Scientific Research

A Study on Measurement of Forest Soil Redox Potential

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ABSTRACT

Redox potential has principal influences on formation and attribute of soils, so it is necessary to research the measurement of soil redox potential. The self-made potentiometer and two indigenous FJA-5 potentiometers were employed to measure the Eh values of fir forest soils *in situ*, which lay in Savage Sea Beauty Spot in Sichuan Province. Simultaneously fresh soils *in situ* were collected and made into suspensions with various soil-water ratios and standing time to measure Eh values. The results demonstrated that the total tendency of Eh values measured by the self-made potentiometer was gradually falling with soil-water ratios increasing and standing time prolonging. There is a great difference between Eh values measured in laboratory and *in situ*. Only *in situ* may the measured Eh values show realistic oxidation-reduction conditions and formation characteristics of forest soil. The self-made potentiometer has a more preferable performance than indigenous FJA-5 potentiometers and it can be applied to measuring forest soil Eh *in situ*.

1. Introduction

Redox reaction is one of the most basic forms of material motion in nature and a vital dynamic phase in soil formation. Redox potential is an intensity index, which decides the direction and extent of redox reaction, and is used for estimating soil's redox ability and showing clearly morphological characteristics and mobile performance of mineral elements in soil profile [1]. So far, Eh value has been mostly measured in soft hydromorphic soils, such as paddy soil [2-11]. For unhydromorphic soils, their Eh values were usually measured after the soil was made into suspensions or disposed else [12-21]. However there are fewer researches on measurement of the forest soil redox potential. The environment and substance composition of soil itself have an extremely profound impact on redox potential, so it is important to research the methods and technologies about measurement of forest soil Eh.

2. Materials and Methods

2.1. Developing Redox Potentiometer Alone

At present most of redox potentiometers made in China are matched with acidimeters. They are usually used to measuring pH and Eh in soil solution. Sometimes they contribute to detect Eh values in paddy soils or other soft

sediment. Hence the special redox potentiometer for the forest soil Eh was made by ourselves and its measured results would be compared with the indigenous FJA-5 potentiometers' results.

A self-developed platinum electrode, a commercially available saturated calomel electrode and a DT-9205B multimeter were combinated into the self-made potentiometer (**Figure 1**). It is necessary to adjust the potential of platinum electrode before measurement so that exact and stable Eh values can be obtained [22-25]. In addition the sand core lies in bottom of saturated calomel electrode should be slightly immersed in saturated KCl to decrease the disturbance of liquid junction potential as far as possible [26,27].

2.2. Experimental Design

There were two experiments, namely, *in situ* test and laboratory test. *In situ* test was achieved in Savage Sea Beauty Spot in Sichuan Province, where the soil under fir forest was tested. The soil layer was respectively Layer A_d, the biggest eluvial horizon, and Layer B_2, the biggest illuvium. Eh values were measured in February 2011. Electrodes of the self-made potentiometer and FJA-5 potentiometers were inserted in the central section of Layer A_d and the electrodes of self-made potentiometer
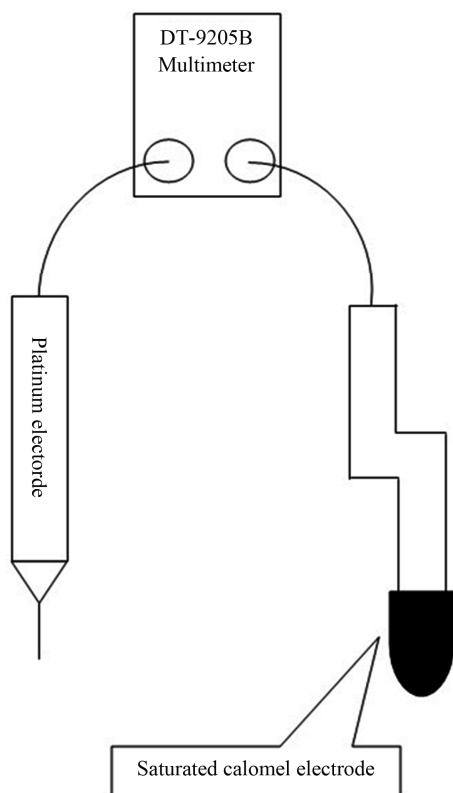
Figure 1. The schematic diagram of the self-made redox potentiometer.

were between that of two FJA-5 potentiometers. And what's more, the distance between platinum electrode and saturated calomel electrode ought to be near (1 - 3 cm), which could lower the resistance and determinate error.

