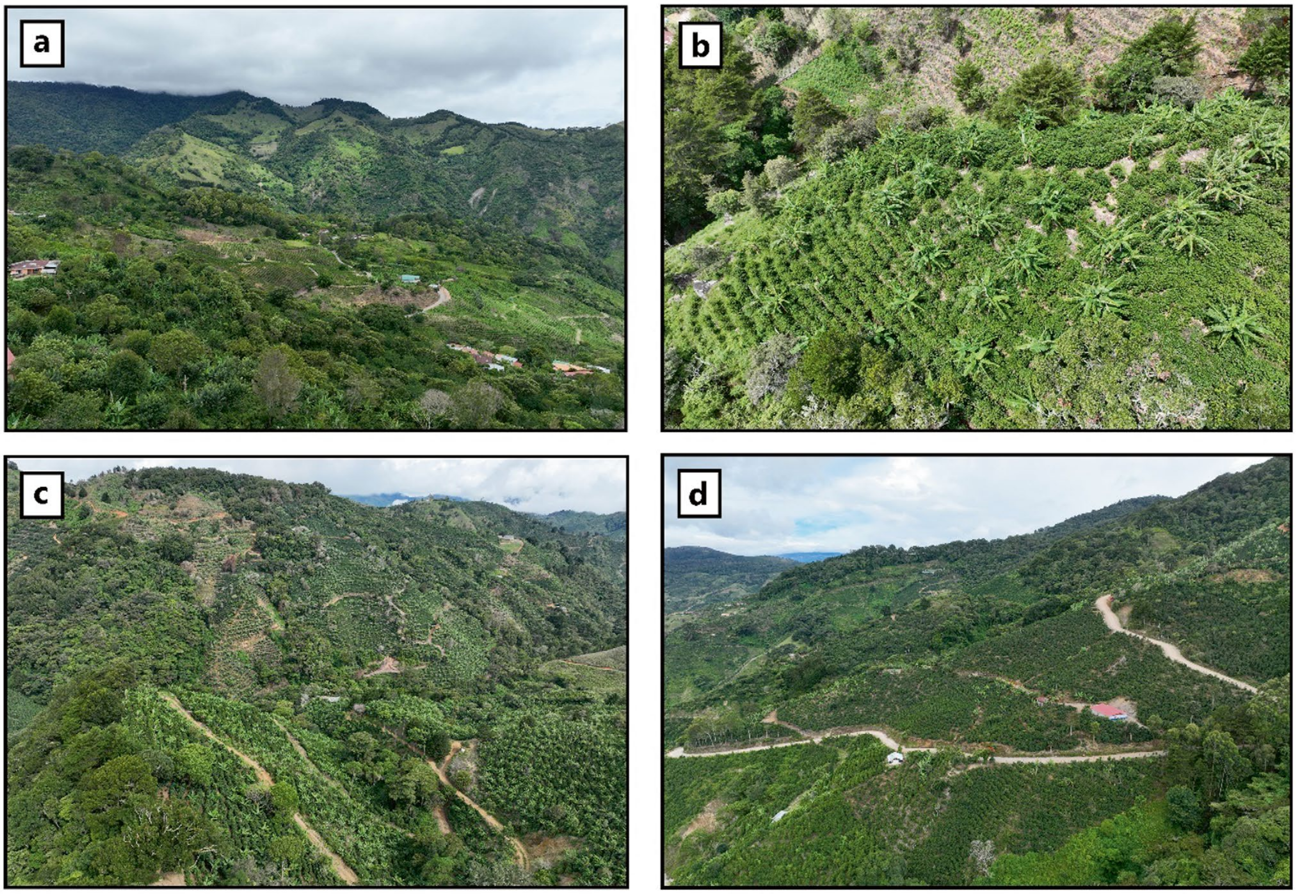

Fig. 11.29 Coffee (*Coffea arabica* L.) landscape and its distribution within the hilly landforms of “Los Santos” (southern Región Central): **a**, **b** Aerial pictures of coffee fields taken in Aserrí municipality, San José, **c**, **d** aerial pictures of coffee fields taken in León Cortés municipality, San José

