The effect of nutrient management on crop moisture utilization and water use efficiency in Indian mustard

Abstract:

A field experiment was conducted during the rabi season of 2017-18 at the Agriculture Farm, Bhagwant University, Ajmer, to investigate the impact of nutrient management on the growth, yield, and quality of mustard. The experiment consisted of a total of 10 treatments arranged in a randomized block design with three replications. The results indicated that the application of nutrient management treatments improved water use efficiency. Specifically, the application of 100% RDF (Recommended Dose of Fertilizer) along with 2% urea and 2% Multiplex spray.

Improving agricultural water use efficiency is a major concern, particularly in areas affected by drought, as it significantly limits grain production worldwide. Efficient water management techniques are essential for crop production in water-scarce regions. Enhancing crop water use efficiency and drought tolerance through genetic improvement and physiological regulation can contribute to more effective water utilization. When water supply is limited, it negatively affects photosynthesis, alters chlorophyll contents and components, and damages the photosynthetic apparatus. It also disrupts photochemical activities and reduces enzyme activity in plants. Water stress inhibits plant growth and photosynthetic abilities by disturbing the balance between the production of reactive oxygen species and the antioxidant defense, resulting in the accumulation of reactive oxygen species that induce oxidative stress to proteins, membrane lipids, and other cellular components. Several approaches are being employed to enhance water use efficiency and minimize the detrimental effects of water stress in crop plants. Proper plant nutrition is a valuable strategy for improving water use efficiency and productivity. Plant nutrients, both macro and micronutrients (including nitrogen, phosphorus, potassium, calcium, magnesium, zinc, boron, iron, manganese, molybdenum, chloride), as well as silicon (a beneficial nutrient), play crucial roles in enhancing water use efficiency in crop plants. In this paper, we discuss effective techniques for improving water use efficiency and provide a detailed exploration of how these nutrients contribute to enhancing water use efficiency in crop plants.

Keywords: Mustard, nutrient, urea, multiplex, moisture and WUE

INTRODUCTION

Indian mustard (*Brassica juncea* (L.) Czern. & Coss) is the second most significant oilseed crop in India, following soybean. Over the past decade, it has been extensively cultivated in northern India. Rapeseed-mustard contributes around 26.0 percent to the overall oilseed production in the country. Currently, domestic production of edible oils fulfills only 50% of the total demand, with the remainder being imported. To bridge the substantial gap between consumption and domestic production, there are two potential approaches: expanding the cultivation area for oilseed crops such as rapeseed, mustard, sunflower, and soybean, or increasing the productivity per unit area. The primary fatty acids found in rapeseed and mustard oil are oleic, linoleic, linolenic, ecosenoic, and erucic acids. The Indian mustard variety specifically exhibits a high content of these fatty acids (Chauhan *et al*., 2007). Fats and oils provide 9 kilocalories of energy per gram, while carbohydrates and proteins supply approximately kilocalories of energy per gram (Alam *et al*., 2014). Moreover, fats and oils serve as a source of essential fatty acids and are utilized in the synthesis of phospholipids, which are vital components of active tissues such as the brain, nerves, and liver in both humans and other animals.

To produce the additional quantity of oilseed, the only option to enhance productivity under limited resource conditions. The imbalanced and inadequate supply of fertilizers accompanied by restricted use of organic manures not only leads to limit the yield potential but soils also get deficient in the nutrients which deteriorate the soil health with decline in crop response. The differential trends in seed yield of Indian mustard under a particular agro-climatic condition have been noticed due to varying moisture and nutrient status of soil. It is responsive to plant nutrients especially nitrogen phosphorus and sulphur. Nutrients play a pivotal role in increasing the seed yield in mustard. Foliar application of major nutrients like nitrogen and potassium was found to be as good as soil application. Nitrogen is the most important nutrient, which determines the growth of the mustard crop and increases the amount of protein and yield. Phosphorus and potash are known to be efficiently utilized in the presence of nitrogen. Sulphur is a crucial element for rapeseed-mustard in determining its seed yield, oil content, quality and resistance to various biotic and abiotic stresses. Besides promoting chlorophyll formation and oil synthesis, it is an important constituent of seed protein, amino acids, various enzymes and glucosinolate. The favourable influence of zinc application on yield of mustard may be attributed to its role in various enzymatic reactions, growth processes, hormone production and protein synthesis and also the translocation of photosynthates to seed thereby leading to higher seed yield (Bhadauria *et al.,* 2012). Boron helps to maintain balance between sugar and starch, translocation of sugar and carbohydrates, pollination and seed reproduction, cell division, nitrogen metabolism, protein formation as well as cell wall formation etc. (Trivedi, 2015). The objectives of this study were to examine the effect of nutrient management on quality and nutrient uptake by crop.

