

1 **Soil nutrient contents and stoichiometry within aggregate size classes varied with tea**
2 **plantation age and soil depth in the southern Guangxi of China**

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8 **ABSTRACT**

9 Soil ecological stoichiometry offers a tool to explore the distribution, cycling, limitation, and
10 balance of chemical elements in tea plantation ecosystems. This study aimed to explore how soil
11 organic C (OC) and nutrient contents (total N (TN), total P (TP), Ca^{2+} , Mg^{2+} , Fe^{2+} , and Mn^{2+}) as
12 well as their stoichiometric ratios (C/N, C/P, N/P, Ca/Mg, and Fe/Mn) varied with tea plantation
13 age (8, 17, 25, and 43 years) and soil depth (0-10, 10-20, 20-40, and 40-60 cm) within aggregates
14 in the southern Guangxi of China. Our results showed that tea plantation age and soil depth
15 significantly affected soil nutrient stoichiometry in different sizes of aggregates. Among
16 different ages of tea plantations, soil OC, TN, and TP contents as well as C/N, C/P, and N/P
17 ratios significantly decreased as the soil depth increased. In addition, soil Ca^{2+} and Mg^{2+} contents
18 were significantly lower in the surface soil layer than the deeper soil layer, whereas soil Fe^{2+} and
19 Mn^{2+} contents showed opposite trends, and no significant differences were detected in Ca/Mg
20 and Fe/Mn ratios among different soil depths. At the 0-40 cm soil depth, continuous planting of
21 tea corresponded with increases in soil OC, TN, Fe^{2+} , and Mn^{2+} contents, whereas soil Ca^{2+} and
22 Mg^{2+} contents significantly decreased over time. During the process of tea growth, the losses of
23 soil Ca^{2+} and Mg^{2+} , especially Ca^{2+} (as indicated by the decrease in soil Ca/Mg ratio), led to soil
24 acidification, which reduced Fe^{2+} absorption and enhanced Mn^{2+} uptake by tea plants (as
25 indicated by the increase in soil Fe/Mn ratio). In general, tea plantation age affected the

26 variations of soil nutrient contents and stoichiometry, and such effects were more obvious at the
27 0-40 cm soil depth in contrast to the 40-60 cm soil depth.

28 **KEYWORDS**

29 Tea plantation age; Soil depth; Soil aggregate; Ecological stoichiometry

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31 **1. Introduction**

32 In the past century, under the remarkable increase in population pressure, continuous tillage
33 and deforestation resulted in the dramatic decrease in soil fertility level in the southern Guangxi
34 of China (Jiang et al., 2018). To overcome these existing challenges, the Chinese government
35 has rolled out the Grain for Green program in the hope of alleviating land deterioration via
36 converting farmlands to forest lands or grass lands (Zeng et al., 2020). Since the initiation of this
37 program, the south part of Guangxi has begun transforming farmlands into tea (*Camellia sinensis*
38 L.) plantations as per the local geography and natural resources (Zhang et al., 2017). Tea, as a
39 pivotal cash crop, is commonly cultivated in the developing nations, particularly in China, India,
40 Kenya, and Sri Lanka. China is the world's largest producer of tea, with the tea-planting area
41 reaching 3.17 million hectares in 2020, and it shows an elevating trend in the future (Chinese
42 Tea Committee, 2020). Guangxi has the subtropic monsoon climate and marks the key
43 tea-planting region in China. According to the statistics from Chinese Tea Committee (2020),
44 over 80% tea plantations of Guangxi are situated at the impoverished counties, and tea-planting
45 industry turns to be the staple industry on which poor counties depend to throw off poverty.

46 Ecological stoichiometry offers a tool to explore the distribution, cycling, restriction, and
47 balance of nutrients in terrestrial ecosystems (Yu et al., 2019), and is an invaluable tool for
48 identifying the influencing factors and driving mechanisms in ecological processes (Su et al.,
49 2019). Carbon (C) is the most commonly seen element in plants (Prescott et al., 2020), and
50 nitrogen (N) and phosphorus (P) are critical control factors for the growth of plants (Krouk and
51 Kiba, 2020). The relationships amongst C, N, and P are coupled (Elser et al., 2003) and their

52 stoichiometric ratios (C/N, C/P, and N/P) reflect the nutrient status during the process of soil
53 genesis, making them important indicators of soil quality (Bai et al., 2020). Additionally,
54 calcium (Ca), magnesium (Mg), iron (Fe), and manganese (Mn) are pivotal metallic nutritive
55 elements for the development of plants (Liu et al., 2021a). The contents of soil total Ca, Mg, Fe,
56 and Mn may exceed the demand of a single plant by more than a thousand-fold and cannot
57 sensitively reflect the needs of plants (Miner et al., 2018), but the contents of these nutrients'
58 available fractions may be insufficient or redundant, resulting in the deficiencies or abundances
59 of plant nutrients (Otero et al., 2013). Thus, soil exchangeable Ca and Mg, together with the
60 available Fe and Mn significantly affect the development of plants.

61 Over the past decade, soil nutrient stoichiometry (mainly C-N-P, rather than Ca-Mg or
62 Fe-Mn) has been broadly investigated across the world (Tian et al., 2010; Yang et al., 2013;
63 Zhang et al., 2016; Yue et al., 2017; Yu et al., 2018; Qiao et al., 2020). It has been widely
64 acknowledged amongst these studies that soil depth is vital for the regulation of soil nutrient
65 stoichiometry. Several studies have identified the decreasing trend of soil organic C (OC), total
66 N (TN), and total P (TP) contents with increasing soil depth (Yue et al., 2017; Yu et al., 2018;
67 Qiao et al., 2020), whereas conflicting vertical patterns have been observed for soil C/N, C/P,
68 and N/P ratios. For instance, a decreasing trend of the C/P and N/P ratios were observed with
69 increasing soil depth, according to the data of the 2nd soil investigation in China (Tian et al.,
70 2010). Nevertheless, a larger C/N ratio in the deeper soil layer, not the surface soil layer, was
71 identified in a mollisol plain in the northeast China, because soil total C was measured and
72 carbonates were observed in the deeper soil layer (Zhang et al., 2016). Moreover, the C/N ratio
73 showed no remarkable change with soil depth in an investigation of alpine grassland on the
74 Qingzang Plateau (Yang et al., 2013). As shown above, inconsistent vertical patterns have been
75 reported for the C-N-P stoichiometric ratios in different soil ecosystems.

76 As the basic unit of soil structure, soil aggregates are complex ensembles composed of
77 primary particles and organic matter (OM) (Tisdall and Oades, 1982). According to the

78 differences in binding agents, soil aggregates can be classified into microaggregates (< 0.25 mm)
79 and macroaggregates (> 0.25 mm) (Tisdall and Oades, 1982). In general, persistent binding
80 agents (including chemically stable OM and polyvalent metal cation complexes) contribute to
81 the binding of primary particles into microaggregates (Six et al., 2004). On the contrary,
82 temporary binding agents (including fungal hyphae, plant roots, and polysaccharides) aggregate
83 with microaggregates, which facilitate to the formation of macroaggregates (Six et al., 2004).
84 Soil aggregates with various sizes have different abilities in the supply and reserve of soil OC
85 and nutrients. Thus, to improve the comprehension on the structure and function of soil
86 ecosystems, more efforts should be made to observe the soil nutrient stoichiometry within
87 aggregates (Xu et al., 2019; Cui et al., 2021). Recently, although lots of studies have reported the
88 OC, TN, and TP distribution in different sizes of aggregates, these studies have shown different
89 results. To be specific, some studies reveal the significant increases in the OC, TN, and TP
90 contents with decreasing aggregate size (Sarker et al., 2018; Piazza et al., 2020), while other
91 studies observe opposite trends (Lu et al., 2019; Liu et al., 2021b). Further, the changes in soil
92 OC, TN, and TP contents within aggregates have received great attention, while soil
93 exchangeable alkaline-earth metals (i.e., Ca^{2+} and Mg^{2+}) and available micronutrients (i.e., Fe^{2+}
94 and Mn^{2+}) are less often investigated.

95 Our previous studies indicated that the landuse shift from farmlands to tea plantations
96 ameliorated the soil fertility level (Zheng et al., 2011). However, during the process of tea
97 growth, the variation of soil nutrient stoichiometry remains unclear. Meanwhile, since tea serves
98 as a deep-rooted plant, it is vital to understand how nutrient stoichiometry changes with the
99 increasing soil depth in tea plantation ecosystems. Thus, this study was carried out to investigate
100 how soil OC and nutrient contents as well as their stoichiometric ratios varied with tea plantation
101 age (8, 17, 25, and 43 years) and soil depth (0-10, 10-20, 20-40, and 40-60 cm) within aggregates
102 (< 0.25, 0.25-1, 1-2, and > 2 mm). We hypothesized that (i) soil OC and TN contents would
103 increase with tea plantation age due to the annual fertilization, and (ii) decreases in soil Ca^{2+} and

104 Mg²⁺ contents would be accompanied by increases in soil Fe²⁺ and Mn²⁺ contents because of soil
105 acidification during the process of tea growth.

106 **2. Materials and methods**

107 2.1. Experiment site

108 In January 2019, this study was completed at the Hengxian Agriculture Experiment Center
109 of Guangxi University (altitude of 557-563 m and slope degree of 13-15 °). The climate at the
110 experiment site is dominated by subtropic monsoon climate, with the yearly average rainfall and
111 temperature being 1304 mm and 21.6 °C, respectively. Exposed soil horizon occurs early in the
112 Mesozoic, which gradually forms the Ultisols agrotypic (IUSS Working Group, 2014). As early
113 as in 1960s, due to the high economic value of tea, massive hectares of farmlands were
114 developed to tea plantations in this region.

115 The “*Baimao* tea” refers to a major cultivar in this area, and the ages of these tea plantations
116 are distinct. Managed by different owners, tea plantations were both experimental trials
117 (Guangxi University) and commercial plantings. In the tea-planting course, the tillage method
118 was no tillage and tea-planting density was almost 6×10^4 plants ha⁻¹. Herbicides were not
119 applied and yellow sticky boards were used to prohibit pests, because this color might attract
120 pests and got them stuck on the boards. In addition, all the tea plants were subject to slight
121 pruning in September each year.

122 An annual fertilizer regime in tea plantations was shown below. Both 0.65 Mg ha⁻¹ complex
123 fertilizer (granule, N-P₂O₅-K₂O: 18%-6%-6%) and 12 Mg ha⁻¹ swine manure (slurry,
124 N-P₂O₅-K₂O: 0.54%-0.48%-0.36%) were applied vertically below tree crown yearly in
125 mid-November as the basal fertilizer at the surrounding region. Subsequently, the top-dressing,
126 applied to the site treated with replenished basal fertilizer, was replenished thrice per year. Both
127 1.2 Mg ha⁻¹ complex fertilizer and 0.5 Mg ha⁻¹ urea were applied onto soil surface in mid-March,
128 while 0.65 Mg ha⁻¹ complex fertilizer and 0.3 Mg ha⁻¹ urea were applied in late-June and in
129 early-September.

