ORIGINAL ARTICLE

Utilisation of coal ash to improve acid soil

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Abstract

Im-Erb, R., Bamroongrugsa, N., Kawashima, K., Amano, T. and Kato, S.

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Songklanakarin J. Sci. Technol., 2004, 26(5) : 697-708

The study on utilization of coal ash to improve acid soil was carried out in a greenhouse at the Land Development Regional Office 1, Pathum Thani Province, Central Thailand, from January-May 2003. Fly ash mixture (fly ash plus gypsum and lime at the proportion 5:4:1) and clinker ash mixture (clinker ash plus gypsum and lime at the proportion 5:4:1) were used as soil amendments at varying rates i.e., 0, 6.25,12.5, 18.75 and 25 t/ha to improve the soil. The aim of this study was to determine the effect of application of coal ash on acid soil and the growth of a vegetable (Chinese kale). Chinese kale cultivars were planted in a randomized complete block design with three replications. Pak Chong soil series (Ultisols) was used as the growth medium. Twenty-day-old seedlings were transplanted in 270 pots (two plants per pot) containing acid soil with different treatments of coal ash mixture which were as follows: 1) control, 2) fly ash mixture 6.25 t/ha, 3) fly ash mixture 12.5 t/ha, 4) fly ash mixture 18.75 t/ha, 5) fly ash mixture 25 t/ha, 6) clinker ash mixture 6.25 t/ha, 7) clinker ash mixture 12.5 t/ha, 8) clinker ash mixture 18.75 t/ha and 9) clinker ash mixture 25 t/ha. Chemical fertilizers were applied at the rate of 250 kg/ha using a grade of 15-15-15 of N, P and K, respectively. Plants were harvested 40 days after transplanting. Among the treatments, application of fly ash mixture at a rate of 25t/ha (4t/rai) substantially increased soil pH up to 5.7. Fly ash was found more effective

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Received, 26 January 2004 Accepted, 5 April 2004

than clinker ash in increasing soil pH. The highest yield of Chinese kale was also obtained when fly ash mixture was applied at a rate of 25 t/ha followed by fly ash mixture at 18.75 t/ha and clinker ash mixture at 18.75 t/ha with an average yield per plant of 4.980, 3.743 and 3.447 grams, respectively. It can be concluded that the application of coal ash mixture, either fly- or clinker ash, at 18.75-25 t/ha (3-4 t/rai) was the most effective in terms of plant yield. The use of coal ash mixture increased cation exchange capacity, base saturation percentage and Ca, Mg and S contents in the soil as well as plant uptake of N. The concentrations of heavy metals in the soil (Cd, As, Co, Cr, Cu, Hg, Ni, Pb and Zn) were found to be within permissible levels while Cd, Cr and Ni in the plants were at critical levels for health.

Key words : acid soils, coal ash, fly ash, clinker ash, acid soil improvement

บทคัดย่อ

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การปรับปรุงดินกรดโดยใช้เถ้าถ่านหิน

ว. สงขลานครินทร์ วทท. 2547 26(5) : 697-708

การปรับปรุงดินกรดโดยใช้เถ้าถ่านหิน ได้ดำเนินการในเรือนเพาะชำ บริเวณสำนักงานพัฒนาที่ดินเขต 1 จังหวัดปทุมธานี ระหว่างมกราคม-พฤษภาคม 2546 วัสดุที่ใช้ในการปรับปรุงดิน ได้แก่ เถ้าลอยและเถ้าหยาบของถ่านหิน ผสมกับยิปซั่มและปูนขาว (อัตราส่วน 5:4:1) ในอัตราต่าง ๆ คือ 0, 6, 25, 12.5, 18.75 และ 25 ตัน/เฮกแตร์ วัตถุประสงค์ของการวิจัย เพื่อศึกษาผลของดินกรดต่อการปรับปรุงดินด้วยเถ้าถ่านหินและการเจริญเติบโตพืชผัก (คะน้า) วางแผนการทดลองแบบ Randomized Complete Block Design (RCBD) จำนวน 3 ซ้ำ ใช้ดินจากชุดดินปากช่องเพื่อเป็นเครื่องปลูกพืช ใช้กล้าอายุ 20 วันสำหรับการย้ายปลูกในกระถาง 270 ใบ (2 ต้น/กระถาง) ที่ใส่ดินและตำรับการทดลองต่าง ๆ ได้แก่ 1) ควบคุม 2) ใส่เถ้าลอยผสม 6.25 ตัน/เฮกแตร์ 3) ใส่เถ้าลอยผสม 12.5 ตัน/เฮกแตร์ 4) ใส่เถ้าลอยผสม 18.75 ตัน/เฮกแตร์ 5) ใส่เถ้าลอยผสม 25 ตัน/เฮกแตร์ 6) ใส่เถ้าหยาบผสม 6.25 ตัน/เฮกแตร์ 7) ใส่เถ้าหยาบผสม 12.5 ตัน/เฮกแตร์ 8) ใส่เถ้าหยาบผสม 18.75 ตัน/เฮกแตร์ 9) ใส่เถ้าหยาบผสม 25 ตัน/เฮกแตร์ ใช้ปุ๋ยเคมีสูตร 15-15-15 ของ NPK อัตรา 250 กก./เฮกแตร์ (40 กก/ไร่) เก็บเกี่ยวเมื่ออายุพืช 40 วันหลังการย้ายกล้า จากการทดลองพบว่า ในระหว่างตำรับการทดลอง การใส่เถ้าลอยผสม 25 ตัน/เฮกแตร์ (4 ตัน/ไร่) ทำให้ค่าความเป็นกรดเป็นด่างของดินเพิ่มขึ้นสูงสุดเท่ากับ 5.7 เมื่อเปรียบเทียบกันระหว่างเถ้าถ่านหิน 2 ชนิด เถ้าลอยจะมีประสิทธิภาพมากกว่าเถ้าหยาบในการปรับระดับความเป็นกรดเป็นด่าง ในด้านผลผลิตของคะน้าพบว่าได้เพิ่มสูงสุดเมื่อใส่เถ้าลอยผสม 25 ตัน/เฮกแตร์ รองลงมาได้แก่เถ้าลอยผสม 18.75 ตัน/เฮกแตร์ และเถ้าหยาบผสม 18.75 ตัน/เฮกแตร์ ซึ่งให้น้ำหนักเฉลี่ยคะน้า/ต้นเท่ากับ 4.98, 3.74 และ 3.44 กรัม ตามลำดับ และการใส่เถ้าถ่านหินผสม 18.75-25 ตัน/เฮกแตร์ (3-4 ตัน/ไร่) จะมีประสิทธิภาพดีที่สุดในการเพิ่มผลผลิตคะน้า การใส่เถ้าถ่านหินช่วยเพิ่ม CEC เปอร์เซ็นต์การอิ่มตัวด้วยไอออนบวกที่เป็นด่าง ปริมาณ Ca, Mg และ S ในดิน ตลอดจนการดูดใช้ N ของพืช นอกจากนี้ พบว่าธาตุโลหะหนักในดินได้แก่ Cd, As, Co, Cr, Cu, Hg, Ni, Pb และ Zn มีปริมาณในระดับที่ยังไม่เป็นอันตราย แต่ในพืชพบว่า Cd, Cr และ Ni อยู่ในระดับวิกฤต

