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Full Length Research Paper

Phenotypic plasticity of leaf length to an environmental gradient in *Khaya ivorensis* (Meliaceae) populations in Ghana

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Khaya ivorensis **encountears different ecological conditions in its native habitats in Ghana. The demand for this species has led to severe depletion of the natural stand, thus threatened with extinction. To address the dwindling populations demands intervention for restoration and establishment of plantations. The goal of reforestation is to establish a new generation of trees with optimal growth and adaptedness. Doing this requires knowledge of relative level of plastic response to environmental variables to aid general seed transfer which could be implemented by forest managers. In this study we employed Environmental Standardized Plasticity index (EPSI) and one-way ANOVA to understand the level of phenotypic plasticity in leaflet morphology to environmental gradient. Highly significant (P<0.0001) plastic response in leaf length was observed among the populations in relation to precipitation, temperature, altitude and latitude. The results suggested South-North clinal relationship to leaf length. The observed clinal variation in leaf length with environmental variables provide suitable framework for matching each provenance site or population to designate ecological zone, under premise each population has adapted to the local environmental conditions.**

Key words: Clinal variation, *Khaya ivorensis,* climate change.

INTRODUCTION

Khaya ivorensis A. Chev. (Family Meliaceae, sub-family Swietenoideae) among the most important economic tropical hardwood timber tree species of Africa (Ofori et al., 2007). *K. ivorensis* is evergreen, monoecious, very large tree up to 60 m tall, with the bole branchless for up to 30 m, usually straight and cylindrical. *K. ivorensis* is deciduous only in drier climates. The species are distributed through coastal West Africa, Cote d'Ivoire through Ghana and southern Nigeria to Cameroon, growing mostly in rainforest but extending into dry forests (Irvine, 1961). *K. ivorensis* wood is the major source of foreign exchange to countries in West Africa where it is found (Opuni-Frimpong et al., 2008). In fact, *Khaya* species is the fourth moving timber species in Ghana (TIDD, 2009). The bark is used by traditional healers in West Africa in form of decoction for the treatment of certain aliments (Bumah et al., 2005). The growing demand for this species has led to severe depletion of the natural stand, thus threatened with extinction (Hawthorne, 1993). To address the dwindling natural stand of *K. ivorensis* requires intervention for restoration and establishment of plantations. The goal of reforestation is to establish a new generation of trees with optimal growth and adaptedness. Doing this requires knowledge of relative level of plastic response to environmental variables to aid general seed transfer which could be implemented by forest managers. For this purposes, therefore phenotypic variability should be described by environmental predicators (Zhang, 2005). This is under premise that level of adaptedness could be marched to environmental heterogeneity (Gianoli and Gonzalez-Teuber, 2005). Adaptive phenotypic plasticity is the potential for an organism to produce range of different relative fit phenotypes in multiple environments. It is now been recognized that plasticity has many ecological benefits (Schlichting, 1986).

In the tropics abiotic factors such as rainfall amounts emanating from drought, intensive solar irradiation and high temperature are prominent in limiting the distribution and abundance of plants (Brown, 1984; Swaine, 1996;

Wright, 1992). Most plants cannot escape those stresses so have to tolerate large diurnal and seasonal environment. Perennial plants respond to environmental changes primarily by phenotypic plasticity (Rebio De Casas et al., 2007). In plant the primary organ which responses to environmental cues is the foliage. The plastic nature of plants modular construction allows integration of foliage organs between several habitats (Buzzaz, 1991), which may bring about niche differentiation (Burghardt et al., 2008). The understanding of plasticity in diverse environment has been given prominence in forecasting plant response to environmental change caused by global warming or anthropogenic disturbances (Valladares et al., 2007). *K. ivorensis* encounters different ecological conditions in its native habitats in Ghana. The species is distributed in three main ecological zones (Wet Evergreen, Moist Evergreen and Moist semi-deciduous forest zones) (Figure 1), with isolated patches of populations in riverine habitats in dry semi-deciduous forest zones. Due to the heterogeneous nature of *K. ivorensis* habitat, it can therefore be assumed that, the species has developed adaptive phenotypic plasticity to enable it to occupy all the natural range. The aim of this paper is to explore the pattern of phenotypic plasticity in relation to quantitative leaf morphological traits along precipitation, altitudinal and temperature gradients occupied by *K. ivorensis* in Ghana. For the purposes of developing suitable guidelines for matching genotypes with appropriate planting sites.

