Final Report of Findings

for

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and

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by

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EXECUTIVE SUMMARY

Potential use of a wastewater treatment plant sludge (SW204) and a spent active carbon (SW411) as a soil conditioner and to increase plant growth

The main purpose of this study were to determine whether two recycled materials, a wastewater treatment plant sludge (SW204) and a spent active carbon (SW411), were effective and safe to be used in the environment as a soil conditioner and to increase plant growth. Two test crops were used: kangkung (*Ipomoea reptans*) and cow grass (*Axonopus compressus*). Both crops were grown on three types of soils: a sandy clay loam, sandy clay, and clay soil. The soil treatments were NPK 15:15:15 fertilizer, NPK+SW204, and NPK+SW411, and they were applied at a rate of 1.5 t ha^{-1} for the NPK 15:15:15 fertilizer and 30 t ha^{-1} each for SW204 and SW411. The soil treatments were applied evenly onto the soil surface, and applications were done only once prior to planting. The field experiments were carried out under a rain shelter, with 5-mm daily watering of plants. Kangkung was planted in planting trays and the grass in polybags. Plastic bags were taped at the bottom of the planting trays and polybags to collect daily leachates. The kangkung experiment was carried out in two planting cycles (26 days for each cycle) and the grass experiment in a single planting cycle, lasting 89 days. Soil, plant, and leachate were analyzed for their nutrient (N, P, K, Ca, and Mg) and heavy metal (Sb, As, Ba, Zn, Cd, Cr, Cr^{6+}, Co, Cu, Pb, Hg, Ni, Ag, Se, V, Mo, Tl, and Be) concentrations. The soils were also analyzed for soil pH, carbon content, and for several soil physical properties (bulk density, aggregation, aggregate stability, and soil water characteristics). SW204 and SW411 were found to be good soil conditioners. Both these organic materials were rich in N and K plant nutrients. Consequently, cow grass and kangkung had benefitted from the application of SW204 and SW411. The beneficial effects of SW204 and SW411 depended on the soil type. Overall, however, plant growth of kangkung and grass were the highest (in terms of their fresh and dry biomass weights) on soils treated with these organic materials. SW204 and SW411 were rich in N and K which suggest that they could be a good source of nutrients for oil palm, which has a high demand of N and K. Soils additionally treated with SW204 and SW411 also experienced lower P losses via leaching, compared with soils treated only with NPK fertilizer. In the grass experiment, SW204 and SW411 improved several soil physical properties, possibly due to the increased root and soil microbial activities that would in turn improve soil structure. The organic matter content in SW204 and SW411 were also high, and their addition into the soil had helped to increase the C content in the soil. Nonetheless, this study suggested that SW204 and SW411 would better be applied as a split application (*i.e.*, applied frequently but in small doses) rather than as a single large dose. This is to reduce nutrient losses via leaching when not all their nutrients can

be immediately used by the plants. To minimize P fixation, both SW204 and SW411 would also have to applied as close as possible to the plant roots. Finally, analysis of the 18 heavy metal elements in the SW204 and SW411, soils, plants (kangkung and cow grass), and leachate revealed that these heavy metals were either undetected or present in very small amounts that were very far below the maximum allowable levels according to Malaysia's safety standards. The SW204 and SW411 also had undetectable presence of semivolatile and volatile organics, pesticides, PCBs, and miscellaneous (such as asbestos and furan). Consequently, this study has showed that SW204 and SW411 are safe to be applied as a soil conditioner.

<u>**FULL REPORT**</u>

Potential use of a wastewater treatment plant sludge (SW204) and a spent active carbon (SW411) as a soil conditioner and to increase plant growth

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1. OBJECTIVES OF STUDY

The general objectives of this study were to determine whether two recycled materials, a wastewater treatment plant sludge (SW204) and a spent active carbon (SW411), are effective and safe to be used in the environment as a soil conditioner and to increase plant growth.

The specific objectives of this study were:

1. To determine the effectiveness of SW204 and SW411 to increase the growth and yield of a food crop, water spinach (*Ipomoea reptans* or kangkung), grown in three types of soils.
2. To determine the effectiveness of SW204 and SW411 to increase the growth of a non-food crop, cow grass (*Axonopus compressus*), grown in three types of soils.
3. To determine the safety of using SW204 and SW411 as a soil conditioner by determining:
    a) the amount of soil nutrients and heavy metal elements lost via leaching due to the application of SW204 and SW411 on these three soil types, and
    b) the amount of heavy metal elements in the test crops (kangkung and grass).

2. METHODOLOGY

2.1 Kangkung (two planting cycles)

Kangkung or water spinach (*Ipomoea reptans*) was used as a test food crop. The kangkung was grown on three types of soils, which were: Bungor series (Typic Paleudult), Serdang series (Typic Paleudult), and Munchong series (Typic Hapludox). These soils were selected because they had different soil textures from one another, from coarse- to fine-textured soils. The Bungor series is a sandy clay loam (SCL) soil, Serdang a sandy clay (SC) soil, and Munchong a clay (C) soil. These soils, sampled from soil depths 0 to 150 mm, were from various agricultural fields located at the Uni. Putra Malaysia Serdang campus (2.992829° N, 101.704663° E).

Kangkung seeds were germinated in seed trays, and after one week, they were transplanted into larger planting trays, measuring 170 x 630 x 200 mm in width, length, and height, respectively, so that each tray had a total of evenly spaced 22 seedlings. Each tray also had 15 kg of a given soil type.

The soil treatments were: 1) only NPK fertilizer, 2) NPK with SW204, and 3) NPK with SW411. The NPK 15:15:15 fertilizer was applied once prior to transplanting and at a rate of 15 g per tray (approximately 1.5 t ha^{-1}), which is that recommended by Vimala and Chan (1990). SW204 and SW411 were also each applied once prior to transplanting but at a rate of 270 g per tray (approximately 30 t ha^{-1}). The NPK fertilizer, SW204, and SW411 were applied evenly on the soil surface.

In short, there were nine treatments (3 soil types x 3 applied materials), with 3 replications per treatment. The total number of planting trays was thus 9 treatments x 3 replications, or 27. The experiment was arranged in a RCB (Randomized Completely Block) design, under a rain shelter located at Field No. 16, Faculty of Agriculture, UPM Serdang (2.984650° N, 101.734984° E) for more effective control of the water input and monitoring of plant growth and nutrient losses via leaching (via the bottom of trays).

Prior to transplanting, 20 kangkung seedlings were sampled for their initial biomass weight, plant nutrient content, as well as the concentration of any heavy metal elements. Also prior to transplant, the initial soil characteristics for each soil type was determined for its pH and concentrations of carbon, nutrients (N, P, K, Ca, and Mg), and heavy metal elements.

Water was supplied each day in the morning to the plants at a rate of 5 mm per tray for all treatments. Every planting tray had 15 uniformly spaced holes at the bottom to allow discharge of water out of the tray, via leaching. This leachate was collected via attached plastic bags at the bottom of each tray to determine the amount of water as well as the amount of nutrients and heavy metals (if any) lost from the soil via leaching. The plastic bags were also taped to the tray to prevent evaporative losses of the leachate.

At the end of four weeks after transplanting, all kangkung plants were destructively sampled for the final biomass weight and their carbon and nutrient status as well as for any heavy metal concentrations.

Without discarding any soil from the planting trays, kangkung was planted again for the second planting cycle. In other words, this experiment was repeated for the second time. This second cycle was carried out in the exact manner as described for the first cycle, except no additional fertilizer, SW204, and SW411 were applied in this second cycle.

The first planting cycle started with transplanting on Apr. 29. 2017 and ended by the destruction sampling of kangkung on May 25, 2017. The second planting cycle started immediately after the first cycle with transplanting on May 26, 2017 and ended on Jun. 21, 2017.

Soil water content was measured every two weeks throughout the experiment using the FieldScout TDR 100 Soil Moisture Meter (Spectrum Technologies Inc., Illinois, USA). Soil samples were collected three times: before the start of the first planting cycle (initial), at the end of the first planting cycle, and after the second planting cycle.

Soil samples were air-dried for one week in the soil laboratory prior to any analysis. Bulk density of undisturbed soil samples were determined using the core ring method (Blake and Hartge, 1986), and aggregate stability was measured by the wet-sieving method by Kemper and Rosenau (1986). For aggregation, the air-dried soil samples were placed on a set of nested sieves and shaken to separate the aggregates into 8.0, 4.76, 2.83, 2.0, 1.0, 0.5, 0.3, and <0.3 mm size fractions (Kemper and Rosenau, 1986). The aggregate size distribution was represented by the mean weight diameter (MWD) index (van Bavel, 1949). The pipette method by Teh and Jamal (2006) was used to determine the soil particle size distribution (texture).

Soil water retention curve for matric potentials 0.0 to -1.5 MPa was measured by the pressure plate method (Richards, 1947). Soil water content at saturation (SAT), field capacity (FC), and permanent wilting point (PWP) were considered as the amount of water held in the soil at 0.0, -0.03, and -1.5 MPa, respectively. Soil available water content (AWC) was calculated as the difference between the soil water content at FC and PWP. The power function $y = ax^{-b}$ is fitted to the soil water retention data, where b is the slope of the soil water retention. The larger the b, the steeper the slope, and the less able the soil is able to hold onto the water.

For chemical analysis, samples of soil, whole plant, and leachate were given to ES Laboratories (M) Sdn. Bhd., an independent and accredited laboratory for analysis on the concentration of nutrients, carbon, and heavy metals.

2.2 Grass (one planting cycle)

The potential use of SW204 and SW411 as a soil conditioner and to increase plant growth was further tested on a second test plant, a non-food crop: cow grass (*Axonopus compressus*).

Mature grass was transplanted and grown in cylindrical polybags, each measuring 240 mm in diameter and 200 mm in height. Each polybag was filled with 8 kg of a given soil type. The same three soil types, as described earlier, were used upon which to grow the grass. The number of treatments and replications were the same, as well as the application rates of the recycled materials. The NPK 15:15:15 fertilizer was applied at a rate of 5 g per polybag, and SW204 and SW411 were each applied at 90 g per polybag.

The layout of the field experiment and parameters measured as described earlier for kangkung were repeated for the grass experiment. Pre-grown (matured) cow grass was cut to size and transplanted into the polybags (size and numbers as described earlier). Note that the kangkung and grass experiments were carried out simultaneously and at the same rain shelter location.

Watering was carried out daily in the morning at a rate of 5 mm per polybag. The polybags had evenly spaced holes to allow discharge of excess water from the soil. Daily leachate was collected via plastic bags taped to the polybags (to prevent evaporative losses) and pooled for chemical analysis of the leachate. The leachate collected was analyzed for nutrient and heavy metal concentrations. The grass was grown for three months, then destructively sampled for the dry biomass weight and whole plant nutrient, carbon, and heavy metal content.

The grass was transplanted on Feb. 9, 2017 and destruction sampling of the grass was on May 5, 2017.

Like in the kangkung experiment, the same soil physical analysis were carried out in the manner as previously described. Soil samples were collected before the grass transplanting and after the destruction sampling of the grass. Samples of soil, whole plant, and leachate were given to the same ES Laboratories (M) Sdn. Bhd., an independent and accredited laboratory, for chemical analysis on the concentration of nutrients, carbon, and heavy metals.

2.3 Statistical analysis

ANOVA (Analysis of Variance) was used to determine significant effects of SW204 and SW411 on plant growth, soil properties, and leaching.

Detection of a significant main effect was followed up by mean separation test according to Fisher's LSD test to detect significant differences between the means.

Detection of a significant interaction effect was followed up simple effects test to detect significant differences between treatments for a given soil type or planting cycle. Simple effect test was according to LSD with Bonferroni adjusted alpha levels to reduce the risk of Type I error.

Statistical analysis was carried out using IBM SPSS software ver. 20 (International Business Machines Corp., New York, USA).

3. RESULTS AND DISCUSSION

3.1 Initial properties

The complete chemical properties of SW204 and SW411 are listed in the Appendices. Both SW204 and SW411 contained large amounts of plant macro nutrients N, P, and K (Table 1).

Table 1.Chemical properties of SW204 and SW411. Units (except for pH) are expressed on a dry weight basis.

Property	SW204	SW411
N (mg kg^{-1})	44000.0	41000.0
P (mg kg^{-1})	1000.0	1700.0
K (mg kg^{-1})	63000.0	22000.0
Moisture (%)	9.8	58.5
Organic matter (%)	80.6	40.8
pH	8.7	7.5

Compared with the nutrient content in oil palm fronds and empty fruit bunches (Moradi et al., 2013), SW204 and SW411 had, on average, four times more N and three times more P. SW204 was particularly rich in K, containing three times more K than in SW411 and empty fruit bunches and four times more K than in oil palm fronds. SW204 also contained two times more organic matter than SW411. More than half of SW411 was moisture, compared to only 10% of SW204. Finally, both SW204 and SW411 were neutral to basic.

The soil properties of Bungor, Serdang, and Munchong series were typical of these soil types (Table 2). Bungor series, due to the its high sand content, was a coarse-textured soil, and in contrast, the Munchong series, due to its high clay content, was a fine-textured soil. Because these three soils were sampled from the top soil (0–150 mm depth), the carbon content in these soils (1.3 to 1.9%) were expectedly higher than if the soils were sampled from the subsoils or lower soil depths. These soils were also acidic with pH between 3 and 4, typical of Malaysian mineral soils.

Table 2. Mean (± s.e.) of initial physico-chemical properties of the sandy clay loam (SCL), sandy clay (SC), and clay (C) soils. Units (except for pH) are expressed on a dry weight basis.

Property	**Bungor (SCL)**	**Serdang (SC)**	**Munchong (C)**
Clay (<2 µm) (%)	24.38 (± 0.20)	38.55 (± 1.09)	78.71 (± 0.05)
Sand (0.5 – 2 mm) (%)	64.73 (± 1.07)	50.84 (± 2.19)	7.73 (± 1.03)
Carbon (%)	1.89 (± 0.08)	1.27 (± 0.06)	1.83 (± 0.04)
pH	4.39 (± 0.02)	4.37 (± 0.02)	3.38 (± 0.03)
N (mg kg^{-1})	4049.33 (± 61.85)	3463.33 (± 137.70)	6464.00 (± 1388.53)
P (mg kg^{-1})	286.67 (± 4.06)	165.67 (± 9.24)	386.33 (± 45.85)
K (mg kg^{-1})	1715.00 (± 89.11)	3055.67 (± 90.19)	407.33 (± 26.77)
Ca (mg kg^{-1})	172.00 (± 7.77)	186.33 (± 17.75)	99.00 (± 9.17)
Mg (mg kg^{-1})	193.33 (± 2.33)	53.00 (± 4.62)	87.00 (± 11.93)

The complete initial plant properties of kangkung and cow grass are listed in the Appendices. Both these plants, prior to their transplanting and soil treatment application, were rich in K, where about 2% of their dry biomass consisted of K (Table 3). The N content in both plants were also similar to each other, about 0.5%. Both plants comprised large amounts of water, particularly for kangkung, where more than 90% of the plant comprised moisture compared with 82% of grass. Compared with mature grass, young kangkung plants had more P by three times, Ca by nearly three times, and Mg by two times.

Table 3. Mean (± s.e.) of initial plant properties of kangkung (one week old) and cow grass (mature) prior to their transplanting and any treatment applications. Units are expressed on a dry weight basis.

