MEASUREMENT OF POSSIBLE CROSS-CONTAMINATION OF SOIL SAMPLES DURING SOIL CORING WITH THE SPLIT-BARREL OR BUCKET AUGER METHODS

August, 1987

ENVIRONMENTAL HAZARDS ASSESSMENT PROGRAM

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EH 87-06

Measurement of Possible Cross-Contamination of Soil Samples During Soil Coring with the Split-Barrel or Bucket Auger Methods

by

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August, 1987

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EXECUTIVE SUMMARY

The extent of contamination that occurs during soil sampling was examined for the split-barrel, hollow auger method used by the Environmental Hazards Assessment Program, California Department of Food and Agriculture, and for a manual bucket auger method. The study was conducted at Fresno, California on a sandy soil of the Hanford series. Contamination was measured by appling tracer to the surface of soil, immediately followed by sampling to a 10 foot depth in 6-inch segments. The tracer contained bromide which was not found in background samples. Thus, the presence of bromide in samples below the surface layer indicated contamination of samples. Three 6-inch samples were taken at one time with the split-barrel method whereas single 6-inch samples were obtained with the hand auger.

Bromide was detected with both methods in samples obtained below the first 6-inch segment. For the split-barrel, hollow auger method, a low level of contamination was measured in the two 6-inch segments located beneath the surface segment (three 6-inch soil segments were obtained with each split-barrel sample). Since the tip of the sampling device must pass through the first segment before encountering the lower segments to fill the sampler, some tracer must have been carried-over from the surface to lower samples. The next three samples obtained with a clean split-barrel sampler did not contain tracer. Some additional contamination was measured sporadically; only 5 of 45 samples obtained beneath the three segments from the first split-barrel sample had detectable levels of bromide. Overall, the highest level of contamination in subsoil samples, averaged over the three replicate cores, was 5% of the level measured in the first 6 inch segment.

For the hand auger method, a nearly continuous low level of contamination was measured in samples taken below the surface soil sample. Since the surface soil in the test holes was not supported during sampling, contamination could have occurred by crumbling of the surface soil into the open hole. The average level of contamination did not exceed 1% of the value measured in the first 6-inch sample. This value was lower than observed with the split-barrel, hollow auger method probably due to removal of some soil from the top of samples prior to packaging.

In another comparison of the methods, the distribution of bromide was compared from plots where the tracer was known to be distributed throughout the subsurface soil. The curves for both methods were the same indicating that contamination should pose no problem where a continuous distribution of a target compound is observed in a soil column. However, caution should be used during interpretation when sharp discontinuities are observed between contiguous segments. It should also be noted that results may differ depending on soil type so similar studies may be necessary to document specific patterns of contamination.

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INTRODUCTION

The Environmental Hazards Assessment Program, California Department of Food and Agriculture, has utilized a well known method to obtain deep undisturbed soil cores for investigations on the movement of pesticides to ground water (Zalkin et. al., 1984). The method uses a Moss wireline sampling system located within hollow-stem flight augers that are driven by a conventional motorized drilling rig. This study was conducted to determine whether cross contamination of samples occurs during the drilling procedure. Contamination was also tested for samples taken with a hand-driven bucket auger and results were compared between the two methods.

MATERIALS AND METHODS

Experimental Design

The amount of contamination introduced into samples during the drilling process was determined by adding an inorganic salt, potassium bromide, as a tracer to the soil surface; 625.3 g of KBr was dissolved in 1 liter of water which was then broadcast over a 20 x 20 foot area, a rate approximately equal to 100 pounds bromide per acre. Three replicate cores to ten-foot depth were taken with 1) a split-barrel, hollow auger, Mobile drill and 2) a hand auger approximately 2 hours after application of tracer. The concentration of bromide was measured in each 6-inch soil segment.

An additional comparison was made between methods for the measurement of bromide distributed in subsoil taken from a separate test plot where tracer had been previously applied to soil and then exposed to winter rain. Three replicate cores to 10-feet were taken with each method and the concentration of bromide was measured in each 6-inch segment.

Sampling Method

For the split-barrel, hollow auger drilling method, the procedure of Zalkin *et. al*. (1984) was followed. Three 6-inch stainless steel sleeves, 2.4 inches inner-diameter, were placed in a 20-inch split-barrel sampler. The split-barrel sampler was lowered and locked into the body of a hollow-stem flight auger with the head projecting a few inches ahead of the auger. Soil samples

were obtained through a combination of downward pressing and rotation of the auger. When 20 inches of soil had been collected, the split-barrel sampler was removed from the auger. Two inches of soil from the head of the cutting tip was discarded and the 3 stainless steel tubes packaged. The split-barrel sampler was washed with soapy water and rinsed with water between sample collection.

For the hand-auger method, the auger was screwed into the soil to obtain a 6-inch sample. Approximately 2 inches of soil was discarded from the top of the sample before removal from the auger into a paper bag. The bucket auger was washed with soapy water and rinsed with water between sample collection. The soil in the bag was mixed and a subsample transferred into a 1 quart bottle for transport to the laboratory.

