



Variability of Soil Carbon and Nitrogen in Switchgrass and Big bluestem Fields in Northwestern Pennsylvania

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INTRODUCTION

Rising costs of petroleum-based fuels, environmental effects of carbon-dioxide emissions and other air pollutants, and concerns over reliance on foreign oil sources are driving investigations into alternative sources of energy. Plant biomass, a nearly carbon neutral option for renewable energy, takes advantage of the energy capture capability of photosynthesis in plant tissues, providing energy that can be used when plant material is directly or indirectly combusted (McLaughlin et al. 1999). Biomass has long been an important fuel source, and presently makes up approximately 62% of the world's supply of alternative energy sources (Demirbas 2005). Current estimates suggest that within the next fifty years, energy obtained from biomass could increase four-fold (Berndes et al. 2003).

Among sources of biomass-derived energy, perennial grasses are receiving a great deal of attention. In particular, switchgrass (*Panicum virgatum*) and big bluestem (*Andropogon gerardii*) are easy to cultivate and establish, are native, and are resistant to drought. Because they are perennial plants, they do not require annual plowing to prepare soils, thus reducing disturbance to soil and minimizing threats from erosion. Use of perennial plants has also been shown to provide well established habitat for grassland birds and other species (Roth et al. 2005). Furthermore, switchgrass and big bluestem are non-invasive grasses, and can grow well in many areas (Fike et al. 2006a). If used for ethanol production, perennial grasses are fifteen times more efficient than corn (McLaughlin and Walsh 1998).

Despite their attributes, large-scale use of perennial grasses raises a host of potential concerns. Growing biofuels requires large amounts of land that could otherwise be maintained in agriculture or forests. In addition, harvesting biofuels will result in removal of nutrients from soil and may well require broad-scale use of fertilizers, with potential concerns over eutrophication of surface waters. Switchgrass fields also tend to be grown in monocultures, which often require an increased use of fertilizers and pesticides to maintain production and to stave off molds and invasive insects (Horrihan et al. 2002).

For perennial grass crop production to be most efficient for commercial operation, it will be valuable for agronomists to maintain a relatively uniform rate for biomass production. A study conducted in Northwest Pennsylvania (Bowden et al. 2008) measured variation in biomass production of two strains of switchgrass and big bluestem, finding a wide variation of biomass production within fields. For example, biomass yield ranged from 0.46 to 1.33 kg m⁻² for different sampling sites within the same field of big bluestem. Similar results have been found across a wide range of switchgrass strains (Lemus et al. 2002).

One explanation for the variability in growth may be variation in soil nutrient content; variability in soil nutrients can influence the variation in plant biomass (Bransby et al. 1998). If soil nutrient supplies are low, then plants must make trade-offs in size, reproductive efforts, or biomass allocation among aboveground and belowground tissues (Andel and Vera 1977, Biere 1995). Soil fertility also affects rates of nutrient uptake and allocation within plants; soils with higher concentrations of nutrients produce plants with more nutrients in their roots and seeds (Andel and Vera 1977).

To understand the causes of variation in biomass, the objective of this study was to quantify the variability of soils in three fields of perennial biofuel grass, switchgrass Cave-In-Rock, switchgrass Shawnee, and big bluestem. We hypothesized that soil nitrogen and carbon concentrations would vary similarly with biomass among the three fields, and would explain a large part of the observed variation in aboveground biomass.

METHODS

This study was conducted in Northwest Pennsylvania in April 2008. We sampled soil from three different fields that were each approximately 10 hectares in area (Appendix 1). Two of the fields each contained a different switchgrass cultivar: Switchgrass Shawnee and Switchgrass Cave-in-Rock; the third field had been planted to big bluestem. All fields were converted to switchgrass from corn in about 1999, and were fertilized yearly in May with 40 pounds per acre of nitrogen. The sampled areas of the field were about 200 x 200 meters and were 3-20 meters away from forest and road edges.

We used a systematic and random sampling technique to collect 32 mineral soil samples within each field. We randomly established four parallel transects running within each field. Soil samples were collected every 25 meters along each transect, starting at 25 meters from the transect beginning and ending 200 meters away. We used an Oakfield soil sorer to collect soil samples of 10 cm depth and 1.8 cm diameter.