130 2.2. Experiment design

131 In general, examining the same location persistently has been considered as an effective
132 approach to monitor the variations of soil with time (Sparling et al., 2003). Nevertheless, the
133 challenges in long-time soil monitoring have made it urgent to develop the substitutional
134 approaches to investigate the changes in soil over time, amongst which the most common
135 approach is the ‘space-for-time’ alternative (Zanella et al., 2018).

136 In this study, this approach was used to explore the variation of soil nutrient stoichiometry
137 in a chronological sequence of tea plantations. In general, confounding factors existed in the
138 spatial variations of soil, hence the present study managed to mitigate such effects by choosing
139 tea plantations, which were cultured with the same tea variety (“*Baimao* tea”) with different
140 planting ages (8, 17, 25, and 43 years), and were located at the same unit associated with
141 geomorphological status.

142 Each of the 4 tea plantation age groups was replicated in 5 locations for a total of 20
143 experimental units (Figure 1). Separation amongst these units was completed with distances of >
144 800 m between each other, thereby decreasing the spatial autocorrelation and avoiding the
145 pseudo-replication. For every unit ($S \approx 1 \times 10^4 \text{ m}^2$), a plot ($S = 20 \text{ m} \times 20 \text{ m}$) was randomly
146 established with distance of > 50 m away from the unit margin.

147 2.3. Litter and soil sampling

148 For every plot, 5 surface litter (a stock) specimens were acquired from the surface of soil in
149 the 5 randomly chosen subplots ($S = 1 \text{ m} \times 1 \text{ m}$), which were afterwards integrated into a
150 composite litter specimen. In total, 20 (4 tea plantation ages \times 5 replicates) composite litter
151 specimens were desiccated at 80 °C until the weight became constant. Then, the weights of these
152 desiccated litter specimens were measured, and the litter C (Nelson and Sommers, 1996) and N
153 (Bremner, 1996) contents were measured. The amounts of litter were 821, 974, 786, and 648 g
154 m^{-2} in the 8, 17, 25, and 43 years of tea plantations, respectively, and the C/N ratios of litter were
155 14.23, 12.68, 17.32, and 21.37, respectively.

156 Soil sampling was completed at the same sites of litter sampling. For every plot, 5 soil
157 specimens were acquired by a spade from every soil layer (i.e., 0-10, 10-20, 20-40, and 40-60
158 cm) in the 5 subplots ($S = 1 \text{ m} \times 1 \text{ m}$), which were afterward integrated into a composite soil
159 specimen. In total, 80 (4 tea plantation ages \times 4 soil layers \times 5 replicates) composite soil
160 specimens were gently separated into the naturally formed aggregates, and were then sieved by a
161 5-mm sifter to remove small stones, coarse roots, and macrofauna. Afterwards, soil specimens
162 were used for the aggregate separation. For every plot, another 5 soil specimens were randomly
163 chosen via cutting rings (volume = 100 cm^3 , diameter = 50.46 mm, and depth = 50 mm) from
164 every soil layer to measure the bulk density, clay ($< 0.002 \text{ mm}$), pH, OC, and nutrients of bulk
165 soil.

166 2.4. Soil aggregate separation

167 According to the wet screening process, 250 g of every composite soil specimen was sieved
168 via the 2, 1, and 0.25 mm sieves successively (Kemper and Chepil, 1965). To be specific, the
169 composite soil specimens were soaked in distilled water for 15 min, and were then shaken in the
170 vertical direction for 15 min at the 1 s^{-1} oscillating rate and 5 cm amplitude. Consequently, we
171 obtained 4 different sizes of aggregates, covering microaggregates ($< 0.25 \text{ mm}$), fine (0.25-1
172 mm), medium (1-2 mm), and coarse ($> 2 \text{ mm}$) macroaggregates. All the aggregates were
173 desiccated and weighed, and later the aggregate-related OC and nutrients were measured.

174 2.5. Soil property analyses

175 Prior to the analyses of soil physical-chemical properties, soil specimens were subject to
176 atmospheric drying under indoor temperature condition. According to the cutting ring method
177 (Lu, 2000), soil specimens were oven-dried at $105 \text{ }^\circ\text{C}$ until constant weight, so as to measure the
178 bulk density. Soil clay was measured by the hydrometer (TM-85, Veichi, China) (Lu, 2000). Soil
179 pH was measured by the glassy electrode (MT-5000, Ehsy, China), with the ratio of soil : water
180 (mass : volume) being 1 : 2.5 (Lu, 2000). Soil OC and TN were measured via the acid dichromate
181 wet oxidation method (Nelson and Sommers, 1996) and the micro-Kjeldahl method (Bremner,

182 1996), respectively. Soil TP was measured via the molybdate blue colorimetry method (Bray and
183 Kurtz, 1945). Soil exchangeable alkaline-earth metals (i.e., Ca^{2+} and Mg^{2+}) were measured by the
184 ammonium acetate ($\text{CH}_3\text{COONH}_4$) (Thomas, 1982). Briefly, 2.5 g of every aggregate fraction
185 was weighed into the Erlenmeyer flask to blend with 50 mL 1 M $\text{CH}_3\text{COONH}_4$ (pH = 7.0). The
186 extract liquid was agitated for 30 min under 150 rpm, and then sieved via Whatman No. 2 V
187 filtration paper (quantitative and ashfree). Soil available micronutrients (i.e., Fe^{2+} and Mn^{2+})
188 were measured by the diethylenetriamine pentaacetic acid (DTPA) (Lindsay and Norvell, 1978).
189 Briefly, 10 g of every aggregate fraction was weighed into the Erlenmeyer flask to blend with 20
190 mL 0.005 M DTPA + 0.01 M CaCl_2 + 0.1 M TEA (triethanolamine) (pH = 7.0). The extract
191 liquid was agitated for 2 h under 180 rpm, and then sieved. The entire extractable metallic
192 cations were measured by the atomic absorption spectrometer (AAS, Shimadzu, Japan). In this
193 study, 5 standard specimens (GBW-07401), 5 blank specimens, and 80 analytical replicates
194 (accounted for 20% of the total soil specimens) were used to control quality. The difference
195 between analytical replicates was consistently less than 5%.

196 2.6. Calculations and statistics

197 The mean weight diameter (MWD, mm) was utilized to indicate the stability of soil
198 aggregates. To be specific, the higher MWD value indicated the stronger aggregate stability
199 (Kemper and Chepil, 1965):

$$200 \text{ MWD} = \sum_{i=1}^4 (X_i \times M_i),$$

201 in the formula, X_i indicates the i^{th} size aggregates' mean diameter (mm) and M_i indicates the
202 i^{th} size aggregates' proportion (% in weight).

203 SPSS 22.0 software (SPSS, Inc., Chicago, IL, USA) was used for statistic analysis (Table
204 1). Means were tested by the Tukey's HSD and the significant level was set at $p \leq 0.05$.
205 Two-way analysis of variance (ANOVA) was used for exploring the effects of soil depth, tea
206 plantation age, and their interactions on the physico-chemical properties of bulk soil. Three-way
207 ANOVA was used for exploring the effects of soil depth, tea plantation age, aggregate size, and

208 their interactions on the physico-chemical properties of soil aggregates. Besides that, Pearson
209 correlation analysis was utilized to test the relationships between pH and stoichiometric ratios
210 (i.e., Ca/Mg and Fe/Mn) in bulk soil during the process of tea growth.

211 **3. Results**

212 3.1. Soil bulk density, clay content, and pH

213 At the 0-10 and 10-20 cm soil depths, bulk density significantly decreased within the first
214 17 years and afterwards significantly increased, whereas the effect of tea plantation age on the
215 bulk density is limiting at the 20-40 and 40-60 cm soil depths (Tables 1 and 2). Regardless of the
216 tea plantation age, a significant increase in bulk density was observed as the soil depth increased.
217 A two-way ANOVA analysis showed that the effects of soil depth, tea plantation age, and their
218 interactions on the clay content were not significant (Tables 1 and 2). Soil pH significantly
219 decreased during the process of tea growth (Tables 1 and 2). Moreover, no significant variation
220 in soil pH was observed with the increasing soil depth.

221 3.2. Composition and stability of soil aggregates

222 At the 0-10 and 10-20 cm soil depths, continuous planting of tea resulted in significant
223 variations in the proportions of different sizes of aggregates, apart from the medium and fine
224 macroaggregates (Table 3). To be specific, the proportions of coarse macroaggregates
225 significantly rose within the first 17 years and then significantly dropped, whereas the
226 proportions of microaggregates displayed an opposite trend over time. At the same time, the
227 greatest value of soil MWD was identified in the tea plantations of 17 years (Table 3). Notably,
228 the role of tea plantation age in the aggregate composition and stability is limited at the 20-40
229 and 40-60 cm soil depths. Across the 4 tea plantation ages, the coarse macroaggregates were
230 dominant at the 0-10 cm soil depth, accounting for 32.60%-53.18% of bulk soil. However, at the
231 10-20, 20-40, and 40-60 cm soil depths, the microaggregates were dominant, accounting for
232 33.80%-49.51%, 42.12%-48.24%, and 44.80%-49.45%, respectively. According to the obtained

233 results, the coarse macroaggregate proportions significantly reduced while the microaggregate
234 proportions significantly elevated with the increasing soil depth.

235 3.3. Contents of soil C, N, and P

236 Within aggregate size classes, soil OC (Figure 2) and TN (Figure 3) contents significantly
237 increased with the increasing aggregate size, while the distribution of soil TP (Figure 4) was
238 even in different sizes of aggregates. From 8 to 43 years of tea plantations, the OC and TN
239 contents in soil aggregates were significantly elevated by 22%-35% and 14%-24%, 11%-22%
240 and 9%-17%, and 8%-18% and 9%-13% at the 0-10, 10-20, and 20-40 cm soil depths,
241 respectively. Nevertheless, there existed no significant variation in the aggregate-related TP
242 content. Furthermore, at the 40-60 cm soil depth, the aggregate-related OC, TN, and TP contents
243 did not exhibit significant variations over time. Regardless of the tea plantation age, significant
244 decreases in the aggregate-related OC, TN, and TP contents were observed as the soil depth
245 increased.

246 3.4. Stoichiometric ratios of soil C, N, and P

247 A three-way ANOVA analysis revealed that the lone and interactive effects of soil depth,
248 tea plantation age, and aggregate size on the C/P and N/P ratios were significant, and the effects
249 of soil depth, aggregate size, and their interactions on the C/N ratio were significant (Table 1). In
250 this study, significant increases in aggregate-related C/N (Table S1), C/P (Table S2), and N/P
251 (Table S3) ratios were accompanied by the increasing aggregate size. At the 0-10, 10-20, and
252 20-40 cm soil depths, aggregate-related C/N ratio did not exhibit significant variation while
253 aggregate-related C/P and N/P ratios significantly increased with increasing tea plantation age.
254 Moreover, there was little role of tea plantation age in the aggregate-related C/N, C/P, and N/P
255 ratios at the 40-60 cm soil depth. Among different ages of tea plantations, aggregate-related C/N,
256 C/P, and N/P ratios significantly dropped as the soil depth increased. For example, at the 0-10
257 cm soil depth, aggregate-related C/N, C/P, and N/P ratios across the 4 tea plantation ages
258 fluctuated in 20.81-23.04, 28.81-37.07, and 1.31-1.67, respectively. In the meanwhile, at the

259 40-60 cm soil depth, aggregate-related C/N, C/P, and N/P ratios fluctuated in 16.41-20.74,
260 13.44-22.88, and 0.84-1.08, respectively.

