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Effects of Volcanic Ash on Soil Nitrogen Mineralization and Accompanying CO₂ Production¹

Abstract

For four dominant agricultural soils from eastern Washington, treatment with moderate to heavy applications of ash from the 18 May 1980 eruption of Mt. St. Helens resulted in a slight decrease in microbial activity as evidenced by CO₂ evolution, but in little change in the amount of inorganic N produced during a standardized 28-day incubation. The effects are of insufficient magnitude to affect crop production or the nitrogen levels of groundwaters in the region.

Introduction

Crops in eastern Washington typically obtain one-third to one-half of their annual nitrogen needs from the mineralization of organic soil reserves (Leggett 1959). The eruption of Mt. St. Helens on 18 May 1980 covered much of eastern Washington's prime agricultural land with a layer of volcanic ash. Analysis of the ash has demonstrated relatively high levels of soluble salts (Fruchter *et al.* 1980, Table 5) which have previously been shown to affect nitrogen mineralization in soils (Agarwal *et al.* 1971, Broadbent and Nakashima 1971, Heilman 1975). In addition, ash constituents such as toxic metals may adversely impact soil microbial transformations.

Addition of nitrogen-free inorganic salts to soils generally results in increased inorganic nitrogen production (Agarwal *et al.* 1971, Broadbent and Nakashima 1971, Heilman 1975). The mechanisms responsible for the increase are not well understood nor agreed upon. Salts do not appear to increase microbial respiration (Agarwal *et al.* 1971). Nitrification has generally been inhibited concurrently, although the increase in ammonium levels is usually much greater than the corresponding decrease in nitrate levels (Agarwal *et al.* 1971).

The volcanic ash that extensively covered eastern Washington croplands may have created a salt effect similar to that in the laboratory experiments described above. The purpose of this study was to determine the effects of volcanic ash additions on soil nitrogen mineralization and microbial activity.

Methods and Materials

Four benchmark soils typifying several hundred thousand hectares of eastern Wash-

¹Scientific Paper No. 5807, College of Agriculture Research Center, Washington State University, Pullman, Washington 99164. Project 0382.

ington cropland were used in this study. Since bulk samples of these soils had been obtained three weeks prior to the eruption of Mt. St. Helens on 18 May 1980, they did not include ash. Selected properties of the soils are listed in Table 1.

TABLE 1. Selected properties of the soils studied.

Soil Series	Classification	pH	Inorganic N ^a	Total N	Organic Matter
			ppm		%
Ritzville	Calcicorthidic Haploxeroll	6.5	9.7	625	1.5
Palouse	Pachic Ultic Haploxeroll	6.2	8.8	1405	3.2
Shano	Xerollic Camborthid	7.1	3.1	585	0.8
Warden	Xerollic Camborthid	6.8	41.7	649	1.8

^aNO₃⁻ + NH₄⁺

Each soil was sampled to a depth of 15 cm, placed in an airtight plastic bag, and frozen until subsequent usage. The ash used in the study was a composite sample collected from the ashfall at Pullman, Whitman Co., Washington. Average chemical analysis of samples collected statewide is shown in Table 2 (Fruchter *et al.* 1980).

TABLE 2. Average chemical properties of volcanic ash from the 18 May 1980 eruption of Mt. St. Helens (Fruchter *et al.* 1980).

Total Analysis	(%)	Total Analysis	(%)
SiO ₂	65.0	MgO	2.2
Al ₂ O ₃	16.9	K ₂ O	1.5
Fe ₂ O ₃	4.8	TiO ₂	0.7
CaO	4.9	P ₂ O ₅	0.4
Na ₂ O	4.6	MnO	0.1
Water-Soluble Constituents (at 1:1 water content)			
	(mg/1, range)		(mg/1, range)
Cl ⁻	100-330	Na ⁺	81-340
NO ₃ ⁻	0-51	Mg ²⁺	11-65
SO ₄ ²⁻	260-1200	K ⁺	20-66
NH ₄ ⁺	3.3-18	Ca ²⁺	85-580
pH (1:1)	5.7-6.9	EC (mmho/cm), 1:1 ^a	1.0-4.1
		50% H ₂ O content ^b	1.9-8.1

^aCalculated as Σ cations (meq/liter) ÷ 10.

^bTo approximate saturation extract values.

After air drying the frozen soil for 24 hrs, 15 g subsamples were placed in 125 ml erlenmeyer flasks. Moisture content was determined by oven drying a separate subsample. Sufficient ash to provide the equivalent of 0, 45, 90, 134, 224, or 448 mt ash/ha-15 cm of field soil was mixed with the soil in each flask. Water was added to provide a moisture content of 30 percent by weight, and each resultant mixture was distributed with a spatula around the periphery of the flask bottom. Four milliliters of 1N KOH were placed in a small cup which was then placed in the bottom of each flask to trap the CO₂ evolved. Flasks were stoppered and incubated at 25° ± 0.5°C for 7, 14, 21, or 28 days. Every 3 days flasks were aerated by removing the stoppers for 10 minutes. A second set of flasks, without CO₂ traps, were used to monitor soil pH.

