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Morphophysiological Traits, Biochemical Characteristic and Productivity of Wheat under Water and Nitrogen-Colimitation: Pathways to Improve Water and N Uptake

Nawab Ali and Mohammad Akmal

Abstract

Drought stress is the most prominent limiting factor and abiotic stress that manipulates the physiological pathway, biochemical traits and hence negatively affects wheat crop productivity. The global nitrogen (N) recovery indicated that about two-fifths of N inputs are lost in the ecosystems through emission, denitrification, gaseous loss, leaching, surface runoff and volatilization etc. Farmers are using higher rates of N to harvest maximum yield but about 50–60% of applied N to crop field is not utilized by the plants and are lost to environment causing environmental pollution. These deleterious environmental consequences need to be reduced by efficient management of N and/or water. N-availability is often regulated by soil water; hence crop is experiencing N- and water-limitation simultaneously. There is great impetus to optimize their uptake through interconnectedness of water and N for yield determination of wheat because of the water scarcity and N losses. It is further advocate that there is need to investigate the intricate role of economizing N rate and water simultaneously for wheat crop growth, yield and backing quality may be beneficial to be investigate.

Keywords: drought, water-N co-limitation, physio biochemical traits of wheat, N losses, NUE and WUE

1. Introduction

Wheat is one of the most important staple food crops supporting the world population. It ranks the second most important cereal crop of the world grown on about 220 million hectares (mha) area with 716 million tons food grain production and 3.2 tons per hectare productivity globally [1]. The current wheat production meets the demand for the existing population, but we will have to increase the production with time keeping in view to achieve the target of 858 million tons by 2050 against the current production globally [2]. Hence about 1.5% annual increase in next three decades should be kept under consideration to feed the overwhelming population. Similarly, about 37% of the wheat is cultivated as rainfed where drought

is the most dominant constraint to limit wheat production [3]. Wheat is extensively grown in Asia, where Pakistan ranks eight in term of production (25 million tons) in the world [4]. The productivity of wheat is less than the 2.89 million tons per hectare for population with annual increment of 1.8% [5]. Wheat production affected by various biotic and abiotic stresses. Among the abiotic stress, water stress is affecting the vegetative growth and ultimately affecting yield of the wheat crop [6] (**Figure 1**).

Drought stress is the most prominent factor in crop production that affects the yield stability in the world [6]. Likewise, in rainfed areas the erratic rainfall is also the prime factor that limits crop productivity in in semiarid areas [7]. The occurrence of insufficient rainfall which does not meet the water requirement of the crop life cycle in certain areas occasionally cause the total crop failure [8]. The use of ground water is practice for crop production, and this ground water is declining with time with significant adverse effect on the water table due to the non-judicious use of the ground water resources [9]. Therefore, certain water conservation measures and water saving strategies and techniques should be adopted to cope with this adverse condition thereby conserving the precipitation water in the rhizosphere for the optimum crop production [10, 11].

As an essential macronutrient of plants, N is necessary for the vegetative growth, biomass, protein synthesis and the photosynthetic machinery of the crops [12]. This N is available in various forms in the rhizosphere, i.e. organic, such as in the form of amino acid and proteins, and inorganic forms, urea, nitrate ions (NO_3^-), ammonium ions (NH_4^+) and is also found in the form of other nitrogenous compounds [13]. Of them, only NO_3^- and NH_4^+ are the forms of soil N that are easily taken by the plants through roots from the rhizosphere [14]. The aforesaid two forms need enough soil moisture for efficient absorption through the plant roots because of their high mobility in water [15]. The soil water is extracted by the plants through its roots and thereby using it for various physiological processes, maintaining internal temperature and for the process of transpiration [16]. Plant uptake various nutrients from soil solution including N for the optimum growth and development. In drought prone areas or areas where there is less and/or no water availability because of the shortage of water or undependable nature of the

Figure 1.
Schematic representation of the drought effect on physiological processes, growth and yield.

rainfall, plants are with lower N uptake and hence the overall physiological process and activity of N assimilation enzyme is also retarded [17, 18]. Therefore, the plants ability to uptake N from the soil is not only the function of N concentration and availability in soil but also the soil moisture in the root zone [19].

