Soil taxonomy and suitability assessment on typical tobacco-planting farmlands in Guizhou, Southwest China

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Abstract

The classification accuracy of tobacco soil in Guizhou Province remains to be verified. In this paper, 36 typical tobacco-planting farmlands were selected in various regions of Guizhou, and soil taxonomy of the farmlands was identified according to the information of soil-forming factors, profile morphological characteristics and measured data of soil physiochemical properties. Meanwhile, the suitability of the farmlands for tobacco planting was also briefly assessed. The diagnostic horizons of the surveyed farmlands include anthrostatic epipedon, ochric epipedon, hydric horizon, Fe-leached horizon, LAC-ferric horizon, argic horizon, agric horizon and cambic horizon. The diagnostic characteristics included anthrostatic-, perudic-, aquic- and udic-soil moisture regimes, gleyic features, redoxic features, lithologic character of carbonate rocks, humic property and ferric property, etc. Their soils of the farmlands belonged to Anthrosols, Ferrosols, Argosols, Cambosols and Primosols in soil orders, and there were 4, 8, 7, 5 and 1 soil subgroups in Anthrosols, Ferrosols, Argosols, Cambosols and Primosols, respectively. Soil textures of the farmlands included sandy loam, silt loam, loam, silty clay loam, clay loam, silty clay and clay, and 29 (80.6%) farmlands were unsuitable in texture for tobacco planting due to the clayey texture; 34 (94.4%) farmlands were unsuitable in plough thickness (less than 30 cm) for tobacco planting. For soil chemical properties of plough layer, pH ranged from 4.7 to 8.5, SOM from 12.3 to 55.5 g/kg, available nitrogen from 51.5 to 257.3 mg/kg, available phosphorus from 4.3 to 99.94 mg/kg, available potassium from 95 to 885 mg/kg, available Zn from 0.04 to 3.97 mg/kg, available Mo from 0.68 to 7.45 mg/kg and available B from 0.07 to 1.76 mg/kg; all spanned from the low grades to high grades. 16 (44.4%), 17 (47.2%), 13 (26.1%), 26 (72.2%), 30 (83.3%), 26 (72.2%), 20 (55.6%) and 30 (83.3%) of the farmlands were unsuitable in pH, SOM, available nitrogen, available phosphorus, available potassium, available Zn, available Mo and available B for tobacco planting, respectively. This study provides a theoretical basis for the sustainable development of tobacco field soil conservation and flue-cured tobacco production.

Keywords Typical tobacco-planting farmland · Soil taxonomy · Soil genetic classification · Suitability assessment · Guizhou

1 Introduction

Soil conditions can determine or influence the yield, quality and aroma characteristics of tobacco [2, 12]. Guizhou Province is one of the main tobacco-planting regions in

China, and its tobacco-planting area is second only to Yunnan Province [20]. So far, there is information available on the properties of tobacco-planting soils in Guizhou which disclosed some problems in soils [6, 16–18]. There are many kinds of soil types in Guizhou due to its vast territory

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and complex mountainous landform which lead to great and diverse spatial variation in soil-forming factors [9]. Soil classification is the important basis for the comprehensive and scientific recognition of soil resources. It is of significance to identify correctly the soil types and find soil problems to adopt the effective measures in guaranteeing sustainability of tobacco-planting farmlands. However, soil types cited in the most published studies related with Guizhou Province are mainly from soil genetic classification established during 1980s [3, 4, 16, 18, 19]. Comparatively speaking, soil taxonomy based on diagnostic horizons and diagnostic characteristics represents the international tendency in soil classification, and it is more quantitative and scientific than soil genetic taxonomy [5]. In recent years, some studies have been conducted on soil taxonomy of tobacco-planting farmlands in various regions of China [21, 22, 28], including Guizhou Province [27]. Those studies not only internationalized the results in soil classification, but also reflected more scientifically the characteristics of studied soils, which is of significance to adjust the regional planting division of tobacco and to adopt the effective measures in promoting soil quality for high yield and quality of tobacco. However, soil taxonomy in those studies was identified preliminarily according to the obtained information of soil-forming factors and morphological characteristics of soil profiles in the field survey with little or no quantitative measured data of soil physicochemical properties, which may lead to mis-identification for soil taxonomy.

In this paper, the typical tobacco-planting farmlands were selected in various regions of Guizhou, and soil taxonomy of the farmlands was identified by comprehensively considering the information of the field survey on soil-forming factors, morphological characteristics of soil profiles and quantitative measured data of soil physicochemical properties. Meanwhile, the suitability of the farmlands was also briefly assessed for tobacco planting.

