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Effect of elemental sulphur on soil micronutrients mobility

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ABSTRACT

To elucidate the effect of elemental sulphur (S) on nutrient release and its relationship with soil pH, maize plants were grown for 45 days under glasshouse conditions with 0, 20 and 40 days of soil incubation with different amounts of elemental sulphur including 0, 0.5, 1 and 2g S kg^{-1} soil. Soil samples were retrieved before and after maize planting and were extracted by un-buffered and neutral solutions of $CaCl_2$. The nutrients in the solution were determined by an inductively coupled plasma spectrometer. The results exhibited that addition of elemental sulphur significantly increased concentration of micronutrients in Bintang Series soil. Additionally, the release and mobility of each nutrient started at specific pH. The pH value at which Fe, Al, Zn and Mn concentrations significantly increased are 3.94, 5.26, 5.26 and 6.29, respectively. In conclusion, when used in appropriate amounts, elemental sulphur can efficiently enhance soil fertility by providing micronutrients for balanced fertilization.

Key words: Elemental sulphur, soil pH, Soil nutrients.

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INTRODUCTION

It is well-known that the availability of essential nutrients affect yield and yield components of crops (Ye et al., 2011). The availability of nutrients in soils depends on soil characteristics especially soil pH (Chien et al., 2011; Lindsay, 1979; Shenker and Chen, 2005;Wang et al., 2006). Fertilization and addition of acidifying amendments are common practices in high pH soils to enhance nutrient availability and improve plant performance (Karimizarchi et al., 2014a). As a soil amendment for increasing soil nutrient solubility, elemental sulphur (S) is of special interest since it possesses a slow release acidifying characteristic and is readily available (Chien et al., 2011). The acidifying characteristic of S originates from its microbial oxidation to sulphuric acid over time (Vidyalakshmi et al., 2009).
There are contrasting reports on the effect of elemental S on soil pH and nutrient availability (Klikocka, 2011; Safaa et al., 2013;Skwierawska et al., 2012). The effectiveness of elemental sulphur application on nutrient solubility was not observed in some soils (De la Fuente et al., 2008; Sameni and Kasraian, 2004; Shenker and Chen, 2005;Skwierawska et al., 2012). At the same time, the positive effect of elemental sulphur on soil nutrient solubility is reported by Cui et al. (2004). The increased release of soil nutrients from unavailable to available pools could be due to soil pH changes because of S application (Ye et al., 2010). Lambers et al. (2008) reported that high concentrations of hydrogen ions cause modest increases in nutrient input by increasing weathering rate, but even greater loss of base cations by leaching. Protons first displace cations from the exchange complex on clay minerals and soil organic matter.
Different soils may show diverse responses to soil acidification as an effective strategy for soil nutrient solubility enhancement (Wang et al., 2006). Therefore, it is necessary to find the optimum sulphur dose to obtain optimum pH for each soil. This would provide optimum

nutrient concentration and concurrently extreme soil acidification and its consequences such as nutrient toxicity for plants is avoided. As minimal research data are released on impacts of elemental S addition on pH and nutrient release in Bintang Series soils, this present study was carried out to quantify the effect of elemental S on Bintang Series soil nutrient.

MATERIALS AND METHODS

To evaluate the effect of elemental S and soil pH on soil micronutrient solubility, the Bintang Series soil was treated with four doses of elemental sulphur, 0, 0.5, 1 and 2g S kg^{-1} soil, and incubated for 0, 20 and 40 days before maize planting in 30cm (diameter) by 50cm (height) plastic pots. Then maize plants were grown for 45 days under greenhouse conditions at University of Putra, Malaysia. Soil samples were retrieved at planting and harvesting stages and subjected to nutrient analysis.

Site description

Located in Perlis, Malaysia (6° 31' 01.61" N and 100° 10' 12.43" E), the A horizon (0-20cm) of Bintang Series soil was collected, air dried and ground to pass through 2mm mesh size before use. As reported by Karimizarchi et al. (2014b), the area is under natural vegetation (forest). The Bintang Series soil with a pH value of 7.5 developed on limestone materials and is low in organic matter and extractable micronutrients including Fe, Mn, Zn and Cu.