All CO₂ traps were analyzed weekly by transferring trap contents to a 125 ml erlenmeyer flask, adding 10 ml 1 N BaCl₂ and titrating with standardized HCl to the phenolphthalein endpoint. The CO₂ traps were then refilled with the flasks re-

incubated. The CO₂ evolved during successive time periods was summed to give cumulative CO₂ evolved for each treatment.

At weekly intervals one flask from each treatment (0, 45, 90, 134, 224, or 448 mt ash/ha) was extracted by shaking with 50 ml of 2 N KCl for 45 minutes. Extracts were then filtered and analyzed for NH₄⁺ and NO₃⁻ using a steam distillation procedure (Bremner 1965). pH values for the second set of flasks were measured using a 1:1 (w:v) soil:water suspension, following a 30-minute equilibration period.

Results and Discussion

The effect of incorporated ash on microbial activity can be estimated from the CO₂-evolution data (Table 3a). Evolution of CO₂ generally decreased with increasing rates of ash application, with the lowest CO₂ evolution (least microbial activity) usually associated with samples amended with 224 or 448 mt ash/ha. Control samples of Palouse soil from Whitman Co. evolved less CO₂ than treatments receiving intermediate rates of ash application, though the lowest rates of CO₂ evolution still corresponded to the highest rates of ash amendment. Such trends may be related to the high organic matter content of the Palouse soil. Rates of CO₂ evolution were consistently, and often dramatically, lower for the 14 to 21 day interval. The reason for this phenomenon is unknown, for microbial activity had increased once more by the 21 to 28 day interval. The trend may be related to cyclic senescence of sample biomass (Knapp 1980).

The heterotrophic organisms responsible for CO₂ evolution are also largely respon-

TABLE 3. Trends over time for cumulative CO₂ evolution, inorganic N release, and pH of ash-amended soils.

Soil	Rate of ash addition (mt/ha)	(a)						(b)			
		Days of incubation				Days of incubation					
		7	14	21	28	7	14	21	28		
		CO ₂ evolved (mg-C/100g soil)				Inorganic-N release (ppm)					
Palouse	0	7.0	9.8	10.8	14.6	5.6	16.2	19.9	25.3		
	45	7.7	10.6	11.6	16.4	5.0	16.8	18.8	21.9		
	90	7.5	10.2	10.7	16.5	7.7	17.7	18.5	20.5		
	134	8.8	11.2	11.7	16.5	7.8	16.9	19.2	19.9		
	224	5.5	8.6	9.4	12.2	4.9	17.0	18.5	22.5		
	448	5.6	8.8	9.8	12.6	6.9	18.4	18.9	20.2		
Warden	0	15.2	25.9	30.7	40.9	37.9	52.9	37.8	25.2		
	45	12.9	20.9	25.7	32.5	37.1	50.2	46.0	40.1		
	90	15.4	24.2	29.0	35.7	36.5	52.5	41.7	38.5		
	134	13.6	22.4	27.4	34.5	41.2	38.5	47.9	48.4		
	224	13.9	23.1	28.1	34.6	46.2	44.7	53.8	59.7		
	448	13.2	20.5	25.9	31.7	45.7	40.0	50.1	59.2		
Ritzville	0	5.0	10.6	13.9	16.8	4.3	6.0	7.5	10.2		
	45	5.2	9.9	12.4	15.1	3.4	7.0	7.5	12.2		
	90	5.0	9.4	11.5	13.8	5.8	6.3	9.4	11.9		
	134	5.0	9.4	11.5	14.0	4.7	7.0	9.7	12.2		
	224	4.4	8.2	10.1	12.4	3.8	6.5	10.0	11.8		
	448	4.0	8.3	9.7	11.6	3.8	5.5	13.5	14.3		
Shano	0	4.2	7.8	9.3	11.2	4.8	5.9	9.0	11.1		
	45	4.2	7.1	8.5	10.0	4.8	6.6	9.4	12.3		
	90	4.0	6.9	8.4	9.9	4.4	5.8	9.1	11.6		
	134	3.4	6.8	8.4	10.3	4.6	6.9	8.8	10.6		
	224	3.0	6.4	7.6	8.9	4.9	5.1	9.8	10.9		
	448	3.1	5.5	6.4	7.5	3.5	4.3	7.4	9.8		

sible for the mineralization of organic nitrogen; therefore, lower rates of CO₂ evolution normally would be associated with lower rates of inorganic nitrogen production. Data in Table 3b show many deviations from this anticipated trend, however. The Warden, Ritzville, and Shano soils, for example, produced more inorganic nitrogen in 28 days in the presence of added ash. Paradoxically, the Palouse soil control produced a greater amount of nitrogen than several of the ash-treated Palouse samples, despite an opposite trend with respect to CO₂ production.