Property	**Kangkung**	**Grass**
N (mg kg^{-1})	5065.33 (± 74.42)	4265.53 (± 1217.07)
P (mg kg^{-1})	6907.67 (± 789.16)	2290.67 (± 506.41)
K (mg kg^{-1})	20189.67 (± 1165.52)	220946.33 (± 981.20)
Ca (mg kg^{-1})	4292.67 (± 378.41)	1515.33 (± 85.26)
Mg (mg kg^{-1})	7398.67 (± 688.95)	3892.33 (± 174.38)
Moisture (%)	92.97 (± 0.41)	82.07 (± 0.69)

3.2 Kangkung experiment

Recall that there were three main effects in this experiment: soil treatments (T) (NPK, NPK+SW204, and NPK+SW411), soil types (S) (sandy clay loam, sandy clay, and clay soils), and planting cycles (C) (first and second planting cycle) (Table 4 – 6).

The partial eta squared η_p^2 in these tables indicate the effect of size or the degree of effect (*e.g.*, main or interaction effect) on a given dependent variable (*e.g.*, soil and plant properties). In other words, η_p^2 measures how strongly two or more variables are related or how large is the difference between groups. Consequently, the larger the η_p^2, the better because the stronger is the measured effect or difference. As a very general rule of thumb, η_p^2 = 0.01 is considered a small effect, η_p^2 = 0.06 a medium effect, and η_p^2 = 0.14 a large effect (Cohen, 1988).

Analysis of variance (ANOVA) revealed that the η_p^2 for all the significant main and interaction effects were equal or larger than 0.14, generally indicating large effect sizes or group differences were detected (Table 4 – 6).

Table 4. Statistical significance (and partial eta squared η_p^2) of the main and interaction effects on the chemical properties and plant growth in the kangkung experiment. Main effect T is the soil treatments, S is the soil types, and C is the planting cycles. Note: soil pH and C were measured only at the start and end of experiment, so there is no Cycle (C) effect for these two properties.

Property	**T**	**T x S**	**T x C**	**T x S x C**
Soil pH	*** ($\eta_p^2 = 0.843$)	ns	–	–
Soil C	*** ($\eta_p^2 = 0.772$)	ns	–	–
Soil nutrient content				
N, P, Mg	ns	ns	ns	ns
K	** ($\eta_p^2 = 0.180$)	** ($\eta_p^2 = 0.432$)	* ($\eta_p^2 = 0.140$)	ns
Ca	*** ($\eta_p^2 = 0.400$)	*** ($\eta_p^2 = 0.418$)	ns	ns
Plant nutrient content				
N	*** ($\eta_p^2 = 0.427$)	*** ($\eta_p^2 = 0.412$)	* ($\eta_p^2 = 0.151$)	ns
P	ns	ns	ns	ns
K	*** ($\eta_p^2 = 0.247$)	ns	ns	ns
Ca	** ($\eta_p^2 = 0.187$)	ns	ns	ns
Mg	*** ($\eta_p^2 = 0.387$)	ns	ns	ns
Plant fresh weight	*** ($\eta_p^2 = 0.556$)	** ($\eta_p^2 = 0.257$)	*** ($\eta_p^2 = 0.407$)	ns
Plant dry weight	** ($\eta_p^2 = 0.186$)	ns	*** ($\eta_p^2 = 0.382$)	ns
Soil water content	*** ($\eta_p^2 = 0.366$)	ns	*** ($\eta_p^2 = 0.371$)	** ($\eta_p^2 = 0.239$)

** p<0.10; ** p<0.05; *** p<0.01; ^{ns} p>0.10*

Overall, the soil treatments (either as a main or interaction effect) had a significant effect (p<0.10) on plant fresh and dry biomass weight, soil water content, soil pH, soil content in C, K, and Ca, and plant nutrient content in N, K, Ca, and Mg. Only soil N, P, and Mg and plant P showed no significant change (p>0.10) due to the treatments. The three-way interaction between the main effects (TxSxC) was not significant (p>0.10) for most soil and plant properties, except for soil water content and nutrient content in the leachate (Table 4 and 6). In short, the ANOVA results revealed that the effect of SW204 and SW411 on soil and plant properties would generally depend on the soil type and planting cycle.

Table 5. Statistical significance (and partial eta squared η_p^2) of the main and interaction effects on the soil physical properties in the kangkung experiment. Main effect T is the soil treatments, S is the soil types, and C is the planting cycles. Note: the soil physical properties were measured only at the start and end of experiment, so there is no Cycle (C) effect.

Property	**T**	**T x S**
Bulk density	ns	ns
Aggregation	ns	* ($\eta_p^2 = 0.385$)
Aggregate stability	ns	ns
Soil water retention		
Saturation	ns	ns
Field capacity	** ($\eta_p^2 = 0.316$)	ns
Permanent wilting point	ns	ns
Available water content	ns	ns
Slope	ns	ns

** p<0.10; ** p<0.05; *** p<0.01; ^{ns} p>0.10*

Table 6. Statistical significance (and partial eta squared η_p^2) of the main and interaction effects on cumulative leachate volume and nutrient contents in the leachate in the kangkung experiment. Main effect T is the soil treatments, S is the soil types, and C is the planting cycles.

Property	**T**	**T x S**	**T x C**	**T x S x C**
Leachate volume	ns	ns	ns	ns
Nutrient content				
N	*** ($\eta_p^2 = 0.361$)	* ($\eta_p^2 = 0.206$)	ns	* ($\eta_p^2 = 0.232$)
P	*** ($\eta_p^2 = 0.290$)	ns	ns	** ($\eta_p^2 = 0.288$)
K	*** ($\eta_p^2 = 0.742$)	** ($\eta_p^2 = 0.248$)	*** ($\eta_p^2 = 0.440$)	** ($\eta_p^2 = 0.276$)
Ca	** ($\eta_p^2 = 0.190$)	ns	** ($\eta_p^2 = 0.160$)	ns
Mg	*** ($\eta_p^2 = 0.353$)	ns	*** ($\eta_p^2 = 0.292$)	ns

** p<0.10; ** p<0.05; *** p<0.01; ^{ns} p>0.10*

The beneficial effect of SW204 and SW411 on plant growth depended on the soil type. Overall, however, total plant biomass (both fresh and dry weights) for kangkung was the highest in the SW204 soil treatment, followed by SW411, and NPK (Fig. 1 – 5). Nonetheless, SW204 and SW411 had a significant effect on plant biomass only for sandy clay and clay soils (Fig. 1) and only during the second planting cycle (Fig. 2 and 4). The poorer growth in the second cycle could be due to the higher soil Ca:Mg ratio in the second cycle, which depressed plant growth. The soil Ca:Mg ratio for the first and second cycle were 0.9 and 1.2, respectively.

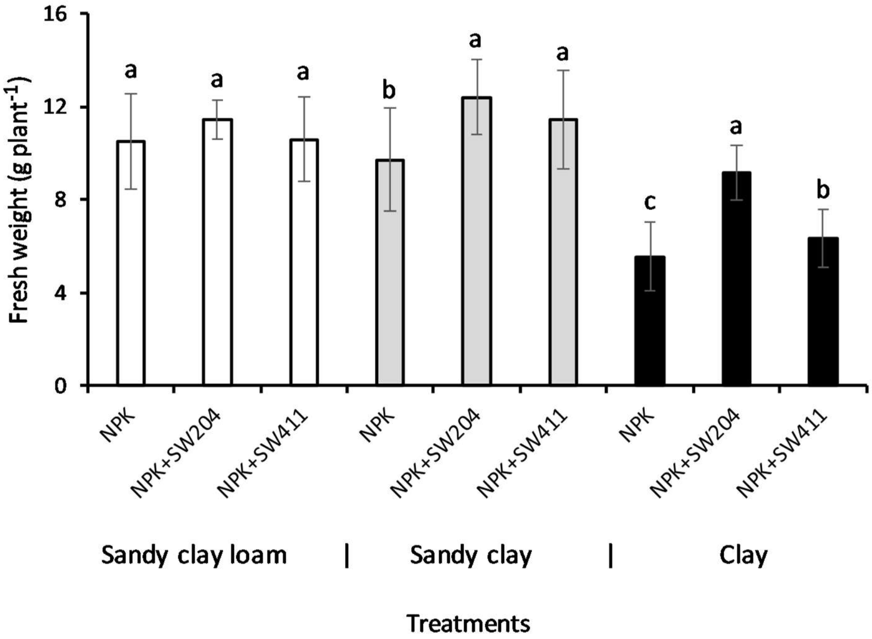

Fig. 1. Total plant fresh weight, averaged (± s.e.) across the two planting cycles, due to the effect of the treatments applied on different soil types in the kangkung experiment. For the same soil type, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

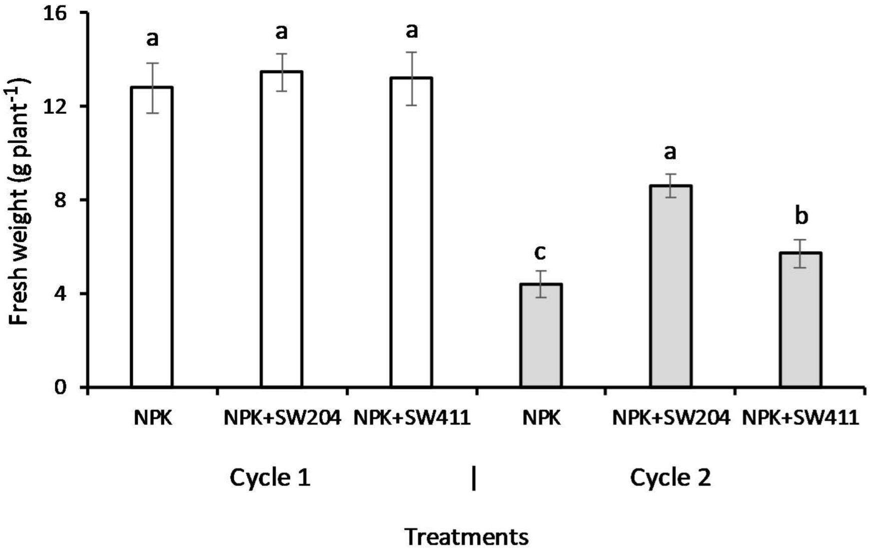

Fig. 2. Total plant fresh weight, averaged (± s.e.) across all soil types, due to the effect of the treatments in the two planting cycles in the kangkung experiment. For the same planting cycle, means with the same letter are not significantly different ($p>0.05$) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

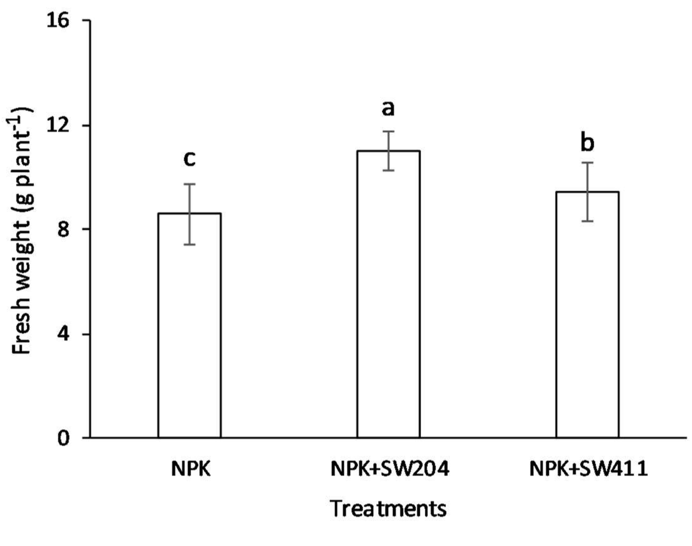

Fig. 3. Total plant fresh weight, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different ($p>0.05$) from one another according to the mean separation test by LSD.

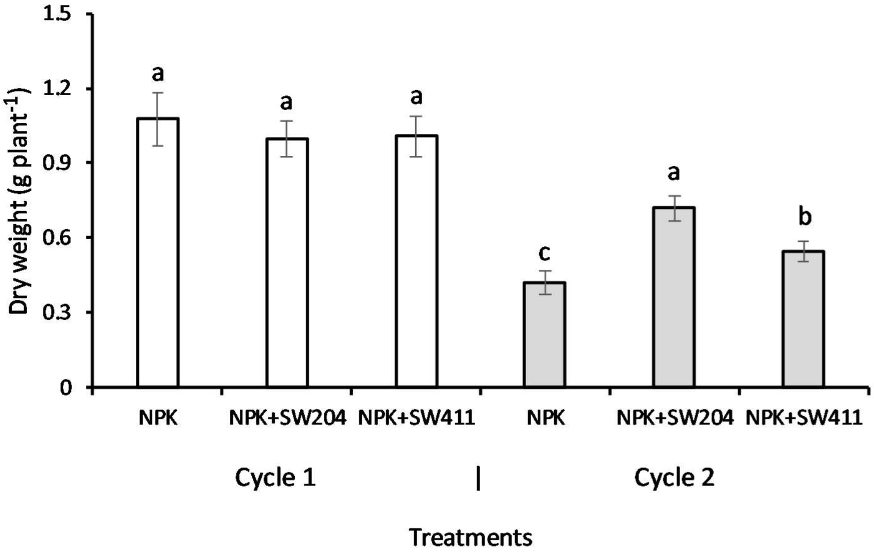

Fig. 4. Total plant dry weight, averaged (± s.e.) across all soil types, due to the effect of the treatments in the two planting cycles in the kangkung experiment. For the same planting cycle, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

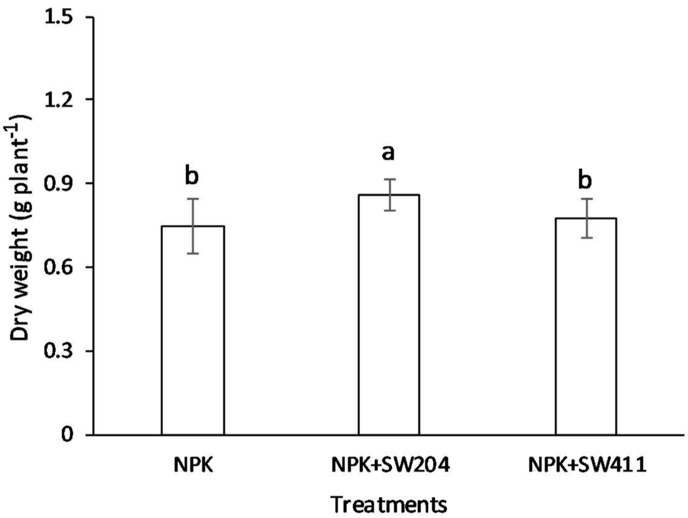

Fig. 5. Total plant dry weight, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

Detailed analysis and discussion of the results are presented in Appendix A (pg. 27). Overall, SW204- and SW411-treated soils gave the highest plant biomass due to the high nutrient K demand by kangkung, which was provided by SW204 and SW411 (as they both have high K content; Table 1). High organic matter content in both SW204 and SW411 also caused treated soils by them to have an overall higher C content than in the solely NPK-treated soils. Nonetheless, due to the high nutrient content in SW204 and SW411, soils treated by both these materials experienced the highest nutrient losses via leaching. The exception was P because P is intrinsically immobile (fixed) in soils. Overall, soils treated with SW204 and SW411 contained higher soil water content than soils treated only with NPK.