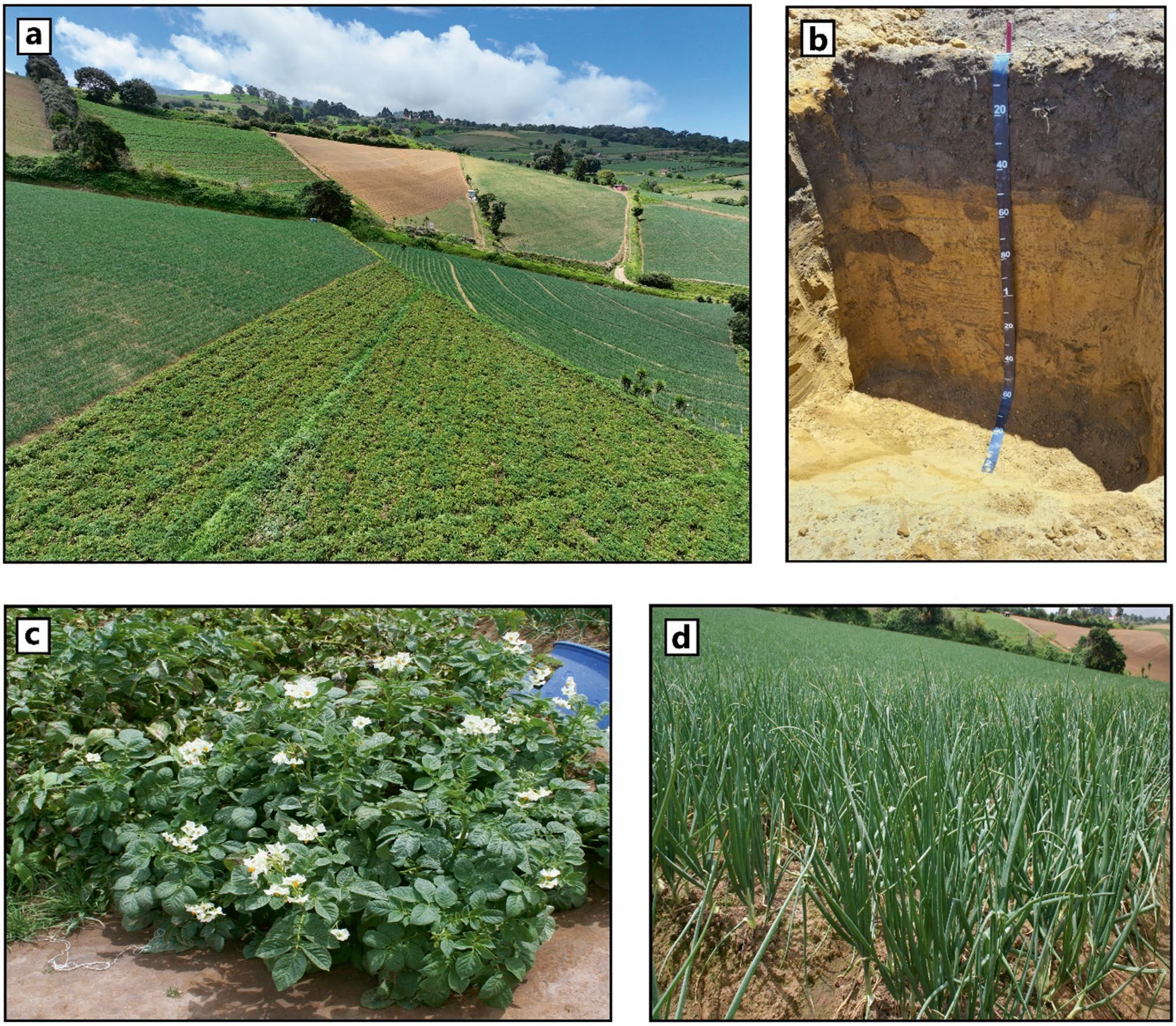

Fig. 11.30 Horticultural extensive crops in the northern sector of Región Central: **a** Aerial picture of potato (*Solanum tuberosum* L.) and onion (*Allium cepa* L.) fields in Cartago, **b** typical soil profile (*Humic Haplustands*), **c**, **d** potato and onion plants at the same location. *Photo B courtesy of. M. Sandí*

