Available online at http://www.ifgdg.org

Int. J. Biol. Chem. Sci. 12(4): 1824-1835, August 2018

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Impact of drought on growth and yield of wheat as affected by mulch

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ACKNOWLEDGEMENTS

Grants from the National Natural Science Foundation of China (50309003).

ABSTRACT

A decrease of water resources around the globe in irrigated agriculture has resulted in a steep decline in irrigation water availability. Therefore, management options for efficient use of available irrigation water are inevitable. Deciding the critical time, frequency and amount of irrigation are compulsory to achieve higher outputs. Hence, the impact of drought and mulch on the growth, yield and yield components of wheat were examined in a green house. The objective was to determine measures, which if taken will enhanced resistance to drought and increase yield of wheat with improved soil conservation. Six treatments were considered under no-mulch and with mulch condition and irrigation overtime and stage of crop growth. The result shows that there was an increase of 4.49%, 10.38% and 10.29% on biomass accumulation of wheat due to variation in mulch under full irrigation, mild and severe stress respectively. The research also revealed that under full irrigation, mulch slightly increases grain yield (0.98%). However, under mild and severe stress, a decrease of 16.42% and 24.32% was observed under mulch condition. Further field studies are needed to extrapolate the findings to a wider range of seasonal and site conditions.

Keywords: Water Use Efficiency, irrigation water, green house, rice mulch, yield, wheat.

INTRODUCTION

Wheat (*Triticum aestivum* L) is one of the most important crops in the world. In 2013, the global annual production of wheat was 718.13 million tons, thus, feeding about one fifth of the human population (FAO, 2014). The rapidly increasing population will need to double the current wheat production until 2050 to ensure effective food supply for future generations (Beddington, 2011).

Wheat is quite sensitive to water stress. Therefore, it needs frequent irrigation for good growth and yield (Alderfasi and Nielsen, 2001). Usman (2013) and Yu et al. (2013) stated that water shortage is among the major abiotic stress that limits the productivity of cereals. It often causes nutrient deficiency

DOI: https://dx.doi.org/10.4314/ijbcs.v12i4.24

particularly phosphorus (Haefele et al., 2006). Average wheat yields throughout the world approach only 30 to 60% of maximum attainable yields, with water deficits and elevated temperatures causing the greatest reduction (Saddique et al., 2000).

The percentage of drought affected areas in the world has doubled from the 1970s to the early 2000s and developing countries are the most affected, specially the Sahel region of Africa (Isendahl and Schmidt, 2006). Therefore, an appropriate management of irrigation is necessary to preserve water resources, quantitatively and qualitatively, and to produce more food with the available water. Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas (Al-Jamal et al., 1999). Panda et al. (2003) stated that an appropriate deficit irrigation system with fresh water can increase irrigation efficiency without significantly decreasing yield. Response of wheat to growth water deficits vary depending on wheat varieties and growth stages. Jalota et al. (2006) reported that the anthesis to grain development period is the most sensitive stage to water stress in wheat in Northwest India. Zhang et al. (2006) concluded from an experiment that water stress or drought should be avoided at the booting and heading stage of spring wheat.

In addition to deficit irrigation, straw mulch dampens the influence of environmental factors on soil by increasing soil temperature and controlling diurnal/seasonal fluctuations in soil temperature (Li et al., 2013). It also enhances the soil biotic activity of earth worms (Lal, 2000) and improves, to a certain extent, soil structure and quality (Govaerts et al., 2007). Chakraborty et al. (2010) reported that rice straw mulch increased wheat grain yield, reduced crop water use by 3-11% and improved Water Used Efficiency (WUE) by 25% compared with no mulch. Information about the impact of drought and rice mulch on the growth and yield of winter wheat under controlled conditions are scanty. Thus, the objectives of the study were: (1) To examine the effects of rice straw mulch in combination with seedling stage drought on wheat growth and yield; (2) To investigate the impacts of mulch and water stress on harvest index, harvest ratio and yield components of winter wheat.

MATERIALS AND METHODS

Experimental site

A green house experiment was conducted from November 2005 to May 2006 at the experimental farm of Agricultural Engineering Department, Hohai University, Nanjing, China ($31^0$95' N latitude and $118^0$83' E longitude) (Figure 1). The climate is sub-humid with an average rainfall of 1106 millimeter (mm) per year. The mean temperature, relative humidity, air temperature and air humidity were measured with an electronic hygrometer during the growing period of wheat is given in Table 1.

