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# Seed Germination and Growth Parameters of *Zea mays* L. as Influenced by Municipal Solid Waste Incineration Fly Ash (MSWIFA) and Sewage Sludge (SS) Amended Soil

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## Abstract

Seed germination trials have relevance in measuring soil toxicity. The current study was therefore conducted to investigate the effect of municipal solid waste incineration fly ash (MSWIFA) and sewage sludge (SS) from the Phuket municipal waste incinerator and wastewater treatment plant as fertilizer substitutes on seed germination and growth parameters of sweet corn (*Zea mays* L.). A field experiment was conducted at the National Corn and Sorghum Research Station, Nakhon Ratchasima Province, using a randomized complete block design (RCBD). The treatments conditions were: 1) non-amended soil, 2) 378.125 kg MSWIFA $ha^{-1}$, 3) 543.75 kg SS $ha^{-1}$, 4) 756.25 kg MSWIFA $ha^{-1}$, 5) 1087.5 kg SS $ha^{-1}$, and 6) 378.125 kg MSWIFA $ha^{-1}$ + 543.75 kg SS $ha^{-1}$. The results indicated that application rates of MSWIFA and SS have profound effects on plant establishment and growth characteristics. The highest germination index (22.26), vigor index (146.4), leaf number (5.65), and fresh and dry weight (5.78 and 2.35 g $plant^{-1}$), respecttively) were recorded from seeds treated with SS (1087.5 kg $ha^{-1}$), while the highest seed germination was found in 378.125 kg MSWIFA $ha^{-1}$ + 543.75 kg SS $ha^{-1}$. The result suggested the alternative use of MSWIFA and SS without addition of fertilizer on agricultural soils.

**Keywords:** Municipal solid waste; Incineration fly ash; Sewage sludge; Sweet corn; *Zea mays* L.

## Introduction

Population increase and the rapid growth of tourism in Phuket Province, Southern Thailand have greatly exacerbated the problem of disposal of environmentally harmful waste products. The fast-increasing volume of municipal waste is already overwhelming the capacity of Phuket Municipality to incinerate these types of waste [1]. The disposal of municipal solid waste incineration fly ash (MSWIFA) and sewage sludge (SS) from the wastewater treatment plant of Phuket Municipality requires consideration of an integrated waste management strategy. Thus, reuse and recycling of these wastes might be an environmentally friendly and cost-effective approach, offering the benefit of recycling residuals rather than disposing of them. The use of some types of waste as a soil ameliorant for soil quality improvement is of special interest.

MSWIFA consists of hollow spheres, and contains high concentrations of aluminum oxides and hydroxides which might be used to adsorb pollutants such as heavy metals. Moreover, MSWIFA can also be used as a soil additive due to its capacity to supply sufficient amount of plant nutrients (Cu, Mg, S, K, P, Fe, Mn, Zn, etc.) as well as its physical structure that can improve chemical and physical properties of soils due to its high pH. When used as a soil amendment, MSWIFA has favorable effects on soil water holding capacity and aeration [2]. Sewage sludge has been regarded as a problematic solid waste, mainly due to the presence of toxic elements (Cd, Cr, Pb, etc.). Nevertheless, sewage sludge is a good source of essential plant nutrients (Ca, Cu, Mg, K, P, S, Fe, Zn, etc.) for plant growth and can improve soil properties. The characteristics of sewage sludge can vary depending on the individual source and treatment process. In Thailand, more than 47% by weight basis of sewage sludge comprises organic waste [3]. The combination of sewage sludge with MSWIFA may have synergistic effects in improving soil quality by countering problems such as waterlogging, contamination with pathogenic microorganisms, loss of soil structure, and a lowering of the availability of metals in amended soils [4].

Soil amendments can be used as fertilizer substitutes, and can improve soil fertility and promote plant growth. The effectiveness of different amendments in increasing soil fertility is well covered in the literature; however, relatively few studies have been reported on the efficacy of the combination of MSWIFA and sewage sludge from Phuket Municipality as fertilizer substitutes.