Samples were dried for 5 days at 60° C. To remove non-soil material, we passed the samples through a 2mm sieve. Then we measured out between 0.4500 and 0.6500 grams of each sample and used a Leco CNS Determinator to determine total soil nitrogen and carbon concentrations.

RESULTS

Variation Among Fields

A wide range of soil nitrogen and carbon levels existed among the three different sites (Table 1, Appendix 2). For example, the two switchgrass sites had similar N concentrations, however big bluestem site had a concentration nearly 40% greater than the concentration at the switchgrass Cave-In-Rock site (Table 1). Likewise, soil carbon also varied among sites. The average concentration of carbon at the big bluestem site was approximately 20% higher than concentrations at the Cave-in-Rock site. Soil in the field of big bluestem had the highest nitrogen and carbon concentrations of the three fields. Soil C and N in switchgrass Cave-in-Rock and switchgrass Shawnee were similar, and were lower than the big bluestem site.

Table 1. Variability of soil nitrogen and carbon concentration across sites

	% Nitrogen			% Carbon		
	Big Bluestem	Shawnee	Cave-in-Rock	Big Bluestem	Shawnee	Cave-in-Rock
Mean	0.208	0.153	0.150	3.00	2.49	2.52
Std. Error	0.007	0.008	0.010	0.09	0.11	0.16
Maximum	0.289	0.288	0.353	3.90	4.29	6.46
Minimum	0.140	0.087	0.073	2.21	1.52	1.52
Range	0.149	0.201	0.280	1.69	2.77	4.94
Coefficient of Variation (%) (std dev/mean)	18.9	29.1	37.3	16.3	25.8	36.2

Variation Within Fields

Nitrogen levels differed substantially within a single field (Fig. 1). The variation among the eight locations along each of the four transects was high. For example, within the Shawnee field, the nitrogen concentrations varied from 0.11% to 0.20% among transect locations. Soil carbon levels also varied within each field; in the field of Big Bluestem, average concentrations of soil carbon by transect location varied from 2.51% to 3.48%. Switchgrass Cave-in-Rock had the widest range (1.42%) between highest and lowest values by transect location (Fig. 2). Cave-in-Rock was the most variable for both carbon and nitrogen, with relative variations of 36.2% and 37.3%, respectively (Table 1). Big Bluestem was the least variable in carbon and nitrogen concentrations relative variations of 16.3% and 18.9%, respectively.

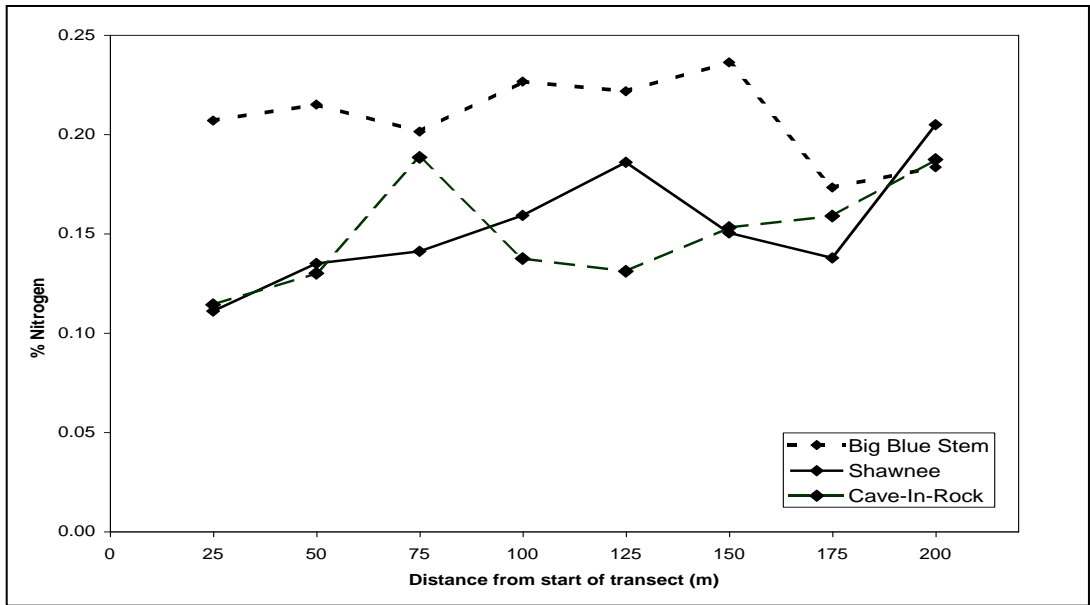


Figure 1. Soil N along transects within three perennial grass fields in northwestern Pennsylvania.