The soil of the experimental site is clay loam with 33.81% clay, 65% silt, 0.97% sand and a pH (1:2.5 soil: water) of 7.96, the organic matter content is 12.26 mg/kg, the total nitrogen (N) is 0.15%, the total phosphorus is 33.09 mg/kg. Wheat variety 158 was used as a test crop, is well adapted to the environmental conditions of Beijing, Hebei and Jiangsu province. It is one of the most used wheat variety and one of the largest foodstuffs in planting area in China.

Experimental setup

The experimental design is a Randomized Block Design with three replications. Each plot is 2.25 m x 1.5 m. The seed was sown in rows of 25 cm width and at a depth of sowing of 5 cm. Prior to sowing; urea was applied in rows 10 cm deep at the rate of 375 kg/ha for all plots. The application of nitrogen fertilizer prior to sowing is a common practice of famers in China. Rice residue was applied as mulch at the rate of 6 t/ha, 15 days after wheat emergence to some plots. Mulch residues have been cut into pieces of nearly 5 cm prior to application. The treatment structure is a factorial with two factors: factor 1 is mulching with 2 levels (with and without), factor 2 is water stress with 3 levels (no stress, mild and severe stress). Six treatments were considered :(1) No mulch - No stress (-M-S), (2) Plus mulch - No stress (+M-S), (3) No mulch - Mild stress at seedling stage (-M+S1), (4) Plus mulch - Mild stress at seedling stage (+M+S1), (5) No mulch - Severe stress at seedling stage (-M+S2), (6) Plus mulch - Severe stress at seedling stage (+M+S2).

Pipes of 5 cm diameters, 15, 35 and 55 cm length were inserted in both plots and pots. 5cm of each pipe is kept above ground to avoid water entry during irrigation. These pipes are used for soil moisture measurements and should remain closed with covers except during measurements.

Soil water content at 0-60 cm depth was measured with neutron probe meter (MPM-160B) at intervals of 7-10 days. The water absorbed from the soil for a given interval was taken as the decrease in soil water in 0-60 cm depth interval. Evapotranspiration for the same interval was considered to be the total amount of water absorbed from the soil and irrigated water. On the other hand, plant height, number of leaves, number of tillers and plant stem diameter were measured at three weeks interval. Prior to measurement, 4 utile plants have been selected from each plot and labeled making 12 plants per treatment. Two lines of wheat were considered as border (as we are in a controlled green house condition). So four lines of wheat have been used in the calculation of biomass yield. Wheat of utile plots were harvested 140 days after sowing, oven dry for 72 hours at 105 ^{o}C and thereafter weight.

The harvest index (HI) was calculated as:

$$\mathrm{HI} = \frac{\text{Grain yield}}{\text{Grain yield} + \text{Straw yield}}$$

(Ali et al., 2007)

The harvest ratio was calculated as:

$$\mathrm{HR} = \frac{\text{Grain yield}}{\text{Straw yield}}$$

Statistical analyses

All statistical analyses were performed using General Linear Models (GLM) procedures in SPSS, Version 20 package. (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.). Two way ANOVA analyses were carried out over all six treatments to test explicitly the effects of deficit irrigation and mulch on growth parameters of maize. Water application and mulch application were treated as fixed factors in all the analyses while plant diameter, and height, number of leaves, number of tillers, plant biomass, and grain yield, length of spike, number of grain per spike, grain weight per spike, thousand grain weight as dependent variables. The tests of correlations were carried out between number of tillers and plant diameter, plant height and number of leaves and between and grain yield and various yield components.

Table 1: Mean values of climatic parameters at the experimental site [a)] (green house).

Month	**Selected weather data**		
	T [b)] (^{0}C)	**RH [c)] (%)**	**AH [d)] (^{0}C)**
December	8.42	45.83	9.02
January	8.25	42.06	7.25
February	5.83	48.66	4.58
March	16.41	38.16	16.33
April	27.33	39.83	26.94
May	27.68	41.83	27.37

[a)] The readings were for 8:30 am; [b)] T (temperature); [c)] RH (relative humidity); [d)] AH (air humidity).

