**ABSTRACT**

Sulphur (S) has received limited attention by researchers, agronomists and planters involved in oil palm cultivation, despite the fact that the requirement at tissue level – as indicated by published critical concentrations in Frond #17 – is the same for S and magnesium (Mg) (0.2%). The continuous trend toward S-free fertilisers (urea, rock phosphate, KCl, dolomite) in Indonesia, together with high leaching rates of sulphate, have putatively reduced the S availability in many oil palm estates. However, this has rarely been addressed up to now. The BMP (Best Management Practice) project on sustainable oil palm intensification of the IPNI SEA programme carried out at six sites, which are representatives for current management practices in oil palm cultivation, revealed a very low S status throughout, as determined by the S concentration in Frond #17, with mean values of 0.12%-0.13% S. After evaluating available literature a downward adjustment of the published critical S concentration – considering a critical N:S ratio of 15:1 and a critical N concentration of 2.3% – 0.15% seems appropriate. Considering the more relevant adequate N concentration range of 2.4%-2.8%, an adequate range for S of 0.16% - 0.19% is proposed. The results clearly indicate a very low S status even when evaluated using these adjusted critical S concentrations. Researchers, agronomists and planters are encouraged to pay more attention to the S supply and to the determination of S in foliar analysis. Until the proposed critical S concentrations are supported through experimental data, it is recommended that S-containing fertilisers are administered at S-deficient sites at about 1:10 of the N supply. Potentially, a wide range of S-containing fertilisers could be used. Kieserite (MgSO$_4$·H$_2$O) seems particularly suitable due to its market availability and because both macronutrient elements contained are required in similar amounts by oil palm.

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**ABSTRAK**

Keperluan sulfur (S) bagi tanaman sawit tidak diberi perhatian yang sewajarnya oleh penanam sawit dan ahli agronomi walaupun fakta menunjukkan bahwa nilai kritikal kepekatan S dan Mg untuk Pelepah 17 adalah sama (0.2%). Di Indonesia, penggunaan berterusan baja tanpa kandungan S (urea, batuan fosfat, KCl dan dolomit) serta kadar larut resap sulfat yang tinggi telah menyebabkan kedapatan S berkurangan di kebanyakan ladang sawit. Bagaimanapun, ini jarang diperbincangkan sehingga kini. Pihak IPNI SEA programme yang menjalankan projek amalan pengurusan terbaik (BMP) bagi sawit mampan di enam kawasan telah mendedahkan berlakunya keadaan status S yang sangat rendah dengan kepekatan S Pelepah 17 pada nilai purata 0.12%-0.13%. Selepas penilaian bahan rujukan, pelarasan menunjukkan nilai kritikal kepekatan S dengan nisbah kritikal N:S pada nilai 15:1, maka nilai kritikal kepekatan N antara 2.3% hingga 0.15% adalah sesuai. Berdasarkan julat nilai kepekatan N yang mencukupi iaitu antara 2.4%-2.8%, maka dicadangkan julat nilai kepekatan S yang mencukupi adalah antara 0.16%-0.19%. Keputusan ini jelas menunjukkan bahawa status S adalah sangat rendah walaupun dinilai dengan menggunakan kepekatan kritikal S yang telah dilaraskan. Para penyelidik, ahli agronomi dan penanam sawit adalah digalakkan untuk memberi lebih perhatian terhadap bekalan S serta penentuan status S dalam analisis daun. Sehingga...
oil palm, fertilisation, fertilisers, requirement, sulphur.

INTRODUCTION

The nutrient element sulphur (S) has received much less attention than other macronutrients (compare Goh and Härdter, 2003), although, S and magnesium (Mg) are required in similar amounts by oil palm, with published critical values in Frond #17 of 0.2% for both nutrients (Fairhurst et al., 2005). S fulfills various functions in plant metabolism. It is a constituent of S-containing amino acids and hence proteins, which is why the requirement of S is closely linked to that of nitrogen (N). In addition, S is also essentially involved in oil synthesis, and a strong response of several oil crops to S supply has frequently been reported (Pasricha and Aulakh, 1991). However, similar reports for oil palm are apparently lacking.