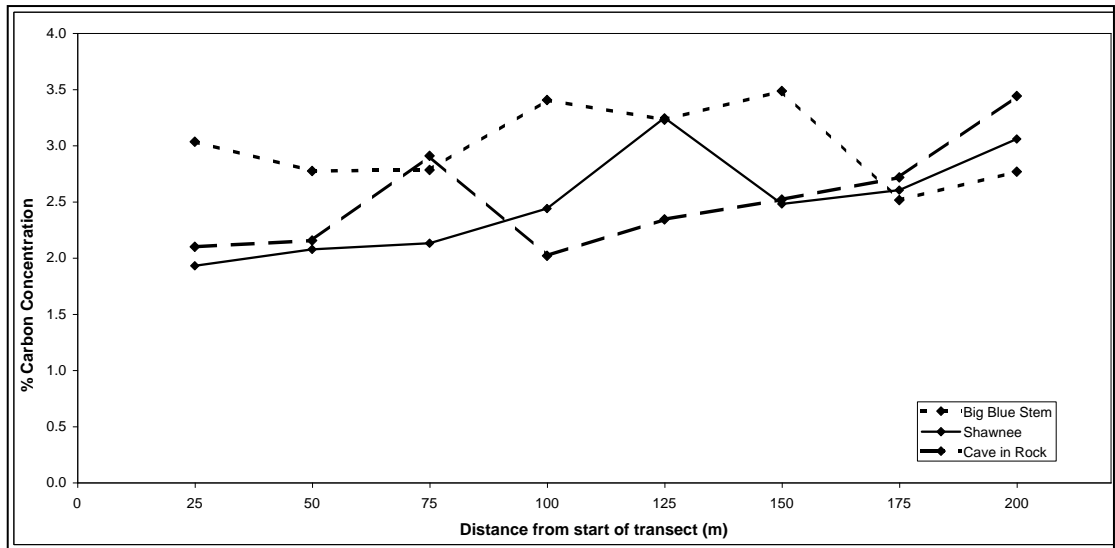


Figure 2. Soil C along transects within three perennial grass fields in northwestern Pennsylvania.

The topography of the fields had no discernable effect on the concentrations of nitrogen and carbon (Fig. 1, 2). At the Cave-in-Rock and big bluestem sites, elevation was greatest at the 25m locations, with an approximate 20 m decline in elevation to the final sampling location at 200m. At the Shawnee site, elevation was highest at the midpoint of the transect, with an approximate 5m decline in elevation to the ends of the transects. A higher concentration of nutrients was not present at lower elevations along the transects.

DISCUSSION

Differences in biomass among the sites may be explained by differences in soil nitrogen concentrations that we measured among the sites. The big bluestem site had the greatest biomass (9.42 Mg ha⁻¹) compared with (6.80 Mg ha⁻¹) tons/acre for Shawnee and (8.10 Mg ha⁻¹) tons/acre for Cave-In-Rock (Bowden et al. 2008), as well as the highest soil nitrogen and carbon of the three sites. Despite its large biomass production, however, the higher tissue nitrogen concentrations of big bluestem compared to the switchgrass varieties indicate that of the three grasses studied, it was not the most efficient user of nitrogen (biomass production per unit nitrogen). This higher nitrogen need suggests that it is likely to be more productive on sites with higher soil nitrogen availability. In contrast, switchgrass Cave-In-Rock had the highest within-field variability of soil nitrogen of the three fields and the lowest concentration of nitrogen within plant tissues. Furthermore, Cave-In-Rock also had the lowest relative variation in biomass (Bowden et al. 2008). This disconnect between variability in nitrogen and variability in biomass might suggest that this plant uses nitrogen efficiently, and other factors, including other soil nutrients, organic matter, and soil moisture may control the variability of biomass across the site (Fike et al 2006b).

