10th National Convention on Statistics (NCS)
EDSA Shangri-La Hotel
October 1-2, 2007

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Felino P. Lansigan and Arnold R. Salvacion

For additional information, please contact:

Author's name : Dr. Felino P. Lansigan
Designation : Professor
Affiliation : Institute of Statistics, University of the Philippines0 Los Baños
Address : College, Los Baños, Laguna 4031
Tel. no. : (049) 536-2381
E-mail : fplansigan@uplb.edu.ph

Co-author's name : Arnold R. Salvacion
Designation : University Research Associate
Affiliation : Institute of Statistics, University of the Philippines Los Baños
Address : College, Los Baños, Laguna 4031
Tel. no. : (049) 536-2381
E-mail : arnold_salvacion@yahoo.com

Assessing the Effect of Climate Change on Rice and Corn Yields in Selected Provinces in the Philippines[1]

by

Felino P. Lansiganand Arnold R. Salvacion[2]

Abstract

Climate change is one of the major concerns nowadays. Doubling of atmospheric carbon dioxide (CO_2) concentration, and increase in the air temperature are the most likely predicted scenarios of climate change. Agricultural crop production is most vulnerable to these changes since any change in climate translates to change in weather which is an important factor in agriculture. Atmospheric CO_2 concentration and air temperature have direct impact on crops. Doubling of atmospheric CO_2, and increase in air temperature could greatly influence crop growth and development, specifically their photosynthetic activities. Plants' response to certain changes is dependent on the photosynthetic pathway that the plant uses. Rice and corn use different photosynthetic pathways; C_3 pathway for rice crop, and C_4 pathway for corn crop explain the difference on the response behavior of these two crops to climate change. The effect of climate change on yields of rice and corn in selected areas in the Philippines were simulated under 10 different climate change scenarios in three selected provinces, namely: Ilagan, Isabela; Los Baños, Laguna; and Malaybalay, Bukidnon. Yield simulation was done using two CERES (Crop-Environment REsource Synthesis) models, namely, CERES-Rice and CERES-Maize. Simulation results showed that rice and corn yields tend to decrease. There is a greater percent relative change as well as higher coefficient of variation (cv) in yields of rice compared to yields of corn for the three locations.

Keywords: climate change, simulated yields, CERES-Rice, CERES-Maize

INTRODUCTION

Climate change is defined as a statistically significant variation in either the mean state of the climate or in its, variability, persisting for an extended period (typically decades or longer). It may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of atmosphere or in land use (IPCC, 2001). The United Nations Framework Convention on Climate Change (UNFCCC), defines climate change as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. One of the established generalizations about global change is that atmospheric CO_2 concentration has increased as a result of anthropogenic emissions principally from the burning of fossil fuels, and clearing and burning of forest (Fitter, et al., 2002).

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[1] Paper presented during the 10th National Convention on Statistics at the EDSA Shangri-la Plaza Hotel, Mandaluyong City, Philippines on 1-2 October 2007

[2] Professor, and University Research Associate, Institute of Statistics, University of the Philippines Los Baños (UPLB), College Laguna 4031 Philippines

Agriculture is sensitive to short term changes in weather and to seasonal, annual and longer term variations in climate (STOA, 1999). The relationship between climate changes and agriculture is particularly important issue, as the world's food production resources are already under pressure from rapidly increasing population (Mathews and Stephens, 2002). The agronomic impacts of global climate change will depend upon how temperature, precipitation, and solar radiation change over time (STOA, 1999). Agricultural crop production might be significantly affected by the predicted changes in climate and atmospheric CO_2 (Rosenzweig and Hillel, 1998, Tubiello et al., 2000). Elevated CO_2 alone increases plant photosynthesis, and thus increases crop yields (Kimball, 1983, Tubiello et al., 2000). But the predicted changes in temperature and precipitation might further affect crop yields, by hastening plant development, and by altering the water and nutrient budget in the fields, and modifying plant stress (Long, 1991, Tubiello et al, 2000).