Plant growth and management:

Sweet maize (*Zea mays* L.) seeds were germinated in laboratory conditions and transplanted into plastic pots after 24 hours. Each pot contained 10kg soil and received three plants that were thinned to one within one week. By weighing each pot, plants were irrigated daily to maintain 90 percent soil field capacity moisture content. All plants were supplied with 120kg N ha^{-1} in the form of urea, 60kg P_2O_5 in the form of triple superphosphate and 40kg K_2O in the form of muriate of potash((MARDI, 2008).

Plant available soil nutrient extraction and determination

Soil micronutrients, including Fe, Mn, and Zn, were extracted by $CaCl_2$ un-buffered and neutral extracting solution (Jones, 2001; Ye et al., 2011) as follows: 5g air dried soil was shaken for 2 hours with 25ml 0.01M $CaCl_2$ solution. To obtain a clear solution, it was centrifuged for 15Min. at 3000 rpm and then filtered. The concentrations of nutrients were determined by an inductively coupled plasma spectrometer (ICP-OES), PerkinElmer, Optima 8300. Soil pH was measured in a soil water suspension (10g soil to 25ml deionized water) 24 hours after shaking for 30Min. on a reciprocal shaker (Hlavay et al., 2004).

Statistical analysis

The relationship between plant available soil nutrients and soil acidity were subjected to different regression models at probability level of 0.05 with the help of Sigmaplot software. Using SAS 9.1, Anova analysis and DMRT's test at $\alpha = 0.05$ was employed to determine the significant differences among the treatment means for plant available soil nutrients.

RESULTS

Effect of elemental S on soil pH

Soil pH was greatly affected by sulphur application doses (Table 1). For instance, incubation of soil for 40 days with sulphur application doses of 0.5, 1 and 2g kg^{-1} soil decreased the pH by 0.76, 1.97 and 2.62 in comparison with the background of 7.42, respectively.

The dependence of soil pH to incubation time and growth stage (Table 1) shows that oxidation of elemental sulphur is time consuming and that incubation time of 20 days is not enough for complete oxidation of applied S in this study. As shown in Table 1, there is no significant difference in soil pH between incubation times for all sulphur application doses at harvest, indicating that elemental sulphur had been totally oxidized to sulphate at harvest.

In addition, soil pH for treatments not receiving elemental sulphur was significantly different during the growing season. Averaged across timing, the figure decreased by 0.52 units from planting to harvest. This can be attributed to low buffering capacity of Bintang series soil, irrigation and fertilizer management and the interactions between soil and plant during the growing season.

In order to drive a method for predicting the likely outcome of S additions in Bintang Series soil, the relationship between sulphur dose and soil pH was modelled (Figure 1). Regarding the soil pH at harvest, the relationship between soil pH and sulphur application dose was linear, pH= 6.94-1.52 S and $R^2 = 0.98^{**}$. In the other words with each unit increase in S dose, soil pH decreases by around 1.52 units. Averaged across timing, soil pH was 7.03, 6.29, 5.26 and 3.94 for sulphur application doses of 0, 0.5, 1 and 2 g S kg^{-1} soil, respectively.

As outlined above, sulphur addition decreases soil pH

Table 1. Soil pH changes in response to elemental sulphur timing (0, 20 and 40 days application before planting) and application doses (g S kg^{-1} soil) at planting and at harvest.

Sulphur dose (g S kg^{-1} soil)	Soil pH							
	At planting Incubation period (days)				At harvest Incubation period (days)			
	0	20	40	Mean	0	20	40	Mean
0	7.51Aa	7.44Aab	7.42Ab	7.45Aa	6.99Aa	6.92Aa	6.88Aa	6.93Ab
0.5	7.26Ba	6.75Bb	6.66Bb	6.89Ba	6.30Ba	6.23Ba	6.34Ba	6.29Bb
1	7.22Ca	6.27Cb	5.45Cc	6.31Ca	5.35Ca	5.27Ca	5.17Ca	5.26Cb
2	7.34Ca	5.44Db	4.80Db	5.86Da	3.90Db	3.86Db	4.06Da	3.94Db

Means within column followed by the same capital letter and means within rows followed by the same small letter are not significant at the 0.05 level, according to DMRT test at 5% level.

