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RESEARCH ARTICLE

Smart Control of Water Flow and Depth Within Rice Field for Improving Irrigation Management and Mitigating Methane Emission.

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Abstract

A two-year field experiments were carried out at the Experimental Farm of the Central Laboratory for Agricultural Climate, Agriculture Research Center, Egypt during 2015 and 2016 successive rice seasons. such investigation aimed to study the productivity and CH_4 emission capacity of two Egyptian rice varieties (Sakha101 and Sakha106) under different irrigation water depths (4, 8 and 12 cm) from the soil surface. Innovated siphon container were connected to a water valve to maintain the continually of the water head at the desired depths. The water depth treatments were laid out in a randomized complete block design with four replications for each variety in both seasons. A combined analysis was used between the two varieties in each season to interpret the data. Plant height cm, root length cm and chlorophyll SPAD at 30 and 55 days after transplanting, panicle length cm, number of tillers m^{-2}, number of grains $panicle^{-1}$, number of unfilled grains $panicle^{-1}$, 1000-grain weight, grain yield t ha^{-1}, straw yield t ha^{-1} and harvest index were recorded. Methane fluxes were measured by using closed chamber method. Water depth affected significantly all studied characteristics. The maximum values of most of the studied characteristics were recorded at 8 cm water depth. On the other hand, the lowest values were observed at 12 cm water depth. CH_4 emission was dramatically reduced by decrease the water depth. There was significant correlation coefficient between methane emission and all studied agronomic characteristics except 1000-grain weight and harvest index. The methane emission from rice fields decreased significantly with the increase of plant growth and yield. Irrigation water depth at 8 cm seem to be the recommendable treatment to achieve the promising rice yield and methane mitigation value.

Introduction:-

Egypt is facing limited water resources, according to fast increase of population growth and its corresponding economic activities which caused a reduction in the per capita share of the limited fresh water resources. Rice crop is one of the major cereal crops feeding the Egyptian population. All of the rice areas in Egypt are under lowland

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irrigated rice. These rice areas require a large amount of irrigation water. Most of the rice farmers think that increasing water depth in their rice fields up to maximum level will reflect directly on rice grain yield irrespective to these hazardous side effect on environmental system. Talpur *et al.* (2013) reported that the maximum plant survival and tallest average plant height were recorded in 5 cm water depth compared to 10, 15 and 20 cm from cultivation till to mid stage of growth. The maximum water depth of 20 cm produced the shortest root, while 5 cm produced the longest root. The weight of 1000 grains has more affected by a deeper water depth as compared to shallower water depth but the total yield was opposite of these. It was observed that the number of grains loss due to excessive water depth has an adverse impact as compared to deficient water depths.

Kima *et al.* (2014) indicated that water reductions at the vegetative stage delayed plant growth and affected grain filling rate and 1000-grain weight, but the recovery process induced by effective rainfall contribution was such that grain yield was not affected. In water scarcity context, applying 180% of soil saturation water seems suitable for increasing both rice production and irrigation water productivity in tropical climate conditions. They argue that, rather than the daily application of the small amount of water, saturated soil culture practice can be adopted in the specific agro-climatic zone by adjusting the irrigation water depth according to the irrigation intervals. Weekly application of a 3 cm water depth above soil surface can be recommended to farmers as an alternative to save irrigation water, time, energy, and increase outputs.