3.2.1 Before and after treatments

At the end of the kangkung experiment, all the soil treatments (NPK, SW204, and SW411) had significantly increased C and nutrient contents in the soils (Table 7). This was due to the addition of nutrients by the treatments into the soils.

Table 7. Means (± s.e.) of several soil chemical properties in the kangkung experiment, before (initial) and after the experiment.

	Before treatment	**After treatment (end of experiment)**		
Property	**(Initial)**	**NPK**	**NPK+SW204**	**NPK+SW411**
pH	4.05 (± 0.17)	4.38** (± 0.11)	4.26** (± 0.10)	4.05^{ns} (± 0.08)
C	1.67 (± 0.10)	1.91** (± 0.14)	2.86** (± 0.22)	2.57** (± 0.21)
N	4658.89 (± 611.04)	3497.89** (± 495.78)	3049.44** (± 162.70)	2963.00** (± 412.90)
P	279.56 (± 34.66)	704.44** (± 42.14)	719.89** (± 45.66)	696.11** (± 23.39)
K	1726.00 (± 384.09)	3090.00** (± 817.62)	3031.22** (± 681.29)	3017.33** (± 603.15)
Ca	152.44 (± 14.87)	312.44** (± 37.05)	273.78** (± 35.37)	250.67** (± 27.55)
Mg	111.11 (± 21.46)	267.22** (± 41.25)	276.56** (± 31.34)	236.89** (± 26.94)

*For the same soil property, after treatment means followed by either ** or ^{ns} indicate significant ($p<0.05$) or non-significant ($p>0.05$) difference, respectively, from the before treatment (initial) mean, according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).*

The exception was soil N which declined after the experiment. Its decline is possibly due to plant uptake of N for growth and leaching (as well as evaporative) losses. SW204 and SW411 added organic matter into the soil; thus, raising the soil C. The presence of plants such as kangkung would also increase soil C through increased soil microbial activities and root turnover. Only SW411 did not significantly increased ($p>0.05$) soil pH. This could be due to the nitrification of the added N into nitrates and the loss of these nitrates via leaching (as discussed previously).

3.3 Grass experiment

There were two main effects: soil treatments (T) and soil types (S) (note: no planting cycle (C) in the grass experiment). ANOVA revealed that the soil treatments had a significant effect (either as a main or interaction effect) ($p<0.10$) on soil C, N, and Mg, plant N, plant biomass weight (both fresh and dry weights), several soil physical properties (bulk density, aggregation, aggregate stability and saturation), leachate volume, and the P, K, Ca, and Mg contents in the leachate (Table 8 – 10) . The partial eta squared η_p^2 for all the significant effects were larger than 0.14, generally indicating a large effect of size.

Table 8. Statistical significance (and partial eta squared η_p^2) of the main and interaction effects on the chemical properties and plant growth in the grass experiment. Main effect T is the soil treatments and S is the soil types.

Property	**T**	**T x S**
Soil pH	ns	ns
Soil C	** ($\eta_p^2 = 0.338$)	* ($\eta_p^2 = 0.423$)
Soil nutrient content		
N	*** ($\eta_p^2 = 0.605$)	ns
P, K, Ca	ns	ns
Mg	* ($\eta_p^2 = 0.301$)	ns
Plant nutrient content		
N	* ($\eta_p^2 = 0.288$)	ns
P, K, Ca, Mg	ns	ns
Total plant fresh weight	** ($\eta_p^2 = 0.387$)	ns
Total plant dry weight	*** ($\eta_p^2 = 0.523$)	* ($\eta_p^2 = 0.406$)
Soil water content	ns	ns

** p<0.10; ** p<0.05; *** p<0.01; [ns] p>0.10*

Table 9. Statistical significance (and partial eta squared η_p^2) of the main and interaction effects on the soil physical properties in the grass experiment. Main effect T is the soil treatments and S is the soil types.

Property	**T**	**T x S**
Bulk density	ns	*** ($\eta_p^2 = 0.586$)
Aggregation	ns	* ($\eta_p^2 = 0.401$)
Aggregate stability	ns	*** ($\eta_p^2 = 0.582$)
Soil water retention		
Saturation	** ($\eta_p^2 = 0.379$)	ns
Field capacity	ns	ns
Permanent wilting point	ns	ns
Available water content	ns	ns
Slope	ns	ns

** p<0.10; ** p<0.05; *** p<0.01; ^{ns} p>0.10*

Table 10. Statistical significance (and partial eta squared η_p^2) of the main and interaction effects on cumulative leachate volume and nutrient contents in the leachate in the grass experiment. Main effect T is the soil treatments and S is the soil types.

Property	**T**	**T x S**
Leachate volume	* ($\eta_p^2 = 0.255$)	ns
Nutrient content		
N	ns	ns
P	*** ($\eta_p^2 = 0.522$)	ns
K	* ($\eta_p^2 = 0.273$)	ns
Ca	*** ($\eta_p^2 = 0.658$)	ns
Mg	** ($\eta_p^2 = 0.350$)	ns

** p<0.10; ** p<0.05; *** p<0.01; ^{ns} p>0.10*

The fresh and dry weights of grass grown on soils treated with SW204 and SW411, particularly the sandy clay loam and sandy clay soils, were the highest compared to grass grown on soils treated only with NPK fertilizer (Fig. 6 – 8). Averaged across all soil types, SW204 gave the largest plant biomass compared to other the treatments (Fig. 6 and 7).

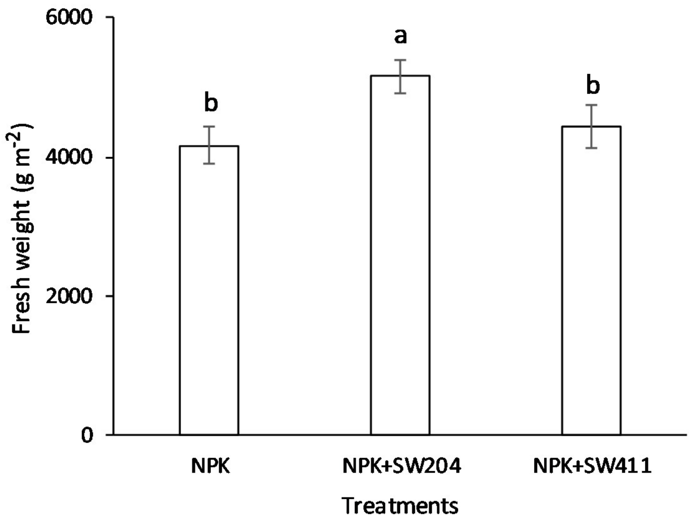

Fig. 6. Cumulative total plant fresh weight, averaged (± s.e.) across all soil types, due to the effect of the treatments in the grass experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

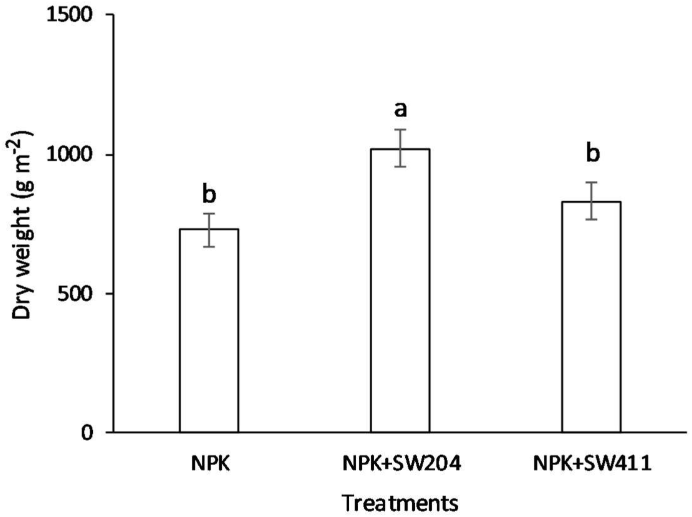

Fig. 7. Cumulative total plant dry weight, averaged (± s.e.) across all soil types, due to the effect of the treatments in the grass experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

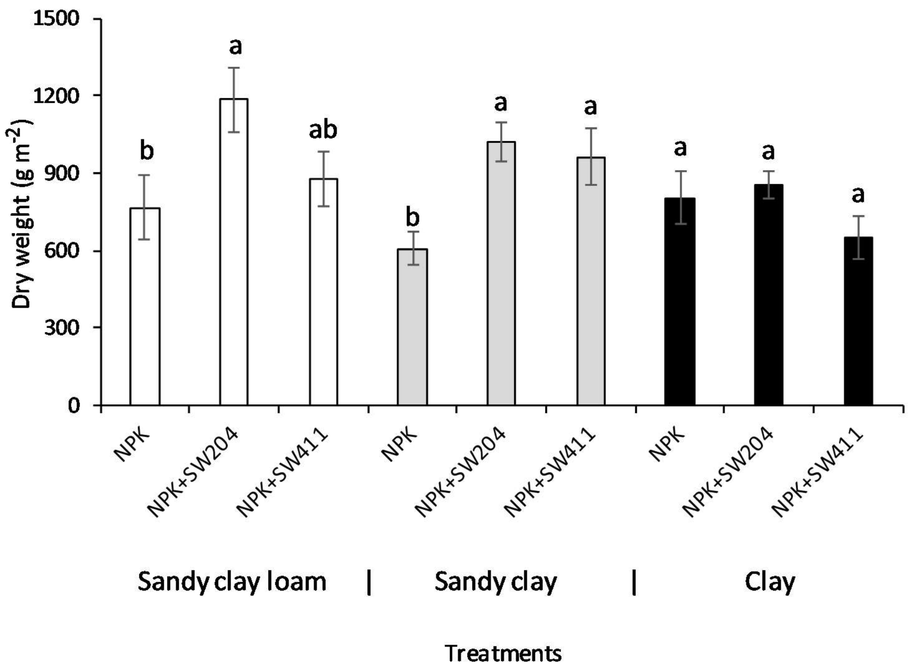

Fig. 8. Mean (± s.e.) of cumulative total plant dry weight due to the effect of the treatments applied on different soil types in the grass experiment. For the same soil type, means with the same letter are not significantly different ($p>0.05$) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

Detailed analysis and discussion of the results are presented in Appendix B (pg. 45). Grass has a high nutrient demand for N then K. Consequently, grass grown on the soils treated with SW204 and SW411 (which were rich in N and K) produced higher plant biomass than the grass grown on soils treated only with NPK. The grass N content in the SW204- and SW411-treated soils were also higher than that in the sole NPK-treated soils. Like in the kangkung experiment, higher soil C contents were also observed in soils treated with SW204 and SW411 because of the high organic matter content in both these materials. Due to high nutrient content in both SW204 and SW411, soils treated with these materials experienced higher losses of nutrients via leaching, compared to the soil treated only with NPK. Again, like that observed in the kangkung experiment, only P was the exception. P losses via leaching was the lowest in the soils treated with SW204 and SW411. This is because P is mostly immobile in the soil, but the application of NPK provided more soluble P into the soils, where these forms of P could be easily leached away. Addition of either SW204 and SW411 had helped to reduce the P leaching losses.

3.3.1 Before and after treatments

Compared to the initial soil properties (before addition of any soil treatments), the nutrients-rich soil treatments generally had increased ($p<0.05$) soil pH, C, P, Ca, and Mg (Table 11). Only soil N was significantly lower ($p<0.05$) and soil K was not significantly different ($p>0.05$) from the initial soil N and K, respectively. Recall that grass has the highest demand for N, then K. This meant that large quantities of soil N and K were taken up by the grass during the experiment, causing a net reduction in soil N and no difference in soil K at the end of the experiment.

Table 11. Means (± s.e.) of several soil chemical properties in the grass experiment, before (initial) and after treatment application.

	Before treatment	**After treatment (end of experiment)**		
Property	**(Initial)**	**NPK**	**NPK+SW204**	**NPK+SW411**
pH	4.05 (± 0.17)	4.51** (± 0.12)	4.36** (± 0.09)	4.46** (± 0.10)
C	1.67 (± 0.10)	1.92** (± 0.16)	2.17** (± 0.08)	2.11** (± 0.12)
N	4658.89 (± 611.04)	1612.33** (± 102.16)	2471.22** (± 194.14)	1734.33** (± 154.61)
P	279.56 (± 34.66)	515.33^{ns} (± 76.27)	610.67** (± 124.13)	767.89** (± 154.61)
K	1726.00 (± 384.09)	2260.67^{ns} (± 273.95)	2108.00^{ns} (± 398.21)	1851.33^{ns} (± 358.65)
Ca	152.44 (± 14.87)	445.00** (± 69.54)	339.00** (± 40.46)	295.56^{ns} (± 24.31)
Mg	111.11 (± 21.46)	323.44** (± 37.11)	276.22** (± 24.78)	225.00** (± 29.86)

*For the same soil property, after treatment means followed by either ** or ^{ns} indicate significant ($p<0.05$) or non-significant ($p>0.05$) difference, respectively, from the before treatment (initial) mean, according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).*

3.4 Concentration of heavy metals

A total of 18 heavy metals were analyzed in this study. They were antimony (Sb), arsenic (As), barium (Ba), zinc (Zn), cadmium (Cd), chromium (Cr), chromium hexavalent (Cr^{6+}), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), silver (Ag), selenium (Se), vanadium (V), molybdenum (Mo), thallium (Tl), and beryllium (Be). These heavy elements were either undetectable (not present or very scarcely detectable) or present in concentrations *very much below* the maximum allowable levels according to Malaysian safety standards. Even for the detected heavy elements, their mean concentration values were still very much below the maximum allowable levels (Table 12).

Table 12. Mean concentration of heavy metals detected in the plants (kangkung and cow grass), soils (sandy clay loam, sandy clay, and clay soils), and leachate (from both kangkung and grass grown on all soil types). Values in brackets denote the maximum allowable level according to the Malaysian safety standards. Note: weights are expressed on a per dry weight basis.

	($mg\ kg^{-1}$)			($mg\ L^{-1}$)
Heavy metal	**Kangkung**	**Grass**	**Soils**	**Leachate**
Sb	0.31 (500)	*nd*	0.43 (500)	*nd*
As	*nd*	*nd*	0.12 (500)	0.026 (5)
Ba	6.97 (10000)	3.15 (10000)	8.89 (10000)	0.41 (100)
Zn	28.00 (5000)	39.07 (5000)	10.91 (5000)	0.522 (50)
Cd	*nd*	*nd*	0.09 (100)	*nd*
Cr	5.3 (2500)	8.77 (2500)	67.90 (2500)	*nd*
Cr^{6+}	*nd*	2.22 (500)	*nd*	*nd*
Co	*nd*	*nd*	0.28 (8000)	*nd*
Cu	15.59 (2500)	11.61 (2500)	8.58 (2500)	0.041 (25)
Pb	*nd*	0.67 (1000)	1.09 (1000)	*nd*
Hg	*nd*	*nd*	*nd*	*nd*
Ni	3.31 (2000)	3.91 (2000)	14.60 (2000)	*nd*
Ag	0.63 (500)	*nd*	*nd*	*nd*
Se	0.19 (100)	*nd*	*nd*	*nd*
V	*nd*	1.11 (2400)	72.64 (2400)	0.012 (24)
Mo	*nd*	*nd*	*nd*	*nd*
Tl	0.05 (700)	1.07 (700)	*nd*	0.02 (7)
Be	*nd*	*nd*	*nd*	*nd*

nd – not detected

Elemental analysis of SW204 and SW411 also revealed that heavy metals were mostly non-detectable or if present, their amounts were extremely low, far below the maximum safe levels according to the Malaysian safety standards. Semivolatile and volatile organics, pesticides, PCBs, and miscellaneous (such as asbestos and furan) in the SW204 and SW411 were also undetectable.