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Fly ash (FA) is a residue left after coal ash has been burned; it is collected from gas stack using specialized devices. Fly ash properties are diverse and depend on the nature of the coal and the combustion process (Karapanagioti and Atalay, 2001). Alkalinity is an important FA characteristic. Some FA materials have pH values as low as 4, while others have pH as high as 12.0. The subbituminous and lignite coal ashes produce alkaline solutions upon contact with water. The alkalinity depends on the calcium content since this element is in the form of highly reactive CaO. Addition of a small quantity of FA can result in a significant increase of solution pH. Trace metal desorption from FA decreases with increasing pH (Theis and Wirth, 1977). Most trace metals show minimum release at pH values around 9. The adsorption degree of trace metals from FA is determined by the solubilization extent of their oxide forms. Ash obtained from coal could be used as soil amendment in agriculture. However, the utilization of coal ash for liming and fertilizing vegetable was studied, using red beet, cabbage and celerlac as experimental plants. It was shown that there was a greater increase in the yield of vegetable plants when soil was applied with brown coal ash (Beresniewicz and Nowosielski, 1982). Conversely, burning coals in furnaces of thermoelectric power plants has the effect of releasing large amount of gaseous pollutants, heavy metals and ash, with the result that 2,630 ha of land in Romania were taken out of cultivation (Capitanu *et al*., 2001).

An estimate of land degradation from the available data has shown that the world is losing at least ten hectares of arable land every five minutes, five from of soil erosion; three from soil salinization; one from other types of soil degradation including acidification; and one from non-agricultural uses (Buringh, 1979). Such land degradation is a problem which poses a serious threat to welfare of mankind. The problem has accelerated in recent decades, precisely at a time when population growth and rising expectations have begun to demand an enormous increase in food production. As acidity was one of the problem and degraded soils, acid soils are widely distributed all over the world with many production constraints. Van Wambeke (1976) estimated that they extend nearly half the area of the potential arable land in the world.

Acid soils in Thailand are scattered throughout the country with a total area of 22.8 million ha. Acid soils are mainly in the Northeast region, with an area of 10.4 million ha. The areas in the South, the Central Plain, and Northern, Western and Eastern regions are 4.3, 4.0, 3.04, and 1.12 million ha respectively (Chareonchamratcheap *et al*., 1997). The vast majority of the acid soils are Ultisols (around 22.6 million ha) while the remainder are Oxisols. These soils are characterized by low pH and their major constraints are low cation exchange capacity (CEC) and base saturation, high acidity, aluminum toxicity, manganese toxicity, iron toxicity and infertility. Although acid soils as a problem soil have long been experienced in the country, their magnitude and intensity are continuously increasing as a result of inappropriate soil use for agriculture, deforestation, and soil mismanagement in recent decades, thus increasing the magnitude of the problems that must be solved in order to face the demands of future food needs. Increasing interest in studying the problem of acid soils is a result of their widespread distribution in the country, representing 44% of the total land which is generally used for agricultural production. The aim of this study was to determine the effect of the application of coal ash on acid soil and the growth of a vegetable crop (Chinese kale), as a possible solution to rehabilitate acid soils and reduce their impact on crop production.