Methane is the second most important culprit of GHGs. Its emissions rose by about 40% from 1970, with an 85% increase from the combustion and use of fossil fuels. Agriculture, however, is the largest source of CH_4 emissions (Aulakh *et al.,* 2001). Agricultural lands (used for agricultural production, managed grassland and permanent crops including agro-forestry and bio-energy crops) occupy about 40-50% of the Earth's land surface and release a significant amount of CO_2, CH_4, and N_2O in atmosphere (Cole *et al.,* 1997; IPCC, 2001and Paustian *et al*., 2004). Agriculture accounts for 10-12% of total global anthropogenic emissions of GHGs. This sector contributes about 47% and 58% of total anthropogenic emissions of CH_4 and N_2O, respectively, with a wide range of uncertainty in the estimates of both the agricultural contribution and the anthropogenic total. Globally, agricultural CH_4 emission increased by 17% from 1990 to 2005, an average annual emission increase of 58 Mt CO_2-eq yr^{-1}. Methane is produced when organic materials are decomposed anarobically. Water management practices have a strong influence on the processes involved in CH_4 emission from rice paddy fields. The presence of surface standing water is essential for the development of the anaerobic conditions in paddy soil by limiting the transport of atmospheric oxygen into the soil. In the Japanese rice cultivation; short-term floodwater drainage is commonly performed to aerate the paddy soil during the flooding period to prevent some negative effects of soil reduction on the growth of rice plant. Yagi and Minami (1990) detected a decrease in CH_4 emission rates during the period of midsummer drainage in Japanese rice paddy fields. Sass *et al.* (1992) demonstrated that CH_4 emission rates varied markedly with water regime, showing the lowest emission with multiple intermittent draining practices.

Zheng Bing-song, *et al.* (2006) reported that water deficiency is one of the primary yield-limiting factors in rice. Different rice genotypes showed different relative root parameters and relative nutrition content and water use efficiency under different water supply conditions (0 cm (submerged), 40 cm and 80 cm groundwater levels below the soil surface). The length and number of adventitious root are more important than seminal root length in water and nutrition uptake, and maintaining the grain yield and increasing dry matter, but the adventitious root number could not be served as an index for screening drought-resistant genotypes.

the main target of this work was to throw light on the role of irrigation water depth in rice field in mitigating methane emission in relation to growth, yield and yield components of rice crop.

Materials and Methods:-

Two years field experiment were carried out at the Experimental Farm of the Central Laboratory for Agricultural Climate, Agriculture Research Center, Egypt during 2015 and 2016 successive rice seasons. such experments were conducted to study the performance of two rice varieties (Sakha101 and Sakha106) under different irrigation water depths (4, 8 and 12 cm) from the soil surface. Irrigation water depths were kept using a smart control flow system (Fig. 1). Innovated siphon container were connected to a water valve and flow meter to maintain the continually of the water head at the desired depths under low pressure. The depths of water were controlled in each replicate through a perpendicular wires installed over the container of the siphon that poise by water balance. The water depth treatments were laid out in a randomized complete block design with four replications for each variety in both

seasons. A combined analysis was used between the two varieties in each season to interpret the data. Correlation analysis was done by Pearson correlation coefficient method using the PC software SPSS Ver. 14.
Seeds of the two varieties were soaked in water for 24 hours before sowing the nursery, then drained and incubated for 48 hours to hasten the germination. Pre-germinated seeds were uniformly broadcasted in the nurseries on 1^{st} and 3^{rd} of May in the two seasons, respectively. The permanent field was well prepared. Seedlings were carefully pulled form nursery after 25 days from sowing and transferred to the permanent field. Seedlings were handly transplanted in hills at the rate of 2-3 seedlings $hill^{-1}$ and at the spacing of 20x20 cm between hills and rows. The plot size was 12 m^2 (2×6m). The all recommended cultural practices were applied for each variety.
The studied growth characteristics were plant height (cm), root length (cm) and chlorophyll SPAD at 30 and 55 days after transplanting. Chlorophyll meter (model SPAD-502, MINOLTA, Japan) was used to determine the leaves chlorophyll content. The studied yield attributes traits were panicle length (cm), number of tillers m^{-2}, number of grains $panicle^{-1}$, number of unfilled grain $panicle^{-1}$, 1000-grain (g) weight, grain yield (t ha^{-1}), straw yield (t ha^{-1})and harvest index.
Methane fluxes were measured by using closed chamber method. This measurement system was a modified version of the system originally described by Schutz *et al*.,1990. For the measurements, an air-tight acrylic glass chamber (15 cm in diameter and 1 m high) was carefully placed on the wood frame. One day before the recording of CH_4, this wooden frame was placed at a randomly selected measuring site inside each plot. In each replicate, two chambers were inserted into the soil after flooding. The closure period was 1 h, during which two gas samples from inside the chambers were taken at 30 min intervals. Methane emission was measured at 8.00–10.00 am and at 15.00–17.00 pm, and the average value was used as the flux value for the day. Methane emission rates were recorded after 65 days of transplanting. Average air temperature (32°C) was recorded just before measuring the CH_4 emissions. Methane concentration in the sampled air was measured using a FID-GC (Shimadzu GC-14APF).
Statistical analysis: The analysis of variance by means of "MSTATC" computer software package was carried out as combined analysis for the two varieties in each season according to Gomez and Gomez (1984).