MATERIALS AND METHODS

The study site

This study was conducted in High Forest Zone (HFZ) (Figure 1) within six forest reserves in Ghana which cut across all the natural range of *K. ivorensis* (between longitudes 3° 15´´ W and 0° 12´´ E, and latitude 4° 44´´and 7° 30´´ N) (Hall and Swaine, 1976). The area has a two peak rainfall during April to July and September to November. The rainfall varies between 1200 - 2200 mm per annum (Swaine, 1996; Gyau-Boakye and Tumbulto, 2006). There is a comparatively short dry season during January and February (Hall and Swaine, 1976).

The relative humidity is always high and is seldom below 85% (Odoom, 1998). The mean minimum temperature ranges from 21 - 23°C and mean maximum temperature is from 30 - 35°C. The mean annual evapotranspiration rate is low in southern Ghana (80 mm) and higher in the north (190 mm). In the Ghana soil classification system (Brammer, 1962), the soils in the forest zone are grouped under forest oxysols and ochrosols according to the FAO classification these soil types would be termed as Ferralsols and Acrisols respectively (ISSS/ISRIC/FAO, 1998; Greenland and Kowal, 1960).

Data collection

A total of 120 matured trees were sampled from six provenance sites (Figure 1). The minimum distance between each tree on average was about 100 m along a transect, this was done to prevent sampling adults trees from the same parents or pedigree. Twenty trees were sampled for each provenance sites or locality. The leaves samples were collected between May and July during the peak of the rainy season. The sampling methods and design were the same for each provenance site. Fifty leaves per tree at the provenance sites were sampled at random. The sampled leaves were taken from prominent young branches in the upper most part of the crown usually over 30 m above ground where the leaves have adequate light interception. This was done to ensure that the leaves were as much as possible disease and pest infestation free, and with a limited shading effect and of the same age, and they were collected from fully opened or expanded mature leaves of the current year. In total 2400 leaves were measured from *K. ivorensis*. The leaves were scanned using an Epson Expression 1640 XL flat bed scanner connected to a personnel computer running image analysis program (WinFOLIA 4.0, Regent Instrument Inc. Canada) to capture the measurements of the various morphological characters automatically. However, interactive procedure was used to measure leaf length (LL) and leaf maximal width (LMW).

Statistical analysis

Morphological relationship change with overall body size and body size often varies among population (McCoy et al., 2006). In order to correct this anomaly from allometric effect; we performed size correction, by regressing leaflet overall size as the square root of the product of total leaflet length and width against linear leaflet parameters. The residuals were then used as input for successive analyses (Blue and Jensen, 1988). Environmentally standardized plasticity index (ESPI) was computed for six linear morphological traits to measure the level of phenotypic plasticity among the populations. ESPI is defined as follows:

$$ESPI = \frac{(X - x)}{|(E - e)|}$$

where X and x are the maximum and minimum phenotypic values of a given population across different environments, respectively and E and e are mean environmental values and at which X and x were achieved (Valladares et al. (2006). In this study the environmental factors used in the study were mean annual precipitation, mean maximum temperature, latitude and altitude for each provenance site from a data generated over 30 years period by Ghana Meteorological Services Department. The differences in ESPI between populations for three linear morphometric variables were evaluated with one-way ANOVA and post hoc Tukey test was conducted considering populations as a factor. All the analyses were done using XLSTAT software package (Addinsoft SARL, Paris, France, 2009).