Opened the power supply of DT-9205B multimeter linked with the self-made potentiometer and record the numerical value in display screen after it was stable. When the amplitude of fluctuation of the numerical value was less than 1 mv in five minutes, the value was deemed to be stable. Here it was emphasized that the numerical value in display screen only meaned the potential difference between platinum electrode and saturated calomel electrode instead of Eh value. The Eh value must be the summation of this potential difference and the constant potential provided by saturated calomel electrode at corresponding temperature. Simultaneously opened the power supply of FJA-5 potentiometers and the numerical value in display screen was exactly the Eh value. After finishment of Eh measurement in Layer A_d, all electrodes were taken out and washed by distilled water, then they were cleaned by dry filter papers to continue measuring Eh values of Layer B_2 with the same method. Eh values of each layer were repeatedly measured three times. Furthermore fresh soil of both Layer A_d and Layer B_2 were collected, preserved with fresh-keep-

ing packaging and brought back to laboratory.

10 g fresh soil samples were weighed and put in 50-ml beakers with high pattern in which additional distilled water with different volumes were mixed and suspend-sions with different soil-water ratios were formed. These suspensions had five soil-water ratios together, that was, 1:1, 1:2, 1:3, 1:4 and 1:5. As far as they were formed, the standing time was began to be recorded, which was respectively 0, 1, 2, 6, 12, 24, 48, 96, 144, 192 and 240 hours. Then Eh values were measured under varied soil-water ratio and standing time by the self-made potentiometer and FJA-5 potentiometers. As same as *in situ* test, Eh values were repeatedly measured three times. At last average values were worked out to draw the curve graph where Eh values were changing with changed soil-water ratios and standing time.

3. Results and Discussion

3.1. Laboratory Analysis

The Eh values measured by the self-made potentiometer were gradually falling with soil-water ratios increasing and standing time prolonging (**Figure 2**), whereas the Eh values measured by FJA-5 potentiometers were sometimes high and sometimes low, and irregular (**Figures 3** and **4**). The approximate tendency of Eh values of various suspensions with incremental soil-water ratios and prolonged standing time could be analysed according to Nernst Equation

$$Eh = E^0 + \frac{RT}{nF} LOG \frac{OX}{RED} \qquad [28].$$

If soil-water ratio is smaller, the concentration of redox systems in soil is higher, the oxidizing matters' oxidation capability is more powerful, even the concentration of oxidizing matters (*OX*) is greater than that of re-
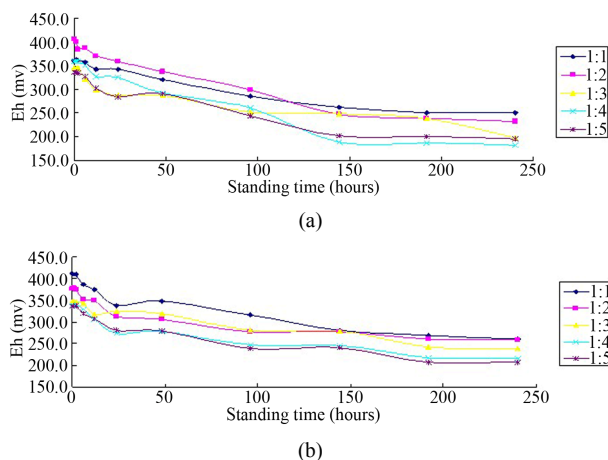