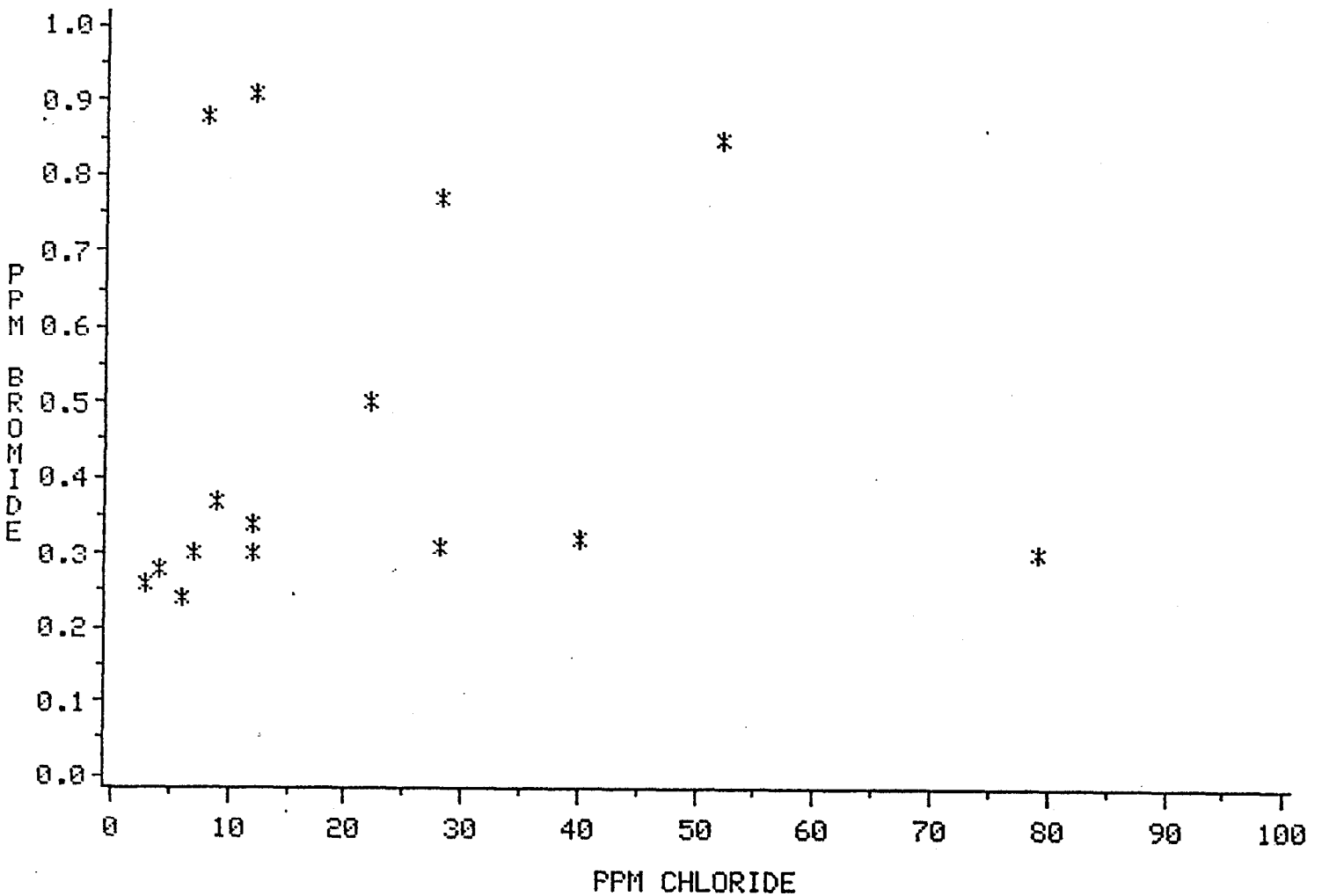
Chemical Analysis

The concentration of bromide was determined by the specific ion electrode method by APPL Laboratory, Fresno, California. The minimum detection limit was 0.2 ppm on a w/w basis. Since the presence of bromide was sufficient to indicate contamination, results were reported on a fresh weight basis. Chloride was a potential positive interference in the method so the concentration of chloride was also measured in some subsoil segments taken from the surface addition plot where bromide had been detected (Table 1). A scatter plot of bromide vs chloride concentration in bromide-contaminated segments indicated no significant relationship (Figure 1). Thus, bromide analyses appeared independent of soil chloride concentration for this study.

Table 1. Concentration of bromide and chloride, expressed in ppm (w/w) on a fresh weight basis, in soil segments where bromide was detected.

BROMIDE	CHLORIDE
0.91	12
0.50	22
0.30	12
0.32	40
0.34	12
0.30	79
0.30	7
0.85	52
0.31	28
0.88	8
0.26	3
0.28	4
0.77	28
0.24	6
0.37	9

Figure 1. Co-distribution of chloride and bromide in soil segments where bromide was detected.



RESULTS AND DISCUSSION

Contamination of Subsoil in Cores from the Surface Addition Plot

Three background cores were obtained in sites located adjacent to the treated plot. Since no bromide was detected at an MDL of 0.2 ppm down to the 10 foot depth in those cores, any bromide detected in the subsoil in the surface addition plots was considered contamination.

