Tea Q. 50 (4) 175-182, 1981. Printed in Sri Lanka.

MINERALOGY OF ACIDIC TEA SOILS AND SORPTION OF PHOSPHATE

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Marked increase in soil acidity associated with continuous use of $(NH_4)_2SO_4$ on tea soils has been observed in the Sylhet District of Bangladesh. The resultant low soil pH is accompanied with high exchangeable Al. These soils are dominated with kaolinite, mica and gibbsite. Electron micrographs showed some electron dense particles, the principal components of which were irregular platy with large number of tubular particles, probably halloysite. The clay particles were coated with iron oxides. Considerable amounts of small rod shaped discrete dense particles probably ferrihydrite were also present in the electron micrographs.

Good correlations were found between the P sorped and readily exchangeable Al (r=0.87) and acidified oxalate extractable Al (r=0.80). Adsorption of phosphate was much higher in the most acidic soils. The low productivity of large areas of infertile acid Tea plantation soils appears to be related to high aluminium, unavailable phosphate and low calcium. The possibility of rock phosphates as a suitable fertilizer to enhance tea productivity is discussed.

INTRODUCTION

It has been reported that many tea soils of Bangladesh are depleted of essential elements (Karim and Rahman, 1980). Considerable amounts of clay size fraction were also removed over years of tea cultivation (Hasan *et al*, 1974). The dominant forms of clay present in these soils are 1 : 1 type of clay and sesquioxides (Karim *et al*, 1978). Continuous tea cultivation on the same land area for a century together with heavy $(NH_4)_2SO_4$ fertilizer applications have affected the soil physicochemical properties leading to accelerated degradation. Decrease in soil pH has at the same time increased exchangeable Al in the surfaces of clay lattices (Karim and Rahman, 1980).

Considering the severity of this problem the Government of Bangladesh has initiated a rehabilitation programme in order to keep the tea industries viable. Such programme should also include a balanced fertility programme to ameliorate the acid infertility of these old tea soils where nutrient status and mineralogical composition have been seriously altered.

In very acidic soils many di-or trivalent cations like aluminium and iron limit plant growth and phosphate is likely to be "fixed" by insoluble alumino-ferrous complex. A considerable proportion of the phosphate adsorbed either by aluminium or iron in soils rapidly loses isotopic exchangeability (Tandon and Kurtz, 1968). It is hypothesized that the poor crop response to applied phosphatic fertilizer and other nutrients on such soils is associated with the induced high active and reserve acidity. A study was initiated to investigate the phosphate adsorption capacity of different old tea soils and to determine the relationship of phosphate sorption to soil pH and various forms of aluminium and iron present in soils.

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MATERIALS AND METHODS

Soil from old tea estates of Jagcherra, Baraoorah, Mazdehee, Amo, Nalua, Kapnapahar, Udnacherra, Rashidpur, Daragoon and Nurjahan were collected. Active fractions of iron and aluminium were extracted by acidified oxalate dissolution procedure (Tamm, 1922, Schwertmann, 1964) and exchangeable Al was removed by leaching with an unbuffered 1N KCl solution. Iron and aluminium was determined by atomic absorption spectrophotometer.

For electron microscopy drops of 0.02 per cent clay suspensions in distilled water were spotted on to carbon-coated collodion on copper grids and examined in a Seimens Em IA electron microscope at the Rothamsted Experimental Station in England.

1 gm of finely ground oven dried soil was shaken with 20 ml of 1 ppm phosphorus solution for different time intervals. At the end of the shaking period an aliquot of the suspension was filtered through a millipore filter (<0.22—μm) and the final phosphorus concentration was determined by the ascorbic acid method (Kuo and Lotse, 1972) and the absorbence was read at 810 mμ on a spectrophotometer. The amount of phosphorus sorbed was calculated as the difference between the initial and final concentrations.