Consequently, this study has shown that SW204 and SW411 are safe to be applied in the environment.

Note that statistical analysis of the heavy metal contents in the kangkung, grass, soils, and leachate were not done for two reasons: 1) most of the heavy metals were non-detectable or even if detected, their presence were detected in only some but not all the replicates, and 2) even when a certain element was detected, its amount detected was extremely small and far below the maximum safe level; thus, their statistical analysis would not be meaningful or have a practical significance.

4. CONCLUSION

This study showed that SW204 and SW411 were good soil conditioners. Both these organic materials were rich in N and K plant nutrients. Consequently, crops with high nutrient demand for N (such as cow grass) and K (such as kangkung) would benefit from the application of SW204 and SW411. Overall, plant growth of kangkung and cow grass were the highest (in terms of their fresh and dry biomass weights) on soils treated with these organic materials. That SW204 and SW411 were rich in N and K meant that they could be a good source of nutrients for Malaysia's most important crop, oil palm, which has a high demand of N and even higher for K. Soils additionally treated with SW204 and SW411 also experienced lower P losses via leaching, compared with soils treated only with NPK fertilizer. In the grass experiment, SW204 and SW411 improved several soil physical properties, possibly due to the increased root and soil microbial activities that would in turn improve soil structure. The organic matter content in SW204 and SW411 were high. Consequently, their addition into the soil had helped to increase the C content in the soil. Organic matter is the lifeblood of soils, where increased soil organic matter would often improve many soil properties. Nonetheless, this study suggested that SW204 and SW411 would be better applied as a split application (*i.e.*, applied frequently but in small quantities each time) rather than as a single large dose. This is to reduce nutrient losses via leaching when not all their nutrients can be immediately used by the plants. To minimize P fixation, both SW204 and SW411 would also have to applied as close as possible to the plant roots.

Lastly, analysis of the 18 heavy metal elements in the SW204 and SW411, soils, plants (kangkung and cow grass), and leachate revealed that these heavy metals were either undetected or present in amounts that were very far below the maximum allowable levels according to Malaysia's safety standards. The SW204 and SW411 also had undetectable presence of semivolatile and volatile organics, pesticides, PCBs, and miscellaneous (such as asbestos and furan). Consequently, this study has showed that SW204 and SW411 are safe to be applied as a soil conditioner.

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Appendix A

Analysis and discussion of the results from the kangkung experiment

The plant biomass in the SW204 treatment was the highest because the plants in this soil treatment had the highest plant K and Mg contents compared with the other two soil treatments (Fig. A.1 and A.2). Kangkung has a high nutrient demand for K. Susila et al. (2012) determined that kangkung's K nutrient demand for maximum plant biomass on Ultisol soils is four and six times more than N and P, respectively. One of reasons for kangkung's high K demand is this plant naturally has a very high K content in the plant, as found in this study (Table 3 and Fig. A.1), as well as found by other researchers. Doka *et al.* (2014) and Umar *et al.* (2007), for instance, reported that the K content in *Ipomoea aquatica* (a semi-aquatic type of kangkung) was by far the highest among the other nutrients. Moreover, these researchers recommended kangkung to be a regular human food diet due to this plant's high K (as well as Fe) content. As shown in Table 1, SW204 had the highest K content, and its high K content was beneficial to encourage higher kangkung growth.

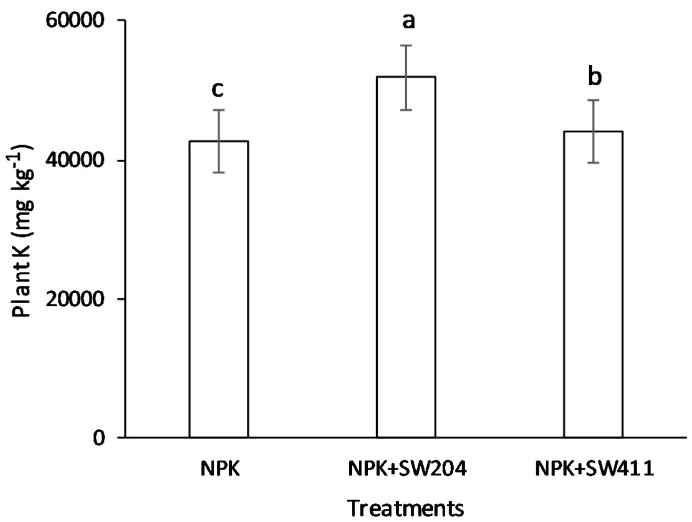

Fig. A.1. Plant K, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different ($p>0.05$) from one another according to the mean separation test by LSD.

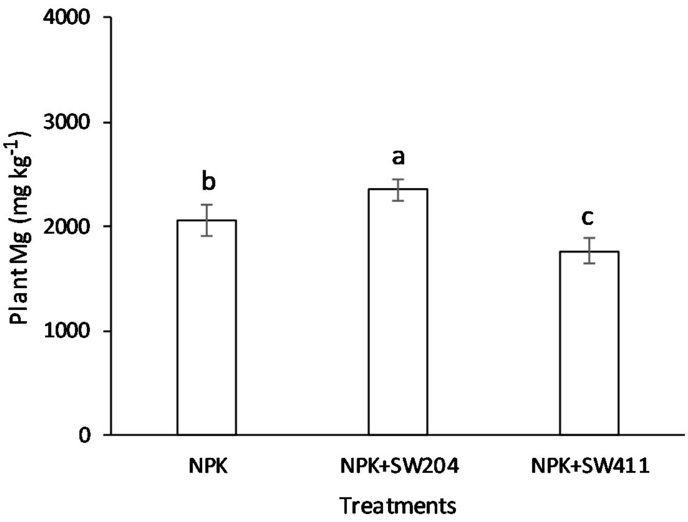

Fig. A.2. Plant Mg, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different ($p>0.05$) from one another according to the mean separation test by LSD.

That SW204 was rich in K, as well as in N, makes it a potential source of nutrients for oil palm. Oil palm's uptake of K is by far the largest among all nutrients (Teh, 2016; Ng, 1977). Tan (1977, 1976), for instance, reported that the nutrient demand, in kg ha^{-1} yr^{-1}, by mature oil palm is 287 to 387 K, compared with 191 to 267 N, 32 to 42 P, 85 to 114 Ca, and 48 to 67 Mg.

N and Ca are antagonistic to K and Mg, respectively (Mengel et al., 2001). This means that high K and Mg uptake by a plant tend to reduce the plant's intake of N and Ca. Since kangkung in the SW204 had the highest plant nutrient content in K and Mg, the plant's N and Ca contents in this soil treatment were conversely the lowest among the treatments (Fig. A.3 and A.4).

The soil treatments had a significant effect ($p<0.10$) on soil C, pH, Ca, and K (Fig. A.5 – A.9). Due to the high organic matter content in the SW204 and SW411 (Table 1), it is not surprising that soils treated with both these materials had higher soil C than soils applied only with NPK fertilizer (Fig. A.5).

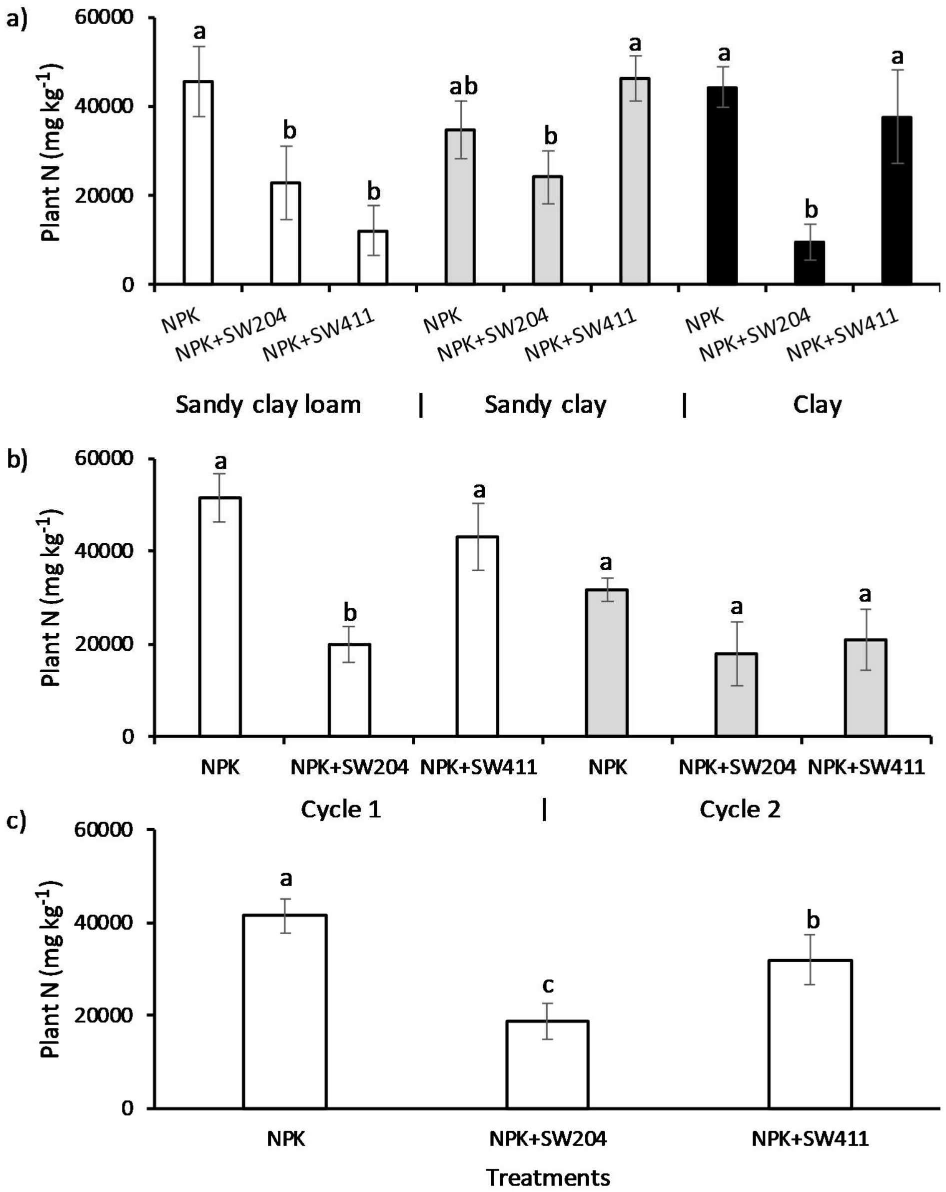

Fig. A.3. Mean (± s.e.) of plant N due to the effect of the treatments in the kangkung experiment when plant N is averaged across: a) both planting cycles, b) all soil types, and c) all soil types and planting cycles. For the same soil type or planting cycle, means with the same letter are not significantly different ($p>0.05$) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels) (for charts a and b) and mean separation test by LSD (for chart c).

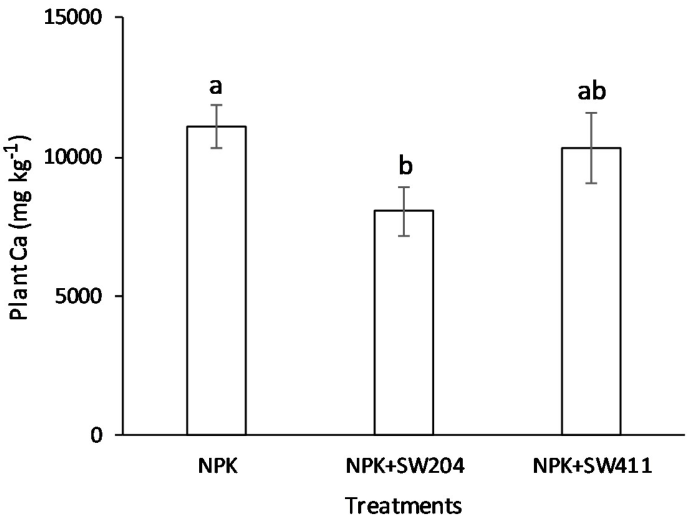

Fig. A.4. Plant Ca, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

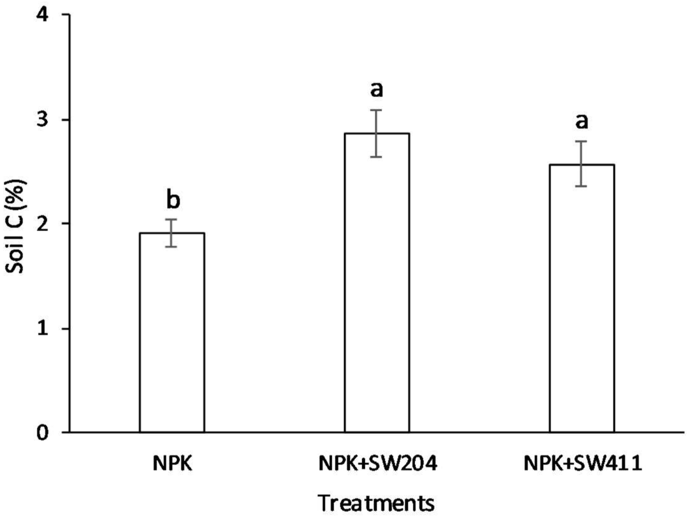

Fig. A.5. Soil C, averaged (± s.e.) across all soil types, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

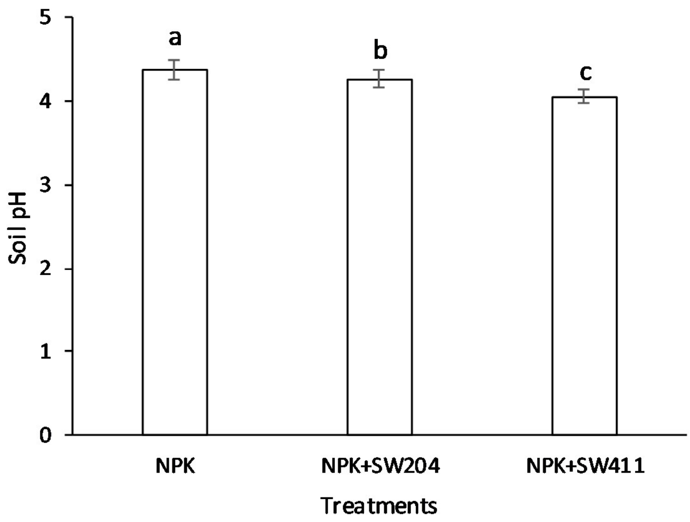

Fig. A.6. Soil pH, averaged (± s.e.) across all soil types, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