Contamination of soil samples with bromide was observed with both methods in cores taken from the plot where a band of bromide tracer had been added to the surface soil. However, the pattern of contamination was different for each method. For the split-barrel, hollow auger drilling method, a large amount of bromide was detected, as expected, in the first segment (0-6 inches) but a much smaller amount was also detected in the second and third segments at 6-12 and 12-18 inches, respectively. No bromide was detected in the next three segments (20-38 inch depth) obtained with the second split-barrel sample (Table 2). This pattern indicated that bromide was moved within the first split-barrel sample to deeper segments after the head of the sampler had passed through the initial surface layer of bromide. Although samples were clean in the second split-barrel sample, low concentrations of bromide were detected sporadically throughout the remaining segments; excluding the 3 segments in the first split-barrel sample, 5 out of 45 segments obtained from the three replicate cores had detectable levels of bromide. Since no pattern was evident and chloride apparently was not an interference in the detection of bromide, the cause for contamination could not be determined. The level of sporadic contamination in segments, averaged over the replicate three cores, ranged from 0.2% to 4% of the

Table 2. Concentration in ppm (w/w) on a fresh weight basis of bromide in soil segments in three replicate cores obtained with the split-barrel, hollow auger drilling method from surface addition and winter rain-exposed plots. Values less than the MDL of 0.2 ppm are denoted as 0.

Upper and Lower Depth (Inches)	Surface Addition Plot Core 1	Surface Addition Plot Core 2	Surface Addition Plot Core 3	Winter Rain Plot Core 1	Winter Rain Plot Core 2	Winter Rain Plot Core 3
000-006	60.67	40.28	3.69	0.28	0.36	0.28
006-012	4.20	0.24	0.34	0.00	0.00	0.00
012-018	4.27	0.00	0.68	0.00	0.00	0.00
020-026	0.00	0.00	0.00	0.26	0.24	0.00
026-032	0.00	0.00	0.00	0.26	0.00	0.00
032-038	0.00	0.00	0.00	0.32	0.00	0.00
040-046	0.88	0.48	0.00	0.30	0.00	0.29
046-052	0.00	0.00	0.00	0.90	0.00	0.30
052-058	0.00	0.00	0.00	3.43	0.00	0.34
060-066	4.15	0.00	0.00	4.74	0.81	0.82
066-072	0.00	0.40	0.00	2.02	2.07	1.51
072-078	0.00	0.00	0.00	3.15	2.27	1.34
080-086	0.00	0.00	0.24	3.79	2.81	1.61
086-092	0.00	0.00	0.00	3.29	2.99	1.43
092-098	0.00	0.00	0.00	3.03	2.14	1.95
100-106	0.00	0.00	0.00	2.08	0.89	1.73
106-112	0.00	0.00	0.00	2.04	0.74	2.04
112-118	0.00	0.00	0.00	1.56	0.70	1.39

value measured in the first 0-6 inch segment (Table 3).

For the hand auger method, the pattern of contamination was more frequent and continuous starting at the second segment (Table 4). However, the average level of contamination was lower than with the split-barrel drilling method, ranging from 0.1% to 1.0% of the value measured in the first segment (Table 5). Although contamination of segments was more prevalent with the hand auger method than with the split-barrel, hollow auger drilling method, the actual amount of contamination was less, perhaps due to the removal of soil from the surface of each hand auger sample prior to packaging.

Comparison of Subsoil Bromide Distribution in Winter Rain-exposed Plot

The distribution of bromide in the winter rain plot was compared between the split-barrel, hollow auger drilling and hand auger methods (Tables 2 and 4). Regressions were conducted to describe the concentration of bromide in each segment, averaged over the three replicate cores, as it varied with depth (Tables 3 and 5). All possible r-square analyses of models for the first- through sixth-order of depth indicated that for both models over 90% of the variation was measured with a model that included the first, second, and third oder terms (Appdendix I). A line-test of models indicated no significance difference in the regressions and the estimates of the coefficient were similar for each model (Table 6). Thus, nearly identical distributions were measured with either method. It should be noted that correction of the data for the actual water content in each segment may have had some affect on these results. It should also be noted that the pattern of contamination may differ with soil type and, hence, may require specific testing.

Table 3. Average concentration in ppm (w/w) on a fresh weight basis of bromide in soil segments obtained with the split-barrel, hollow auger drilling method from surface addition and winter rain-exposed plots. Values less than the MDL of 0.2 ppm included as a 0 value in the average.

Upper and Lower Depth (Inches)	Surface Addition Plot			Winter Rain Plot		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
000-006	3	34.88	28.87	3	0.31	0.05
006-012	3	1.59	2.26	3	0.00	0.00
012-018	3	1.65	2.29	3	0.00	0.00
020-026	3	0.00	0.00	3	0.17	0.14
032-038	3	0.00	0.00	3	0.11	0.18
040-046	3	0.45	0.44	3	0.20	0.17
046-052	3	0.00	0.00	3	0.40	0.46
052-058	3	0.00	0.00	3	1.26	1.86
060-066	3	1.38	2.40	3	1.79	1.69
066-072	3	0.13	0.23	3	1.87	0.31
072-078	3	0.00	0.00	3	2.25	0.91
080-086	3	0.08	0.14	3	2.74	1.09
086-092	3	0.00	0.00	3	2.57	1.00
092-098	3	0.00	0.00	3	2.37	0.58
100-106	3	0.00	0.00	3	1.57	0.61
106-112	3	0.00	0.00	3	1.61	0.75
112-118	3	0.00	0.00	3	1.22	0.46

Table 4. Concentration in ppm (w/w) on a fresh weight basis of bromide in soil segments in three replicate cores obtained with the hand-driven bucket auger from surface addition and winter rain-exposed plots. Values less than the MDL of 0.2 ppm denoted as 0.

