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Interactive effect of nutrient and excess soil moisture stress in maize crops with special reference to Redox potential

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Abstract
Soil redox potential (Eh) and pH are fundamentals parameters for plants growth. Measuring soil redox is essential but complex due to the lack of measurement reliability resulting from high temporal variability and metrological challenges. This paper proposes practical advancements for measuring redox in aerobic soils using soil water testing kits. The study of soil redox (Eh) in maize crop field under excess soil moisture (ESM) stress condition. The experimental results showed statistically significant redox potential in various treatments, Maximum oxidation i.e. +501.67mv was noted in variety CM-500 under normal condition using nitrogen 60 kg ha^{-1} and phosphorus 40kg ha^{-1} ($V_1F_1M_0$). Whereas, $V_2F_1M_0$ and $V_2F_3M_0$ were showed statistically at par. The maximum reduction was observed in $V_1F_9M_1$ (-119.67mv). The study of maize growth in soil reveals extremely harmful impact resulting from too high and/or too low Eh values.

Keywords: Redox potential, soil, excess moisture, maize, nutrient

Introduction
Many types of biogeochemical reactions have regulated by oxidation – reduction process. Concentration of oxidants and reductants in the environment is determined the Redox Potential (E_h). The redox potential of soil, water, and marine systems is a measure of electrochemical potential or electron availability within these systems. Electrons are essential to all inorganic and organic chemical reactions. The inorganic oxidants such as oxygen, nitrate, nitrite, manganese, iron, sulfate, and CO_2, whereas several organic substrates and reduced inorganic compounds reductants. Among the abiotic stresses, moisture stress play a major role reduction of crop yield. Under excess soil moisture induced imbalance oxidation- reduction resulted nutrient availability is affected and ultimately crop yield is reduced. Among the cereal crops, maize has third position globally on basis of their production and acreage. In case of India maize total cultivated area is 8.17 mha and total production of 27.23mt, with an average productivity of 2.4t ha^{-1}, contributing about 9% to the indian food basket (). Production and productivity is lower than China and other maize growing countries. There are several types of stresses are causes of lower production, like biotic and abiotic. Among the abiotic stresses excess soil moisture caused by flooding, higher water table and waterlogging is a major constrain of lower production (Bange *et al*. 2004; Dickin and Wright 2008) [1, 3]. Keeping in view of the above, objective of this study determine the redox potential of maize crop under excess soil moisture stress.

Materials and Methods
The experimental material consisted of two varieties i.e. CM-500 (V_1) and CM-119 (V_2) with two moisture levels *viz*. Control (M_0) and Excess soil moisture (M_1) with three levels of nitrogen (60, 120 and 180kg ha^{-1}) and three levels of phosphorus (40,80 and 120kg ha^{-1}). A total nine treatments was framed and given below All the fertilizers combinations were used in both cultivars under two moisture levels in three replications. The experiment was designed in factorial randomized block design.

F_1	N =60 kg ha^{-1}	P=40 kg ha^{-1}
F_2	N=60 kg ha^{-1}	P=60 kg ha^{-1}
F_3	N=60 kg ha^{-1}	P=80 kg ha^{-1}
F_4	N =120 kg ha^{-1}	P=40 kg ha^{-1}
F_5	N=120 kg ha^{-1}	P=60 kg ha^{-1}
F_6	N=120 kg ha^{-1}	P=80 kg ha^{-1}
F_7	N=180 kg ha^{-1}	P=40 kg ha^{-1}
F_8	N=180 kg ha^{-1}	P=60 kg ha^{-1}
F_9	N=180 kg ha^{-1}	P=80 kg ha^{-1}

The experiment was conducted in filed condition with the plot size 2.5 m × 2.15 m, row spacing 0.75m and plant to plant spacing was maintained 0.25m. The nutrients were applied manually before the sowing through urea, single super phosphate and murate of potash. Half amount of nitrogen applied as per treatment and full dose of phosphorus and potash were applied as basal dressing. The balance dose of nitrogen was applied 30 and 45 days of sowing. The soil redox potential was estimated by soil water analysis kit (Model E161).