The high variability of soil nutrients within the sites generally matches the high variability in biomass production observed in a previous study at these sites (Bowden et al. 2008). Nitrogen is often a limiting nutrient for agricultural plants, thus it is not surprising that we observed a linkage between soil and biomass variability. Similarly, the amount of carbon in the soil is indicative of the soil organic matter content, which contains other nutrients ultimately available for plant growth (Granato et al 2004). Variations in soil organic matter across the sites can also be expected to influence biomass variability across the sites. Despite these linkages, however, the relationship between biomass production and soil nitrogen is not necessarily straightforward. In agronomic settings, doubling the rate of nitrogen application does not necessarily double the amount of biomass produced (Fike et al. 2006b). Other plant growth limiting factors can certainly influence biomass production.

We were somewhat surprised that we did not observe a relationship between elevation along the transects and either biomass production or soil N and C content. In other studies, upland and lowland varieties of switchgrass, along with topographic differences in soil moisture content have been linked to topographic differences in production. From a management standpoint, this can be important because grass varieties in upland areas increased their production more than did lowland varieties in response to nitrogen application (Fike et al 2006b). Different switchgrass varieties appear to react very differently to application of nitrogen (Lemus et al. 2002).

Despite our positive correlation of biomass and soil variability, however, our study did not measure biomass and soil parameters at the same locations within each field. Soil nitrogen, as a critical plant nutrient, is likely influencing plant matter production, however measuring both soil nutrient concentrations and biomass production for each sample plot would help to better determine the strength of this correlation.

Understanding controls of biomass variability of perennial grasses being considered as alternative energy sources will help resource professionals maximize efficiency of plant productivity. The relationship between bioenergy crops and the nitrogen content in soil is critical when considering their potential cultivation and management of nitrogen application. Early indications in a study conducted by McLaughlin et al. (1999) suggest that lower amounts of nitrogen are needed for stands of switchgrass that have been fully established. To use nitrogen amendments effectively and efficiently, it will be important to know the proper amount of nitrogen required to efficiently maximize biomass yield, thus avoiding excessive economic and environmental costs associated with fertilizer additions.