Figure 2. The variational curves of Eh values in Layer A_d (a) and Layer B_2 (b) measured by the self-made potentiometer. 1:1, 1:2, 1:3, 1:4 and 1:5 were the soil-water ratios.
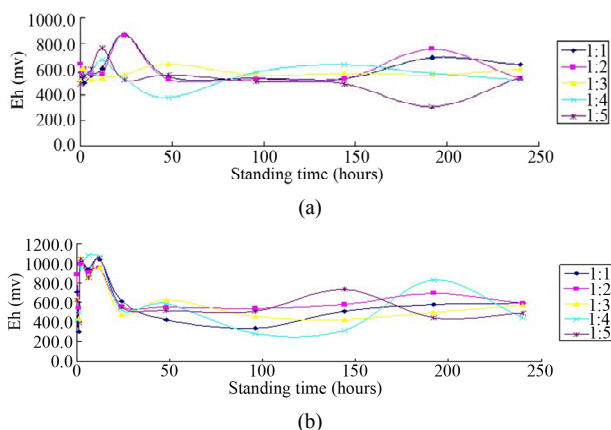

Figure 3. The variational curves of Eh values in Layer A$_d$ (a) and Layer B$_2$ (b) measured by the first FJA-5 potentiometer. 1:1, 1:2, 1:3, 1:4 and 1:5 were the soil-water ratios.
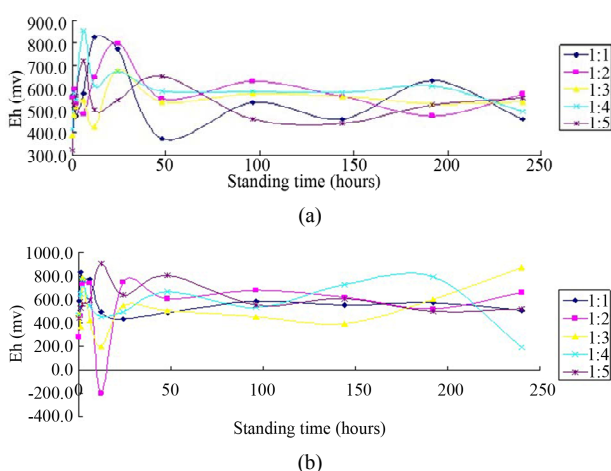

Figure 4. The variational curves of Eh values in Layer A$_d$ (a) and Layer B$_2$ (b) measured by the second FJA-5 potentiometer. 1:1, 1:2, 1:3, 1:4 and 1:5 were the soil-water ratios.

ducing matters (*RED*), then the Eh value is higher. However, with soil-water ratio amplifying, the concentration of redox systems is decreasing little by little, the reducing matters' reduction capability is just improving and this moment the concentration of reducing matters (*RED*) will exceed the oxidizing matters (*OX*), as a result the Eh value is falling by degress. Furthermore soil is isolated from the atmosphere outside more and more seriously when standing time is infinitely prolonging, the reduction condition is more and more superior, and then the concentration of reducing matters (*RED*) is more and more greater. Thereupon the Eh value will be more and more lower.

From what had been analysed above, the approximate tendency of Eh values measured by the self-made potentiometer was coincident with the consequence deduced from Nernst Equation, while the total trend of Eh values detected by FJA-5 potentiometers was not. Willis (1932), Quispel (1947) and Bohn (1968) considered consensually

that Eh was related to water levels, moisture content, soil structure and the amount of oxidational and reducible materials as well as it was only possible to detect oxidation-reduction conditions in soils when the measurements were carried out *in situ* after making Eh measurements on soil pastes or suspensions [18,29,30].

3.2. *In Situ* Analysis

Eh values measured *in situ* were showed by **Table 1**. In order to examine the precision and reappearance, coefficient of variation was employed. It was noticed that '0' (**Table 1**) should not be involved in averaging when calculating coefficient of variation.

