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Effect of soil temperature gradient on potassium movement in controlled paddy field

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Abstract
Soil surface and subsurface temperatures create a temperature gradient in the soil environment. This temperature gradient induces a driving force for soil moisture movement from a deeper layer to the upper soil surface. Salts and plant nutrient migrate along with the soil moisture and accumulate at the surface during evaporation, and the nutrient at the surface are washed away along with the runoff causing water pollution. Hence, it is necessary to measure soil temperature, and plant nutrients spatially and temporally from paddy field experiments to investigate the effect of soil temperature gradient on potassium migration. Field experiments were conducted during Kharif 2018-19 in the rice field, without the application of fertilizer for investigating the effect of soil temperature gradient on potassium status in the paddy field. The result found a temperature gradient in the top layer was more compared to the bottom layer. Soil temperature followed the same trend to average air temperature. Depths of ponding water create an effect on soil temperature. Soil temperature decreased with increasing ponding depths. Soil potassium concentration at the surface was increased with increasing temperature gradient in the topsoil layer.

Keywords: soil temperature gradient, potassium concentration gradient, soil potassium migration, paddy field

Introduction
The nutrient concentration of surface and subsurface waters has changed into a dangerous worldwide environmental and ecological problem, which has tremendously accelerated the potential risks of the eutrophication of surface water and toxic contamination of groundwater (Bouman *et al*., 2002, Ghosh *et al*., 1998) [3, 5]. Most of the chemical fertilizer loads primarily originate from agricultural fields, especially during the rice growing seasons, in which a tremendous amount of fertilizers are utilized in crops. In paddy fields, the applied fertilizers, after dissolution, are not only transported over and infiltrate into the soil but are also diffused out and channelled in all possible directions due to the transverse variation of water velocity and depth (Sharpley and A. N., 1997, Strelkoff *et al*., 2003) [11, 12].
Precipitation and temperature are significant climatic factors in determining soil-nutrients. The study of temperature effect on soil-nutrients interactions may promote an understanding of the nature of nutrient adsorption and give information pertinent to the forecasting of nutrient transport in soil. Such information is of particular interest in arid and semiarid regions, where under irrigation, significant fluctuations in soil water content and temperature occur over short periods. The change of thermodynamic conditions drives the mass transfer and phase change in both water and soil-nutrient(Milly and P. P. D., 1984). Also, the direction of nutrient migration is an important issue for soil (Bechtold *et al*. 2011) [2]. The temperature gradient induces a driving force for soil moisture movement from a deeper layer to the upper soil surface (Lakshmi *et al*., 2003) [6]. Soil temperature has a profound effect on the organic N availability in the soil. It has been evident that soil temperature is positively correlated with the urea rate of diffusion of the urea. Urea hydrolysis in the soil accelerates with the increase in the temperature (Pang *et al*. 1977; Sadeghi *et al*. 1988) [8, 9].
Increase in the hydrolysis will lead to the more significant accumulation of nitrate in the soil immediately after the application of the fertilizer, which may be a severe concern for nitrate leaching (Agehara and Warncke, 2005, Tan *et al*., 2018) [1, 13]. To the contrary, the anaerobic mineralization of the microbial N and P increased during winter to early spring then after it declined with the rise in the temperature. The decline in microbial P and N were estimated to be 25 kg/ha P and 27 kg/ha N respectively (Sarathchandra *et al*. 1989) [10]. Soil temperature not only affects the nutrients in the soil but also impacts the plant system.

In the peat soils, the increase in the soil temperature increased the number of root tips and the elemental concentration in the roots and stems (Domisch *et al*. 2002) [4]. Therefore, the effect of temperature on water and solute transport behavior in paddy soil is required. The temperature gradient is one of the reasons for heat transfer; it can affect the nutrient migration within the soil. So, there is a need to study nutrient migration from this perspective. Understanding about the contribution of soil temperature to the loss of nutrients from the root zone, the process of soil salinization, and potential long-term pollutant movement from prairie soils to the groundwater zone is essential. The direction and amount of soilwater flow between two different locations in the soil profile can be determined from the total soil-water potentials at these locations. Soil-water potential changes according to the position, surface tension, and osmotic pressure. Surface tension and osmotic pressure both are a function of temperature. Till now very few studies were conducted on the effect of soil root zone temperature gradient on plant nutrient migration concentration at the field scale. So, an attempt was made in this study to investigate the influence of the soil matrix temperature gradient on the potassium migration in the paddy field. The specific objectives of this study are: 1) To measure soil temperature, potassium concentration from a paddy field during the growing season. 2) To investigate the effect of soil temperature gradient on potassium status.