Materials and Methods

The project was conducted in a greenhouse at Land Development Regional Office 1, Pratum Thani province, Thailand, from January - May 2003. The experiment was arranged in a randomized complete block design with 3 replications, comprising of 9 treatments which were as follows: 1) control, 2) fly ash mixture 1.0 t/rai, 3) fly ash mixture 2 t/rai, 4) fly ash mixture 3 t/rai, 5) fly ash mixture 4 t/rai, 6) clinker ash mixture 1.0 t/rai, 7) clinker ash mixture 2.0 t/rai, 8) clinker ash mixture 3.0 t/rai, 9) clinker ash mixture 4.0 t/rai.

Fly ash and clinker ash with gypsum and lime in a proportion of 5:4:1. were used in this experiment. Although the coal ash has high pH but the reaction of this amendment is not able to neutralize the acid soil due to its calcium carbonate equivalent (CCE) being low (Table 1) Liming is

Table 1. Chemical analyses of lime, gypsum, fly ash, clinkler ash and water samples.

Specimens, Reference of method	Lime	Gypsum	Fly ash	Clinker ash	Water	Fert. (P_2O_5)	Fert. (K_2O)
pH (1:1 H_2O)	12.30	8.10	12.30	9.10	6.90		
CCE (%)	98.7	-	26.56	26.56	-		
P (mg kg^{-1})	-	7.00	1.00	23.00	-		
K (mg kg^{-1})	-	60.00	190.00	60.00	-		
Zn (mg kg^{-1})	21.90	2.40	182.00	49.50	0.30		
Cu (mg kg^{-1})	5.80	2.90	41.30	31.80	0.30		
Pb (mg kg^{-1})	67.60	15.10	70.00	12.80	0.42	200.00	50.00
Cd (mg kg^{-1})	8.60	0.10	3.90	3.00	0.02		
Cr (mg kg^{-1})	13.30	18.30	26.80	19.50	0.30		
Ni (mg kg^{-1})	23.80	17.70	68.60	56.00	0.22		
Co (mg kg^{-1})	27.80	7.90	32.60	25.10	0.11		
Hg (mg kg^{-1})	0.05	0.60	0.22	0.12	0.0001		
As (mg kg^{-1})	0.25	3.00	37.40	1.10	0.0005	50.00	0.50

needed to improve acid condition of soil. Application rate of chemical fertilizer was 40 kg/rai using a grade of 15-15-15 (NPK). Soil (Pak Chong soil series) was collected from Pak Chong district, Nakhon Ratchasima province with a depth of 10-40 cm. To avoid the other chemical contamination, filtered water was used for watering the plants. A Chinese kale cultivar (*Brassicas oleracea* L.; var. alboglabra. Bailey) was chosen as the experimental plant. Seeds were cleaned in distilled water for a minute and germinated in seed beds at normal temperature (32-30ºC). Twenty-day old seedlings were transplanted into 270 pots, containing acid soil (4.68 kg/pot) with treatments, depending on designated level of coal ash mixture. Shoot material was harvested 40 days after transplanting. From each pot, 2 complete shoots were cut at soil level and weighed. The plant material was carefully rinsed with distilled water to remove surface contamination. This material was dried at 65ºC for 96 hrs, reweighed and ground.

The specimens (soil, water, plants, lime, gypsum, fly ash, clinker ash, and chemical fertilizer) were analyzed before and after harvesting (Table 1, 2). For plant analysis, sodium, calcium, magnesium, manganese, zinc, iron, copper, potassium, sulfur and aluminum were determined on nitric perchloric acid digests of plant tissues by atomic absorption spectrophotometry and phosphorus content by the molybdate-vanadate colorimetric method (Kitson and Mellon, 1944). Aluminum was determined by aluminon method. Sulfur was determined by turbidimetric method. On soils, the methods were as follows: pH by 1:1 H_2O, OM content by Walkley and Black method; available phosphorus by Bray II; potassium, calcium, magnesium and sodium were determined on NH_4 OAc pH 7 extracts of soil by atomic absorption spectrophotometry; exchangeable aluminum by aluminon method; zinc, manganese, iron and copper were determined on DTPA extracts of soil by atomic absorption spectrophotometry; mercury and arsenic were determined on sulfuric hydrochloric acid digests of soil by flameless hydridegenerator; lead, nickel, cadmium, chromium and cobalt were determined on nitric perchloric acid digests of soil by atomic absorption spectrophotometry; available sulfur was determined on 0.01 M. Ca (H_2PO_4) extracts of soil by turbidimetric method (Page *et al.*, 1997). The coal ash specimens were determined by the same methods for soil analysis.