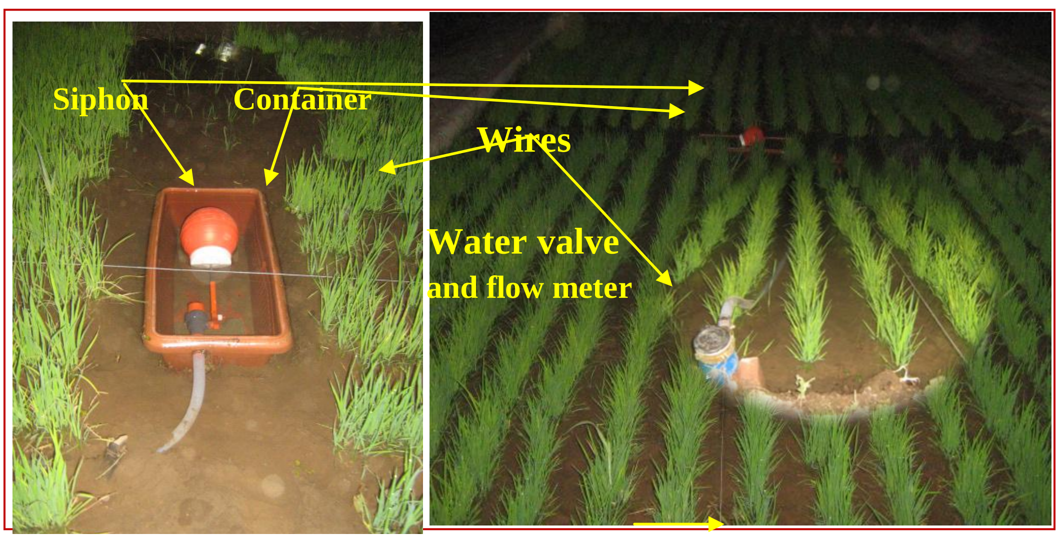

Fig 1. Smart control of irrigation water flows to experimental plots.

Results and Discussion:-

Plant height at 30 and 55 DAT was varied significantly among different treatments combinations (Tables 1 and 2). At 30 DAT, the highest values of plant height were recorded when irrigation water was kept at 4 cm in depth for the two varieties. On the other hand, 8 cm water depth recorded the tallest plants at 55 DAT. These results were true in both the experimental seasons of 2015 and 2016 are in harmony with those of Talpur *et al*. (2013) and Kima *et al*. (2014).

Table 1. Plant height (cm), root length (cm) and leaf chlorophyll content (SPAD) of the two rice varieties at 30 DAT as affected by water depth treatments.

Treatments		Plant height cm		Root length cm		Chlorophyll SPAD	
Variety	Water depth cm	2015	2016	2015	2016	2015	2016
Sakha 101	4	51.50a	49.44b	12.36ab	12.36ab	33.99ab	32.96a
	8	49.44b	45.32d	8.24c	8.24c	32.96b	30.90b
	12	43.26d	45.45d	8.19c	8.79c	29.77c	30.88b
Sakha 106	4	51.50a	51.50a	13.39a	12.36ab	35.02a	33.99a
	8	47.38c	47.38c	10.30bc	10.30bc	33.99ab	30.90b
	12	48.41c	48.41bc	9.79c	8.76c	30.90c	29.87b

Means of each column designated by the same letter are not significantly different at 5% level using Duncan's multiple range test.