Materials and Methods

Study Area

Field experiments were conducted in the experimental farm of the Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur (22.315377º N latitude and 87.315342º E longitude), India. The climate of Kharagpur is classified as sub humid, sub-tropical. The soil at the experimental site is an acid lateritic sandy loam and taxonomically grouped under the order alfisol and it receives an average annual rainfall of 1600mm with the occurrence of 70-75% of total rainfall in the Kharif season. The study area has an automatic weather station facility to monitor daily weather data. The paddy crop was grown at study area in since last five years.

Field Experiments

Field experiments were carried out for rice crop (short duration and high yielding rice variety of MTU1010) during Kharif 2018-19 with a dimension of 10m×10m. Before puddling, the soil was collected from the surface, 15, 35 and 75cm depth in each plot to measure the physical and chemical properties (pH, OC, EC, available K, available P, and total N) of the soil by using standard methods.

Table 1: Initial soil chemical properties in experiment plot at different depths

Depths, cm/ Parameters	EC, ms/cm	pH	OC, %	K, ppm	TKP, ppm	TKN, ppm
0	265	6.2	0.83	6.39	157.49	3.37
15	199	6.8	0.84	4.31	396.29	2.94
35	210	6.7	0.56	9.2	484.19	3.67
75	154	6.4	0.45	12.29	577.55	3.4

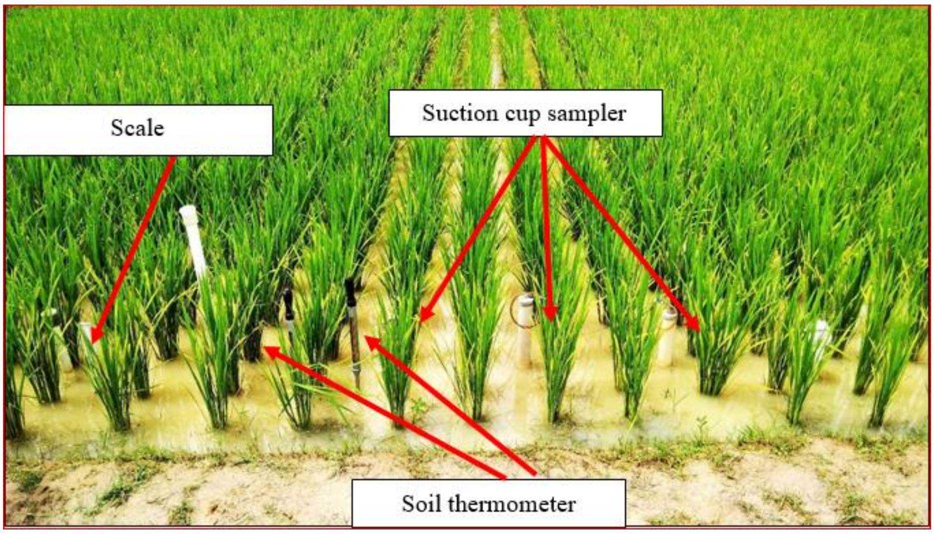

Fig 1: Different type of instruments installed in the field.