Soil water and Nitrogen (N) are considered as the key limiting factors for maximizing plant growth, yield and quality [20]. The effect of these limiting factors is most prominent in the growing area where water stress is prevalent [21]. All the metabolic processes, biomass assimilation, growth functions and nutrients allocation in the plants are controlled by the interaction of N and water [22]. It is therefore kept in mind that wheat yield might be increased when crop ins not restricted with both N and water supply. For the availability of N optimum moisture in soil is needed. Contrary to this, enough amount of N needs to be in soil to make use of water available. In most areas, wheat yield is affected by the drought induced N deficit. Wheat morphology, physiology and biochemical character is also affected by water stress and nitrogen dynamics in the rhizosphere.

2. Morphophysiological, biochemicals and yield of wheat under water and N-colimitation

Water and N availability, the most limiting crop growth factors affecting adversely the morphological traits, physiology of the crop, alter the biochemical changes in the grains and shoots and final yield of the crop [23]. The resource use efficiency of N and water for the crop is the need of the day. Water stress adversely affects the vegetative growth, physiological processes, biochemical properties of the grains and shoots [24] (**Figure 2**). The amount of N applied to the crop is determined by the soil moisture status, amount and frequency and frequency of precipitation during the crop growth season [25]. The higher photosynthesis, water use efficiency (NUE) and water uptake could be achieved with optimum N supply under optimum water supply [26]. Leaf anatomy, leaf rolling, leaf hairs, stomatal positions and opening/closing, are the traits of wheat crop to withstand with under various environmental stresses especially water

Figure 2.
Morphological, physiological and biochemical dynamics of plants affected by water stress.

deficit [27]. Likewise, the photosynthesis rate, transpiration, osmotic potential, relative water contents, stomatal conductance are also affected by water and N depletion [28]. Rubisco efficiency, photochemical efficiency, reactive oxygen species, antioxidants defense system, abscisic acid generation, proline accumulation, polyamines generation, increase in antioxidative enzymes, carbohydrate and protein dynamics, amylose and amylopectin contents are affected by under water and N colimitation [29].

2.1 Morphological traits of wheat under water and N colimitation

The strong association of WUE and NUE are observed commonly in different agriculture systems including crop husbandry [29]. Certain management practices which are in the way to enhance N and/or WUE at the same time are considered beneficial in term of production cost for the crops especially cereals thereby economizing water and N inputs separately [30]. The morphological attributes of the wheat crop especially the leaf traits i.e. leaf shape, size, expansion, leaf area, senescence, waxiness, leaf hairs and pubescence and the cuticle tolerance of the wheat is affected under water limited conditions [31, 32]. Similarly, the root characteristics i.e. dry weight, density and root length are adversely affected by soil moisture limitation in the rhizosphere [33]. Despite this, the vegetative and reproductive stages of the wheat crop are also affected by water deficit and limited N supply [34]. The better strategies adopted by the plants by modifying its life cycles to theses abiotic stresses (i.e. water and N deficit) are early maturation, small plant size and reduced leaf area for the drought tolerance [35]. It is observed that under water limitation, the flag leaf length is increased, and no significant change was observed in leaf width [36]. Hence, leaf expansion is the function of water extracted from the rhizosphere through root and its abundance in plant tissues [37]. A decrease in leaf number, size and longevity may be observed under water and N limitation subsequently and their non availability alone as well [37]. In wheat crop, the leaf development is significantly affected by soil moisture depletion thereby decreasing overall biomass [38]. Similarly, N is considered as the integral part of the plant and plays a key role in increasing the leaf area, plant height and finally biomass of the plant under optimum supply [39]. Therefore, both water and N are equally important, their distribution and prevalence should keep in mind as there is a strong linkage between water and N limited supply [40]. Better morphological attributes with less production cost could be achieved under N and water colimitation.