Macro-nutrients

Nitrogen:- Nitrogen (N) is an essential macronutrient for plants and plays a crucial role in various aspects of plant growth and metabolism. It affects the photosynthetic capacity of leaves by increasing the production of stromal and thylakoid proteins, which are important for photosynthesis (Makino *et al*., 1992). Nitrogen is also a vital component of DNA, RNA, chlorophyll, and other molecules involved in cell metabolism.

When plants experience water stress, the absorption and utilization of nutrients, including nitrogen, become critical for their growth and productivity. Water stress can lead to a decrease in nutrient uptake, particularly nitrogen, which can contribute to reduced crop yield. Even if the crop has roots that penetrate deeper into wetter parts of the soil, nutrients concentrated in dry surface layers may be inaccessible to plants (Wright, 1982).

The availability of nitrogen and the response to nitrogen fertilizers or other nitrogen sources are closely related to the ability of plant roots to absorb water from the soil. When the water inside the plant falls below a certain threshold, stomata close, resulting in reduced transpiration and water transport through the plant. This, in turn, affects the roots' ability to absorb water and nutrients as effectively as under normal conditions. In dry soils, nutrient uptake inhibition by plants is also related to nutrient transport through mass flow and diffusion in the soil (Mackay & Barber, 1985; Seiffert *et al*., 1995), which can decrease nutrient availability at the root surface and reduce mineralization of organic nutrients (Bloem *et al*., 1992; Walworth, 1992). Severe drought can further impede nutrient transport to the root surface by causing root shrinkage and loss of soil-root contact (North & Nobel, 1997).

Applying inorganic fertilizers, including nitrogen, has been reported to mitigate the adverse effects of water stress by improving the water use efficiency (WUE) of crop growth and development (Marschner, 1995; Payne *et al*., 1995; Raun & Johnson, 1999). Under mild water stress, low doses of nitrogen can increase grain yield in winter wheat, but under severe water stress, high nitrogen application can have detrimental effects (Nielsen & Halvorson, 1991). Studies have observed a non-significant interaction between drought and nitrogen supply for various root parameters and nitrogen flux (Eghball & Maranville, 1993). Under different intensities of water stress, wheat plants grown under high fertility conditions performed better than those under low fertility conditions (Kathju *et al*., 1990). Nitrogen application has also been shown to minimize the adverse effects of drought on dry matter and grain yield in pearl millet (Ashraf *et al.*, 2001).

Overall, in dryland agriculture where water is a limiting factor, applying nitrogen fertilizers to an appropriate extent can be considered as part of drought mitigation management, as it can help improve plant performance and yield under water stress conditions

Phosphorus

Phosphorus (P) is an essential nutrient for plants and plays a crucial role in various physiological processes. It is a constituent of nucleic acids, phospholipids, phosphoproteins, dinucleotide, and adenosine triphosphate (ATP). These compounds are involved in energy storage and transfer, photosynthesis, enzyme regulation, and carbohydrate transport (Hu & Schmidhalter, 2001).

Soils in arid areas, such as those in Mediterranean regions, are often calcareous and have high pH levels. In the semi-arid tropics, soils are rich in aluminum and iron oxides, and the pH levels are low. Both soil types have a strong tendency for phosphorus fixation, which means that phosphorus becomes unavailable for plant uptake (Oertli, 1991).

It is generally observed that the uptake of phosphorus by crop plants is reduced under dry soil conditions (Pinkerton & Simpson, 1986). Even under relatively mild drought stress, the translocation of phosphorus to the shoots is severely restricted (Rasnick, 1970). However, Liebersbach *et al*. (2004) reported that the large amount of molecular exudates, mainly mucilage, from plants in dry soil can counteract the reduced mobility of phosphorus under such conditions. Turner (1985) also highlighted that phosphorus deficiency seems to be one of the earliest effects of mild to moderate drought stress in soil-grown plants.