Table 2. Plant height (cm), root length (cm) and leaf chlorophyll content (SPAD) of the two rice varieties at 55 DAT as affected by water depth treatments.

Treatments		Plant height cm		Root length cm		Chlorophyll SPAD	
Variety	Water depth cm	2015	2016	2015	2016	2015	2016
Sakha 101	4	76.22cd	71.07c	17.51c	18.54b	42.23b	41.20bc
	8	83.43ab	78.28b	19.67b	19.57ab	44.21ab	43.26ab
	12	71.07e	67.68d	12.36e	13.39c	38.11c	38.11d
Sakha 106	4	80.34bc	78.28b	19.57b	18.54b	43.26ab	41.20bc
	8	86.52a	82.40a	21.66a	20.59a	44.99a	44.77a
	12	74.16de	73.13c	14.49d	14.42c	39.14c	39.14cd

Means of each column designated by the same letter are not significantly different at 5% level using Duncan's multiple range test.

In both seasons the length of rice roots showed significant differences with the water depths for both varieties (Tables 1 and 2). The longest length of root was measured in 4 cm water depth at 30 DAT and in 8 cm water depth at 55 DAT. Increasing water depth to 12 cm decreased root length significantly. Obvious reduction in either plant height or root length of rice plant grown in depth (12cm) at 30 and 55 DAT could be attributed to the deleterious impact of poor aeration on plant -water-soil relation and their address effects on growth criterion of rice plant. These results are in harmony with Zheng Bing-song *et al*. (2006), Talpur *et al.* (2013) and Kima *et al.* (2014). De Datta (1981) emphasized that extremely deep water resulted in poor growth and yield. Roots were deeper in Sakha106 compared to Sakha101. Ascha *et al.* (2005) reported that plant becomes adapted to water deficiency through the possession of pronounced root system, which maximizes water capture and allows access to water at depth.

Application of various water depths in rice varieties showed a significant impact on leave chlorophyll content at 30 and 55 DAT as shown in Tables 1 and 2. Chlorophyll content at 30 DAT decreased gradually by increasing water depth from 5 up to 12 cm while, at 55 DAT the highest values were recorded at 8 cm water depth for both varieties. Chlorophyll content in Sakha 106 was slightly higher than those in Sakha101. Kima *et al.* (2014) found a similar trend and reported that under shallow water depth, plants reduced evapotranspiration that led photosynthesis decrease which in turn induced chlorophyll decrease.

In both seasons panicle length was affected significantly by different treatments (Table 3). The longest panicles were observed when 4 cm water depth was applied either to Sakha101 or to Sakha106. Number of tillers per meter square was affected significantly by different water depth. Application of 8 cm irrigation water depth to Sakha101 recorded the highest number of tillers followed by the same water depth to Sakha106. Data in Table 3 showed also that water depth treatments affected significantly number of grain per panicle. Sakha101 at 8 cm water depth produced the highest number of grains per panicle followed by Sakha106 at the same depth. All above mention results were fact in either 2015 or 2016 experimental seasons. Similar trend was found by Talpur *et al.* (2013) and Kima *et al.* (2014).

Table 3. Panicle length (cm), number of tillers m^{-2}, number of grains/panicle and number of unfilled grains of the two rice varieties as affected by water depth treatments.