2.2 Physiological response of wheat under water and N colimitation

In regulating plant growth, N plays vital role with a prominent impact on the crop physiology under drought induced N deficit [41]. The biomass of the wheat crop is not only affected under low N availability, but does significantly increased under optimum water supply, mainly because of the higher N content in the rhizosphere which clarifies that with the optimum N supply the presence of adequate availability of soil moisture is therefore essential for biomass, yield and physiological attributes of the wheat crop [42]. The N deficiency the sensitivity of the stomata under water deficit condition in drought prone areas [43]. The leaf photosynthesis rate is significantly affected by the optimum supply of both N and water to the crop [44]. Increase in the photosynthetic activity and biomass accumulation is observed under optimum water and limited N supply [45]. Water use efficiency (WUE) is enhanced through photosynthesis, stomatal conductance and mesophyll conductance in wheat crop and thus ultimately increasing N uptake and nitrogen use efficiency (NUE) [46].

Non availability of soil moisture will not only affect N supply but also have bad effect on N cycling [47]. Thus, water plays vital role in the availability of N in the soil solution to crop and thereby enhancing the photosynthesis process, translocation of assimilates, metabolism and conversion efficiency of the crop [48].

2.3 Biochemical traits of wheat crop under water stress and N limitation

Certain different compounds and metabolites that are accumulated in the crop under water deficit conditions to cope with the drought stress imposition [49]. These metabolites are of key importance because of their peculiar biochemical routes and thereby enhancing the tolerance mechanism in crop plants [50]. A cross talk between various biochemical substances and metabolites are initiated through drought signaling [51]. Various substances are accumulated in the plants body under abiotic stresses especially water stress. Under water limited conditions, proline a key metabolite, that is accumulated in higher concentration under dehydration [52]. The antioxidation enzymes that scavenge the ROS (reactive oxygen species) through various osmo-protection processes that includes stability of the membrane, osmotic adjustment and gene signaling are strongly associated [52]. The vital role in drought tolerance and strong defensive antioxidant mechanism in wheat genotypes are strongly correlated with high proline concentration [53]. The genotypes grown in rainfed areas having high proline concentration compared with the ones grown in irrigated and/or humid areas [54]. Various internal physiological processes are taking place under the crop plants to cope with the drought stress [55]. Plant growth is inhibited, water loss and stomatal closure are regulated, guard cell ion translocation is alternated under water stress through the translocation of ABA from roots to leaves [56]. The wheat crop having less ABA accumulation in leaves are considered to be susceptible to drought stress compared to those which accumulate high proline contents in leaves are drought tolerant [57]. Similarly, the wheat genotypes with high proline concentration in the leaves exhibited better water use efficiency [58]. In wheat crop auxin is considered as negative regulator for drought stress. Similarly, the indole acetic acid (IAA) contents also decreasing under water limitation [59]. The antioxidant enzymes (POD), H₂O₂, glutathionse (GSH), proline, and malondialdehyde (MDA) concentrations are measured maximum in the wheat plants subjected to water stress [60].

2.4 Yield and yield contributing traits

Most of the yield traits that are associated with the improved productivity in water limited areas are complex and polygenic in nature [61]. Drought stress significantly affected the yield and yield attributes of wheat compared with well water conditions [62]. Thousand kernel weight decreased by 16% under water limited condition thereby affecting overall grain production of wheat crop under drought prone environments [63]. Similarly, the most important yield contributing trait i.e. grain number were also affected by the water stress with less grain number in the crop under drought stress imposition [64]. All the yield components are affected by the drought stress, but the effect was more prominent on grain weight and grain number that contribute to the economic yield of the crop [65]. Water stress causes reduction in grain number to a greater degree that size of the grain, hence grain number exhibiting more plasticity that rest of the components [66]. The narrow variability and low plasticity of the grain size under water stress environments resulting in efficient transport of the pre anthesis assimilates to sink [67]. The reproduction process in the plants is severely affected by water stress, cereal crops exhibits a strong adaptive mechanism up to some extent through the accumulation

of the photosynthates in various parts i.e. stem and roots in early growth phase and having the ability to reallocate the assimilates to the sink in reproductive phase of development [68]. The efficient use of the resources like limited water and N rates are the better strategy for wheat production [69]. For primary productivity photosynthetic capacity of the crop plants is the key to higher yield [70]. Water use efficiency provides a simplest mean of assessing whether yield is limited by water supply or other factors and is considered an important component of adaptation to water deficit conditions [71]. As the amount of water used is strongly affected by crop management, a good understanding of crop management effects on WUE may provide researchers opportunities to identify and select appropriate crop management practices for improved water use efficiency [72]. Limited supplemental irrigation and fertilization during the growth season can significantly increase WUE and wheat yield [73].