2 Methods and materials

2.1 Natural and socio-economic profile of Guizhou Province

Guizhou is located in the Southwest China (103°36'–109°35'E, 24°37'–29°13'N, See Fig. 1) with a total area of $17.62 \times 10^4 \text{ km}^2$, it has a subtropical humid monsoon climate, and the mean annual sunshine duration, temperature, precipitation, dryness and frost-free period are about 1100–1400 h, 12–18 °C, 850–1300 mm, 0.27–0.58 and 250–350 d, respectively. The landform in Guizhou is mountain–plateau with the altitude of 148–2904 m, about 92.5% of its total area is mountains and hills, and 61.9% of

Fig. 1 Location map of Guizhou province, China (marked in red)

its total area is karst landform. Soil genetic types mainly are yellow soil, lime soil, red soil, yellow–brown soil, skeleton soil and purple soil, constituting 46.4%, 17.5%, 7.2%, 6.2%, 6.0% and 5.6% of the total soil area, respectively [19]. The land-use types of tobacco-planting farmlands are mainly the drylands under the rotation of tobacco–maize or other dry crops and a few of paddy farmlands under tobacco–rice rotation.

Guizhou Province is one of the poorest areas in China. According to the national economy and society developed statistical bulletin 2018, the per capita disposable income of rural residents in Guizhou Province is 9716 yuan, accounting for 66.5% of the national average. The number of poverty is about 1.55 million, accounting for 9.3% of the total poverty. In China, the benefits of tobaccos are significantly higher than other crops, and tobacco cultivation is mainly concentrated in an area with relatively poor social economy.

2.2 Selection of typical tobacco-planting farmlands

The location of typical tobacco-planting farmlands was determined according to the spatial distribution of soil genetic types and 1:250,000 soil map [3], the tobacco-planting areas in various regions and the farmland information in stable production of high-quality tobacco provided by the provincial and regional tobacco companies in Guizhou. In total, 36 farmlands were selected from 25 counties or districts of main tobacco-planting regions in Guizhou Province (See Fig. 2 and Table 1).

Fig. 2 Location of typical tobacco-planting farmlands studied in Guizhou province

2.3 Field survey, soil sampling and measurement, soil taxonomy

Field survey was conducted in October 2017 after the complete harvest of tobacco. During the survey, the standard soil pit with 1.0 m in width and 1.2 m in depth was dug in the centre of each farmland, and the information of soil-forming factors was investigated which include climatic condition, terrain, parent material, land-use type and crop-rotation pattern. The soil profile was layered according to the observed morphological characteristics [27], and then, about 1.5 kg was collected from each horizon [25].

The air-dried soil samples were grinded and passed the sieves of 0.84 mm, 0.25 mm and 0.15 mm diameters, respectively. Soil texture composition was determined by pipette method, pH by potentiometer method, soil organic matter (SOM) by Kjeldahl method, available nitrogen (A-N) by alkali-diffusion method, available phosphorus (A-P) by molybdenum antimony colorimetric method, available potassium (A-K) by flamephotometer method, available zinc (A-Zn) and molybdenum (A-Mo) by ABS spectrophotometer method, available boron (A-B) by ICP-AES method, CEC by ammoniumacetate-EDTA method, exchangeable Ca^{2+} and Mg^{2+} by EDTA method, exchangeable Na^{+} and K^{+} by flamephotometer method, exchangeable H^{+} and Al^{3+} by potentiometric method, free iron by Fe DCB-O-phenanthroline method [1, 26]. Finally, the diagnostic horizons, diagnostic characteristics and soil taxonomy of farmlands were determined according to Chinese Soil Taxonomy [5].

Soil temperature at 50 cm depth in most regions in Guizhou is higher than 16 °C, belonging to the thermic temperature regime except in Xishui and Weining counties

where it is 9–16 °C, and belonging to the mesic temperature regime [7, 24].

According to the definition of soil moisture regime (STM) in Chinese Soil Taxonomy [5], STM of each farmland is determined by the following principles: Firstly, if a farmland has planted rice for years, then it is anthrostatic SMR; secondly, if a farmland is located in a plain or valley near a river, and soil pedon can be saturated by rainfall or groundwater in a period, then it is aquic or stagnic SMR; thirdly, if a farmland is located in a slope or in a plain or valley far from a river, and soil pedon cannot be saturated by rainfall or groundwater, then its SMR is decided according to the information of regional dryness [13].

2.4 Suitability assessment for tobacco planting

Soil thickness, texture and slope are important factors for soil suitability evaluation. For the cultivation of flue-cured tobacco, sunny flat terraces and hilly lands should be selected, with slope less than 25° and ridge height higher than 30 cm. Therefore, physical properties including pedon thickness, the thickness and texture of plough layer were used to assess the suitability of farmland for tobacco planting. According to the growth characteristics of tobacco and its requirement for soil conditions, here ≥ 50 cm is defined as suitable for pedon thickness, ≥ 30 cm as suitable for plough layer thickness, and loamy sand, sandy loam, loam and silt loam as suitable for plough layer textures. Chemical properties including pH, SOM, A-N, A-P, A-K, A-Zn, A-Mo and A-B were used to assess the suitability of farmland for tobacco planting, and their suitable grades were simplified according to the comprehensive analysis on the published studies [16, 18] and current situation of soil characteristics and tobacco yield and quality (see Table 2).

