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Anthropic pedogenesis of purple rock fragments in Sichuan Basin, China

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Abstract

Considerable amounts of rock fragments are found in many "Purple soils" developed from purple rocks in the Sichuan basin of southwestern China. We describe the effects of anthropic pedogenetic processes on purple rock fragments associated with soil amelioration by determining changes in rock fragment size distribution, transformation of P and K of purple rocks into soils, and the complexing of purple rock particles (soil mineral particles) with organic matter during anthropic pedogenesis of "Purple soils" in Sichuan basin of southwestern China. The pedogenetic capacity of rock fragments can be expressed by the content of <2.0 mm particles as weathered products of rock fragment disintegration. The pedogenetic capacity of the purple rocks studied ranges from 0.3% to 6.2% under natural conditions. The rates of P and K transformed from purple rocks are closely associated with the pedogenetic capacity of rock fragments(r = 0.891**; 0.961**, n = 16). Digging (simulated by sieving) and crop planting facilitate pedogenesis of purple rock fragments and their mineral nutrient transformations. The soil mineral particles preserve 18%–36% of the organic carbon added as corn straw. The organic carbon is complexed after corn straw is mixed with <1.0 mm soil mineral particles for 1 year. The improvement of newly reclaimed purple soils is enhanced by the complexing effect of organic substances with purple rock particles. The pedogenesis of purple rock in Sichaun basin can be accelerated by anthropic activity, such as tillage, crop planting, fertilization, and land reclamation.

Keywords: Pedogensis; Rock fragment; Complexing of organo-mineral; Mineral nutrient; Purple soil

1. Introduction

Each year, about 75 billion tons of soils are eroded from the world's terrestrial ecosystems. Most agricultural land in the world is losing soil at rates ranging from 13 to 40 tons ha^{-1} year^{-1}. As soil is formed very slowly, this means that soil is being lost 13–40 times faster than an estimated rate of renewal (David and Nadia, 1998). The serious soil and water loss from sloping lands reduces soil depth and nutrient supply, as well as crop yield (David and Nadia, 1998; Napier et al., 2000; Shui et al., 2003; Huang et al., 2003). Soil and water loss from sloping land is a tremendous threat to the sustainable development of agriculture in mountainous and hilly regions (Yu et al., 2002; Yang et al., 2002).

Rock fragments refer to all mineral particles >5 mm in diameter according to Nyssen et al. (2002) or mineral particles larger than 2 mm according to Van Wesemael et al. (1995a,b). Lots of rock fragments exist in soils because of serious soil erosion or to new reclamation of Regosol lithic materials. The presence of rock fragments modifies soil physical and chemical properties, as well as agronomical characteristics like yield (Poesen and Lavee, 1994; Poesen et al., 1999; Isabelle et al., 2003). Particular attention has been paid to the density of soils containing rock fragments, the spatial distribution and movement of rock fragments in top soils, the effects of rock fragments on some key hydrological processes, thermal properties of top soils, physical soil degradation, soil erosion and soil productivity (Poesen and Lavee, 1994). Soil properties such as porosity, effective cation exchange capacity, total N, and organic C content are often functions of the degree of weathering of the rock fragments (Corti et al., 1998).

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When rock fragments are neglected, the available water content can be greatly overestimated (Isabelle et al., 2003). Soil chemical composition is commonly related to underlying bedrock including the predominance of magnesium over calcium and the relatively high concentrations of nickel (Kataeva et al., 2004). Holloway et al. (2001) used fresh rock and weathered material to simulate nitrogen release from rock and soil under field conditions and confirmed that geologic nitrogen, when present, may be a large and reactive pool that may contribute as a non-point source of nitrate contamination to surface and ground waters. But due attention has scarcely been paid to pedogenetic research (Cousin et al., 2003; Certini et al., 2004).

Pedogenesis has mainly been concerned with erosion, sedimentation, soil formation and weathering (Van Wesemael et al., 1995a,b; Muggler and Buurman, 2000), mineral weathering, oxidation, illuviation of clay (Lee et al., 2004), and the influence of soil-forming processes on the composition of organic carbon in subsoils (Rumpel et al., 2002). But few pedogenesis studies have been about the effects of rock fragments in soil amelioration or soil fertilization.