It was clear in **Table 1** that coefficient of variation of Eh values got from the self-made potentiometer was much less than 1%, while that of values got from FJA-5 potentiometers was much bigger. Thus it was considered that the measurement results of the self-made potentiometer had relatively higher precision and better reappearance.

Soil redox potential is closely related to moisture, porosity, ventilated extent and content of organic matter [1,6,9], so them of soil *in situ* were revealed in **Table 2**. Seen from which, the contents of moisture and organic matter in Layer A$_d$ were obviously higher than that of Layer B$_2$, as well as porosity and ventilated extent were smaller than that of Layer B$_2$, thereupon the Eh value of Layer A$_d$ ought to be lower than Layer B$_2$. From what **Table 1** showed, the Eh values of Layer A$_d$ measured by the self-made potentiometer were all lower than Layer B$_2$, while the results got from FJA-5 potentiometers were

Table 1. Soil Eh values measured *in situ*.

Soil Layer		Eh Values, mv			Coefficient of Variation, %
A$_d$	△	585.6	384.7	595.2	22.78
	○	386.1	385.1	386.1	0.15
	▽	520.6	459.7	0	8.59
B$_2$	△	323.7	285.5	337.4	8.52
	○	494.8	494.8	493.8	0.12
	▽	377.9	311.3	0	9.66

△, Eh values measured by the first FJA-5 potentiometer; ○, Eh values measured by the self-made potentiometer; ▽, Eh values measured by the second FJA-5 potentiometer.

Table 2. Soil moisture, porosity, ventilated extent and contents of organic matter.

Soil Layer	Moisture, %	Porosity, %	Ventilated Extent, %	Contents of Organic Matter, %
A$_d$	33.64	40.6	22.77	5.3556
B$_2$	12.35	49.72	28.65	1.3484

opposite. It has been proved that oxidation processes occupy primary superiority in formation of forest soil, however moisture and organic matter often accumulate in surface layer so that redox potential of surface soil will be lower than that of bottom soil [31]. This difference may vary from several or dozens of millivolts to hundreds of millivolts. Usually there is a buffer slightly influenced by moisture and organic matter below Layer A_1, such as Layer A_d [31]. In summary, Eh values measured by the self-made potentiometer could objectively reflect the oxidation-reduction conditions and formation characteristics of forest soil in field.

The significance of difference between Eh values measured by the self-made potentiometer and by FJA-5 potentiometers was tested. Similarly "0" (**Table 1**) should not be involved in averaging and the test results were displayed in **Table 3**. It was found in **Table 3** that the interclass differences ($\triangle$ & $\triangledown$) were not significant ($P > 0.05$) regardless of Layer A_d or B_2, while in interblock differences, except that the difference between Eh values of Layer A_d measured by the self-made potentiometer and by the first FJA-5 potentiometer ($\circ$ & $\triangle$) was not significant ($P > 0.05$), the others were very significant ($P < 0.01$). This test manifested that the measurement results of the self-made potentiometer had higher precision and accuracy than FJA-5 potentiometers. The measurement results obtained from FJA-5 potentiometers were hardly able to reflect the oxidation-reduction conditions and formation characteristics of soil in field.

To move forward a single step, significance of differences between Eh values measured *in situ* and in laboratory by the self-made potentiometer were tested. The result demonstrated that there was a significant ($P < 0.05$) or very significant difference ($P < 0.01$) between Eh values measured *in situ* and at each soil-water ratio and standing time in Layer A_d (**Appendix 1**), and that for Layer B_2, only exsited very significant difference ($P < 0.01$) (**Appendix 2**). So it is safely concluded that if for-est soils are brought back to laboratory and made into suspensions for redox potential, there will be a great difference compared with the measurement *in situ* and the Eh values measured in suspensions cannot completely reflect the actual oxidation-reduction conditions of forest soil.

