Review Article

Interaction effects of nutrient and water on crop production system under dry and irrigated agriculture

Abstract

Many areas in India, including dryland areas, are under stress from two main obstacles to agricultural output, namely, inadequate soil nutrients and a scarcity of water. In most rainfed regions, except for a few places that can conduct irrigation, low precipitation levels and their erratic distribution usually result in soil water deficiency which leads to water as well as the instances of nutritional stress. Additionally, serious wind and water erosion derived from sparse vegetation coverage, windy climate, and frequent rainstorms along with human activities very frequently results in significant nutrient stress and soil deterioration. Hence, in sustainable agricultural production systems, soil water and nutrient stress are major concerns. In crop production systems, the interplay between water and nutrients might yield favourable results, contingent on the growth stages, volumes, combinations, and balance of the crops. The notable fluctuations in precipitation from year to year have a substantial impact on the water and nutrient condition of the soil as well as how they interact with crops. In irrigated areas, water and nutrients have interdependent effects. Efficient water management can enhance nutrient availability and transformation in soil or fertilizers. Water boosts plant nutrient content, uptake, and overall efficiency. Water scarcity stresses plants, impeding root growth and nutrient absorption. It also makes sap in their primitive xylem more viscous, which hinders the transfer of nutrients and decreases their availability, mobility, uptake, and efficiency. Additionally, it has been discovered that there is typically a strong, nearly linear correlation between crop yield and nutrient and water management techniques. Water availability and nutrient efficiency are therefore intimately related. The water state of the soil should be taken into consideration when applying nutrients in a balanced manner, taking into account their types, ratios, amounts, timing, and methods, in addition to their capacity to give nutrients. Therefore, determining the best time or growth stage to add water and nutrients to various crops, as well as how water and nutrients interact, are essential for a sustainable crop production system.

Key words: Dryland areas, Shortage of water supply, Deficiency of soil nutrients,Interactions, Water supply, Nutrient efficiency

1 Introduction

Water is a major factor involved in nutrient availability to plants. In general, mineral nutrients and water are taken up from the soil by the plants and transported upward, whereas products of photosynthesis (photosynthate) are produced in green leaves and transported downward. Mineral nutrients and water move throughout the tissues of plants, starting at the root hairs, which take up water from the soil, moving through the tracheid and vessel components of the vascular system (collectively referred to as the xylem), and finally ending in the parenchyma cells, which discharge water into the leaf intercellular spaces. Most of the plant nutrients are present as ions in the soil, and henceall are water-soluble.When plants take water from the soil, along with water the nutrients also pass from the soil and reach plants. In this transportation of waterfrom roots to other parts like leaves, the nutrients also move with water according to concentration difference.Ultimately, water affects plant nutrient content, plant uptake of nutrients overall, and plant nutrient utilization efficiency (NUE).Depending on the different stages of crop growth, volumes, combinations, and balance, crop output may be positively or negatively impacted by the way that water and nutrients interact.In dryland ecosystems, the effects of nutrients and water sometimes conflict with one another. Soil water and nutrient status are greatly impacted by notable annual fluctuations in precipitation, as well as by the interaction effect. As the soil-water content diminishes, some less-soluble nutrients may precipitate out from the soil solution and become unavailable to plants. These minerals have the ability to break down and re-emerge when the soil gets wet again. Water and nutrients each serve a different purpose, but they are connected to and affect one another. This write-up aims to summarize research information related to nutrient and water management on root growth, plant physiological activities, photosynthesis, soil-water storage, crop yield, nutrient and water use efficiency (WUE) in irrigated agriculture.

2 Input (water x nutrient) interactions

Interaction can happen because the response of one factor is modified by the impact of other factors. By limiting, managing, or monitoring plant function, one can either support the other or impose constraints on it. Depending on the crop's growth stages, quantities, combinations, and balance, the interaction between them could affect crop yield in a positive or bad way. Only in the case of the rational supply of nutrients and water, based on the state of water to supply nutrients, can the synergic and supplementary effect be achieved, making both play a much higher role than their sequential additive effect. This is their positive interaction, a bonus by adding to the outcome but not in costs.

Positive interaction follows ‘Liebig’s law of the minimum’. For example, when two factors are insufficient, the inclusion of one more won't significantly affectcrop growth and yields, whereas the use of both factorstogether will exert a significantly bigger impact on crop performance. The interaction responses become stronger in case of acute scarcity or deficiency of a particular factor(s).In addition to achieving maximum yield, excellent quality, and high NUE, it's critical to completely comprehend and make use of their beneficial interaction to safeguard the environment from the negative consequences of fertilizer use (Li *et al.*, 2001a,b, 2002a,b; Fang *et al.*, 2006;Shaaban, 2006).

According to various soil-fertility studies, interactions can be positive, negative or zero. Gains resulting from the negative interaction of two components (water and nutrients)are lower than if they were applied separately. Such interaction may occur as a result of one treatment being substituted for another or interfering with another treatment. In agricultural crops, many times yield gains owing to the application of a single nutrient can lower the concentration of another nutrient, but higher yield results in greater uptake of that nutrient. This is known as the dilution effect, which should be distinguished from an antagonistic effect.

3 Availability of nutrients and water for the plant

Soil and water are two essential natural resources that are required for plant growth. The mechanical stability and nutrient storage which are necessary for the growth of plants are provided by soil.However, processes necessary for plant existence depend on water. Hence, understanding the interactions between soil, water, and plants is necessary for the producer to efficiently handle these resources to produce crops.

Nutrients reach the root surface by mass flow and diffusion in the soil water. The transfer of dissolved nutrients into a plant during its transpiration process is known as mass flow. Most of the transfer of nitrate (NO^{3-}), sulphate ($SO^{4=}$), calcium (Ca^{2+}), and magnesium (Mg^{2+}) is handled by this mechanism. When it comes to diffusion, nutrients are moved to the root surface in reaction to a gradient in concentration. To achieve equilibrium, there is a net migration of nutrients to the area with lower concentrations when they are detected in one area at a higher concentration than in another. Thus, nutrients travel to the root surface where they can be absorbed when there is a high concentration in the soil solution and a low concentration at the root. This holds significance for the transportation of potassium (K) and phosphorus (P). Micronutrients are generally supplied to plant roots by diffusion in soil.

Therefore, low soil-moisture conditions reduce the micronutrient uptake. Plants require smaller quantities of micronutrients than macronutrients; thus, drought stress effects on micronutrient deficiency are not as serious as for macronutrients.On the other hand, high soil moisture levels are usually linked to shortages in iron (Fe) and zinc (Zn). When roots are intercepted, their expansion puts them in communication with nutrient-rich soil colloids. The nutrients are subsequently taken up by the root. Despite being a small channel for nutrient transfer overall, it is an important pathway of magnesium and calcium transport. The actual pathway by which nutrients enter the root can be either active (requiring energy; an ion or "carrier" molecule transports the nutrients into the root) or passive (no energy required; they enter with water).