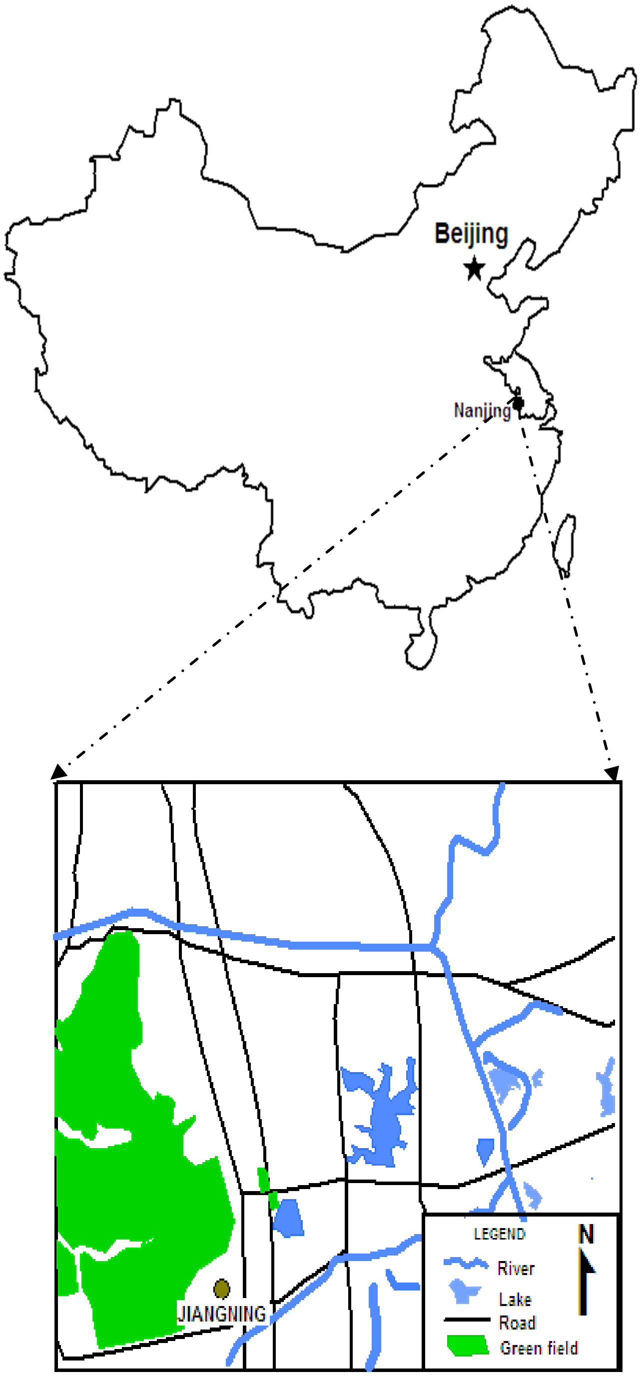

Figure 1: Map of China showing the location of the experimental site.
Source: Map.aspx.

RESULTS

Irrigation water used

Table 2 shows the **Irrigation water used** for different treatments during the growing of wheat. Mulch has reduced the amount of water needed to grow wheat under full irrigation, mild and severe treatments. The **Irrigation water used** was higher for no mulch no stress treatments (248.57 mm) compared with plus mulch no stress (212.71 mm). Similar pattern was observed under mild and severe treatments (Table 2).

Effect of treatment on number of tillers and plant stem diameter

Figures 2 and 3 showed the number of tillers and plant stem diameter of the six treatments. Mulch significantly ($p<0.5$) affects number of tillers at 40, 60 Days After Sowing (DAS) and at 40, 60 and 80 DAS for plant stem diameter. However, water and the interaction of mulch and water have no significant effect on plant stem diameter during the whole growing period of wheat.

Effect of treatment on plant height and number of leaves

Figures 4 and 5 showed the plant height and number of leaves of the six treatments.