4. Conclusions

For resreaches on redox process of unhydromorphic soils such as forest soil, if soil samples are made into suspensions, their Eh values will change with changed soil-water ratio and standing time and it is difficult to determine appropriate soil-water ratio and standing time. The Eh values measured at varied soil-water ratio and standing time have significant or very significant differences with that measured *in situ*. So Eh measurement *in situ* should be gradually promoted.

The methods and technologies about measurement of unhydromorphic soil Eh *in situ* still need to face a lot of problems and challenges in study on soil electrochemistry. Through preliminary analysis on Eh values measured *in situ* and in laboratory, it can be definitely deemed that the measurement results of the self-made potentiometer have relatively higher precision and accuracy and that the self-made potentiometer can be applied to measuring forest soil Eh *in situ*.

5. Acknowledgements

Table 3. Significance of differences of Eh values.

Soil Layer	Source of Variation		F	P-value	F crit
A_d	Interblock	$\circ$ & $\triangle$	3.9554	0.1176	7.7086
		$\circ$ & $\triangledown$	35.5390**	0.0039	7.7086
	Interclass	$\triangle$ & $\triangledown$	0.1959	0.6809	7.7086
B_2	Interblock	$\circ$ & $\triangle$	136.7974**	0.0003	7.7086
		$\circ$ & $\triangledown$	55.9376**	0.0017	7.7086
	Interclass	$\triangle$ & $\triangledown$	1.4266	0.2983	7.7086

$\triangle$, Eh values measured by the first FJA-5 potentiometer; $\circ$, Eh values measured by the self-made potentiometer; $\triangledown$, Eh values measured by the second FJA-5 potentiometer; **Significance of difference is at the $P < 0.01$ level.

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Appendix 1

Significance of differences between Eh values measured *in situ* and in laboratory (Layer A$_d$).

Soil-water Ratio	Standing Time, hours	Source of Variation		F	*P*-value	F crit
		Suspension Eh	*In situ* Eh			
		360.9	386.1			
	0	360.9	385.1	2708.48[**]	8.1589E-07	21.1977
		361.9	386.1			
		363.1	386.1			
	1	362.1	385.1	2380.50[**]	1.0558E-06	21.1977
		363.1	386.1			
		363	386.1			
	2	361	385.1	1045.46[**]	5.4547E-06	21.1977
		361	386.1			
		357.1	386.1			
	6	357.1	385.1	7396.00[**]	1.0959E-07	21.1977
		357.1	386.1			
		342	386.1			
	12	342	385.1	17239.69[**]	2.018E-08	21.1977
		342	386.1			
		343	386.1			
1:1	24	344	385.1	8102.65[**]	9.1315E-08	21.1977
		343	386.1			
		320.9	386.1			
	48	320.9	385.1	37869.16[**]	4.1832E-09	21.1977
		320.9	386.1			
		286.5	386.1			
	96	286.5	385.1	88684.84[**]	7.6282E-10	21.1977
		286.5	386.1			
		262	386.1			
	144	262	385.1	137863.69[**]	3.1567E-10	21.1977
		262	386.1			
		251.3	386.1			
	192	251.3	385.1	162731.56[**]	2.2656E-10	21.1977
		251.3	386.1			
		250	386.1			
	240	250	385.1	82539.85[**]	8.8062E-10	21.1977
		251	386.1			

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		407.2	386.1		
	0	407.2	385.1	4134.49**	3.50435E-07	21.1977
		407.2	386.1		
		402	386.1		
	1	402	385.1	2371.69**	1.06369E-06	21.1977
		402	386.1		
		384.7	386.1		
	2	384.7	385.1	10.24*	0.03290081	21.1977
		384.7	386.1		
		388	386.1		
	6	389	385.1	37.84**	0.00354206	21.1977
		389	386.1		
		371.7	386.1		
	12	371.7	385.1	1780.84**	1.88485E-06	21.1977
		371.7	386.1		
		360	386.1		
1:2	24	361	385.1	2910.85**	7.06511E-07	21.1977
		360	386.1		
		338.1	386.1		
	48	338.1	385.1	10082.00**	5.8989E-08	21.1977
		339.1	386.1		
		298	386.1		
	96	299	385.1	34138.85**	5.14717E-09	21.1977
		299	386.1		
		247.2	386.1		
	144	247.2	385.1	172806.49**	2.00916E-10	21.1977
		247.2	386.1		
		238	386.1		
	192	238	385.1	196514.89**	1.55362E-10	21.1977
		238	386.1		
		231.3	386.1		
	240	231.3	385.1	214739.56**	1.30111E-10	21.1977
		231.3	386.1		