Several studies using temperature gradient tunnels (TGTs), crop simulation models, and field experiments have been conducted to evaluate the effects of climate change particularly to temperature increase, and/or doubled CO_2 concentration on crop (rice) growth and development (Lansigan, 2001). Yoshino et al., (1988) predicted the effect of climate change on lowland rice yield in Japan while Solomon and Leemans (1990) in a worldwide study, use a very simple model and long-term monthly monthly-average climatic data predicted the effect of climate change in rice yield for current growing environment (Matthews and Stephens, 2002). Tubiello et al., (2000) and Tsvetsinskaya et al., (2004) studied the effect of climate change in crop production in the United States.

Rice (*Oryza sativa L.*) and corn (*Zea mays L.*) are the most two important grain crops in the Philippines. The former served as the major staple food while the latter is the major source of feed materials for the country's livestock industry. In 2004, the areas devoted to rice and corn production were 4.1M ha and 2.5M ha amounting to an annual production of 14.5M tons and 5.4M tons, respectively (BAS, 2004). Based on official statistics, the projected population of the country for the year 2005 was 85.2M (NSO, 2005) which consumed about 8.2M tons of rice and 0.3M tons of corn (FAO, 2006) for food alone. Hence, it is important to quantify the effects of climate change on producutivity for these two crops.

The objective of this paper is to compare the yield responses of rice and corn crops to anticipated climate change (characterized by an increase in air temperature, and doubling of atmospheric CO_2) using the weather data from three selected provinces in the Philippines (Fig.1), namely: Ilagan, Isabela; Los Baños, Laguna; and Malaybalay, Bukidnon.

METHODOLOGY

In order to evaluate impact of climate change on the yield of rice and corn, different climate change scenarios were simulated using the (Crop-Environment REsource Synthesis for rice and corn) model – i.e. CERES-Rice and CERES-Maize - which are both under the DSSAT v4. software (Hoogenboom, et al., 2003).

Ten (10) climate change scenarios (Table 1) were used to evaluate the crops' response to climate change. These scenarios involved current and potential climate change with increase in air temperature, and doubling of atmospheric CO_2.

Each climate change scenario was simulated using the existing historical data of each selected provinces. Cultural management specific to each crop, soil data of each location, and a representative planning date (mid-May) were used as inputs for the simulation. Genetic coefficients for rice and corn (Tables 2a and 2b) (from DSSAT v4. database, and from Lansiganet al., 2002 for corn), which are described therein were also used as inputs for the simulating yields.

Within and between location comparisons of mean simulated yields of both crops for each of the climate scenarios were done. To measure yield variability at different scenarios, coefficient of variation (cv) were computed. Relative changes in mean yields were calculated for each scenario relative to the current atmospheric condition (herein denoted as Scenario 1) .

RESULTS AND DISCUSSION

In general an increase in CO_2 level was found to increase yield while increase in temperature reduced yield (Matthews et al., 2002). Increase in yield was due to the increase in photosynthesis resulting from higher CO_2 concentration. Distinction in the response of the two crops to climate change could be observed since each uses two different photosynthetic pathways for carbon assimilation, rice uses the Calvin or C_3 pathway while corn uses the C_4 pathway. In general C_3 crops (i.e. wheat, rice, and soybeans) respond more to CO_2 enrichment than C_4 crops (i.e. maize, sorghum, sugarcane, and millet) (EPA, 2006). But photosynthetically, these plants (C_3) are underachievers because, on the one hand, they assimilate atmospheric CO2 into sugars but, on the other hand, part of the potential for sugar production is lost by respiration in daylight, releasing CO2 into the atmosphere, a wasteful process termed photorespiration (Ku, 2000). The rate of dry matter production in plants exhibiting photorespiration is lower than in plants without photorespiration (e.g. the C_4 species) (Afonso-Alejar, et al., 1999). C_4 plants have higher optimum temperature than C_3 plants, photosynthetic rates of C_3 deceases beyond 30-35°C. The CO_2 concentrating mechanism in C_4 species allows the leaf to maintain high photosynthetic rate at lower intercellular CO_2 values, and in hot dry climates the C_4 cycle reduces photorespiration and water loss (Alfonso-Alejar et al., 1999).