261 3.5. Contents of soil alkaline-earth metals and micronutrients

262 Within aggregate size classes, soil exchangeable alkaline-earth metals (i.e., Ca^{2+} and Mg^{2+})
263 were more concentrated in the microaggregates (Figures 5 and 6). However, soil available
264 micronutrients (i.e., Fe^{2+} and Mn^{2+}) were mainly found in the coarse macroaggregates (Figures 7
265 and 8). From 8 to 43 years of tea plantations, the Ca^{2+} and Mg^{2+} contents in soil aggregates were
266 significantly reduced by 31%-38% and 10%-24%, 23%-27% and 9%-18%, and 10%-16% and
267 5%-8% at the 0-10, 10-20, and 20-40 cm soil depths, respectively. From 8 to 43 years of tea
268 plantations, however, the Fe^{2+} and Mn^{2+} contents in soil aggregates were significantly elevated
269 by 16%-27% and 6%-9%, 11%-15% and 4%-7%, and 7%-12% and 3%-5%, respectively. In
270 addition, at the 40-60 cm soil depth, the contents of aggregate-related exchangeable
271 alkaline-earth metals and available micronutrients did not present significant variations over
272 time. Irrespective of the tea plantation age, significant increases in the aggregate-related Ca^{2+} and
273 Mg^{2+} contents were observed with the increasing soil depth, whereas the aggregate-related Fe^{2+}
274 and Mn^{2+} contents showed an opposite trend.

275 3.6. Stoichiometric ratios of soil alkaline-earth metals and micronutrients

276 A three-way ANOVA analysis demonstrated that the effect of tea plantation age on the
277 Ca/Mg and Fe/Mn ratios in soil aggregates was significant (Table 1). In this study, soil Ca/Mg
278 (Table S4) and Fe/Mn (Table S5) ratios did not vary among different sizes of aggregates. At the
279 0-10, 10-20, and 20-40 cm soil depths, aggregate-related Ca/Mg ratio significantly decreased
280 while aggregate-related Fe/Mn ratio significantly increased in the tea-planting course. Moreover,
281 there was little role of tea plantation age in the aggregate-related Ca/Mg and Fe/Mn ratios at the
282 40-60 cm soil depth. In tea plantations, no significant variations were observed amongst different
283 soil depths in aggregate-related Ca/Mg and Fe/Mn ratios. For example, at the 0-10 cm soil depth,
284 aggregate-related Ca/Mg and Fe/Mn ratios across the 4 tea plantation ages ranged from 1.81 to

285 1.96 and 0.76 to 0.85, respectively. Meanwhile, at the 40-60 cm soil depth, aggregate-related
286 Ca/Mg and Fe/Mn ratios ranged from 1.88 to 1.92 and 0.78 to 0.82, respectively.

287 **4. Discussion**

288 4.1. Composition and stability of soil aggregates

289 Tea plantation age significantly influenced the aggregate composition and stability at the
290 0-10 and 10-20 cm soil depths, whereas the effect at the 20-40 and 40-60 cm soil depths was
291 extremely limited. In the early (8-17 years) period, tea planting was conducive to the transition
292 from microaggregates to coarse macroaggregates at the 0-10 and 10-20 cm soil depths (Table 3).
293 Comparatively, in the middle (17-25 years) and late (25-43 years) periods, tea planting induced
294 coarse macroaggregate destruction and microaggregate release (Table 3). According to the
295 hierarchical concept of soil aggregates (Six et al., 2004), the quality of plant litter returning to the
296 soil determines the distribution of decomposition products of litter in different sizes of
297 aggregates, ultimately impacting the aggregate composition. In the early period of tea planting,
298 tea litter displayed greater availability (as indicated by the lower litter C/N ratio), revealing that
299 the decomposition products of litter were easily combined into the coarse macroaggregates,
300 thereby fostering the formation of coarse macroaggregates (Tisdall and Oades, 1982). Reversely,
301 in the middle and late periods of tea planting, tea plants naturally encountered aging processes
302 and litter was progressively subjected to decomposition, inducing the decomposition of coarse
303 macroaggregates into microaggregates (Six and Paustian, 2014). Moreover, the reduced litter
304 amount and covering area after 17 years of tea planting enhanced the rainfall eluviation and
305 artificial interferences (i.e., pruning of tea plants and application of fertilizers), which could also
306 cause the destruction of coarse macroaggregates. In the tea-planting course, variation in
307 aggregate stability was indicated via the change of MWD value (Table 3). At the 0-10 and 10-20
308 cm soil depths, the MWD value was the greatest in the 17 years of tea planting, which was
309 associated with the highest proportions of coarse macroaggregates in the 17-year tea plantations.

310 The above findings indicated that the 17-year tea plantations exhibited stronger aggregate
311 stability in contrast to other plantations at the 0-10 and 10-20 cm soil depths.

312 Regardless of the tea plantation age, coarse macroaggregates were dominant in the topsoil
313 (0-10 cm) while microaggregates were dominant in the subsoil (10-60 cm), suggesting
314 transformation of aggregate composition from coarse macroaggregate-prevailing to
315 microaggregate-prevailing with increasing soil depth (Table 3). In addition, similar outcomes
316 were corroborated by Li et al. (2015) and Zhu et al. (2017) from studies on tea plantations in the
317 southwest Sichuan of China. In this study, coarse macroaggregates were the prevailing fractions
318 in the topsoil, not the subsoil, which was caused by the surface cumulation of soil OC (Figure 2).
319 As an essential cementing agent, soil OC could foster the formation of coarse macroaggregates
320 (Al-Kaisi et al., 2014). Moreover, the reduced proportions of coarse macroaggregates as the soil
321 depth increased were also resulted from the elevated soil compactness (as indicated by the bulk
322 density) (Table 2). Soil densification could prevent the growth of plant roots, hence causing the
323 activities of soil microorganisms decreased, especially soil fungi (Kurmi et al., 2020). Reduced
324 activities of soil fungi could diminish the production of polysaccharose and glomalin-related soil
325 protein (GRSP) from the fungal hyphae, thereby inducing the proportions of soil
326 macroaggregates decreased (Ji et al., 2019). Similarly, as per our past studies (Wang et al.,
327 2017b; Zhu et al., 2019), soil microbial activities and GRSP content served as the vital effects in
328 the formation and stabilisation of soil macroaggregates, and also presented the higher levels in
329 the topsoil compared with the subsoil in tea plantation ecosystems. With the increasing soil
330 depth, the decrease in MWD value was mainly associated with the change of soil aggregate
331 composition (Table 3), especially for the decomposition of coarse macroaggregates into
332 microaggregates, implying that the topsoil exhibited stronger aggregate stability in contrast to the
333 subsoil.

334 4.2. Contents of soil C, N, and P

335 In this study, more contents of soil OC and TN could be detected in coarse macroaggregates
336 (Figures 2 and 3), which conformed to the findings of Six et al. (2004) that macroaggregates
337 were comprised of microaggregates via temporary binding agents. Meanwhile, macroaggregates
338 could provide the protection for the OM, causing the cumulation of OC and TN in
339 macroaggregates. Different from soil OC and TN, soil TP was evenly distributed in different
340 sizes of aggregates (Figure 4). Moreover, Bhatnagar and Miller (1985) also detected similar
341 outcomes from soil specimens subjected to fresh poultry manure treatments, and promoted the
342 mechanisms influencing the distribution of TP in soil aggregates. Specifically, (i) introduced P
343 was firstly adsorbed by clay particulates in soil and clay particulates were discrepant in different
344 sizes of aggregates, and (ii) introduced P had selective absorptive properties for the different
345 sizes of aggregates. According to our findings, stochasticity seems to be one probable
346 mechanism that sheds light on the TP distribution in soil aggregates.

347 Tea plantation age could positively affect the cumulation of soil OC and TN, while such
348 positive effects were more obvious at the 0-40 cm soil depth in contrast to the 40-60 cm soil
349 depth. In this study, soil OC and TN contents exhibited a significant growing trend over time
350 (Figures 2 and 3), which was possibly associated with the following mechanisms. At first,
351 numerous long-period tests had demonstrated the proactive roles of manure and chemical
352 fertilizer applications in soil OM cumulation (Tong et al., 2009; Zhou et al., 2013). Similarly, in
353 the tea-planting course, growing soil OC and TN contents were probably caused by the
354 application of substantial swine manure every year ($12 \text{ Mg ha}^{-1} \text{ year}^{-1}$) in this tea-planting region
355 (Wang and Ye, 2020). Second, plants serve as the prime OM sources in soil via root exudates
356 and litter remains (Franklin et al., 2020). In the tea-planting course, soil OC and TN cumulation
357 probably occurred as a result of the growing root systems and the increasing amounts of
358 aboveground litter attained from trimmed branches and leaves. Third, no tillage could provide
359 physical protection for the OM combined with soil aggregates, then further improving soil OC

360 and TN sequestration (Wulanningtyas et al., 2021). Notably, although the positive correlations of
361 OC and TN contents with clay content in soil have been reported, this study revealed that
362 significant increases in the OC and TN contents were accompanied by no significant variation in
363 the clay content during the process of tea growth (Table 2). Similarly, Li et al. (2015) and Wang
364 et al. (2018) also discovered as well that the changes of soil OC and TN contents were not
365 influenced by the clay content over time in tea plantation ecosystems, mainly because soil OC
366 and TN contents primarily depend on fertilization, tillage, root exudates, and litter remains,
367 whereas soil clay content is mainly controlled by its parent material (Rakhsh et al., 2020).
368 Different from soil OC and TN, regardless of the soil depth, there existed no significant
369 difference in soil TP content amongst different aged tea plantations (Figure 4), implying the
370 resistance of soil TP content to the change of tea plantation age. Moreover, previous studies
371 verified that soil TP content was not associated with the tea plantation age (Wu et al., 2018; Yan
372 et al., 2018), as soil P primarily derives from the weathering release of soil minerals, instead of
373 the short-period biology cycle (Cui et al., 2019). In tea plantation ecosystems, the decreasing OC,
374 TN, and TP contents with the increasing soil depth (Figures 2, 3, and 4) coincided with some
375 previous findings in other ecosystems, including tropic forests, bushlands, and grasslands (Stone
376 and Plante, 2014; Yu et al., 2018; Qiao et al., 2020). In this study, the higher contents of OC, TN,
377 and TP in the topsoil were associated with the higher OM input, where the soil OM content in
378 the topsoil was enriched by the input of surface tea litter, root debris and exudates, and swine
379 manure.