Purple soils, classified as Regosols in FAO Taxonomy or Entisols in USDA Taxonomy (He, 2003), are formed from purple rocks or their weathering products, and are mainly distributed in the Sichuan basin of southwestern China. Purple rocks are characterized by fast physical weathering, and are broken up by anthropic activities into rock fragments or gravels, in which crops are directly planted. The purple rocks are generally regarded as a nutrient reservoir because of nutrient enrichment especially phosphorus and potassium (He, 2003). Nutrient's released in the weathering process of purple rock fragments is a major source of nutrients in the Purple soils (Zhu et al., 1999). The purple rock fragments can be changed into fertile soils by reasonable planting and fertilization practices. New land resources have become scarce in the Sichuan basin as a result of high population, severe soil erosion and unreasonable land use. It is very important for agriculture in the Sichuan basin to study mechanisms to accelerate the transformation of purple rock fragments into soil materials.

Our objective was to examine effects of anthropic pedogenesis of purple rock fragments on soil amelioration by determining changes in rock fragment size distribution, transformation of P and K in purple rocks into soil nutrients, and the complexing of purple rock particles (soil mineral particles) with organic matter during pedogenesis.

2. Materials and methods

2.1. Purple rocks

The Sichuan basin, located in southwestern China, has an area of 165,000 km^2 with elevations from 200–700 m high, and is subtropical with an annual mean temperature of 14–19 °C and annual rainfall of 1000–1400 mm. The Sichuan basin is also known as the "Red Basin" because it is mainly covered by red or purple rock series of the Trias–Cretaceous system, from which the purple soils are developed and formed.

The fresh purple rocks studied include: dark purple shale of Feixiangguan Formation of the Trias system (T_1f); brown purple sandy mudstone of Penglai Formation (J_3p); red brown purple mudstone of Suining Formation (J_3s); and gray brown purple sandy mudstone of Shaximiao Formation (J_2s) of the Jurassic system. Some physical and chemical properties of these purple rocks are given in Table 1.

2.2. Pedogenetic capacity

5 kg of 50–100 mm fresh purple rock gravels were placed in pots, 20 cm in diameter and 25 cm in height, with small holes at the bottom. Dishes under the pots collected the leached solution. Treatments were as follows. The weathering products of purple rock gravels were sieved to >10 mm, 10–7 mm, 7–5 mm, 5–3 mm, 3–2 mm, 2–1 mm, and <1 mm particle sizes under natural conditions (D_0), sieving after 6 months (to represent digging once yearly) (D_1), and sieving after 3 and 6 months (digging twice yearly) (D_2). The sieving process is used to simulate digging of a newly reclaimed soil: bringing the rock fragments or gravels to the soil surface to accelerate weathering of rock gravels or soil formation processes. The <2 mm particles in weathered products are referred to as soil particles. After sieving, the <2 mm soil particles were used to determine soil properties, and the rock gravels remained to continue weathering in the pots. The experiment was carried out from October 2001 to October 2002.

Table 1
Physical and chemical properties of purple rocks studied

Formation	Sampling site	pH	Total P (g kg^{-1})	Total K (g kg^{-1})	Density (Mg m^{-3})	Bulk density (Mg m^{-3})	Porosity (%)
T_1f	Beibei, Chongqing	7.94	0.500	15.24	2.76	2.52	8.7
J_2s	Beibei, Chongqing	7.20	0.868	23.31	2.72	2.51	7.7
J_3s	Tongnan, Chongqing	8.15	0.522	16.39	2.76	2.51	9.0
J_3p	Tongnan, Chongqing	8.08	0.663	17.67	2.77	2.53	8.7

The pedogenetic capacity of purple rock fragments is estimated by the content of <2 mm particles (soil fine particles) as weathered products of purple rock fragments.

During the experimental stage, solutions leached from the pots were collected to determine their P and K content. The transformation capacities of P and K from the rocks into soil during pedogenetic processes was estimated by the total quantity of P and K in the leachates and in the soil fraction of weathered products.

2.3. Effect of crop planting on pedogenesis

5 kg of 5–10 mm purple rock fragments were placed in pots in the field, and wheat was planted with 0(C_0), 10(C_1), 20(C_2), and 30(C_3) individual plants per pot, and then sorghum are planted with 0, 3, 6, and 9 individual plants per pot, respectively.