Sweet corn (*Zea mays* L.) was chosen for the seed germination studies because it is one of Thailand's most important crops [3, 5]. Germination of seeds is one of the most critical phases of the plant life [6] and is highly vulnerable to environmental factors, particularly soil moisture, soil nutrients and soil temperature [7]. Therefore, this research aims to investtigate the effect of MSWIFA and sewage sludge (SS) as fertilizer substitutes on seed germination and growth parameters of sweet corn (*Zea mays* L.) in its early growth stages. Seed germination can be used as a bioindicator for measuring soil toxicity [8]. Such an investigation may therefore help in evaluation of the potential use of MSWIFA and sewage sludge in agricultural fields as a quick and reliable test to assess final crop yield and quality.

## Methodology

### 1) Description of the study area

The field experiment was conducted in October 2015 at National Corn and Sorghum Research Station (Suwan Farm), Kasetsart University, Nakhon Ratchasima Province, Northeastern of Thailand (Lat. 14º 38' 44''N; Long. 101º 18' 59''E). The location of the study area is shown in Figure 1. Average temperatures during the experiment ranged from 22 to 30 °C with the average monthly precipitation of 4.1 mm [9].

### 2) Preparation and analysis of soil, municipal solid waste incineration fly ash (MSWIFA), sewage sludge (SS), and seeds of sweet corn

Soil samples were collected for characterization at 0 to 15 cm depths prior to commencement of the field trials. Samples were air-dried, ground and sieved through a stainless steel 2-mm sieve, then stored in low-density polyethylene (LDPE) plastic zip-lock bags at room temperature ready for determination of physicochemical characteristics using standard methodologies.

Sweet corn *(Zea mays* L.) single-cross hybrid "Insee 2" obtained from the National Corn and Sorghum Research Station (Suwan Farm) was used in this experiment for plant analysis. The seeds were sieved for size separation before mixing with metalaxyl to control fungal infections. Subsequently, the seeds were air-dried and the healthy ones selected for planting.

Samples of municipal solid waste incineration fly ash (MSWIFA) was collected from the mass-burn incinerator, while sewage sludge (SS) was collected from the wastewater treatment plant of Phuket Municipality. The samples of MSWIFA and SS were air-dried, ground and sieved through a stainless steel 2-mm sieve and characterized before use as soil amendments. The physicochemical characteristics of the amendments and the soil were determined, including pH (1:1 and 1:2 for soil to water ratio, and amendments to water ratio, respectively) [10], electrical conductivity (EC), organic matter content (%OM) by the Walkley-Black procedure [11], cation exchange capacity (CEC), exchangeable potassium (exc.-K) using 1 N $NH_4OAc$ extraction (pH 7), total nitrogen (total-N) by the Kjeldahl procedure, available phosphorus (avail. -P) by Bray II method, soil texture analysis using the pipette method and metal analysis according to the USEPA method 3052 protocol [12].


**Figure 1** Experimental study site

**3) Sweet corn field experiment**

The sweet corn experiment was laid out in a randomized complete block design (RCBD) with four replicates for a short-term period of 1 month under normal field conditions and agricultural practices. The field experiment was designed to test whether the use of these waste materials as fertilizer substitutes can promote seed germination and growth of the sweet corn. For field preparation, soils were prepared by plowing, sowing and exposing to natural sunlight for 7-15 days prior to application of the amendment. The sub-plots were 6 m long and 3 m wide, with 9 rows with 30 cm intra-row and 75 cm inter-row spacing. Each sub-plot was spaced 1 m apart and 2 m spacing between blocks. Seeds were planted in rows with three seeds per hill; seedlings were thinned to a single plant per hill two weeks after emergence. Treatment details are shown in Table 1.

The study comprised eighteen treatments, with 6 main treatments (including non-amendment as control) and 2 sub-treatments of the applied fertilizer (including non-fertilizer) with 4 replicates per treatment. Therefore, there were 48 sub-plots in the experiment. The commonly used chemical fertilizer (15-15-15) for the initial soil dressing for sweet corn is used at a rate of 93.75 kg ha$^{-1}$ [13]. Therefore, the specified ratio of the amendment used in this study was based on the mentioned recommended fertilizer rate. The field was prepared and managed by the farmer according to standard corn growing practice. In each treatment, the amendments were applied at once before planting as banding incorporation throughout the experiment. All MS-WIFA-SS-fertilizer mixtures were then weighed and mixed by hand until homogenous. All sub-plots were watered using sprinkler after seeding and planting, and irrigated once a week using sprinkler. Disease and insect prevalence was also checked regularly.