Change in yield and yield variability within location for both rice and corn and were computed to measure the effect of the increasing air temperature and the doubling of atmospheric CO_2 concentration (Table 3 and Table 4). Change in yield was calculated through percent relative change (referenced to Scenario 1 or the actual atmospheric condition) in yield while yield variability was measured by computing the coefficient of variation (cv). Across location mean simulated yield of both crops were compared to determine the difference of crop response in spatial level (Tables 5 and 6).

Change in Yield

Percent relative change in yield serves as a measure of change in yield (increase or decrease) as affected by climate change in reference to the actual atmospheric condition. In terms of relative change in simulated yield, rice showed a greater change in yield compared with corn as affected by increase in temperature at both atmospheric CO_2 concentrations.

At 330 ppm atmospheric CO_2 concentration, percent relative change in simulated yield of rice in Ilagan, Isabela ranges from -17.0% to 13.7% percent compared to corn which ranges from -2.3% to -15.1%. In Los Baños, Laguna the percent relative change in simulated rice yield range from -7.3% to -31.0% while -5.9% to -31.2% was calculated from corn. The percent relative change in simulated yield observed in Malaybalay, Bukidnon gave a range of -7.1% to -28.8% for rice and -25.3% to -33.1% for corn.

For certain location and level of temperature increase, the percent relative change in simulated rice yield was also greater compared to corn when atmospheric CO_2 concentration was doubled (660 ppm). This is exhibited in Malaybalay, Bukidnon, where the percent relative change in simulated rice yield 3.7% to 92.6% compared to 9.8% to 26.9% in corn. The relative change in simulated yields in Los Baños, Laguna ranges from -8.5% to 61.5% for rice while 14.6% to 28.4% in corn. In Ilagan, Isabela the maximum range value of the percent relative change in simulated yield of rice and corn was the same (8.5%) but lower minimum range value of -11.6% for rice compared to -4.8% for corn.

Yield Variability

In measuring yield variability, coefficient of variation was computed for each scenario. The effect of increasing air temperature and doubling of atmospheric CO_2 concentration in terms of simulated yield variation was higher in simulated rice compared to corn.

With increasing air temperature, the computed cv of simulated rice yields ranges from 48.6% to 59.7% and 56.5% to 69.1 percent in Ilagan, Isabela is almost twice the cv of simulated corn yields, 27.9% to 37.2% and 28.8% to 35.7%, at 330 ppm and 660 ppm atmospheric CO_2 concentration, respectively. The cv in Los Baños, Laguna ranged from 44.9% to 64.2% for simulated rice yield and 49.8% to 74.5% for simulated corn yields, at 330 ppm atmospheric CO_2 concentration. At 660 ppm atmospheric CO_2 concentration cv ranges from 31.2% to 46.6% for rice, and from 24.0% to 29.5% for corn yields . In the case of Malaybalay, Bukidnon cv is from 66.4% to 79.6%, and from 47.5% to 71.1% were calculated from simulated rice and corn yields at 330 ppm atmospheric $CO_{2.}$ Yields in Malaybalay also show high differences of the range of cv between the two crops at 660 ppm atmospheric CO_2 with cv of 41.6% to 60.5% for rice, and 12.0% to 19.3% for corn.