The grain, stems and leaves were harvested after ripening. The biomass of wheat and sorghum is reported as dry-weight. The release capacities of P and K under crop planting were estimated by the total quantity of P and K in plants, soils and leached solutions.

2.4. Complexing of purple rock particles with organic matter

Experiment in the laboratory: 500 g of <2 mm fresh rock particles was mixed with corn straw (containing 51.3% C), glucose (40% C), and peat (37.5% C) according to rock particle:organic carbon ratio of 25:1, and were put in saltmouthed bottles. The C:N = 25:1 in the mixtures was regulated with urea. Water contents of the mixture were adjusted to 250 g kg^{-1}. After being well mixed, the saltmouthed bottles were placed in the greenhouse at a temperature of 25 °C for 1 year (from October 2001 to October 2002), and were sampled to determine the degree of complexing of organic substances with rock particles.

Experiment in the field: 500 g of <2 mm fresh rock particles were mixed with corn straw, glucose, and peat according to rock particle:organic carbon ratio of 25:1, and were put in nylon bags with 300 mesh. The C:N = 25:1 was regulated with urea. Then the bags were buried in the field at a 15 cm depth for 1 year (from October 2001 to October 2002), and were sampled to determine the degree of complexing of organic substances with rock particles.

2.5. Fractionation of soil organo-mineral complexes

The bulk soils were separated by ultrasonic method, and isolated with 2.0 Mg m^{-3} density of HgI_2–KI solution into light fraction (organic carbon) and heavy fraction (organic carbon). The organic carbon was determined with a $K_2Cr_2O_7$ volumetric method (Xiong, 1985).

The soil particle size distribution, and the total P and K in soil, leached solutions, and plants were measured according to the ISSAS methods (1978). Soil pH was measured with an acidometer.

3. Result and discussion

3.1. Pedogenetic capacity of purple rocks

3.1.1. Rock fragment size distributions

After 1 year pedogenesis of fresh purple rock fragments of 50–100 mm size under natural conditions, rock fragment size distributions of weathering products vary among four types of purple rocks (Table 1). The weathering products of the purple rocks of T_1f are mainly characterized by >10 mm rock fragments. The content of >5 mm rock fragments accounts for 977 g kg^{-1} of weathering products, of which >10 mm rock fragments were 887 g kg^{-1}. Actually, 50–100 mm fresh purple rock fragments of T_1f under natural conditions were only slightly broken up during 1 year pedogenesis, and most rock fragments of T_1f were unchanged. The pedogenesis of fresh rock fragments of J_3s and J_3p behaved like that of T_1f, and contents of >5 mm rock fragments were 887 and 837 g kg^{-1}, respectively. But, >5 mm rock fragments were only 483 g kg^{-1} of the weathering products of fresh J_2s rocks, and the content of 5–3 mm rock fragments was the highest of the rock fragment size distributions. The sequence of pedogenetic capacities of fresh purple rock fragments is J_2s > J_3s > J_3p > T_1f.

Large rock fragments are rapidly brought to the soil surface by kinetic sieving through tillage or digging, which maybe result in rock fragments accumulating on the soil surface and finer particles sedimentating within the soil (Nyssen et al., 2002). Table 2 shows that rock fragments added to the soil surface by sieving can accelerate physical weathering of rock fragments compared with those under natural conditions. The accelerating effect differs among various purple rocks. The content of >5 mm rock fragments in weathering products of purple rock of J_3p decrease from 837 to 530 g kg^{-1}, while the rock fragments of T_1f only change from 978 to 953 g kg^{-1}.

3.1.2. Pedogenetic capacity

As particles less than 2 mm in weathering products are referred to as soil particles, pedogenetic capacity of rock fragments can be expressed by the content of <2 mm particles. The pedogenetic capacity of these purple rocks ranged from 0.3% to 6.2% under natural conditions. This suggests that the capacities of purple rocks under natural conditions are much higher compared with other types of sedimentary rock, such as limestone, that often take 120–400 years to generate 1 cm of soil (Trudgill, 1985). The pedogenetic capacity of purple rocks varies among types of purple rocks as shown in Table 2. The pedogenetic capacity of rock fragments of J_2s is 20 times higher than that of T_1f. The differences among pedogenetic capacities of various rock fragments are associated with their