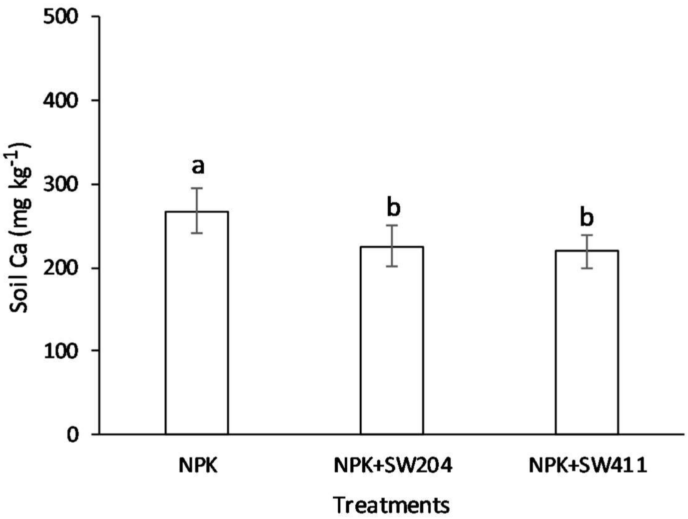

Fig. A.7. Soil Ca, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

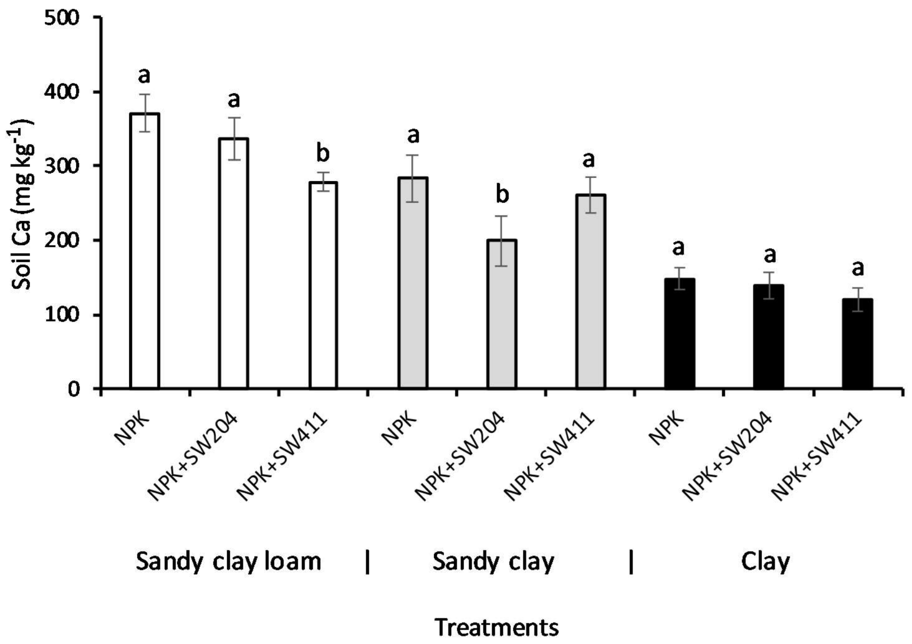

Fig. A.8. Soil Ca, averaged (± s.e.) across the two planting cycles, due to the effect of the treatments applied on different soil types in the kangkung experiment. For the same soil type, means with the same letter are not significantly different ($p>0.05$) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

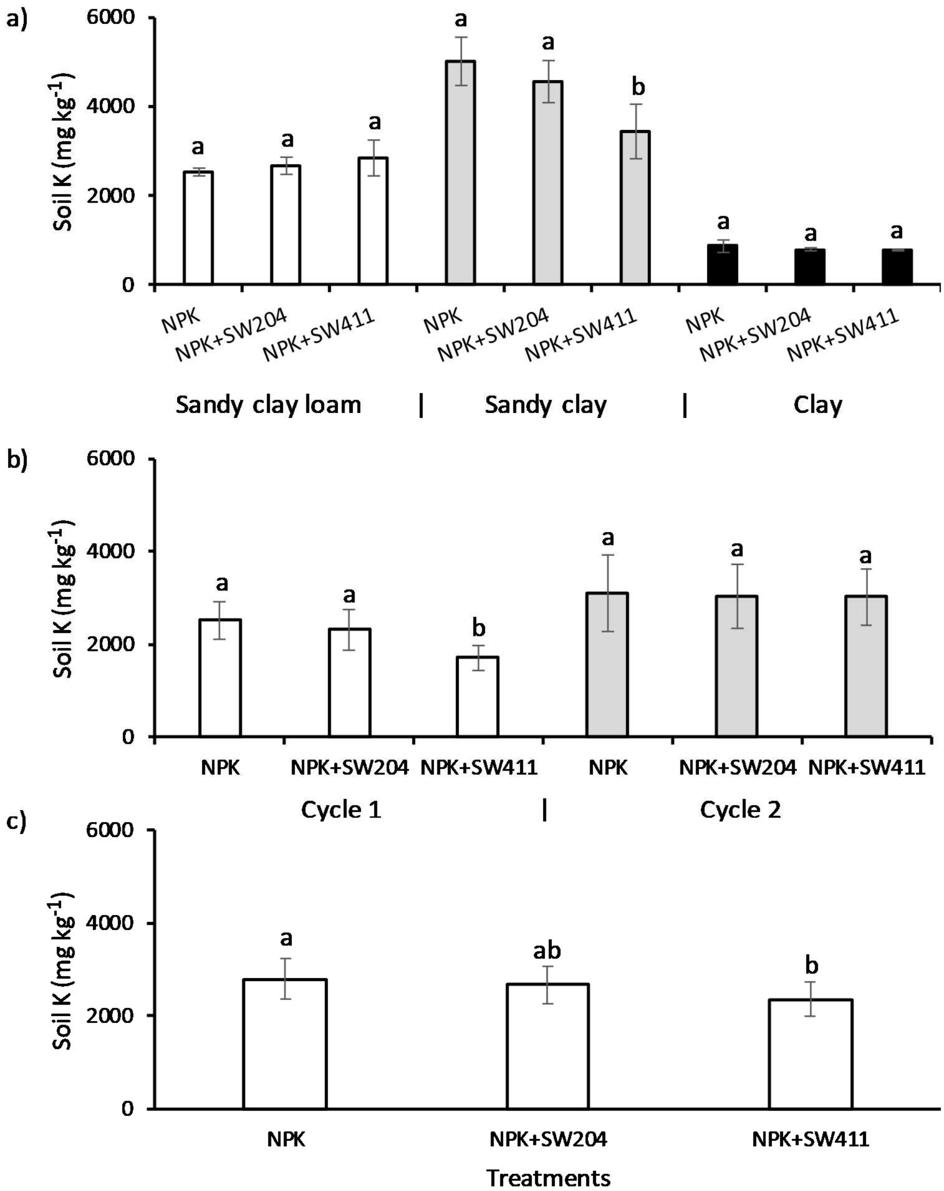

Fig. A.9. Mean (± s.e.) of soil K due to the effect of the treatments in the kangkung experiment when soil K is averaged across: a) both planting cycles, b) all soil types, and c) all soil types and planting cycles. For the same soil type or planting cycle, means with the same letter are not significantly different ($p>0.05$) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels) (for charts a and b) and mean separation test by LSD (for chart c).

Nonetheless, soil pH was the highest in soils treated only with NPK, followed by SW204, then SW411 (Fig. A.6). The lower soil pH in the SW204- and SW411-treated soils is possibly because of the high N losses from these soils (Fig. A.10 – A.12). Recall that both SW204 and SW411 had large amounts of N (Table 1), and the excess of N, unused by the kangkung, are vulnerable to losses via leaching (Fig. A.12). Addition of organic materials to soils can increase nitrification of N into nitrate, a form of N that can be directly taken up by plants, but if these nitrates are lost via leaching, their losses can lower the soil pH (McCauley et al., 2017). Most of these losses had occurred in the clay soil (Fig. A.10 and A.11). The poorer growth of kangkung in the clay soil (Fig. 1) due to its intrinsically low soil K (Fig. A.9a and Table 2) meant lesser N being taken up by the plant and more N available for leaching losses, compared to kangkung grown on other soil types.

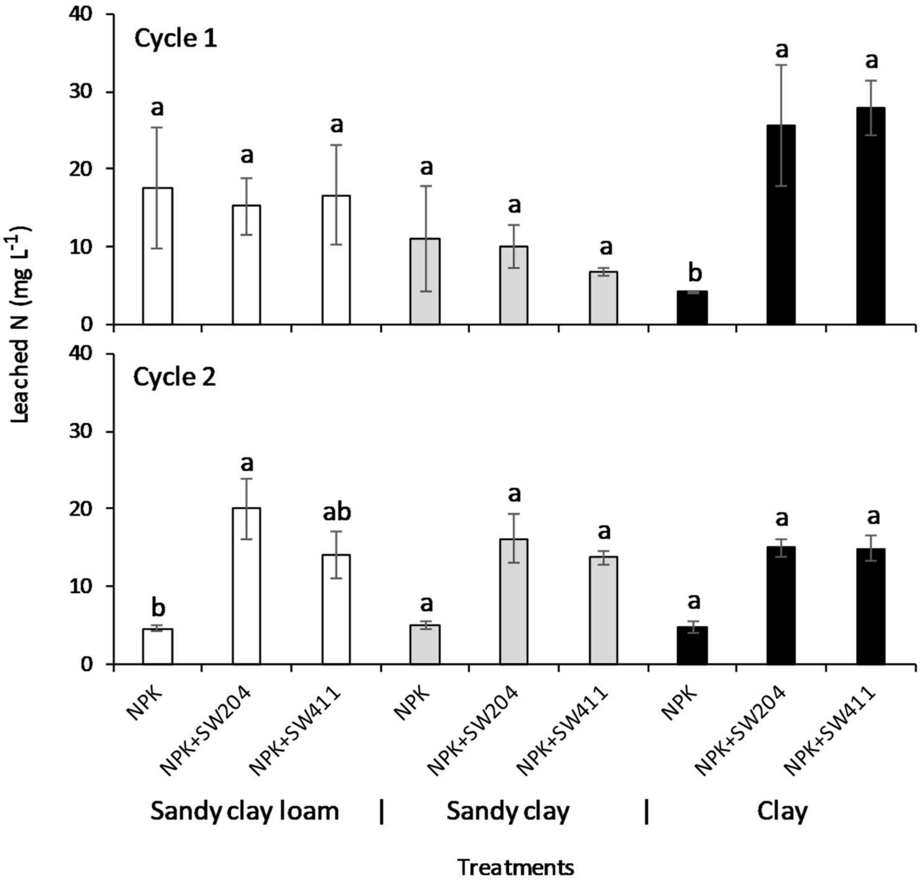

Fig. A.10. Mean (± s.e.) total leached N in the kangkung experiment due to the effect of the treatments applied on different soil types in the two planting cycles. For the same planting cycle and soil type, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

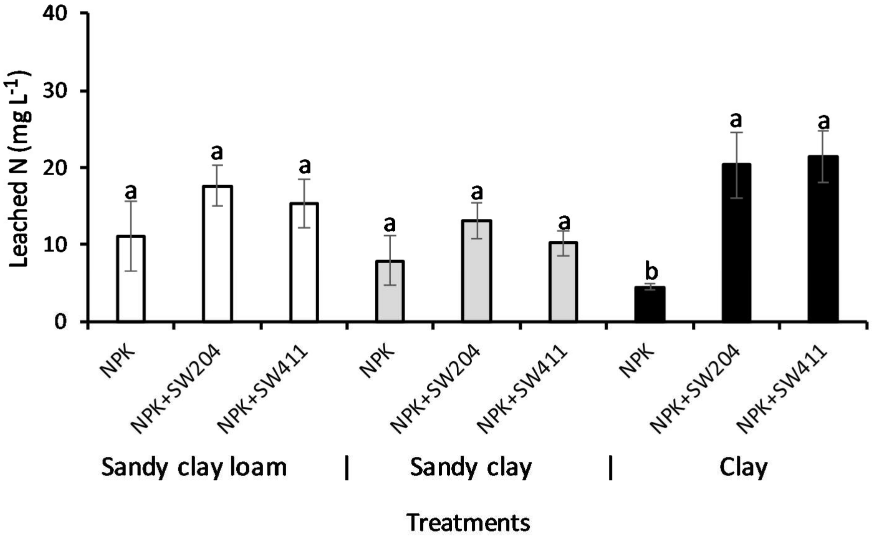

Fig. A.11. Total leached N, averaged (± s.e.) across the two planting cycles, due to the effect of the treatments applied on different soil types in the kangkung experiment. For the same soil type, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

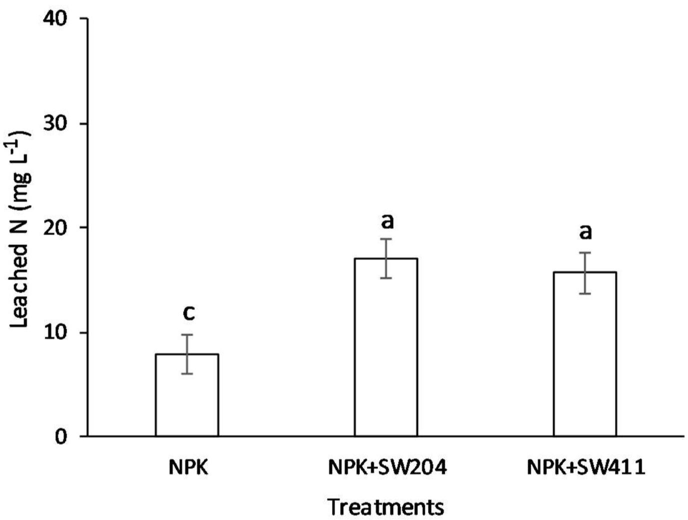

Fig. A.12. Total leached N, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

SW204 had the highest K content (Table 1). Consequently, soils treated with SW204 also had the most K losses via leaching (Fig. A.13 – A.16). The Ca and Mg content in SW204 and SW411 were not measured in this study, but it is likely that both these organic materials contain Ca and Mg in relatively large quantities too, like for their N, P, and K contents. Consequently, SW204- and SW411-treated soils contributed larger Ca and Mg leaching losses than soils applied only with NPK (Fig. A.17 – A.20).