LITERATURE CITED

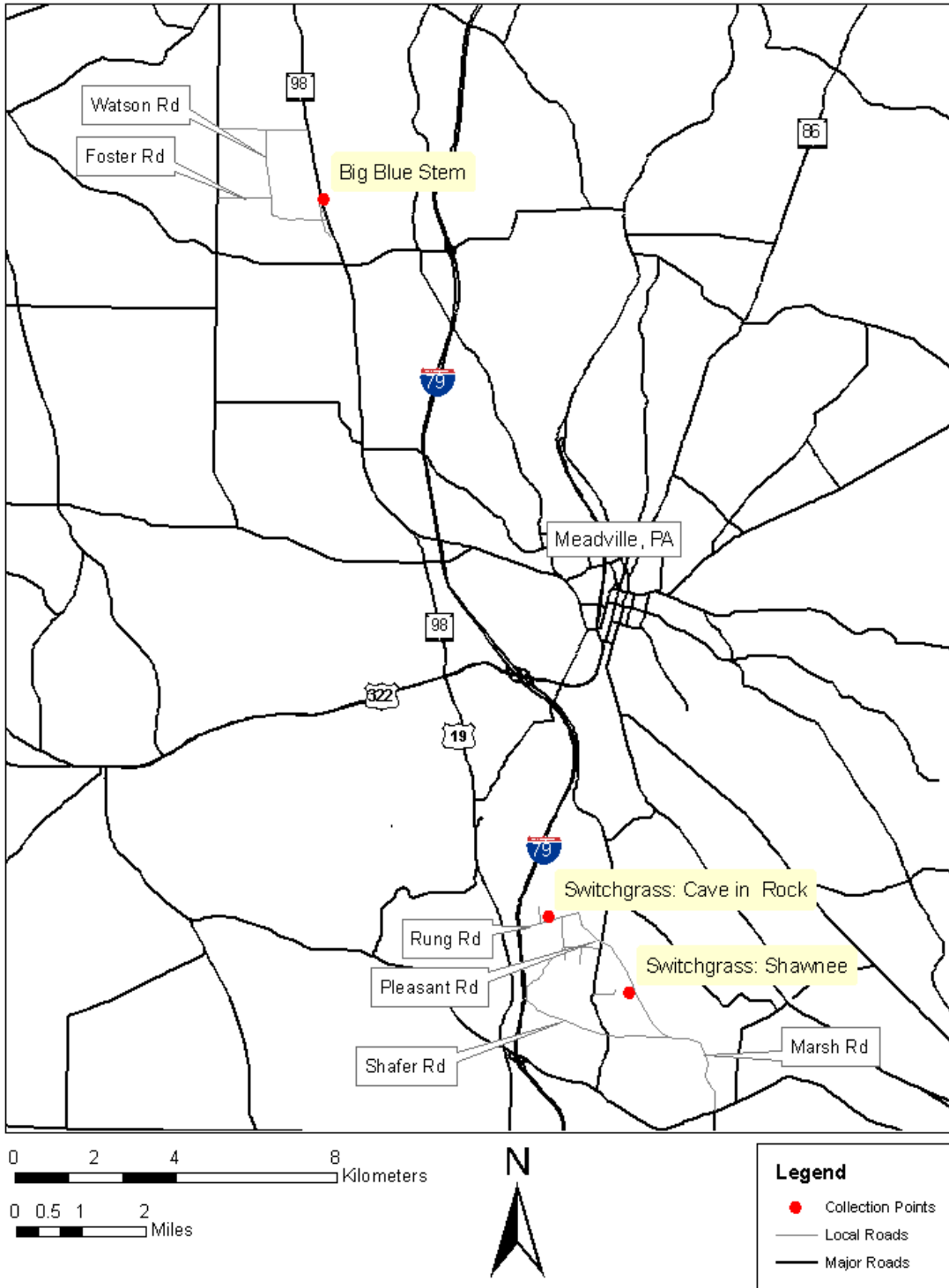
Andel J. and F. Vera. 1977. Reproductive allocation in *Senecio sylvaticus* and *Chamaenerion angustifolium* in relation to mineral nutrition. *The Journal of Ecology* 65:747-758.

- Berndes G., M. Hoogwijk, and R. van den Broek. 2003. The contribution of biomass in the future global energy supply: A review of 17 studies. *Biomass and Bioenergy* 25(1):1-28.
- Biere A. 1995. Genotypic and plastic variation in plant size: Effects on fecundity and allocation patterns in *Lychnis flos-cuculi* along a gradient of natural soil fertility. *The Journal of Ecology* 83: 629-642.
- Bowden, R.D., L. Alexander, C. Buseck, R. Campbell, J. Campbell-Heredia, A. Conroy, L. Cover, J. Fago, M. Findley, E. Gordon, B. Greiner, R.J. Hollihan, A. Lee, T. Ludwig, B. Marcy-Quay, M. Martin, A. Pfeifer, M. Robelo, L. J. Scalera, A. Silling, N. Silva, E. Thornton, T. Wetsell, and K. Wills. 2008. Biomass, nitrogen, and ash content in stands of switchgrass and big bluestem in northwestern Pennsylvania. Allegheny College Center for Environmental and Economic Development Publication 2008-4.
- Bransby D.I., D.J. Parrish, and S.B. McLaughlin. 1998. A review of carbon and nitrogen balances in switchgrass grown for energy. *Biomass and Bioenergy* 14: 379-384.
- Demirbas, A. 2005. Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues. *Progress in Energy and Combustion Science* 31: 171-192.
- Fike J.H., D.J. Parrish, D.D. Wolf, J.A. Balasko, J.T. Green Jr., M. Rasnake, and J.H. Reynolds. 2006a. Switchgrass production for the upper southeastern USA: Influence of cultivar and cutting frequency on biomass yields. *Biomass and Bioenergy* 30: 207-213.
- Fike J.H., D.J. Parrish, D.D. Wolf, J.A. Balasko, J.T. Green Jr, M.Rasnake, ad J.H. Reynolds. 2006b. Long-term yield potential of switchgrass-for-biofuel systems. *Biomass and Bioenergy* 30: 198-206.
- Granato T. C., I.P Richard, J.K. George, C.R. Carlson, Jr., P. Tata, and C. Lue-Hing. 2004. Trace element concentrations in soil, corn leaves, and grain after cessation of biosolids applications. *Journal of Environmental Quality* 33: 2078-2089.
- Horrigan, L., R.S. Lawrence and P. Walker. 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental Health Perspectives* 110: 445-456.
- Lemus R., C.E. Brummer, K.J. Moore, N.E. Molstad, C.L.Burras, and M.F. Barker. 2002. Biomass yield and quality of 20 switchgrass populations in southern Iowa, USA. *Biomass and Bioenergy* 23:433-442.
- McLaughlin S, J. Bouton, D. Bransby, B. Conger, W. Ocumpaugh, D. Parrish, D. Taliaferro, K. Vogel, and S.Wullscheleger. 1999. Developing Switchgrass as a Bioenergy Crop. *Perspectives on new crops and New Uses*. In: J. Janick (ed.), *Perspectives on new crops and new uses*. ASHS Press, Alexandria, VA.
- McLaughlin S.B, and M.E. Walsh. 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy. *Biomass and Bioenergy* 14:317-324
- Roth, A M., D.W. Sample, C.A. Ribic, L. Paine, D.J. Undersander, and G.A. Bartelt. 2005. Grassland bird response to harvesting switchgrass as a biomass energy crop. *Biomass and Bioenergy* 28:490-498.