3. Pathways to improve water and N use efficiency

3.1 Approaches for enhancing water use efficiency (WUE)

Certain agronomic, soil management strategies that may improve the WUE are discussed as under.

3.1.1 Agronomic perspectives

The water use efficiency is the function of the agronomic practices that includes tillage practices, drought resistant and adaptive cultivars, soil fertility and pest management [74]. The crop growth and yield tends to increase under no till system or incorporation of the crop residues which directly influences the availability of soil moisture [75]. Similarly, WUE of the wheat crop enhanced under optimum sowing window, row spacing and seed rate which ultimately increments in wheat production [76]. Decreasing row spacing and increasing seed rate could enhance water soil moisture and thereby increasing water use efficiency [77]. Under optimum row spacing weeds growth is discouraged and hence crop may uptake nutrients and water efficiently [78]. Adjustment in the crop growth season through alteration of the sowing dates keeping in view the seasonal transpiration demand [79]. Early sown crop under conservation agriculture could also increase WUE of grain crops. Drought resistant cultivars resulting in high WUE than the cultivars which are drought susceptible [80]. A well-prepared sowing beds and leveled fields are the prerequisites for water saving and greater yield harvesting. The laser leveling is considered as the effective method responsible for various benefits i.e. germination uniformity, irrigation time reduction, decrease in pest and decreasing production cost [80]. The exogeneous application of certain compounds like silicon, selenium, potassium, hydrogel etc. increase the water use efficiency of the wheat crop under stressful environments, decreasing the adverse effects of biotic and abiotic stresses, enhance bioavailability of nutrients, photosynthetic efficiency and better light harvesting [81].

3.1.2 Soil management perspective

The crop yield and WUE could be significantly increased under better soil management practices through increasing water holding capacity (WHC), ease in soil moisture extraction and by decreasing the water losses through leaching [82]. Increment in WUE could be observed under good soil management practices,

that causes soil moisture dynamics by evaporation and infiltration to soil that tends to increase soil water retention capacity and organic matter contents [83]. It is observed over various types and classes of soils, increment in water content at field capacity (FC) is greater than that at permanent wilting point (PWP) when soil organic matter contents are increased [84]. There is also a chance to conserve soil moisture through albedo under high plant density and narrow row spacing [85]. Compared to no tillage, disturbance taken place through tillage practices are more prominent in moisture loss through evaporation. The soil evaporation could be reduced up to 50% by crop residue incorporation [86]. This shows the gaps related to soil management that are responsible and having potential to improve WUE.

3.1.3 Physiological and anatomical perspective

3.1.3.1 Stomatal physiology and biochemistry dynamics

High stomatal conductance in needs more water to fix per unit leaf area for increasing the soil and water use during transpiration [87]. For increasing WUE, during peak hours of the day when transpiration is high by preventing the loss of water from the leaves through prevention by sensitivity of the stomata. Through the process of transpiration water is lost in the form vapor which facilitates CO₂ uptake [88]. Thus stomata plays a vital role in increasing WUE, thereby controlling the water loss in the form of vapor and CO₂ gain [89]. The opening and closing of stomata is also regulated by the environment determinants [90]. Stomatal moment is controlled by the transport and osmotically active solute accumulation and the guard cells lateral moments [91]. In most of the plant leaves, stomata are separated through an epidermal cell creating space for opening and closing [92]. In certain plant species, the clustering of stomata is also considered a better strategy for lowering evaporation demand and this phenomenon in the crop plants is considered better adaptation in drought prone areas [93].