RESULTS AND DISCUSSION

Soil pH

Tea is a moderately acid loving crop. The optimum range of soil pH is generally considered to be between 5.0 and 5.8. It has been noted that the old tea areas have reported decreased yields. Table 1 shows that 75 to 100 per cent of old tea soils have the pH ranging between 3.3 and 4.3. But soils of non tea area, developed on the same parent materials and top sequence have the pH ranging mostly between 4.4 and 5.0. The shifting of pH is pronounced in the old tea soils of Baraoorah, Jagcherra and Nalua. The decrease of pH was probably favoured by continuous use of $(NH_4)_2SO_4$. At such low pH most of the soils contain free Al^{3+} ion in solution, about 85 per cent of exchange sites are occupied by Al^{3+} ion (Karim and Rahman, 1980). Besides low tea yields and poor quality leaf are also frequently reported from these old tea soils. Their rehabilitation would require application of lime and restoration of physico-chemical and biological environment of soil to support an economically viable tea garden. Such rehabilitation is both costly and impracticable. Other alternatives to restore acid infertility must be explored.

TABLE 1 — *Percentage of soils of tea and non tea areas at different pH ranges.*

	Tea Area		*Non Tea Area*		
Name of Tea Estates	*pH ranges 3.3-4.3*	*pH ranges 4.4-5.1*	*pH ranges 3.3-4.3*	*pH ranges 4.4-5.0*	*pH ranges 5.1-5.8*
Baraoorah	100	0	0	100	
Jagcherra	100	0	40	60	
Mazdehee	85	15	0	100	
Amo	90	10	0	100	
Nalua	100	0	0	100	
Kapnapahar	75	25	0	57	43
Rashidpur	78	22	16	84	
Nurjahan	87	13	2	98	

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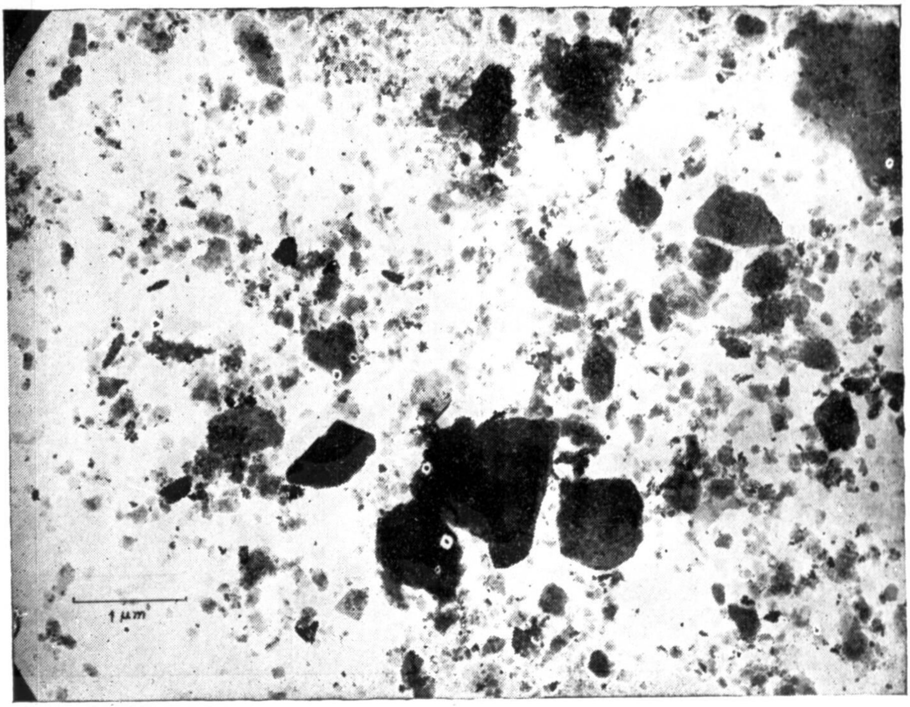

Fig. 1. — Electron micrograph of clay fraction of Rashidpur Tea Estate Soil (pH 3.8)