Fig. 11.31 Highlands of Cartago (Northern Región Central) and their agricultural landscapes: **a**, **b** Sloped landforms cultivated with onion, **c**, **d** slopes cultivated with potato (two contrasting crop stages)

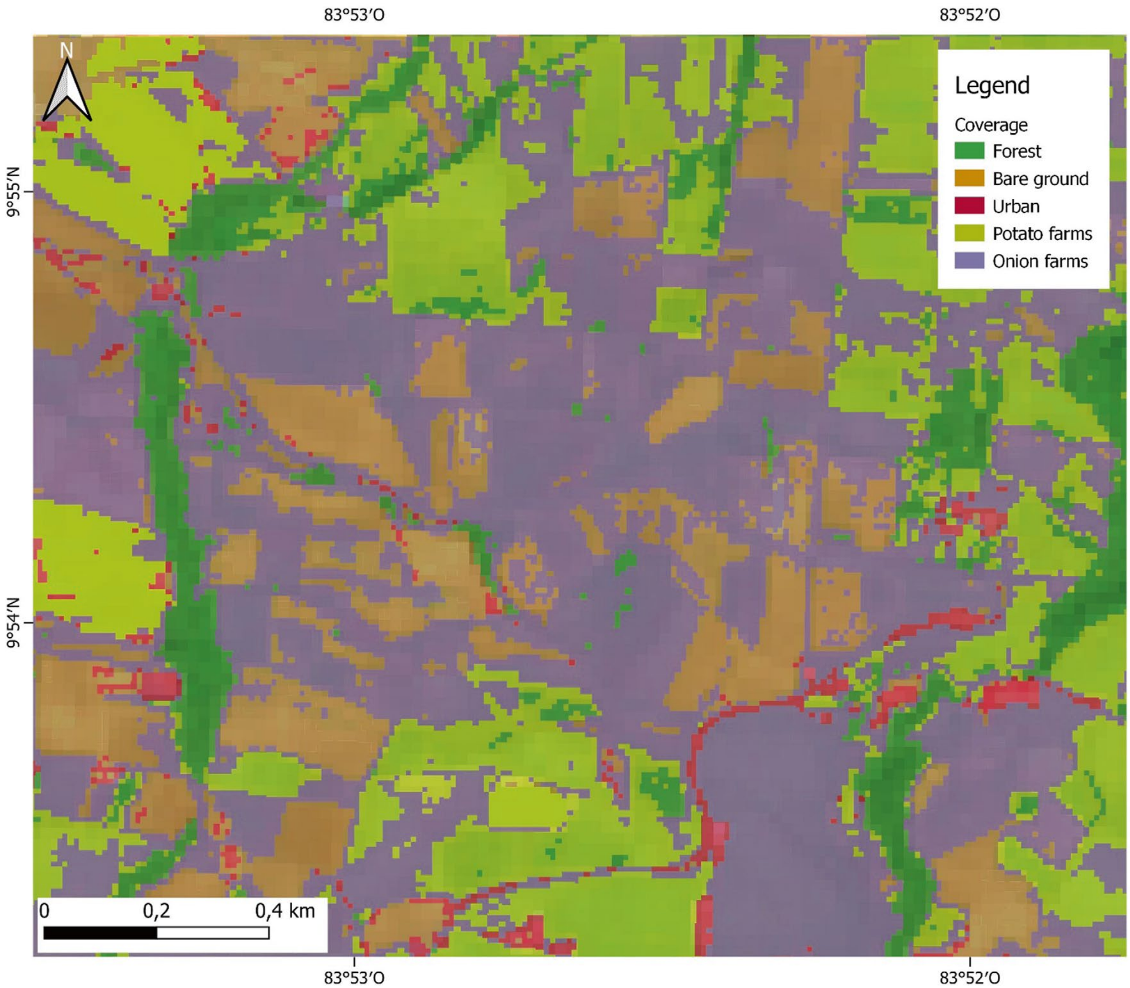

Fig. 11.32 Land coverage and soil use in the northern sector of the Región Central. Land cover map generated using machine learning technics and supervised classification from Sentinel-2 Images (ESA, 2023)

