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Flue Gas Desulphurization Gypsum as a Soil Amendment in the Growth of Wild Rye and Poplar (Hybrid 275 and Weser 6) Clones in Lusatia, Germany

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Abstract: The aim of this study is to investigate effects of FGD gypsum on virgin clay (>43%) soils in Lusatia, Germany carried out from year 2005 till year 2008. A thorough understanding of various processes controlling persistence, retention and leaching of contaminants is required for proper long-term management and disposal of industrial wastes such as Fly Ash (FA), Flue Gas Desulphurization (FGD) gypsum etc., which are major coal combustion by-products resulting from electric power generation. The FGD gypsum is selected as a substitute for calcium carbonate in amelioration of virgin clay soils in Lusatia. Pot experiments have been evaluated with the wild rye species where as the investigations at open cast mining pit Nochten were evaluated with two different kinds of Poplar clones (Hybrid 275 and Weser 6). Slight reduction in pH with strong increase in electrical conductivity has been observed with increasing the FGD gypsum concentrations. Electrical conductivity obtained was more then 2 mS cm^{-1} with 16 times the FGD gypsum concentration. Even though the pH and the electrical conductivity did not give positive results, germination success achieved was good, with which the average biomass produced was also good. Nutritional elements lied in between optimum ranges. Accumulation of heavy metals reduced with the 100% FGD gypsum substitution compared to that of 100% lime. The Poplar clones showed good growth at open mining field Nochten. Proportional growth was observed. Significant differences in diameters and heights with respect to different variants were not observed. However, a difference with respect to biomass has been observed. Acceptance of the FGD-gypsum has been clearly observed with biomass produced under both the Poplar clones. Acceptance of FGD gypsum observed was comparatively higher with the Hybrid 275 compared to the Weser 6, which could be correlated to the genotype of the Hybrid 275.

Key words: FGD gypsum, lime, structural development, amelioration

INTRODUCTION

This study verifies the substitution of Flue Gas Desulphurization (FGD) gypsum instead of lime as Ca^{2+} source in the amelioration of virgin clay soils at open cast mining pit Nochten, Saxony, Germany starting from the year 2005 till year 2009.

Electric power plants must operate stack scrubbers to reduce sulfur emissions (Clean Air Act), which results in production of the FGD gypsum as an additional waste by-product (Reich, 1992). Removal of sulfur dioxide from flue gas produced by coal burning power plants has increased the availability of by-products that may be useful as soil amendments for

Table 1: FGD-gypsum as analyzed by BTU and Vattenfall and are compared with fertilizer and sewage sludge regulations

	Analysis FGD gypsum		Fertilizer regulations		Sewage sludge regulation	
	BTU	Vattenfall	Identification	Limit value	Maximum	Limit value
Element	(mg kg^{-1})					
Arsenic	-	0.58	20	40	-	-
Lead	3.98	4.66	125	150	100	900
Cadmium	0.03	<0.6	1	-	1.5 (1)	10 (5)
Chromium	1.29	1.16	300	-	100	900
Nickel	0.52	<0.83	40	80	50	200
Mercury	-	0.55	0.5	1	1	8
Thallium	-	5.65	0.5	1	-	-
Copper	3.55	2.49	-	70	60	800
Zink	-	5.07	-	1000	200 (150)	2500 (2000)

BTU: Brandenburg University of Technology Cottbus, Germany

agriculture (Ritchey *et al*., 1996). Introduction of the FGD gypsum at agricultural and forest plantation sites would result in complete reduction of the FGD gypsum deposition over convictable economic cycle. Even though the FGD gypsum is highly pure (96%) (Ritchey *et al*., 1996) it still contains some potential toxic elements as given in Table 1. Table 1 shows information on the toxic elements analyzed by Vattenfall AG and KO GmbH (Vattenfall) and also at the Brandenburg University of Technology (BTU) along with the guide line values specified by Fertilizer regulations and Sewage Sludge regulation. The Fertilizer and Sewage Sludge regulations specify guide lines for the usage of secondary by products (FGD gypsum) in agricultural and forestry management in Germany (Werther and Ogada, 1999). The open cast mining pit Nochten was chosen to investigate ameliorative effects of the FGD gypsum on clayey substrates. Ameliorative effects of the FGD gypsum are compared with the ameliorative effects of lime (standard ameliorative substance). If the FGD gypsum application results in a similar or better amelioration in comparison with lime, the application of FGD gypsum could improve agricultural and forestry recultivation in Lusatia while simultaneously decreasing the demand for landfill space to the deposit of FGD gypsum (Shainberg *et al*., 1989).