RESULTS AND DISCUSSION

Plasticity in leaflet length (LL) differed significantly (P<0.0001) (Table 1) among the populations related to amount of precipitation. The general observation was that ESPI increased with mean annual precipitation with Ankasa Conservation (ANK) recording the highest ESPI, followed by Tano Nimiri Forest Reserve (TNM) (Figure 2). Kajeas Forest Reserve (KFR) and Bobiri Butterfly Sanctuary (BBS) recording smallest values of ESPI (two population not significantly different from Tukey's test P>0.05), corresponding to lowest rainfall amount of the provenance sites studied Figure 2). Subiri Forest

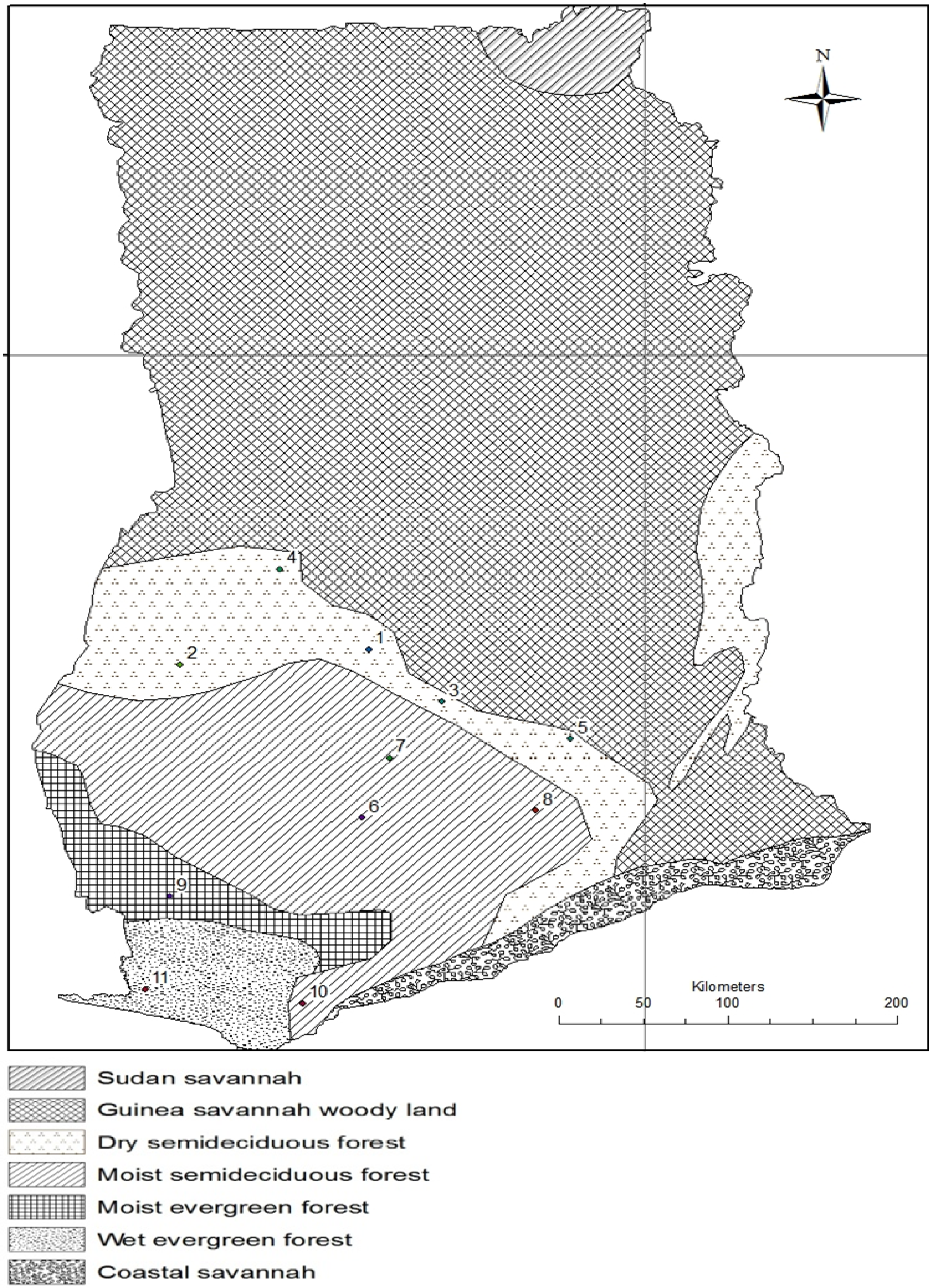

Figure 1. Location of the 6 populations of *Khaya ivorensis* in Forest Reserves in High Forest Zone of Ghana. Ankasa Conservation (ANK)-11, Subiri Forest Reserve (SFR)-10, Tano Nimiri Forest Reserve (TNM)-9, Pra-Anum Headwaters Forest Reserve (PAH)-6, Bobiri Butterfly Sanctuary (BBS)-7, Kajeas Forest Reserve (KFR)-8.