S has not received the same attention as the macronutrients N, phosphorus (P) and potassium (K) in oil palm nutrient management. Presumably, this is because most of the early research on oil palm nutrition was carried out in Malaysia, where ammonium sulphate was considered the superior N source for decades and apparently less costly dolomite has been used in preference to kieserite (MgSO\(_4\) · H\(_2\)O). Other S-containing fertilisers (single and double superphosphates, partially acidulated rock phosphates, SOP) never played a major role in oil palm fertilisation. The burning of forests has also been reduced in recent years. As a consequence, the S input has consequently been diminished over the years, due to the continuous removal of S with the fresh fruit bunch and losses because of leaching. In fact, as early as the 1980s several publications had already addressed the issue and predicted a more widespread occurrence of S deficiency, as the trend towards high-analysis fertilisers and higher-yielding varieties continued (Ng et al., 1988; Sumbak, 1983). Consequently, a decline of the S status of oil palm in Indonesia was anticipated, but to our knowledge no specific study has been published addressing this issue, except for an incidental observation by Wigena et al. (2006) of below adequate leaf S concentration (0.14%) under a S-free fertiliser treatment and an early report of S-deficiency in nursery seedlings in North Sumatra (Turner et al., 1983). In the course of the Best Management Practice (BMP) project on sustainable oil palm intensification of the IPNI SEA programme (Donough et al., 2009) nutrient status analyses have been carried out and are used to assess the S status of oil palm in Indonesia.

MATERIALS AND METHODS

Since July 2006, IPNI SEA has established 30 commercial blocks (total area 1080 ha) with BMP in partnership with five collaborating plantation groups in three locations in Sumatra (two in north, one in south Sumatra) and three locations in Kalimantan (west, central and east). These six sites span a wide range of conditions where oil palm is currently grown in Indonesia (Donough et al., 2009). At each site, five blocks were managed by the plantation partners using standard commercial estate practices (REF), while another set of five blocks were managed according to BMP principles. The BMP treatments did not specifically address the S fertiliser management of oil palm and hence, only the results obtained for the REF are presented. These results are considered highly representative for the majority of oil palm plantations in Indonesia. Measurements of plant nutrient status were taken between 2007 and 2011. Leaf sampling palms (LSP) were selected on a 10-in-10 fixed grid system and sampled as detailed by Fairhurst and Härdter (2003). Dried leaves were transferred to polyethylene bags and sent to Asian Agri Laboratory (Tebing Tinggi, north Sumatra) for N and S analysis by the Kjeldahl and gravimetric procedure, respectively.

In Indonesia, urea has been the most often used N source for decades and apparently less costly dolomite has been used in preference to kieserite (MgSO\(_4\) · H\(_2\)O). Other S-containing fertilisers (single and double superphosphates, partially acidulated rock phosphates, SOP) never played a major role in oil palm fertilisation. The burning of forests has also been reduced in recent years. As a consequence, the S input has consequently been diminished over the years, due to the continuous removal of S with the fresh fruit bunch and losses because of leaching. In fact, as early as the 1980s several publications had already addressed the issue and predicted a more widespread occurrence of S deficiency, as the trend towards high-analysis fertilisers and higher-yielding varieties continued (Ng et al., 1988; Sumbak, 1983). Consequently, a decline of the S status of oil palm in Indonesia was anticipated, but to our knowledge no specific study has been published addressing this issue, except for an incidental observation by Wigena et al. (2006) of below adequate leaf S concentration (0.14%) under a S-free fertiliser treatment and an early report of S-deficiency in nursery seedlings in North Sumatra (Turner et al., 1983). In the course of the Best Management Practice (BMP) project on sustainable oil palm intensification of the IPNI SEA programme (Donough et al., 2009) nutrient status analyses have been carried out and are used to assess the S status of oil palm in Indonesia.