The application of phosphorus fertilizer can significantly improve plant growth under drought conditions (Ackerson, 1985; Studer, 1993; Garg *et al*., 2004). The positive effects of phosphorus on plant growth under drought stress have been attributed to increased stomatal conductance (Bruck *et al*., 2000), enhanced photosynthesis (Ackerson, 1985), higher cell membrane stability, improved water relations (Sawwan *et al*., 2000), and increased water-use efficiency. Priming seeds with nutrient solutions containing limiting nutrients like phosphorus and zinc under drought conditions has been shown to improve the establishment of barley (Ajouri *et al*., 2004). Smith (2002) suggested that strategies involving the overexpression of genes encoding high-affinity phosphorus transporters could be important in increasing nutrient uptake, particularly in phosphorus-deficient soils of semi-arid tropics.

In summary, phosphorus is crucial for plant growth and is involved in various physiological processes. Under dry soil conditions, phosphorus uptake by plants is typically reduced, but the application of phosphorus fertilizer can significantly enhance plant growth and mitigate the negative effects of drought stress. Future strategies for improving nutrient uptake may involve genetic approaches, such as overexpressing genes responsible for high-affinity phosphorus transporters, particularly in regions with phosphorus-deficient soils in semi-arid tropics.

Material method :-

Soil moisture studies

To convert the moisture percentage by weight into depth of water (in mm), the following formula was used:

Depth of water (mm) = Moisture percentage by weight × Bulk density × Depth of soil sample (cm) / 100

Here's an explanation of the variables used in the formula:

Moisture percentage by weight: This represents the moisture content of the soil sample expressed as a percentage of its weight.

Bulk density: It refers to the mass of dry soil per unit volume, typically expressed in g/cm^3. Bulk density is used to estimate the volume of soil represented by the weight of the sample.

Depth of soil sample: This indicates the depth of the soil sample collected for analysis, typically measured in centimeters.

By applying this formula, the moisture percentage by weight is multiplied by the bulk density and the depth of the soil sample, then divided by 100 to obtain the depth of water in millimeters. It's important to note that the bulk density used in the formula should be specific to the soil type and conditions of the study area. Additionally, this formula assumes a homogeneous distribution of moisture within the soil sample

Moisture content = Bulk density (g cm-3) × Soil depth (cm) × moisture (%) by wt.

Periodical moisture used

The formula provided by Singh and Singh (1978) calculates the periodical moisture use (MU) between two stages using the following equation:

MU = (Sm1 - Sm2) × BD × D / 100

Here's an explanation of the variables used in the formula:

MU: Moisture use in between two stages, expressed in millimeters (mm).

Sm1: Soil moisture at the first stage, represented as a percentage (%).

Sm2: Soil moisture at the second stage, also expressed as a percentage (%).

BD: Bulk density of the soil, measured in grams per cubic centimeter (g/cm^3).

D: Soil depth between the two stages, measured in centimeters (cm).

To calculate the moisture use, you subtract the soil moisture at the second stage (Sm2) from the soil moisture at the first stage (Sm1). The difference is multiplied by the bulk density (BD) and the soil depth (D), and divided by 100. It's important to note that the bulk density used in the formula should be specific to the soil type and conditions of the study area. Additionally, this formula assumes a homogeneous distribution of moisture within the soil profile between the two stages.

Total moisture used

To calculate the total moisture used by the crop (in millimeters, mm), the following factors are taken into consideration:

(i) The amount of soil moisture available at the time of sowing.

(ii) The amount of effective rainfall received during the crop period.

(iii) The amount of soil moisture remaining after the crop harvest.

(iv) The fluctuation of the groundwater table, which is considered negligible in this case.

The exact method for calculating the total moisture used may vary depending on the specific parameters and measurements available. However, a general approach would involve adding up the contributions from each of these factors.

For example:

Total moisture used = Soil moisture at sowing + Effective rainfall during the crop period - Soil moisture remaining after harvest the fluctuation of the groundwater table is considered negligible and not included in the calculation. It's important to note that the values for soil moisture, effective rainfall, and groundwater table fluctuations should be measured or estimated using appropriate methods and techniques specific to the study area.

Moisture use from different layers of soil:

To calculate the moisture use by the crop from different layers of soil (0-15 cm, 15-30 cm, and 30-60 cm), you can sum up the moisture used by the crop at each specific depth under different stages of crop growth.

For example, let's consider the moisture use at each depth for two stages of crop growth: Stage 1 and Stage 2.