The open cast mining site Nochten was primarily dominated by sandy substrates up to 50 m depth till 2003, where a change in profile towards clayey substrates has been observed in year 2004. Quaternary substrates useful for obtaining maximum yield stretch only up to depths less than 10 m as shown in Fig. 1. Tertiary layers consisting of clay substrates stretch up to a maximum depth of around 50 m. Coal layer designated as Raunoer sequence consists of four clay layers together (Anke and Knuth, 1982; Nowel *et al*., 1995; Narra, 2008). These clay layers are enclosed by gravelly sand horizons as given in Table 2. Surface cover has been dominated by clayey substrates approximately up to 225 hectares (Narra, 2008). Geological occurrence of Nochten surface clay covers about 14.5 Mio t or 7 Mio m^3 (Narra, 2008). Nochten surface clay is represented as two-layered kaolinitic clay and possesses smaller source ability contrary to that of three-layered clay minerals, like Montmorillonit and Vercumit.

Ideal percentage of clay in soil should be $\leq$20%. Percentage of clay above 20% hinders root growth and when the clay percentage is $\geq$40%, root growth will be limited (Miller, 2001). Nochten surface clay ranged in between 43 and 55% having a pH of 4.2. The higher clay presence and the lower pH value indicate higher burnt lime (CaO) requirement in amelioration.

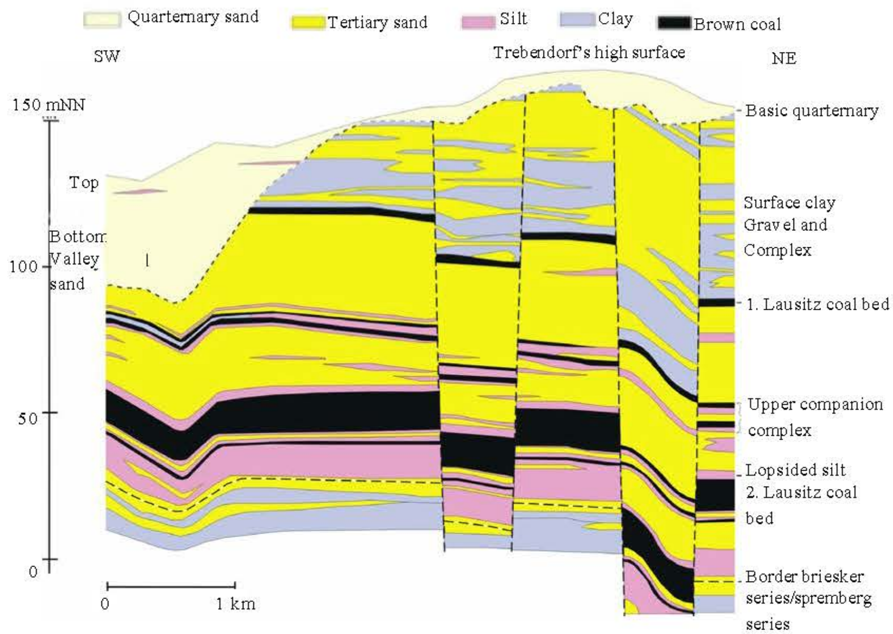

Fig. 1: Geological cross section at open cast mining field Nochten (Narra, 2008)

Table 2: Average grain size distribution in four clay horizons from Raunoer sequence

Clay horizons	Sand	Silt	Clay	Clay min-max
	($g\ 100\ g^{-1}$)			
1	10	35	55	23-86
2	22	29	49	15-85
3	36	21	43	11-91
4	12	28	60	17-99

Anke and Knuth (1982), Nowel *et al.* (1994), Narra (2008)

MATERIALS AND METHODS

Wild rye (*Secale multicaule* L.) in cultural attempts, the Hybrid 275 (*P. maximowiczii* Henry *x P. trichocarpa* Torr. et Gray) and the Weser 6 (*P. trichocarpa* Torr. et Gray) were used in field experiments for evaluating effect of the FGD-gypsum increments under the plant growth related aspects from year 2005 till year 2008. Cultural attempts were carried out in the Greenhouse in the year 2005. The field experiments were carried out from year 2005 till year 2008.

After the consecutive mining operations such as excavation, transportation and deposition, on average the sand-clay mixture over the surface was 65% sand and 35% clay (Narra, 2008). This average mixture was taken into consideration in all the investigations carried out in green house with wild rye species. Wild rye was used in recultivation for the protection from wind and water erosion, as wild rye exhibits high growing potential even under unfavorable environmental conditions.