Table 2
Changes in fragment size distribution during pedogenetic process

Rock type	Sieving	Weathering time (month)	Fragment size distribution (mm, g kg^{-1})							>5 mm rock fragment (g kg^{-1})	Pedogenetic capacity (%)
			>10	10–7	7–5	5–3	3–2	2–1	<1		
T_1f	D_2	12	842.7	71.7	38.3	27.3	13.0	3.2	3.7	952.7	0.69
		6	860.2	69.5	30.2	24.7	9.6	2.8	3.0	959.9	0.58
		3	921.1	40.5	24.4	11.4	1.5	0.7	0.3	986.1	0.10
	D_1	12	861.5	73.3	30.8	25.5	4.3	2.2	2.5	965.5	0.47
		6	907.3	46.6	27.9	13.8	2.1	1.0	1.3	981.8	0.23
	D_0	12	887.0	68.7	21.9	16.8	2.7	1.3	1.7	977.5	0.30
J_2s	D_2	12	157.8	29.5	107.7	300.3	106.3	166.7	81.6	295.0	24.84
		6	231.9	52.6	148.3	322.4	105.2	86.1	53.5	432.8	13.96
		3	272.9	112.4	182.5	240.7	84.8	74.6	32.1	567.8	10.67
	D_1	12	217.0	28.3	82.4	339.7	123.5	149.7	59.4	327.7	20.91
		6	263.0	54.5	135.7	331.6	87.7	85.9	41.6	453.2	12.75
	D_0	12	286.0	76.4	120.6	389.2	65.9	37.7	24.2	483.0	6.19
J_3s	D_2	12	608.1	98.4	62.6	97.9	18.5	78.7	35.8	769.1	11.45
		6	722.4	99.8	58.2	50.5	17.0	36.7	15.4	880.4	5.21
		3	890.3	36.4	26.4	30.2	7.5	3.9	5.3	953.1	0.92
	D_1	12	705.5	88.1	51.2	82.2	10.4	46.0	16.6	844.8	6.26
		6	808.9	63.7	39.0	64.7	15.6	4.8	3.3	911.6	0.81
	D_0	12	777.5	65.3	44.1	73.2	19.7	9.1	11.1	886.9	2.02
J_3p	D_2	12	321.3	104.6	104.1	214.6	60.8	116.5	78.1	530.0	19.46
		6	659.4	96.2	112.1	65.0	29.3	25.1	12.9	867.7	3.80
		3	795.5	115.2	32.3	30.7	12.6	9.5	4.2	943.0	1.37
	D_1	12	543.6	106.8	72.1	114.8	36.8	92.4	33.5	722.5	12.59
		6	752.4	97.1	50.2	48.1	23.8	17.9	10.5	899.7	2.84
	D_0	12	693.3	86.7	57.2	83.1	27.9	28.9	22.9	837.2	5.18

D_0: no digging; D_1: digging once a year; D_2: digging twice yearly.

mineralogical composition and particle size distribution. The purple rocks of J_3p, J_3s, and J_2s formed from river alluvial under mild-humid conditions of Jurassic system, and their particle size distribution and mineralogical composition varied greatly. The purple rocks of T_1f had more homogeneous textures and mineralogy, and were deposited in continental margin shallow seas under torrid desiccation conditions (He, 2003).

There is a significant effect of kinetic sieving through tillage or digging on the pedogenetic capacity of purple rocks. After sieving twice yearly, the pedogenetic capacities of purple rocks of J_2s, J_3s, and J_3p were increased 4.0, 5.7, and 3.8 times compared with those under natural conditions, respectively. In particular, the pedogenetic capacity of J_2s rocks was 24.8%, which implies that it will take about 5 years to transform the purple rock fragments into soil particles.

After 1 year weathering under natural conditions, 9.4%–34.1% of 5–10 mm purple rock fragments changed into <5 mm rock particles (Table 3). Therefore, weathering capacity and pedogenetic capacity of 5–10 mm purple rock fragments are much higher than those of 50–100 mm fresh purple rock fragments because of higher rock fragment surface areas. The weathering capacity and pedogenetic capacity of 5–10 mm purple rock fragments of J_2s is much stronger than those in other rock types. 13.6% of 5–10 mm purple rock fragments was transformed into soil particles, and was more than 3 times higher than for T_1f rock fragments.