**4) Germination study**

Seed germination was recorded daily up to day 9, after the planting and watering. Five seedlings were randomly selected from each sub-plot and the averages of the following parameters were calculated; 1) seed emergence of 2 mm radicle at time of observation was determined by counting the number of seeds emerging. Then, the seed germination percentage [(the number of seeds emerged/the number of seeds sown) x 100] was determined for each of the treatments; 2) fourteen days after seedling emergence, plant height (cm) and plant weight (dry weight and fresh weight, g plant$^{-1}$) were measured; 3) coefficient of germination were calculated according to Taye et al. (2013) as co-efficient of germination = $(A_1+A_2+\ldots+A_X)/(A_1T_1 + A_2T_2+\ldots+A_XT_X) \times 100$, where A1 is the number of seedlings counted on the first day and T1 is the number of days until the last collection and so on [14]; 4) Germination Index (GI) = ∑ [number of seeds emerged on the day/day after planting]; and 5) Vigor Index (*VI*) was calculated by multiplying seed germination (%) and seedling length (cm) according to Cao et al. (2008) [15].

**Table 1** Treatments used in this experiment

| Main treatments | Sub-Treatments |
|---|---|
| M1: Non-amended soil (Ctrl) | F1: No fertilizer |
| M2: 378.125 kg MSWIFA ha$^{-1}$ | F2: 93.75 kg fertilizer ha$^{-1}$ |
| M3: 543.75 kg SS ha$^{-1}$ | F3: 187.5 kg fertilizer ha$^{-1}$ |
| M4: 756.25 kg MSWIFA ha$^{-1}$ | |
| M5: 1087.5 kg SS ha$^{-1}$ | |
| M6: 378.125 kg MSWIFA ha$^{-1}$ + 543.75 kg SS ha$^{-1}$ | |

### 5) Statistical analysis

Statistical analysis was based on two-way analysis of variance (ANOVA) for comparison of statistical significance among different treatments using Statistical Product and Service Solutions (SPSS) version 17.0 and Duncan's test at *p<0.05 was used for mean separation.

## Results and Discussion

### 1) Characteristic of soil, municipal solid waste incineration fly ash (MSWIFA), and sewage sludge (SS)

Characteristics of the soil, MSWIFA, and SS used in this study are shown in Table 2. The soil used for in this study had inherently low nutrient content compared to both MSWIFA and SS. The soil was neutral (pH 7.3), predominantly comprising a clay fraction with very little silt and some sand (Table 2). Based on the percentage composition of clay, slit and sand, soils can be classified as clay according to the Soil Survey and Classification Division, Land Development Department [16]. The studied soil had low nitrogen, phosphorus and potassium contents (Table 2). Cd and Pb concentrations were 24.79 and 34.13 mg $kg^{-1}$, respectively, which fall within the soil quality standard for habitats and agricultural purposes in Thailand (37 mg $kg^{-1}$ and 400 mg $kg^{-1}$, respectively) [17].

For the amendments, the pH of MSWIFA and SS were 11.5 and 7.1, respectively. Concentrations of Cd and Pb were 77.48 and 794 mg $kg^{-1}$ and 34.49 and 52 mg $kg^{-1}$ for MSWIFA and SS, respectively. In terms of essential plant nutrients, MSWIFA had the highest exc.-K of 45,063 mg $kg^{-1}$, while SS exhibited the highest amounts of total-N (3.24%) and avail.-P (1,375 mg $kg^{-1}$). These high nutrient levels make both materials suitable as fertilizer substitutes. However, the high concentrations of heavy metals, especially in MSWIFA, present the important concern limiting its use for agricultural purposes.

Numerous studies have been conducted on heavy metal accumulation in plants using MSWIFA and SS as soil amendments. It has been reported that heavy metal concentrations in a mixture of fly ash (FA) and SS were substantially below the toxicity limits and the results indicated that use of a mixture of FA and SS poses no risk to the food chain [18]. Phytotoxicity studies of the SS - FA mixture with *Zea mays* L. showed that bioavailability of Zn, Cu, and Co were all decreased by addition of FA [19]. In addition, a reduction of the most bioavailable form of Cd in treated soils (35.4-54.5%) and its transformation into an insoluble fraction was observed when boiler ash was used as a soil amendment; this study highlighted the beneficial effects of waste-products in promoting sugarcane growth and Cd stabilization in soil [20]. Therefore, in order to minimize the associated risk of elevated Cd and Pb concentrations in the MSWIFA used in this study, plant uptake of heavy metals were also investigated.