During the pot-experiments, temperature is specified to 16°C (8 h) at night and 24°C (16 h) during daytime (Prasad *et al*., 2008). Clay is added to sand in aggregate size classes of <2, 2-6 and 6-20 mm. The mixture consists of Pleistocene sand 0.975 l (1.55025 kg) and clay 0.525 l (0.588 kg) in each of the pots, which results in a complete material mass of 2.1382 kg

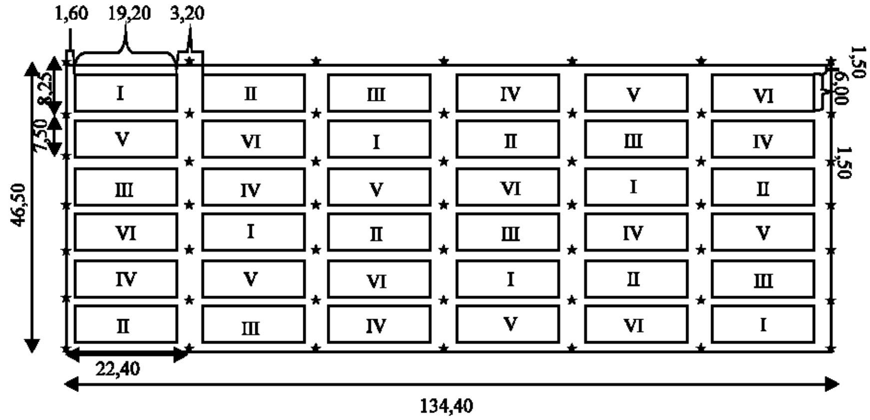

Fig. 2: Plan of field test as Latin square. Roman numbers of plots correspond to respective lime and gypsum variants

Table 3: Different variants used in cultural attempts and at field Nochten to evaluate effect of FGD-gypsum

Variants	Culture (n = 27) dt ha^{-1}	Field (n = 384) dt ha^{-1}	Ameliorations
1	6.6	20	Lime (1x)
2	6.6	20	Lime (0.5x) + Gypsum (0.5x)
3	6.6	20	Gypsum (1x)
4	13.2	40	Gypsum (2x)
5	26.4	60	Gypsum (4x)
6	52.8	120	Gypsum (8x)
7	105.6	---------	Gypsum (16x)

under each pot. The sand-clay mixtures are filled into open clay pots with a volume of 1.5 L after the addition of lime and/or FGD gypsum. After the pots are prepared they are watered (tap water) in two periods so that the planned water content can be adjusted within the pots. The watering is done to obtain three different soil characteristic moisture states: (1) Dry (approx. 20 volume. %), (2) fresh (approx. 30 volume.%) and (3) Wet (approx. 40 volume.%). The pots are watered every third day. In addition to the actual measured weight of the pots, the total weight is calculated based on the amount of water supplied into the pots. The positioning of pots in the greenhouse is conducted randomly via numeric allocation. In order to keep the influence of location-dependent lighting as small as possible, the positions of the pots are changed every three days after watering.

Germination of wild rye is carried out with tap water for 8 days. Cultural attempts are evaluated with the soil pH value, soil electrical conductivity, plant biomass, heavy metals accumulation etc., after 5 weeks of the growth.

Field investigations are evaluated only with six variants having six repetitions. Field investigations (N 51°26', E 14°39') were carried over 2.064 ha divided into 36 subplots having dimensions of 6×19.2 m each. Distance between the subplots 1.5 m (rows) and 3.2 m (columns) has been chosen for avoiding material transfer from one plot into another as shown in Fig. 2. Planting distance is about 0.75 m with a row distance of 0.8 m, which corresponds to a planting density of 0.6 m^2 for each plant and 16,666 trees per hectare. Poplar (Hybrid 275 and Weser 6) shoots were planted on 25th April 2005 and has been fertilized on 3rd June 2005 with NPK (60 80 60). Field investigations were evaluated with the nutritional elements, stem volume and biomass production every 6 months by measuring diameters and heights till two and a half years.

Burnt lime (CaO) requirement was measured based on the method suggested by Scheffer and Schachtschabel (2002). Indicated lime requirement of 6.6 dt ha^{-1} in cultural attempts is based on 1.3 g cm^{-3} bulk density (agricultural default value) where as 20 dt ha^{-1} in field investigations was based on 20 cm amelioration depth. Table 3 gives the different concentrations of the FGD gypsum and lime used in cultural experiments and field investigations.

RESULTS AND DISCUSSION

Cultural Attempts

A decrease in pH is observed with the FGD gypsum increments compared to lime (5.9 to 4.8). The pH values on average were above 4.8 slightly higher then that of sand-clay mixture (4.2) with out amendment. Alva (1993) has also observed a pH range between 4 and 6 with the application of FGD gypsum. Chan and Heenan (1998) observed a similar trend (decreasing) with respect to depths and also with respect to time (1 to 3 years). It has been stated by Clark *et al.* (2001) that even with high quantities of the FGD gypsum used, pH could not be increased which is noted by him as a constraint due to low percentage of CaO presence.