Water application significantly affect plant height at 40, 60 Days After Sowing (DAS) and number of leaves at 60, 120, 140 DAS (Figures 3 and 4). After water recovery, mild stress treatment has the highest plant height (93.20 cm). Mulch significantly ($p<0.5$) affects number of leaves at 60 and 80 DAS. Plant height are positively correlated with number of leaves except at 100 DAS ($r = 0.228$).

Effect of treatment on plant biomass, harvest index and harvest ratio

Mean shoot biomass, grain yield, harvest index and harvest ratio for various treatments are presented in Table 3. Mulch increases shoot biomass by 4.49, 10.38 and 10.29% under full irrigation, mild and severe stress respectively. While for grain yield, an increase of 0.98%, 16.42% and 24.32% was observed for full irrigation, mild and severe stress respectively. The lowest harvest ratio (0.43) was obtained under no mulch plus mild stress treatment and the highest harvest ratio (0.47) was obtained under plus mulch plus severe stress treatment. Similar pattern was observed for harvest ratio.

Table 2: Irrigation water used in millimeter for different treatments during the growing of winter wheat.

Date	Treatments [a]					
	-M-S	**+M-S**	**-M+S1**	**+M+S1**	**-M+S2**	**+M+S2**
November 20	23.70	23.70	23.70	23.70	23.70	23.70
December 25	29.62	23.40	10.66	19.55		
January 22	11.85	15.40				
March 14	50.37	41.18	45.33	40	40.29	34.96
April 2	54.22	40.59	43.85	34.96	33.18	32.59
April 11	27.85	25.48	21.62	17.48	21.33	18.66
April 22	50.96	42.96	43.55	34.96	41.77	40
Total	248.57	212.71	188.71	170.65	160.27	149.92

[a] –M-S (no mulch no stress); +M-S (plus mulch no stress); -M+S1 (no mulch plus mild stress); +M+S1 (plus mulch plus mild stress); -M+S2 (no mulch plus severe stress); +M+S2 (plus mulch plus severe stress).

Effect of treatment on yield and yield components of winter wheat

Results show that mulch reduces the spike length of wheat irrespective of water application (Table 4). Under full irrigation and slight stress, mulch reduce grain number per spike, grain weight per spike and thousand grain of wheat. A decrease of 17.35% in number of grain per spike was observed under mild stress with mulch application. The watering pattern significantly ($p<0.5$) affects thousand grain weights (Table 4).

There is a significant positive correlation between spike length and number of grain per spike ($r=0.928$) and between number of grain and weight of grains ($r=0.902$) (Table 5). Weight of grains are also significantly correlated with grain number per spike ($r=0.967$). This suggests that these variables have important effect on yield formation.

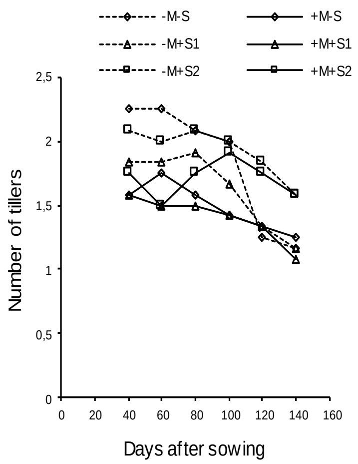

Figure 2: Number of tillers in response to varying treatments.
–M-S (no mulch no stress); +M-S (plus mulch no stress); -M+S1 (no mulch plus mild stress); +M+S1 (plus mulch plus mild stress); -M+S2 (no mulch plus severe stress); +M+S2 (plus mulch plus severe stress).

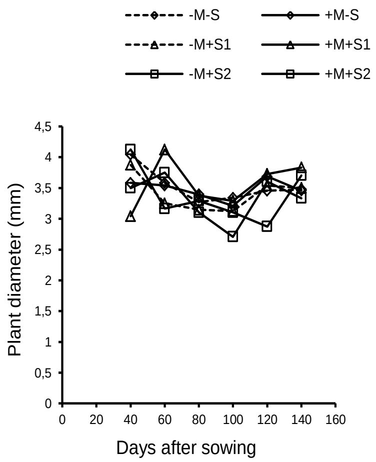

Figure 3: Plant diameter in response to varying treatments.
–M-S (no mulch no stress); +M-S (plus mulch no stress); -M+S1 (no mulch plus mild stress); +M+S1 (plus mulch plus mild stress); -M+S2 (no mulch plus severe stress); +M+S2 (plus mulch plus severe stress).