380 4.3. Stoichiometric ratios of soil C, N, and P

381 Soil C/N, C/P, and N/P ratios serve as vital indicators of soil health (Liu et al., 2018), which
382 can be employed to explore C circulation and guiding the equilibrium between N and P in soil
383 ecosystems (Sardans et al., 2012). In this study, soil C/N ratio grew with increasing aggregate
384 size (Table S1), indicating that the OM in macroaggregates was younger and more unstable in
385 contrast to microaggregates (Six et al., 2004). Meanwhile, the OM associated with

386 microaggregates experienced more degradation, resulting in the lower C/N ratio in the
387 microaggregates (Xu et al., 2019). Among different ages of tea plantations, soil OC and TN were
388 predominantly distributed in the coarse macroaggregates, whereas the TP was evenly distributed
389 in different sizes of aggregates. As a result, the associations of C/P and N/P ratios to aggregate
390 size primarily depended on the relationships of OC and TN contents with aggregate size (Tables
391 S2 and S3). As far as we know, the changes of soil C/P and N/P ratios within aggregates are
392 rarely examined, even though these kinds of knowledge are imperative due to the
393 biogeochemical cycles of N and P being influenced by the dynamics of soil aggregates (Cui et al.,
394 2021). Consequently, the impact generated by the aggregate size on the C/P and N/P ratios is
395 required to be studied more for the accurate forecast of soil N and P cycling under natural or
396 man-intervened ecosystems.

397 Irrespective of the soil depth, soil C/N ratio showed little significant variation in the
398 tea-planting course (Table S1). Meanwhile, tea plantation age significantly affected soil C/P and
399 N/P ratios at the 0-40 cm soil depth, rather than the 40-60 cm soil depth (Tables S2 and S3). Soil
400 C/N ratio is generally treated as the critical indicator which can affect the formation and
401 degradation of soil OM (Khan et al., 2016). Since response of soil TN content to soil
402 environment change is almost the same as soil OC content (Wang et al., 2018), soil C/N ratio did
403 not present significant difference amongst different aged tea plantations (Table S1). Similarly,
404 Zhou et al. (2018) proved that no close correlation existed between soil C/N ratio and vegetation
405 coverage, because C and N are structure elements and their cumulation and consumption in soil
406 remain relatively consistent. Soil C/P ratio is the indicator suggesting P effectiveness, and higher
407 C/P ratio often denotes lower P effectiveness (Khan et al., 2016). In acidic soil (Table 2),
408 available P was adsorbed on the surfaces of Fe/Al oxides and clay minerals in a preferential way,
409 because Fe/Al oxides and clay minerals with greater surface areas could afford enough sites to
410 available P adsorption (Wu et al., 2018). Therefore, as the tea plantation age increased, soil
411 acidification generated the decrease in P effectiveness (evidenced by the significant increase in

412 soil C/P ratio) (Table S2). Soil N and P are the prohibiting factors mostly observed during the
413 process of plant growth, and thus, N/P ratio can be utilized as an efficient indicator that shows
414 nutrient restriction (Khan et al., 2016). In this study, soil N/P ratio significantly increased in the
415 tea-planting course (Table S3), mainly because soil TN content experienced significant increase
416 while no such significant change was observed in TP content over time.

417 Regardless of the tea plantation age, soil C/N ratio decreased with the increasing soil depth
418 (Table S1), which coincided with the results from Cao et al. (2015), Feng and Bao (2017), and
419 Yu et al. (2019). They suggested that the decrease in soil C/N ratio as the soil depth increased
420 was triggered by the older and more processed OM in the deeper soil layer. Moreover, in this
421 study, the lower soil C/P and N/P ratios in the subsoil (Tables S2 and S3) backed the outcomes
422 of past studies in terrestrial ecosystems of China, which were on the foundation of the data
423 obtained from both the 2nd soil investigation in China (Tian et al., 2010) and the Chinese
424 Ecosystem Research Network (CERN) (Chai et al., 2015).

425 Across the 4 tea plantation ages, the mean contents of OC and TN in bulk soil (0-20 cm)
426 were 16.70 and 0.77 g kg⁻¹, respectively, which were below the mean contents of OC (21.30 g
427 kg⁻¹) and TN (2.17 g kg⁻¹) in Chinese tea plantations (Sun et al., 2020; Xie et al., 2020).
428 Moreover, in this tea-planting region, the mean content of TP in bulk soil (0-20 cm) was 0.57 g
429 kg⁻¹, corresponding to the moderate level in Chinese tea plantations, where TP content varied in
430 the range of 0.35-1.20 g kg⁻¹ (Wu et al., 2018; Sun et al., 2020). Herein, soil C/N ratio is higher
431 compared with other tea-planting regions in China, whereas soil C/P and N/P ratios are much
432 lower (Sun et al., 2020). The above findings are primarily associated with the lower contents of
433 soil OC and TN, especially TN. In general, N is the most limiting element in the net primary
434 production of tea plantation ecosystems (Miner et al., 2018). Besides, this phenomenon also
435 appeared in the southern Guangxi of China.

436 4.4. Contents of soil alkaline-earth metals and micronutrients

437 According to the findings from Adesodun et al. (2007) and Emadi et al. (2009), the higher

438 contents of exchangeable alkaline-earth metals (including Ca^{2+} and Mg^{2+}) were detected in both
439 2-4.76 and < 0.25 mm aggregates in the non-tillage soil. However, in the tillage course, the
440 contents of these two cations decreased in the 2-4.76 mm aggregates and increased in the < 0.25
441 mm aggregates, revealing that the tillage practice could lead soil Ca^{2+} and Mg^{2+} to redistribute in
442 different sizes of aggregates. Comparatively, this study exhibited that the distribution of soil Ca^{2+}
443 and Mg^{2+} in aggregates was similar among different ages of tea plantations (Figures 5 and 6),
444 suggesting that the distribution of these two cations in aggregates was seldom influenced by the
445 tea plantation age. Specifically, coarse macroaggregates had the lowest contents of Ca^{2+} and
446 Mg^{2+} , whereas microaggregates exhibited the highest contents. These findings could be ascribed
447 to the larger specific surface areas of microaggregates (Adesodun et al., 2007), which increased
448 microaggregates' adsorption to Ca^{2+} and Mg^{2+} derived from root exudates, litter remains, and
449 manure (Emadi et al., 2009). Different from exchangeable alkaline-earth metals, the contents of
450 soil available micronutrients (including Fe^{2+} and Mn^{2+}) usually correspond to the content of soil
451 OM (Wang et al., 2017a), which are more abundant in macroaggregates (Six et al., 2004).
452 Moreover, this study also found that the Fe^{2+} and Mn^{2+} had a similar distribution pattern with OC
453 within aggregates (Figures 7 and 8). Since the decomposition products of litter can be easily
454 integrated to the coarse macroaggregates (Six et al., 2004), the nutrient cycling of plant-soil
455 systems might contribute to the higher contents of soil Fe^{2+} and Mn^{2+} in the coarse
456 macroaggregates (Wang et al., 2017a).

457 At the 0-40 cm soil depth, the contents of soil Ca^{2+} and Mg^{2+} significantly decreased over
458 time (Figures 5 and 6), which might be caused by the applications of urea and NH_4^+ -N fertilizer
459 in the tea-planting course for increasing tea leaf outputs. Urea hydrolysis can promote the
460 production of ammonium ions which are readily nitrified into nitrate, and the excessive proton
461 produced by the nitrification can compete for the adsorption sites with Ca^{2+} and Mg^{2+} (Wang et
462 al., 2017a). As a result, these cations were easy to lose from soil in the manner of leaching.
463 Except at the 40-60 cm soil depth, continuous planting of tea generated the significant increases

464 in soil Fe^{2+} and Mn^{2+} contents (Figures 7 and 8), which were elevated by 7%-27% and 3%-9%
465 from 8 to 43 years of tea planting, respectively. This phenomenon was possibly caused by the
466 soil acidification (Table 2), stimulating the release of soil Fe^{2+} and Mn^{2+} by mineralization and
467 desorption from soil OM and minerals (Wang et al., 2017a). Tea, as an aluminium (Al)
468 cumulating crop, is capable of cumulating Al in leaves (Li et al., 2016). Soil acidification in the
469 tea-planting course was due to the substantial tea litter into the soil annually through trimmed
470 branches and leaves (Li et al., 2016). At the same time, the rhizosphere deposition of massive
471 organic acids (i.e., malate, lemon acid, and oxalate acid) around the tea roots could provoke
472 localized acidification (Xue et al., 2006). Apart from that, to increase the output of tea, tea
473 plantations needed to apply N fertilizers (i.e., urea and $\text{NH}_4^+\text{-N}$), thus leading to soil acidification
474 by the NH_4^+ nitrification (Yang et al., 2018). Across the 4 tea plantation ages, the contents of soil
475 Fe^{2+} and Mn^{2+} were higher in the topsoil than the subsoil (Figures 7 and 8), primarily due to the
476 usage of swine manure and the inputs of tea litter and roots in the topsoil (Miner et al., 2018).
477 Nevertheless, the contents of soil Ca^{2+} and Mg^{2+} showed an opposite trend as the soil depth
478 increased (Figures 5 and 6), because soil Ca^{2+} and Mg^{2+} were easy to move from topsoil to
479 subsoil in the manner of leaching (Hansen et al., 2017).

480 4.5. Stoichiometric ratios of soil alkaline-earth metals and micronutrients

481 Tea plantation age exerted a significant influence on the Ca/Mg and Fe/Mn ratios at the
482 0-40 cm soil depth, rather than the 40-60 cm soil depth (Tables S4 and S5). To be specific, a
483 significant decline in the Ca/Mg ratio was found at the 0-40 cm soil depth over time. From 8 to
484 43 years of tea planting, the contents of Ca^{2+} and Mg^{2+} at the 0-40 cm soil depth decreased by
485 10%-38% and 5%-24%, respectively, revealing that the role of tea plantation age in the content
486 of soil Ca^{2+} was greater than that of soil Mg^{2+} (Figures 5 and 6). Lu et al. (2014) suggested that
487 the selective losses of soil exchangeable alkaline-earth metals ($\text{Ca}^{2+} > \text{Mg}^{2+}$) could lead to the
488 disequilibrium of soil metal ions in forest ecosystems. Similarly, in this study, the preferential
489 loss of soil Ca^{2+} relative to Mg^{2+} was the prime reason for the significant decline in the soil

490 Ca/Mg ratio in the tea-planting course. The depletion of soil exchangeable alkaline-earth metals
491 (especially Ca^{2+}) could generate the decrease in soil buffering capacity and soil acidification
492 (Hansen et al., 2017). Thus, the Ca/Mg ratio at the 0-40 cm soil depth was positively related ($p \leq$
493 0.05) to soil pH across the 4 tea plantation ages (Figure S1). Soil acidification accelerated the
494 mineralization and desorption of soil available micronutrients from soil OM and minerals (Wang
495 et al., 2017a), which was conducive to the significant increases in Fe^{2+} and Mn^{2+} contents at the
496 0-40 cm soil depth, especially Fe^{2+} (Figures 7 and 8). In a chronological sequence of tea
497 plantations, the negative relationship ($p \leq 0.05$) of soil Fe/Mn ratio with soil pH in different soil
498 depths indicated more cumulation of soil Fe^{2+} relative to Mn^{2+} over time (Figure S1).
499 Furthermore, during the process of tea plant uptake, the change of soil Fe/Mn ratio was also
500 triggered by the antagonistic relationship between soil Fe^{2+} and Mn^{2+} (Wang et al., 2017a). Tian
501 et al. (2016) discovered that soil acidification could reduce Fe^{2+} absorption and enhance Mn^{2+}
502 uptake by various plant species, causing the increase in soil Fe/Mn ratio and threatening plant
503 productivity.