Upper and Lower Depth (Inches)	Surface Addition Plots Core 1	Surface Addition Plots Core 2	Surface Addition Plots Core 3	Winter Rain Plots Core 1	Winter Rain Plots Core 2	Winter Rain Plots Core 3
000-006	89.91	41.54	57.58	0.32	0.42	0.26
006-012	0.91	0.85	0.77	0.31	0.29	0.00
012-018	0.50	0.48	0.24	0.25	0.26	0.00
018-024	0.29	0.00	0.00	0.00	0.30	0.00
024-030	0.38	0.32	0.00	0.26	0.68	0.00
030-036	0.30	0.69	0.00	0.26	0.87	0.36
036-042	0.30	0.31	0.00	0.00	0.65	0.78
042-048	0.38	0.26	0.00	0.00	1.99	1.20
048-054	0.28	0.27	0.00	0.00	2.18	1.31
054-060	0.32	0.88	0.37	0.00	2.20	1.11
060-066	0.34	0.26	0.00	0.00	4.02	1.32
066-072	0.30	0.28	0.00	0.00	4.32	5.19
072-078	0.30	0.00	0.00	0.93	3.06	5.78
078-084	0.00	0.00	0.00	0.93	3.06	5.78
084-090	0.00	0.00	0.66	2.21	2.14	4.94
090-096	0.00	0.00	0.26	1.43	1.31	4.99
096-102	0.00	0.36	0.24	1.00	1.55	4.73
102-108	0.00	0.00	0.00	1.43	0.76	5.26
108-114	0.00	0.00	0.00	1.68	0.44	3.27
114-120	0.00	0.00	0.00	1.40	0.38	2.94

Table 5. Average concentration in ppm (w/w) on a fresh weight basis of bromide in soil segments obtained with the hand-driven bucket auger from surface addition and winter rain-exposed plots. Values less than the MDL of 0.2 ppm included as a 0 value in the average.

Upper and Lower Depth (Inches)	Surface Addition Plot			Winter Rain Plot		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
000-006	3	63.01	24.64	3	0.33	0.08
006-012	3	0.84	0.07	3	0.20	0.17
012-018	3	0.41	0.14	3	0.17	0.15
018-024	3	0.10	0.17	3	0.10	0.17
024-030	3	0.23	0.20	3	0.31	0.34
030-036	3	0.33	0.35	3	0.50	0.33
036-042	3	0.20	0.18	3	0.48	0.42
042-048	3	0.21	0.19	3	1.06	1.00
048-054	3	0.18	0.16	3	1.16	1.10
054-060	3	0.52	0.31	3	1.10	1.10
060-066	3	0.20	0.18	3	1.78	2.05
066-072	3	0.19	0.17	3	3.17	2.78
072-078	3	0.10	0.17	3	3.26	2.43
078-084	3	0.00	0.00	3	3.14	1.77
084-090	3	0.22	0.38	3	3.10	1.60
090-096	3	0.09	0.15	3	2.58	2.09
096-102	3	0.20	0.18	3	2.43	2.01
102-108	3	0.00	0.00	3	2.48	2.43
108-114	3	0.00	0.00	3	1.80	1.42
114-120	3	0.00	0.00	3	1.57	1.29

Table 6. Estimated coefficients for a full third-order linear model of the concentration of bromide expressed as a function of depth for data obtained from the winter rain-exposed plots for either the split-barrel, hollow auger drilling method or the hand-driven bucket auger sampling methods.

Sampling Method	Estimated Coefficient and Standard Error for			
	Intercept	First-Order	Second-Order	Third-Order
Split-barrel	0.656±0.235	-0.0876±0.0175	0.00266±0.00035	-0.000016±0.000002
Hand-driven	0.656±0.322	-0.0759±0.0233	0.00259±0.00045	-0.000016±0.000002

CONCLUSIONS

1. Contamination of soil samples was measured in both the split-barrel, hollow auger and hand auger coring methods.

1.1. With respect to the split-barrel, hollow auger drilling method, carry-over of bromide was detected in segments located within the first split-barrel sample in the test plot where bromide was added to the surface. The average maximum contamination in a segment was 5% the value in the first 6-inch sample. Contamination was infrequent and sporadic in subsequent split-barrel samples and ranged from 0.2% to 4% of the value of the first 6-inch sample.

1.2. With respect to the hand auger method, contamination of segments below the first 6-inch sample was measured in a more frequent and continuous pattern than observed with the split-barrel, hollow auger method. However, the maximum value averaged only 1% the value measured in the first 6-inch segment.

2. No significant difference was measured between methods in the regression of bromide concentration with depth for data obtained from plots previously exposed to winter rain. Both regressions were full third-order models with similar estimated values for the regression coefficients. Even though there were some differences in the scaling of the independent factor, both methods indicated the same distribution of bromide with depth.

3. The soil in this study was sandy in texture. Since patterns of contamination may vary with soil type, additional tests may be required in order to determine specific patterns of contamination.