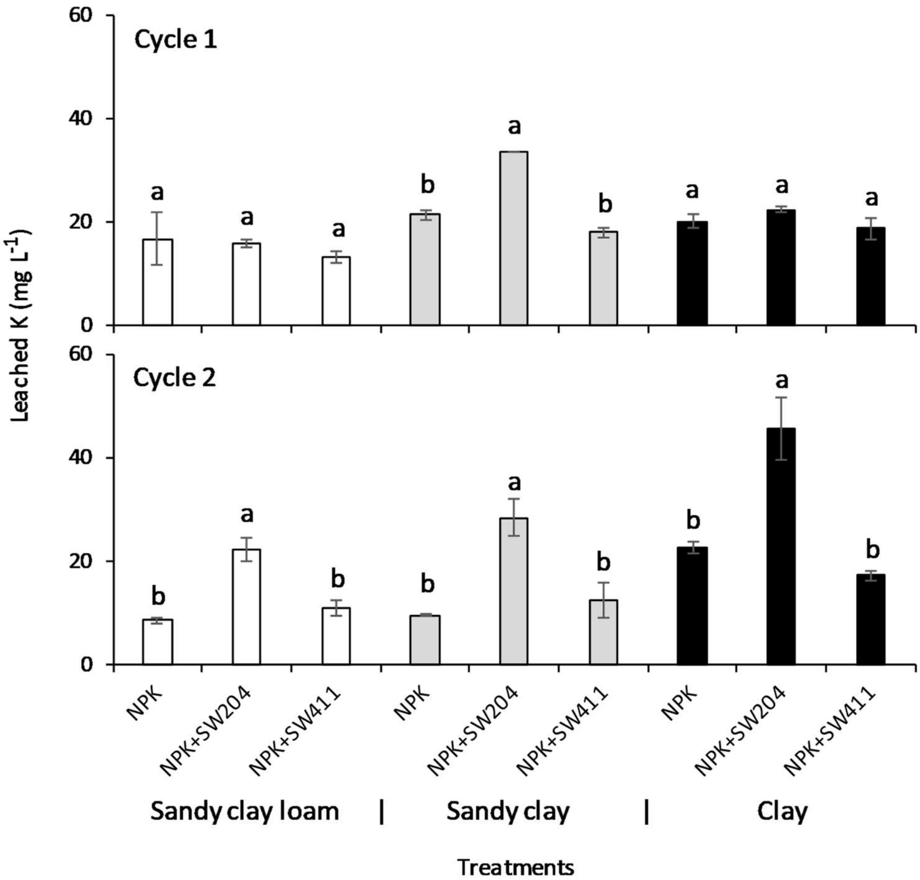

Fig. A.13. Mean (± s.e.) total leached K in the kangkung experiment due to the effect of the treatments applied on different soil types in the two planting cycles. For the same planting cycle and soil type, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

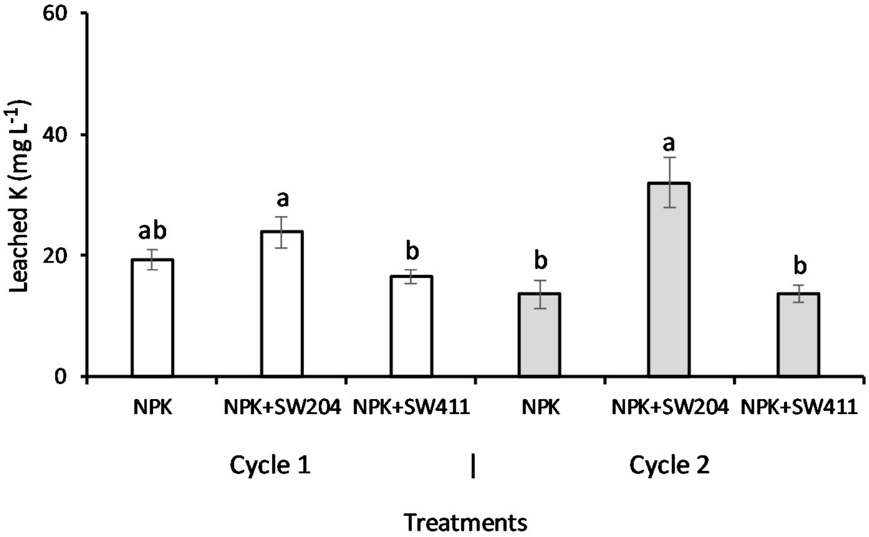

Fig. A.14. Total leached K, averaged (± s.e.) across all soil types, due to the effect of the treatments in the two planting cycles in the kangkung experiment. For the same planting cycle, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

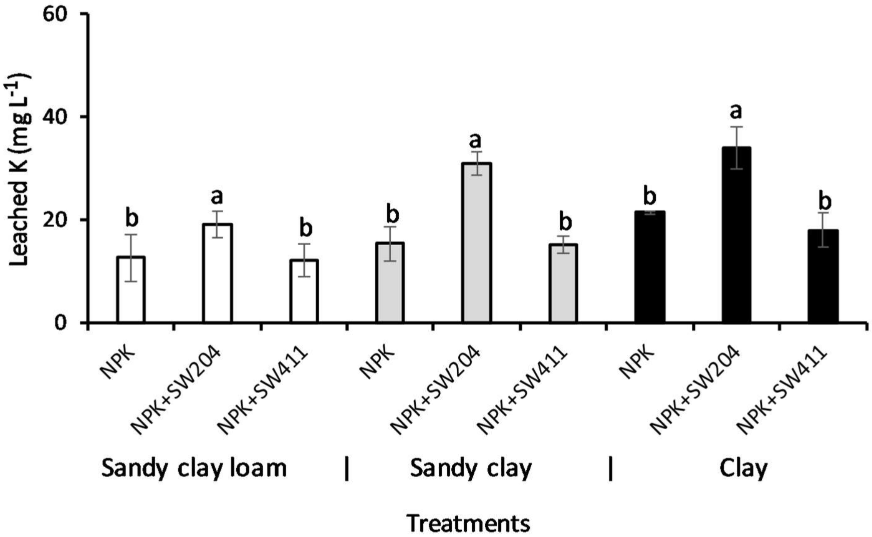

Fig. A.15. Total leached K, averaged (± s.e.) across the two planting cycles, due to the effect of the treatments applied on different soil types in the kangkung experiment. For the same soil type, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

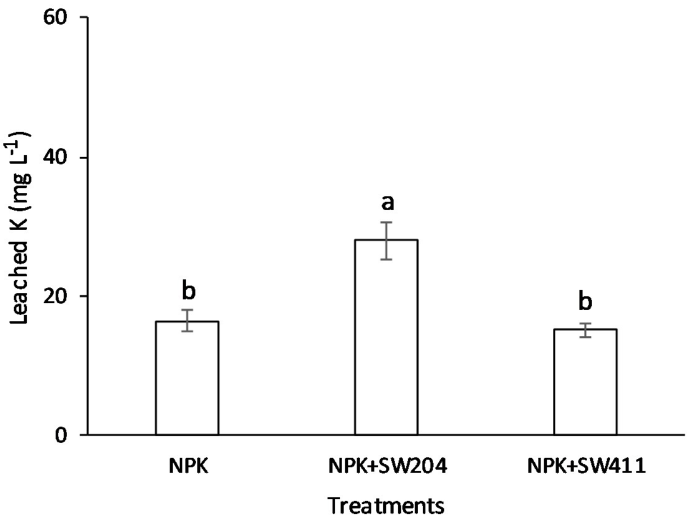

Fig. A.16. Total leached K, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

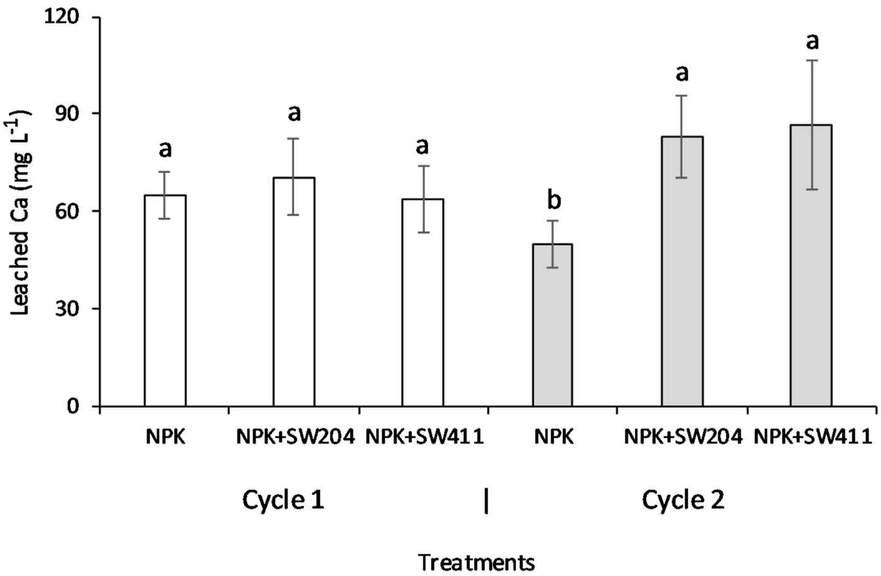

Fig. A.17. Total leached Ca, averaged (± s.e.) across all soil types, due to the effect of the treatments in the two planting cycles in the kangkung experiment. For the same planting cycle, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

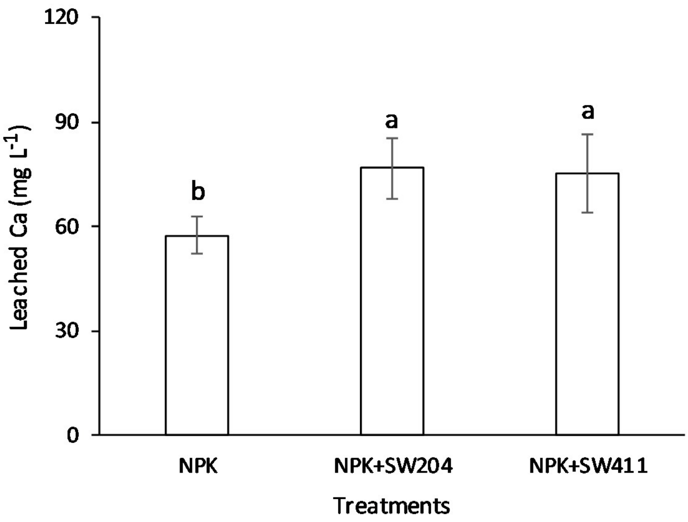

Fig. A.18. Total leached Ca, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

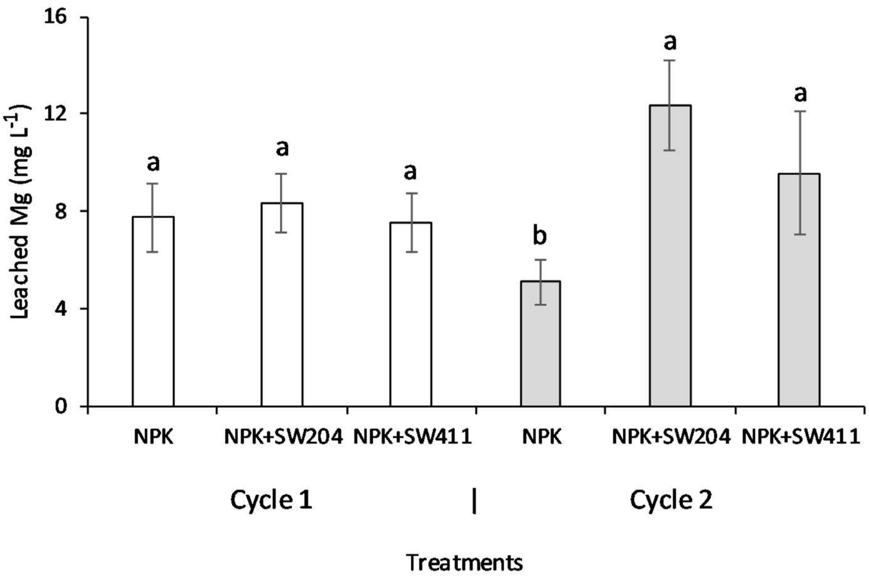

Fig. A.19. Total leached Mg, averaged (± s.e.) across all soil types, due to the effect of the treatments in the two planting cycles in the kangkung experiment. For the same planting cycle, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

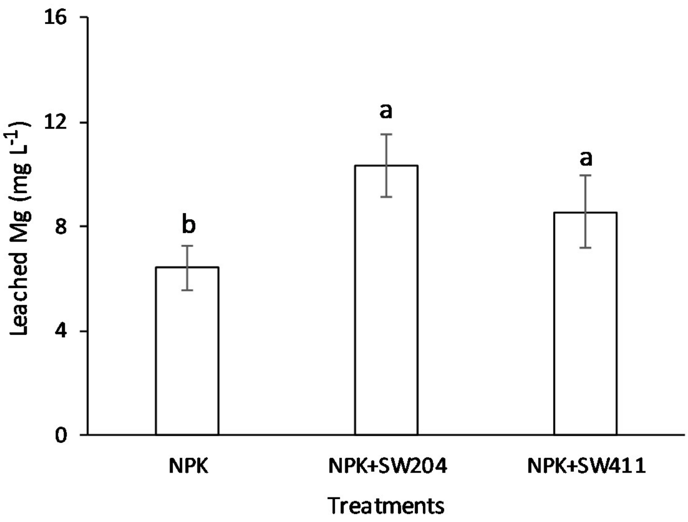

Fig. A.20. Total leached Mg, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

Unlike the leaching losses of other elements, the leaching loss of P was the lower for SW204-treated soils compared with the solely NPK-treated soils (Fig. A.21 and A.22). P has different mobility in the soil than other nutrients. In tropical soils like in Malaysia, P is largely immobile in the soil and little P is lost via leaching. P is most available to plants as ionic forms in the soil solution within soil pH 6 to 7.5 – and it is in these forms that the soluble and mobile P is most easily lost via leaching. But at soil pH below this range (like in this study; Table 1), P is mostly fixed by Fe and Al and are mostly immobile and unavailable to the plants.

P availability is akin to a chemical equilibrium reaction, where P moves back and forth between stages of non-labile P (slowly available), labile P (weakly available), and soil solution P (readily available) (Weil and Brady, 2017). As soil solution P is removed by plant root uptake, for instance, more P becomes available from the non-labile and labile P to replace that taken up by the plant. But adding P fertilizer can ironically remove soluble P from the soil solution, as the soluble P fertilizer reverts to non-labile and labile forms. This is why P fertilizer placement is important in agriculture to reduce P fixation. Preferably, P fertilizers should be placed as close as possible to the roots, minimizing the contact with the soil.

The application of SW204 to the soils would have increased soil P, but most of the P in these soils could be immobile and less vulnerable to leaching, compared with soils treated only with the NPK fertilizer. The

NPK fertilizer is very soluble, with faster release of soluble P into the soil solution; thus, more vulnerable to leaching loss of P.