The maximum permissible levels for heavy metal content in soil for the United Kingdom and normal background levels of heavy metals in soils from Thailand were used as parameters to define

Table 2. An average of chemical analyses of soil samples before planting and after harvesting (First Group)

Treatment	pH	OM (%)	LimeReq. (kg.$CaCO_3$/rai)	CEC (Cmol kg^{-1})	P (mg kg^{-1})	K^+ (mg kg^{-1})	Ca^{++} (mg kg^{-1})	Mg^{++} (mg kg^{-1})	Na^+ (mg kg^{-1})	Mn^{++} (mg kg^{-1})	Fe^{++} (mg kg^{-1})	SO_2^{-4} - S (mg kg^{-1})	Al^{+++} (mg kg^{-1})
Before	4.50	1.80	1075.00	14.00	3.00	180.00	320.00	200.00	39.70	12.80	9.60	137.50	23.70
T1	4.33de	0.63	1030.33	15.13	3.00e	149.88abc	466.93g	222.75d	53.70a-d	3.87bcd	9.10b	174.87f	99.47
T2	4.37de	0.70	806.00	15.20	4.67cd	151.19abc	1082.16e	227.21d	55.17ab	1.23d	14.47a	370.87e	95.23
T3	4.70c	0.67	673.00	15.47	6.00b	159.01a	1559.78c	254.34ab	55.93ab	9.20a	9.83b	532.03cde	88.57
T4	5.23b	0.63	538.00	15.27	6.33b	155.10ab	1914.49b	264.06a	56.63a	7.80abc	13.73a	822.93ab	91.80
T5	5.77a	0.63	0	15.53	7.00a	136.86de	2189.70a	269.73a	54.27abc	5.57abc	9.50b	989.60a	105.10
T6	4.30e	0.70	851.00	15.13	4.33d	129.03e	621.91g	228.42cd	47.53e	3.53cd	8.17b	506.97de	97.70
T7	4.40d	0.63	851.00	14.87	5.00c	142.06cd	903.80f	238.55bcd	50.50b-e	9.40a	9.27b	586.80cd	97.33
T8	4.73c	0.60	673.00	15.27	6.00b	148.58bc	1343.35d	253.13abc	48.53de	8.20ab	4.33c	732.67bc	88.47
T9	5.20b	0.63	538.00	15.67	6.00b	147.28bc	1915.16b	230.45bcd	48.97cde	7.67abc	9.10b	854.20ab	96.83
CV(%)	0.90	9.20	-	2.80	-	3.40	7.60	5.60	5.70	36.60	21.20	18.20	8.20
Sig.	**	ns	**	ns	**	**	**	**	**	**	**	**	

ns = non-significant
Means followed by a common letter are not significantly different at the 5% level by DMRT.

Table 3. An average of chemical analyses of soil samples before planting and after harvesting (Second Group)

Treatment	As (mg kg^{-1})	Cd (mg kg^{-1})	Co (mg kg^{-1})	Cr (mg kg^{-1})	Cu (mg kg^{-1})	Hg (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})	Zn (mg kg^{-1})	%BS	Al Sat.	Mg Sat.	Ca Sat.
Before	0.32	0.80	22.50	48.80	1.10	0.02	52.10	30.90	1.60	33.93	5.38	39.44	43.83
T1	0.29	1.23	10.27ab	56.30abc	0.70bc	0.11b	30.50a	13.80b	0.23b	31.17f	3.87a	37.38a	47.46g
T2	0.25	1.07	9.90ab	60.80a	0.77ab	0.12b	25.03ab	11.27b	0.30a	51.77e	2.42bcd	23.18d	66.85d
T3	0.27	1.47	13.60a	58.77ab	0.63cd	0.17a	25.87ab	19.87b	0.20bc	67.77c	2.01cde	19.56e	72.81b
T4	0.24	1.53	12.33a	52.47cde	0.80a	0.15a	30.80a	14.70b	0.33a	80.82b	1.65e	17.34f	76.22a
T5	0.24	1.10	4.83c	56.07abc	0.67cd	0.12b	21.67abc	31.37a	0.30a	88.05a	1.60e	16.06f	78.48a
T6	0.21	1.27	7.03bc	50.47de	0.60cd	0.11b	25.73ab	14.27b	0.20bc	36.14f	3.58a	33.16b	54.72f
T7	0.22	1.17	8.83abc	48.80e	0.50ef	0.10b	20.47bc	12.93b	0.17c	47.11e	2.92b	27.27c	62.63e
T8	0.21	1.13	7.43bc	54.43bcd	0.47f	0.11b	13.97c	12.17b	0.20bc	61.17d	2.51bc	21.78d	69.97c
T9	0.23	1.67	6.63bc	56.27abc	0.57de	0.12b	24.47ab	18.63b	0.20bc	76.55b	1.88de	15.49f	78.17a
CV(%)	15.60	25.10	27.90	5.40	-	8.50	21.20	29.40	12.80	5.20	13.60	4.70	2.30
Sig.	ns	ns	*	**	**	**	*	**	**	**	**	**	**

Means followed by a common letter are not significantly dfferent at the 5% level by DMRT.

critical heavy metal content in this experiment. Critical levels for various heavy metal concentrations in plants specified by Kabata-Pendias and Pendias (1984) were used as standards for heavy metal content in Chinese kale (Table 4.).

Results and Discussion

Soil Analysis

The effect of soil chemical properties on the application of the coal ash mixture is shown in Table 1, 2 and 3. Application of coal ash mixture resulted in an increase of soil pH when compared to the control, except in treatment 6. The pH increase was more pronounced in treatments 3, 4, 5, 8, and 9, particularly in treatment 5 which increased the pH to 5.7. Comparison of the application of the two different types of coal ash at the same rate among treatments suggests that fly ash has a higher potential to increase pH than clinker ash. This may be due to theirs particle size or fine fly ash fraction that was more effective than the coarse one (clinker ash).