The ability of calcium sulfate to slightly increase the pH is dependent on the nature and amounts of clay minerals in the soil. Parfitt and Smart (1978) and Rajan (1978) observed an increase in pH when sesquioxide minerals such as Al- and Fe-oxides predominate. An increase in pH is due to the displacement of sulfate anions by hydroxyl groups in greater amounts as compared to the displacement of Al by Ca. When there are lower contents of sesquioxides, the displacement of Al is less and a decrease in pH is observed (Chang and Thomas, 1963).

The pH values remain above an average value of 4.8, which has to be attributed to the fact that the FGD gypsum contains approx. 1% of $CaCO_3$. Due to the high presence of clay in the substrate mixtures, it is conceivable that a neutralization procedure as described in Eq. 1 has taken place (Parfitt and Smart, 1978; Rajan, 1978). In strongly sour soil with pH values <5.5, the pH value of soil is determined hardly under CO_2^- partial pressure. Aluminum in acid determines the pH value, which depends on exchangeable aluminum in clay mineral surfaces and also on organic substances in equilibrium (Chang and Thomas, 1963). With the lime application it was observed that the calcium ions exchange with aluminum and hydrogen-ions, whereby the base solution aluminum hydroxide forms and the pH value of soil rises (Eq.1).

$$\text{(Aust.)}\,\frac{AL}{H} + 2CaCO_3 + H_2O \rightarrow \text{(Aust.)}\,Ca_2 + Al(OH)_3 + 2CO_2 \qquad (1)$$

With the background of the necessity to raise the pH value of recultivation locations (to a minimum of 5.5) at the Nochten open cast mining site, the application of FGD gypsum is not an option, as even with large quantities of the FGD gypsum application there is no increase in the pH values as compared to the lime application.

The FGD gypsum ($CaSO_4$) is a salt from sulfuric acid (H_2SO_4), which dissociates in water into both sulfuric acid and calcium hydroxide (Eq. 2) (Narra, 2008). Electrical conductivity is directly proportional to the salt concentration in soil i.e., Higher the salt concentration in the soil solution, electrical conductivity values of the soil are also higher. This connection between electrical conductivity and salt concentration is clearly observed and is depicted in

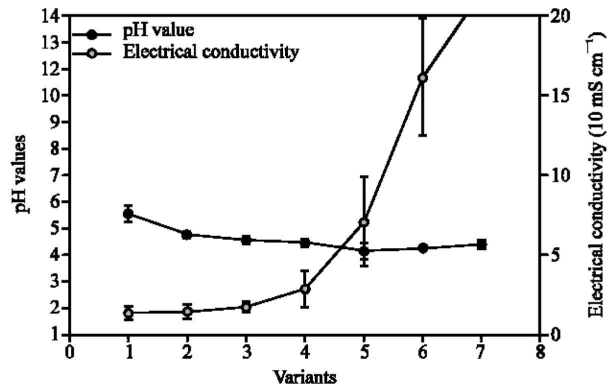

Fig. 3: pH and electrical conductivity values to find out the point of intersection by which the maximum appropriate amount of FGD-gypsum

Fig. 3. Sumner (2009) observed that gypsum has an ability to deliver calcium ions in sesquioxide soils. During this process gypsum is reduced as given in Eq. 2. High concentration of calcium in soil solution is the real reason for changes in preferential physical effects. Levy and Sumner (1998) have observed higher solubility with the FGD gypsum (2.3 mS cm^{-1}) compared to solubility of the lime (0.02 mS cm^{-1}). Maximum electrical conductivity (2.15 mS cm^{-1}) obtained with variant 7 is almost equal to the solubility of FGD gypsum. Agostini *et al.* (2003) also found an increase in electrical conductivity with the FGD gypsum compared to natural gypsum. Increase in the electrical conductivity could be due to the flocculation process under gone with the FGD gypsum along restoration (Agostini *et al.*, 2003). Higher electrical conductivity values are obtained with lower water content (20%) and lower clay particle sizes (<2 mm) which could be due to high presence of salt and less dissolution. The electrical conductivity values decreased with increase in water contents and clay aggregate sizes indicating high dissolution and functioning of gypsum over clay aggregates in disruption. The FGD gypsum application quantities should be optimized to minimize sulphate leaching and cat-ion losses (Alves and Lavorenti, 2004). Alves and Lavorenti (2004) also stated that gypsum application quantity is proportional to the subsurface soil clay content. The amelioration of acidic soil requires gypsum application in concentrations varying from 10 to 100% (Narra, 2008). Higher concentrations of gypsum mostly results positively in a deeper effective rooting depth, thus a better availability of water and nutrients for all the deep rooted plants (Lehmann, 2003). Irrigation water should not exceed electrical conductivity of 2 mS cm^{-1} as there will be efflorescence especially with salt-sensitive plants. The cultural experiments variant 7 with 16 times the FGD gypsum concentration has been taken out in field investigations due to its higher electrical conductivity (>2 mS cm^{-1}).