In a field experiment conducted at Akola(Maharashtra) during *kharif* 2020-21,it was observed that the uptake of nutrients by aerobic rice (cv. Avishkar) varied greatly as a result of the various fertilizer amounts applied through fertigation, which also affected the availability of nutrients and water (Kakade *et al.*, 2023). The drip fertigation in five splits using the 125% recommended dose of N and K (RDNK) revealed the highest uptake of N (133.93 kg ha^{-1}), P (26.99 kg ha^{-1}), and K (137.34 kg ha^{-1}), resulting in 38.43, 40.21, and 28.01% greater N, P, and K uptake, respectively, than 100% RDF applied to the soil using a traditional technique. Water use efficiency (WUE) was also maximum (4.14 kg ha^{-1} mm^{-1}) under this treatment. It was comparable, though, to drip fertigation of 100% RDNK in 5 Splits. The greater nitrogen uptake under drip fertigation levels in splits may have resulted from the higher accessible soil moisture brought on by the drip irrigation system's continuous water supply on alternate days. In addition to promoting root foraging and vegetative growth, the fertigation of nitrogen and potassium increased the amount of nutrients that could be absorbed and translocated at higher drip fertigation levels.On the contrary, the least amount of nutritional absorption (96.75 kg N, 19.25 kg P, and 107.29 kg K ha^{-1}) was noted when applying soil by drip irrigation with 100% RDF (N in 3 Splits).At lower fertilizer doses, the crop absorbed less nutrients due to the decreased availability of nutrients at lower fertigation dosages. Large fertilizer applications during the traditional soil application process led to increased nutrient volatilization losses, which decreased the amount of nutrients available to crops during later growth stages. It once more demonstrates that improved nutrient availability mostly happens during fertigation as a result of increased moisture and nutrient availability during all growth phases.

4 Nutrient and water interaction in crop production system

The impact of one factor on another with respect to crop growth and yield is known as interaction. There may be positive or negative interactions of nutrients that occur either in soil or plants. Higher crop yield results from the beneficial interactions of nutrients, and crop productivity can be increased by taking these relationships into account. Conversely, while creating agronomic packages for a crop, all adverse interactions should be avoided as they will reduce crop yield. The knowledge about interactions occurring in soils or plants or both is required to develop appropriate and efficient technologies. Further, this will help to refine the existing ones to increase agricultural production.Antagonistic and synergistic effects are the two primary categories of interaction effects in general. Antagonistic effect means a rise in concentration of any nutrient element will decrease the action of another nutrient (negative effect). A synergistic effect occurs when the concentration of one nutritional element increases and positively affects the action of another nutrient element. Stress on soil water restricts agricultural yield even in regions where annual precipitation exceeds growing season evapotranspiration. Likewise, stresses caused by nutrient deficiencies reduce the plant's ability to use water efficiently and ultimately affect crop productivity and profits.

Water and nutrient interactionsexist very much in crop production systems. In West Bengal (India), significant improvement inthe seed yield of mungbean (cv. PDM 139) due positive interaction of irrigation and boron levels (Mondal *et al.*, 2012).The interaction effect (irrigation x B) was positive, and a higher seed yield of 898 kg ha^{-1} was obtained when the plant received 0.2% foliar spray of borax at the flowering stage along with 3 irrigations at branching, pre-flowering, and pod development stages**.**Since the mungbean crop was cultivated during the summer season, sufficient availability of soil moisture during crop growth especially during its critical growth periods, might augment its initial stand establishment and subsequent crop vigour, resulting in maximization of seed production. In addition to that, the foliar spray of B was instrumental in increasing $podsplant^{-1}$, $seedspod^{-1}$ and test weight which resulted in higher seed yield. At the same location, Ray *et al.* (2015) found a positive interaction effect of sulphur (S) and irrigation on the mustard crop. Two irrigations (at 30 DAS and 60 DAS) in combination with 60 kg S ha^{-1}were found to be effective in improving yield attributes, yield, oil percent, and S uptake of Indian mustard (cv. Varuna, T-59) during the winter season.

5 Effect of nutrient availability on crop performance and water use

5.1Root growth

Roots are a major part of a plant and play a very important role in plant growth. In addition to fixing and supporting plants, the main function of roots is to absorb water and nutrients. Li *et al.* (1978, 1979, 1994) demonstrated that a sensible nitrogenous and phosphorus fertilizer supply boosted wheat root growth and yield. This yield gain had a strong linear correlation with crop root mass. While nutrients and water can travel, roots provide a purpose that cannot be substituted by their mobility.At Modipuram (Uttar Pradesh), it was found that rational use of nitrogenous and phosphorus fertilizer increased wheat root growth (root length, weight, and root mass density) and finally yield, the crop biomass showed a strong correlation with yield gain (Singh *et al.*, 2005, 2010).The top part of the root zone contains the majority of the plant's roots. Water applied during irrigation is frequently kept below the depth of the crop's roots. This rooting depth is typically not reached until 30 to 50 days following planting for annual crops. Therefore, there must be a sizable difference in the amount of water being extracted by plant roots depending on thedepth of the soil. When a soil profile is uniform, the usual pattern of water extraction represents 40%, 30%, 20%, and 10% extraction from 0-15cm, 15-30cm, 30-45 cm, and 45-60cm, respectively which may vary due to local soil and climatic conditions.

Here are some of the modifications to root development and its dispersion behaviour that occur when nutrient and water supply conditions change.

a) In drylands, the importance of roots increases even further because the topsoil is frequently dry and devoid of nutrients, while the deep soil is usually moist with some available nutrients. As a result, plants may depend more on the nutrients and water found in the deep soil layers than in the topsoil. Some drought-resistant crops may have developed large root branches and surface areas as a result of plants reaching deep roots to survive in such conditions.

b) In dry areas, it was found that fertilization caused roots to grow swiftly into deep soil layers in order to absorb water stored during the summer-fallowing period(Smith, 1954). Later, Brown (1972) found that water absorbed by wheat was limited to 91 cm depth without fertilization, while doubling the water intake soil depth and increasing its use efficiency by 56% with N application.

c) The magnitude of fertilization role is closely related to soil fertility.In a soil poor in plant nutrients, rational addition of either organic orinorganic fertilizer can make root growth stronger and have a greater ability to penetrate through the compact, hard-pan layer to draw water and nutrients out of the subsurface (Marschner, 1986).