2.5 Data processing and thematic mapping

Data were analysed with Microsoft Excel 2013 and IBM Statistics SPSS20.0, and the map of the spatial distribution of typical farmlands was edited on the platform of Esri Arc-GIS 10.3.

3 Results

3.1 Determination of soil taxonomy

Table 3 shows soil taxonomy of studied typical tobacco-planting farmlands in Guizhou. P16, P17, P19, P21, P22, P34 and P36 had planted rice more than 20 years, they have anthrostatic epipedon (plough layer + plough pan), hydric horizon, anthrostatic SMR and redoxic

Table 1 Basic information of typical tobacco-planting farmlands in Guizhou province

Farmland	Location (town, county or district)	Land-use type	Landform	Parent material	Soil genetic type (group-specie) ^a
P1	Yungui, Weining(up)	Sloping dryland	Slope	Dolomite	Yellow brown soil-Dahuipaotu
P2	Yungui, Weining(down)	Dryland	Valley	Diluvium/alluvium	Yellow soil-Huangshanitu
P3	Caohai, Weining	Sloping dryland	Slope	limestone	Terra rossa
P4	Xiaohai, Weining	Dryland	Foothill-valley	Diluvium/deluvium	Yellow brown soil-Houdahui-paoni
P5	Qixingguan, Bijie	Sloping dryland	Slope	Limestone	Yellow soil-Huangnitu
P6	Gantang, Qianxi	Sloping dryland	Slope	Limestone	Yellow soil-Dahuangnitu
P7	Dezhuo, Hezhang	Dryland	Valley	Diluvium/alluvium	Chao soil-Dashalitu
P8	Kele, Hezhang	Sloping terrace dryland	Slope	Dolomite	Yellow soil-Dahuangnitu
P9	Zhudong, Panzhou	Dryland	Valley	Diluvium/alluvium	Terra fusca
P10	A'ga, Shuicheng	Sloping terrace dryland	Slope	Dolomite	Yellow soil-Huangnitu
P11	Nankai, Shuicheng	Sloping terrace dryland	Slope	Limestone	Terra rossa
P12	Baling, Xingren	Sloping terrace dryland	Slope	Limestone	Yellow soil-Huangniannitu
P13	Panshui, Pu'an	Terrace dryland	Diluvium	Volcaniclastic rock	Acid skeleton soil
P14	Yanla, Xixiu	Dryland	Valley	Diluvium/alluvium	Dark yellow brown soil-Huipaoni
P15	Xuanpu, Xixiu	Sloping dryland	Slope	limestone	Yellow soil-Houhuangni
P16	Xinmin, Bozhou (down)	Paddy field	Valley	Diluvium/alluvium	Hydromorphic paddy soil
P17	Xinmin, Bozhou(up)	Terrace paddy field	Slope	Dolomite	Submergienc paddy soil
P18	Fenghua, Suiyang	Dryland	Valley	Diluvium/alluvium	Bleached yellow soil-Baishanni
P19	Puchang, Suiyang	Paddy field	Valley	Diluvium/alluvium	Submergienc paddy soil
P20	Xieba, Zheng'an	Sloping dryland	Slope	Dolomite	Yellowish red soil-Houhuang-hongni
P21	Fuxing, Meitan	Paddy field	Valley	Diluvium/alluvium	Degleyed paddy soil
P22	Goupitan, Yuqing	Paddy field	Valley	Diluvium/alluvium	Gleyed paddy soil
P23	Baini, Yuqing	Terrace paddy field	Slope	Purple shale	Calcic purplish soil
P24	Yingwuxi, Sinan	Terrace paddy field	Slope	Limestone	Weakly developed yellow soil
P25	Shigu, Shiqian	Sloping terrace dryland	Slope	Limestone	Yellow soil-Houdahuanghongni
P26	Guangzhao, Qinglong	Sloping terrace dryland	Slope	Limestone	Yellow rendzina
P27	Longgang, Kaiyang	Sloping terrace dryland	Slope	Dolomite	Yellow soil-Huangshatu
P28	Xiaoqing, Xiuwen	Sloping terrace dryland	Slope	Dolomite	Rendzina
P29	Chengzhai, Xishui	Sloping terrace dryland	Slope	Purple sandstone	Acid purplish soil
P30	Wuma, Renhuai	Sloping dryland	Slope	Purple sandstone	Neutral purplish soil
P31	Dafengdong, Kaili	Sloping dryland	Slope	limestone	Yellow soil-Huangshanitu
P32	Duma, Tianzhu	Terrace dryland	Slope	Slate	Yellowish red soil-Houhuang-hongni
P33	Gaoniang, Tianzhu	Terrace dryland	Slope	Tuff	Yellowish red soil-Houhuang-hongsha
P34	Jinshan, Fuquan	Paddy field	Valley	Diluvium/alluvium	Percogenic paddy soil
P35	Xinpu, Guiding	Sloping terrace dryland	Slope	limestone	Yellow rendina
P36	Yunwu, Guiding	Paddy field	Valley	Diluvium/alluvium	Hydromorphic paddy soil