$$Fe_2(OH)_2 + CaSO_4 \rightarrow Fe_2OHSO_4 + Ca^{2+} + OH^- \quad (2)$$

Patriquin *et al.* (1993) proposed a ratio between the pH and electrical conductivity to be equal to 1 in soil for determining coupling/decoupling phenomena. Values of the pH and electrical conductivity are plotted together in Fig. 3 such that a relation can be obtained between the pH and electrical conductivity. Both the pH and electrical conductivity curves cross each other in between the variants 4 and 5, indicating variant 5 as the maximum amount

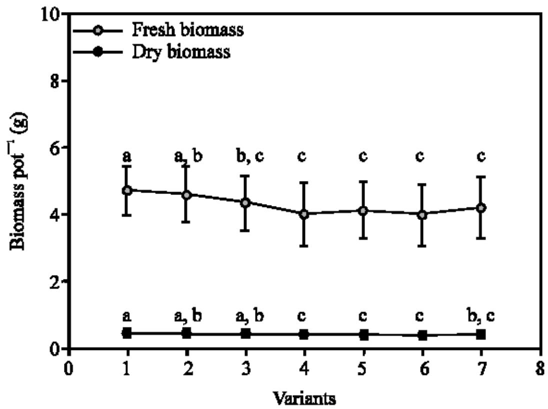

Fig. 4: Fresh and dry biomass with wild rye. Different letters indicate different significance

of FGD gypsum appropriate for the amelioration purpose. The pH to EC ratio is one at this point of intersection whereas, above this point the value is less then one. The pH values range between 6 and 8 is generally considered as neutral zone and lies in between the variants 4 and 5 also indicating that variants 6 and 7 show very high electrical conductivity values. It is observed that biomass production and yield rate in case of variants 6 and 7 are low, which also supports this model. It is also well known that the yield of plants and biomass production is very good with the pH values between 6.0 and 6.8. There is an eight to ten fold range in salt tolerance of agricultural crops (Maas, 1984) based on which the application concentrations of different variants are chosen. From Fig. 3 and with the results, it becomes clear that variants 6 and 7 are not effective in biomass production, where the application range is eight fold and sixteen fold respectively.

This pH-electrical conductivity model is scale dependent with variation in electrical conductivity but with regard to pH, the scale (1 to 14) is constant. Scale of electrical conductivity can be fixed based on the definition given by U.S. Salinity Laboratory for salt soils, where maximum electrical conductivity in agricultural soils is 2 mS cm^{-1}. Thus, fixing both the axis is taken as an advantage in the modeling pH and electrical conductivity values together in finding out appropriate maximum amount of the FGD gypsum amendment for achieving higher yield through which higher biomass. Electrical conductivity units 10 mS cm^{-1} is chosen as to equate the effect of logarithm to base 10 from pH values.

Germination success of the wild rye seeds with different concentrations of FGD gypsum and Lime on average was $\geq$90%. Even though there is a decrease in the pH and increase in the electrical conductivity values with variants there is no specific trend observed in case of germability, which could be related to the characteristics of wild rye growing even under extreme conditions (Potter, 1951). Germination success gives an idea on the growth, which could be the reason that biomass produced by wild rye did not show any particular trend with respect to different variants as shown in Fig. 4. Higher biomass is obtained with higher water content (40%) and lower clay grain sizes (<2 mm) which could be due to higher dissolution and less clay presence helping the salt FGD gypsum in performing amelioration effectively. The germability after the application of the 100% lime and the 100% FGD gypsum treatments is similar but there is a small decrease in the germability for variant 2 where a combination of 50% lime and the 50% FGD gypsum is used. With an increase in the FGD gypsum concentrations, biomass production decreased.

Table 4: Nutritional elements in wild rye (*Secale multicaule* L.)