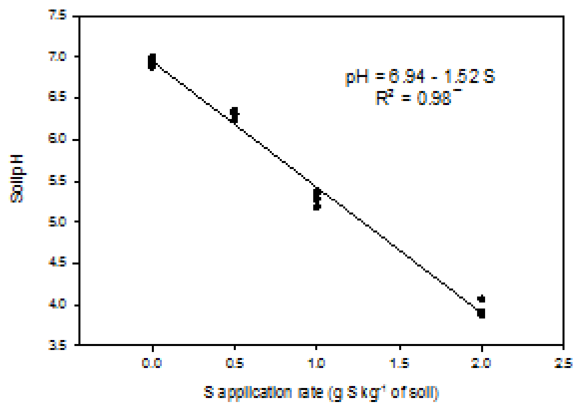

Figure 1. Soil pH changes in response to elemental sulphur application dose.

Table 2. Pearson correlation coefficients between soil pH and nutrients concentration (n=72).

	Al	Fe	Mn	Zn	pH
Al	1.00				
Fe	0.85**	1.00			
Mn	0.74**	0.59**	1.00		
Zn	0.93**	0.77**	0.78**	1.00	
pH	-0.75**	-0.60**	-0.86**	-0.78**	1.00

Values of r followed by ** or * are significant at α= 0.01 and α=0.05, respectively. ns = non-significant.

and it may affect the release of soil nutrients. Therefore, the correlation between soil nutrient availability and soil pH was studied. Data showed the strong and significant correlation between soil pH and soil nutrient concentrations (Table 2). This is in line with the general opinion of positive effect of soil acidification on soil nutrient solubility (Bolan et al., 2003; Lindsay, 1979; Pendias, 2001; Wang et al., 2006), and signifies that with decreasing soil pH the soil nutrient release was increased.

To better understand the pattern of nutrient release due to the elemental sulphur management, the bioleaching of soil nutrient as a function of sulphur application dose and timing in Bintang Series soil was elucidated. Additionally, as the acidity produced on oxidation of elemental sulphur in soil was known to increase the solubility of micronutrients (Khan and Mazid, 2011), the relationship between soil pH and nutrient release for Bintang Series soil was quantified.

Effect of elemental S and soil acidity on soil Al release

Application of elemental sulphur at a range of 0 to 1g kg^{-1}

Table 3. Soil Al changes in response to elemental sulphur timing (0, 20 and 40 days application before planting) and application doses (g S kg^{-1} soil) at planting and harvest.

Sulphur dose (g S kg^{-1} soil)	Soil Al (mg kg^{-1} soil)							
	At planting Incubation period (days)				At harvest Incubation period (days)			
	0	20	40	Mean	0	20	40	Mean
0	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
0.5	Tr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
1	Tr	0.38Bb	1.09Ba	0.49Bb	0.98Ba	0.66Ba	0.65Ba	0.76Ba
2	Tr	1.7Aa	1.88Aa	1.19Ab	21.78Ba	18.84Ba	15.12Ba	18.58Aa

Means within column followed by the same capital letter and means within rows followed by the same small letter are not significant at the 0.05 level, according to DMRT test at 5% level. Tr: traces.

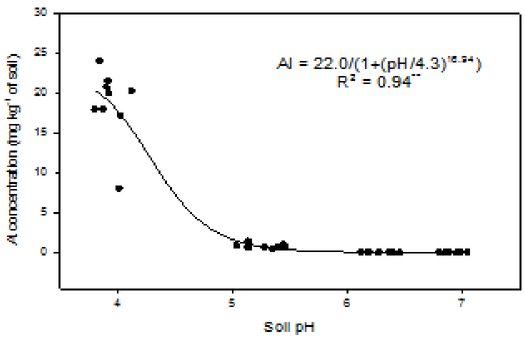

Figure 2. Effect of soil pH on Al concentration in Bintang Series soil.

of soil did not significantly affect the concentration of Al. However, the highest dose of sulphur, 2g kg^{-1} of soil, significantly increased soil extractable Al at planting and harvest (Table 3). Averaged across incubation days, application of 2g S kg^{-1} of soil significantly increased extractable Al from the background of traces, prior to S application, to 1.19 and 18.58 mg kg^{-1} at planting and harvest, respectively. This suggests that sulphur application dose has significant effect on Al solubility and it may be related to the acidifying effect of elemental sulphur. As the acidity produced on oxidation of elemental sulphur in soil was known to increase the release of nutrients, such as Fe, Zn, and Mn (Khan and Mazid, 2011).The relationship between Al release and pH under conditions of this experiment was studied. Data gathered showed that soil Al concentration did not changed from pH 7 to 6.5 and a sharp increase in Al concentration was observed at pH around 5 (Figure 2).