d) Different nutrients affect root growth and dispersion in different ways (Anghinoni and Barber, 1980). When roots penetrate intoparts of the soil containing abundant mineral elements, they branch profusely (Weaver and Clements, 1938).

e) Plants' capacity to draw water and mineral nutrients from the soil is correlated with the size of their root systems. The annual production of roots in natural ecosystems may easilysurpass that of shoots;therefore, in many respects, the aboveground portionsof a plant represent only ‘the tip of an iceberg’. Plant roots mayalso grow continuously throughout the year.

f) Proliferation of roots, however, depends on the water and mineral availability in the immediate microenvironment (rhizosphere zone) around the root.Root growth is sluggish in an arid or nutrient-poor rhizosphere and accelerates with improved rhizosphere conditions.

g) It is true that the sole application of P fertilizer increased root growth in the soil-surface only, but the combined application of P and N fertilizers extended the root distribution to the entire soil profile where plant roots could penetrate. The combined application of N and P fertilizers lengthened roots in both the deep and top soil layers, as demonstrated by Brown *et al.* (1987).

h) Sub-soiling has no impact on the depth of roots; however, adding fertilizer to sub-soil results in deep roots.

The growth and activity of roots are much affected by crop management practices and the soil environment. In Khurda (Odisha), Thakur *et al.* (2020) recorded the highest root dry weight a medium-duration rice (cv. Surendra) at the tillering stage under SRI–INM (System of rice intensification-Integrated nutrient management), followed by SRI–organic fertilization and CMP (Conventional management practices) plants with either mode of fertilization. Since SRI relies on planting single seedlings, each plant's estimated root dry weight was five to seven times greater than it was for CMP. All three crop growth stages showed a similar pattern, with the grain-filling stage showing the most variation.The maximum root dry weight was obtained under SRI–INM, followed by CMP–INM, on a unit area (m^{-2}) basis. At every growth stage, the SRI–organic treatment exhibited a considerably higher root dry weight m^{-2} than the CMP–organic treatment. Therefore, when comparing SRI to conventional management approaches, a notable improvement in rice plant root growth was seen. This improvement may be related to distinct effects on soil structure and functioning as defined by nutrient management practices. In contrast to SRI practices, the standard recommendations for conventional rice cultivation are to use mineral fertilizers, keeping paddy fields continuously flooded with high planting density. These practices result in shallow and degenerated root systems (Kar *et al.*,1974) with reduced root activity (Yang *et al.*,2004). However, continuous water-logging of the soil is detrimental to rice root growth and significantly decreases root activity (Sahrawat,2000; Yang *et al.*,2004). Onthe contrary, keeping paddy field soils moist but unflooded as followed in SRI practice, has several advantages for expanded and more active root systems and for altering the above-ground crop physiology and performance.

5.2Plant physiological characteristics

Crop nutrition is essential for numerous physiological functions, and its improper application may impair many metabolic processes in crop plants. The mineral nutrient elements, being constituents of cell structures and cell metabolites, play vital rolesin cell osmotic relations and turgor-related processes, energy transfer reactions, enzyme-catalysed reactions, and plant reproduction.A rational nutrient input can improve plant physiological activities in various manners, as stated below.

a) Balanced fertilization with N, P, and K increases the amount of cell solutes, which causes the osmotic pressure to decrease. Lower osmotic pressure promotes cell elongation, the opening of stomata, and photosynthesis in addition to helping to maintain turgor pressure.
b) Nutrient input affects plant water status and its tolerance to drought. Application of organic or inorganic fertilizer enhances plant water status in dry soil circumstances by increasing plant water potential, encouraging plants to maintain higher water content in tissue, and increasing the ratio of free to bound water.
c) Transpiration has both negative and positive impacts on plant growth, as it causes water loss from plants and increases water uptake. The process of water absorption via the transpiration-pulling force cannot happen without transpiration. Increased water transpiration can lessen the likelihood of water loss by evaporation.
d) Potassium plays an important role in regulating stomatal resistance and controlling the water status of plants. Under normal water supply, transpiration increases with fertilization. Whereas, in water deficit conditions fertilization reduces the transpiration rate.

Improvement of the physiological growth of plantsis highly governed by water and nutrient management practices. At Gayeshpur, Nadia (West Bengal), Alipatra*et al.* (2019) found that the sunflower (cv. Aditya) crop receiving 3 irrigations (at 30, 60 and 80 DAS) attained the maximum height at 100 DAS, leaf area index (LAI) at 75 DAS, total dry matter accumulation (TDMA) at 100 DAS and crop-growth rate (CGR) at 50-75 DAS (11.7, 24.8, 23.3 and 61.5% more than the crop irrigated once respectively). At harvest maturity (120 DAS), the basal girth and capitulum diameter of the tested sunflower hybrid were greater when grown with three irrigations (20.6 and 11.6% more than that of the crop receiving single irrigation, respectively). High-frequency water management (three irrigations) might have provided at least the daily water requirement of each plant, and hence, maintained a high soil matric potential in the rhizosphere to reduce water stress. Further, ample irrigation water might have enhanced the plant growth with higher biomass associated with more leaves, and larger stem girth with increased shoot water content. On the other hand, low growth parameter response to drought stress (single irrigation) may result from decreased hydraulic conductivity of leaf cells, which in turn, decreases water transport and hinders both cell enlargement and cell division, and finally leaf development (Gholamhoseini*et al.*, 2013). The water stress results in less evapotranspiration (ET) by closure of the stomata, and reduced assimilation of carbon and biomass production (Demir *et al.*, 2006). The nutrient management practice, consisting of 80 kg N, 40 kg P, 40 kg K, 1.5 kg B and 25 kg S ha^{-1}, significantly and synergistically increased plant height at 100DAS, LAI at 75 DAS, TDMA at 100 DAS, CGR during 50-75 DAS, basal girth at 120 DAS and capitulum diameter of hybrid sunflower (9.6, 65.1, 49.7, 49.0, 11.6 and 11.9% higher values than the crop in farmer fertilizer practice (FFP) plot, respectively.Similar positive responses to sulphur (Sheoran*et al.*, 2013) and boron (Bhattacharyya *et al.*, 2015) application regarding plant height, stem girth, and head diameter in sunflower had also been reported. If there had been enough S available, there could have been a higher rate of cell multiplication, elongation, expansion, production of photosynthates, and their translocation to sink, which ultimately increased the plant height and other growth attributes (Kumar *et al.*, 2011). Moreover, these results support previous findings of Shekhawat and Shivay (2008), who reported increased dry mass of vegetative parts and well-developed capitulum associated with less conversion of sugars into starch where B sprays were applied, while the reproductive parts were small and deformed with lower B spray concentrations.