3.1.3. Crop planting

Crop planting can significantly accelerate weathering and pedogenesis of purple rock fragments (Table 3). Under high density (C_1) crop planting, 43.9% of 5–10 mm rock fragments of J_2s are broken up to <2 mm soil particles. It suggests that when purple rocks of J_2s are broken up to rock fragments of 5–10 mm, it maybe only take about 3 years for the fragments to be completely changed into soil particles. But transformation of purple rocks of T_1f into soil particles may take 15 years or longer.

There is a significant difference among biomass of various densities of crop planting. The weathering and

Table 3
Effect of crop planting on the pedogenetic capacities of purple rock

Rock type	Item	C_0	C_1	C_2	C_3
T_1f	>5 mm rock fragment (g kg^{-1})	904.4	891.5	875.6	583.7
	Pedogenetic capacity (%)	4.34	4.97	6.12	7.51
J_2s	>5 mm rock fragment (g kg^{-1})	659.4	581.9	349.5	216.6
	Pedogenetic capacity (%)	13.60	19.30	31.36	43.94
J_3s	>5 mm rock fragment (g kg^{-1})	787.7	694.6	502.2	311.3
	Pedogenetic capacity (%)	8.35	14.24	26.71	33.19
J_3p	>5 mm rock fragment (g kg^{-1})	737.6	616.4	381.8	291.8
	Pedogenetic capacity (%)	9.26	16.17	27.50	39.22

C_0: none of wheat plants per pot; C_1: 10 of wheat plants per pot; C_2: 20 of wheat plants per pot; C_3: 30 of wheat plants per pot.

pedogenesis of purple rock fragments is dependent upon biomass of crop biomass, especially the roots ($r=0.968$**, $n=12$). The rock fragment disintegration is enhanced by root growth and water and nutrient uptake, thus planting crops plays an important role in anthropic pedogenesis of purple rocks.

3.2. Transformation capacity of P and K during pedogenesis of purple rocks

3.2.1. Transformation capacity

When rock fragments are broken up into soil particles, mineral nutrients in rock fragments are also changed into soil nutrients. It is these transformations from rock fragments to soil that enables the soil to continually supply crops with mineral nutrients. The rates of P and K transformed from purple rocks are closely associated with pedogenetic capacity of rock fragments($r=0.891$**; 0.961**, $n=16$, respectively), indicating their dependence on the pedogenetic capacity of purple rocks. Like the pedogenetic capacity of purple rocks, the rates of P and K transformation differ widely as shown in Table 4. Rates of P and K transformations are lowest in the purple rock of T_1f, and highest in the purple rocks of J_2s. Rates of P and K transformed in the purple rocks of J_2s are 3.5 times and 4.8 times higher than those of T_1f, respectively. The sequence of rates of P and K transformed is $J_2s>J_3s>J_3p>T_1f$.

Sieving has a great influence on rates of P and K transformed in the rock fragments. The rates of P and K transformed from the rock fragments of J_2s are increased about 25% by sieving twice yearly compared with about 13% under natural conditions. P and K transformed in the rock fragments of T_1f also increased from about 0.3% and 1.2% under natural conditions to 3.8% and 2.8% by sieving twice yearly. P and K transformed in the rock fragments of J_3s and J_3p are increased 2.9 and 2.4, 5.7 and 4.4 times by sieving twice yearly compared with those under natural conditions, respectively. The effect of sieving on P and K transformation in the rock fragments is $T_1f>J_3p>J_3s>J_2s$, and $J_3p>T_1f$, $J_3s>J_2s$, respectively.

Of mineral nutrients transformed from rock fragments under natural conditions, some are retained in soil particles, and others are lost by leaching. The total quantities of mineral nutrients transformed vary in these purple rocks. The P and K transformed in purple rocks of T_1f mainly occur in the leachates, while P and K transformed in purple rocks of J_2s and J_3p are mostly retained in the soil particles. These differences are associated with pedogenetic capacities of the purple rocks. P transformed in purple rocks of J_3s mostly exists in the leached solution, while K is in the soil.

Under natural conditions, rates of P and K transformed from 5–10 mm purple rock fragments are higher than those from 50–100 mm purple rock fragments (compare Tables 4 and 5). The rate of P transformed in purple rock of T_1f is increased from 0.3% in 50–100 mm purple rock fragments to 6.8% in 5–10 mm purple rock fragments, and the rate of K from 1.2% in 50–100 mm purple rock fragments to 5.6% in 5–10 mm purple rock fragments. The rates of P transformed in 5–10 mm purple rock fragments of J_3s and J_3p are 1.24 and 2.17, 3.69 and 2.58 times higher than those in 50–100 mm purple rock fragments, respectively.