Table 1. The results of one-way ANOVA of environmental plasticity index (ESPI), showing effect of mean annual precipitation, mean annual temperature, altitude and latitude on leaf length (LL) of *K. ivorensis.*

ESPI	Variance components		P-value
	Population (%)	Error (%)	
Precipitation	94.64	5.36	<0.0001
Temperature	97.66	2.34	<0.0001
Altitude	96.50	3.50	<0.0001
Latitude	97.63	2.37	<0.0001

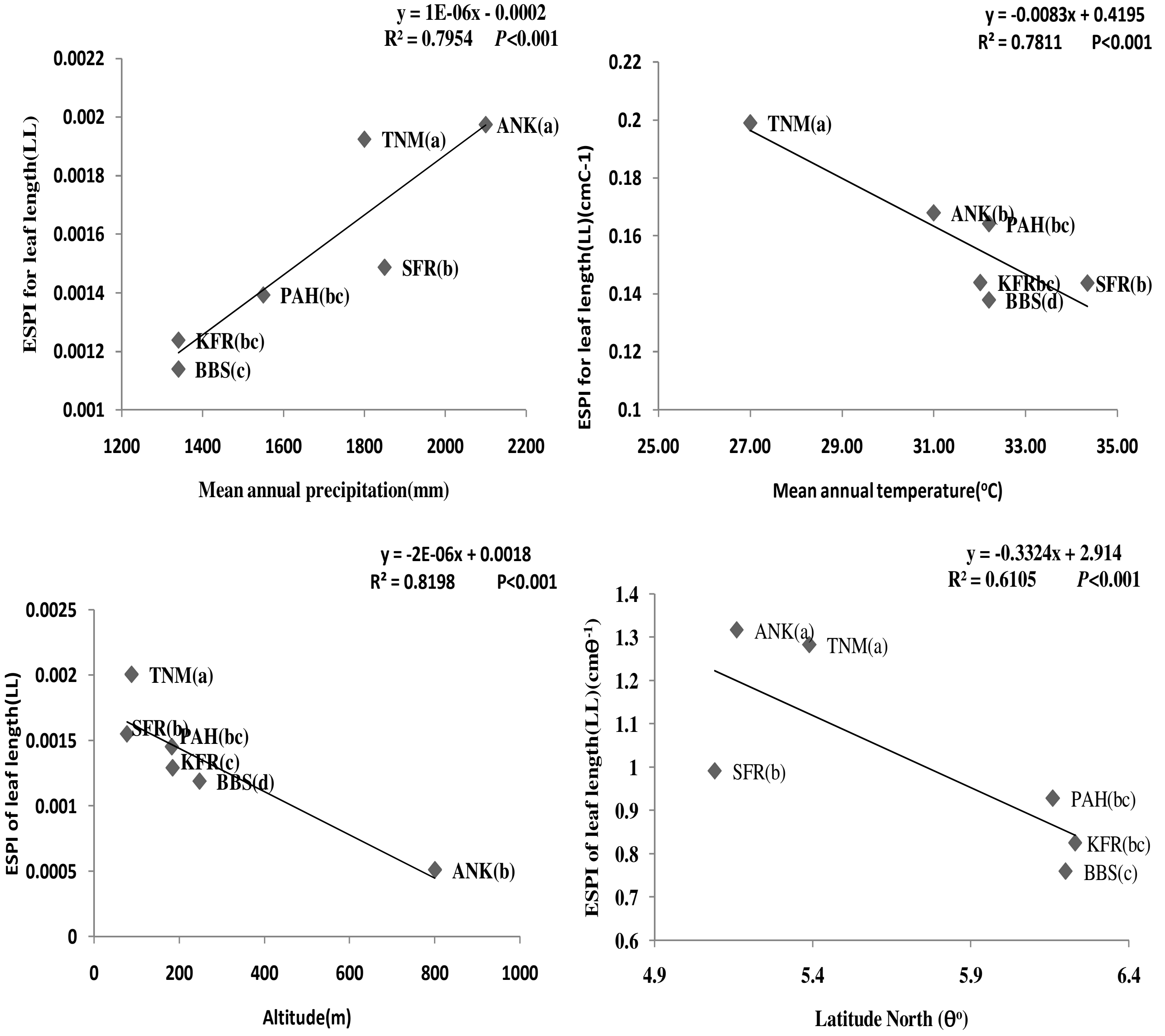

Figure 2. Relationship between site mean environmental standardized plasticity index (ESPI) for leaflet length (LL) and mean annual precipitation, mean annual temperature, altitude, latitude at 6 provenance sites: Pra-Anum Headwaters Forest Reserve(PAH), Bobiri Butterfly Sanctuary(BBS), Subiri Forest Reserve (SFR), Ankasa Conservation(ANK) , Tano Nimiri (TNM) and Kajeas Forest Reserve(KFR). Linear regression fits and associated r^2 and *P* values are given in each panel. Population with different letters in bracket are significantly different from each other (ANOVA, Tukey's test, P<0.05).

Reserve (SFR) and Pra-Anum Headwaters Forest Reserve (PAH), these two populations were intermediate in term of ESPI values recorded. There was strong positive association (R^2= 0.7954; P<0.001) between ESPI and mean annual precipitation from regression analysis.

Thus suggesting South-North cline relationship, with leaflet length (LL) decreased with decreasing amount of rainfall from south to the northern part of the country. This was reaffirmed by regression analysis (R^2 =0.6105; P<0.001) between Latitude North and ESPI. The results indicated ESPI decrease from the south to the north supporting general trend of clinal relationship with precipitation. Similar results have been reported in *Quercus rugosa* by Uribe-Salas et al. (2008) and in two species of *Begonia* by Maclellan (2000). The pattern of ESPI indicates that leaflet size is larger at southern, more moist, whereas leaflet size is gradually smaller towards northward which is a little dryer. This can be seen as mechanism of adaptation to desiccation or result from plastic response (Jensen and Hansen, 2008) to the diverse environments that populations of *Khaya ivorensis* occupy along their natural distribution in Ghana.