Total	Ca	Mg	Fe	Mn	Al	P	Zn	K
	(mg g^{-1})							
1 Lime	8.09	4.32	0.11	0.12	0.15	5.63	0.09	71.20
50% Lime+50% Gypsum	7.77	4.15	0.09	0.10	0.11	5.69	0.10	71.81
1 Gypsum	7.51	4.00	0.11	0.08	0.14	5.37	0.10	71.35
2 Gypsum	7.82	4.17	0.10	0.08	0.11	5.25	0.09	71.45
4 Gypsum	8.05	4.28	0.12	0.08	0.15	5.70	0.10	70.90
8 Gypsum	8.25	4.23	0.12	0.09	0.13	5.33	0.11	69.04
16 Gypsum	8.67	4.18	0.11	0.10	0.13	5.82	0.11	71.05
Optimum values (Clark *et al*., 2001)	6-10	2-10	0.2-0.5	0.05-0.2	<2	5-10	0.15-1	<75

Nutritional elements in the wild rye with various water contents, grain sizes did not show any particular trend with different variants. Table 4 gives the amount of nutritional elements present after 5 weeks of growth in the Wild rye species. All the nutritional values lie with in optimal range except iron and zinc. Values of the zinc are near to that of optimum values as per (Clark *et al*., 2001).

A very slight increase in the concentration of K and Mg is observed for the application of the FGD gypsum which is found at 8 fold (variant 6) and 16 fold (variant 7) higher concentrations. This reduces yield due to leaching process (Gaines *et al*., 1991). Csinos *et al*. (1984) reports that high K and Mg contents increase pod rot and decrease the yield in case of peanuts. Gaines *et al*. (1991) predicts that up to a certain amount of the FGD gypsum amendment, the K and Mg leaching results in the a cation balance which in turn may reduce the pod rot and increase the yield. When this limit is exceeded it results in the reduction of yield as observed for the variants 6 and 7 supporting the model pH vs. electrical conductivity.

Liming consistently stimulates seedling growth throughout the variants. Considering very low levels of the Ca^{2+} and Mg^{2+} and low levels of the K^{+} to be present in the soil mixtures used for the experiments, an addition of Ca, a limiting nutrient, is expected to increase the shoot growth. Liming is known to stimulate seedling growth, especially when it also affects the N-availability (Hüttl and Zöttl, 1993). The beneficial effect of FGD gypsum with higher Ca activity is the complexation of Al with sulphate. The application of lime decreases the concentration of exchangeable Na and Mg with an increase in exchangeable Ca. This can be due to the flocculation effect rather then dispersion (Rengasamy *et al*., 1984).

Accumulation of heavy metals in the wild rye was very low. Chromium, nickel and copper increased with increasing the FGD gypsum concentration and with the highest level of application a reduction has been observed reflecting the pH-dependent solubility and availability. Cadmium and zinc concentrations in the plant varied only slightly. Lead content is higher in lime variants. Heavy metal content was not dependent on the FGD gypsum application concentrations. Legal basis for FGD gypsum application is based on fertilizer regulations.

Heavy metals are far below identification limits in the FGD gypsum except thallium. The thallium concentration is 6 fold higher then the limit value specified under fertilizer regulations. The thallium is below detection limits in the wild rye. The thallium content in the FGD gypsum should be reduced completely to use it as a fertilizer. Use of lime in the low thallium lime lignite for incineration is a possibility (optimization of combustion processes). Maximum heavy metals obtained in the wild rye are low to normal in the plants, which are given in Table 5.

Gabriella and Attila (2005) observed that liming and lignite added to polluted soil decreased plant metal uptake especially the Cd and Zn to a highest degree (24-36%).

Table 5: Maximum values obtained in Wild rye (*Secale multicaule* L.) along with normal and critical values in plants

		Elements in plants	
Element	Wild rye	Normal	Critical
Lead	0.25	1-5	10-20
Cadmium	0.24	<0.1-1	5-10
Chromium	0.90	<0.1-1	1-2
Nickel	4.53	0.1-5	20-30
Thallium	nm*	<0.5-5	20-30
Copper	13.62	3-15	15-20
Zink	110.00	15-150	150-200

*nm: Not measured

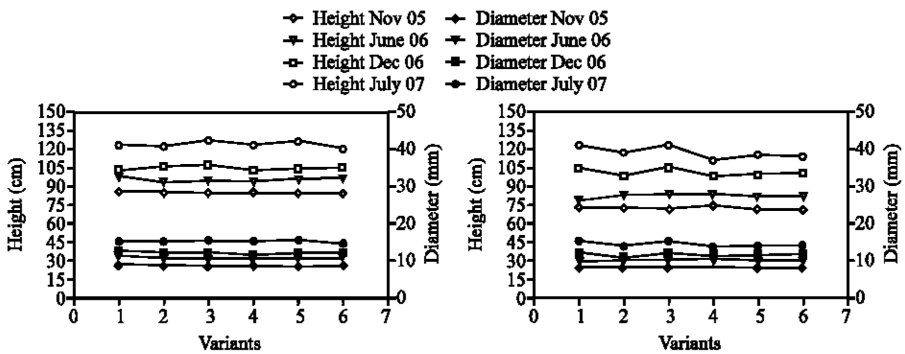

Fig. 5: Proportionate growth of the Hybrid 275 and theWeser 6

Gabriella and Attila (2005) also observed a complex effect i.e., the soluble soil metal concentrations decreased after liming (except for Cu and Pb solubility) due to chemical and physical bounding of the lime and lignite.