3.2.2. Crop planting

In the same way, crop planting can also facilitate the transformation of rock fragment mineral nutrients because of crop uptake of nutrients from rock fragments. The higher the density of crop planting, the higher the crop biomass, and the stronger the effect of crop planting on the transformation of rock fragment mineral nutrients. The rate of P and K transformed in 5–10 mm rock fragments of T_1f under high density (C_3) of crop planting is increased 2.15 times and 1.92 times compared with those under natural condition. It is very important that the rates of P transformation from the rock fragments of Jurassic system

Table 4
The transformation capacities of P and K during pedogenesis of purple rocks

Rocks	Treatment	P				K			
		Soil (mg kg^{-1})	Leached solution (mg kg^{-1})	Total P transformed (mg kg^{-1})	Rate (%)	Soil (mg kg^{-1})	Leached solution (mg kg^{-1})	Total K transformed (mg kg^{-1})	Rate (%)
T_1f	D_2	3.2	17.5	19.2	3.84	87.1	342.1	423.7	2.78
	D_1	2.1	12.8	13.4	2.68	65.6	337.5	397.6	2.60
	D_0	1.9	1.3	1.7	0.34	62.4	132.5	189.4	1.24
J_2s	D_2	195.6	23.2	217.3	25.03	5649.5	175.0	5819.0	24.96
	D_1	179.5	19.2	197.2	22.72	4833.5	144.6	4972.6	21.33
	D_0	109.2	8.1	115.8	13.34	3065.4	83.5	3143.4	13.48
J_3s	D_2	53.8	76.5	128.8	24.67	1476.3	207.3	1678.1	10.24
	D_1	28.7	43.9	71.1	13.62	985.4	158.3	1138.2	6.94
	D_0	21.2	25.4	45.1	8.64	653.8	58.4	706.7	4.31
J_3p	D_2	108.6	31.8	138.9	20.95	2638.2	450.2	3082.9	17.45
	D_1	83.7	21.2	103.4	15.59	1944.4	362.9	2301.8	13.03
	D_0	21.2	4.8	24.5	3.69	631.4	68.2	694.1	3.93

The contents of P and K in rainfall were 1.5 and 5.5 mg kg^{-1} rock fragments (expressed by rock fragment as base), separately.
Rate implied that the rate of P or K was transformed from rock fragments to soil.
D_0: no digging; D_1: digging once a year; D_2: digging twice yearly.

Table 5
Effect of crop planting on transformation capacities of P and K

Rocks	Treatment	Soil (mg kg^{-1})	Leached solution (mg kg^{-1})	Crop uptake (mg kg^{-1})	Total P transformed (mg kg^{-1})	Rate (%)
P						
T_1f	C_0	21.7	13.7	0	34.2	6.84
	C_1	24.8	15.4	12.3	51.3	10.26
	C_2	30.6	17.0	23.1	69.5	13.90
	C_3	37.5	19.2	30.4	85.9	17.18
J_2s	C_0	108.0	21.1	0	127.9	14.74
	C_1	161.5	26.1	14.7	201.1	23.17
	C_2	262.2	32.8	23.1	316.9	36.50
	C_3	351.4	35.0	30.4	415.6	47.88
J_3s	C_0	43.6	17.1	0	59.5	11.40
	C_1	68.3	19.7	10.7	97.5	18.68
	C_2	119.4	23.8	23.8	165.8	31.76
	C_3	157.2	26.7	31.4	214.1	41.01
J_3p	C_0	45.4	18.7	0	62.9	9.49
	C_1	87.2	25.5	13.6	125.1	18.87
	C_2	182.3	29.3	23.1	233.5	35.22
	C_3	240.0	33.9	30.4	303.1	45.72
K						
T_1f	C_0	661.3	188.7	0	845.7	5.55
	C_1	757.3	218.0	67.5	1038.5	6.81
	C_2	932.5	250.8	150.8	1329.8	8.73
	C_3	1144.3	287.2	198.4	1625.6	10.67
J_2s	C_0	3169.7	112.4	0	3277.8	14.06
	C_1	4498.2	162.9	67.0	4723.8	20.27
	C_2	7309.1	193.7	156.4	7654.9	32.84
	C_3	10241.1	250.4	205.8	10693.0	45.87
J_3s	C_0	1368.3	169.2	0	1533.2	9.35
	C_1	2333.5	187.4	60.9	2577.5	15.73
	C_2	4377.0	243.1	158.5	4774.3	29.13
	C_3	5438.8	275.3	208.5	5918.3	36.11
J_3p	C_0	1636.0	159.5	0	1791.2	10.14
	C_1	2856.9	169.3	68.1	3090.0	17.49
	C_2	4858.7	192.8	161.3	5208.5	29.48
	C_3	6929.4	227.7	243.3	7396.1	41.86