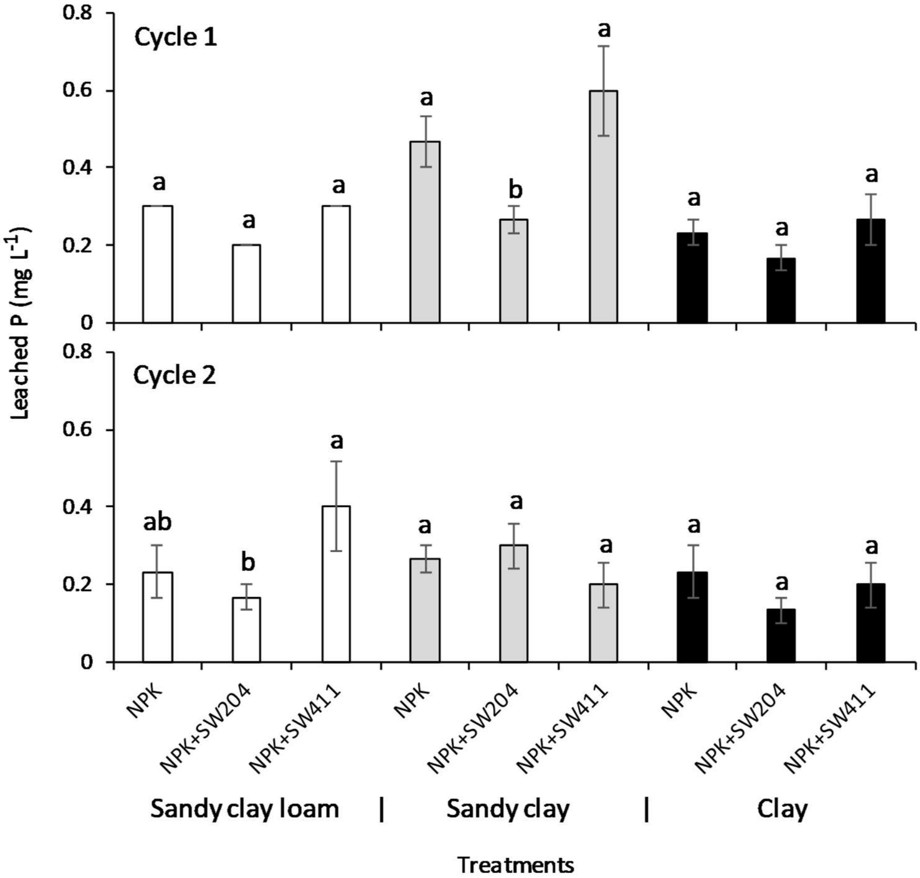

Fig. A.21. Mean (± s.e.) total leached P in the kangkung experiment due to the effect of the treatments applied on different soil types in the two planting cycles. For the same planting cycle and soil type, means with the same letter are not significantly different ($p>0.05$) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

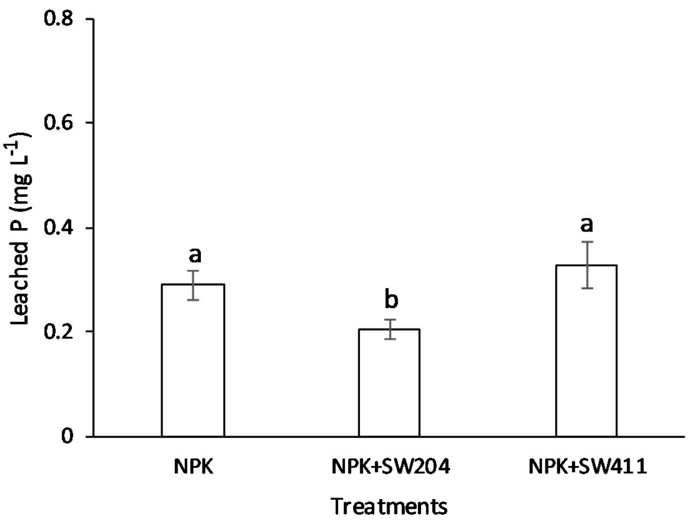

Fig. A.22. Total leached P, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

Mean soil water content was generally the highest in soils treated with SW204 and SW411 compared with soils treated only with NPK (Fig. A.23 – A.25). The differences in soil water content between treatments mostly occurred during the first planting cycle (Fig. A.23 and A.24).

Compared with changes to the soil chemical properties, there were much lesser significant changes for the soil physical properties (Table 5). Only soil aggregation and field capacity were significantly affected (p<0.10) by the soil treatments, but their trends were less clear and their significant differences weaker than that observed for the soil chemical and plant properties. The effect of organic matter on soil physical properties would also depend on the initial soil conditions. The three types of soils used in this study were not problematic soils in terms of their soil physical condition. The mean aggregation, aggregate stability, and bulk density for these three soils were 3.3 mm, 77%, and 1.04 Mg m^{-3}, respectively. These values are indicative of relatively good soil structure and perhaps why they were less sensitive to SW204 and SW411 treatments. Another possibility is the low plant biomass per unit area for kangkung, so there were less root and soil microbial activities that are often important to improve soil structure (Tisdall and Oades, 1982).

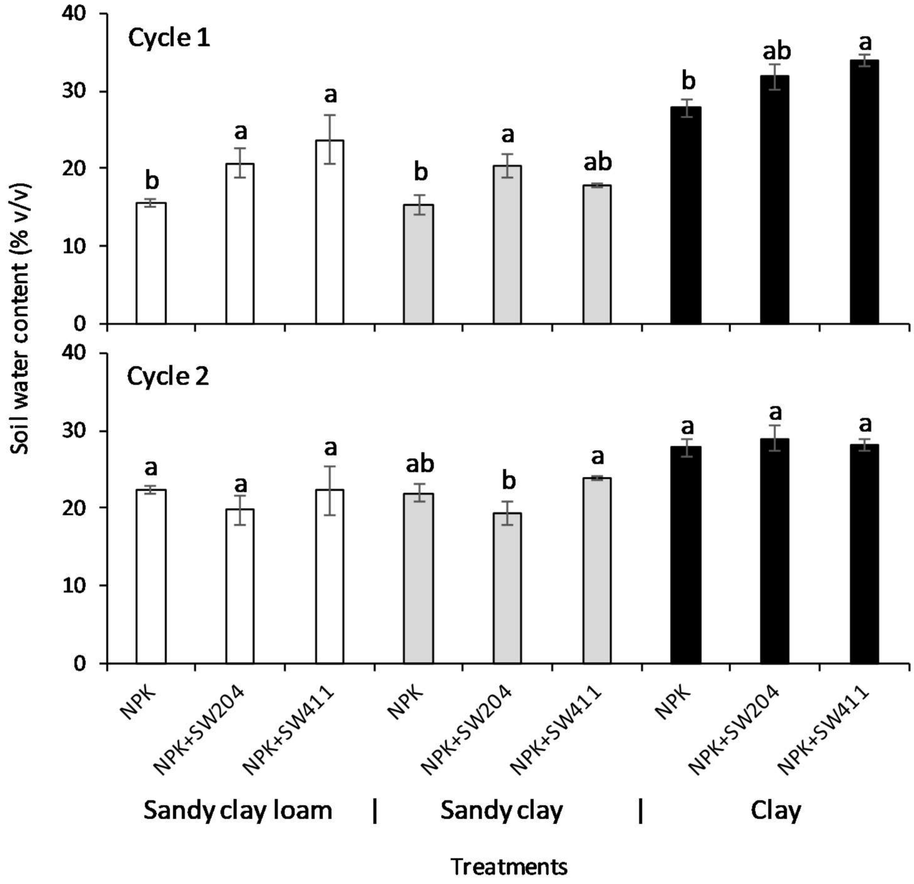

Fig. A.23. Mean (± s.e.) volumetric soil water content in the kangkung experiment due to the effect of the treatments applied on different soil types in the two planting cycles. For the same planting cycle and soil type, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

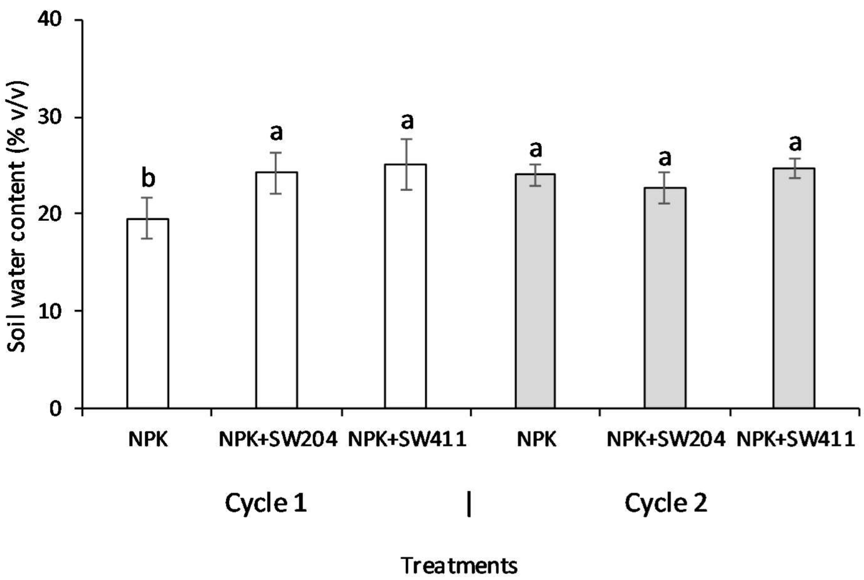

Fig. A.24. Volumetric soil water content, averaged (± s.e.) across all soil types, due to the effect of the treatments in the two planting cycles in the kangkung experiment. For the same planting cycle, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

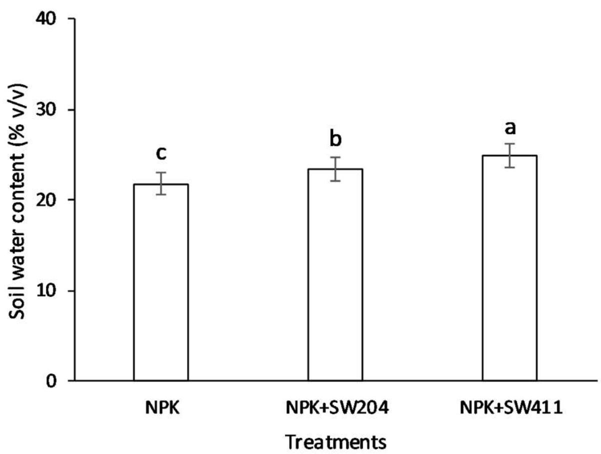

Fig. A.25. Volumetric soil water content, averaged (± s.e.) across all soil types and the two planting cycles, due to the effect of the treatments in the kangkung experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

Appendix B

Analysis and discussion of the results from the grass experiment

Unlike kangkung which required more K than N, cow grass, like most other grasses, have a larger requirement instead for N than K. The actual nutrient demand for grasses would vary according to the grass species, but generally, grasses require N:P:K ratios of 7:1:4 or 7:1:2 (Bell and McKay, 2016). Specifically for cow grass, however, Chin (2013) recommended N:P:K ratio of 4:1:2. In other words, the demand for N by cow grass is two times more than K and four times more than P. SW204 supplied the highest amount of N on a per dry weight basis (Table 1). Consequently, grass growth was the highest in soils treated with SW204 (Fig. 6 and 7), and these soils also had the highest amount of soil N (Fig. B.1).

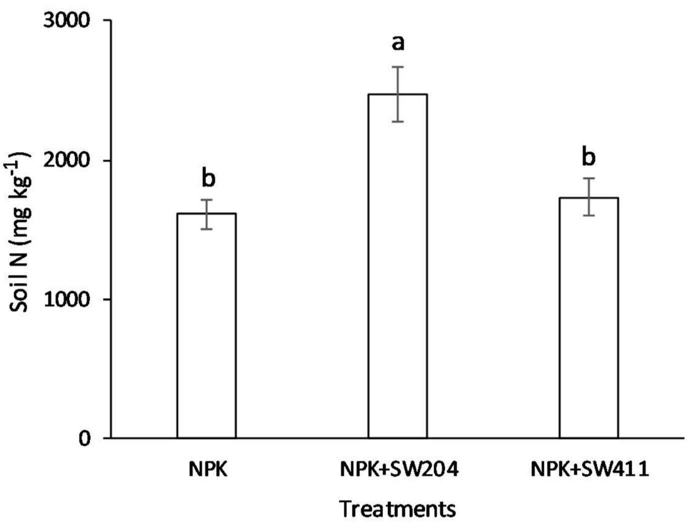

Fig. B.1. Soil N, averaged (± s.e.) across all soil types, due to the effect of the treatments in the grass experiment. Means with the same letter are not significantly different ($p>0.05$) from one another according to the mean separation test by LSD.

Due to the high N content in both SW204 and SW411, N uptake by the grass grown on soils treated by both these materials would also be larger than the grass uptake of N in soils treated only with NPK. This is why plant N in both SW204 and SW411 was generally higher than in the NPK treatment (Fig. B.2). Other than soil N, the soil treatments also significantly affected soil Mg and C (Fig. B.3 and B.4). As expected, soil C would increase in soils treated with either SW204 or SW411 because both these materials were rich in organic matter (Table 1). Nonetheless, Fig, B.5 shows that the differences in soil C between soil treatments were only for the sandy clay soil.

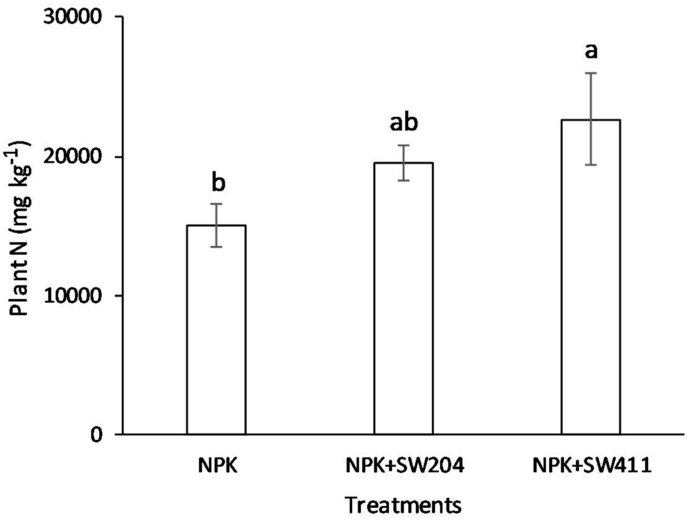

Fig. B.2. Plant N, averaged (± s.e.) across all soil types, due to the effect of the treatments in the grass experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

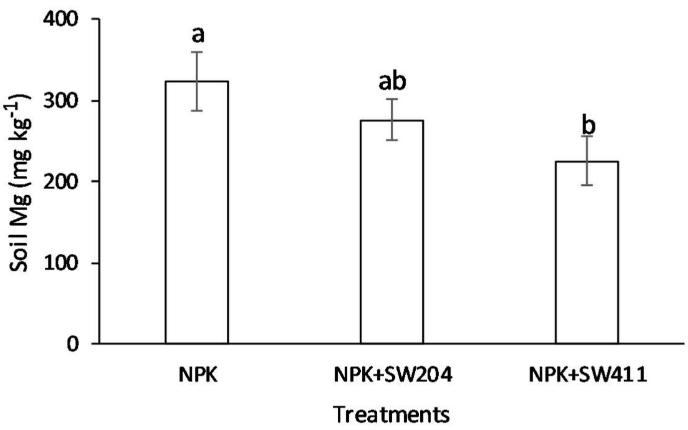

Fig. B.3. Soil Mg, averaged (± s.e.) across all soil types, due to the effect of the treatments in the grass experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

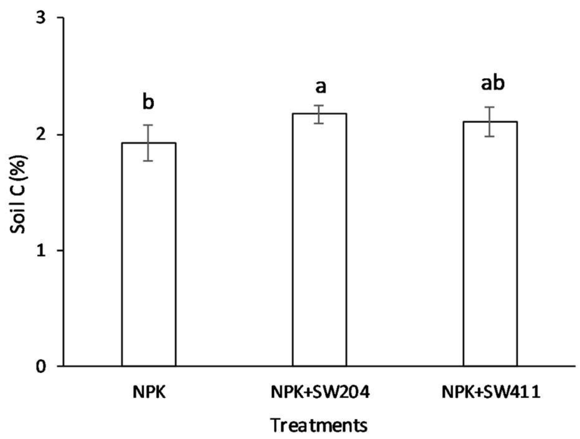

Fig. B.4. Soil C, averaged (± s.e.) across all soil types, due to the effect of the treatments in the grass experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

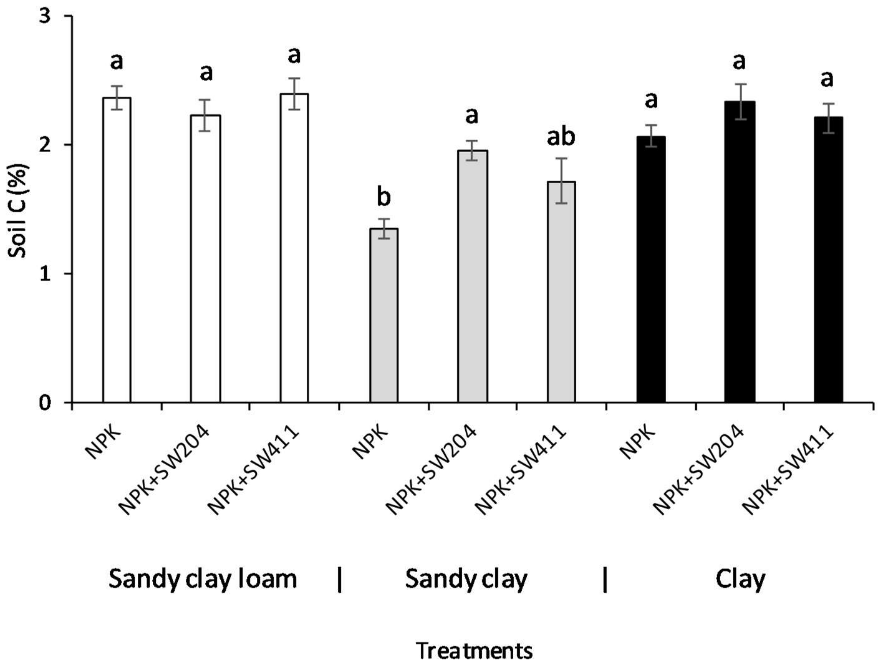

Fig. B.5. Mean (± s.e.) soil C due to the effect of the treatments applied on different soil types in the grass experiment. For the same soil type, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

Unlike in the kangkung experiment, clearer trends were observed in the grass experiment on the effects of the soil treatments on the soil physical properties. SW204 and SW411 generally improved several soil physical properties, but only for the clay soil (Fig. B.6 – B.8). The larger biomass per unit area for grass, compared to kangkung, meant more root and soil microbial activities in the grass experiment. Such increased activities can help to make larger improvement to soil physical properties, as observed by many workers such as Whalley et al. (2005).