504 **5. Conclusions**

505 To conclude, soil OC, TN, and TP contents as well as C/N, C/P, and N/P ratios decreased as
506 the soil depth increased. Moreover, soil Ca^{2+} and Mg^{2+} contents were lower in the topsoil than
507 the subsoil, whereas soil Fe^{2+} and Mn^{2+} contents showed an opposite trend, and no differences
508 were detected amongst different soil depths in soil Ca/Mg and Fe/Mn ratios. At the 0-40 cm soil
509 depth, continuous planting of tea was favorable to the increases in soil OC, TN, Fe^{2+} , and Mn^{2+}
510 contents, whereas soil Ca^{2+} and Mg^{2+} contents decreased over time, thus supporting our
511 hypotheses. Compared with other tea-planting regions in China, soil C/N ratio is higher in this
512 tea-planting region, whereas soil C/P and N/P ratios are much lower, suggesting that soil OC and
513 TN contents in this study were lower, especially TN. In the tea-planting course, the losses of soil
514 Ca^{2+} and Mg^{2+} , especially Ca^{2+} (as indicated by the decrease in soil Ca/Mg ratio), could lead to
515 the soil acidification. Meanwhile, soil acidification could reduce Fe^{2+} absorption and enhance

516 Mn²⁺ uptake by tea plants (as indicated by the increase in soil Fe/Mn ratio). In general, tea
517 plantation age could influence the variations in soil nutrient contents and stoichiometry, whereas
518 such effects were more obvious at the 0-40 cm soil depth in contrast to the 40-60 cm soil depth.

519 **Data availability**

520 The data supporting the discovered information here can be presented by the relevant author
521 based on reasonable requests.

522 **Author contribution**

523 S.W. and S.Y. designed the experiments; L.M. carried out the experiments; S.W. and L.M.
524 analyzed the experimental results; L.M., S.W. and S.Y. wrote and edited the manuscript.

525 **Competing interests**

526 The authors declare no conflict of interest.

527 **Acknowledgments**

528 This study was funded by the Natural Science Foundation of Guangxi (No.
529 2019GXNSFBA185012), the Innovation Project of Guangxi Graduate Education (No.
530 YCSW2022114), and the Cooperation Project of Dagui Mountain Forest Farm (No. 202200100).
531 The authors would like to express their gratitude to the editor and innominate referees for giving
532 conducive advises and optimizing this article.

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778

Table 1 Three-way ANOVA regarding the effects of soil depth, tea plantation age, aggregate size, and their interactions on the physico-chemical properties of soil aggregates, and Two-way ANOVA regarding the effects of soil depth, tea plantation age, and their interactions on the physico-chemical properties of bulk soil.

Soil properties	Three-way ANOVA							Two-way ANOVA		
	S	T	A	S × T	S × A	T × A	S × T × A	S	T	S × T
Bulk density								*	*	*
Clay								NS	NS	NS
pH								NS	*	NS
MWD								*	*	*
Aggregate proportion	*	*	**	*	*	*	*			
Organic C	**	**	**	**	**	**	**	**	**	**
Total N	**	**	**	**	**	**	**	**	**	**
Total P	*	NS	NS	NS	NS	NS	NS	*	NS	NS
Exchangeable Ca ²⁺	*	**	*	*	*	*	*	*	**	*
Exchangeable Mg ²⁺	*	*	*	*	*	*	*	*	*	*
Available Fe ²⁺	*	**	*	*	*	*	*	*	**	*
Available Mn ²⁺	*	*	*	*	*	*	*	*	*	*
C/N ratio	*	NS	*	NS	*	NS	NS	*	NS	NS
C/P ratio	*	*	*	*	*	*	*	*	*	*
N/P ratio	*	*	*	*	*	*	*	*	*	*
Ca/Mg ratio	NS	*	NS	NS	NS	NS	NS	NS	*	NS
Fe/Mn ratio	NS	*	NS	NS	NS	NS	NS	NS	*	NS

S: soil depth; T: tea plantation age; A: aggregate size. **, *, and NS indicate significant differences at $p < 0.01$, $p \leq 0.05$, and $p > 0.05$ (not significant), respectively.

Table 2 Effects of soil depth and tea plantation age on the bulk density, clay, and pH in bulk soil.

Soil depth	Tea plantation age	Bulk density (g cm ⁻³)	Clay (%)	pH
0-10 cm	8 years	1.28 ± 0.02 b	34.69 ± 3.21 a	4.57 ± 0.02 a
	17 years	1.20 ± 0.02 c	35.91 ± 2.77 a	4.49 ± 0.01 ab
	25 years	1.26 ± 0.01 bc	33.12 ± 2.46 a	4.31 ± 0.03 b
	43 years	1.31 ± 0.04 b	35.08 ± 2.41 a	4.15 ± 0.02 c
10-20 cm	8 years	1.30 ± 0.03 b	34.88 ± 2.08 a	4.55 ± 0.03 a
	17 years	1.22 ± 0.03 c	32.59 ± 3.02 a	4.50 ± 0.01 a
	25 years	1.30 ± 0.03 b	34.92 ± 3.67 a	4.33 ± 0.02 b
	43 years	1.29 ± 0.02 b	32.35 ± 2.68 a	4.17 ± 0.02 c
20-40 cm	8 years	1.32 ± 0.04 ab	35.26 ± 1.45 a	4.60 ± 0.04 a
	17 years	1.31 ± 0.01 b	34.57 ± 4.12 a	4.53 ± 0.02 a
	25 years	1.34 ± 0.01 ab	34.51 ± 3.21 a	4.34 ± 0.04 b
	43 years	1.33 ± 0.04 ab	34.29 ± 3.54 a	4.19 ± 0.03 c
40-60 cm	8 years	1.36 ± 0.01 a	34.78 ± 3.66 a	4.58 ± 0.02 a
	17 years	1.37 ± 0.02 a	36.89 ± 2.98 a	4.54 ± 0.03 a
	25 years	1.39 ± 0.02 a	33.68 ± 1.91 a	4.32 ± 0.01 b
	43 years	1.38 ± 0.03 a	35.81 ± 3.69 a	4.21 ± 0.01 bc

Data represent the mean of 5 replicates ± standard deviations. Means in the same column with the same lower case letter are not significantly different ($p > 0.05$) among different soil depths and tea plantation ages.

Table 3 Effects of soil depth and tea plantation age on the aggregate stability and composition.

Soil depth	Tea plantation age	MWD (mm)	Aggregate composition (%)			
			> 2 mm	1-2 mm	0.25-1 mm	< 0.25 mm
0-10 cm	8 years	1.88 ± 0.03 b	44.26 ± 3.24 bA	16.23 ± 2.45 abC	8.46 ± 1.37 abD	31.05 ± 5.78 bcB
	17 years	2.20 ± 0.04 a	53.18 ± 2.78 aA	18.02 ± 1.63 aB	6.69 ± 0.98 bC	22.11 ± 4.01 cB
	25 years	1.78 ± 0.01 b	40.29 ± 4.01 bA	17.97 ± 2.03 aC	8.81 ± 0.88 abD	32.93 ± 3.58 bcB
	43 years	1.53 ± 0.03 c	32.60 ± 3.61 cB	19.61 ± 2.04 aC	7.64 ± 1.57 bD	40.15 ± 4.27 abA
10-20 cm	8 years	1.62 ± 0.02 c	37.31 ± 2.47 cA	13.58 ± 1.56 bB	9.24 ± 2.04 abC	39.87 ± 2.69 abA
	17 years	1.82 ± 0.04 b	43.02 ± 2.69 bA	14.31 ± 1.38 abC	8.87 ± 1.14 abD	33.80 ± 4.58 bB
	25 years	1.56 ± 0.03 c	34.87 ± 1.45 cB	15.03 ± 2.47 abC	9.36 ± 1.09 abD	40.74 ± 3.94 abA
	43 years	1.34 ± 0.02 d	29.24 ± 3.28 dB	13.97 ± 1.65 bC	7.28 ± 0.82 bD	49.51 ± 2.56 aA
20-40 cm	8 years	1.43 ± 0.01 cd	31.25 ± 1.68 cdB	15.47 ± 2.49 abC	7.62 ± 0.47 bD	45.66 ± 4.77 aA
	17 years	1.48 ± 0.03 cd	32.08 ± 3.60 cdB	16.89 ± 2.51 abC	8.91 ± 2.14 abD	42.12 ± 2.05 abA
	25 years	1.39 ± 0.02 d	30.72 ± 3.25 dB	14.23 ± 0.58 abC	6.81 ± 1.36 bD	48.24 ± 3.59 aA
	43 years	1.48 ± 0.03 cd	32.49 ± 2.98 cdB	15.40 ± 2.11 abC	9.05 ± 0.91 abD	43.06 ± 4.32 aA
40-60 cm	8 years	1.30 ± 0.01 d	28.48 ± 2.57 dB	12.02 ± 3.08 bC	10.05 ± 0.58 aC	49.45 ± 3.68 aA
	17 years	1.36 ± 0.02 d	29.68 ± 2.61 dB	13.78 ± 1.14 bC	9.47 ± 1.03 abC	47.07 ± 3.47 aA
	25 years	1.36 ± 0.01 d	30.09 ± 1.47 dB	11.98 ± 0.98 bC	10.64 ± 0.45 aC	47.29 ± 4.01 aA
	43 years	1.34 ± 0.03 d	28.42 ± 3.02 dB	14.33 ± 1.57 abC	12.45 ± 2.13 aC	44.80 ± 2.99 aA

Data represent the mean of 5 replicates ± standard deviations. Means in the same column with the same lower case letter are not significantly different ($p > 0.05$) among different soil depths and tea plantation ages. Means in the same row with the same capital letter are not significantly different ($p > 0.05$) among different sized aggregates.

Figure 1 Location of the experiment site. Tea plantations were cultured with the same tea variety with different planting ages (8, 17, 25, and 43 years), and were located at the same unit associated with geomorphological status. Each of the 4 tea plantation age groups was replicated in 5 locations for a total of 20 experimental units.

Figure 2 Effects of soil depth and tea plantation age on the organic C content in bulk soil and different sized aggregates. Data represent the mean of 5 replicates and error bars represent the standard deviations. Means with the same lower case letter are not significantly different ($p > 0.05$) among different soil depths and tea plantation ages. Means with the same capital letter are not significantly different ($p > 0.05$) among different sized aggregates.