5.3Photosynthetic activity of plants

Photosynthesis is an incredibly important process that allows plants to create their food. This process needs a wide range of various nutrients, each of which has a specific function. Photosynthesis would not be feasible without these substances. Under dry conditions, crop production reduction may be primarily caused by water stress weakening photosynthesis (Wang *et al.*,1992; Xie *et al.*, 1992; Guo *et al.*, 2004). However, other investigators (Xu and Shan, 1992; Zhang and Shan, 1995) demonstrated that the net rate of photosynthesis was not all determined by stomatal resistance. The net rate of photosynthesis of fertilized spring wheat is significantly reduced when soil is extremely dry, although the absolute amount was still higher than that of the unfertilized crop. Such a good effect of a high N rate on reduction of the injury by dry stress might be related to the high activity of mesophyll cells (Xie and Chen, 1990). Application of K increases chlorophyll and chloroplast grana, intensifies Hill reaction, raises the activity of photosynthetic phosphorylation (photo-phosphorylation),and protects the photosynthetic organs from dryness. As a direct result, leaves grow straighter, the light condition gets improved and the photosynthetic organs fully play their role under a more suitable condition of light. Zhou *et al.* (1993) proved that improvement of P nutrition to tobacco resulted in the decline of the compensation point of carbon dioxide, rise of photosynthetic rate, and reduction of photorespiration.

In a semi-arid region in northern China, the effects of bentonite soil amendment on field water□holding capacity, plant available water, and crop photosynthesis and grain quality parameters for foxtail millet(cv. 5 Zhang)production was assessed by Mi *et al*. (2020). The application of bentonite significantly ($P < 0.05$) increased field water□holding capacity and plant available water in the 0-40 cm layer. Bentonite also significantly ($p<0.05$) increased the emergence rate, above□ground dry matter accumulation (AGDM), net photosynthesis rate (Pr), transpiration rate (Tr), soil and plant analysis development (SPAD), and leaf water use efficiency (WUE). The optimum rate of bentonite was determined at 24 mg ha^{-1} for all plant growth and photosynthesis parameters except for grain quality where 18 mg ha^{-1} bentonite had the greatest effect.Increases in Pr, Tr, SPAD and WUE were 3-32%, 2-21%, 1-15% and 0-13% compared with control without bentonite in all three years.

Under conditions of low water availability, the water held in the soil prior to planting and throughout the growing season is crucial for crop productivity. Insufficient stand establishment of crop is a major problem in the semi-arid region along the Great Wall in Inner Mongolia in northern China, which is believed to be a critical factor affecting crop yield.Bentonite amendmentimproved millet emergence rate (ER), AGDM, and photosynthesis parameters at 90 DAS (Pr, Tr, SPAD, and WUE). In addition, the application of bentonite with calcium, magnesium, and potassium (5, 10, 20, 40 mg ha^{-1}) could increase plant biomass by increasing cation exchange capacity (CEC) and making more exchange sites available to hold plant nutrients for plant growth. Nutrient retention by bentonite might also contribute to improvements in crop performance. Nutrients (K, Mg, and Fe) contained in the bentonite couldcontribute to increased crop growth, and improve photosynthesis, and thus enhance AGDM accumulation.Magnesium is a major element in chlorophyll and some of the observed photosynthesis response to bentonitemight be a result of additional magnesium in the bentonite. Drought conditions havea negative effect on photosynthesis processes which affects carbon assimilation and growth by closure of plantleaf stomates and reduced permeability of mesophyll cells. Bentonite amendments increased field water holding capacity and plant available water at 90 DAS. Bentonite significantly ($p<0.05$) increased millet emergence rate, aboveground drymatter accumulation, photosynthesis parameters (Pr, Tr, SPAD, and WUE), and grain quality parameters (protein,fat, and fibre). Bentonite application @ 24 mg ha^{-1}had the greatest effect on crop performance parameters and photosynthesis parameters, while bentonite application @ 18 mg ha^{-1}had the greatest effect on grain quality.

5.4Soil-water storage

Soil organic matter and water storage capacity are closely associated, with water storage capacity being a significant soil attribute that is connected to crop productivity. The amount of organic matter in the soil has a strong correlation with water-holding capacity (WHC). The use of fertilizers, particularly organic fertilizers, increases the soil's capacity to hold water. In addition to improving plant nutrition and increasing soil nutrients, applying organic fertilizer in conjunction with mineral fertilizers also raises soil organic carbon levels. This enhanced soil structure and water-holding capacity, which in turn leads to improved soil fertility, crop output, and water use efficiency (WUE). It also stimulated the creation of an organic mineral colloidal complex.

5.5Reduction of water loss by evaporation

Rational nutrient input leads to an effective use of water by plants through increasing water transpiration and reduction of its evaporation. In fact, with fertilization crops grow vigorously and take up more water from the soil and reduce water loss by evaporation. On the other hand, a larger leaf area under fertilized plot cover the soil surface, decreases soil temperature, and therefore reduces evaporation rate.Mulches protect soil moisture, improve the soil's nutrient status, reduce erosion losses, inhibit weed growth in crop fields,and eliminate pesticide, fertilizer, and heavy metal residues.

Mulches raise the aesthetic and financial value of agricultural landscapes. Mulch will lessen evaporation, assist in maintaining an equal moisture level, shield soil organisms and plant roots from shock, and reduce the need for watering.Banerjee *et al.* (2016) evaluated the performance of potatoes (cv. Kufri Jyoti) at Hooghly (West Bengal) under various irrigation levels and mulching. They found that the crop yielded more table-purpose potatoes and better tuber quality when it was watered at 20 mm CPE and mulched with paddy straw at a rate of 5 t ha^{-1}. Furthermore, it was shown that conditions of moisture stress resulted in a higher proportion of small tubers relative to larger tubers. Compared to no-mulched plots, grade-wise and total tuber number increased significantly in mulched plots by 61.9, 80.6, 94.5, and 85.4% for small-, medium-, and large-sized tuber yield, respectively. The WUE was discovered to be higher in mulched plot (119.5 kg ha^{-1} mm^{-1}) compared to the no-mulch plot (89.1 kg ha^{-1} mm^{-1}). This could be the result of improved plant nutrition and irrigation water absorption and utilization from the soil profile (Singh *et al.*, 2012). Because mulching and irrigation improve soil carbon, soil moisture, and soil temperature, it is also anticipated that these practices will increase potato tuber output (Kumar, 2015; Singh *et al.*, 2015).