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Appendix 1: Locations of sampling sites



Appendix 2: Percent nitrogen and carbon in soils of perennial grasses.

		% N				% C			
		Transects							
	Location (m from start of transect)	A	B	C	D	A	B	C	D
Big bluest em	25	0.1790	0.2515	0.2193	0.1776	2.818	3.563	3.254	2.498
	50	0.2738	0.2049	0.2260	0.1550	3.308	2.899	2.677	2.207
	75	0.2319	0.2182	0.2083	0.1469	2.780	3.333	2.623	2.391
	100	0.2515	0.2076	0.2260	0.2208	3.657	2.967	3.334	3.657
	125	0.2886	0.2174	0.2407	0.1400	3.896	3.284	3.325	2.409
	150	0.2491	0.2283	0.2833	0.1840	3.573	3.483	3.815	3.066
	175	0.1769	0.1671	0.1911	0.1576	2.396	2.370	2.655	2.631
	200	0.1828	0.1982	0.1527	0.1997	2.496	3.023	2.380	3.167
SG Shaw nee	25	0.1282	0.1142	0.1021	0.0993	1.909	2.091	1.676	2.039
	50	0.1642	0.0967	0.1829	0.0958	2.203	1.825	2.754	1.516
	75	0.1547	0.1160	0.1354	0.1580	2.225	1.607	2.047	2.641
	100	0.1850	0.1078	0.2136	0.1301	2.800	2.188	2.525	2.243
	125	0.1921	0.1696	0.2060	0.1756	3.018	2.756	3.969	3.240
	150	0.1783	0.1306	0.2050	0.0872	2.771	2.240	3.285	1.618
	175	0.1552	0.1323	0.1349	0.1284	2.566	2.642	2.817	2.386
	200	0.2028	0.1920	0.2884	0.1361	2.688	3.128	4.286	2.128
SG Cave- in- Rock	25	0.1230	0.1212	0.1399	0.0726	2.315	2.107	2.447	1.520
	50	0.1556	0.1552	0.1149	0.0943	2.009	2.668	1.953	1.985
	75	0.1869	0.1921	0.2000	0.1742	2.404	2.655	3.382	3.186
	100	0.1851	0.1563	0.1266	0.0817	2.462	2.208	1.850	1.550
	125	0.1990	0.0947	0.1516	0.0786	3.146	1.888	2.521	1.810
	150	0.2183	0.1183	0.1140	0.1615	3.308	1.968	1.654	3.142
	175	0.2195	0.0986	0.1421	0.1751	3.149	1.929	2.264	3.520
	200	0.1699	0.0791	0.1472	0.3528	2.847	1.964	2.487	6.462