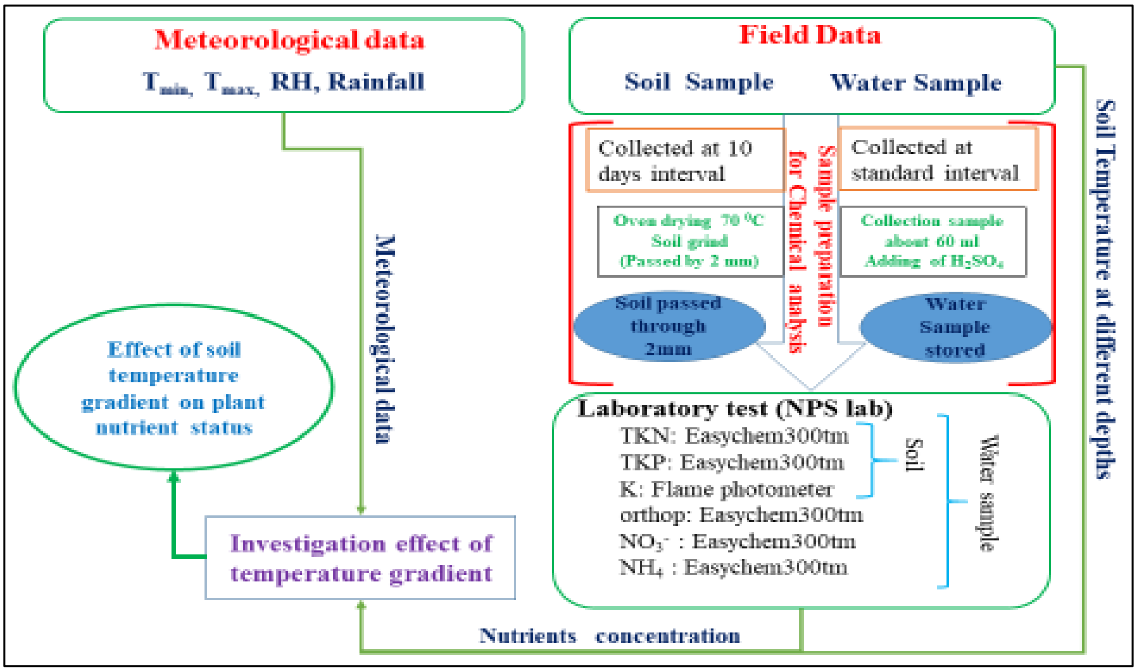

Fig 2: Flowchart for finding the effect of soil temperature gradient on plant nutrients.

In Kharif season 1st Aug 2018, 25 days old seedlings were manually transplanted in the field. At the time of transplanting, 2-3 seedlings per hill were transplanted. The crop totally depended on rainfed water and without fertilizer application. Leachate sample was collecting with the help of suction cup sampler this is installed at 15, 35 and 75 cm soil depths and from ponding water in the plot. In the plot, two piezometers have installed at 25 and 50 cm depths for measuring the pressure head at 25 and 50 cm depths. The ponding water level was measured by the installed scale in the plot. The soil temperature was measured in the plot from 15 and 75 cm soil depths by the help of installed soil thermometers at respective depths, due to their limited availability. The crop was harvested on 30th October 2018.

Data Collection

During the crop growing period the average air temperature and rainfall data were collected. The ponding water depths level was measured in every day. Soil temperature was measured from different depths on a daily basis. Water samples were collected with the help of the suction cup sampler. The suction cup is usually designed having a porous cup at the end of the PVC pipe that is sealed at the top. There is usually one sampling tube attached to the sealed end of a PVC pipe for collecting samples and creating a negative pressure inside the suction cup. The water samples were collected from different depths, daily for the first week, every two days for the second week, every three days for the third week after 20 days this cycle was repeated. Whereas, soil samples were collected at every 10 days' interval from the surface,15±2.5, 35±2.5 and 75±2.5 cm soil depths in throughout the crop growing period.

Sample Analysis

First of all the collected soil samples were oven dried at 70 °C for 24 hr. The oven dried samples were ground and passed through a sieve of 2 mm size. The ground soil samples were then used for nutrient analysis such as total available potassium. Total potassium available in soil was analyzed by the Flame Photometer using the standard method provided by the manufacturer. Total potassium available in leachate sample was analyzed by the flame photometer. For that analysis, the standard method was followed.

Data Analysis

Temperature variation: The variation in soil temperature at different depths in Kharif season was graphically analyzed. analyzed the effect of average air temperature and ponding water depths on soil temperature at various depths. *Soil temperature gradient*: analyzed the effect of average air temperature and ponding depths on the soil temperature gradient. It was shown the relative variation of soil temperature between different depths. The soil temperature gradient between two different soil layers was calculated according to the below equation.

$$\text{Temperature gradient} = \frac{\Delta T}{\Delta x},\ °\text{C/cm}$$

Where:
ΔT = temperature difference between two soil layer, °C
Δx= distance between two soil layer, cm

Effect of temperature gradient on potassium concentrations: graphically analysed the variation in plant macronutrient gradient with a soil temperature gradient. Calculation of plant nutrient concentration gradient between two different soil layer according to the below equation.

$$\text{Nutrient concentration gradient} = \frac{\Delta C}{\Delta x},\ \text{ppm/cm}$$

Where:
ΔC = nutrient concentration difference between two soil layer, ppm
Δx= distance between two soil layer, cm

Results and Discussion

Soil Temperature Variation in Kharif 2018

Figure 3, shows the variation of the soil temperature with the average air temperature. From the figure, it can be observed that soil temperature is following the same trend as the average air temperature. Soil temperature was higher than the average air temperature. This might be due to induced radiation and the internal soil system processes. The depth of standing water has affected the soil temperature at both depths (15 cm and 75 cm). It was observed that there was a decrease in the soil temperature with an increase in the depth of standing water. The dry spots (no rainfall or no ponding) of water was increased the soil temperature. The average air temperature was varying from 22 to 28 °C. Soil temperature at 15 and 75 cm depths vary from 27-33 and 26-31.5 °C respectively.