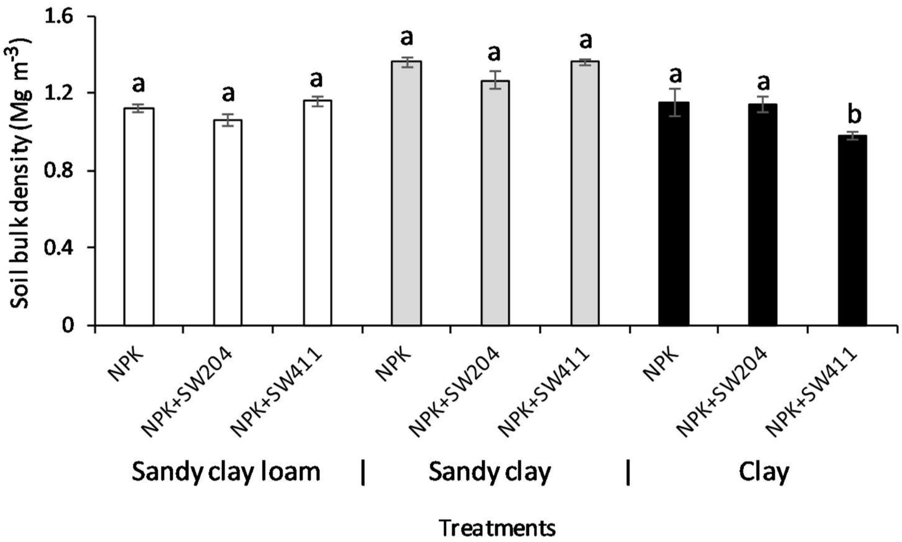

Fig. B.6. Mean (± s.e.) soil bulk density due to the effect of the treatments applied on different soil types in the grass experiment. For the same soil type, means with the same letter are not significantly different ($p>0.05$) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

Both SW204 and SW411 generally lowered bulk density (*i.e.*, making the soil less compact) and increased soil aggregation and aggregate stability. Overall, both SW204 and SW411 increased the saturation point of soils (Fig. B.9), but not the field capacity or permanent wilting point. Soil saturation is more sensitive to changes to soil organic matter additions. This is because soil saturation (and to some degree, field capacity) are driven mostly by the larger soil pores, and these larger pores are more susceptible to soil structural changes, for instance, due to changes in soil management practices, compaction, or organic matter additions (Tisdall and Oades, 1982). The permanent wilting point of soils, however, are influenced by the smaller pores, and these small pores are insensitive to soil structural changes. Instead, the proportion of small pores in the soil are more susceptible by any changes in the soil texture (which were not altered in this study). Consequently, the addition of organic matter such as SW204 and SW411 would more easily affect soil saturation than field capacity or permanent wilting point, as found in this study.

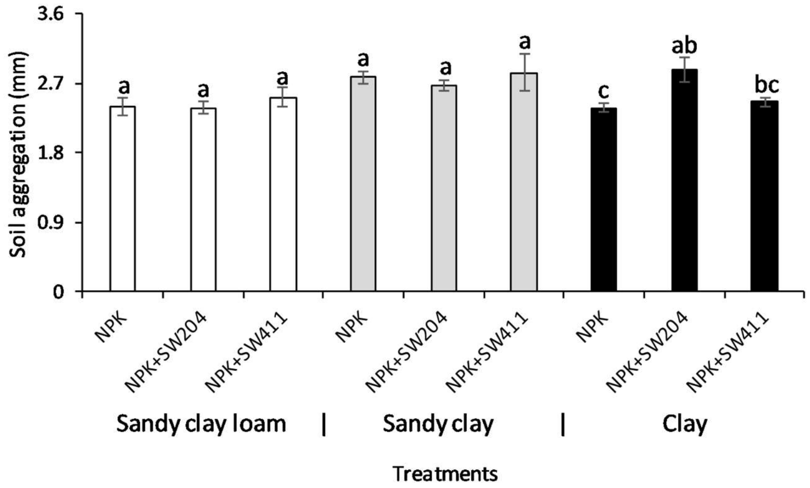

Fig. B.7. Mean (± s.e.) soil aggregation (expressed as mean weight diameter) due to the effect of the treatments applied on different soil types in the grass experiment. For the same soil type, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

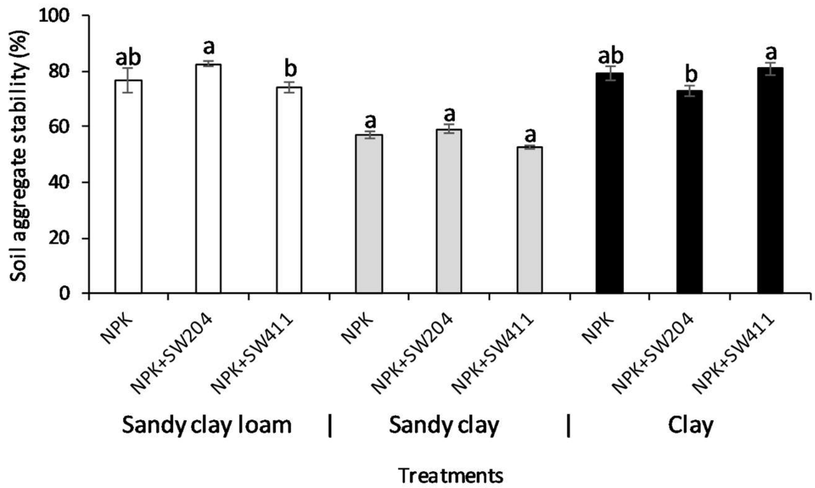

Fig. B.8. Mean (± s.e.) soil aggregate stability due to the effect of the treatments applied on different soil types in the grass experiment. For the same soil type, means with the same letter are not significantly different (p>0.05) from one another according to the simple effect test by LSD (with adjusted Bonferroni alpha levels).

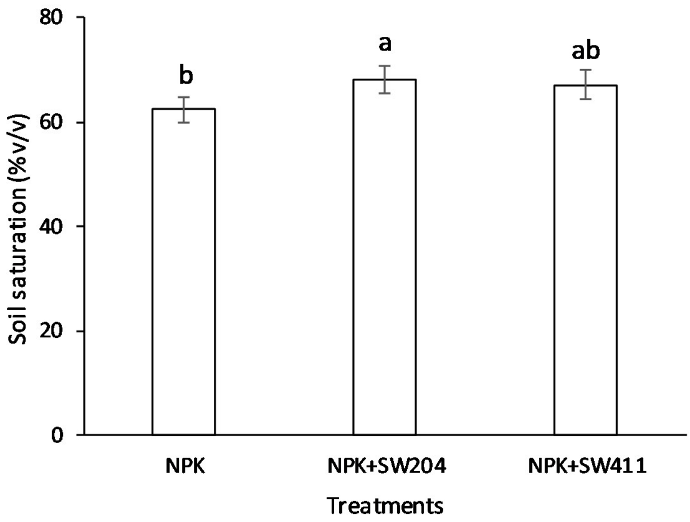

Fig. B.9. Soil saturation point, averaged (± s.e.) across all soil types, due to the effect of the treatments in the grass experiment. Means with the same letter are not significantly different (p>0.05) from one another according to the mean separation test by LSD.

Nonetheless, the SW204 and SW411 did not significantly affect (p>0.10) the available soil water content or the slope of the soil water retention curve (Table 9).

The cumulative total volume of leachate in the grass experiment was on three times lesser per unit ground area than that collected in the kangkung experiment. This is because of the higher biomass of grass per unit area by more than three times compared to the biomass of kangkung per unit area. The greater grass biomass and complete ground cover by the grass meant lesser leaching had occurred compared with that in the kangkung experiment.

Moreover, ANOVA revealed that the treatments had a significant effect on the cumulative total leachate volume (Fig. B.10) and the amount of nutrients leached (Fig. B.11). Due to the better growth (in terms of biomass weight) of grass in the SW204 treatment, the total volume of leachate in this treatment was the lowest (Fig. B.10). Like in the kangkung experiment, high nutrient content in the SW204 and SW411 meant higher losses of K, Ca, and Mg from soils treated with these organic materials in the grass experiment (Fig. B.11).

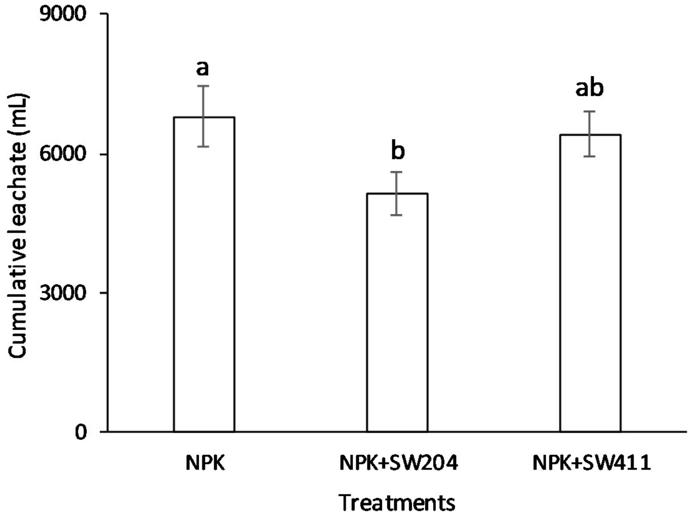

Fig. B.10. Cumulative total leachate volume, averaged (± s.e.) across all soil types, due to the effect of the treatments in the grass experiment. Means with the same letter are not significantly different ($p>0.05$) from one another according to the mean separation test by LSD.

Like in the kangkung experiment, P loss was the highest in the NPK-treated soil, followed by SW204- and SW411-treated soils (Fig. B.11). Recall that the mobility of P in the soil is different from the other nutrients, where P is mostly immobile and very little can be leached. Addition of the soluble NPK fertilizer had possibly caused large amounts of soluble P to be quickly available in the soil solution; thus, vulnerable to leaching. Addition of the organic materials like SW204 and SW411 may have caused the added P to be mostly in immobile forms; thus, less vulnerable to leaching.

The low P leaching losses in the SW204- and SW411-treated soils make both these organic materials a potential source of P nutrient for plants, provided that these organic materials are placed as close as possible to the plant roots (to minimize P fixation). Application of NPK fertilizer alone risks higher loss of P from the soil via leaching, but its loss from the soil would be reduced if the NPK were applied together with either SW204 or SW411.

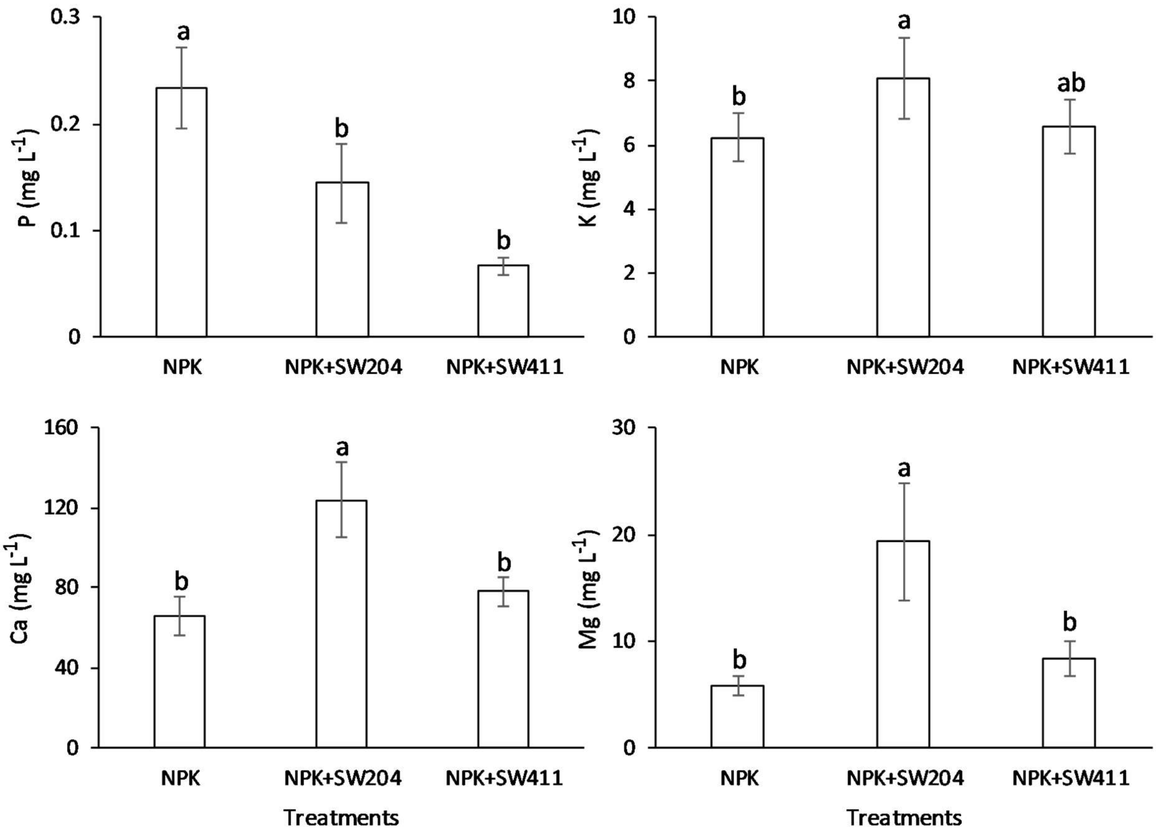

Fig. B.11. Total leachate P, K, Ca, and Mg, averaged (± s.e.) across all soil types, due to the effect of the treatments in the grass experiment. Means with the same letter are not significantly different ($p>0.05$) from one another according to the mean separation test by LSD.