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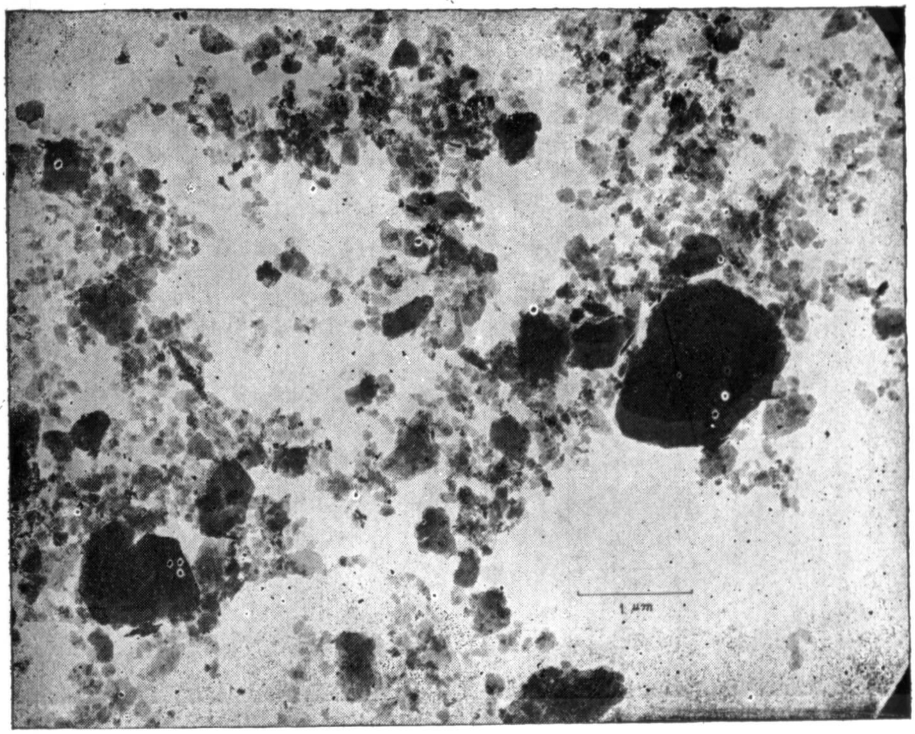

Fig. 2. — Electron micrograph of clay fraction of Nurjahan Tea Estate Soil (*pH 4.2*)

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Electron Micrograph

According to an earlier study by X-ray diffraction all these soils contain larger fraction of kaolinite, mica, trace of vermiculite and some gibbsite and goethite (Karim *et al*, 1978). To investigate more precisely the size and amounts of different minerals present in tea soils and their organisation within soil matrix the mineralogy of two degraded very strongly acidic soils was examined by electron microscope (Fig. 1 and 2). The electron micrographs of these old tea soils showed some electron dense particles, the principal components of which were irregular and platy with a large number of tubular particles; probably halloysite. Similar particles were observed in Noadda series, a laterite-latosol intergrade soil of Bangladesh (Habibullah *et al*, 1971). The halloysite tubes are probably formed by weathering of the vermiculite or mica particles (Roth *et al*, 1966). The clay particles were generally coated with iron oxides. The iron oxide in these soils contain larger proportion of silica (Karim *et al*, 1978). The association of increased silica content may result in the formation of ferrihydrite which gives broad X-ray powder pattern making it difficult to detect by X-ray diffraction in the presence of other soil minerals (Karim, 1980). A considerable amount of small discrete dense particles similar to ferrihydrite synthesised in recent years (Karim, 1977 and Schwertmann and Thalman, 1976) is shown in Fig. 1 & 2.

Sorption of Phosphate

Adsorption of Phosphate by three tea soils in shown Fig. 3. Maximum initial adsorption was found in Rashidpur soil with pH 3.8 and lowest adsorption was found in Kapnapahar soil having pH 4.5. The former soil initially (within 40 minutes) adsorped more than two times of phosphate than the latter which indicated that the lower pH was associated with higher phosphate sorption.

In these soils, Al^{3+} ion and acidified oxalate extracted fraction of aluminium oxide appeared to be primarily responsible for sorption of P (Fig. 4 & 5). A strong correlation ($r=0.87$) exists between the amount of exchangeable Al in the soil and the P adsorped (fig. 4). Depending on pH of the system trivalent aluminium hydrolyzes to monomeric and polymeric hydroxyaluminium complexes. The Al^{3+} ion is predominant below pH 4.7, $Al(OH)^{+}_{2}$ between pH 4.7 and 6.5, $Al(CH)_3^{\circ}$ between pH 6.5 and pH 8.0 and $Al(OH)_4^-$ above pH 8 (Marion *et al*, 1976). All the tea soils studied were below pH 4.7 and variable quantities of aluminium present in these soils are probably Al^{3+} ion.