**Table 2** Characterization of the soil, MSWIFA, and SS used in the experiment

| Properties | Soil | MSWIFA | SS |
|---|---|---|---|
| pH | 7.3 | 11.5 | 7.1 |
| OM[a] (%) | 1.93 | 3.40 | 40.56 |
| EC (dS $m^{-1}$) | 0.49 | 77.60 | 9.38 |
| CEC[b] ($cmol_c$ $kg^{-1}$) | 18.20 | 12.00 | 74.20 |
| Total N[c] (%) | 0.11 | 0.02 | 3.24 |
| Avail-P[d] (mg $kg^{-1}$) | 123 | *ND* | 1,375 |
| Exc-K[e] (mg $kg^{-1}$) | 130.44 | 45,063 | 1,298 |
| Cd conc. (mg $kg^{-1}$) | 24.79 | 77.48 | 34.49 |
| Pb conc. (mg $kg^{-1}$) | 34.13 | 794 | 52 |

*[a]Walkley-Black Method; [b,f]Am.acetate 1N pH 7.0 extraction, [c]Kjeldahl Method, [d]BrayII, [*]ND: not detected*

**2) Impact of MSWIFA and sewage sludge (SS) on seed germination and emergence**

Successful germination and seedling establishment are essential to achieving a good crop of maize [21]. The percentage of seed germination in this study is shown in Table 3. Application of the different amendment rates had no effect on germination ($p>0.05$). Germination on all treatments exceeded 80%, compared with 86.5% for the untreated control. The highest percentage seed germination (89.7%) was observed in F1M6 treatment (378.125 kg MSWIFA $ha^{-1}$ + 543.75 kg SS $ha^{-1}$). The results in this study are in line with those reported by Katiyar et al. (2012) who reported the non-significant effect of fly ash on seed germination of mung bean (*Vigna radiate* L.) [22]. The results indicate that F1M4, F1M5, F1M6, and F2M6 treatments had higher levels of germination compared to the untreated control (F1M1), but the differences were not statistically significant at $p>0.05$. The higher application rate in treatments F1M4 to F1M6 and F2M4 to F2M6 might have resulted in release of N for immediate plant uptake [23].

A similar pattern was observed for germination index (GI), with treatments F1M2-F1M6 and F2M2, F2M4-F2M6 exhibiting higher GI compared to treatments without addition of amendments (F1M1 and F2M1, Table 3). Vigor index (VI) is an important parameter for determining fast and uniform emergence and seedling establishment under a wide range of field conditions [24]. The F1M5 treatment revealed the highest GI value (22.26) and VI (146.4) compared to other treatments. The findings indicated that application of sewage sludge at a rate of 1,087.5 kg $ha^{-1}$ (F1M5) resulted in the most vigorous seedling growth, and can be completely substituted without requiring additional fertilizer.

All treatments showed the same average emergence time of 9 days; thus, there was no observed impact of treatments on time to emergence. The weather at the sampling site during the experiment was relatively cool (21.9 to 30.21 °C) compared to the other growing periods. The time to emergence time might therefore be affected as germination is sensitive to soil temperature [25]. The coefficient of germination (%) is one of the indexes measuring seed germination speed and velocity [26] and the germination uniformity or variability in relation to mean germination time [27]. There was no significant differrence in the coefficient of germination (%) among treated soils ($p>0.05$) throughout the experiment (Table 3). The highest value of coefficient of germination (12.88) was observed under F1M6 with the incorporation of 378.125 kg MSWIFA/ha and 543.75 kg SS $ha^{-1}$. The results indicate that addition of MSWIFA and SS in the soil as fertilizer substitutes have no impact on germination (%) or on the coefficient of germination (%) since all the treatments showed values similar to the F1M1 control. However, treatment F1M6 showed slightly higher levels compared with the other treatments.