Base saturation was found to be drastically increased in all treatments to a maximum of 88% in treatment 5, while treatment 6 showed a slight increase when compared to the control. Among treatments, fly ash showed a greater increase in base saturation than clinker ash. The percentage of aluminum saturation, however, decreased in most treatments when compared to the control. The decrease in Al saturation may have been the result of raised soil pH caused by the application of coal ash mixture. The lowest saturation was found to be 1.6% in treatment 5. Levels observed were lower than critical values for aluminum saturation percentage in crops such as maize and soybean, which were reported to be 5-70% and 5-25% respectively (Bruce, 1986; Adams, 1984). Calcium saturation percentage was significantly increased in every treatment with the maximum saturation observed in treatment 5 (78%). Magnesium saturation percentage showed different percentage decreases among treatments. The lowest observed saturation was at 16 percent in treatment 5. Table 2. shows how the use of coal ash increased the Ca and Mg content of soils in every treatment. The critical values for Ca and Mg saturation percentages, which are used as an indicator of calcium and magnesium deficiency for most plants, are 25-30 and 5% respectively (Kamprath, 1984; Adams, 1984). Both calcium and magnesium levels in this study were found to be higher than the critical values.

Soil iron (Fe) content was significantly increased in treatments 2 and 4 to levels of 14 and 13 mg kg^{-1}, respectively. A decrease in soil pH may cause an increase of Fe content in soil. Fe has

Table 4. Normal background (bkgd), maximum permissible (perm) and critical concentration of heavy metals in soils and critical concentration of heavy metal in plants.

Element	Thailand 1) Bkgd in soil (mg kg^{-1})	United Kingdom 2) Perm in soil (mg kg^{-1})	Critical concs 3) in plants (mg kg^{-1})	Critical concs 4) in plants (mg kg^{-1})
As	30	10	-	5-20
Cd	0.15	3	5-10	5-30
Co	20	-	10-20	15-30
Cr	80	100	1-2	5-30
Cu	45	100	15-20	20-100
Hg	0.10	1	2-5	1-3
Ni	45	50	20-30	10-100
Pb	55	100	10-20	30-300
Zn	70	300	150-200	100-400

Sources: 1) Pongskul, Thailand.(1999), 2) Attewell, United Kingdom.(1993), 3) Sauerbeck. 1982, 4) Kabata-Pendias and Pendias. 1984.

been reported as having a toxic effect on rice in culture solution at levels varying from 10-20 mg kg^{-1} to more than 500 mg kg^{-1} (Ishikuza, 1961; Tanaka *et al.*, 1966). Manganese (Mn) levels increased in treatments 3 and 7 to levels of 9.2 and 9.4 mg kg^{-1} respectively. Aluminum (Al) content did not differ among treatments. Although there was no application of coal ash mixture in treatment 1, the concentration of Al was high, compared to the other treatments (Table 2). The effect of increasing Al content with a low pH condition may result in enhancing release of Al in soil. Al toxicity may result in physiological and biological changes in plants. Normally the adverse effects become greater if the pH decreases to below approximately 5.5. Magnesium (Mg) levels were found to increase, particularly in treatments 3, 4, 5 and 8. In most cases, when the pH level drops to below 4.8, both manganese toxicity and aluminum toxicity are likely to occur (Von Uexkull, 1986).

Heavy metal cations are mobile under acid conditions and so raising the pH by liming usually reduces their bioavailability. Lead (Pb) levels were in general slightly decreased although treatment 5 showed a significant increase when compared to the control. As fly ash and lime has high content of Pb when compared to the other sources (Table 1). The effect of increasing Pb content in soil may result from application rate of lime and fly ash. The highest concentration was found to be 31 mg kg^{-1} in treatment 5. Nickel (Ni) concentration decreased and in treatment 8 fell to as low as 13 mg kg^{-1}. Analysis of cobalt (Co) concentrations showed both slight increases and decreases although treatment 5 showed a significant difference from the control. Arsenic (As) was found in small amounts with a slight decrease observed and a minimum concentration of 0.21 mg kg^{-1} in treatment 8. Zinc (Zn) showed two different effects. In treatments 2, 4 and 5 Zn concentrations were significantly increased while in treatments 3, 6, 7, 8, and 9 there was a decrease. These effects may have been caused by the Zn content of fly ash and clinker ash. Copper (Cu) concentrations were mostly decreased while cadmium (Cd) levels were not different compared to the control. Chromium (Cr) levels, however, decreased in treatments 6 and 7. The lowest amount observed was at 48 mg kg^{-1} in treatment 7. Mercury (Hg) concentrations in treatments 3 and 4 were significantly increased with recorded concentrations of 0.16 and 0.15 mg kg^{-1}, respectively, differing from the control. The change in chemical properties of soil observed in this experiment may be expected to occur as a result of the elemental content of each coal ash type.