Figure 3 Effects of soil depth and tea plantation age on the total N content in bulk soil and different sized aggregates. Data represent the mean of 5 replicates and error bars represent the standard deviations. Means with the same lower case letter are not significantly different ($p > 0.05$) among different soil depths and tea plantation ages. Means with the same capital letter are not significantly different ($p > 0.05$) among different sized aggregates.

Figure 4 Effects of soil depth and tea plantation age on the total P content in bulk soil and different sized aggregates. Data represent the mean of 5 replicates and error bars represent the standard deviations. Means with the same lower case letter are not significantly different ($p > 0.05$) among different soil depths and tea plantation ages. Means with the same capital letter are not significantly different ($p > 0.05$) among different sized aggregates.

Figure 5 Effects of soil depth and tea plantation age on the exchangeable Ca^{2+} content in bulk soil and different sized aggregates. Data represent the mean of 5 replicates and error bars represent the standard deviations. Means with the same lower case letter are not significantly different ($p > 0.05$) among different soil depths and tea plantation ages. Means with the same capital letter are not significantly different ($p > 0.05$) among different sized aggregates.

Figure 6 Effects of soil depth and tea plantation age on the exchangeable Mg^{2+} content in bulk soil and different sized aggregates. Data represent the mean of 5 replicates and error bars represent the standard deviations. Means with the same lower case letter are not significantly different ($p > 0.05$) among different soil depths and tea plantation ages. Means with the same capital letter are not significantly different ($p > 0.05$) among different sized aggregates.

Figure 7 Effects of soil depth and tea plantation age on the available Fe^{2+} content in bulk soil and different sized aggregates. Data represent the mean of 5 replicates and error bars represent the standard deviations. Means with the same lower case letter are not significantly different ($p > 0.05$) among different soil depths and tea plantation ages. Means with the same capital letter are not significantly different ($p > 0.05$) among different sized aggregates.

Figure 8 Effects of soil depth and tea plantation age on the available Mn^{2+} content in bulk soil and different sized aggregates. Data represent the mean of 5 replicates and error bars represent the standard deviations. Means with the same lower case letter are not significantly different ($p > 0.05$) among different soil depths and tea plantation ages. Means with the same capital letter are not significantly different ($p > 0.05$) among different sized aggregates.