Treatments		Panicle length cm		No of tillers m^{-2}		No of grains panicle^{-1}		No of unfilled grains panicle^{-1}	
Variety	Water depth cm	2015	2016	2015	2016	2015	2016	2015	2016
Sakha 101	4	22.66a	21.63a	249.5b	241.3c	121.11b	114.82c	12.27c	18.76b
	8	21.63a	19.57b	272.2a	253.7a	148.30a	144.87a	20.81b	21.58ab
	12	16.48c	15.45c	224.5c	206.3e	106.79c	96.46d	27.07a	22.02a
Sakha 106	4	21.01a	18.54b	240.0b	226.6d	105.06c	112.96c	4.90f	2.61e
	8	19.02b	16.48c	259.6b	243.1bc	118.45bc	123.60b	8.51e	9.69d
	12	14.42d	12.36d	216.3c	203.9e	93.42d	88.58d	13.66d	19.23c

Means of each column designated by the same letter are not significantly different at 5% level using Duncan's multiple range test.

Number of unfilled grains per panicle varied significantly according to water depth treatments (Table 3). Unfilled grains per panicle increased significantly with the increase in water depth for both varieties. The highest number of unfilled grains per panicle was measured at 12 cm water depth by Sakha101 rice variety followed by 8 and 4 cm by Sakha101. Meanwhile 1000-grain weight was affected significantly by water depth treatments (Table 4). Shallow water depth recorded highest values of 1000-grain weight. these results are fairly true in both the two seasons.

Water depth affected significantly grain yield as presented in Table 4. The maximum values of grain yield were recorded by Sakha106 at 8 cm water depth. On the other hand, the lowest values of grain yield were observed by Sakha101 at 12 cm water depth. This is agreed with results obtained by Talpur *et al.* (2013) and Kima *et al.* (2014). Reduction in rice grain yield under 12cm depth treatment in both cultivars and in both seasons could be attributed to the reduction in number of tiller/m2, number of grains/ panicle and the increase in number of unfilled grains/panicle (Table 3) as well as the decrease in 1000-grain weight (Table 4). It can be assumed that the increase in water depth up to 12cm caused a bad aeration conditions around root and shoots of rice plant. Adequate oxygen supplies are necessary to respiration and other essential physiological processes of plant and consequently rice yield and its components of deep water level plots was decreased. Sahka106 produced higher grain yield than Sakha101. This might be due to the substantial yield losses by the large percentage of unfilled grains in Sakha101.

Table 4. Thousand-grain weight (g), grain yield(t ha^{-1}), straw yield (t ha^{-1}) and harvest index of the two rice varieties as affected by water depth treatments.

Treatments		1000-grain weight		Grain yield t ha^{-1}		Straw yield t ha^{-1}		HI	
Variety	Water depth cm	2015	2016	2015	2016	2015	2016	2015	2016
Sakha 101	4	27.78ab	27.10bc	8.63d	8.46d	12.10cd	11.91b	0.416b	0.415c
	8	29.23a	28.93a	9.19bc	9.11bc	12.45c	12.25b	0.425a	0.426a
	12	26.63b	26.63c	7.63e	7.35e	11.44d	10.57c	0.400d	0.410d
Sakha 106	4	27.15b	27.60bc	9.58b	8.63cd	13.66a	12.08b	0.412c	0.417bc
	8	28.08ab	27.99ab	10.46a	10.26a	14.19a	13.73a	0.424a	0.428a
	12	26.80b	26.55c	8.88cd	8.17d	12.44c	11.38c	0.417b	0.418b

Means of each column designated by the same letter are not significantly different at 5% level using Duncan's multiple range test.

Straw yield was affected significantly by water depth treatments (Table 4). Sakah106 at 8 cm water depth produced the highest value of straw yield. Harvest index showed significant difference with the water depths used in this study. The maximum values of harvest index were measured at 8 cm water depth whatever the variety.