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RESULTS AND DISCUSSIONS

Frond #17 typically serves as the plant tissue of choice for assessing the nutrients status of mature oil palm world-wide, as most complete sets of critical values are tabulated for leaf (e.g., Calvez et al., 1976; Sumbak, 1983; Fairhurst et al., 2005). Hence, this leaf was selected for assessing the S status, even though it might be inferred that for nutrients of limited mobility within oil palm (B, Fe, Zn, Cu, and S) sampling younger leaves might be more appropriate. A continuous decline in the S status was apparent at all sites for which almost complete data sets were available (Figure 1). From the very beginning, all samples indicated an S status far below the published critical concentration of 0.2% S (Calvez et al., 1976; Sumbak, 1983; Fairhurst et al., 2005). In a survey on adult oil palm in Colombia, it was also found that the leaf concentration of S in most plantations was also below the 0.2% margin (Dávila et al., 2000). This critical threshold value is based on the early work of Ollagnier and Ochs (1972) and it also agrees with Richards (1972).

It is argued that the limited studies on the S requirement by oil palm do not support the critical S level appropriately. In addition, a range of alternative indicators have been discussed for other crops, mainly the sulphate concentration (Spencer and Freney, 1980; Zhao et al., 1996) and the N:S ratio. Even though the use of the N:S ratio has its limitations (Zhao et al., 1996), stemming partly from the fact that the re-translocation of S within the plant is rather limited as opposed to that of N (Pasricha and Aulakh, 1991), N:S ratios have frequently been used for diagnostic purposes. A recent review (Khurana et al., 2008) listed for wheat, rapeseed-mustard, maize, and alfalfa, all grown in the Indo-Ganges plain, critical N:S ratios of 16, 15.5, 11, and 16, respectively. Juliano et al. (1987) reported normal contents of S-containing amino acids in seed protein of brown rice grown in Bangladesh and Indonesia for N:S ratios up to 15 in the grain, which agrees well with the typical N:S ratio of plant proteins. In an earlier study on N x K interaction in oil palm, neither the fresh fruit bunch yield, nor the N or the S concentrations were significantly affected (Breure

![Figure 1. Time course of the S concentration (a) of Frond #17 and of the N:S ratio (b) at selected sites (means ± SD, n = 5).](image-url)
and Rosenquist, 1977). Based on their data the N:S ratio did not correlate with fresh fruit bunch yield, while on average a N:S ratio of 15.1±0.1 in Frond #17 was observed. Overall, and in the absence of specific studies in oil palm, a critical N:S ratio of 15 seems a reasonable estimate.

Considering a critical N:S ratio of 15 and a well-established critical N concentration in Frond #17 of mature oil palm of 2.3% (Von Uexküll and Fairhurst, 1991), a putative critical S concentration of 0.15% may be deduced. Relating the N:S ratio of 15 to the more relevant adequate N concentration range in Frond #17 of mature oil palm of 2.4% - 2.8% (Fairhurst and Härdter, 2003; Fairhurst et al., 2005), a critical S concentration range of 0.16% - 0.19% is obtained. In agreement, Khalid and Zakaria (1993) did not observe S deficiency symptoms in oil palm receiving variable levels of S including a S-free control for seven years. Overall, in their study leaf S concentration varied from 0.16% to 0.30%, indicating that all samples stayed within the adequate range we here proposed. Lim et al. (1995), in their seven-year study of Cl and S effects on oil palms, also reported no significant differences in leaf S concentrations, varying between 0.17% to 0.24%, between ‘zero-fertiliser’ control plots, S-free fertilised plots and S-supplied plots. There was no significant difference in bunch yield between S-free and S-supplied fertilised plots. Considering this adjusted critical concentration and adequate range of S reveals that even during the initial phase of the BMP project the S status is in the marginal range, and continuously declined as the experiment proceeded. It eventually approached an apparent baseline value of around 0.12% (Figure 1a). Correspondingly, N:S ratios increased steadily during the course of the experiment reaching mean values of above 20 on several sites (Figure 1b). Ratios meeting the proposed critical value of 15/1 were not observed in recent years.