^aGenetic soil types of typical farmlands were decided according to 1:250,000 soil map edited during the 2nd soil survey conducted during 1980s–1990s

features, and thus, they belong to Stagnic Anthrosols. The thickness of anthrostagnic epipedon was 20–45 cm, and the hue of the colour was 7.5YR–2.5Y with the wet value of 4 and wet chroma of 1–2. There were iron and manganese mottling or concretions in hydric horizons. The horizon below 45 cm of P22 was in colour of dark bluish grey and

had ferrous reaction, and thus, it belongs to Typic Gleyic Stagnic Anthrosols. The 20–45 cm horizon of P21 and the 10–30 cm horizon of P34 were in colour of 10YR 5/1 and 2.5Y 5/1, respectively, and had a little iron and manganese mottling, and thus, they belong to Typic Fe-leachi-Stagnic Anthrosols. The free-Fe contents of horizons below 80 cm

Table 2 Suitability classification of physiochemical properties of tobacco-planting soil

Index ^a	pH	SOM (g/kg)	A-N (mg/kg)	A-P (mg/kg)	A-K (mg/kg)	A-Zn (mg/kg)	A-Mo (mg/kg)	A-B (mg/kg)
Low	< 5.5	< 20	< 100	< 15	< 150	< 1.0	< 0.15	< 0.3
Suitable	5.5–7.0	20–35	100–180	15–30	150–220	1.0–2.0	0.15–0.2	0.3–0.6
High	> 7.0	> 35	> 180	> 30	> 220	> 2.0	> 0.2	> 0.6

^aSOM, soil organic matter; A-N, soil available nitrogen; A-P, soil available phosphorus; A-K, soil available potassium; A-Zn, soil available zinc; A-Mo, soil available molybdenum; and A-B, soil available boron

Table 3 Soil taxonomy of typical tobacco-planting farmlands studied in Guizhou

Soil subgroup	Farmland	Diagnostic horizon, diagnostic characteristic and other phenomenon
Typic Gleyi-Stagnic Anthrosols	P22	Anthrostagnic epipedon, Hydragric horizon, Anthrostagnic SMR, Gleyic features
Typic Fe-leachi-Stagnic Anthrosols	P21, P34	Anthrostagnic epipedon, Hydragric horizon, Fe-leachic horizon, Anthrostagnic SMR, Redoxic features
Typic Fe-accumuli-Stagnic Anthrosols	P16, P36	Anthrostagnic epipedon, Hydragric horizon, Anthrostagnic SMR, Redoxic features, Fe accumulation
Typic Hapli-Stagnic Anthrosols	P17, P19	Anthrostagnic epipedon, Hydragric horizon, Anthrostagnic SMR, Redoxic features
Mottlic Hapli-perudic Ferrosols	P27, P33	Ochric epipedon, LAC-ferric horizon, Perudic SMR, Redoxic features
Typic Hapli-perudic Ferrosols	P32	Ochric epipedon, LAC-ferric horizon, Perudic SMR
Leachic Carbonati-Udic Ferrosols	P12	Ochric epipedon, LAC-ferric horizon, Udic SMR, L.C. of carbonate rocks, pH 6.0–6.1
Argic Carbonati-Perudic Ferrosols	P8	Ochric epipedon, LAC-ferric horizon, Argic horizon, Udic SMR, L.C. of carbonate rocks
Xanthic Argi-Udic Ferrosols	P6, P24	Ochric epipedon, LAC-ferric horizon, Argic horizon, Udic SMR, Yellowing phenomenon
Mottlic Argi-Udic Ferrosols	P20, P25	Ochric epipedon, LAC-ferric horizon, Argic horizon, Udic SMR, Redoxic features
Typic Argi-Udic Ferrosols	P3	Ochric epipedon, LAC-ferric horizon, Argic horizon, Udic SMR
Typic Hapli-Udic Ferrosols	P15	Ochric epipedon, LAC-ferric horizon, Udic SMR
Typic Hapli-Perudic Argosols	P28, P31	Ochric epipedon, Argic horizon, Perudic SMR
Humic Carbonati-Udic Argosols	P26	Ochric epipedon, Argic horizon, Udic SMR, L.C. of carbonate rocks, Humic property
Typic Carbonati-Udic Argosols	P11, P35	Ochric epipedon, Argic horizon, Udic SMR, L.C. of carbonate rocks
Ferric Acidi-Perudic Cambosols	P10	Ochric epipedon, Argic horizon, Udic SMR, Ferric property, pH _{KCl} 3.8–4.1
Agric Ferri-Udic Argosols	P4, P9	Ochric epipedon, Argic horizon, Udic SMR, Ferric property
Albic Ferri-Udic Argosols	P5	Ochric epipedon, Argic horizon, Albic horizon, Udic SMR, Ferric property
Mottlic Ferri-Udic Argosols	P1	Ochric epipedon, Argic horizon, Udic SMR, Ferric property, Redoxic features
Typic Ochri-Aquic Cambosols	P7, P14	Ochric epipedon, Cambic horizon, Aquic SMR, Redoxic features
Ferric Acidi-Perudic Cambosols	P18, P29	Ochric epipedon, Cambic horizon, Perudic SMR, Ferric property, pH _{KCl} 3.8–4.4
Calcaric Purpli-Udic Cambosols	P23	Ochric epipedon, Cambic horizon, Udic SMR, Calcaric property, L.C. of Purplish rocks
Typic Purpli-Udic Cambosols	P30	Ochric epipedon, Cambic horizon, Udic SMR, L.C. of Purplish rocks, pH 6.6–6.8
Mottlic Hapli-Udic Cambosols	P2	Ochric epipedon, Cambic horizon, Udic SMR, Redoxic features
Lithic Udic-Orthic Primosols	P13	Ochric epipedon, Udic SMR, Paralithic contact