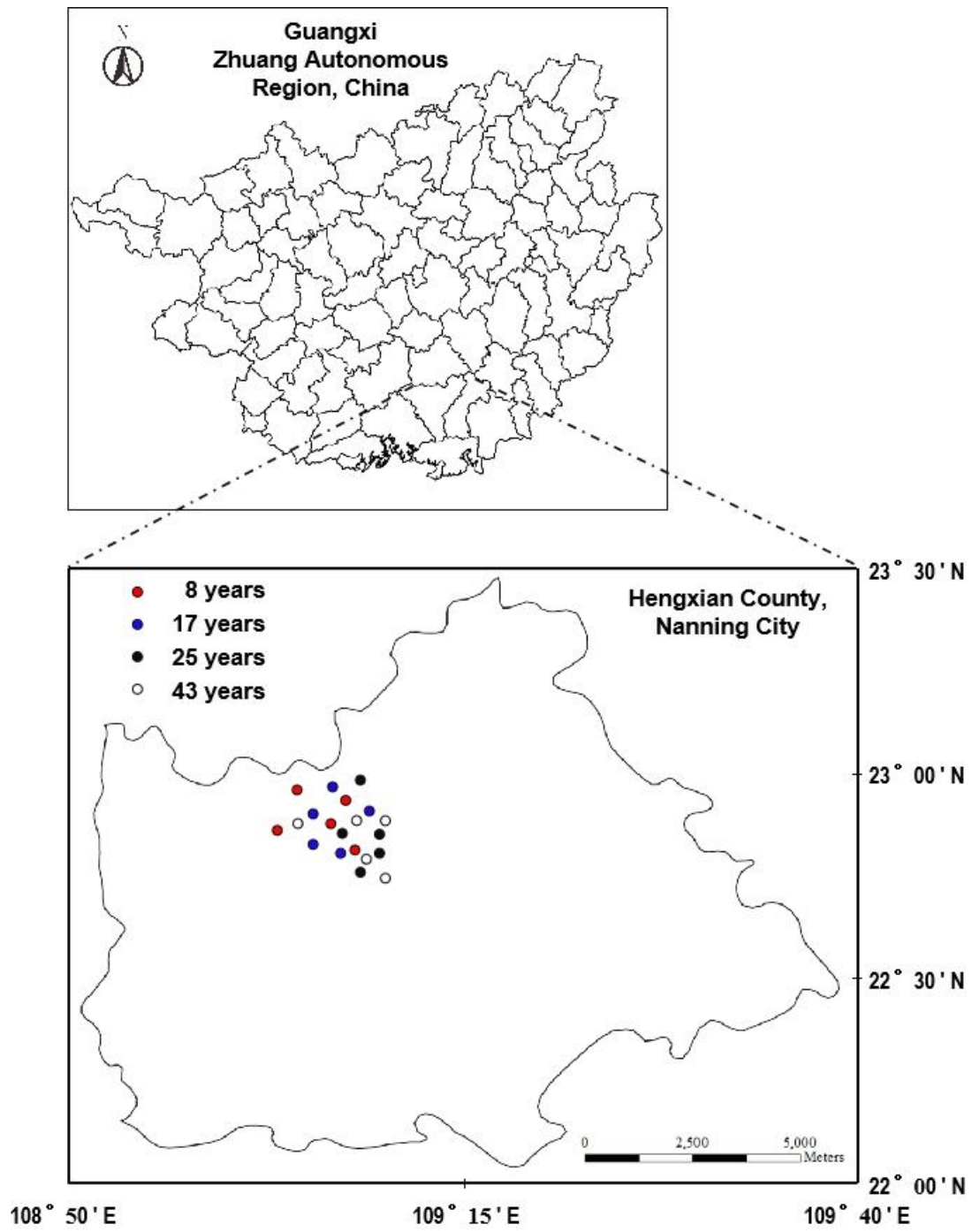


Figure 1

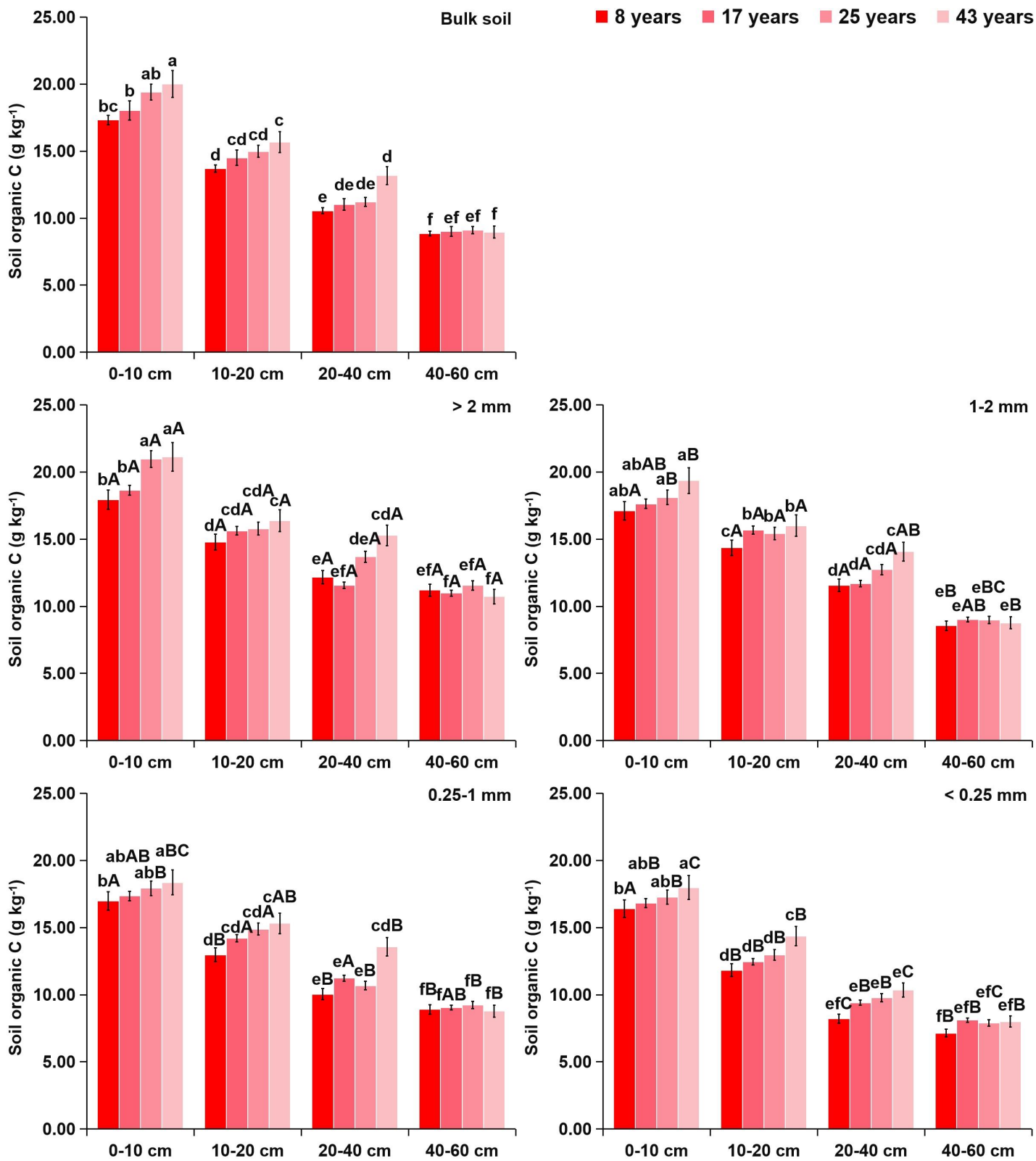


Figure 2

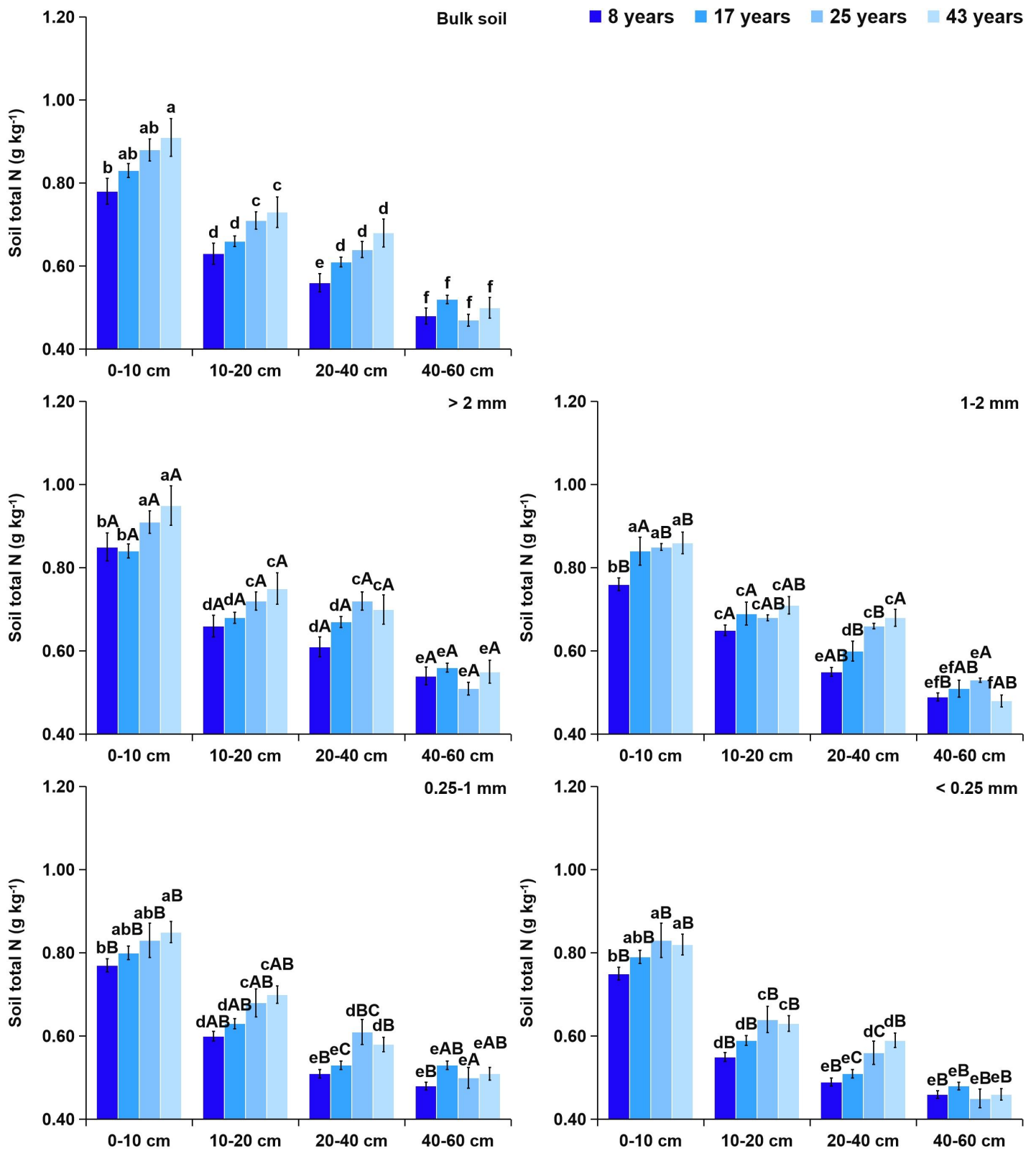


Figure 3

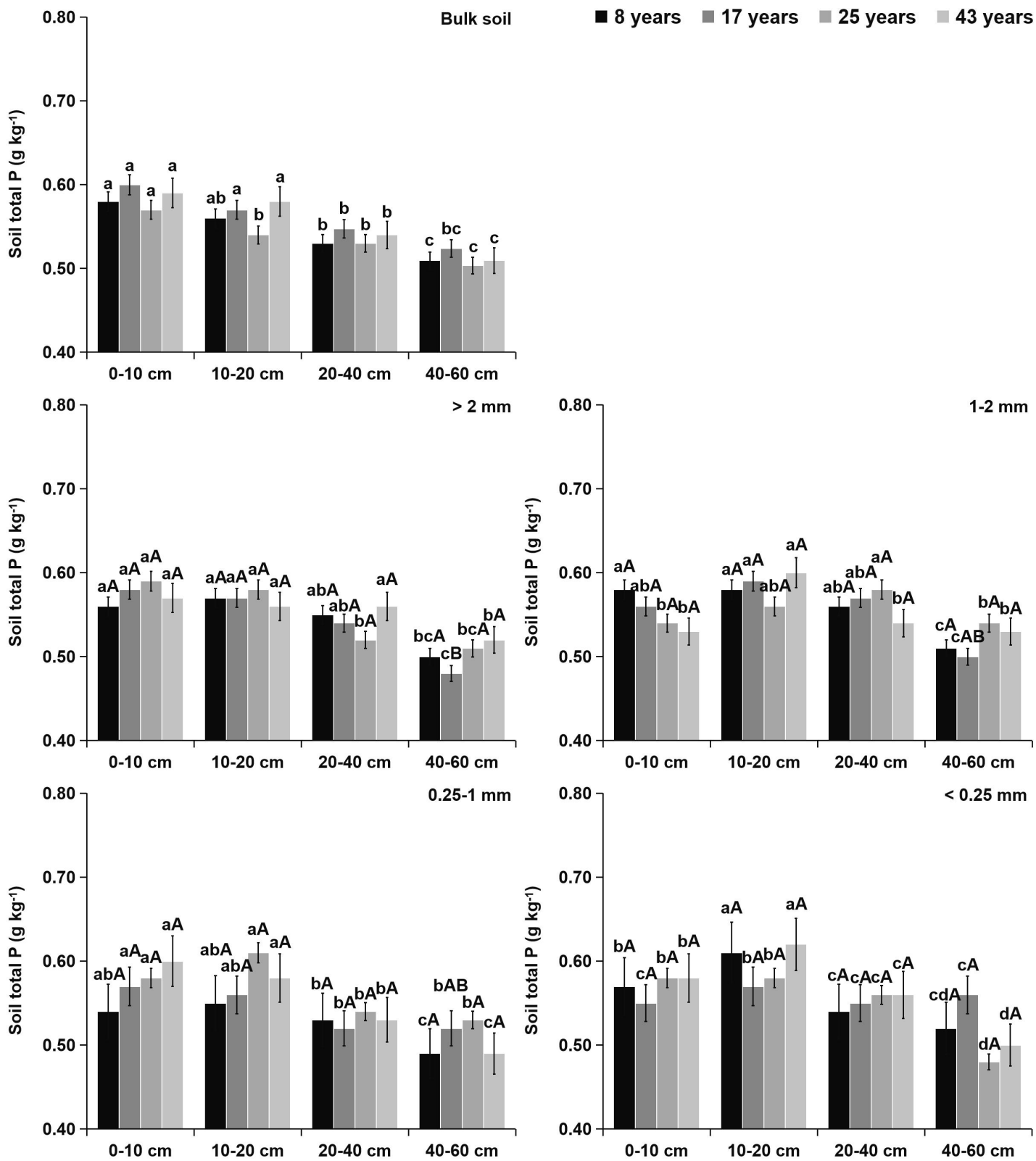


Figure 4