The cultural attempts are counter acting to that of Gabriella and Attila (2005). This could be due to the reason that the FGD gypsum did not increase the pH even with increasing concentrations. The variant 1 (100% lime) showed an increase in the pH values from 4.2 to 5.9 but there wasn't any decrease in the metal concentrations even under this variant.

Field Investigations

Average stature height and root neck diameter of the Hybrid 275 amounts to 124 cm and 15 mm (July 2007) corresponding to an increase of 19 cm, 3 mm (Dec 2006) and 28 cm, 4.5 mm (June 2006). Deviation of stature height is larger with 42% to that of mean values in case of the Hybrid 275. In addition, average stature height and root neck diameter of the Weser 6 amounted 118 cm and 14 mm (July 2007) corresponding to an increase of 18 cm, 2.5 mm (Dec 2006) and 35 cm, 4 mm (June 2006). Deviation of stature height is larger with 50% to that of mean values.

Height of Poplar clones on acid mine spoils ranged from 1 to 5 m after 5 years as observed by Czapowskyj and Safford (1993). Compared to the heights measured by Czapowskyj and Safford (1993) Poplar clones of the Hybrid 275 and Weser 6 at the Nochten showed better growth. Proportionate growth has been observed with both the Poplar tree species (Hybrid 275 and Weser 6) as also observed by Pallardy *et al*. (2003); Czapowskyj and Safford (1993) i.e., with increase in diameter there is a proportionate increase in heights as shown in Fig. 5. Similar to the observations in this research work,

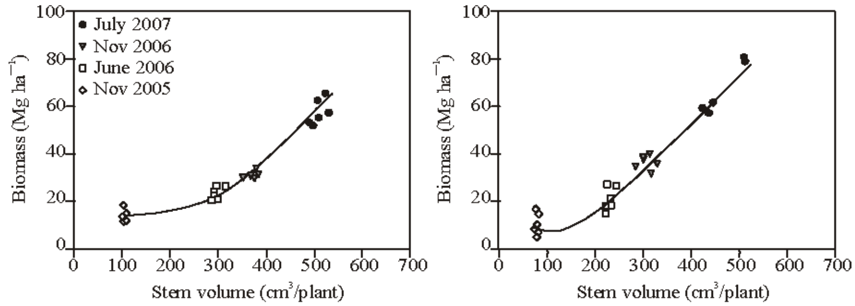

Fig. 6: Stem volume vs. biomass of the Hybrid 275 (left) and the Weser 6 (right)

Moffat and Shaw (1993) also observed proportionate growth with poplar species (lombardy and white poplar). Measured height of the poplar species is comparatively high when the FGD gypsum has been used as an amendment (Moffat and Shaw, 1993).

The mortality rate in both of the poplar species (especially Hybrid 275) was very low. The mortality rate in Hybrid 275 was ranging in between 2 and 5%, whereas in Weser 6 it was ranging in between 20 and 26%. Moffat and Shaw (1993) also observed 100% survival rate with the FGD gypsum amendment compared to other amendments. Differences in the mortality rate between the Hybrid 275 and the Weser 6 are attributable to the variation in rooting capacity which is known widely with genotype within the Poplar tree species (Kozlowski and Pallardy, 1997). Hybrid poplar clone has been in production and distribution as hardwood cuttings for many years, as it is expected to have high success in establishment (Pallardy *et al*., 2003; Czapowskyj and Safford, 1993) which could be concluded with high success rate (very low mortal rate) observed with Hybrid 275.

Similar to the results of Shaw and Moffat (1993) with the FGD gypsum amendment, nutritional elements (N, P, K and Mg) measured are in optimum ranges as suggested by Jug *et al*. (1999). Concentration of nitrogen with lime amendment is below optimum range as observed by Jug *et al*. (1999) in energy forests with poplar stands.