Crop Yield Change and Variability

For rice, the highest increase (92.6%) of simulated yield was observed in Malaybalay, Bukidnon at 660 ppm atmospheric CO_2 concentration with 0°C increase in air temperature while the highest yield decrease (-51.8%) was observed in Los Baños, Laguna at 330 ppm atmospheric CO_2 concentration with 2°C increase in air temperature. The lowest increase (4.2%) and decrease (-7.6%) in yield was observed in Ilagan, Isabela and Malaybalay, Bukidnon, respectively. On the other hand, the highest (79.6%) yield variation was observed in Malaybalay, Bukidnon at 330 ppm atmospheric CO_2 concentration with 0.5°C increase in air temperature while the lowest (31.2%) was observed in Los Baños, Laguna at 660 ppm CO_2 concentration with 0°C increase in air temperature.

For corn, percent relative changes in simulated yield in Los Baños, Laguna (28.4%) at 660 ppm atmospheric CO_2 concentration with 0°C increase in air temperature was the highest increase in yield among the three locations while the lowest increase in yield (0.1%) was calculated from Ilagan, Isabela at 660 ppm atmospheric CO_2 concentration with 1°C increase in air temperature. The highest decrease in corn yield was -33.1% which was observed in Malaybalay, Bukidnon at 330 ppm atmospheric CO_2 concentration with 1.5°C increase in air temperature while the lowest (-2.3%) was observed in Ilagan, Isabela at 330 ppm atmospheric CO_2 concentration with 0.5°C increase in temperature. In terms of yield variation, the highest simulated corn yield cv (74.5%) was computed in Los Baños, Laguna while the lowest (12.8%) was in Malaybalay, Bukidnon.

CONCLUDING REMARKS

Rice and corn respond differently to climate change because of the difference in photosynthetic pathway which determines their efficiency in carbon assimilation and reaction to certain level of temperature that each crop uses. Doubling of atmospheric CO_2 concentration seems to have a positive effect since it results to higher photosynthetic activities, thus, higher yields. Higher photosynthetic activity would mean higher production of photsynthates, which are then converted to different dry matter or plant products. Another effect of climate change is the increase in air temperature, which in effect reduces crop yield due to energy loss in maintenance respiration and other plant processes that were highly affected by the increase in air temperature.

Simulation results showed that under potential climate change, corn performed better than rice. This was exhibited by the lower decrease in yield as measured by percent relative change, and a less variable yield, in terms of coefficient of variation (cv), of simulated yield of corn compared to rice. Within and between location yield difference and variability could be observed due to climate change.

Further investigation should be conducted for the particular site regarding the response of rice to climate change, since it has the same set of input data, except for weather and soil data, but giving a very low simulated yield.