5.6Microbial activities

Nutrients are essential for the growth of microorganisms and are involved in the proper cultivation of microorganisms under both laboratory and natural conditions. Essential nutrients (macro- and micro-nutrients) are very much required by an organism. Macronutrients are necessary in large amounts, while micronutrients tend to be needed in smaller amounts.Microorganisms also have an impact on the availability of nutrients. Denitrification is the word used to describe the microbial-mediated reduction of the nitrate form of nitrogen to several gaseous forms of nitrogen (NO, N_2O, and N_2) under anaerobic conditions (Bolan and Hedley, 2003). The most frequent reporting of this process of N loss occurs in waterlogged settings, where a decrease in oxygen causes a rise in the population of microorganisms that may convert nitrate to nitrogen (N_2) and nitrous oxide (N_2O), which are then prematurely lost to the environment (Fageria, 2002). In addition to water content, the concentration of the N forms NH^{4+} and NO^{3-}, the temperature, and the carbon content can all have an impact on the denitrification process in the soil-plant system (Bolan and Hedley, 2003). Up to 10%–15% of applied nitrogen is lost due to this method of nitrogen loss. Nitrification losses due to heavy texture soil with inadequate natural drainage are more likely to occur (Mosier *et al.*, 2001).

5.7Improvement of wateruse efficiency

The water use efficiency of the crops has a linear relationship with soil fertility.Li (1982) investigated wheat's water use efficiency (WUE) in drylands and found that WUE was increased with soil fertility improvement. The application of fertilizers, particularly organic fertilizers or manures, to dryland soil may increase water content and water potential during the early stages of plant growth by making some ineffective water available to plants. This would have the effect of mobilising WUE. Yao *et al.* (1994) also drew up the same conclusion. The results of field studies conducted at Modipuram, Uttar Pradesh clearly revealed that increasing the N level of rice crop has a direct effect on WUE (Singh *et al.*, 2004).At Akola (Maharashtra), Kakade *et al.* (2023) recorded the highest WUE (4.14 kg ha^{-1} mm^{-1}) of aerobic rice (cv. Avishkar) under dripfertigation in conjunction with 125%

recommended dose of N and K (RDNK) in 5 Splits followedby drip fertigation with 100%RDNK in 5 splits(3.86 kg ha^{-1} mm^{-1}) during *kharif* season. Yet, drip irrigation using 100% RDF through soil application had the lowest WUE (3.69 kg ha^{-1} mm^{-1}).In comparison to drip irrigation with 100% RDF by soil application, drip fertigation with 125% RDNK reported 12.19% greater WUE. This could be because the first scenario involved more carbon assimilated as biomass or grain produced per unit of water utilized by the rice crop. The treatment that yielded the maximum grain yield was also the one with the highest WUE. A similar type of results was also earlier reported by other researchers (Deshmukhand Katake, 2005; Jagadish *et al.,* 2019; Ashrafi*et al.,* 2020).

5.8Soil erosion

Judicious application of nutrients results in better crop establishment and more canopy cover for the crop. Adequate input of nutrients reduces sheet and rill erosion by improving soil quality, soil-water infiltration rate, fertility, and higher crop productivity.Soil erosion caused by wind and water has also a major impacton nutrient availability in soil. As an illustration, wind and water erosion can both remove nitrogen that has been adsorbed on soil particles. In climatically arid and semi-arid regions, wind erosion is a prevalent way for nitrogen loss, but in humid and subhumid environments, water erosion is the most frequently documented mechanism for nitrogen loss. Runoff can dissolve surface-applied nitrate in water after a significant downpour and cause it to be lost (Fageria, 2002).

6 Effect of soil-water supply on nutrient utilization

In nutrient management, an appropriate equilibrium between soil water and soil air is critical since both water and air are required by most processes that release nutrients into the soil. Therefore, it's crucial to keep the soil moist at the right levels.

6.1Nutrient availability

Organic matter and minerals in soil contain nutrient elements. Mineralization of organicmatter and weathering of minerals provide available nutrients for plants, and are the basisof natural soil fertility and major sources of plant nutrients. Fertilizers applied to soil can be changed into either available or unavailable forms. Many factors affect the availability of soil nutrients, and soil water is the most crucial. By converting inaccessible nutrients into available forms, water influences the initial transformation of nutrients in the soil. It also affects the rate of transformation of fertilizers added to the soil. Consequently, it affects the absorption of nutrients, total uptake of nutrients as well as nutrient composition of plants. The availability of nutrients to crop plants and, consequently, the overall amount of absorption, are influenced by dry climates and water stress. Water stress generally inhibits plant growth as well as nutrient uptake; however, the drop in net assimilation rate is more severe than the reduction in nutrient uptake, resulting in a relative increase in nutrient concentration. According to Marschner (1986), alterations in the water supply lead to proportional adjustments in the root distribution within the soil profile and the quantity of nutrients absorbed from various levels. Grimme *et al.* (1981) demonstrated the differences in the absorption of nutrients from various soil layers in various water conditions. For example, spring wheat grown in a soil developed on loess parent material took up 50% K from the deep soil layer at its late growth stages. However, this was changed from year to year with variations in precipitation. In the dry and wetyears, it was 60% and 30%, respectively. Even in topsoil containing highly available P, spring wheat took up 30–40% of P from the deep soil layer under a water-limiting condition. Water status does not only influence the availability ofnutrients existing in the top-soil layer, but also in the deep-soil layer. This is more obvious for N transformation.

At Raichur (Karnataka),Jagadish *et al.* (2019) found that soil-available nutrients status after harvesting of direct-seeded rice was notably greater with fertigation of 125% recommended dose of N (RDN) during *kharif* season, followed by 100% RDN and both were at par, while surface broadcast application resulted in higher soil available nutrients followed by 75% RDN through surface application and both were at par. The rise in nutrient uptake might occur due to increased nutritional availability and water in the root zone as a result of frequent fertigation scheduling, and this ultimately led to better root activity as indicated by increased root volumeand root weight. The reduction in loss of nutrients primarily due to minimum leaching of nutrients in drip fertigation might be the reason for such results. The decrease in the total NPK status of post-harvest soil after surface irrigation and fertilization was probably due to the leaching loss of soluble forms of nutrients beyond the root zone (Anusha, 2015).