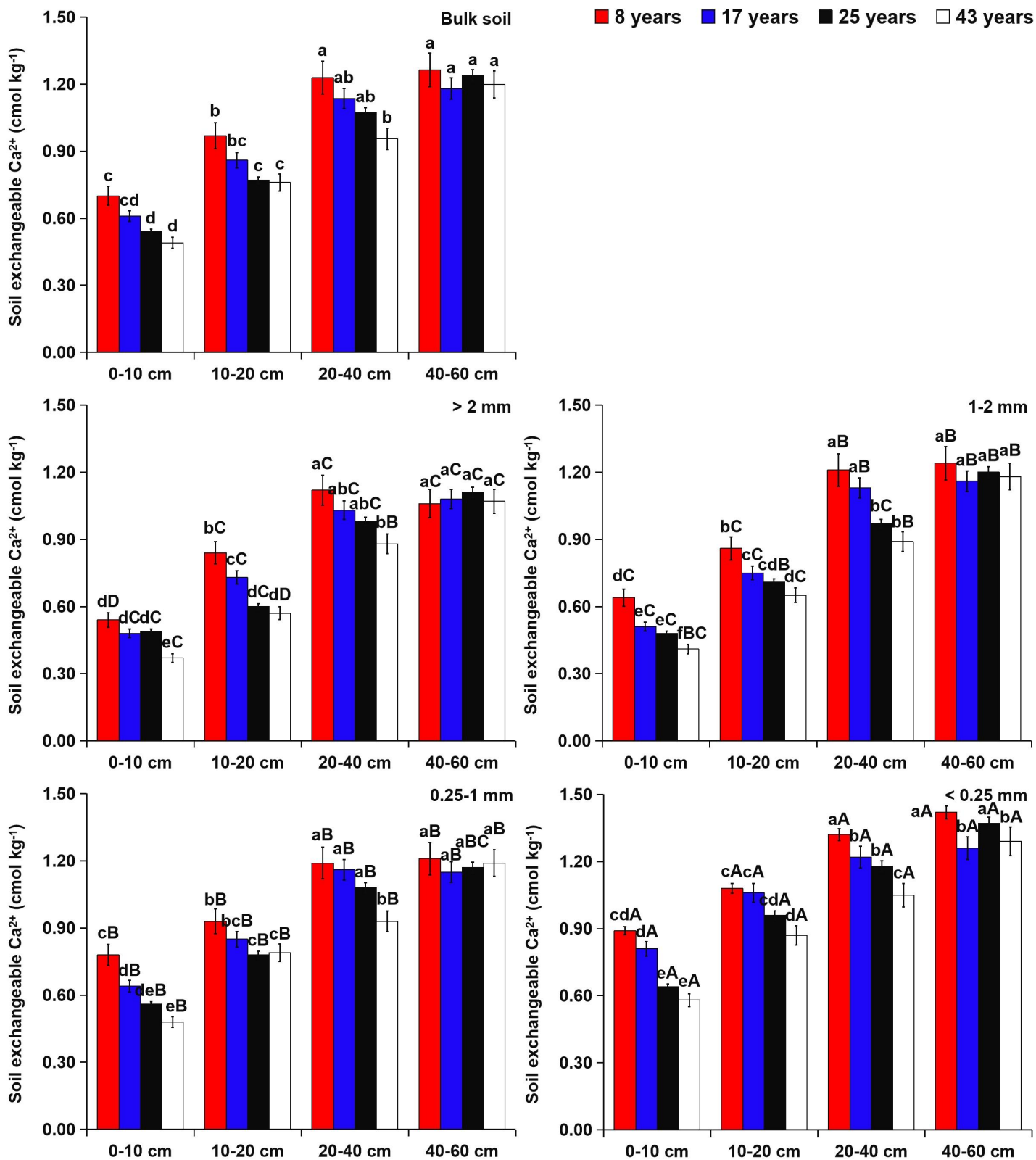


Figure 5

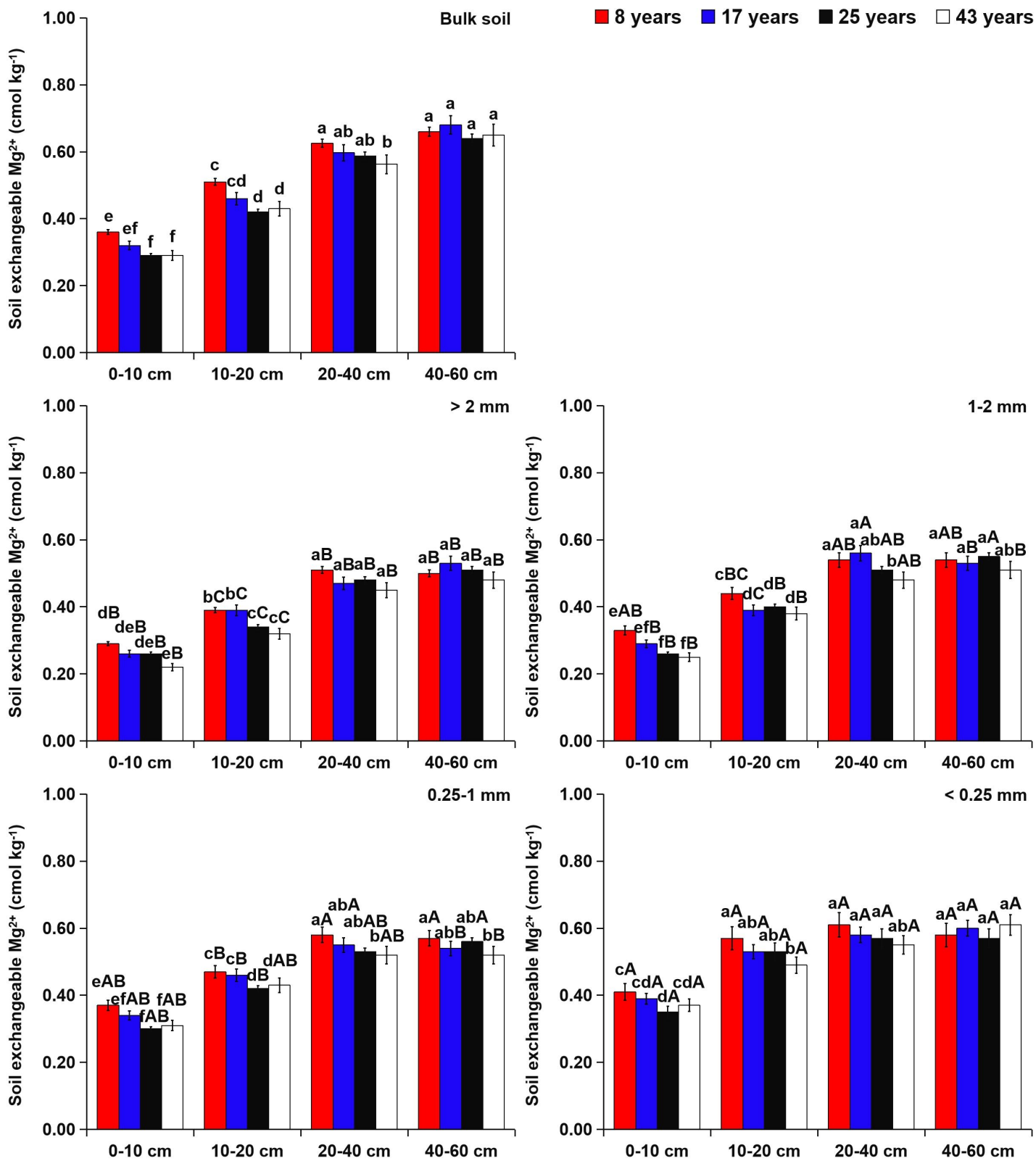


Figure 6

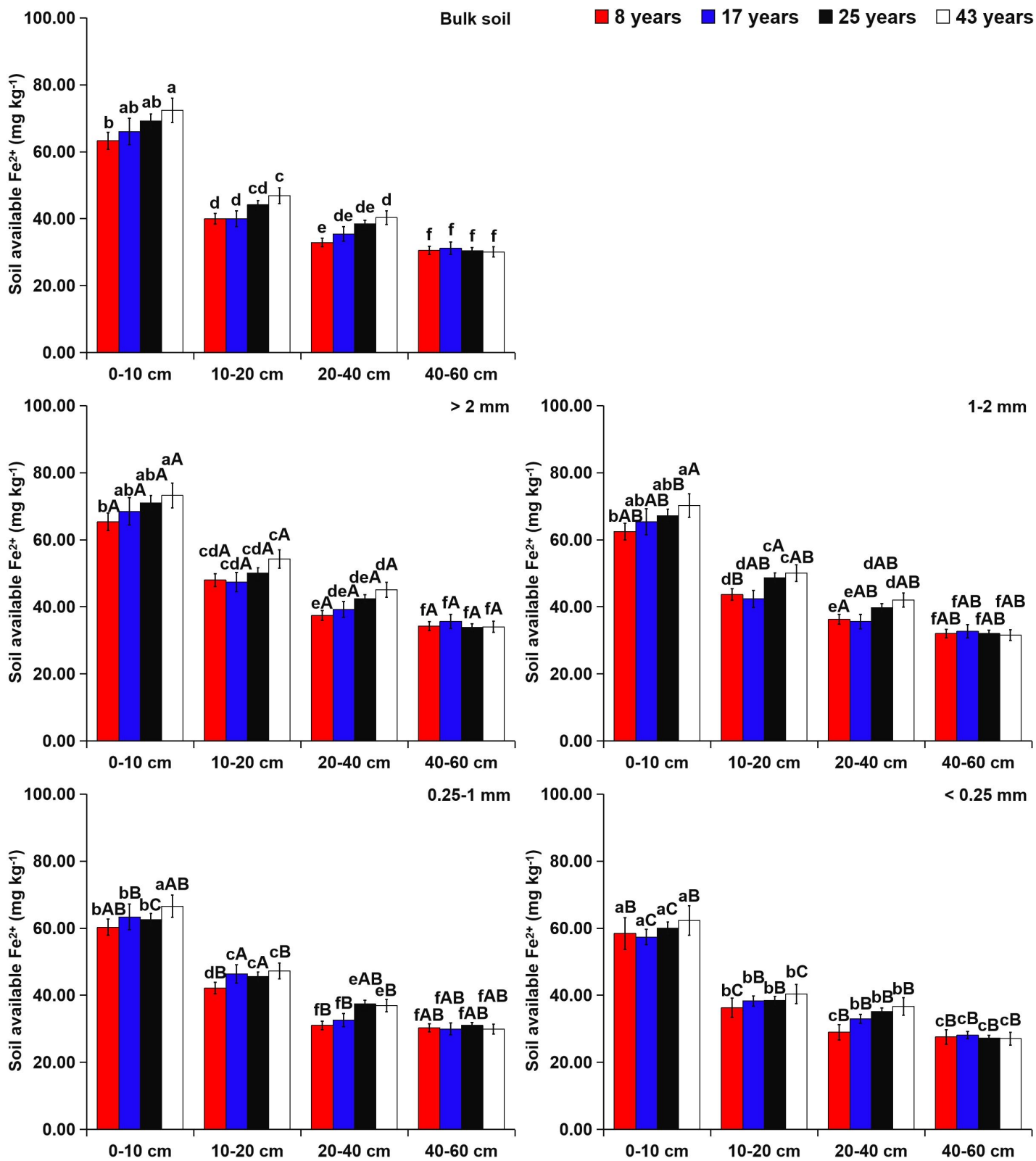


Figure 7

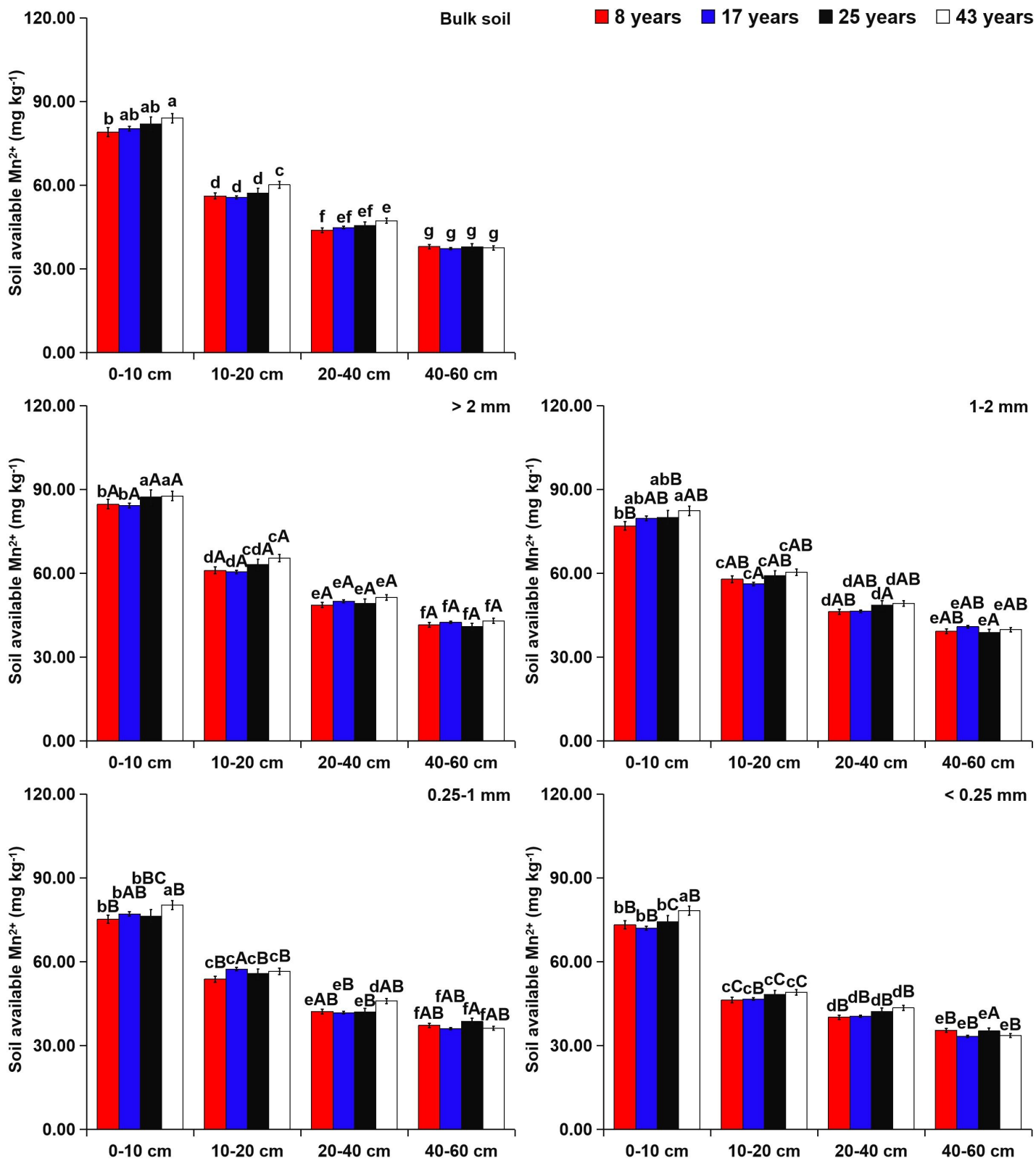


Figure 8