Moisture use from the 0-15 cm depth:

Moisture use at Stage 1 (0-15 cm) + Moisture use at Stage 2 (0-15 cm)

Moisture use from the 15-30 cm depth:

Moisture use at Stage 1 (15-30 cm) + Moisture use at Stage 2 (15-30 cm)

Moisture use from the 30-60 cm depth:

Moisture use at Stage 1 (30-60 cm) + Moisture use at Stage 2 (30-60 cm)

Repeat this calculation for each depth range of interest (e.g., 0-15 cm, 15-30 cm, 30-60 cm) and for each stage of crop growth to determine the moisture use from different layers of the soil.

The moisture use at each depth and stage can be calculated using appropriate methods, such as the formulas or measurements specific to the study and the available data on soil moisture content and crop water requirements.

Water use efficiency (Kg/ha-mm)

To calculate the water use efficiency (WUE) of dry land mustard, you divide the seed yield of the crop by the evapotranspiration (ET) and express it in kg/ha-mm.

Water Use Efficiency (WUE) = Yield (Y) / ET

Here's an explanation of the variables used in the formula:

Y: Yield of the crop in kilograms per hectare (kg/ha).

ET: Evapotranspiration, which represents the amount of water lost through evaporation from the soil surface and transpiration from the plant leaves, measured in millimeters (mm).

To calculate the WUE, you need to determine the seed yield of the mustard crop and the evapotranspiration value. The seed yield is typically measured in kilograms per hectare (kg/ha). Evapotranspiration can be estimated using various methods, such as meteorological data, crop coefficients, and water balance calculations.

The consumptive use of water (CU) is also considered in the calculation of WUE. Consumptive use is the total amount of water used by the crop, taking into account the moisture used from the soil profile, rainfall, and any protective irrigation applied during critical stages.

So, the CU value is derived from the moisture used from the soil profile, rainfall, and protective irrigation from harvested water applied to the crop at critical stages.

Once you have the yield (Y) and the values for ET and CU, you can calculate the water use efficiency (WUE) of the dry land mustard crop by dividing the yield by the evapotranspiration.

Result and Discussion:-Soil and foliar application of nutrients markedly influenced the moisture use by crop and water use efficiency.

Actual moisture use: In the study mentioned, the actual moisture use by the mustard crop was measured under different treatments. The control treatment and the treatment with water spray resulted in the minimum moisture use of 153 mm from the soil profile. On the other hand, the treatment labeled T8, which involved the application of 100% recommended dose of fertilizer (RDF) along with 2% urea and 2% Multiplex spray, showed the maximum moisture use of 213 mm. This indicates that the combination of fertilizer application and foliar spray led to higher utilization of moisture by the crop.

The treatments T9 (100% RDF + 2% Multiplex spray) and T4 (100% RDF) also exhibited relatively higher moisture use, although slightly lower than T8. These results suggest that the application of recommended fertilizer doses, with or without foliar spray, positively influenced the moisture utilization by the mustard crop.

It's important to note that these findings are specific to the mentioned study and may not be directly applicable to other scenarios or crops. Additionally, the specific mechanisms behind the observed increase in moisture use due to fertilizer application and foliar spray would require further investigation.

Water use efficiency (WUE)

In the study, water use efficiency (WUE) was assessed under different treatments. The treatment labeled T10, which involved the combined application of 100% recommended dose of fertilizer (RDF) as basal and 2% urea and 2% Multiplex spray, showed the highest WUE value of 5.00 kg/ha/mm. This indicates that this particular treatment achieved a higher yield per unit of water used compared to other treatments.

The treatment T7 resulted in the second-highest WUE value of 4.83 kg/ha/mm, followed by T9 with a WUE value of 4.73 kg/ha/mm. The treatment T8 had a WUE value of 4.30 kg/ha/mm, which was slightly lower than the top-performing treatments.

On the other hand, the control treatment, which likely did not receive any additional fertilizer or foliar spray, had the lowest WUE value of 2.96 kg/ha/mm. This indicates that without any nutrient management or treatments, the crop achieved a lower yield per unit of water used.