6.2Nutrient movement

During the growing period, crops continuously absorb nutrients and water from the soil with their roots, forming a depleted zone of nutrients and water around their roots. This causes different content of water and nutrients between root zone soil and bulk soil, and thus water from the higher potential point with a distance from roots moves to the lower potential point close to roots, finally reaching its balance. Nutrients dissolved in soil water also move with water, leading to a decrease in the nutrient concentration gradient. Water influences nutrient movement in three ways namely interception, mass flow, and diffusion, and thus influences nutrient uptake by plants directly or indirectly. Some nutrients such as Ca, Mg, and

N are transferred by mass flow, whereas others such as P and K mostly by diffusion. Mengel *et al.* (1969) proved that mass flow, diffusion, and interceptioncontributed 82%, 7%, and 11% of the total N uptake of wheat in drylands, respectively. For crops like sugar beet, spring wheat, and spring barley, Reager *et al.* (1981) found that the contribution of nitrate–N by mass flow occupied 100%, 40%, and 110% of their total N uptake, respectively. The movement of mineral nutrients in soil is essential for crop uptake. Water deficit affects not only affect nutrient amount in solution, but also the movement rate of mass flow and diffusion. The impact of a water shortage on mass flow is according to the extent of the decline in soil water potential, while that of diffusion largely on water potential changes. The role of water on nutrient movement can be studied by determining nutrient concentration changes at different points of soil by using different water treatments over a period of time. If the nutrient concentration is separate from the original, then it suggests that water carries the nutrients from one point to another. Otherwise, there isn'ta movement or the movement cannot be measured (Barber, 1984). However, this method is only suitable for soil without plants. If plants are grown, their roots can extend toward different areas and directly absorb nutrients from points where roots reach, and this may drive nutrient movement in the soil. For this reason, the separation of the role that water plays in comparison to that of plant roots to nutrient movement should be considered.

6.3Nutrient-use efficiency

Although nutrient uptake and water intake are two independent processesin nature, water status in soil greatly affects nutrient uptake and efficiency.Water deficit causes water stress to plants, inhibits plant root growth, reduces the absorbing area and capacity of plant roots, increases the viscosity of sap, and thereby, decreases nutrient uptake and transfer. Zhao and Zhang (1979) demonstrated that when the water content of soil in pots was below the wilting point, N fertilizer added to soil was almost useless to plants, the N recovery being only 1.9%. In contrast to this, when water content was adequate, the N recovery was increased to 35–39%. The studies conducted by Singh *et al.* (2004) at Modipuram (Uttar Pradesh), revealed that continuous submergence of rice fields showed nitrate-N loss than intermittent submergence (irrigation at 2-3 days after disappearance of standing water). Application of excessive N dose further accentuates the nitrate-N loss beyond the root zone.Using the formula, we can calculate the agronomic nutrient use efficiency (AE) -

$$AE = (GY_T – GY_C) / AF_T$$

Where, GY_T = grain yield (kg ha^{-1}) in respective fertilizer treatment

GYc = grain yield (kg ha^{-1}) in respective control treatment

AF_T = amount of applied fertilizer (kg ha^{-1}) in respective fertilizer treatment

Nutrient use efficiency (NUE) depends on the plant's capacity to take up nutrients efficiently from the soil, but also depends on the inner transport, storage, and remobilization of nutrients.Kakade *et al.* (2023) while working on aerobic rice (cv. Avishkar) at Akola (Maharashtra) foundthemaximum nutrient use efficiency of 23.67 under drip fertigation with 75% recommended dose of N and K (RDNK)in 5 splits, followed by drip fertigation with 100%RDNK in 5 splits (19.83), drip irrigation with100% RDF soil application (18.63) and drip fertigation with 125% RDNK in 5splits (17.91). Nutrient use efficiency (NUE) at 75%RDNK was 37.68% more than 100% RDFthrough soil application. When it comes to drip fertigation,there was efficient utilization and preciseapplication of nutrients according to thenutritional requirements of the crop as comparedto conventional soil application of fertilizers which might have resulted in better NUE.A similar kind of result was reported by Modinat*etal.*(2014).At Raichur (Karnataka)Jagadish *et al.* (2019) assessed the impact of irrigation scheduling and fertigation on NUE and WUE of drip-irrigated direct-seeded rice in clay soil. They discovered that with various fertigation schedules, the NUE was significantly higher with 75% RDN through fertigation, followed by RDN through fertigation, while fertigation of higher levels of N (125% RDN) and traditional broadcast periodically of the recommended N resulted in the lower NUE. Application of 125% RDN through fertigation resulted in significantly higher followed by 100% RDN through fertigation, while traditional surface broadcasting of RDN recorded the lower phosphorus use efficiency (PUE) and potassium use efficiency (KUE), followed by fertigation of 75% RDN. Anusha (2015) reported that, maintaining high soil moisture content or higherwater potential favoured high nutrient uptake. Due to decreased soil moisture, which may have decreased nitrate reductase activity, nitrification, and P diffusion from the soil to the root surface, a decrease in total NPK absorption was seen in the non-fertigation condition.

6.4Nutrient distribution in plant

The amount of water in the soil affects the flow of nutrients from plant roots to its aboveground portions. The influence of water deficit on N distribution was different for different crops. Despite roots being mainly responsible for the supply of N in most cases, water contributes a large portion of N to the aboveground part. Dong (1992) discovered that an apple tree's leaf N content dropped when there was a water deficit, and promoted N transferring from new branches to old organs in trees without fructification. Due to different distribution, new organs contained much less N. Such changes were only found in newly growing branches of old trees with fructification. For cereals and leguminous crops, water deficit at later stages only reduced the transfer of photosynthesis products from leaves, but N transferred to seeds and storage proteins were much less influenced. El-Ghamry*et al.* (2017) observed that the distribution of both macro- or micronutrients in snap bean starts from the roots, where the roots are the organ competent fornutrient uptake. The elements in the plant can then pass through the stem, moving to the leaves, where all the vital processes and metabolism take place. Leaves, in turn, transmit metabolic products (proteins, vitamins, minerals, or other components) to grains. From the movement of elements within the bean plant, it was shown that the stems have the lowest nutritional content as theyrepresent only a receptacle between the root and leaves. While, the highest content of these elements within the beans was observed in the leaves, whichrepresent the place where all the vital processes and metabolism occur. The distribution of elements in the bean plant can be arranged in the following order: stems < roots < grains < leaves.