**3) Impact of MSWIFA and SS on seed growth parameters.**

3.1) Number of leaves and shoot height (cm)

After two weeks, five seedlings from each treatment were sampled and measured for leaf number and shoot height (cm). A significantly higher ($p<0.05$) mean number of leaves per plant was observed in F1M5 (1,087.5 kg SS $ha^{-1}$) compared to the control, whilst the lowest average leaf number (4.60) was recorded from F1 M4 (756.25 kg MSWIFA $ha^{-1}$) (Table 3). This indicates that higher application rates of SS, containing significant amounts of total-N (3.24%) and avail.-P (1,375 mg $kg^{-1}$), can stimulate leaf production without the need for chemical fertilizer. In addition, application of F2M4 (756.25 kg MSWIFA $ha^{-1}$ + fertilizer 93.75 kg $ha^{-1}$) significantly ($p<0.05$) increased shoot height (6.75 cm) as compared to the F1M1 control

(5.48 cm). The results indicate that only F2M4 (93.75 kg fertilizer $ha^{-1}$ + 756.25 kg MSWIFA $ha^{-1}$) and F1M5 (1,087.5 kg SS $ha^{-1}$) were statistically different from other treatments in terms of these two seed growth parameters. Similar findings have been previously reported following application of biochar and SS amendments at 15 t $ha^{-1}$ for SS and biochar, and 7.5 t $ha^{-1}$ each for SS and biochar [28].

3.2) Shoot fresh weight and dry weight (g $plant^{-1}$)

Biomass production, expressed in shoots fresh weight and dry weight (g $plant^{-1}$) of sweet corn grown in different treated soils was measured on day 14 (T14) (Figure 2). No significant differences in biomass production were observed among treatments (p>0.05); however, F1M5 showed the highest shoot fresh weight and dry weight (g $plant^{-1}$). This result could be due to the higher levels of N and P in this treatment. The study's results are consistent with another study investigating application of municipal solid waste landfill from Khon Kaen Municipality, Thailand on corn yield (*Zea mays* L.) by Prabpai et al. (2009), who found that corn yield increased by 50, 72, 85 and 71% when 20, 40, 60 and 80% of municipal solid waste landfill were used [3]

**Table 3** Seed germination (%), germination index (GI), vigor index (VI), coefficient of germination (%), shoot height (cm) and number of leaves of the sweet corn (*Zea mays* L.) as affected by MSWIFA and SS.

| Treatments | Seed germination (%) | GI | VI | Coefficient of germination (%) | Shoot height (cm) | No. of leave |
|---|---|---|---|---|---|---|
| F1M1 | 86.5±12[a] | 19.42±5.5[a] | 104±22[a] | 12.29±0.6[a] | 5.48±0.7[abc] | 4.85±0.4[ab] |
| F1M2 | 85.7±12[a] | 19.90±6.6[a] | 103±31[a] | 12.85±0.4[a] | 5.23±0.7[ab] | 4.65±0.4[a] |
| F1M3 | 85.0±7[a] | 19.45±3.6[a] | 106±4.4[a] | 12.12±0.7[a] | 5.55±0.9[abc] | 4.85±0.6[ab] |
| F1M4 | 87.4±9[a] | 21.48±6.4[a] | 105±36[a] | 11.98±0.8[a] | 4.85±0.8[a] | 4.60±0.7[a] |
| F1M5 | 89.5±11[a] | 22.26±5.1[a] | 146±46[b] | 12.19±0.8[a] | 6.53±0.8[cd] | 5.65±0.1[c] |
| F1M6 | 89.7±10[a] | 21.98±4.9[a] | 121±26[ab] | 12.88±0.5[a] | 5.53±0.3[abc] | 5.30±0.7[abc] |
| F2M1 | 79.9±4[a] | 17.37±5.5[a] | 100±5.7[a] | 12.55±0.5[a] | 5.78±0.5[abc] | 5.20±0.3[abc] |
| F2M2 | 83.8±7[a] | 21.59±6.6[a] | 130±16[ab] | 12.49±0.5[a] | 6.05±0.5[bcd] | 5.10±0.4[abc] |
| F2M3 | 82.1±6[a] | 17.33±2.9[a] | 106±14[ab] | 12.47±0.7[a] | 6.18±0.6[bcd] | 5.50±0.1[bc] |
| F2M4 | 84.4±11[a] | 19.60±2.7[a] | 133±26[ab] | 12.11±0.7[a] | 6.75±0.7[d] | 5.00±0.2[abc] |
| F2M5 | 85.0±7[a] | 19.29±1.8[a] | 108±17[ab] | 12.10±1.2[a] | 5.59±0.6[abc] | 4.90±0.8[abc] |
| F2M6 | 88.2±9[a] | 19.84±3.7[a] | 126±19[ab] | 11.87±1.0[a] | 6.25±0.8[bcd] | 5.25±0.2[abc] |