SMR soil moisture regime

of P16 and P36 were 2.2 and 2.6 times of the plough layers, and thus, they belong to Typic Fe-accumuli-Stagnic Anthrosols. The profile of P17 showed weak differentiation and P19 is terrace paddy field with the buried pedon due to the transformation from slope dryland, and thus, they belong to Typic Hapli-Stagnic Anthrosols.

P3, P6, P8, P12, P15, P20, P24, P25, P27, P32 and P33 are drylands, they had ochric epipedons and LAC-ferric horizons, and thus, they belong to Ferrosols. The thickness of ochric epipedon was 10–30 cm, and the dry and

wet values of the colour were 6–7 and 4–6 with a wet chroma of 1–4. (The wet chroma of P15, P20, P24 and P25 was all lower than 3.5, but their thickness of ochric epipedon was 10–18 cm.) LAC-ferric epipedon had a thickness larger than 55 cm, its up boundary of the appearance was 10–65 cm, free-Fe content was 16.4–57.1 g/kg, Fe-freeness was 40.1–91.3%, and CEC₇ was 12.5–23.8 cmol/kg_{clay}. P27 and P33 had perudic SMR and iron and manganese mottling, and thus, they belong to Mottlic Hapli-perudic Ferrosols. P32 has no above characteristic,

and thus belongs to Typic Hapli-perudic Ferrosols. P6 and P24 had partial-perudic moisture regime, and P3, P8, P12, P15, P20 and P25 had udic moisture regime. P8 and P12 had 2–5% debris of limestone or dolomite in the pedons, pH of B horizon of P12 was 6.0–6.1, and thus, they belong to Leachic Carbonati-Udic Ferrosols. The horizon below 65 cm of P8 was argic horizon with clay coating and clay content being 1.25 times of the overlying horizon, and thus, it belongs to Argic Carbonati-Perudic Ferrosols. The horizon below 75 cm of P6 and the horizon below 40 cm of P24 were argic horizons with clay coating and clay contents being about 1.24 times of the overlying horizons, and the pedons showed yellowing phenomenon; thus, they belong to Xanthic Argi-Udic Ferrosols. The horizons below 20 cm or 50 cm of P3, P20 and P25 were argic horizons with clay coating and clay contents being 1.2–2.0 times of the overlying horizons. P20 and P25 had a little iron and manganese mottling in the pedons, and thus, they belong to Mottlic Argic-Udic Ferrosols, while P3 had no mottling in the pedon and belongs to Typic Argic-Udic Ferrosols. The profile of P15 showed weak differentiation and belongs to Typic Hapli-Udic Ferrosols.