Continued

		346.1	386.1		
	0	346.1	385.1	14161.00**	2.9906E-08	21.1977
		346.1	386.1		
		344	386.1		
	1	345	385.1	7601.45**	1.03748E-07	21.1977
		345	386.1		
		346.2	386.1		
	2	346.2	385.1	7164.05**	1.16797E-07	21.1977
		345.2	386.1		
		323.3	386.1		
	6	323.3	385.1	35118.76**	4.86397E-09	21.1977
		323.3	386.1		
		298	386.1		
	12	298	385.1	34400.65**	5.06914E-09	21.1977
		299	386.1		
		287.3	386.1		
1:3	24	287.3	385.1	87261.16**	7.87909E-10	21.1977
		287.3	386.1		
		288	386.1		
	48	287	385.1	43601.05**	3.15567E-09	21.1977
		287	386.1		
		252.6	386.1		
	96	252.6	385.1	159600.25**	2.35541E-10	21.1977
		252.6	386.1		
		249	386.1		
	144	250	385.1	83354.45**	8.63493E-10	21.1977
		250	386.1		
		238.4	386.1		
	192	238.4	385.1	195452.41**	1.57056E-10	21.1977
		238.4	386.1		
		197	386.1		
	240	197	385.1	320695.69**	5.83386E-11	21.1977
		197	386.1		

Continued

		359.6	386.1		
	0	359.6	385.1	6162.25**	1.57835E-07	21.1977
		359.6	386.1		
		359.6	386.1		
	1	359.6	385.1	6162.25**	1.57835E-07	21.1977
		359.6	386.1		
		360	386.1		
	2	360	385.1	3065.45**	6.37119E-07	21.1977
		359	386.1		
		351.8	386.1		
	6	351.8	385.1	10383.61**	5.56129E-08	21.1977
		351.8	386.1		
		327	386.1		
	12	327	385.1	31081.69**	6.20939E-09	21.1977
		327	386.1		
		326	386.1		
1:4	24	327	385.1	15895.45**	2.37369E-08	21.1977
		326	386.1		
		291.8	386.1		
	48	291.8	385.1	79467.61**	9.50024E-10	21.1977
		291.8	386.1		
		262	386.1		
	96	261	385.1	69676.45**	1.23577E-09	21.1977
		261	386.1		
		188.7	386.1		
	144	188.7	385.1	349517.44**	4.9114E-11	21.1977
		188.7	386.1		
		186	386.1		
	192	187	385.1	178383.65**	1.88549E-10	21.1977
		187	386.1		
		182.1	386.1		
	240	183.1	385.1	186050.00**	1.73331E-10	21.1977
		182.1	386.1		

Continued

		335.3	386.1		
	0	335.3	385.1	22921.96**	1.14162E-08	21.1977
		335.3	386.1		
		337.2	386.1		
	1	337.2	385.1	10760.45**	5.17871E-08	21.1977
		336.2	386.1		
		335	386.1		
	2	335	385.1	23195.29**	1.11488E-08	21.1977
		335	386.1		
		327.5	386.1		
	6	327.5	385.1	30555.04**	6.42526E-09	21.1977
		327.5	386.1		
		302.4	386.1		
	12	302.4	385.1	62550.01**	1.53338E-09	21.1977
		302.4	386.1		
		283.1	386.1		
1:5	24	284.1	385.1	46818.00**	2.73693E-09	21.1977
		284.1	386.1		
		290	386.1		
	48	291	385.1	40698.05**	3.62187E-09	21.1977
		291	386.1		
		244	386.1		
	96	244	385.1	90865.85**	7.26638E-10	21.1977
		243	386.1		
		201.5	386.1		
	144	201.5	385.1	305587.84**	6.42495E-11	21.1977
		201.5	386.1		
		201	386.1		
	192	200	385.1	154179.05**	2.52396E-10	21.1977
		201	386.1		
		195.4	386.1		
	240	195.4	385.1	326155.21**	5.64019E-11	21.1977
		195.4	386.1		