Since nitrification (conversion of NH₄⁺ to NO₃⁻, with concurrent release of H⁺) tends to lower soil pH, the effect of volcanic ash additions on soil pH were examined (Table 4). The largest ash-associated change in pH after 28 days of incubation was a further decrease of 0.4 units for the Ritzville soil at the 448 mt/ha ash application rate. Ash-associated changes in pH did not continue over time. Lowering of soil pH can both solubilize organic matter and adversely affect soil microbial populations. Lower pH is particularly inhibitory to the nitrification process. With the relatively small changes in pH observed in this study we do not consider the possibilities of adverse pH changes following ash incorporation to be particularly great. The major pH change for the Warden, Ritzville, and Shano soils occurred in the first seven days of incubation, with subsequent changes inconsistent and of considerably smaller magnitude. Only for the Palouse soil, with its large organic matter content, did the pH continue to decrease with time. Furthermore, the magnitude of the pH decrease for this soil appeared to be independent of the rate of ash addition.

Data such as those of Tables 3a and 3b are difficult to interpret precisely because

TABLE 4. Electrical conductivity, and pH trends over time, for ash-amended soils.

Soil	Rate of ash addition (mt/ha)	Electrical conductivity ^a μmhos/cm	Days of incubation				
			0	7	14	21	28
			pH				
Palouse	0	303	6.20	5.70	5.70	5.70	5.60
	45	354	6.10	5.75	5.60	5.55	5.42
	90	394	6.00	5.80	5.60	5.51	5.45
	134	465	5.95	5.85	5.60	5.50	5.46
	224	586	5.90	5.70	5.57	5.49	5.41
	448	909	5.90	5.60	5.50	5.45	5.34
Warden	0	646	6.80	6.30	6.35	6.22	6.22
	45	646	6.70	6.20	6.20	6.40	6.35
	90	646	6.70	6.40	6.20	6.15	6.40
	134	788	6.70	6.00	6.08	6.15	6.12
	224	909	6.65	6.00	6.14	6.07	5.98
	448	1192	6.60	6.00	6.05	6.10	6.05
Ritzville	0	244	6.55	6.00	6.10	6.50	6.30
	45	364	6.55	6.15	6.13	6.18	6.32
	90	384	6.55	6.15	6.10	6.15	6.30
	134	450	6.50	6.10	6.15	6.02	6.10
	224	586	6.40	6.00	6.09	5.98	6.05
	448	929	5.80	5.95	6.09	5.97	5.90
Shano	0	263	7.15	6.70	6.65	6.65	6.50
	45	313	7.00	6.30	6.60	6.51	6.40
	90	388	7.05	6.30	6.50	6.51	6.40
	134	422	7.10	6.40	6.30	6.49	6.40
	224	513	7.10	6.40	6.40	6.40	6.31
	448	879	7.10	6.42	6.28	6.30	6.23

^aE.C. measured on 1:1 (w:v) soil:H₂O basis.

of the numerous concurrent transformations which occur in incubated samples. For example, the Warden soil evidenced its peak inorganic nitrogen content at 14 days for the 0 to 90 mt/ha treatments, whereas values for the 134 to 448 mt/ha treatments continued to increase over the entire 28-day period. The latter values were also considerably greater than the former. Until this effect diminishes, there could be an increase level of inorganic nitrogen available for crop growth in the Warden soil. The first three treatments (control, 45 mt/ha and 90 mt/ha) for the Warden soil appeared to actually be immobilizing inorganic-N after 14 days, even though the 134, 224, and 448 mt/ha treatments still evidenced net mineralization during the entire period of study.

There was relatively little difference between control and treatment samples with respect to CO₂ evolved or inorganic-N produced for the Palouse, Ritzville, or Shano soils (Tables 3a and 3b). The amounts of soluble salt added in the volcanic ash (Table 2), even at the 224 or 448 mt/ha rates, did not appear sufficient for production of a stimulatory salt effect. The stimulatory effect could be somewhat masked, however, by moisture tension effects or by the presence of other constituents in the ash (such as trace metals) which might be mildly toxic to soil microbial populations. Such an interaction is suggested by the opposite effects observed with respect to CO₂ production and nitrogen mineralization rates.

Conclusions

For four dominant agricultural soils from eastern Washington, treatment with moderate to heavy applications of ash from the 18 May 1980 eruption of Mt. St. Helens resulted in a slight decrease in microbial activity, as evidenced by CO₂ evolution. For three of the four soils, there was little change in the amount of inorganic N produced during a 28-day incubation, suggesting that there should be no change in either plant-available nitrogen or in runoff or leaching of nitrogen as a result of ash incorporation. An increase in plant-available nitrogen following ash incorporation appears probable for crops grown on the Warden soil, possibly due to microbial stimulation when the salt present in volcanic ash is superimposed on already-elevated native levels of salinity. Ash incorporation initially lowered soil pH by 0.2 to 0.4 units at the 224 to 448 mt/ha rates, but no consistent changes in pH were evident over time. While effects of the ash on dominant agricultural soils from eastern Washington are generally consistent (decreased CO₂ evolution, unaffected or slightly affected N mineralization, decreased pH), these effects are of insufficient magnitude to affect crop production or the nitrogen levels of groundwaters in the region.

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Received December 16, 1980

Accepted for publication March 6, 1981