Effect of elemental S and soil acidity on soil Fe release

There is no significant change in extractable Fe due to incubation days at planting at each sulphur dose (Table 4). However, similar to Al (Table 3), application of elemental S at 1 and 2g kg^{-1} significantly increased extractable Fe only at incubation days of 20 and 40. For instance the concentration of Fe at 40 days of incubation significantly increased by 90 and 118 percent, compared to un-amended soil, in soils treated with 1 and 2g S kg^{-1} soil respectively. In addition, the extractability of Fe was significantly affected by growth stage. For instance, averaged across timing, the concentration of Fe increased around 4 times from planting to harvest for highest sulphur application dose. In addition, our data showed that there is a non-linear, strong and significant relation between soil pH and soil Fe release (Figure 3). As it can be seen from the figure, with decreasing soil pH from 7 to 5 the concentration of Fe was not affected. However further pH reduction increased Fe solubility in Bintang Series soil under conditions of this experiment. Being in line with our data, Bolan et al. (2003) reported the low solubility of Fe even under very acid conditions.

Besides, the nonlinear relation between soil pH and Fe release (Figure 3) can be linearized to describe the relationship between –Log Fe and soil acidity; pFe = 0.25 pH - 0.78, R^2= 0.75^{**}.

Effect of elemental S and soil acidity on soil Zn release

Like other nutrients, the solubility of zinc significantly affected by elemental sulphur timing and application

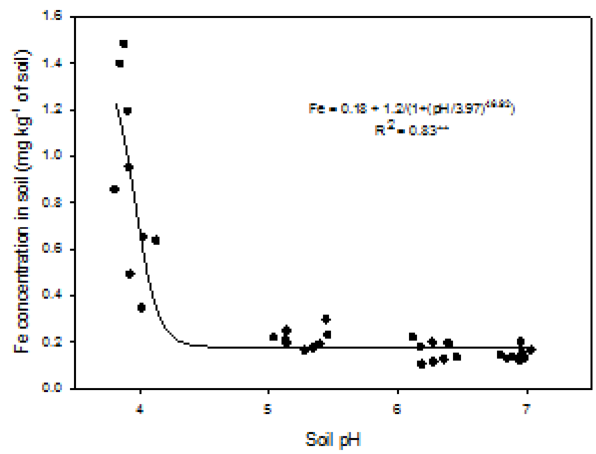

Figure 3. Soil Fe concentration as function of soil pH.

Table 4. Soil Fe changes in response to elemental sulphur timing (0, 20 and 40 days application before planting) and application doses (g S kg^{-1} soil) at planting and at harvest.

Sulphur dose (g S kg^{-1} soil)	Soil Fe (mg kg^{-1} soil) At planting Incubation period (days)				At harvest Incubation period (days)			
	0	20	40	Mean	0	20	40	Mean
0	0.21Aa	0.14BCa	0.11Ba	0.15BCa	0.14Ba	0.16Ba	0.13Ba	0.14Ba
0.5	0.14Aa	0.12Ca	0.09Ba	0.12Cb	0.17Ba	0.17Ba	0.14Ba	0.16Ba
1	0.12Aa	0.18Ba	0.21Aa	0.18ABa	0.25Ba	0.18Bb	0.20Bb	0.21Ba
2	0.15Aa	0.25Aa	0.24Aa	0.21Ab	0.94Aab	1.17Aa	0.54Ab	0.88Aa

Means within column followed by the same capital letter and means within rows followed by the same small letter are not significant at the 0.05 level, according to DMRT test at 5% level.

Table 5. Soil Zn changes in response to elemental sulphur timing (0, 20 and 40 days application before planting) and application doses (g S kg^{-1} soil) at planting and at harvest.