Chemical analysis showed that soil pH in every treatment was in the range of 4.3-5.7, which represents low to very low levels. CEC levels were observed to be moderate. P, Ca, Na, Mn, Fe, and Al saturation were all observed in ranges representing a low content. Mg content was moderate while potassium content was very high. Sulphur content was in the normal range. Plants are comparatively insensitive to high SO_4^{2-} concentration. However, in some saline soils, the concentrations of SO_4^{2-} in soil are 50 mM, resulting plant growth being adversely affected (Mengel and Kirkby, 1987).

The application of coal ash gave higher percentages of base saturation, representing moderate to high levels of base saturation. Mg and Ca saturation percentage were in the ranges expected for non-deficient soil. It is interesting to note that the concentrations of heavy metals recorded in the soil (As, Cd, Co, Cr, Cu, Hg, Ni, Pb, and Zn) were found to be within permissible levels for heavy metals in soil (Table 3).

Element Concentration in Plant Shoots

Diagnosis of the symptoms of nutrient deficiency in Chinese kale grown in acid soil with application of various doses of coal ash was confirmed by analysis of the complete shoots (Table 5, 6). Analysis of the concentration of macro nutrients in shoots showed that nitrogen (N) was highly adsorbed by the plants in treatments where coal ash mixtures were added to the soil, showing significant differences from the control. The highest nitrogen content was found in treatment 7 followed by treatments 4, 3, 6, 9, 5, 8, 2 and 1 at amounts of 6.5, 6.4, 6.4, 6.3, 6.2, 6.1, 6.2, 5.7 and 2.6% respectively. According to Mengel and Kirkby

Table 5. An average of chemical analyses of plant samples (in dry matter) after harvesting (First Group)

Treatment	N (%)	P (%)	K^+ (%)	Ca^{++} (%)	Mg^{++} (%)	Na^+ (mg kg^{-1})	Mn^{++} (mg kg^{-1})	Fe^{++} (mg kg^{-1})	SO_4^{2-} -S (%)	Al^{+++} (%)
T1	2.66b	0.10	1.72b	0.59	0.24b	35.40	272.00c	382.67a	0.29	0.18
T2	5.74a	0.09	2.75a	1.21	0.46a	36.57	338.00b	147.33b	0.31	0.18
T3	6.45a	0.08	2.69a	1.76	0.48a	38.97	251.33cd	151.67b	0.26	0.16
T4	6.46a	0.09	2.41a	1.56	0.45a	39.57	209.33de	131.00b	0.31	0.20
T5	6.13a	0.08	2.38a	1.75	0.41a	36.97	191.00e	142.67b	0.33	0.19
T6	6.35a	0.08	2.26a	1.04	0.45a	36.33	424.00a	201.33b	0.32	0.20
T7	6.52a	0.08	2.40a	1.24	0.47a	37.33	326.33b	193.67b	0.30	0.19
T8	6.21a	0.09	2.74a	1.57	0.40a	38.27	238.67cde	163.00b	0.29	0.27
T9	6.24a	0.11	2.57a	1.37	0.43a	37.67	187.00e	132.00b	0.30	0.21
CV(%)	8.60	19.10	12.00	39.60	14.90	6.10	10.80	38.70	21.30	23.30
Sig.	**	ns	*	ns	**	ns	**	*	ns	ns

Means followed by a common letter are not significantly different at the 5% level by DMRT.

Table 6. An average of chemical analyses of plant samples (in dry matter) after harvesting (Second Group)

Treatment	As (mg kg^{-1})	Cd (mg kg^{-1})	Co (mg kg^{-1})	Cr (mg kg^{-1})	Cu (mg kg^{-1})	Hg (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})	Zn (mg kg^{-1})
T1	0.12	13.17c	5.73b	27.33	4.00d	0.11	31.57	20.10	47.00cd
T2	0.12	13.63bc	14.47b	30.33	10.67ab	0.11	26.07	20.37	85.00ab
T3	0.12	14.10bc	11.50b	24.17	9.33bc	0.11	21.00	22.43	65.67bc
T4	0.12	17.23ab	9.63b	28.40	6.67cd	0.11	22.60	22.07	46.33cd
T5	0.12	18.30a	5.38b	32.97	5.67cd	0.10	31.83	22.63	32.67d
T6	0.12	18.17a	24.70a	31.07	14.33a	0.11	40.20	21.63	88.33a
T7	0.11	18.33a	14.90b	34.40	11.33ab	0.11	35.60	21.47	75.00ab
T8	0.12	18.43a	9.90b	33.43	9.00bc	0.11	22.60	22.43	46.33cd
T9	0.12	16.63abc	11.30b	35.17	7.67bcd	0.11	36.63	21.50	41.33d
CV(%)	4.10	11.80	43.40	27.10	23.10	4.70	35.90	12.20	18.40
Sig.	ns	*	*	ns	**	ns	ns	ns	**

Means followed by a common letter are not significantly different at the 5% level by DMRT.

(1987), NH_4-N uptake takes place most effectively in a neutral medium and is depressed as the pH falls. Phosphorus (P) levels were found not to differ among treatments, with the highest concentration observed in treatment 9 (0.11%). Potassium levels (K) were found to be higher than the control with the highest concentration observed in treatment 2 (2.7%).