6.5Crop yield

In order to address the issue of agricultural productivity and water use, the Food and Agriculture Organisation (FAO) developed a straightforward equation in the late 1970s that states that a loss in yield is correlated with a comparable decrease in evapotranspiration (ET). The yield response to ET is specifically described as

$$(1 - Y_a/Y_x) = K_y\,(1 - ET_a/ET_x)$$

Where,Y_x and Y_a are the maximum and actual yields, ET_x and ET_a are themaximum and actual evapotranspiration, and K_y is a yield response factorrepresenting the effect of a reduction in evapotranspiration on yieldlosses. The K_y values are crop-specific and vary over the growing season according to growth stages with $K_y>1$ (crop response is extremely sensitive to water deficits, and when water use is decreased due to stress, yield decreases are proportionately bigger), $K_y<1$ (crops are more resilient to water shortages, recover from stress to some extent, and show yield decreases that are not proportionate to decreased water usage) and $K_y = 1$ (lower yields are directly correlated with lower water use).The following crop-yield and water relationships and deficit irrigation were analyzed, and the resulting Ky values were determined: alfalfa (1.1), safflower (0.8), sorghum (0.9), soybean (0.85), cotton (0.85), sugarbeet (1.0), groundnut (0.7), sugarcane (1.2), maize (1.25), sunflower (0.95), and potato (1.1). This function pertains to the generation of water and is applicable to all types of crops. K_y succinctly conveys the core of the intricate relationships—which entail several biological, physical, and chemical processes—between a crop's water consumption and production. Considered as one of FAO's landmark accomplishments, this method and the calculation algorithms for calculating yield response to water were published considerably earlier

(Doorenbos and Kassam, 1979) and were widely used globally for a wide range of applications. Jagadish *et al.* (2019) while studying the effect of irrigation scheduling and fertigation on NUE and WUE of drip-irrigated direct-seeded *kharif*rice in clay soil at Raichur (Karnataka) found that, among the fertigation levels, 125% RDN and P and Kbasal was superior to the other fertigation levelsand obtained the maximum grain yield (5205 kgha^{-1}), strawyield (5897 kgha^{-1})as well as yield attributes, *viz.* panicle numberplant^{-1},panicle weight, total grainspanicle^{-1} and test weight in addition to second highest harvest index (0.46). The 100% RDN and P and K basal treatment was next in the order for yield and yield attributesand was comparable to the previous treatment during individualyears, while 100% RDF through surface applicationreported the lowest harvest index, yield attributes, grain yield, and straw yield. Frequent dressings of N through drip irrigation coincided well with the actual needs of the crop, thereby favouredgrowth ultimately resulting in yield improvement. Contrary to this, the surface application failed to match the real-time demandfor nutrients and hence adversely affected yield. Furthermore, in the case of fertigation, there was improved nutrient availability and solubility in the root zone. Anusha (2015) alsoreported similar results. Due to decreased soil suction caused by the soil being kept close to field capacity during the growth period in the active root zone, rice yield under drip fertigation was improved. This promoted improved water use, increased nutrient uptake, and superb soil-water-plant relationship maintenance with increased root zone oxygen concentration (Santhosh, 2016).

For successful crop cultivation in dry areas, full use of groundwater and precipitation including eliminating run-off water or harvesting it for subsequent use, joint application of fertilizers with water-saving irrigation have to play a synergic role. Wang *et al.* (1993) found that a significant interactioncould not be realized for winter wheat and spring maize until a high rate offertilizer is applied. Over-supply of water and N may delay crop maturation by encouragingexcessive vegetative growth, weakening stems, and subsequent lodging, in addition to wasting water and N by excessive uptake and over-consumption. Over-supply of water may lead to nutrient loss by leaching, while shortage of water supply may bring about high nutrient concentration in soil, leading to difficulties for crops to take up water and nutrients; and even making plants die before grain filling (haying-off effect). Based on these considerations, attention should be paid not only to the input of water and nutrients, but also to their rational combination. That is, for the addition of water, one should consider nutrient supply, and for the addition of nutrients, one should consider water coordination, so that limited nutrients and water can produce optimum effect.

7 Some proven technologies for improving the effectiveness of water and nutrient utilization

a) In rice, a lower level of standing water produces more number of tillers. Regarding yield, NUE, and WUE improvement after rice transplanting, a week-long submersion followed by soil moisture maintenance at saturation is just as effective as an ongoing submersion. Consequently, it is necessary to apply irrigation to transplanted rice two to three days after the standing water has disappeared.

b) On sandy-loam soils of Indo-Gangetic Plains, maintaining continuous submergence or saturation or irrigating the rice crop at the appearance of hairline cracks in the soil is equally effective. Application of irrigation at hair-line cracking or 2-3 days after the disappearance of ponded water has to be done to economize the water use and enhanceNUE.

c) On sandy soils, 5 irrigations to wheat are given at different phenological stages (crown-root initiation, tillering, flowering, milk, and dough) in order to obtain a high yield.

d) In wheat, a delay in first irrigation beyond 21 DAS significantly reduces the grain yield, whereas scheduling of irrigation at irrigation water:cumulative pan evaporation (IW:CPE) 1.0 is recommended for the highest grain yield.

e) Band placement of P and splitting of K fertilizer in the irrigated ecosystem was found better over surface broadcasting.

f) Use of leaf-colour chart (LCC) or sensor-based N management synchronizing with irrigation water scheduling results in higher yield, WUE along saving in N.

g) Application of irrigation water only during crucial phases of crop growth and its synchronization with real-time nutrient management will enhance both WUE and NUE.

h) Use of crop residue as surface mulch has to be done to check soil water evaporation, curb weed population, and increase water and nutrient availability.

i) Growing intercrop having less water requirement is done along with more water-needing crops on raised bed and furrow planting technique.

j) Adoptionof 4 Rs stewardship (right time, right method, right source, and right amount) for irrigation water and nutrients is needed for higher efficiency.

k) Use of slow-release fertilizers like sulphur-coated urea, neem-coated urea, and urea super granule and application of irrigation at IW:CPE 1.0 in wheat is needed for high yield and NUE.

l) Conservation tillage, combined with excellent management practices reduces soil micro-climate temperature, improves water intake, creates a deeper root zone, and provides additional water for the crops during the period of moisture shortage.

m) Deeper placement of plant nutrients particularly in water-limiting areas is more likely to give a greater response than placement at or near the surface. Since soil moisture content remains higher in lower profile during dry spells, deeper placement of fertilizer becomes more available to the plants.

n) Fertilizer application through a micro-irrigation system (MIS) which combines both nutrient and water use provides these inputs directly to the root zone and ultimately brings the maximum NUE and WUE.