RECOMMENDATIONS

Since contamination was observed with both methods of sampling, care must be used when reviewing coring data. A few aids for recognizing and minimizing problems with contamination are:

1. If gradual patterns of rising and falling concentrations of chemical with depth are observed, then the problem of contamination should be minimal because carry-over between segments would only be a small portion of the measured value.

2. If discontinuities are observed between contiguous samples such that the value for a segment is much lower than the value of a previous segment, then potential contamination should be considered. With the split-barel, hollow auger method, a 95% difference should be viewed as a warning sign whereas with the hand-auger method, a 99% difference should be viewed as a warning. These limits are based on a minimum replication of 3 cores.

3. A collar should be placed into the ground when the initial surface soil core is taken with the hand auger. This should help prevent crumbling of the walls of the upper surface soil into the open core during subsequent sampling.

4. The open ends of the split-barrel sampling tube should be carefully protected from entry of fugitive particles during transport from the coring to processing site.

REFERENCES

Zalkin, F., M. Willkerson, and R.J. Oshima. 1984. Pesticide Movement to Groundwater. Volume II: Pesticide Contamination in the Soil Provile at DBCP, EDB, Simazine and Carbofuran Appplication Sites. California Department of Food and Agriculture, Sacramento, Ca, 168pp.

APPENDIX A

REGRESSION ANALYSES FOR THE DISTRIBUTION OF BROMIDE IN SOIL SAMPLES TAKEN FROM WINTER RAIN-EXPOSED PLOTS

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MEAN DATA FOR THE SPLIT-BARREL, HOLLOW AUGER DRILLING METHOD

DEPTH (INCHES)	PPM BROMIDE
3	0.31
9	0.00
15	0.00
23	0.17
29	0.09
35	0.11
43	0.20
49	0.40
55	1.26
63	1.79
69	1.87
75	2.25
83	2.74
89	2.57
95	2.37
103	1.57
109	1.61
115	1.22

MEAN DATA FOR THE HAND-DRIVEN, BUCKET AUGER METHOD

DEPTH (INCHES)	PPM BROMIDE
3	0.33
9	0.20
15	0.17
21	0.10
27	0.31
33	0.50
39	0.48
45	1.06
51	1.16
57	1.10
63	1.78
69	3.17
75	3.26
81	3.14
87	3.10
93	2.58
99	2.43
105	2.48
111	1.80
117	1.57

R-SQUARE ANALYSES FOR THE SPLIT-BARREL, HOLLOW AUGER DRILLING METHOD

NUMBER IN MODEL	R-SQUARE	C(P)	VARIABLES IN MODEL
1	0.12029476	409.464	X6
1	0.16925264	385.898	X5
1	0.24190265	350.926	X4
1	0.34749059	300.099	X3
1	0.48786396	232.527	X2
1	0.61370736	171.950	X1
2	0.67116332	146.292	X1 X2
2	0.71760231	123.938	X1 X3
2	0.75577145	105.565	X1 X4
2	0.78325299	92.335696	X1 X5
2	0.79268540	87.795209	X5 X6
2	0.80133693	83.630613	X1 X6
2	0.84840354	60.974122	X2 X3
2	0.85140119	59.531137	X4 X6
2	0.88568488	43.027970	X2 X4
2	0.88765828	42.078031	X4 X5
2	0.89797439	37.112155	X3 X6
2	0.90149101	35.419358	X2 X5
2	0.90377017	34.322237	X2 X6
2	0.91557630	28.157739	X3 X5
2	0.92338172	24.881806	X3 X4
3	0.86321850	55.842628	X1 X5 X6
3	0.87994825	47.789417	X1 X4 X6
3	0.89728867	39.442242	X1 X4 X5
3	0.89977980	38.243083	X1 X3 X6
3	0.90378727	36.314008	X2 X5 X6
3	0.90427987	36.076881	X2 X4 X6
3	0.90673055	34.897197	X2 X3 X6
3	0.91060782	33.030792	X2 X4 X5
3	0.91696106	29.972525	X2 X3 X5
3	0.91706814	29.920981	X1 X3 X5
3	0.91997181	28.523238	X1 X2 X6
3	0.92345791	26.845133	X3 X4 X5
3	0.92414430	26.514725	X3 X4 X6
3	0.92831643	24.506384	X2 X3 X4
3	0.93171872	22.868621	X3 X5 X6
3	0.93344547	22.037412	X1 X3 X4
3	0.93408034	21.731802	X1 X2 X5
3	0.94419937	16.850796	X1 X2 X4
3	0.94559464	16.189155	X1 X2 X3
3	0.94978330	14.172856	X4 X5 X6
4	0.94562376	18.175139	X1 X2 X3 X5
4	0.94565493	18.155322	X1 X2 X3 X6
4	0.94602327	17.982827	X1 X2 X3 X4
4	0.94989838	16.117459	X1 X2 X4 X5
4	0.95200643	15.102709	X1 X2 X4 X6