P1, P4, P5, P9, P10, P11, P26, P28, P31 and P35 are drylands, they had ochric epipedons and argic horizons, and thus, they belong to Argosols. The thickness of ochric epipedon was 18–30 cm, and the dry and wet values of the colour were 5–7 and 4–5 with a wet chroma of 4. (The wet chroma of P1 was 1, but its thickness of ochric epipedon was 20 cm.) The up boundary of argic horizon appearance was 40–80 cm, and the thickness of argic horizons was larger than 55 cm with clay coating, clay contents of argic horizons of P1, P4, P5, P9, P28 and P31 being 1.20–1.60 times of the overlying horizons, while clay contents of argic horizons of P10, P11, P26 and P35 were 1.05–1.17 times of the overlying horizons. P28 and P31 had perudic SMR, and thus, they belong to Typic Hapli-Perudic Argosols. P11, P26 and P35 had 2–75% debris of limestone or dolomite in the pedons, the 45–80 cm horizon of P26 had distinct deposition film of humus, and SOC storage within 1 m depth pedon was 15.9 kg/m²; thus, it belongs to Humic Carbonati-Udic Argosols, and P11 and P35 had no above characteristic and belong to Typic Carbonati-Udic Argosols. pH of P10 pedon was 5.0–5.4, the hue of its B horizon was 5YR, free-Fe content was 27.3–32.1 g/kg, and thus, it belongs to Ferric Acidi-Udic Argosols. The hues of B horizons of P1, P4, P5 and P9 were 5YR–2.5Y, and free-Fe contents were 15.7–65.6 g/kg. The 22–40 cm horizon of P4 and the 35–68 cm horizon of P9 were argic horizons with distinct deposition film of humus, the hues of B horizons of P4 and P9 were 7.5YR and 5YR, free-Fe contents were 15.7–20.9 g/kg and 50.1–65.6 g/kg, thus, and they belong to Agric Ferri-Udic Argosols. The 28–48 cm horizon of P5 was albic horizon with the dry and wet values of 7 and 6

and dry and wet chromas of 2 and 1, and thus, it belongs to Albic Ferri-Udic Argosols. B horizon of P1 had a little iron and manganese mottling or concretions, and thus it belongs to Mottlic Ferri-Udic Argosols.

P2, P7, P14, P18, P23, P29 and P30 are drylands, they had ochric epipedons and cambic horizons, and thus, they belong to Cambosols. The thickness of ochric epipedon was 12–20 cm, and the dry and wet values of the colour were 5–8 and 4–7 with a wet chroma of 1–3. The thickness of cambic horizons was larger than 10 cm with clay contents of 143–418 g/kg. P7 and P14 had aquic SMR, the hue of pedon was 2.5Y with a chroma of 1 and a little iron and manganese mottling, and thus, they belong to Typic Ochri-Aquic Cambosols. P18 and P29 had perudic SMR, free-Fe of the horizon below 30 cm of P18 was 40–56%, the horizon below 20 cm of P29 had a hue of 10RP, free-Fe content of 17.9 g/kg and pH_{KCl} of 3.8–4.4, and thus, they belong to Ferric Acidi-Perudic Cambosols. P2, P23 and P30 had udic SMR, the parent rocks of P23 and P30 are purple shale and purple sandstone, respectively, the hue of the pedons is 10RP, and there are 2–30% debris of purple rocks in the pedons. P23 had light calcaric property with pH of 7.6–7.7, and thus, it belongs to Calcaric Purpli-Udic Cambosols. P30 had no calcaric property with pH of 6.6–6.8, and thus, it belongs to Typic Purpli-Udic Cambosols. The horizon below 40 cm of P2 had a little iron and manganese mottling or concretions, and thus, it belongs to Mottlic Hapli-Udic Cambosols.

P13 is dryland, it only had ochric epipedon, and thus, it belongs to Primosols. The ochric epipedon had a thickness of 20 cm with the wet and dry values of 6 and 5 and wet chroma of 4, it had udic SMR and paralithic contact appeared at 30 cm depth, and thus, it belongs to Lithic Udic-Orthic Primosols.

3.2 Suitability assessment of tobacco planting

It can be seen from Table 4 that only five typical farmlands (13.9% of the total farmlands) were suitable in texture for tobacco planting, and their textures were sandy loam, silt loam and loam, while 29 typical farmlands (80.6% of the total farmlands) were unsuitable in texture for tobacco planting, and their textures were clayey, including silty clay loam, clay loam, silty clay and clay.

Table 5 shows that 33 farmlands (91.7% of the total farmlands) were suitable in soil pedon thickness for tobacco planting, but 34 farmlands (94.4% of the total farmlands) were unsuitable in plough thickness for tobacco planting, and the depth of plough layer was 10–30 cm with a mean of 18.9 cm and standard deviation of 6.2 cm.