These findings suggest that the combined application of recommended fertilizer doses and foliar sprays positively influenced the water use efficiency of the mustard crop in this study. However, without further information about the specific details of each treatment, it's challenging to provide a more comprehensive analysis

Treatment	**WU (mm)**	**WUE (kg/hamm)**
Control	**153**	**2.96**
Water Spray	**153**	**2.97**
2% urea spray	**185**	**3.09**
100% RDF *	**192**	**3.42**
50% RDF + 2% urea spray	**191**	**3.82**
50 %RDF + 2%urea + 2% Multiplex spray	**191**	**4.13**

50 %RDF + 2% Multiplex spray	**170**	**4.83**
100% RDF +2% urea spray	**213**	**4.30**
100 %RDF + 2% Multiplex spray	**195**	**4.73**
100% RDF + 2%urea + 2% Multiplex spray	**191**	**5.00**

Table 1: Water use effeciency

Soil moisture studies

The study on soil moisture focused on the efficient utilization of available water in dry land agriculture. The integrated soil and foliar application of nutrients had a significant influence on water use and water use efficiency (WUE). The treatment T8, which involved the combined application of 100% recommended dose of fertilizers (RDF) as basal and 2% urea and 2% Multiplex spray, showed the highest water use. It was followed by T9, which included 100% RDF and 2% Multiplex spray.

The highest water use efficiency was observed in treatments that combined foliar spray of nutrients (urea and micronutrients) with the full recommended dose of fertilizers. The treatment combining 50% RDF with 2% urea and 2% Multiplex spray also showed relatively high water use efficiency.

Water use efficiency (WUE) is an important factor to consider when selecting crops for dry land conditions. It indicates the yield obtained per unit of water consumed as evapotranspiration by the crop. In this study, the combined application of 100% RDF as basal and 2% each of urea and Multiplex spray demonstrated the highest efficiency in utilizing stored soil moisture. The foliar application of 50% RDF with urea and micronutrients also showed good water use efficiency compared to other treatments. The improved efficiency may be attributed to the effect of nutrients applied through foliar spray, which enhanced crop growth and root penetration, leading to more efficient uptake of soil moisture by the plants.

Overall, these findings suggest that integrated soil and foliar application of nutrients can positively impact water use efficiency and the utilization of stored soil moisture in dryland agriculture.

CONCLUSION

Based on the experimental findings, the following conclusions can be drawn:

The combined foliar application of urea and Multiplex spray, along with the 100% recommended dose of fertilizers, resulted in maximum growth parameters, yield parameters, and overall yield of rain fed mustard. This indicates the effectiveness of this combination in enhancing crop performance.

In the specific agro-climatic conditions of Ajmer under dry land conditions, the application of 2% urea and 2% Multiplex spray, in addition to the recommended dose of 40 kg N, 20 kg P2O5, 20 kg K2O, and 20 kg S per hectare, proved to be highly effective in achieving maximum mustard yield and generating higher profits. Alternatively, the application of 100% RDF with 2% urea spray or 2% Multiplex spray can also be considered suitable for the Ajmer region.

It is important to note that the experiment was conducted for only one year. To ensure the validity and reliability of the conclusions, it is recommended to repeat the experiment for two or three more years. Long-term studies would provide more comprehensive data and insights into the effectiveness and consistency of the observed trends.

In summary, the integrated application of urea, Multiplex spray, and recommended doses of fertilizers showed promising results in terms of crop growth, yield, and profitability in the context of rain fed mustard cultivation in the Ajmer region. However, further research and validation through multiple-year studies are necessary to strengthen the findings and draw more robust conclusions.

Reference:-

Ackerson, R.C. (1985). Osmoregulation in cotton in response to water-stress. Effects of phosphorus fertility. Plant Physiology, 77,309-312.

Ajouri, A., Asgedom, H., & Becker, M. (2004). Seed priming enhances germination and seedling growth of barley under conditions of P and Zn deficiency. Journal of Plant Nutrition and Soil Science, 167, 630-636.

Alam MM, Begum F, Roy P. (2014) .Yield and yield attributes of rapseed-mustard (*Brassica sp.*) genotype grown under late shown condition. Bangladesh Journal of Agriculture Research 39;313-336.

Ashraf, M., Shehbaz, M., & Ashraf, M. Y. (2001). Influence of nitrogen supply and water stress on growth and nitrogen, phosphorous, potassium and calcium contents in pearl millet. Biologia Planterum, 44,459-462.

Bhadauria HS, Nagar N, Mudgal SK. (2012). Effect of micronutrient cations on yield, quality and their uptake by mustard in alluvial soil. Annals Plant Soil Research. 14(2)**:**130-132.

Bloem, J., De Ruiter, P. C., Koopman, G. J., & Brussaard, L. (1992). Microbial numbers and activity in dried and rewatered arable soil under integrated and conventional management. Soil Biology and Biochemistry, 24, 655-665.