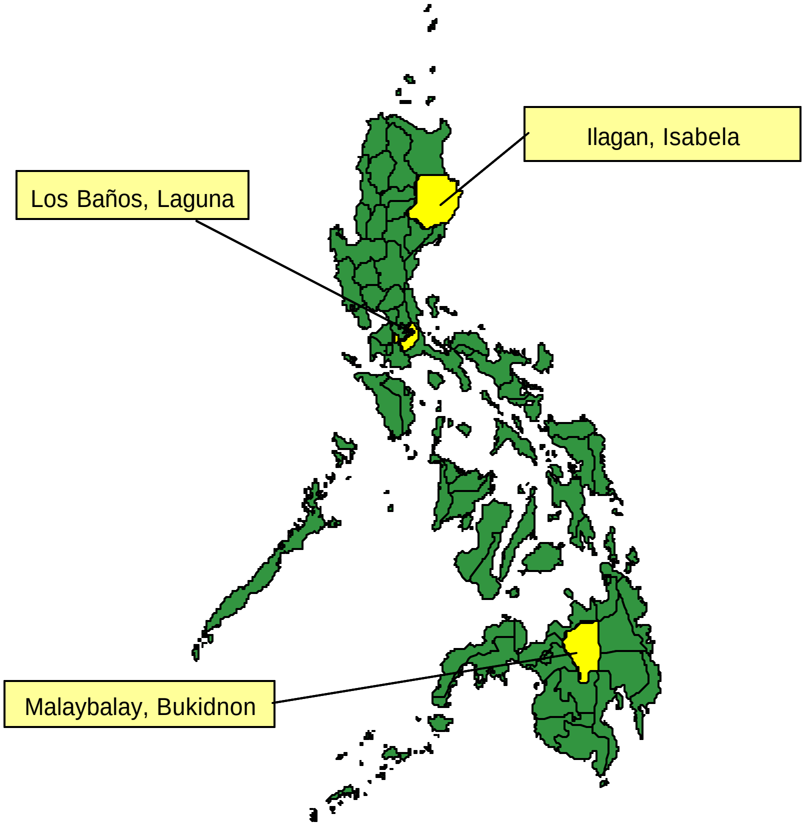

Fig. 1. Map showing the geographical locations of the three (3) study sites, namely; (1) Ilagan, Isabela; (2) Los Baños, Laguna; and (3) Malaybalay, Bukidnon.

Table 1. Climate change scenarios used in simulation of rice and corn yields in Ilagan, Isabela, Los Baños , Laguna, and Malaybalay, Bukidnon .

Scenario	Atmospheric [CO_2] (ppm)	Increase in Temperature (°C)
1	330	0
2	330	0.5
3	330	1.0
4	330	1.5
5	330	2.0
6	660	0
7	660	0.5
8	660	1.0
9	660	1.5
10	660	2.0

Table 2a. Description of crop genetic c oefficients of rice and corn (Tsuji, et al., 1994).

Genetic coefficient	Rice	Corn
P1	Time period (expressed as growing degree days [GDD] in °C above a base temperature of 9°C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod.	Thermal Time from seeding emergence to the end of juvenile phase (expressed in degree days above a base temperature of 8°C)
P5	Time period in GDD °C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9°C	Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8°C)
G2	Single grain weight (g) under ideal growing conditions, i.e. nonlimiting light, water, nutrients, and absence of pests and diseases	Maximum possible number of kernels per plant
G5	+	Kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day)
PHINT	+	Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances
G1	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less lead blades and sheaths plus spikes) at anthesis. A typical value	*

+ - The genetic coefficient is specifically for corn; therefore, there is no corresponding value for rice.

* - The genetic coefficient is specifically for rice; therefore, there is no corresponding value for corn.

Note: The above crop genetic coefficients are those that can be obtained in field experiments. Kindly refers to DSSAT v4. manual or genotype database for the other coefficients needed for simulation, especially those for rice.

Table 2b. Crop genetic coefficients of IR-64 rice variety and IPB 911 corn variety used in simulation of yields.

Genetic coefficient	**IR-64**[a]	**IPB 911**[b]
P1	540	316
P5	490	977
G2	0.25	396
G5	+	691
PHINT	+	42
G1	50	*

Source: [a] – DSSAT v.4 database, [b]–Lansigan et. al, 2002.

Table 3. Percent relative change* and coefficient of variation (CV) of simulated rice yields in Ilagan, Isabela; Los Baños, Laguna; and Malaybalay, Bukidnon.

Scenario ([CO_2], ? Temp)	Locations					
	Ilagan, Isabela		**Los Baños, Laguna**		**Malaybalay, Bukidnon**	
	% Relative Change	**CV (%)**	**% Relative Change**	**CV (%)**	**% Relative Change**	**CV (%)**
1 (330 ppm, 0°C)	-	62.4	-	21.08	-	43.76
2 (330 ppm, 0.5°C)	13.7	80.4	-7.3	22.81	-7.1	35.02
3 (330 ppm, 1.0°C)	-3.3	76.7	-15.3	25.09	-16.5	40.99
4 (330 ppm, 1.5°C)	-7.7	76.4	-22.3	28.51	-22.5	43.21
5 (330 ppm, 2.0°C)	-17.0	70.3	-31.0	34.01	-28.8	50.12
6 (660 ppm, 0°C)	149.0	56.8	40.4	15.18	36.5	23.37
7 (660 ppm, 0.5°C)	134.5	57.2	30.1	16.95	33.5	30.08
8 (660 ppm, 1.0°C)	110.8	60.9	20.6	18.45	18.1	36.36
9 (660 ppm, 1.5°C)	91.6	62.3	11.1	20.19	-0.9	45.62
10 (660 ppm, 2.0°C)	82.0	64.6	1.4	22.70	-10.3	52.90