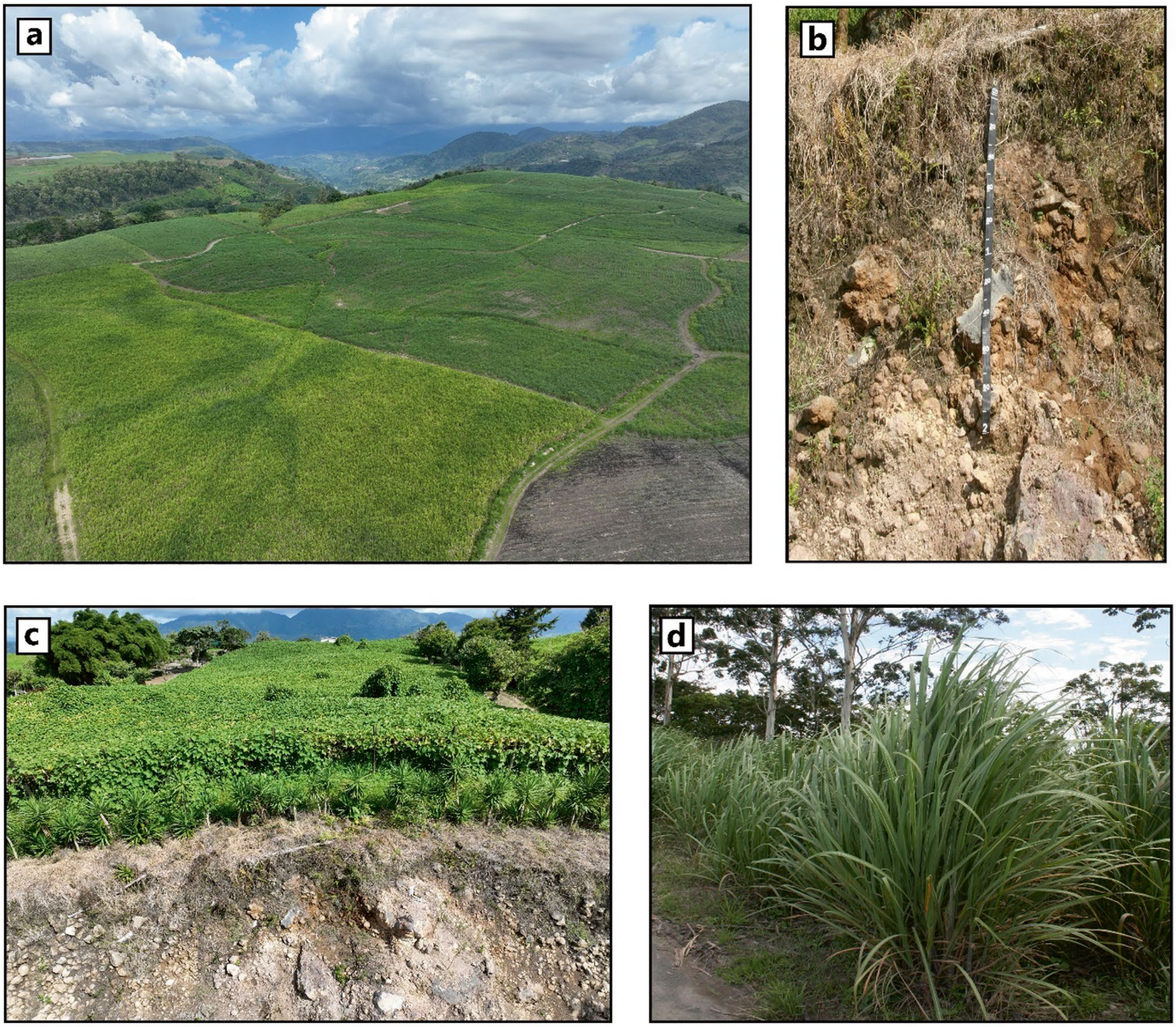

Fig. 11.33 Other extensive crops in the northeastern sector of Región Central: **a** Aerial picture of sugarcane fields (*Saccharum officinarum* L.) in Santiago de Paraíso, Cartago, **b** typical soil profile developed from a lava flow (*Typic Udorthens*), **c** aerial picture of fields cultivated with chayote (*Sechium edule* (Jacq.) Sw.) in Santiago de Paraíso, Cartago, and **d** sugarcane plant observed within this same location

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