8 Research accomplishments, gaps, and future needs

Studies related to the interaction effects of water and nutrients on cropyield and nutrient and WUE were initiated much later because suchresearch concerns multiple factorsand needs several treatments thatare difficult to manage. Because of the short supply of fresh water and fertilizerpollution becoming more serious in the world, there has been a focus onsuch investigations and some achievements have been made in manycountries, either in rainfed areas or in irrigated areas. One of the mainnutrients for concern is N. In rainfed areas, the studies concentrate on Nfertilizer and soil-water interaction, attempting to mobilize soil water playing a full role by rational N fertilization, and producing maximum positiveinteraction effect. In irrigated areas, however, the major emphasis lies on the impactof nitrogenous fertilizers and irrigation to obtain high sustainable yields, while savingwater, controlling groundwater pollution, and reaching high efficiency. By now, a variety of studies have been conducted on different aspects, and greatprogress has been made. Even though, there still existsbelow mentioned issuesthat need further studies in the future.

a) *Delineating drylands into different regions and determining thepriority issue in each region:*Although water shortage is regarded asthe main constraint in dryland areas, it is not always true. In some regions orsome fields in the same region, crops have no response to water application,but have a remarkable response to fertilization. This shows that nutrientdeficiency is the major constraint; without the supply of adequate nutrients,water cannot play its role. For this reason, the delineation of drylands intodifferent regions and the ascertainment of the major constraints related towater or nutrients in a specific region is the priority. It is impossible tohave a good harvest while reducing pollution by application of eitherfertilizer or irrigation until the major constraint is found.

b) *Determination of the most efficient time or growth stage for the inputof nutrients and water to different crops:*Each crop has differentrequirements and sensitivity to water and nutrients at different growth stages,and thus input of nutrients and waterat different stages will have differenteffects. Apparently, there have been reports that at an early stage of a crop, deficiency of waterproduced a compensatory effect, and crop growth, photosynthetic rate,osmotic regulating ability, water-holding capacity of plant cells, energy metabolism, and physiological synthesis were all better in restoring water supply aftera dry spell than those continuously retaining high water supply. For this reason,the input of nutrients and water could achieve the highest efficient use of water only atthe most suitable time and nutrients. Based on such considerations, we shouldinvestigate the crop response to water and nutrient supply at different times,and determine the optimum efficient stage, the stage at which deficiency ofwater or nutrients has no serious influence on crop yield, and the degree ofdeficiency that crops can tolerate or can allow to a certain extent. In such a way,we can take adequate measures to regulate the water supply and use suitable levelsof water and nutrients together at the most efficient stage. Such research hasbeen done for some crops, but not for others.The foundational substrate for plant growth, soil serves as a vital reservoir for the provision of nutrients and water to plants. The only way that the roles of water and nutrients can be seen is through the soil, which has the power to alter the forms and availability of these elements.The soil's ability to hold water determines the quantity and frequency of water input, while the soil's ability to supply nutrients determines the amount that is accessible. As a result, soil qualities have a direct impact on how water and nutrients are added. For the purpose of guiding fertilization and determining the amount and timing of fertilizer application, basic information about available nutrient quantities, their release process, time, and the harmonic degree of their supply from the soil and that taken up by plants under different water conditions can be revealed. Likewise, revealingsoil capacity for water conservation and the availability of water added to soils with different textures and its use efficiency under given conditions canclarify the direction and strategies for management. In addition to soil itself,tillage systems can change soil properties and thus play a great role in waterstorage, utilization, and availability. In dryland areas, both conventional andmulching tillage are used and such characteristics should be connected to plans and management of water and nutrients.

c) *Mechanism of interaction between nutrients and water, particularly how nutrients improve WUE:*Even though the mechanism of the two-factor interaction has been the subject of several studies, these investigations are frequently restricted to a small number of variables, most only in one aspect, and thus results aredifficult to interpret the phenomenon of entire plant behaviour. In fact, any stressfrom water or nutrients not only affects one property, but the entire process inplants. For instance, any stress can influence plant growth, decrease biomass,reduce photosynthetic efficiency, enzyme activity, metabolism process, andothers. As a result, these studies cannot reveal which was the primary cause andwhich was the secondary cause induced by the primary. To comprehend how nutrient deficiencies affect plant water, more attention should bepaid to two aspects namely, water intake and plant retaining water. Radin and Boyer(1982) reported that N-deficiency reduced the root membrane permeability ofsunflower by 50%, leading to a serious inhibition of leaf swelling pressure andexpansioninthe daytime. We recently noticed that the same water stress affected plant development differently. That is, at high temperature, the influence wasserious while at low temperature it was slight. When the temperature was high, the fertilized leaves had a lower temperature than the unfertilized ones, whilethe transpiration velocity (rate) may not be higher. Obviously, in addition tothe influence of water intake and consumption, fertilization may also maintaina proper temperature of plants. This phenomenon makes us assume that one ofthe main aspects of water stress may be caused by the reduction of transpirationand the rise of temperature in the leaf. This could result in a metabolic imbalance, and maintaining a healthy metabolism and controlling plant temperature may be closely related to the availability of nutrients. Investigation starting from such phenomena, we may reveal the nature of water tonutrient supply relation, and that of the supply of nutritional materials ineliminating the dryness stress.

9 Summary and conclusions

India's drylands cover vast regions in western territory. The area experiences a water deficit as a result of low precipitation and irregular rainfall distribution. Sparse vegetationcoverage along with windy climate and frequent rainstorms have led to seriouswind and water erosion, which is further intensified by human activities.Crop output is primarily limited by two factors: an inadequate supply of water and nitrogen stress caused by soil degradation from severe erosion. There is some possibility for agricultural output in places where scarce water resources are not being properly utilized.

In drylands, nutrient input is crucial for crop productivity. Fertilizers, especially organic ones, can improve the amount of organic matter in the soil, increase the amount of water that the soil can hold, encourage the growth of longer roots, and increase the amount of water that the roots can collect from deeper soil layers. As a result, it enhances plant physiological activities such as water status, osmotic pressure regulation, high activity of nitrate reductase in plant leaves, high photosynthesis, and transpiration intensity, while lowering evaporation. It also increases plant tolerance to drought. All of these help plants maximize the efficiency of their water and nutrient absorption.

A significant amount of N can be transferred to the aboveground portion of plants by effective water management, which can also impact the composition of nutrients in plants and the movement of minerals from the soil to the roots and then to the aboveground parts of plants. This can also increase nutrient availability and the transformation of nutrients in fertilizers or soil. Plants that experience a shortage of water experience water stress, which hinders the growth of their roots, diminishes their absorbing areas and capacities, increases the viscosity of sap in the xylem, and reduces their efficiency and uptake of nutrients.

Enough water and nutrients can boost each other's effectiveness and create positive interactions. A lack of water can lead to a high nutrient concentration in the soil, which makes it difficult for crops to absorb and use both water and nutrients, while an excess of either or both might postpone crop maturation by promoting excessive vegetative growth.

In the worst situation, plants can perish and cause the "haying-off" effect. Given the strong relationship between nutrient efficiency and water supply, the soil's water status and nutrient-supplying capability should inform the balanced application of nutrients as well as the types, ratios, amounts, timing, and methods that should be used.

Data availability declaration

The authors did not use any data as such from any online and off-line sources. Hence, there was no need to providea declaration on data availability for the said review article.

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