* % relative change in mean yield is computed with reference to Scenario 1 or the current atmospheric condition

Table 4. Percent relative change* and coefficient of variation (CV) of simulated corn yields in Ilagan, Isabela; Los Baños, Laguna; and Malaybalay, Bukidnon.

Scenario ([CO_2], ? Temp)	Locations					
	Ilagan, Isabela		**Los Baños, Laguna**		**Malaybalay, Bukidnon**	
	% Relative Change	**CV (%)**	**% Relative Change**	**CV (%)**	**% Relative Change**	**CV (%)**
1 (330 ppm, 0°C)	-	37.2	-	49.8	-	47.5
2 (330 ppm, 0.5°C)	-2.3	35.1	-5.9	54.2	-25.3	63.1
3 (330 ppm, 1.0°C)	-4.6	32.5	-13.9	59.7	-31.9	69.2
4 (330 ppm, 1.5°C)	-4.0	33.1	-21.6	66.8	-33.1	69.3
5 (330 ppm, 2.0°C)	-15.1	27.9	-31.2	74.5	-32.0	71.1
6 (660 ppm, 0°C)	12.8	35.7	28.4	24.0	26.9	17.0
7 (660 ppm, 0.5°C)	8.5	31.8	25.9	25.0	21.0	18.9
8 (660 ppm, 1.0°C)	0.1	33.5	22.3	25.9	9.8	12.8
9 (660 ppm, 1.5°C)	-4.4	31.9	18.7	28.5	14.2	19.3
10 (660 ppm, 2.0°C)	-4.8	28.8	14.6	29.5	13.4	15.4

* % relative change in mean yield is computed in reference to Scenario 1 or the current atmospheric condition

Table 5. Comparison of mean simulated rice yields in Ilagan, Isabela; Los Baños, Laguna; and Malaybalay, Bukidnon.

Scenario ([CO$_2$], ?Temp)	**Location Mean Yield (kg/ha)**		
	Ilagan, Isabela	**Los Baños, Laguna**	**Malaybalay, Bukidnon**
1 (330 ppm, 0°C)	$561.0^{\mathbf{CD}\mathit{c}}$	$4641.6^{\mathbf{E}\mathit{a}}$	$3234.8^{\mathbf{BCD}\mathit{b}}$
2 (330 ppm, 0.5°C)	$638.1^{\mathbf{BCD}\mathit{c}}$	$4303.4^{\mathbf{EF}\mathit{a}}$	$3003.8^{\mathbf{CD}\mathit{b}}$
3 (330 ppm, 1.0°C)	$542.3^{\mathbf{CD}\mathit{c}}$	$3932.9^{\mathbf{FG}\mathit{a}}$	$2701.4^{\mathbf{CD}\mathit{b}}$
4 (330 ppm, 1.5°C)	$517.6^{\mathbf{CD}\mathit{c}}$	$3607.3^{\mathbf{GH}\mathit{a}}$	$2506.3^{\mathbf{D}\mathit{b}}$
5 (330 ppm, 2.0°C)	$465.9^{\mathbf{D}\mathit{c}}$	$3204.6^{\mathbf{H}\mathit{a}}$	$2301.6^{\mathbf{D}\mathit{b}}$
6 (660 ppm, 0°C)	$1396.8^{\mathbf{A}\mathit{c}}$	$6515.7^{\mathbf{A}\mathit{a}}$	$4414.9^{\mathbf{A}\mathit{b}}$
7 (660 ppm, 0.5°C)	$1315.6^{\mathbf{A}\mathit{c}}$	$6038.6^{\mathbf{B}\mathit{a}}$	$4317.9^{\mathbf{AB}\mathit{b}}$
8 (660 ppm, 1.0°C)	$1182.8^{\mathbf{AB}\mathit{c}}$	$5598.0^{\mathbf{C}\mathit{a}}$	$3821.9^{\mathbf{ABC}\mathit{b}}$
9 (660 ppm, 1.5°C)	$1074.8^{\mathbf{ABC}\mathit{c}}$	$5155.7^{\mathbf{D}\mathit{a}}$	$3206.2^{\mathbf{BCD}\mathit{b}}$
10 (660 ppm, 2.0°C)	$1020.8^{\mathbf{ABCD}\mathit{c}}$	$4705.6^{\mathbf{E}\mathit{a}}$	$2900.7^{\mathbf{CD}\mathit{b}}$