NUMBER IN MODEL	R-SQUARE	C(P)	VARIABLES IN MODEL
4	0.95731893	12.545422	X1 X2 X5 X6
4	0.95950886	11.491256	X1 X3 X4 X5
4	0.96287261	9.872043	X1 X3 X4 X6
4	0.96736345	7.710283	X2 X3 X4 X5
4	0.96812898	7.341783	X1 X3 X5 X6
4	0.97024183	6.324715	X2 X3 X4 X6
4	0.97357855	4.718517	X2 X3 X5 X6
4	0.97389636	4.565530	X1 X4 X5 X6
4	0.97599007	3.557682	X2 X4 X5 X6
4	0.97630483	3.406163	X3 X4 X5 X6
5	0.97095001	7.983820	X1 X2 X3 X4 X5
5	0.97284174	7.073196	X1 X2 X3 X4 X6
5	0.97471783	6.170102	X1 X2 X3 X5 X6
5	0.97605145	5.528135	X1 X2 X4 X5 X6
5	0.97636742	5.376035	X2 X3 X4 X5 X6
5	0.97650001	5.312213	X1 X3 X4 X5 X6
6	0.97714860	7.000000	X1 X2 X3 X4 X5 X6

R-SQUARE ANALYSES FOR THE HAND-DRIVEN, BUCKET AUGER METHOD

NUMBER IN MODEL	R-SQUARE	C(P)	VARIABLES IN MODEL
1	0.09971381	204.136	X6
1	0.14389746	193.332	X5
1	0.21126560	176.860	X4
1	0.31275401	152.044	X3
1	0.45555316	117.127	X2
1	0.60416943	80.787701	X1
2	0.70215802	58.827726	X1 X2
2	0.71954893	54.575335	X5 X6
2	0.75279609	46.445807	X1 X3
2	0.78797267	37.844500	X4 X6
2	0.78935250	37.507107	X1 X4
2	0.81263068	31.815172	X1 X5
2	0.82556543	28.627941	X1 X6
2	0.83311486	26.806422	X4 X5
2	0.85201929	22.183948	X3 X6
2	0.86558218	18.867577	X2 X3
2	0.88087729	15.127647	X3 X5
2	0.88672217	13.698469	X2 X6
2	0.89004381	12.886267	X2 X4
2	0.89421948	11.865241	X2 X5
2	0.90148294	10.089195	X3 X4
3	0.84877790	24.976525	X1 X5 X6
3	0.85880482	22.524763	X1 X4 X6
3	0.87161840	19.391612	X1 X4 X5
3	0.87205081	19.285881	X1 X3 X6
3	0.88662341	15.722618	X1 X3 X5
3	0.88760271	15.483160	X1 X2 X6
3	0.88874276	15.204399	X2 X3 X6
3	0.89212460	14.377476	X2 X4 X6
3	0.89422033	13.865033	X2 X4 X5
3	0.89488670	13.702095	X2 X3 X5
3	0.89598528	13.433472	X2 X5 X6
3	0.90150747	12.083197	X1 X3 X4
3	0.90166921	12.043649	X1 X2 X5
3	0.90225714	11.899889	X2 X3 X4
3	0.91125207	9.700467	X3 X4 X5
3	0.91346482	9.159410	X1 X2 X4
3	0.91447117	8.913338	X3 X4 X6
3	0.91908682	7.784729	X1 X2 X3
3	0.92301562	6.824068	X3 X5 X6
3	0.93736341	3.315773	X4 X5 X6
4	0.91952564	9.677429	X1 X2 X3 X4
4	0.92038442	9.467443	X1 X2 X3 X5
4	0.92148057	9.199415	X1 X2 X3 X6
4	0.92550093	8.216365	X1 X2 X4 X5
4	0.92814981	7.568666	X1 X2 X4 X6

NUMBER IN MODEL	R-SQUARE	C(P)	VARIABLES IN MODEL
4	0.93327509	6.315443	X1 X2 X5 X6
4	0.93457015	5.998777	X1 X3 X4 X5
4	0.93770106	5.233213	X1 X3 X4 X6
4	0.94062579	4.518063	X2 X3 X4 X5
4	0.94193112	4.198888	X1 X3 X5 X6
4	0.94291913	3.957300	X2 X3 X4 X6
4	0.94526890	3.382739	X2 X3 X5 X6
4	0.94578806	3.255796	X1 X4 X5 X6
4	0.94664904	3.045270	X2 X4 X5 X6
4	0.94673874	3.023337	X3 X4 X5 X6
5	0.94406596	5.676880	X1 X2 X3 X4 X5
5	0.94523496	5.391037	X1 X2 X3 X4 X6
5	0.94620102	5.154820	X1 X2 X3 X5 X6
5	0.94669946	5.032941	X1 X2 X4 X5 X6
5	0.94676676	5.016484	X2 X3 X4 X5 X6
5	0.94678779	5.011343	X1 X3 X4 X5 X6
6	0.94683418	7.000000	X1 X2 X3 X4 X5 X6

REGRESSION ANOVA FOR THE SPLIT-BARREL, HOLLOW AUGER DRILLING METHOD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	3	15.67842143	5.22614048	81.11
ERROR	14	0.90206746	0.06443339	PR > F
CORRECTED TOTAL	17	16.58048889		0.0001

R-SQUARE	C.V.	ROOT MSE	MPPBBR MEAN
0.945595	22.2882	0.25383733	1.13888889

SOURCE	DF	TYPE I SS	F VALUE	PR > F
X1	1	10.17556800	157.92	0.0001
X2	1	0.95264800	14.79	0.0018
X3	1	4.55020543	70.62	0.0001