It can be calculated out from Table 6 that the variable coefficients were 16.1% for pH, 35.9% for SOM, 32.5% for

Table 4 Statistics and assessment on textures of plough layers of typical tobacco-planting farmlands

Grade	Texture	Farmland number	%
Suitable	Sandy loam	1	2.8
	Silt loam	1	2.8
	Loam	5	13.9
	Total	7	19.4
Clayey	Silty clay loam	10	27.8
	Clay loam	5	13.9
	Silty clay	11	30.6
	Clay	3	8.3
	Total	29	80.6

A-N, 74.0% for A-P, 64.6% for A-K, 95.2 for A-Zn, 54.2 for A-Mo and 83.3 for A-B, which suggested great variation existed in all the above chemical properties of farmlands. From Tables 6 and 7, it could be seen that pH, SOM, A-N, A-P, A-K, A-Zn, A-Mo and A-B all were spanned from low-to-high grades, among of which, 16 farmlands (44.4% of the total farmlands), 17 farmlands (47.2% of the total farmlands), 13 farmlands (26.1% of the total farmlands), 26 farmlands (72.2% of the total farmlands), 30 farmlands (83.3% of the total farmlands), 26 farmlands (72.2% of the total farmlands), 20 farmlands (55.6% of the total farmlands) and 30 farmlands (83.3% of the total farmlands) were unsuitable (low grade plus high grade) for tobacco planting in pH, SOM, A-N, A-P, A-K, A-Zn, A-Mo and A-B, respectively.

4 Discussion

4.1 Soil taxonomy of typical farmlands

Guizhou Province is located in subtropical region of Southwest China. In the low altitude area, soils not planted rice usually have the intensive process of desilicification and ferrallitization due to the high temperature and plenty of precipitation, which easily resulted in the formation of LAC-ferric horizon and argic horizon and the appearance of Ferrosols. However, in the higher altitude area, the process of desilicification and ferrallitization is weak in soils, argic horizon is easily formed, but LAC-ferric horizon is seldom appeared, and thus, soils are developed into Argosols but not into Ferrosols [11, 19]. Among of the 36 typical farmlands, 7 (19.4%) belong to Ferrosols (the altitude is ranged from 365 to 2284 m, with a mean of 1158 m), while 11 (30.5%) belong to Argosols (the altitude is ranged from 1018 to 2176 m, with a mean of 1599 m). Soils derived from purple rocks usually face severe soil erosion due to the low altitude but high precipitation and slope terrain, which leads to the weak development of soil pedons [11, 19] and usually belong to Cambosols, for examples, the three typical farmlands derived from purple rocks in this study all are slope drylands with the low altitude of 604–916 m but high precipitation of 1000–1156 mm, and they belong to perudic- or udic-Cambosols.

4.2 Reference between soil genetic classification and soil taxonomy

Here, yellow soil in genetic classification was taken as an example to analyse the reference between soil genetic classification and soil taxonomy. In this study, 13 typical farmlands are yellow soil in genetic classification which is mainly referenced as Ali-Perudic Argosols, Ali-Perudic

Table 5 Assessment on thickness of pedon and plough layers of typical tobacco-planting farmlands

Grade	Pedon thickness		Grade	Plough layer thickness	
	Farmland number	%		Farmland number	%
Shallow (less than 50 cm)	3	8.3	Shallow (less than 30 cm)	34	94.4
Suitable (higher than 50 cm)	33	91.7	Suitable (higher than 30 cm)	2	5.6

Table 6 Statistics of chemical properties of typical tobacco-planting farmlands

	pH	SOM (g/kg)	A-N (mg/kg)	A-P (mg/kg)	A-K (mg/kg)	A-Zn (mg/kg)	A-Mo (mg/kg)	A-B (mg/kg)
Min	4.7–8.5	12.3–55.5	51.5–257.3	4.3–99.94	95–885	0.04–3.97	0.68–7.45	0.07–1.76
Mean $\pm$ S.D	6.2 $\pm$ 1.0	32.3 $\pm$ 11.6	142.0 $\pm$ 46.1	30.40 $\pm$ 22.52	333 $\pm$ 215	0.84 $\pm$ 0.80	2.53 $\pm$ 1.37	0.42 $\pm$ 0.35

Table 7 Assessment on chemical properties of plough layers of typical tobacco-planting farmlands

Grade	pH	SOM (g/kg)		A-N (mg/kg)		A-P (mg/kg)		A-K (mg/kg)		A-Zn (mg/kg)		A-Mo (mg/kg)		A-B (mg/kg)	
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Low	9	25.0	8.3	6	16.7	10	27.8	7	19.4	2	5.6	6	16.7	10	27.8
High	7	19.4	38.9	7	19.4	16	44.4	23	63.9	18	50	24	66.7	16	44.4
Suitable	20	55.6	52.8	23	63.9	10	27.8	6	16.7	16	44.4	6	16.7	10	27.8
total	36	100.0	100.0	36	100.0	36	100.0	36	100.0	36	100	36	100	36	100