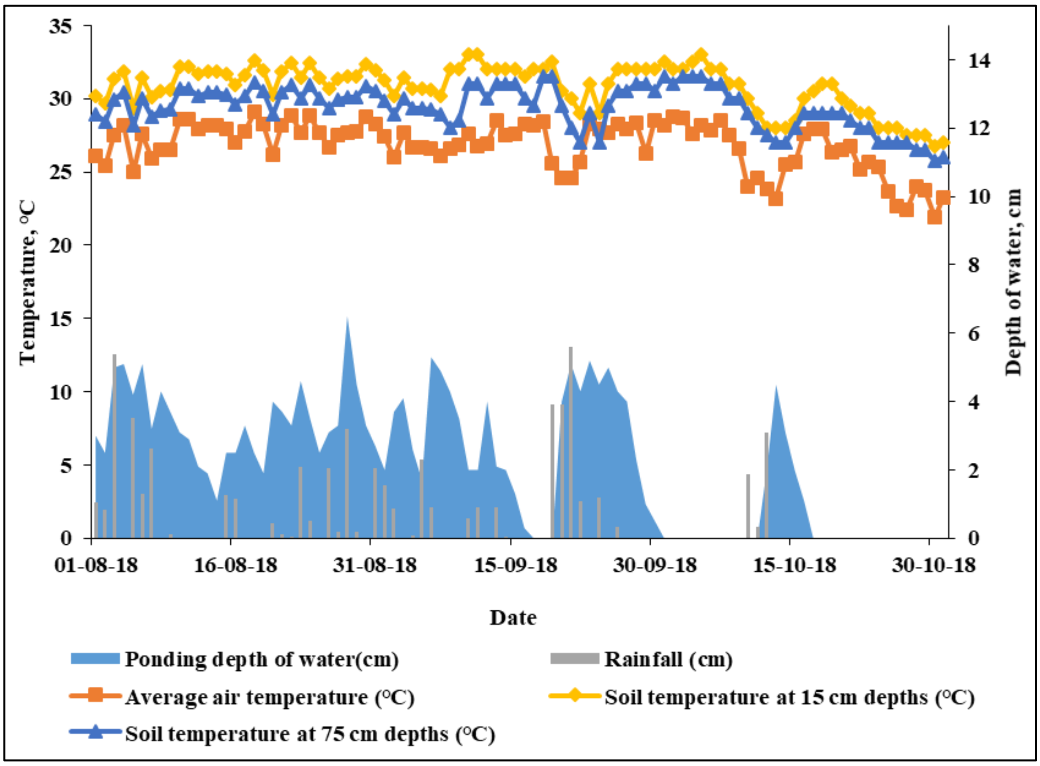

Fig 3: Soil temperature variation with average air temperature in the rainfed plot.

Soil Temperature Gradient Variation in Kharif 2018

Figure 4 shows the variation of the soil temperature gradient at different depths of the soil in the Kharif season in the rainfed plot. From the figure, it can be observed that the top 15 cm depth has the highest temperature gradient; varying from 0.07 to 0.46 °C /cm. Soil layer between 15-75 and 0-75 cm depths has a temperature gradient of -0.066 to 0.018 and -0.012 to 0.078 °C/cm respectively. The temperature gradient below 15 cm was relatively constant during the Kharif season may be due to the shallow water table during the Kharif. The soil temperature gradient in the top 15 cm was increased with rainfall, which indicates the temperature of 15 cm depth soil layer has more temperature than the soil surface.