3.1.3.2 Crop environment, root architecture and harvest index enhancement

Growing of the crops in environments where there is less transpiration will result in higher WUE. The identification and allocation of such areas having less transpiration could be identified through spatial and temporal scale [94]. Enhancement in harvest index increases the water use efficiency, this provides a new research window for increasing WUE in drought prone environments [95]. The harvest index is decreased by the water stress imposition at reproductive stage of the wheat crop, hence certain strategies need to be defined to conserve the soil moisture for the future use in reproductive stage of plant growth and development [96]. Similarly, root canopy and architecture are playing important role in extracting soil moisture [96]. Root density, root angle, root hairs, root type and root length are the characteristics that determines the water uptake from various depths of the rhizosphere [97]. In wheat crop stele and xylem number are considered to be more responsive in wheat crop in water stress conditions because of the more xylem developmental plasticity in wheat crop [98]. In cereal crops, the metaxylem diameter and density are responsible for high WUE [99].

3.2 Approaches for enhancing nitrogen use efficiency (NUE)

The grain production per unit of soil available N is termed as nitrogen use efficiency. Certain approaches that should be kept in mind while enhancing the NUE of grain crop are described as under.

3.2.1 Agronomic perspective

Nitrogen is accepted universally as an essential component of crop production. The climatic condition is different for every crop. There are some of the main factors i.e. rainfall, solar radiation and temperature that significantly influence the demand for nitrogen, influence nitrogen use efficiency (NUE) and crop growth [100]. The demand of N to plant increases as plant grows showing a sigmoid curve (Figure 3). It has generally observed that nitrogen element significantly enhanced the biomass of the plant/crop if it absorbed by plant properly because maximum biomass and plant growth totally determined by the uptake and loss of nitrogen [101]. Yet, due to leaching and volatilization of nitrogen the crop cannot uptake nitrogen easily from the soil because the due to leaching the nitrogen moves down from the below root zone. Thus, efficient nitrogen management could significantly improve the nitrogen use efficiency [102].

Water availability is the essential factor that affected the NUE under limited water availability which is crucial from an environmental and economic standpoint [103]. Maximum nitrogen use efficiency (NUE) in drought tolerant varieties of winter wheat as compared with drought sensitive lines of winter wheat. Drought resistant varieties of wheat crop consistently produced higher yield as compare with drought sensitive varieties [104]. Higher nitrogen use efficiency (NUE) and water use efficiency (WUE) in drought resistant wheat varieties. Nitrogen rate parabolically increased with rainfall, while WUE and NUE were linearly related [105]. Simultaneous enhancement of NUE and WUE were more beneficial than optimization of nitrogen and water individually. It is also stated that low nitrogen application could enhanced the nitrogen use efficiency when supplied it from organic sources rather than commercial. Excess application of nitrogen to the crop could significantly reduce the crop yield and drastically decreased the nitrogen use efficiency. It is therefore, important to obtain the higher nitrogen use efficiency through adaptation of nitrogen management strategies and agronomic practices under deficit irrigation or water stress condition.

3.2.2 Rotation of crops

It is an effective strategy to enhance the nitrogen use efficiency. Effective use of soil resources i.e. nutrient and water and appropriate crop sequences could

Figure 3. Graphical representation of N needed for plant growth/N uptake pattern during life cycle the plant.

maximize the crop yield. Increase in crop yield is associated with crop rotation is known as rotation effect while monoculture practice significantly decreased the crop yield [106]. There is an effective management practice of legumes and non-leguminous crop which linearly enhanced the crop yield and other yield components. Monoculture practice in field significantly declined the crop yield and degraded the soil fertility, while crop rotation is an effective strategy to obtain the higher crop yield [107]. Leguminous crops should be included to enhance the crop yield and also suppress the weeds and decreased the risk of disease infestation. There are the following benefits of crop rotation which enhanced the nutrient use efficiency, water use efficiency, reduced allelopathy and improved soil quality [108]. Cereals are the largest consumers of nitrogen use efficiency as compared with leguminous crop. Crop rotation could reduce the immobilization and residual soil nitrate available for leaching. Leguminous crops increased the soil fertility, enhanced the soil microbial activity and improve the soil structure. Leguminous crop also add nitrogen to the soil from the atmosphere due to presence of nodules in the roots [109]. Rotation practices also enhance the nitrogen use efficiency (NUE). As compared to cereals crop, leguminous crops enhanced the soil fertility, improve soil texture and structure and enhance microbial activity. Rotation practice enhance the nitrogen use efficiency (NUE), However, they also stated from their study that nitrogen supplied to the crop following a legume have been inconsistent [110]. Several studies have been documented that NUE could enhance the crop yield when supplied it from organic sources as compared with inorganic sources. Crop rotation practice significantly increased the nitrogen use efficiency (NUE) and other components.