Most complete data sets for comparison were available for 2009 (Figure 2b). The proposed critical N:S ratio of 15 was not met on any site as mean values ranged from 17.9 to 20.5. Highest values were reported for central and east Kalimantan, but means differed not significantly. The corresponding S concentration indicates that the S status of oil palm was far below published or proposed critical concentrations at all sites sampled (Figure 2a). Highest values were observed in south Sumatra and west Kalimantan, while lowest values were recorded in central and east Kalimantan. These results show that the S status currently appears insufficient at all sites, irrespectively of whether the evaluation is based on published or proposed, critical concentrations. It was calculated that in 2009 the S status on average reached only 80% of the proposed lower adequate S concentration range of 0.16% at all six sites.

Due to its presence in the amino acids methionine and cysteine, S is an essential component of proteins, and hence enzymes. In fact, the key enzyme of photosynthetic CO₂ fixation, Rubisco, is the predominant protein in leaves of C3 plants and represents about 50% of the soluble leaf proteins. In soyabean, it was shown that this fraction declined linearly to below 10% of leaf soluble protein under S deficiency conditions (Sexton et al., 1997). A strong fresh fruit bunch yield response of S-deficient oil palm to S fertilisation is thus to be expected, awaiting experimental validation. In addition, the well-known significance of S supply for oil formation (Pasricha and Aulakh, 1991) further emphasises the importance of securing the S supply for oil palm. Therefore, experiments are currently being established: (1) to re-evaluate the critical S concentration, and (2) to assess the yield response to S supply in field trials.

Even though a yield response to S fertilisation has not been established at full commercial block scale, yet, the substantial impact of S on N use efficiency and oil synthesis may convince oil palm plantation management to secure adequate S supply. This becomes even more obvious in view of the moderate additional costs associated with the supply of S in relation to the potential gains (oil yield). Apart from elementary S, which has a strong acidifying effect (Breure and Rosenquist, 1977), S is usually applied in sulphate form as a component of other fertilisers. Potentially the following sources could be used: ammonium sulphate (SOA), kieserite (MgSO₄·H₂O), single and double superphosphates, partially acidulated rock phosphates, potassium sulphate (SOP), gypsum, and S containing NPK. Some of these sources are fairly costly and therefore not routinely used in oil palm cultivation (e.g. SOP, S containing NPK), while others are not widely available in Indonesia (ammonium sulphate, single and double superphosphates, partially acidulated rock phosphates). For example, SOA is difficult to obtain in many regions of Indonesia and is more expensive per unit N as compared to urea. In addition, SOA contains more S (24% S) than N (21% N) and provides unnecessary high amounts of S. In view of the critical N:S ratio of 15 and the high leaching losses of sulphate, a N:S ratio of 10:1 in the fertiliser regime should be fully adequate to secure the S demand of oil palm. In this regard, kieserite (MgSO₄·H₂O) is a good option as it provides similar amounts of Mg and S (16% Mg, 21% S) matching well the requirements of oil palm for these nutrients.

**CONCLUSION**

Leaf samples taken from six estates being representative of Indonesian conditions indicate a very low S status indeed (range 0.12% - 0.13%). Despite the uncertainty as to the exact critical S concentration in Frond #17, even the lower estimate of 0.15% S that
is based on a critical N:S ratio of 15 and a critical N concentration of 2.3%, is not reached. It is concluded that: (1) oil palm plantations should start to pay more attention to S and perhaps include the determination of the S status in their routine leaf analysis particularly if the fertilisation programme is S-free, (2) a S concentration in Frond #17 of below 0.15% calls for immediate remedy through the application of S-containing fertilisers, (3) a S concentration between 0.15% and 0.17% needs careful attention and the application of S-containing fertilisers might be considered depending on the N status and N:S ratio, and (4) private and public research institutions and agronomists should raise their awareness of S as an essential nutrient for oil palm. In case the application of S is considered, several S-containing fertilisers are principally suitable. For practical reasons (availability in the market, required S dose), kieserite (MgSO₄·H₂O) seems particularly suitable.

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