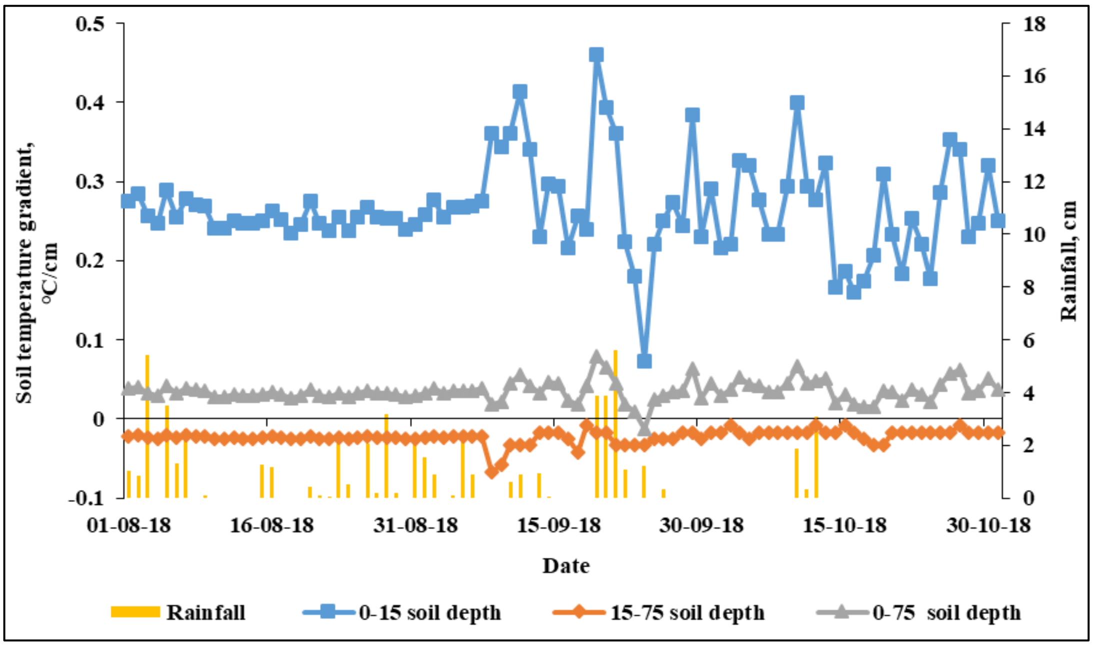

Fig 4: Soil temperature gradient variation in the rainfed plot.

Available soil potassium concentration variation in Kharif 2018

Figure 5 shows the variation of available soil potassium concentration gradient in different soil layers with the temperature gradient. Soil K gradient was negative and higher in magnitude in the topsoil layer. The higher K magnitude is in response to the higher temperature gradient in the topsoil layer. The K concentration gradient was relatively constant, and this may be due to the constant temperature gradient in the lower soil layers. Negative K concentration gradient indicates the K concentration was higher in the top layer relative to the bottom layer.