Sulphur dose (g S kg^{-1} soil)	Soil Zn (mg kg^{-1} soil) At planting Incubation period (days)				At harvest Incubation period (days)			
	0	20	40	Mean	0	20	40	Mean
0	0.02Aa	0.02Ba	0.03Ba	0.02Ba	0.02Ca	0.03Ca	0.03Ba	0.03Ca
0.5	0.01Aa	0.02Ba	0.03Ba	0.02Bb	0.20Ca	0.25Ca	0.15Ba	0.2Ca
1	0.01Ac	0.04ABb	0.06Ba	0.04Bb	1.13Ba	1.55Ba	1.74Ba	1.47Ba
2	0.01Ab	0.06Ab	0.15Aa	0.07Ab	5.58Aa	3.95Aa	5.29Aa	4.94Aa

Means within column followed by the same capital letter and means within rows followed by the same small letter are not significant at the 0.05 level, according to DMRT test at 5% level.

doses (Table 5). The release of Zn in Bintang Series soil started to increase at third sulphur application dose, where the soil pH value decreased from the background of 7.45 to 6.31 (Table 1).

Averaged across S timing, Zn concentration was not significantly affected by elemental sulphur of up t o 1 g S kg^{-1} at planting. The figure for harvest, showed a significant increase of 5.66, 48 and 162 times, compared to the unamended soil, for sulphur application doses of 0.5, 1 and 2 g kg^{-1}, respectively. It should be noted that zinc concentration in all S treatments, except that of untreated soil, significantly increased from planting to harvest; averaged across S timing, the concentration at harvest (4.91 $mgkg^{-1}$) was 70 times more than planting

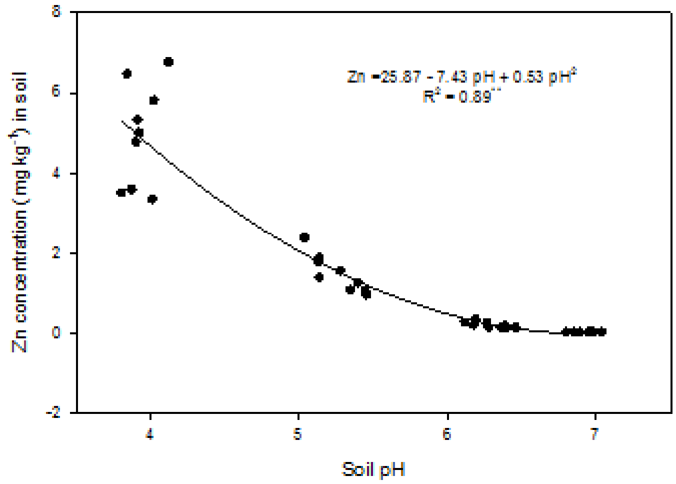

Figure 4. Soil Zn concentration pH dependency in Bintang Series soil.

Table 6. Soil Mn changes in response to elemental sulphur timing (0, 20 and 40 days application before planting) and application doses (g S kg^{-1} soil) at planting and harvest.

Sulphur dose (g S kg^{-1} soil)	Soil Mn (mg kg^{-1} soil)							
	At planting				At harvest			
	Incubation period (days)			Mean	Incubation period (days)			Mean
	0	20	40		0	20	40	
0	2.32Aa	0.56Db	0.60Cb	1.16Ca	1.50Ca	1.79Ba	1.54Ca	1.61Ca
0.5	1.99Ab	5.79Ca	5.71Ca	4.5Ca	7.23Ca	7.27Ba	7.28BCa	7.26Ca
1	1.96Ac	18.81Bb	28.07Ba	16.28Bb	29.41Ba	22.72Ba	27.87Ba	26.67Ba
2	1.84Ac	36.44Ab	68.91Aa	35.73Ab	80.36Aa	63.16Aa	76.7Aa	73.41Aa

Means within column followed by the same capital letter and means within rows followed by the same small letter are not significant at the 0.05 level, according to DMRT test at 5% level.

(0.07 mg kg^{-1}) for the highest S application dose. The figures for second and third sulphur application doses were 10 and 40 times, respectively.

As soil pH was known as the key factor that control the solubility of soil nutrients (Pendias, 2001; Wang et al., 2006) and application of elemental sulphur increased soil acidity under conditions of our experiment (Table 1 and Figure 1) it is most likely that Zn release have a strong and significant relation with soil pH changes. Our data showed that with increasing soil acidity the release of Zn was increased and it followed the non-linear quadratic regression model (Figure 4); Zn = 25.87 - 7.43 pH + 0.53 pH^2, R^2= 0.89^{**}.