SOURCE	DF	TYPE III SS	F VALUE	PR > F
X1	1	1.61147602	25.01	0.0002
X2	1	3.78022426	58.67	0.0001
X3	1	4.55020543	70.62	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	0.65583199	2.80	0.0143	0.23460808
X1	-0.08758007	-5.00	0.0002	0.01751253
X2	0.00265619	7.66	0.0001	0.00034678
X3	-0.0000162	-8.40	0.0001	0.00000193

OBSERVATION	OBSERVED	PREDICTED RESIDUAL	LOWER 95% CLI UPPER 95% CLI
1	0.30666667	0.41655900	-0.26753786
		-0.10989234	1.10065586
2	0.00000000	0.07092292	-0.54477909
		-0.07092292	0.68662492
3	0.00000000	-0.11504093	-0.70583469
		0.11504093	0.47575283
4	0.16666667	-0.15099487	-0.73931044
		0.31766153	0.43732071
5	0.08666667	-0.04624782	-0.63754145
		0.13291449	0.54504581
6	0.10666667	0.14800776	-0.44366483
		-0.04134109	0.73968034

OBSERVATION	OBSERVED	PREDICTED RESIDUAL	LOWER 95% CLI UPPER 95% CLI
7	0.19666667	0.50986949	-0.07723643
		-0.31320282	1.09697541
8	0.40000000	0.83112063	0.24892724
		-0.43112063	1.41331401
9	1.25666667	1.17171657	0.59308452
		0.08495010	1.75034863
10	1.79000000	1.61955524	1.04092318
		0.17044476	2.19818729
11	1.86666667	1.92343141	1.34123802
		-0.05676474	2.50562479
12	2.25333333	2.17648867	1.58938275
		0.07684466	2.76359459
13	2.73666667	2.39846554	1.80679295
		0.33820113	2.99013812
14	2.57000000	2.45108768	1.85979405
		0.11891232	3.04238132
15	2.37333333	2.38272721	1.79441164
		-0.00939388	2.97104278
16	1.56666667	2.06700354	1.47620978
		-0.50033687	2.65779730
17	1.60666667	1.63449262	1.01879061
		-0.02782595	2.25019462
18	1.21666667	1.01083536	0.32673849
		0.20583131	1.69493222

SUM OF RESIDUALS	-0.00000000
SUM OF SQUARED RESIDUALS	0.90206746
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
PRESS STATISTIC	1.52816657
FIRST ORDER AUTOCORRELATION	0.29120182
DURBIN-WATSON D	1.35724295

REGRESSION ANOVA FOR THE HAND-DRIVEN, BUCKET AUGER METHOD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	3	22.93912598	7.64637533	60.58
ERROR	16	2.01948013	0.12621751	PR > F
CORRECTED TOTAL	19	24.95860611		0.0001

R-SQUARE	C.V.	ROOT MSE	MPPBBR MEAN
0.919087	23.1271	0.35527103	1.53616667

SOURCE	DF	TYPE I SS	F VALUE	PR > F
X1	1	15.07922677	119.47	0.0001
X2	1	2.44565870	19.38	0.0004
X3	1	5.41424051	42.90	0.0001

SOURCE	DF	TYPE III SS	F VALUE	PR > F
X1	1	1.33540129	10.58	0.0050
X2	1	4.15038498	32.88	0.0001
X3	1	5.41424051	42.90	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	0.65585363	2.03	0.0588	0.32232301
X1	-0.07587472	-3.25	0.0050	0.02332658
X2	0.00259111	5.73	0.0001	0.00045188
X3	-0.0000162	-6.55	0.0001	0.00000248

OBSERVATION	OBSERVED	PREDICTED RESIDUAL	LOWER 95% CLI UPPER 95% CLI
1	0.33333333	0.45111161 -0.11777828	-0.49024398 1.39246720
2	0.20000000	0.17103930 0.02896070	-0.67812983 1.02020843
3	0.17000000	0.04600213 0.12399787	-0.76731358 0.85931784
4	0.10000000	0.05498356 0.04501644	-0.75165943 0.86162655
5	0.31333333	0.17696702 0.13636632	-0.63252530 0.98645933
6	0.49666667	0.39093595 0.10573072	-0.42067682 1.20254871

OBSERVATION	OBSERVED	PREDICTED RESIDUAL	LOWER 95% CLI UPPER 95% CLI
7	0.47666667	0.67587379	-0.13384878
		-0.19920712	1.48559636
8	1.06333333	1.01076399	0.20617156
		0.05256935	1.81535642
9	1.16333333	1.37458997	0.57579510
		-0.21125664	2.17338485
10	1.10333333	1.74633520	0.95128305
		-0.64300187	2.54138735
11	1.78000000	2.10498310	1.30993095
		-0.32498310	2.90003525
12	3.17000000	2.42951711	1.63072223
		0.74048289	3.22831199
13	3.25666667	2.69892068	1.89432825
		0.55774599	3.50351311
14	3.14333333	2.89217725	2.08245468
		0.25115609	3.70189982
15	3.09666667	2.98827025	2.17665748
		0.10839642	3.79988302
16	2.57666667	2.96618313	2.15669082
		-0.38951646	3.77567545
17	2.42666667	2.80489933	1.99825634
		-0.37823266	3.61154232
18	2.48333333	2.48340229	1.67008658
		-0.00006895	3.29671800
19	1.79666667	1.98067544	1.13150631
		-0.18400878	2.82984458
20	1.57333333	1.27570224	0.33434665
		0.29763109	2.21705783