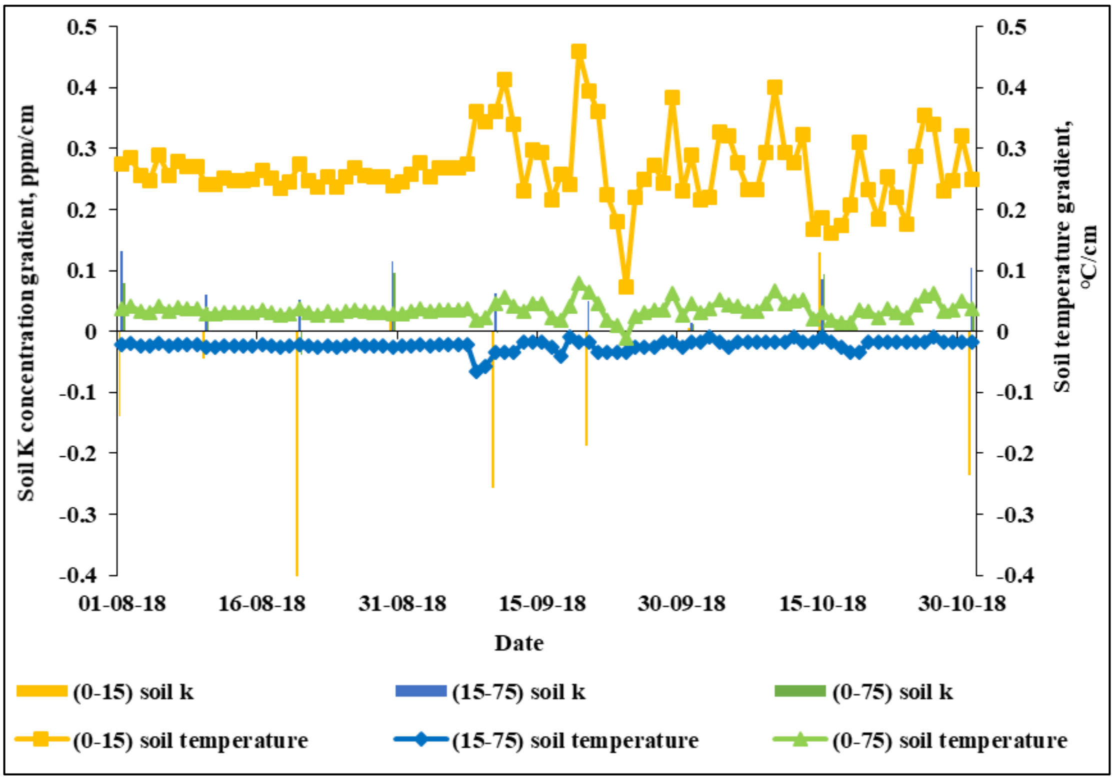

Fig 5: Available soil potassium concentration gradient at different soil layer in the rainfed plot.

Potassium Concentration Gradient Variation in Leachate sample

Figure 6, shows the variation of potassium concentration gradient in the leachate with temperature gradient in the rainfed plot at different depths. Variation in the K concentration gradient in the topsoil layer was high (-0.15 to 0.212 ppm/cm). Variation in K concentration gradient did not follow any trend with a temperature gradient. Leachate K concentration at the surface also depends on rainfall. The K concentration gradient in the other layer was very less.

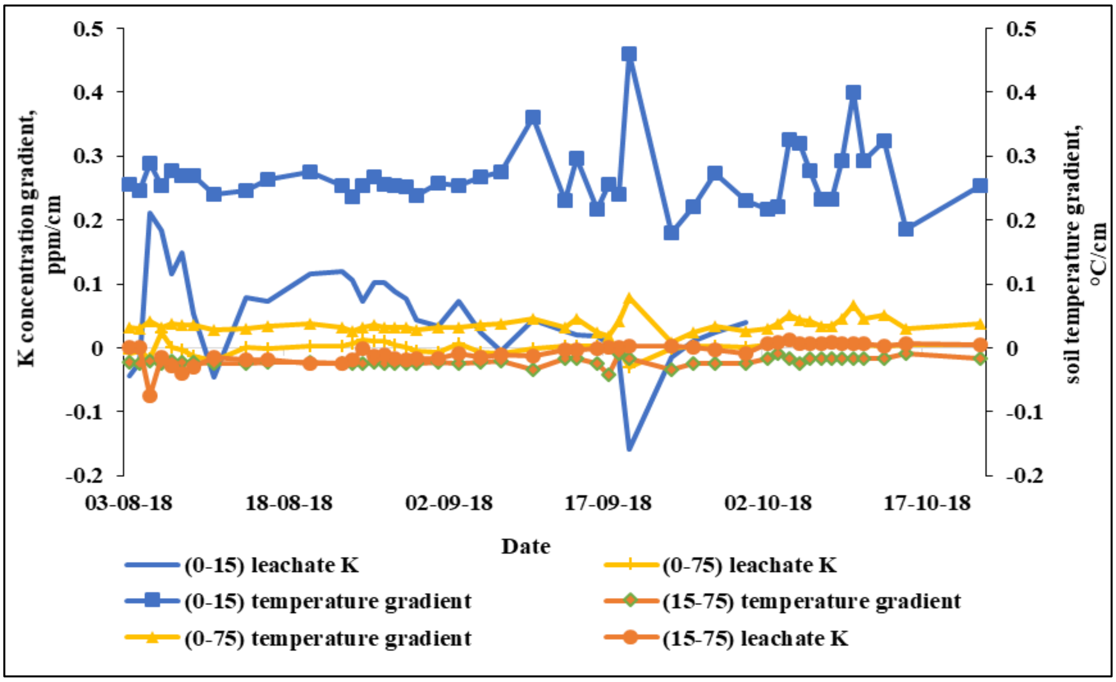

Fig 6: Variation of leachate potassium concentration gradient with temperature gradient in the rainfed plot.

Conclusions

The main aim of the present study was to investigate the effect of the soil thermal gradient on the movement of the potassium in the soil. Field experiments were carried out for rice crop. Soil temperature followed the average air temperature trend in crop growing period seasons. Soil temperature was more than the average air temperature in the Kharif season. The soil temperature gradient between the top layer (0 to 15 cm depths) was more (positive) compare to other temperature gradient and highly fluctuating. The soil temperature gradient in the other layer was almost constant through ought the season. Soil potassium gradient was negative and higher magnitude in the topsoil layer in Kharif season. It was shown the potassium concentration was increased at the surface with increasing soil temperature.

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