Methane emission values obtained under the three water depths in the two experimental seasons are presented in table 5. Methane flux ranged from 0.288-0.597 and 0.278-0.566 mg m^{-2}hr^{-1} in both seasons respectively. There was a significant differences in CH_4 emission values among water depths. Available results in Table 5 clear that methane emission values were increased as irrigation water depth increased. increasing water depth from 4cm to 8cm and 12cm level increase CH_4 emission from Sakha 101 plots by 28.6 and 107.1 % respectively in 1st season and by 9.4 and 89.6% in the second one. Analogous values for Sakha 106 cultivars plots were 17.9 and 89.37 % in 2015 and 14,9 and 92.6 % in 2016 season, respectively. There for, management of irrigation water level in rice fields can be used as a smart tool for mitigating CH_4 emission in irrigated paddy field. Variation in CH_4 emission rate was also detected between the two investigated cultivars. Sakha 101 plots emitted more CH_4 (2.448 mg/m^2/ha) as a total of the two seasons comparing with 2.307 mg/m^2/ha for Sakha 106. Our data showed, CH_4 emission was dramatically reduced by decrease the water depth wherein, suitable water management practice can be established by assessing appropriate controlling the irrigation and flow rate to reduce CH_4 emission with any adverse effects on yield and soil fertility. These results confirm the phenomena that the aeration under 3 cm water depthin paddy soil led to decrease methane emission. However, under 12 cm of water depth, reduction condition was prevailing which provide a good condition to emit more methane than under oxidized zone. Genotypic differences in the emission of methane from rice paddies are reported also by Nirmali Gogoi *et al.* (2008).

Table 5. Methane emission as affected by rice verities and water depth treatments.

Treatments		Methane mg m^{-2} hr^{-1}	
Variety	Water depth cm	2015	2016
Sakha 101	4	0.2884d	0.2987c
	8	0.3708b	0.3269b
	12	0.5974a	0.5665a
Sakha 106	4	0.2884d	0.2781d
	8	0.3399c	0.3196b
	12	0.5459a	0.5356a

Means of each column designated by the same letter are not significantly different at 5% level using Duncan's multiple range test.

Regarding the correlation coefficient between methane emission and the studied agronomic characteristics, data in Table 6 revealed that there was significant correlation coefficient between methane emission and all studied agronomic characteristics except 1000-grain weight and harvest index. The correlation coefficient was highly significant and positive between methane emission and number of unfilled grain per panicle. On other hand, it was highly significant and negative between methane emission and each of chlorophyll content SPAD at 30 DAT, root length at 55 DAT, chlorophyll content SPAD at 55 DAT, panicle length, number of tillers per m^2 and straw yield. The correlation coefficient was significant and negative between methane emission and each of plant height at 30 and 55 DAT, root length at 30 DAT, number of grains per panicle and grain yield. These results demonstrated that methane emission from rice fields decreased significantly with the increase in the rice plant growth and yield. Denier *et al.* (2002) and Ali *et al.* (2009) reported similar trend.

Table 6. Correlation coefficient between methane emission and agronomic characters.

Characters	Methane
Plant height at 30 DAT	-0.650*
Root length at 30 DAT	-0.681*
Chlorophyll SPAD at 30 DAT	-0.782**
Plant height at 55 DAT	-0.619*
Root length at 55 DAT	-0.883**
Chlorophyll SPAD at 55 DAT	-0.817**
Panicle length	-0.779**
Number of tillers m^{-2}	-0.741**
Number of grains panicle^{-1}	-0.626*
Number of unfilled grains panicle^{-1}	0.855**
1000-grain weight	-0.522
Grain yield	-0.595*
Straw yield	-0.726**
HI	0.172

*Correlation is significant at the 0.05 level (2- tailed).
** Correlation is significant at the 0.01 level (2- tailed).

Conclusion:-

Rice yield and CH_4 emission were positively affected significantly by irrigation water depth. Methane emission was dramatically reduced by decrease the water depth. Irrigation water depth at 8cm seem to be recommendable treatment to obtain the promising rice yield and CH_4 mitigation value. There was significant correlation coefficient between methane emission and all studied agronomic characteristics except 1000-grain weight and harvest index. The methane emission from rice field decreased significantly with the increase of rice plant growth and yield.

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