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	2.01948013
SUM OF SQUARED RESIDUALS - ERROR SS	0.00000000
PRESS STATISTIC	3.09896702
FIRST ORDER AUTOCORRELATION	0.35579567
DURBIN-WATSON D	1.23767482

REGRESSION ANOVA FOR COMBINED DATA FROM BOTH SAMPLING METHODS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	3	38.35963482	12.78654494	93.00
ERROR	34	4.67468828	0.13749083	PR > F
CORRECTED TOTAL	37	43.03432310		0.0001

R-SQUARE	C.V.	ROOT MSE	MPPBBR MEAN
0.891373	27.5076	0.37079756	1.34798246

SOURCE	DF	TYPE I SS	F VALUE	PR > F
X1	1	25.30324917	184.04	0.0001
X2	1	3.21444889	23.38	0.0001
X3	1	9.84193676	71.58	0.0001

SOURCE	DF	TYPE III SS	F VALUE	PR > F
X1	1	2.87748407	20.93	0.0001
X2	1	7.83627631	56.99	0.0001
X3	1	9.84193676	71.58	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	0.64842833	2.70	0.0107	0.23996333
X1	-0.08057444	-4.57	0.0001	0.01761277
X2	0.00260175	7.55	0.0001	0.00034463
X3	-0.0000161	-8.46	0.0001	0.00000190

OBSERVATION	OBSERVED	PREDICTED RESIDUAL	LOWER 95% CLI UPPER 95% CLI
1	0.30666667	0.42968604 -0.12301937	-0.42455073 1.28392281
2	0.00000000	0.12226219 -0.12226219	-0.68142997 0.92595434
3	0.00000000	-0.02913719 0.02913719	-0.81433446 0.75606008
4	0.16666667	-0.02436608 0.19103275	-0.80702387 0.75829170
5	0.08666667	0.10713911 -0.02047245	-0.67744121 0.89171944
6	0.10666667	0.32510947 -0.21844280	-0.45985795 1.11007688
7	0.19666667	0.71417016 -0.51750349	-0.06792202 1.49626233

OBSERVATION	OBSERVED	PREDICTED RESIDUAL	LOWER 95% CLI UPPER 95% CLI
8	0.40000000	1.05274000	0.27391002
		-0.65274000	1.83156997
9	1.25666667	1.40821567	0.63186668
		-0.15154900	2.18456466
10	1.79000000	1.87241340	1.09633302
		-0.08241340	2.64849378
11	1.86666667	2.18618348	1.40791056
		-0.31951681	2.96445639
12	2.25333333	2.44730007	1.66579978
		-0.19396674	3.22880035
13	2.73666667	2.67748230	1.89271788
		0.05918436	3.46224672
14	2.57000000	2.73458821	1.94978449
		-0.16458821	3.51939194
15	2.37333333	2.66948132	1.88648658
		-0.29614798	3.45247605
16	1.56666667	2.35649551	1.57254899
		-0.78982885	3.14044203
17	1.60666667	1.92507285	1.12644922
		-0.31840619	2.72369649
18	1.21666667	1.30187807	0.45982388
		-0.08521140	2.14393225
19	0.33333333	0.42968604	-0.42455073
		-0.09635271	1.28392281
20	0.20000000	0.12226219	-0.68142997
		0.07773781	0.92595434
21	0.17000000	-0.02913719	-0.81433446
		0.19913719	0.75606008
22	0.10000000	-0.04537989	-0.82761127
		0.14537989	0.73685150
23	0.31333333	0.05266630	-0.73133133
		0.26066703	0.83666393
24	0.49666667	0.24413358	-0.54096889
		0.25253309	1.02923605
25	0.47666667	0.50815415	-0.27576999
		-0.03148748	1.29207828
26	1.06333333	0.82386021	0.04284769
		0.23947313	1.60487272
27	1.16333333	1.17038397	0.39253799
		-0.00705064	1.94822995
28	1.10333333	1.52685763	0.75094467
		-0.42352430	2.30277059
29	1.78000000	1.87241340	1.09633302
		-0.09241340	2.64849378
30	3.17000000	2.18618348	1.40791056
		0.98381652	2.96445639
31	3.25666667	2.44730007	1.66579978
		0.80936660	3.22880035
32	3.14333333	2.63489538	1.85066666
		0.50843796	3.41912409

OBSERVATION	OBSERVED	PREDICTED RESIDUAL	LOWER 95% CLI UPPER 95% CLI
33	3.09666667	2.72810160	1.94304462
		0.36856506	3.51315859
34	2.57666667	2.70605095	1.92237001
		-0.12938429	3.48973190
35	2.42666667	2.54787563	1.76568318
		-0.12120896	3.33006808
36	2.48333333	2.23270784	1.44598553
		0.25062549	3.01943015
37	1.79666667	1.73967978	0.93069036
		0.05698689	2.54866920
38	1.57333333	1.04792366	0.18170134
		0.52540967	1.91414598

SUM OF RESIDUALS	0.00000000
SUM OF SQUARED RESIDUALS	4.67468828
SUM OF SQUARED RESIDUALS - ERROR SS	-0.00000000
PRESS STATISTIC	5.77810312
FIRST ORDER AUTOCORRELATION	0.57076059
DURBIN-WATSON D	0.79618822