Bruck, H., Payne, W. A., & Sattelmacher, B. (2000). Effects of phosphorus and water supply on yield, transpirational water use efficiency, and carbon isotope discrimination of pearl millet. Crop Science, 40,120-125.

Chauhan JS, Bhadauria VPS, Singh M, Singh KH, Kumar (2007) A. Quality characteristics and their interrelationship in Indian rapseed-mustard (Brassica sp.) verities. Indian Journal of Agriculture Sciences. ;77:616-620.

Eghball, B. & Maranville, J. W. (1993). Root development and nitrogen influx of corn genotypes grown under combined drought and nitrogen stresses. Agronomy Journal, 85, 147-152

Hu, Y. & Schmidhalter, U. (2001). Effects of salinity and macronutrient levels on micronutrients in wheat. Journal of Plant Nutrition, 24, 273-281.

Kathju, S., Vyas, S. P., Garg, B. K., & Lahiri, A. N. (1990). Fertility induced improvement in performance and metabolism of wheat under different intensities of water stress. Proceedings of the International Congress of Plant Physiology, 88,854-858. New Delhi, India.

Liebersbach, H., Steingrobe, B., & Claassen, N. (2004). Roots regulate ion transport in the rhizosphere to counteract reduced mobility in dry soil. Plant and Soil, 260,79-88

Mackay, A. D. & Barber, S. A. (1985). Soil moisture effects on root growth and phosphorus uptake by corn. Agronomy Journal, 177,519-523.

Makino, A., Sakashita, H., Hidema, J., Mae, T., Ojima, K., & Osmond, B. (1992). Distinctive responses of ribulose-1, 5-bisphosphate carboxylase and carbonic anhydrase in wheat leaves to nitrogen nutrition and their possible relationships to CO2 transfer resistance. Plant Physiology, 100,1737-1743.

Marschner, H. (1995). Mineral nutrition of higher plants (2nd edn). San Diego, CA: Academic Press.

Nielsen,D.C.& Halvorson, A. D. (1991). Nitrogen fertility influence on water stress and yield of winter wheat. Agronomy Journal, 83,1065-1070.

North, G. B. & Nobel, P. S. (1997). Root-soil contact for the desert succulent Agava deserti in wet and drying soil. Journal of Experimental Botany, 38,2068-2081.

Oertli, J. J. (1991). Nutrient management under water and salinity stress. In Proceedings of the symposium on nutrient management for sustained productivity, pp. 138-165. Department of Soils, Punjab Agricultural University, Ludhiana, India

Payne, W. A., Hossner, L. R., Onken, A. B., & Wedt, C. W. (1995). Nitrogen and phosphorus uptake in pearl millet and its relation to nutrient and transpiration efficiency. Agronomy Journal, 87,425-431.

Pinkerton, A. & Simpson, J. R. (1986). Interactions of surface drying and subsurface nutrients affecting plant-growth on acidic soil profiles from an old pasture. Australian Journal of Experimental Agriculture, 26,681-689.

Rasnick, M. (1970). Effect of mannitol and polyethylene glycol on phosphorus uptake by maize plants. Annals of Botany, 34,497-502.

Raun, W. R. & Johnson, G. V. (1999). Improving nitrogen use efficiency for cereal production. Agronomy Journal, 91,357-363.

Sawwan, J., Shibli, R. A., Swaidat, I., & Tahat, M. (2000). Phosphorus regulates osmotic potential and growth of African violet under in vitro-induced water deficit. Journal of Plant Nutrition, 23,759-771.

Seiffert, S., Kaselowsky, J., Jungk, A., & Claassen, N. (1995). Observed and calculated potassium uptake by maize as affected by soil water content and bulk density. Agronomy Journal, 87,1070-1077.

Studer, C. (1993). Interactive effects of N-P-K-nutrition and water stress on the development of young maize plants. Ph.D. Thesis, ETHZ, Zurich, Switzerland.

Tripathi MK, Chaturvedi S, Shukla DK, Mahapatra BS(2010). Yield performance and quality in Indian mustard (Brassica juncea) as affected by integrated nutrient management. Indian Journal of Agronomy. ; 55:138-142.

Walworth, J. L. (1992). Soil drying and rewetting, or freezing and thawing, affects soil solution composition. Soil Science Society of American Journals, 56,433-437

Wright, D. (1982). Crop physiology. In R. J. Halley (ed.) Agricultural note book, pp. 69-82. London: Butterworth Scientific.