Results and Discussion

Oxidation–reduction process in soil was significantly affected by excess soil moisture (ESM) stress and nutrient application. ESM was more important to record the redox potential. In oxidized condition redox potential showed positive (+) value and in highly reduced condition it gives negative (-). That pattern are regulate the nutrient availability and ultimately affect the crop growth and yield. Under highly reduced condition (anoxia) accumulation of reduced substances such as NO_2, Mg^{2+}, $Fe2^{+}$ and H_2S, as well as intermediates of microbial carbon metabolism such as acetic and butyric acid and showed toxic effect (Drew and Lynch, 1980) [4].

The data revealed that non-significant result for redox potential when both varieties were compared. The highly reduced condition (+166.33mv) was noted in F9 level of fertilizer and highly oxidized (+341mv) determined in F_1 level of fertilizer. Under moisture level, highly reduced (+159.98mv) condition was observed in Excess soil moisture stress condition compared to control condition (+473.89mv). Treatment combination (variety x moisture) results showed statistically significant, the variety CM-500 showed maximum oxidation (+473.33mv) under normal condition, whereas maximum reduction i.e. +148.87mv was observed in same variety under excess moisture condition (Table 1). The interactive effect of fertilizers and variety showed non-significant. The interaction between fertilizer and moisture was observed statistically significant and highly reduced (-126.67mv) in F_9M_1. Highly oxidized (+500mv) in f_1M_1 treatment. Overall significant results were observed in all the treatments and their interactions. Maximum oxidation i.e. +501.67mv was noted in variety CM-500 under normal condition using nitrogen 60 kg ha^{-1} and phosphorus 40kg ha^{-1} ($V_1F_1M_0$). Whereas, $V_2F_1M_0$ and $V_2F_3M_0$ were showed statistically at par. The maximum reduction was observed in $V_1F_9M_1$ (-119.67mv) similar findings was reported by Phillips, 1999 [10]. Husson (2013) [6] proposed a favourable soil Eh for plant growth in the range of +350 to +500 mV vs SHE, with an optimal range between +400 and +450 mV vs SHE. Soil Eh impact on plant growth has been extensively studied in anaerobic wetlands conditions (Kögel-Knabner *et al*. 2010; Mitsch and Gosselink 2015; Shao *et al*. 2016) [7, 8, 11]. Very few plants, and fewer crops, are able to sustain anaerobic conditions (< 350 mV vs SHE) for long periods of time (several weeks) (Dwire *et al*. 2006) [5]. It would be particularly useful to define more ranges of redox in order to better evaluate their impact on maize growth. Further works should be supported out to improve the elucidation of redox potential and better maize production under excess moisture stress conditions.

Table 1: Interactive effect of moisture and nutrient on Redox (Eh) potential in maize crop field

Variety	Moisture level	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	Average
V_1	M_0	+501.67	+478.33	+476.67	+478.33	+465.00	+485.00	+471.67	+448.33	+455.00	+473.33
	M_1	+175.00	+178.33	+186.33	+171.67	+176.33	+150.00	+151.67	+121.33	-119.67	+148.87
	Average	+338.33	+328.33	+331.50	+325.00	+320.67	+317.50	+311.67	+284.83	+167.66	+311.10
V_2	M_0	+498.33	+478.33	+491.67	+478.33	+473.33	+466.67	+468.33	+463.33	+451.67	+474.44
	M_1	+191.67	+181.67	+181.67	+191.67	+178.33	+179.67	+166.67	+155.00	-121.67	+163.04
	Average	+345.00	+330.00	+336.67	+335.00	+325.83	+323.17	+317.50	+309.17	+165.00	+318.74
C at 5%	M=3.762 V=NS F=8.842 Interaction VXM=5.320 Interaction FXV= NS Interaction FXM=11.286 Interaction VXMXF=15.961										

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