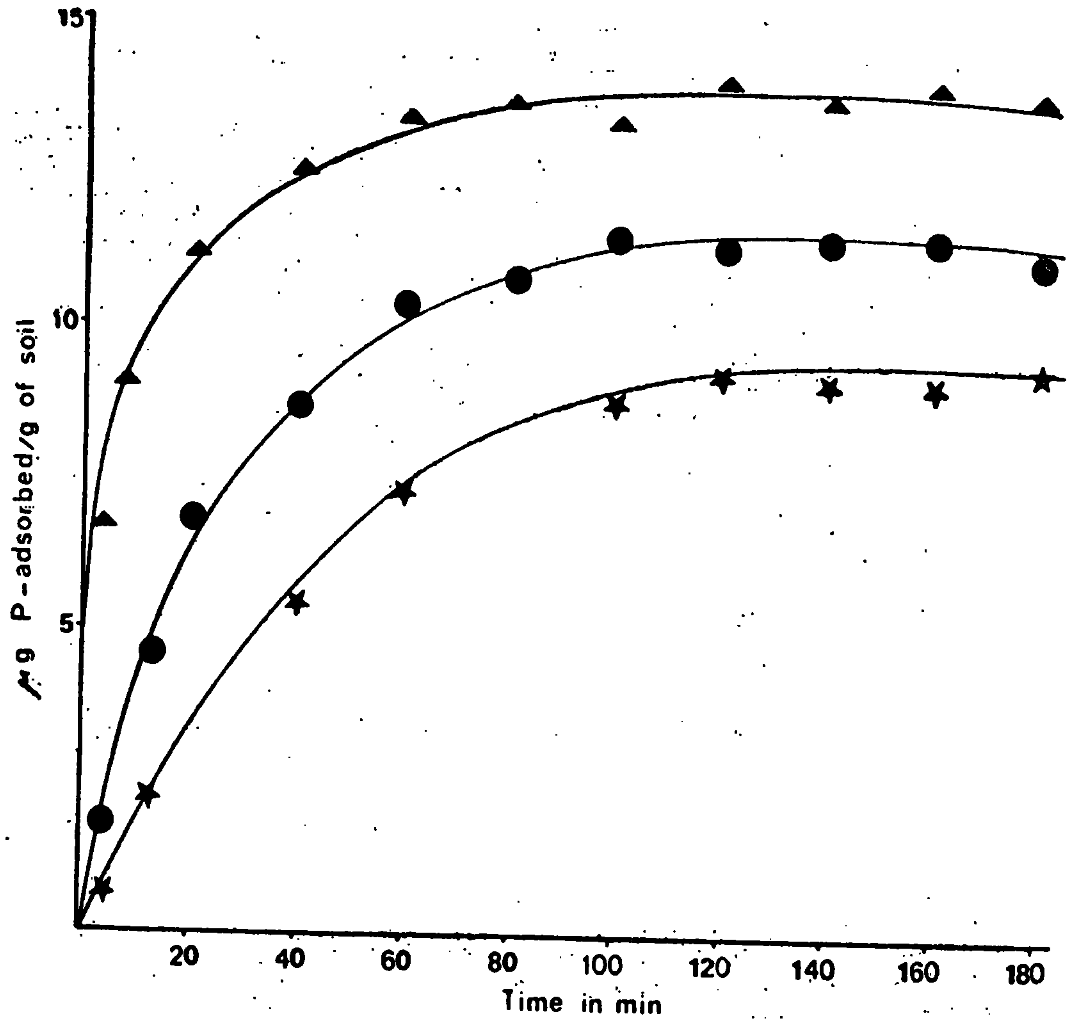

Fig. 3. — Phosphate adsorption by three Tea soils ▲—▲ Rashidpur Tea Estate soil (pH 3.8) ●—● Nurjahan Tea Estate soil (pH 4.2) ★—★ Kapnapahar Tea Estate soil (pH 4.5)