Means within each column followed by the same **bold** uppercase letter are not significantly different at 5% level of significance.

Means within each row followed by the same *italic* lowercase letter are not significantly different at 5% level of significance

Table 6. Comparison of mean simulated corn yields in Ilagan, Isabela; Los Baños, Laguna; and Malaybalay, Bukidnon.

Scenario ([CO$_2$], ? Temp)	**Location Mean Yield (kg/ha)**		
	Ilagan, Isabela	**Los Baños, Laguna**	**Malaybalay, Bukidnon**
1 (330 ppm, 0°C)	$2053.0^{\mathbf{A}\mathit{a}}$	$2671.0^{\mathbf{BC}\mathit{a}}$	$2069.7^{\mathbf{AB}\mathit{a}}$
2 (330 ppm, 0.5°C)	$2005.6^{\mathbf{A}\mathit{ab}}$	$2512.2^{\mathbf{DC}\mathit{a}}$	$1545.5^{\mathbf{BC}\mathit{b}}$
3 (330 ppm, 1.0°C)	$1958.9^{\mathbf{A}\mathit{ab}}$	$2298.7^{\mathbf{DCE}\mathit{b}}$	$1410.0^{\mathbf{BC}\mathit{b}}$
4 (330 ppm, 1.5°C)	$1971.3^{\mathbf{A}\mathit{a}}$	$2094.4^{\mathbf{DE}\mathit{a}}$	$1383.8^{\mathbf{C}\mathit{a}}$
5 (330 ppm, 2.0°C)	$1743.9^{\mathbf{A}\mathit{a}}$	$1836.5^{\mathbf{E}\mathit{a}}$	$1408.2^{\mathbf{BC}\mathit{a}}$
6 (660 ppm, 0°C)	$2315.9^{\mathbf{A}\mathit{b}}$	$3430.3^{\mathbf{A}\mathit{a}}$	$2625.5^{\mathbf{A}\mathit{b}}$
7 (660 ppm, 0.5°C)	$2227.5^{\mathbf{A}\mathit{b}}$	$3363.5^{\mathbf{A}\mathit{a}}$	$2504.6^{\mathbf{A}\mathit{b}}$
8 (660 ppm, 1.0°C)	$2055.6^{\mathbf{A}\mathit{b}}$	$3265.9^{\mathbf{A}\mathit{a}}$	$2273.4^{\mathbf{A}\mathit{a}}$
9 (660 ppm, 1.5°C)	$1962.6^{\mathbf{A}\mathit{b}}$	$3171.1^{\mathbf{A}\mathit{a}}$	$2364.4^{\mathbf{A}\mathit{b}}$
10 (660 ppm, 2.0°C)	$1954.6^{\mathbf{A}\mathit{b}}$	$3059.9^{\mathbf{AB}\mathit{a}}$	$2346.7^{\mathbf{A}\mathit{a}}$

Means within each column followed by the same **bold** uppercase letter are not significantly different at 5% level of significance.

Means within each row followed by the same *italic* lowercase letter are not significantly different at 5% level of significance

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