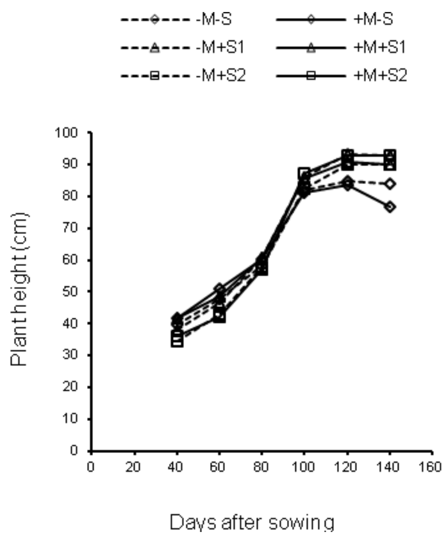

Figure 4: Plant height of wheat in response to varying treatments.
–M-S (no mulch no stress); +M-S (plus mulch no stress); -M+S1 (no mulch plus mild stress); +M+S1 (plus mulch plus mild stress); -M+S2 (no mulch plus severe stress); +M+S2 (plus mulch plus severe stress).

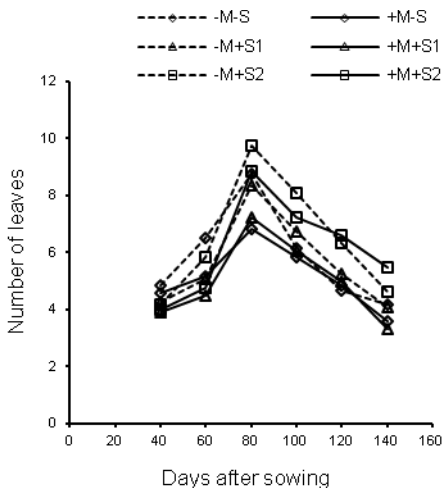

Figure 5: Number of leaves of wheat in response to varying treatment.
–M-S (no mulch no stress); +M-S (plus mulch no stress); -M+S1 (no mulch plus mild stress); +M+S1 (plus mulch plus mild stress); -M+S2 (no mulch plus severe stress); +M+S2 (plus mulch plus severe stress).

Table 3: Total biomass, grain yield and harvest index of winter wheat.

Treatments [a)]	Shoot biomass (kg/ha)	Grain yield (kg/ha)	Total biomass (kg/ha)	Harvest index	Harvest ratio
-M-S	3164.45	2603.26	5767.70	0.45	0.82
+M-S	3306.67	2628.74	5935.41	0.44	0.79
-M+S1	4294.82	3228.52	7523.33	0.43	0.75
+M+S1	4740.74	3758.76	8499.50	0.44	0.79

-M+S2	3266.67	2556.50	5823.17	0.44	0.78
+M+S2	3602.96	3178.25	6781.22	0.47	0.88

[a] –M-S (no mulch no stress); +M-S (plus mulch no stress); -M+S1 (no mulch plus mild stress); +M+S1 (plus mulch plus mild stress); -M+S2 (no mulch plus severe stress); +M+S2 (plus mulch plus severe stress).

Table 4: Yield and yield components of winter wheat under treatments.

Treatments [a]	**Yield components of winter wheat [b]**				
	GY (kg ha^{-1}) [c]	**LS (cm) [c]**	**NG [c]**	**GWPS (g) [c]**	**TGW (g) [c]**
-M-S	3164.445 a	9.080 a	35.133 a	1.659 a	46.582 a
+M-S	3306.667 a	8.980 a	34.440 a	1.602 a	45.709 a
-M+S1	4294.815 b	9.097 a	36.700 a	1.651 a	44.624 a
+M+S1	4740.741 b	8.953 a	30.333 a	1.453 a	45.743 a
-M+S2	3266.667 a	9.087 a	35.667 a	1.568 a	43.745 b
+M+S2	3602.963 a	8.940 a	35.767 a	1.602 a	44.634 b

[a] –M-S (no mulch no stress); +M-S (plus mulch no stress); -M+S1 (no mulch plus mild stress); +M+S1 (plus mulch plus mild stress); -M+S2 (no mulch plus severe stress); +M+S2 (plus mulch plus severe stress). [b] GY, grain yield; LS, length of spike; NG, number of grain per spike; GWPS, grain weight per spike; TGW, thousand grain weight. [c] Different letters denote significant differences between treatments at $p < 0.05$.