[**]Significance of difference is at the $P < 0.01$ level; [*]Significance of difference is at the $P < 0.05$ level.

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Appendix 2

Significance of differences between Eh values measured *in situ* and in laboratory (Layer B$_2$).

Soil-water Ratio	Standing Time, hours	Source of Variation		F	*P*-value	F crit
		Suspension Eh	*In situ* Eh			
		412.1	494.8			
	0	411.1	494.8	30776.81**	6.333E-09	21.1977
		412.1	493.8			
		410	494.8			
	1	410	494.8	64211.56**	1.4551E-09	21.1977
		410	493.8			
		409.5	494.8			
	2	410.5	494.8	32232.61**	5.7739E-09	21.1977
		409.5	493.8			
		385.5	494.8			
	6	385.5	494.8	106863.61**	5.2537E-10	21.1977
		385.5	493.8			
		375	494.8			
	12	375	494.8	128450.56**	3.6363E-10	21.1977
		375	493.8			
		337.2	494.8			
1:1	24	338.2	494.8	105093.27**	5.4322E-10	21.1977
		337.1	493.8			
		346.6	494.8			
	48	347.6	494.8	97947.38**	6.2537E-10	21.1977
		346.6	493.8			
		316.4	494.8			
	96	317.4	494.8	142151.12**	2.969E-10	21.1977
		316.4	493.8			
		282	494.8			
	144	281	494.8	204416.18**	1.436E-10	21.1977
		281	493.8			
		268.4	494.8			
	192	268.4	494.8	459955.24**	2.836E-11	21.1977
		268.4	493.8			
		261	494.8			
	240	262	494.8	244580.18**	1.003E-10	21.1977
		261	493.8			

Continued

		376.3	494.8		
	0	376.3	494.8	125670.25**	3.799E-10	21.1977
		376.3	493.8		
		377	494.8		
	1	378	494.8	61390.08**	1.592E-09	21.1977
		378	493.8		
		374.7	494.8		
	2	373.7	494.8	65268.85**	1.408E-09	21.1977
		373.7	493.8		
		352.6	494.8		
	6	353.6	494.8	90142.58**	7.383E-10	21.1977
		352.6	493.8		
		349	494.8		
	12	350	494.8	94786.58**	6.678E-10	21.1977
		349	493.8		
		312.2	494.8		
1:2	24	312.1	494.8	296246.53**	6.837E-11	21.1977
		312.1	493.8		
		306.3	494.8		
	48	306.3	494.8	318660.25**	5.909E-11	21.1977
		306.3	493.8		
		278	494.8		
	96	278	494.8	421720.36**	3.374E-11	21.1977
		278	493.8		
		278.1	494.8		
	144	277.2	494.8	221885.34**	1.219E-10	21.1977
		277.1	493.8		
		261	494.8		
	192	262	494.8	244580.18**	1.003E-10	21.1977
		261	493.8		
		258	494.8		
	240	259	494.8	250915.28**	9.53E-11	21.1977
		258	493.8		