Ca, Na and S levels all showed a similar trend. Concentrations of these elements showed no difference among treatments but were all higher than in the control. In contrast, iron Fe was adsorbed in the control to a higher concentration than in other treatments. It has been reported, however that high concentrations of Fe in rice leaves can range between 300-1000 ug Fe g^{-1} dry weight (Ottow *et al.*, 1983). Mg concentration increased in every treatment when compared to the control. The highest quantity was found in treatment 3 (0.48%). Aluminum was generally found in high concentrations but did not differ among treatments. Mengel and Kirkby (1987) reported that higher plants contain about 200 mg kg^{-1} Al on a dry weight basis, which is nine times lower than the control level in this study. In some plants, such as tea, Al levels may be as high as 2,000-5,000 mg kg^{-1}. Mn concentrations either decreased or increased depending upon the treatment. Treatments 2, 6, and 7 showed an increase while treatments 3, 4, 5, 8 and 9 showed a decrease. The highest and the lowest concentrations were observed in treatments 6 and 5 at 424 and 191 mg kg^{-1} respectively. In normal plants Mn concentration is usually between 40-120 mg kg^{-1} (Von Uexkull, 1986).

For heavy metals, the uptake of As, Cr, Hg, Ni and Pb did not differ among treatments. Cd concentration increased significantly in treatments 4, 5, 6, 7, and 8 when compared to the control. The highest concentration observed was 18.43 mg kg^{-1} in treatment 8. Co was present in slightly increased quantities, with the highest concentration in treatment 6 (24.70 mg kg^{-1}). The concentrations of Cu and Zn showed a similar trend, which was a significant increase in the majority of treatments when compared to the control. Normally the uptake of various plant nutrients depends upon pH, and nutrients are taken up at a higher rate in slightly acidic condition. However, in some cases, ion competition, antagonism, or synergism among or between ions may occur, resulting in unusual uptake patterns. The absorption of cations is a more or less nonspecific process, depending mainly on the concentration of cation species in the nutrient medium (Mengel and Kirkby, 1987). However, the supply of one cation species may result in lowered concentrations of other cation species. In addition, antagonism between elements can occur in foliar absorption as well as in the roots, and the accompanying ions may also show a biological effect (Chamel, 1986).

In conclusion, it was found that the results of analysis of the heavy metal content of plant specimens showed that As, Co, Cu, Hg, Pb and Zn were not found at critical levels whereas Cd, Cr and Ni concentrations were elevated and are considered to be in the critical range reported by Kabata-Pendias and Pendias (1984).

Plant Yields

The results in Table 7 and Figure 1 showed that plants seem to respond to the application of coal ash mixture. The application of fly ash mixture at 4 tons/rai gave the highest yield of Chinese kale followed by fly ash mixture applied at 3 tons/rai, clinker ash mixture at 3 tons/rai,

Table 7. Fresh yield, dry matter yield and height of Chinese kale grown on acid soil with nine treatments of coal ash mixture. (1 hectare = 6.25 rai)

Treatment	Mean fresh yield of shoot (g/plant)	Mean dry matter of shoot (g/plant)	Mean plant height (cm)
T1 (control)	0.45e	0.07g	6.49f
T2 Fly ash mixture 1.0 t/rai	2.09cd	0.29def	9.03cd
T3 Fly ash mixture 2.0 t/rai	2.97bc	0.41cde	10.29bc
T4 Fly ash mixture 3.0 t/rai	3.74b	0.66ab	11.47b
T5 Fly ash mixture 4.0 t/rai	4.98a	0.76a	13.18a
T6 Clinker ash mixture 1.0 t/rai	1.21de	0.17fg	7.39ef
T7 Clinker ash mixture 2.0 t/rai	1.627d	0.230efg	8.293de
T8 Clinker ash mixture 3.0 t/rai	3.45b	0.52bc	10.52bc
T9 Clinker ash mixture 4.0 t/rai	3.27b	0.48bcd	10.88b
CV(%)	22.1	28.9	8.8
Sig.	**	**	**

Means followed by a common letter are not significantly different at the 5% level by DMRT