Stem volumes vs. biomasses of the poplar clones are plotted together in Fig. 6 to verify of the growth rate with respect to time (6 months time interval). Exponential growth rate has been observed for both the Poplar clones as also observed by Fang *et al*. (2005). The Weser 6 exhibited higher exponential growth compared to the Hybrid 275, which could be due to the increasing number of branches with increase in growth. In case of the Hybrid 275 till June 2006 linear growth has been observed where the average height is 96 cm and there after exponential growth is observed (Dec 2006 and July 2007). Sudden change from linear growth to exponential growth can be explained with stature characteristics of the Hybrid 275. The Hybrid 275 grows as a single stature till approx. 100 cm, there after branches are developed increasing biomass exponentially.

Model (biomass vs. volume) of estimating biomass by knowing volume and angle of inclination as shown in Fig. 7 is plant dependent as an increasing angle of inclination has been observed with Weser 6, where as with Hybrid 275 having constant angle of inclination (11°) biomass can always be estimated once root neck diameters and stature heights are known. For the Weser 6 this model would also function when increase in angle of inclination stabilizes. Stabilization is expected in the Weser 6 as observations show a reduction in increase of inclination angle (from 7 to 3°). This model is based on increasing salt (the FGD gypsum) concentrations.

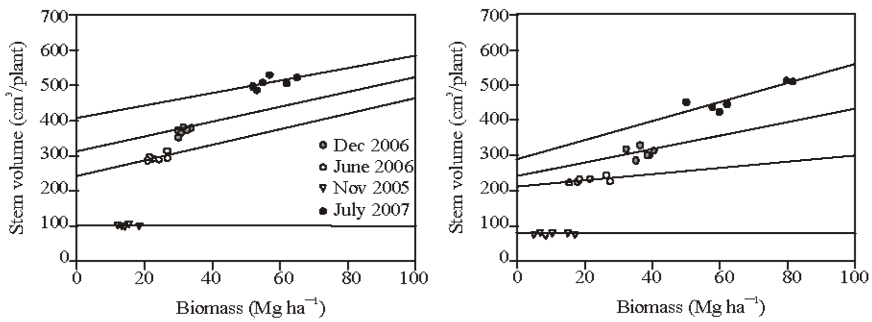

Fig. 7: Biomass vs. stem volume of the Hybrid 275 and the Weser 6

CONCLUSIONS

The soil pH values obtained are below neutral indicating that the pH of soil could not be increased with the FGD gypsum amendment as in case of lime. Electrical conductivity increased tremendously with increase in concentrations of the FGD gypsum as described by Agostini *et al.* (2003) and reaches up to its maximum solubility value.

Slight decrease in biomass of the wild rye is observed with increase in the FGD-gypsum concentrations till variant 4 and with further increase the values stabilize. A specific difference in biomass is observed in case of pots with different water contents, however with different grain sizes there is not much of difference with respect to variants. Maximum biomass has been produced with 40% water content due to high gypsum solubility and dispersion properties. Dry biomass produced is 10 fold less then fresh biomass.

Slight increase and decrease is observed in the values of nutritional elements obtained from the wild rye, but in general there is no particular trend. All nutritional elements lie with in optimum ranges as specified by Clark *et al.* (2001). Sulfur presence is a bit high, which could be due to the presence of readily reacting sulfur in the FGD gypsum. Sulphur in the FGD gypsum complexes with the aluminum (Al) and reduces the concentrations of the Al, supporting this reduction in the Al is observed. Elements Fe and the Zn are found to be less then optimum values. The heavy metals present in the FGD gypsum as analyzed are under optimum ranges except in case of thallium which also lies below the critical limit for plants. Accumulation of heavy metals from pot-experiments did not show any specific trend (increase or decrease) even with addition of the FGD gypsum at higher concentrations, toxicity was not observed.

Height to diameter ratio is almost equal to 1 indicating proportionate growth with both the poplar clones. Death rate of the Weser 6 is 6 to 7 fold higher compared to the Hybrid 275. The heights of Hybrid 275 are every time higher compared to the Weser 6; this could be due to the effect of side influences in the Weser 6. Clear trend has been observed with biomass, biomass produced increased with increase in concentrations of the FGD gypsum till variant 5 with the Hybrid 275, however in case of the Weser 6 maximum biomass is obtained with variant 3 and there after with increase in the FGD gypsum content biomass decreased. Model volume vs. biomass showed an exponential growth for both Poplar clones. Model biomass vs. volume gave a good co-relation using which biomass could be found out directly with height and diameter measurements. Substitution of lime by the FGD gypsum did not show any negative effects with the wild rye and also with the two different poplar clones (the Hybrid 275 and the Weser 6).

The results obtained with the cultural experiments with wild rye species and the field investigations with two kinds of Poplar clones (Hybrid 275 and Weser 6) show that the FGD gypsum can act as a substitute for the traditional soil ameliorant Lime especially in the soil with high clay contents.

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