Table 5: Correlation analyses between spike length, grain number per spike and grain weight of wheat.

	Parameters		
Parameters	**Spike length**	**Grain number/spike**	**Grain weight**
Spike length	1000	0.928**	0.902**
Grain number/spike	0.928**	1000	0.967**
Grain weight	0.902**	0.967**	1000

** Significant at the 0.01 probability level.

DISCUSSION

Compared to treatment without mulching, straw mulching has many benefits to crop production (Stagnari et al., 2014). Many researchers stated that soil amendment with organic matter provide soil with minerals elements and stimulate microbial activities and increase density of soil macrofauna (Traoré et al., 2012; Toundou et al., 2014). Chakraborty et al. (2008) indicated that mulching reduces unproductive evaporation from the soil surface, so more water is available for transpiration, which is of benefit in water limited conditions and plant water status is maintained. Similar findings were reported by Rahman et al. (2005). In the present study, we found that, mulch application has reduced the amount of water needed to grow wheat. Our findings are in line with those of Pervaiz et al. (2009) who concluded that mulch increase soil moisture contents and soil organic matter but decreased soil strength and bulk density compared to control. The higher soil moisture status indicated role of mulch in conserving the moisture in soil, though the effects between mulches varied (Chakraborty et al., 2008). Conserving water at lower depths might have been useful to crops during grain filling, even though irrigation or rainwater was not available to the crop (Li et al., 1999) and might have positive effect on yield of wheat, which is in conformity with the findings of Niu et al. (2004). It is reported that straw mulching can help to improve maize yield and yield components because it can effectively improve soil nutrient availability, increase plant growth (Fang et al., 2011) and influence soil physical and chemical properties (Jin et al., 2009). In the present study, we found that, mulch application increases shoot biomass by 4.49%, 10.38% and 10.29% under full irrigation, mild and serious stress respectively. These results corroborate the findings of Tolk et al. (1999) who reported that mulch increased grain yield by 17% and above ground biomass by 19%. Chaudhary et al. (1994) examined the effect of three rates of mulches, that is 2, 4 and 6 tones/ha and noted that mulch application appreciably improved the grain and straw yields.

The height and number of leaves of wheat were more where mulch and more irrigation water were applied because of improved availability of water contents for plant growth. These results concurred with those of Gordon et al. (2008) who found that plants cultivated on mulched soil were higher than plants from the control plot; however, treatments consisting of mulch and row covers produced significantly higher plants than treatments without row covers. Irrigation plays a vital role in vegetative growth of plant and causing improvement plant height. Findings of the present study are similar to the findings of Yazar et al. (2012) who observed highest maize plant height in full irrigation. Different irrigation regimes were found to have significant effect on the straw yield. Straw yield exhibited the tendency of increasing with the influence of irrigation levels. This might be due to the luxuriant vegetative growth in terms of plant height and number of tillers per plant. In the present study, we found that, the watering pattern significantly affects thousand grain weights. Our findings are in line with those of Singh et al. (1991) who reported that thousand grain weights varied significantly with variable number of irrigation. The application of deficit irrigation negatively responded on the plant height, subsequently reducing the grain yield (English, 2010). Hassan et al. (2016) reported that various plant growth attributes were reduced under different water stress conditions.

Conclusion

Rice straw mulch applied at the rate of 6 t/ha reduced the amount of water needed to grow wheat irrespective of the severity of stress. Mild stress at seedling stage produces higher biomass. Early growth stage water deficit induce minimal reduction on wheat yield.

Further research should consider carrying this work on the field unlike the case here where all the parameters are controlled under the ambient green house conditions.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

IA did the field work and the writing of manuscript; HAS participates in writing of manuscript; DT participates in the conception of the work; ZZY, GXP, WW participate in the conception of the work.

ACKNOWLEDGEMENTS

We are grateful to Mr Abulahi Babatundé, Bayelsa state, Nigeria for correcting this manuscript.

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