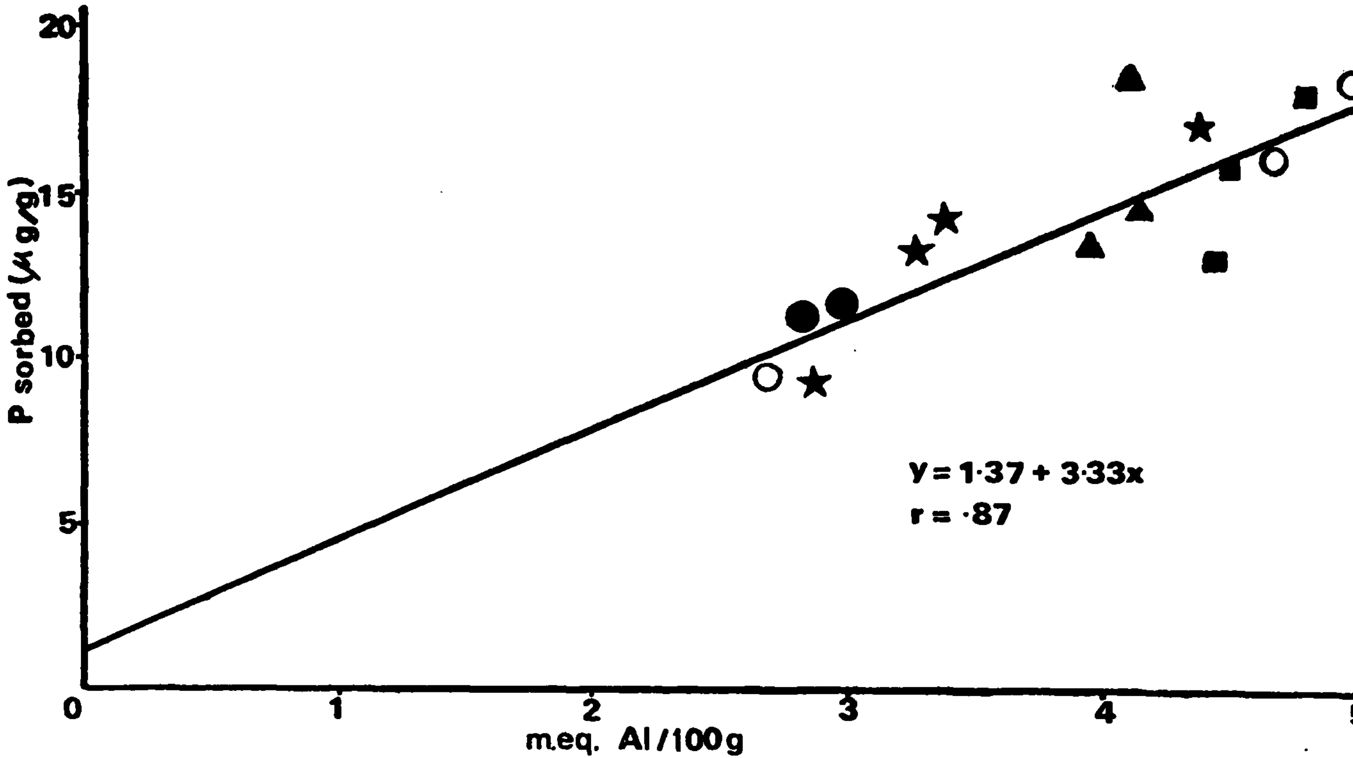

Fig. 4.— Correlation between exchangeable aluminium and P sorbed by different tea soils