The most important consequence of this is that, there is likelihood of phenotype-environmental matching. Thus suggesting seed collected from one ecological zone could be either planted in the same area or a step southward to the original zone. The most striking result is the relationship between mean annual temperature and ESPI, which was significant (R^2=0.7811; P<0.001) and negatively associated with other. Similar result was obtained between ESPI and altitude (R^2=0.8198; P<0.001) (Figure 2). Highest ESPI values in response to environmental temperature were recorded by Tano Nimiri Forest Reserve (TNM), followed by Ankasa Conservation (ANK), the lowest was Bobiri Butterfly Sanctuary (BBS).

The ANOVA results for both temperature and altitude in relation to ESPI of leaf length (LL) were significant (P<0.0001), indicating difference in ESPI among the six populations of *Khaya ivorensis* investigated. There is general increase in temperature from the coast in the south to the north, the same pattern as amount of precipitation. This variation in temperature across the country is more noticeable during the Harmattan (Is a dry and dusty West African trade wind, which blows south from Sahara desert) season. Thus the interaction between rainfall amounts and temperature define the characteristics of each ecological zone.

Leaf morphology varies with increasing altitude and this is generally connected to temperature (Hovenden and Vander Schoor, 2005). Morphological traits like leaf size, thickness and specific leaf area are strongly influenced by altitude. Hovenden and Vander (2004) reported that leaf length tend to decrease with increasing altitude. In general smaller or slander leaves have reduce boundary of layer resistance and are thus capable of regulating their temperature through better convective cooling of leaf area (Parkhurst and Loucks, 1972). As a result small leaves are usually associated or adapted to high temperature and arid conditions. The change in leaflet length (LL) values across the environment and steep nature of regression plots indicate high degree of reaction norms of plasticity to environmental variables investigated. However, not all the environmental variables elicited the same degree of plasticity in leaflet length (LL). The observed clinal variation in leaflet length (LL) with environmental variables provide suitable framework for matching each provenance site or population to designate ecological zone, under premise each population has adapted to the local environmental conditions. On this basis for optimum performance of *K. ivorensis*, plantations and restoration efforts should be planned in a way that seeds from specific provenance site are used in the same ecological zone or move to wetter part of the country.

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