Means followed by different letters are significantly different at 5% level of probability
Where: F1M1 = no fertilizer and no amendment (Ctrl); F1M2 = no fertilizer + 378.125 kg MSWIFA $ha^{-1}$; F1M3 = no fertilizer + 543.75 kg SS $ha^{-1}$; F1M4 = no fertilizer + 756.25 kg MSWIFA $ha^{-1}$; F1M5 = no fertilizer + 1087.5 kg SS $ha^{-1}$; F1M6 = no fertilizer + 378.125 kg MSWIFA $ha^{-1}$ + 543.75 kg SS $ha^{-1}$; F2M1 = 93.75 kg fertilizer $ha^{-1}$ + no amendment ; F2M2 = 93.75 kg fertilizer $ha^{-1}$ + 378.125 kg MSWIFA $ha^{-1}$; F2M3 = 93.75 kg fertilizer $ha^{-1}$ + 543.75 kg SS $ha^{-1}$; F2M4 = 93.75 kg fertilizer $ha^{-1}$ + 756.25 kg MSWIFA $ha^{-1}$; F2M5 = 93.75 kg fertilizer $ha^{-1}$ + 1087.5 kg SS $ha^{-1}$; F2M6 = 93.75 kg fertilizer $ha^{-1}$ + 378.125 kg MSWIFA $ha^{-1}$ + 543.75 kg SS $ha^{-1}$; F3M1 = 187.5 kg fertilizer $ha^{-1}$+ no amendment; F3M2 = 187.5 kg fertilizer $ha^{-1}$+ 378.125 kg MSWIFA $ha^{-1}$; F3M3 =187.5 kg fertilizer $ha^{-1}$+ 543.75 kg SS $ha^{-1}$; F3M4 = 187.5 kg fertilizer $ha^{-1}$+ 756.25 kg MSWIFA $ha^{-1}$; F3M5 = 187.5 kg fertilizer $ha^{-1}$+ 1087.5 kg SS $ha^{-1}$; F3M6 = 187.5 kg fertilizer $ha^{-1}$+ 378.125 kg MSWIFA $ha^{-1}$ + 543.75 kg SS $ha^{-1}$

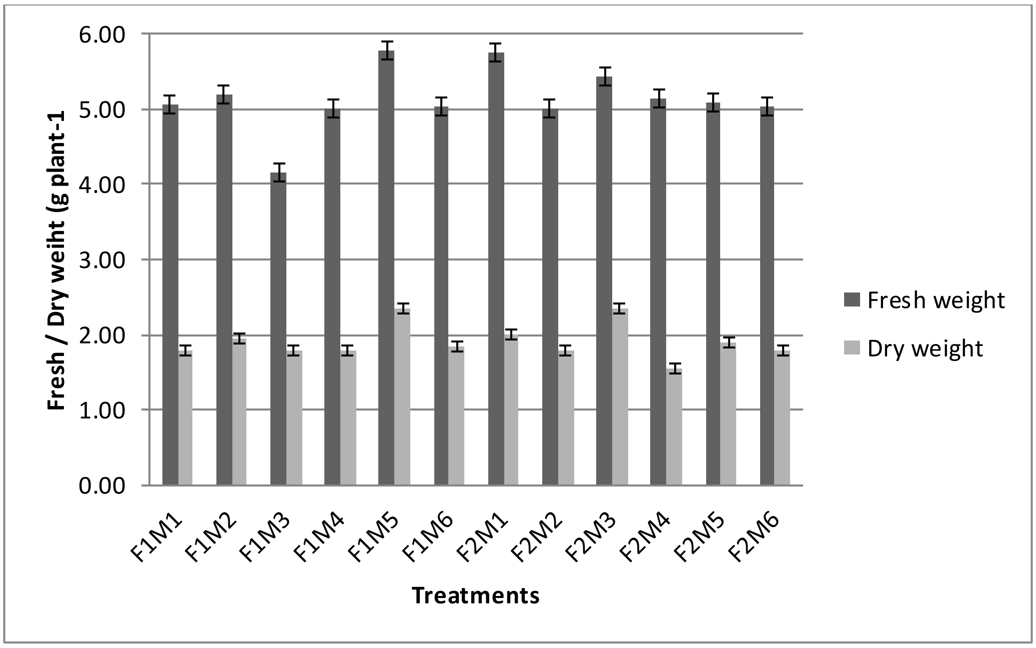


**Figure 2** Shoot fresh weight and dry weight (g plant$^{-1}$) of the sweet corn grown in different treated soils at 14 days.