□ *Udnacherra* ● *Rashidpur*

▲ *Nurjahan*

● *Daragon* ★ *Jagcherra*

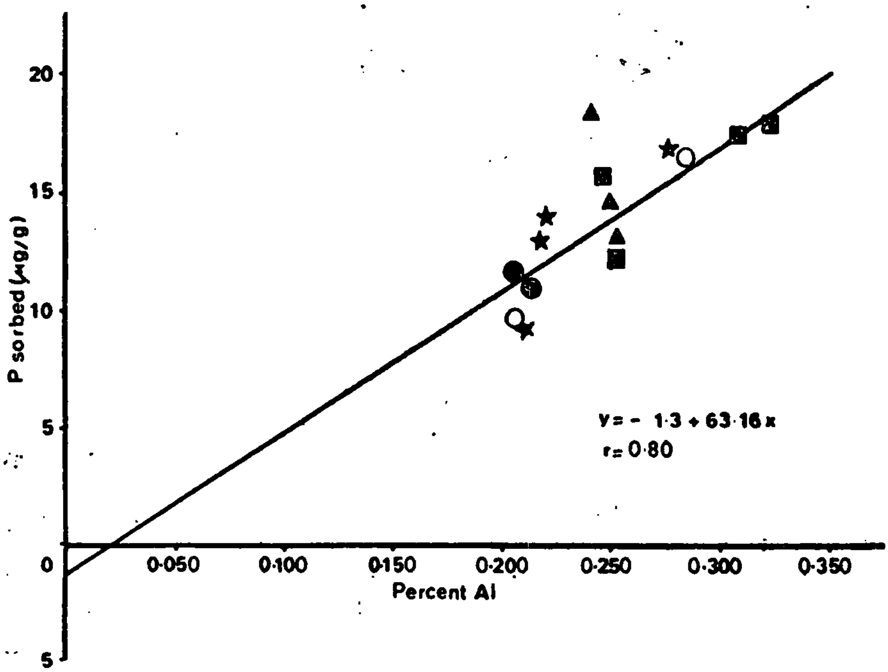

Fig. 5. — Correlation between acidified oxalate extracted aluminium and P sorbed by different tea soils ■ *Udnacherra* ▲ *Nurjahan* ○ *Daragaon* ● *Rashidpur*. ★ *Jagcherra*

The sorption of phosphate is possibly due to the formation of clay aluminium phosphate complexes in acidic tea soils. It may be illustrated by the following equation :

$$\text{Clay Particles} \begin{cases} Al\,PO_4 + 3\,OH^- = Al\,(OH)_3 + PO_4^{\equiv} \\ Al\,(OH)_3 \\ Al\,PO_4 + 3\,OH^- = Al\,(OH)_3 + PO_4^{\equiv} \end{cases}$$

With an increase in pH or hydroxyl ion activity aluminium phosphates release phosphate in soluble form and the aluminium remains insoluble as hydroxide. Conversely with a decrease in soil pH the clay aluminium reacts with phosphate in solution to form insoluble aluminum phosphate. The above reaction provides a possible explanation for the initial fast rate of adsorption which was noted to be faster in the most acidic soil having maximum exchangeable Al (Fig. 3 and 4).

The amount of phosphate sorbed by acidic tea soils was also significantly correlated ($r = 0.80$) with acidified oxalate extracted aluminium oxide (Fig. 5). This fraction of aluminium oxide has larger surface area which would account for the high sorption of phosphate from soil solution. Adsorption of phosphate by aluminium oxides may be explained by the ligand exchange reaction (Hingston *et al*, 1971).

These soils contain comparatively small amount of acidified oxalate extracted iron compared to the fraction of aluminium (Karim and Rahman, 1980). Sorption was not significantly related to acidified oxalate extracted iron ($r = 0.26$). Some small rod shaped discrete particles synonymous to ferrihydrite was observed in the electron micrographs. Ferrihydrite which has a large specific surface and is relatively insoluble in acidified oxalate reagents (Karim, 1977) may be responsible for sorption of some phosphate in these soils. But in acidic tea soils exchangeable Al^{3+} ion and amorphous fraction of Al oxides which are extracted with acidified oxalate reagents can be assigned the major role in phosphate sorption, since all the acidic tea soils contain these fractions of aluminium in larger quantities.

The tea soils in Bangladesh are severely depleted of Ca (0.004%) and the exchange sites contained over 85% Al (Karim and Rahman, 1980). The clay minerals in these soils are largely altered (Figs. 1 and 2), with dominance of kaolinite, halloysite, goethite, gibbsite and ferrihydrite (Karim *et al*, 1978). Most of these soils have low pH (table 1). Application of high residual acidic fertilizer should be discontinued in these soils while calcium levels should likely be increased. Studies using relatively less soluble phosphatic fertilizers which have the advantage to maintain phosphate availability for longer duration should be initiated in strongly acidic perennial tea plantation soils. The comparative efficiency of various phosphatic fertilizers, including rock phosphate together with economic methods of application should be urgently investigated as a means of ameliorating both phosphate and calcium nutrient status to increase tea plantation productivity.

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