The increase in Zn concentration at pH values of less than 6.31 is in line with Wang et al. (2006) who reported the ineffectiveness of soil pH reduction from 7.5 to 6 on the solubility of Zn.

Additionally, data gathered showed that the non-linear regression model describing soil Zn release due to acidity production can be linearized, if logarithm of Zn concentration be correlated with soil pH; log Zn = 3.66 – 0.72 pH, R^2= 0.93^{**}.

Effect of elemental S and soil acidity on soil Mn release

Results showed that timing and dose of elemental S had significant effect on Mn release in Bintang Series soil (Table 6). In contrast to Fe, Cu and Al, the increase in Mn release started from the second S dose (Table 6) where the soil pH value decreased from the background of 7.45 to 6.3 (Table 1). Averaged across S timing, Mn concentration was observed to have been significantly increased from untreated soil (1.16mg kg^{-1}) to highest sulphur application dose (35.73mg kg^{-1}) by 29.8 times at planting. The figure for harvest, showed a significant increase of 3.5, 15.56 and 44.59 times compared to the background of 1.61 for sulphur application doses of 0.5, 1 and 2g S kg^{-1}, respectively. It should be noted that Mn concentration in all S treatments progressively increased during the growing season; averaged across S timing, the concentration at harvest was 1.9 times more than planting for the highest S application dose. The figure for second and third sulphur application doses were 1.61 and 1.63 times, respectively. In line with our hypothesis,

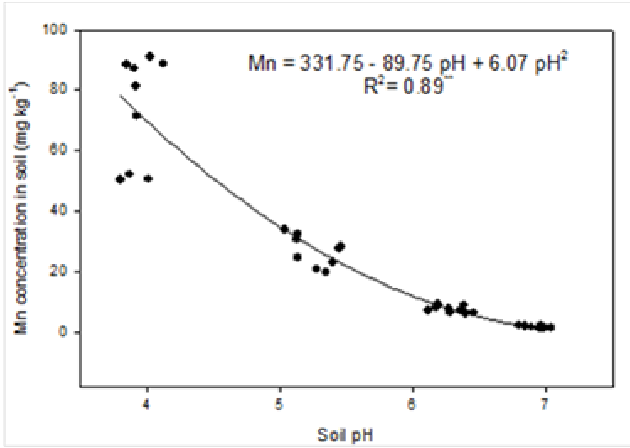

Figure 5. Effect of soil pH on the Mn concentration in Bintang Series soil.

addition of elemental sulphur decreased soil pH (Table 1) and it may be considered as a plausible explanation for soil Mn release under conditions of our experiment. The significant and strong Pearson coefficient correlation between soil pH and Mn concentration (Table 2) supported our assumption and its pattern followed quadratic regression model, Mn=331.75 - 89.75 pH + 6.07 pH^2, as exhibited in (Figure 5).

DISCUSSION

The availability of soil nutrients for plant growth and development would be mainly dependent upon soil acidity. Therefore, the main objective of the present study was to examine the influence of elemental sulphur dose as a soil acidulates on soil acidity as well as soil nutrient mobility for plants. According to Vidyalakshmi et al. (2009) elemental sulphur oxidation produces protons and it may increases soil acidity. The results of present study revealed that application of elemental sulphur decreased soil pH (Figure 1). These results are in agreement with laboratory and field study conducted by Owen et al. (1999) where they modeled the relationship between elemental sulphur application dose and soil pH and found that application of 4 tons of S per hectare linearly decreased soil pH from 7 to 4.8. They reported a slight decrease in soil pH with 8ton S ha^{-1} compared to 4 ton ha^{-1}, and the minimum pH of 4.2 was reached at S dose of 12 ton ha^{-1}.