**Conclusion**

Different application rates of municipal solid waste incineration fly ash (MSWIFA) and sewage sludge (SS) had profound effects on plant establishment and growth characteristics of sweet corn relative to the conventional NPK fertilizer (15-15-15) application. The highest germination index (22.26), vigor index (146.4), average leaf numbers (5.65), and fresh and dry weight (5.78 and 2.35 g plant$^{-1}$, respectively) were recorded from maize seeds treated with SS (F1M5, 1087.5 kg ha$^{-1}$), while the highest percentage seed germination and coefficient of germination were found with the F1M6 treatment (378.125 kg MSWIFA ha$^{-1}$ + 543.75 kg SS ha$^{-1}$). Both MSWIFA and SS treatments were found to promote germination and growth parameters as compared to the control. These results support consideration of these materials as potential soil amendments. Nevertheless, the long term effect of repeated application of these materials and heavy metal accumulation in plants still requires further investigation.

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**References**

[1] PJT Technology Company Limited. 2010. Available: http://www.pjt.co.th/show_productdetail.php?c3=26 Accessed 18 November 2015

[2] Jamil-Khan, M. and Qasim, M. 2008. Integrated use of boiler ash as organic fertilizer and soil conditioner with NPK in calcareous soil. Songklanakarin Journal of Science and Technology 30: 281-289.

[3] Prabpai, S., Charerntanyarak, L., Siri, B., Moore, M.R. and Noller, B.N. 2009. Effects of residues from municipal solid

waste landfill on corn yield and heavy metal content. Waste Management 29: 2316-2320.

[4] Alvarenga, P., Gonçalves, A.P., Baião, N., Fernandes, R.M., Varennes, A., Vallini, G., Duarte, E. and Cunha-Queda, A.C. 2008. Assessment of chemical, biochemical and ecotoxicological aspects in a mine soil amended with sludge of either urban or industrial origin. Chemosphere 72: 1774-1781.

[5] Napasintuwong Orachos. 2015. Agricultural and Resource Economics Working Paper. Maize Seed Industry in Thailand: Development, Current Situation, and Prospect. ARE Working Paper No. 2558/1. Available: http://agri.eco.ku.ac.th/RePEc/kau/wpaper/are201502.pdf Accessed 12 September 2015

[6] Khayatnezhad, M., Gholamin, R., Jamaati-e-Somarin, S. and Zabihi-e-Mahmoodabad, R. 2010. Effects of Peg Stress on Corn Cultivars (*Zea mays* L.) At Germination Stage. World Applied Sciences Journal 11(5): 504-506.

[7] Ginwal, H.S., Phartyal, S.S., Rawat, P.S. and Srivastava, R.L. 2005. Seed Source Variation in Morphology, Germination and Seedling Growth of Jatropha curcas Linn. in Central India. Silvae Genetica 54(2): 76-80.

[8] Korade, D.L. and Fuleka, M.H. 2009. Effect of organic contaminants on seed germination of Lolium multiflorum in soil. Biology and Medicine 1(1): 28-34.

[9] Thai Meteorological Department. 2015. Weather Forecast. Available: http://www.tmd.go.th/en/province.php?id=20 Accessed 09 November 2015

[10] Jayasinghe, G.Y., Tokashiki, Y., Arachchi, I.D. and Arakaki, M. 2010. Sewage sludge sugarcane trash based compost and synthetic aggregates as peat substitutes in containerized media for crop production. Journal of Hazardous Materials 174: 700-706.

[11] Nelson, D.W. and Sommers, L.E. 1996. Carbon and organic matter. In: Sparks DL et al. (ed) Methods of soil analysis: Part 3 Chemical Methods, 3rd ed.: Agron. Monogr, 9. ASA and SSSA, Madison, Wisconsin.

[12] US EPA Method 3052. 1996. Microwave assisted acid digestion of siliceous and organically based matrices. Available: http://www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/3052.pdf. Accessed 15 May 2012

[13] The Office of Agricultural Research and Extension Office of Agricultural Research and Extension Maejo University. 2015. Techniques and practice for Sweet corn. Available: http://research.rae.mju.ac.th/raebase/index.php/knowledge/blog2/crops-menu/109-corn3. Accessed 26 Nov 2015 (in Thai).