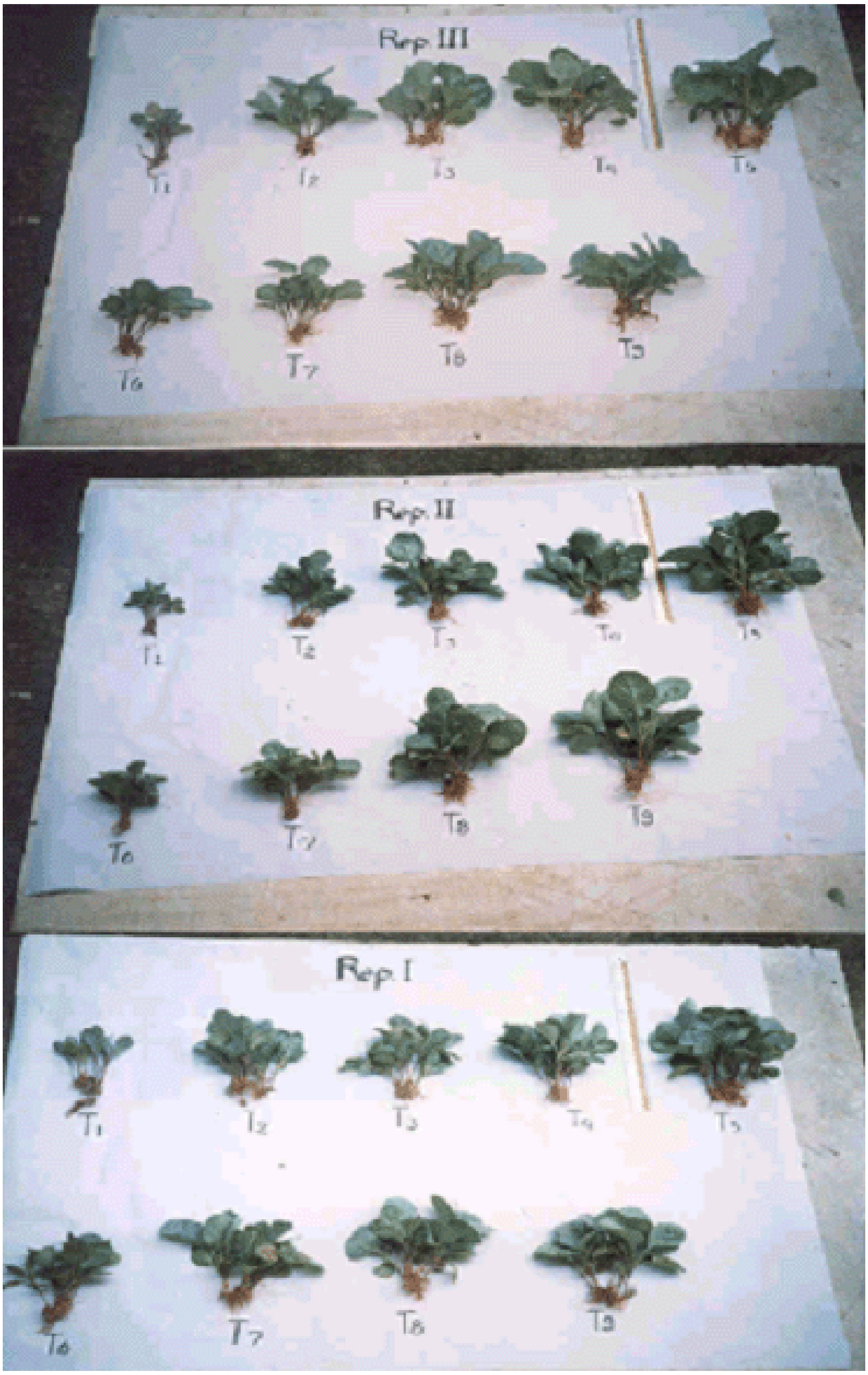

Figure 1. Response of Chinese kale to different treatments of coal ash in 3 replications (at 40 days after transplanting).

clinker ash mixture at 4 tons/rai, fly ash mixture at 2.0 tons/ rai, fly ash mixture at 1 tons/rai, clinker ash mixture at 2.0 tons/rai, clinker ash mixture at 1.0 tons/rai, and finally the control. Average yields per plant for each treatment are shown in Table 7. It should be noted that the fresh yield of Chinese kale plants in the greenhouse experiment appeared to be much lower than the yield under field conditions during the same growing period. This may have been the result of unfavorable conditions for growth in the greenhouse, for example an imbalance of nutrients in the soil, unsuitable soil pH for the growth of Chinese kale, high temperature within the greenhouse, physical structure of the soil, or the limited size of pots used.

It can be seen in Table 7 that the dry matter yield gave the same trend as the fresh yield. The application of fly ash mixture at 4 tons/rai gave the highest yield and followed by fly ash mixture at 3 tons/rai, with the control showing the lowest yield. The effect of coal ash on plant height also showed a similar trend. The application of fly ash mixture at 4 tons/rai gave the greatest height followed by fly ash mixture at 3 tons/ rai.

The application of fly ash mixture gave a higher increase in yield and soil pH than clinker ash mixture. Similarly, Beresniewicz and Nowosielski (1982) reported that the use of brown coal ash with lime for fertilizing and liming vegetable plants over a three year period increased vegetable yields (red beet, cabbage, and celeriac). Ash application at levels of 15-30 tons/ha also increased the germination energy of barley whereas a dose of 60-120 tons / ha decreased protein content in barley and rye grain (Stankowski and Meller, 1995).

Conclusions

The yield of Chinese kale grown on acid soil to which coal ash mixtures had been applied showed a promising increase. The highest yield was found when fly ash was added at 25 tons/ha or 4 tons/rai (4.98 g fresh weight per plant). Addition of fly ash mixture at 18.75-25 tons/ha or 3.0-4.0 tons/rai appeared to be the most effective application when compared to the control. Use of coal ash mixture also improved soil properties such as CEC and base saturation percentage and increased contents of Ca, Mg, and S in soil as well as enhancing plant uptake of N. The use of fly ash and clinker ash mixture at the same doses showed that both were effective in increasing of soil pH, although fly ash was more effective than clinker ash. The concentration of heavy metals in the soil (Cd, As, Co, Cr, Cu, Hg, Ni, Pb, and Zn) was found at permissible levels while Cd, Cr and Ni were at critical levels in plants.

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