Cambosols, or Alliti-Perudic Ferrosols in Chinese Soil Taxonomy [5]. However, P18, P27 and P31 (yellow soil in genetic classification) had perudic SMR and were Perudic Cambosols, Argosols or Ferrosols, but they could not be classified as Ali-Perudic Cambosols, Ali-Perudic Argosols or Alliti-Perudic Ferrosols because they had no Alic property or Allitic property. P2, P5, P6, P8, P10, P12, P15, P24 and P25 (yellow soil in genetic classification) had udic SMR and neither had no Alic property or Allitic property, and thus, they could not be classified as Ali-Perudic Cambosols, Ali-Perudic Argosols or Alliti-Perudic Ferrosols. The poor reference of the above yellow-soil farmlands with soil taxonomy could be attributed to the following reasons: Firstly, as a recent study found that soil type decided during the 2nd soil survey in 1980s–1990s is not accurate because it was mainly determined by the rough bioclimatic zone but not by reliable soil properties [23]. Secondly, the soil map of 1:250,000 scale is too rough to accurately determine soil genetic types of farmlands since the great spatial heterogeneity of Guizhou due to its mountainous complex terrain. Thirdly, the reference itself between soil genetic classification and soil taxonomy cited is an approximate Refs. [5, 8].

4.3 Suitability assessment of farmlands for tobacco-planting

In order to tell the problems and countermeasures of tobacco farmlands simply and easily, this evaluation is only a preliminary evaluation of the suitability of each indicator. Therefore, there is no conventional quantitative comprehensive evaluation of soil quality for all indexes. In addition, the areas of tobacco planting in Guizhou Province and other parts of China are basically poor regions, so the suitability evaluation does not consider the socio-economic factors. Due to either horizontal terraces or gentle slopes (2°–5°), and contour ridge, the loss of soil and water is very little and slope factor is not considered.

It could be seen from Tables 5 and 7 that the main soil problems existed in chemical properties of typical farmlands for tobacco planting are the shallow plough layer, clayey texture, acid and high contents in SOM, A-P, A-K and trace elements. The problem of shallow plough layer could be attributed not only to inevitable soil erosion because 20 farmlands (55.6% of the total farmlands) were sloping drylands or sloping terrace drylands and high precipitation in Guizhou Province, but also to the rotary tillage popularly adopted in China with the regular tillage depth of 10–15 cm when planting maize or other dry crops [14]. The acid problem could be attributed to intense leaching loss of soil base ions due to high precipitation (mean annual precipitation is 850–1600 mm) in Guizhou Province and larger amount application of acid chemical

fertilizers [10, 15]. The problems of high contents in SOM, A-P, A-K and trace elements could be attributed to the intense application of organic and potassium fertilizers for tobacco planting and intense application of compound fertilizers of high phosphorus for planting other crops. Studies conducted in 2003 and 2004 found the insufficient application of organic fertilizer (in 1999, farmyard manure was only about 315 kg/667 m²; rape seed cake was only about 2.6 kg/667 m²), overuse of nitrogen fertilizer but insufficient potassium fertilizer, and overuse of B fertilizer in tobacco planting [6, 16–18], and then, more organic fertilizer, potassium and B fertilizers have been annually applied to overcome those problems during tobacco-planting season.

Further, this study disclosed that ‘low’ and ‘high’ situations unsuitable for tobacco planting are co-existed in all measured chemical properties and no perfect farmland is existed in all chemical properties for tobacco planting. It indicates that soil survey is needed to understand soil conditions and find soil problems in tobacco-planting farmlands, which is significant for adopting the effective measures such as deep plough, using dolomite powders to remedy acid soil, fertilization by soil test to overcome soil problems for the sustainable production of tobacco.

5 Conclusion

This study showed that the diagnostic horizons of the surveyed 36 typical tobacco-planting farmlands in Guizhou Province included anthrostatic epipedon, ochric epipedon, hydric horizon, Fe-leachic horizon, LAC-ferric horizon, argic horizon, agric horizon and cambic horizon, while the diagnostic characteristics included anthrostatic SMR, perodic SMR, aquic SMR, udic SMR, gleyic features, redoxic features, L.C. of carbonate rocks, humic property and ferric property. The soils of farmlands belonged to Anthrosols, Ferrosols, Argosols, Cambosols and Primosols in soil orders, among of which, four subgroups in Anthrosols, eight subgroups in Ferrosols, seven subgroups in Argosols, five subgroups in Cambosols and one subgroup in Primosols. No farmland was perfectly suitable in soil conditions for tobacco planting, and the main soil problems were shallow plough layer, acid and higher contents of SOM, available phosphorus, potassium and trace elements mainly due to overuse of fertilizers. Regular soil survey is needed to find soil problems for adopting effective measures to improve soil quality and guarantee the sustainable production of tobacco.

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Compliance with ethical standards

Conflict of interest The authors declare no conflicts of interest.

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