[14] Taye, W., Laekemariam, F. and Gidago, G. 2013. Seed Germination, Emergence and Seedling Vigor of Maize as Influenced by Pre-Sowing Fungicides Seed Treatment. E3 Journal of Agricultural Research and Development 3(3): 035-041.

[15] Cao, D.D., Hu, J., Huang, X.X., Wang, X.J. , Guan, Y.J. and Wang, Z.F. 2008. Relationships between changes of kernel nutritive components and seed vigor during development stages of $F_1$ seeds of *sh* $_2$ sweet corn. Journal of Zhejiang University. Science. B 9(12): 964-968.

[16] The Soil Survey and Classification Division, the Land Development Department. 2012. http://osl101.ldd.go.th/survey_1/class_03_ult.htm. Accessed 5 May 2012

[17] Pollution Control Department, Ministry of Natural Resources and Environment. 2015. Soil Quality Standards, Notification of National Environmental Board No. 25, B.E. 2004. Available: http://www.pcd.

go.th/info_serv/en_reg_std_soil01.html. Accessed 29 October 2015

[18] Huapeng, N., Shengrong, L., Junfeng, S. and Meijuan, Y. 2012. Characteristics of heavy metal accumulation on fly ash- and sewage sludge-amended calcific soil. Chinese Journal of Geochemistry (31): 181-186.

[19] Masto, R.E., Sunar, K.K., Sengupta, T., Ram, L.C., Rout, T.K., Selvi, V.A., George, J. and Sinha, A.K. 2012. Evaluation of the co-application of fly ash and sewage sludge on soil biological and biochemical quality. Environmental Technology 33(8): 897-905.

[20] Akkajit, P., DeSutter, T. and Tongcumpou, C. 2013. Short-term effects of sugarcane waste-products from ethanol production plant as soil amendments on sugarcane growth and metal stabilization. Environmental Science: Processes and Impact 15: 947-954.

[21] Sikder, S., Hasan, M.A. and Hossain, M.S. 2009. Germination Characteristics and Mobilization of Seed Reserves in Maize Varieties as Influenced by Temperature Regimes. Journal of Agriculture & Rural Development 7(1&2): 51-56.

[22] Katiyar, D., Singh, A., Malaviya, P., Pant, D. and Abraham, G. 2012. Impact of Fly-Ash-amended soil on growth and yield of crop plants. International Journal of Environment and Waste Management 10(2/3): 150-162.

[23] Baloyi, T.C., Kutu, F.R. and Du Preez, C.C. 2010. Assessment of variable application rates of biological amendment substances on establishment and growth characteristics of maize plants. African Journal of Biotechnology 9(46): 7847-7852.

[24] Mondo, V.H.V, Cicero, S.M., Dourado-Neto, D., Pupim, T.L. and Neves Dias, M.A.N. 2013. Seed vigor and initial growth of corn crop. Journal of Seed Science 35(1): 64-69.

[25] Department of Agronomy, Kansas State University. 2015. Corn Growth & Development. http://webcache.googleusercontent.com/search?q=cache:cMpPUXe0vagJ:www.agronomy.k-state.edu/extension/crop-production/corn/corn-growth-and-development.html+&cd=1&hl=th&ct=clnk&gl=th Accessed 06 September 2015

[26] Ashkan, A. and Jalal, M. 2013. Effects of Salinity Stress on seed germination and seedling vigor indices of two Halophytic Plant Species (Agropyron elongatum and A. pectiniforme). International Journal of Agriculture and Crop Sciences 5(22), 2669-2676.

[27] Sarma, B. and Gogo, N. 2015. Germination and seedling growth of Okra (*Abelmoschus esculentus* L.) as influenced by organic amendments. Cogent Food & Agriculture 1:1-6. Available: http://www.tandfonline.com/doi/pdf/10.1080/23311932.2015.1030906 Accessed 09 October 2015

[28] Gwenzi, W., Muzava, M., Mapanda, F. and Tauro, T.P. 2015. Comparative short-term effects of sewage sludge and its biochar on soil properties, maize growth and uptake of nutrients on a tropical clay soil in *Zimbabwe*. Available: http://www.chinaagrisci.com/Jwk_zgnykxen/EN/article/downloadArticleFile.do?attachType=PDF&id=10154 Accessed 09 October 2015