Soil pH is well recognized as an important factor affecting soil nutrient mobility and may result in plant performance (Lindsay, 19799 and Chein et al., 2011). While some authors demonstrated the positive effect of elemental sulphur on soil nutrient mobility (Klikocka, 2011), Sameni and Kasraian (2004) did not found the nutrient mobility change due to elemental sulphur addition to soil. As stated by Lambers et al. (2008) and Viani et al. (2014), the increase of weathering dose, the change in oxidation state of some nutrients and the displace of cations from exchangeable sites due to high concentration of hydrogen ions account for the increases in soil nutrient solubility. Results from this study shows that elemental sulphur significantly increased Al, Fe, Mn and Zn mobility. The increase in Al mobility at pH around 5 under conditions of our experiment (Figure 2) is in line with the data presented by Franz et al. (2007), Ward et al. (2011) and McBride (1994). The release of plant available Al at pH 5.5 and less was reported by Franz et al. (2007). McBride (1994) revealed that once soil pH lowered much below 5.5, aluminosilicate clays and Al hydroxide minerals begin to dissolve, releasing Al- hydroxyl cations and Al^{3+} that then exchange other cations from soil colloids resulting in the buildup of Al concentration in soil solution. Hesterberg et al. (1993) modeled changes in the solubility of some trace elements in soil as a result of acidification and they found that Zn, Cd, and Al solubilities increased exponentially with decreasing pH and Ca concentration. Figure 2 showed that Al solubility followed soil pH that fitted with the non-linear regression model,but it can be linearized if the relationship between log of Al concentration as a function of soil pH was considered, log Al = 7.5 – 1.56 pH, R^2= 0.92**. Regarding the solubility equation of gibbsite (pAl = 3pH–8.5) that with one unit decrease in soil pH the Al solubility increases 10^3 times, that of our conditions decreased less and was equal to $10^{1.56}$ times.

The increase in Fe mobility due to S addition in present study (Table 4) is in line with Shenkr and Chen (2005) observation. They reported the role of elemental S as an easy to apply possibility for soil pH reduction and to increase soil Fe release. The linear function of soil Fe with soil pH (Log Fe = 0.78-0.25 pH, R^2=0.75**) is similar to the stability diagrams for Fe as function of pH that developed by Lindsay (1979); Log Fe^{2+} = 15.75 - (pe + pH) - 2pH, however with each unit decrease in soil pH, the Log Fe under conditions of our experiment would increase by 0.25 units while that of Lindsay would increase by 2 units. This difference in the rate of Fe change due to soil pH reduction can be attributed to the differences in soil properties as well as the assumptions was considered by Lindsay (1979).

In line with our finding, Hesterberg et al. (1993) modelled changes in the solubility of some trace elements in soil as a result of acidification. They found that Zn solubility increased exponentially with decreasing pH and Ca concentration (Wang et al., 2006). Besides, Bolan et al. (2003) reported that Zinc activity increases rapidly with decreasing pH, indicating that Zn nutritional problems are seldom encountered in soils at pH value below 5.5 provided sufficient Zn. Although the strong and significant linear regression model that relates Zn solubility to soil pH under conditions of our experiment (log Zn = 3.66 – 0.72 pH, R^2= 0.93^{**}) is similar to that of Lindsay (1979), Log Zn^{2+} = 5.8 – 2pH, that indicates 10^2 times increase in Zn with 1 unit decrease in pH, with each unit decrease in soil pH Zn release in Bintang Series soil increases $10^{0.72}$ times. This difference in effect of soil pH on the degree of Zn solubility can be attributed to differences between Bintang Series soil and the soil considered by Lindsay (1979). The pH-dependency of Zn solubility that is governed by a complex mixture of mechanisms including adsorption on sesquioxides, co-precipitation with Al, and complexation with organic matter was previously documented (Bolan et al., 2003).

It was documented that pH is the master variables and it control the solubility of soil nutrients (Pendias, 2001; Wang et al., 2006). The stability diagram for Mn as functions of pH was presented by Lindsay (1979); Log Mn^{2+} = 25.27 – (pe + pH) – 2pH. As it is clear from the equation, the linear regression model explained the relationship between log Mn and pH and with each unit increase in acidity, Log Mn increased 2 times and that of Mn 100 times. The nonlinear relationship between Mn and soil pH under conditions of our study (Figure 5) can be linearized if the relationship between log of Mn concentration as a function of soil pH was considered, Log Mn = 4.05 – 0.53 pH. With different coefficients, this equation is similar to that of Lindsay (1979).

Conclusion

In conclusion, the present study provides evidence that elemental sulphur, which is considered to be a soil amendment, is able to increase soil nutrient mobility by reduction of Bintang Series soil pH. With each unit increase in S dose, soil pH decreases by around 1.52 units. In addition, the release and solubility of each nutrient in Bintang Series soil started at specific pH. The pH value at which Fe, Al, Zn and Mn concentration significantly increased are 3.94, 5.26, 5.26 and 6.29 respectively.

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