Continued

		346.8	494.8			
	0	346.7	494.8	194393.67**	1.588E-10	21.1977
		346.8	493.8			
		346.9	494.8			
	1	346.9	494.8	193955.21**	1.595E-10	21.1977
		347	493.8			
		345.3	494.8			
	2	345.3	494.8	200256.25**	1.496E-10	21.1977
		345.3	493.8			
		342.1	494.8			
	6	342.1	494.8	208940.41**	1.374E-10	21.1977
		342.1	493.8			
		317.3	494.8			
	12	317.3	494.8	279590.06**	7.675E-11	21.1977
		317.4	493.8			
		324.1	494.8			
1:3	24	324.1	494.8	261223.21**	8.793E-11	21.1977
		324.1	493.8			
		320.1	494.8			
	48	320	494.8	271131.57**	8.162E-11	21.1977
		320	493.8			
		281.5	494.8			
	96	281.5	494.8	404025.19**	3.676E-11	21.1977
		281.6	493.8			
		279.3	494.8			
	144	279.3	494.8	207690.13**	1.391E-10	21.1977
		280.3	493.8			
		243	494.8			
	192	243	494.8	569119.36**	1.852E-11	21.1977
		243	493.8			
		239.2	494.8			
	240	239.2	494.8	586449.64**	1.745E-11	21.1977
		239.2	493.8			

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Continued

		338.1	494.8			
	0	338.1	494.8	220054.81[**]	1.239E-10	21.1977
		338.1	493.8			
		338	494.8			
	1	338	494.8	110638.08[**]	4.901E-10	21.1977
		337	493.8			
		340.3	494.8			
	2	340.3	494.8	213906.25[**]	1.311E-10	21.1977
		340.3	493.8			
		329.5	494.8			
	6	329.5	494.8	244926.01[**]	1E-10	21.1977
		329.5	493.8			
		305.1	494.8			
	12	305.2	494.8	319317.24[**]	5.884E-11	21.1977
		305.2	493.8			
		274.4	494.8			
1:4	24	274.4	494.8	319317.24[**]	5.884E-11	21.1977
		274.4	493.8			
		276.6	494.8			
	48	276.7	494.8	422704.51[**]	3.358E-11	21.1977
		276.7	493.8			
		247.2	494.8			
	96	247.2	494.8	550267.24[**]	1.982E-11	21.1977
		247.2	493.8			
		245.1	494.8			
	144	245.1	494.8	559653.61[**]	1.916E-11	21.1977
		245.1	493.8			
		216.3	494.8			
	192	216.3	494.8	696390.25[**]	1.237E-11	21.1977
		216.3	493.8			
		215.2	494.8			
	240	215.2	494.8	701908.84[**]	1.218E-11	21.1977
		215.2	493.8			

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Continued

		336.7	494.8		
	0	336.7	494.8	224012.89**	1.196E-10	21.1977
		336.7	493.8		
		336.4	494.8		
	1	336.5	494.8	222451.49**	1.212E-10	21.1977
		336.5	493.8		
		338.1	494.8		
	2	338.1	494.8	220054.81**	1.239E-10	21.1977
		338.1	493.8		
		319.9	494.8		
	6	319.9	494.8	274261.69**	7.976E-11	21.1977
		319.9	493.8		
		307.7	494.8		
	12	307.7	494.8	313936.09**	6.088E-11	21.1977
		307.7	493.8		
		280.3	494.8		
1:5	24	280.3	494.8	205761.13**	1.417E-10	21.1977
		281.3	493.8		
		279.5	494.8		
	48	279.5	494.8	415896.01**	3.469E-11	21.1977
		279.5	493.8		
		238.8	494.8		
	96	238.8	494.8	588289.00**	1.734E-11	21.1977
		238.8	493.8		
		240.2	494.8		
	144	240.2	494.8	581863.84**	1.772E-11	21.1977
		240.2	493.8		
		207	494.8		
	192	207	494.8	743733.76**	1.085E-11	21.1977
		207	493.8		
		206.4	494.8		
	240	206.4	494.8	746841.64**	1.076E-11	21.1977
		206.4	493.8		

[**]Significance of difference is at the $P < 0.01$ level; [*]Significance of difference is at the $P < 0.05$ level.