The contents of P and K in rainfall were 1.2 and 4.3 mg kg^{-1} rock fragments (expressed by rock fragment as base), separately.
C_0: none of wheat plants per pot; C_1: 10 of wheat plants per pot; C_2: 20 of wheat plants per pot; C_3: 30 of wheat plants per pot.

(J_2s, J_3s, and J_3p) are from 41% to 48% under high density (C_3) of crop planting. The rates of K transformed in the purple rock fragments of Jurassic system are slightly lower than those of P. The purple rocks widely distributed in Sichuan basin of southwestern China have strong capacity for mineral nutrient transformation from rock fragments to soils under heavy crop planting.

The distribution of mineral nutrients transformed from the purple rocks that occur in the soil, leachates, and crops greatly differ as a result of the rates of P and K transformations. 22.5%–30.0% of P and 17.7%–21.0% of K transformed from the purple rocks of T_1f are lost in solution, 43.6%–48.3% of P and 70.4%–72.9% of K remained in soil particles, and 24.0%–35.4% P and 6.5%–12.2% of K was absorbed by the crops. While P and K transformed from the purple rocks of J_2s, J_3s, and J_3p remain mostly in the soil particles, less is absorbed by crops. 8.4%–20.4% of P and 2.5%–7.2% of K is leached and lost in solution. Overall, there are not too many differences among quantities of P and K leached in solution and absorbed by crops in various purple rock fragments. The distinctions among quantities of P and K transformed from the purple rocks mainly rely on quantities of P and K kept in soil particles, i.e. soil mineral nutrient reservoir.

3.3. Interaction of purple rock particles with organic materials

A key process of pedogenesis is the complexing of soil particles (<2 mm particle) with organic carbon (Schulten and Leinweber, 2000). When organic substances are mixed with <1.0 mm soil mineral particles (or fresh rock fragments) under given moisture and temperature conditions, some of the organic carbon will be decomposed by microorganism or enzymes, and some will be kept in the soil complexed with mineral particles. It is shown in Table 6 that 8.0%–84.8% of organic carbon added remained in the soils, and 6.2%–36.0% of organic carbon added are

Table 6
Complexing of parent rock particles with organic materials

Rocks	Item	Laboratory				Field			
		Organic carbon (g kg^{-1})	Light fraction organic carbon (g kg^{-1})	Heavy fraction organic carbon (g kg^{-1})	Degree of organo-mineral complexing (%)	Organic carbon (g kg^{-1})	Light fraction organic carbon (g kg^{-1})	Heavy fraction organic carbon(g kg^{-1})	Degree of organo-mineral complexing (%)
T_1f	Straw	15.86	3.56	12.30	77.6	18.51	4.11	14.40	77.8
	Peat	31.31	25.2	6.11	19.5	31.75	24.98	6.77	21.3
	Glucose	3.64	0.05	3.59	98.6	4.06	1.12	2.94	72.4
J_2s	Straw	12.10	4.86	7.24	59.8	17.90	4.88	13.02	72.7
	Peat	31.75	25.17	6.58	20.7	32.64	25.86	6.78	20.8
	Glucose	3.18	0.88	2.83	89.0	3.77	1.04	2.73	72.4
J_3s	Straw	16.23	5.96	10.27	63.3	22.05	8.54	13.51	61.3
	Peat	32.56	23.84	6.72	20.6	33.76	25.99	7.77	23.0
	Glucose	2.67	0.19	2.48	92.9	3.57	0.87	2.70	75.6
J_3p	Straw	16.41	5.31	11.10	67.6	20.81	6.9	13.91	66.8
	Peat	33.12	25.67	7.45	22.5	33.92	26.83	7.09	20.9
	Glucose	3.42	0.62	2.80	81.8	3.89	1.13	2.76	71.0

complexed with the smaller soil mineral particles. The contents of organic carbon and heavy fraction organic carbon in mixtures placed in the field are somewhat higher than those in the laboratory due to higher decomposition of organic carbon under the relative high temperature in the laboratory. There are not many differences between degrees of organo-mineral complexing in mixtures of soil mineral particles with straw or peat under greenhouse and field conditions. But degrees of organo-mineral complexing in mixtures of soil mineral particles and glucose in the laboratory are higher than those in the field.

The quantities of organic carbon conserved by soil mineral particles are strongly dependent on the types of organic carbon added to the soil particles. The added glucose is easily decomposed and only a little remains with the soil mineral particles resulting in lower contents of organic carbon in these mixtures after 1 year. The peat is hardly utilized by microorganisms or enzymes and mostly remains in the soil resulting in low degrees of organo-mineral complexing in these soils. 18.1%–36.0% of organic carbon added as straw is complexed after the straw is mixed with <1.0 mm soil mineral particles for 1 year. This is much higher than those for peat or glucose.

4. Summary

Considerable amounts of rock fragments occur in the "Purple soils" developed from purple rocks in the Sichuan basin of southwestern China. Purple rock fragments are easily subjected to physical weathering, which could be accelerated by anthropic activities. Moreover, it is very important for agricultural production in Sichuan basin that purple rock fragments are changed into soil particles (<2.0 mm particle size). The pedogenetic capacity of rock fragments can be expressed as the content of <2.0 mm particles in the weathering products and ranges from 0.3% to 6.2% under natural conditions. Kinetic sieving through tillage or digging increases the pedogenetic capacity of purple rocks. After sieving twice yearly, the pedogenetic capacities of J_2s, J_3s, and J_3p purple rocks are increased 4.0, 5.7, and 3.8 times, respectively, compared to those under natural conditions. In particular, pedogenetic capacity of J_2s rock fragments was 24.8%, which implies that it will take about 5 years to transform the rock fragments into soil particles. When purple rocks of J_2s are broken to 5–10 mm sizes and densely rooted crops are planted, it maybe only take about 3 years to changed them into soil particles. The transformation of T_1f purple rock fragments into soil particle may take 15 years or longer.

The rates of P and K transformed in purple rocks are closely associated with pedogenetic capacity of rock fragments($r=0.891^{**}$; 0.961^{**}, $n=16$). Rate of P and K transformation are lowest in the T_1f rocks, and highest in those of J_2s. Under natural condition, rates of P and K transformed in 5–10 mm rock fragments are higher than those in 50–100 mm rock fragments. The quantities of P and K transformed mainly relate to the quantities of P and K that are retained in soil particles, i.e. soil mineral nutrient reservoir. Crop planting facilitates the transformation and fate of rock fragment mineral nutrients due to uptake of mineral nutrients by crops. The higher the density of crops planted, the higher the biomass, and the stronger the effect on the transformation of rock fragment nutrients.

The rate of P transformed in the rock fragments of the Jurassic system (J_2s, J_3s, and J_3p) ranged from 41% to 48% under high density (C_3) crop planting indicating a strong capacity of nutrient transformation from rock fragments to soils. The results show that the characteristics of high fertility in these purple soils are associated with nutrient dissolution and release during the pedogenetic process. The fact that nutrients released from fresh purple rocks also influence eutrophication of water bodies should not be underestimated.

About 8%–85% of organic carbon remained in the soils, of which 6%–36% was complexed organic carbon. 18%–36% of organic carbon added by corn straw was conserved in complexed form after mixing with <1.0 mm soil mineral particles for 1 year, and was much higher than from peat or glucose mixtures. The improvement of newly reclaimed purple soils can be accelerated by complexing organic substances with purple rock particles. After ameliorating with corn straw for 2 or 3 years, the content of the heavy fraction of organic carbon in the soils may approach the average content in local agricultural soils. Corn straw is the best conditioner in newly reclaimed soils or Regosols developed from purple rocks. Our research indicates that the pedogenesis of purple rocks in the Sichaun basin of southwestern China can be enhanced by anthropic activities, such as tillage, crop planting, straw application, and land reclamation.

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