3.2.3 Irrigation management

Irrigation management is an appropriate strategy to improve the water use efficiency and fertilizer use efficiency. Border and furrow irrigation are traditional method used for vegetable and field crops [111]. These two practices are generally associated with higher percolation losses which resulted in low nitrogen use efficiency (NUE) and water use efficiency (WUE). These traditional methods are increasingly becoming difficult in the changing climate scenario. Adoption of water efficient irrigation and other modern irrigation techniques are the best strategies to obtain the higher NUE and WUE. Many researchers confirmed that deficit irrigation strategy enhance the WUE and NUE (water use and nitrogen use efficiency) [112]. According the several authors, maximum recovery efficiency, of nitrogen applied is due to high irrigation of overhead sprinklers. Strategy of water management is linked with the nitrogen nutrition and significantly affects the NUE and WUE [113]. Water application and their adjustment is to match the actual crop demand which is an effective management technique for obtaining higher NUE and WUE.

3.2.4 Nitrogen source and placement method

The uptake efficiency of most of the crops is dependent on the N source and application method. Nitrogen is lost (**Figure 4**) through urease hydrolysis to atmosphere when applied to the soil surface from urea based N source, this is because of the increased soil pH resulting its volatilization [114]. Farmers are increasing the application rate to their field for optimum productivity but in vain because this have a deleterious effect on soil, atmosphere and aquatic bodies as well [115]. Certain slow N release fertilizers are manufactured with the aim to reduce the losses [116]. The NUE could be maximized and losses are reduced under proper N application strategies [117]. Side dressing or band application, mixing in soil, injecting to soil sub surface of N fertilizers are the different strategies that could enhance the N

Figure 4. Schematic diagram showing various processes of N cycle in soil plant atmosphere system.

efficiency than the broadcast application. Surface broadcast N application resulting in greater loss as ammonia-N to atmosphere, this could be minimized if banded, side dressed, placed with or below seed, or injected to soil [118].

3.2.5 Physiological perspective

The vital factor which is responsible for growth and development of the crop is nitrogen, increases various traits of the crop thereby improving final yield [119]. The N availability affects the carbon and N partitioning between roots and shoots of the crop [120]. Under high N availability, the root shoot ratio decreases because of the prominent growth of shoots [121], this varies among varieties and cultivars. The timing of N availability is of utmost importance in wheat crop where it affects all the yield parameters especially tiller density, spike compactness, grain number, kernel weight and grain N and protein concentration [122]. Wheat crop store and sequester the N in vegetative stage, this stored N is re allocated to the grains during reproductive stage, of them some become the part of cell wall. In grain crops, about 50–70% of the N is translocated and accumulated at maturity [123]. The N harvest index could be improved by the sequestration of N in shoots and grains. Alteration in leaf area index and specific leaf N can enhance the NUE. Understanding these physiological characteristics that regulate plant N uptake, grain N uptake, root N uptake, assimilatory process, redistribution of N within the cell, and leaf structure and architecture can help improve NUE physiologically [124]. N uptake and LAI were found directly proportional for NUE and wheat productivity [125]. Under N- and water-limited conditions the overexpressing a downstream N assimilation gene called alanine amino transferase has increased N uptake and use efficiency [126]. Another way of increasing N uptake in plants is enhancing larger and deeper roots that can capture more available N in the soil profile. Vigorous root and shoot growth are necessary for higher N recovery [127].

4. The intricate relationship between nitrogen and water colimitation

Various literatures are present and research work has been done on the nitrogen and water stress individually but there is need to explore the intricate effect of both

Figure 5.
 The intricate relationship of water and N for optimum N uptake affecting plant physiological processes.

N and/or water (**Figure 5**) thereby decreasing cost of production of wheat crop and to enhance the grain and biomass yield [128]. Both the water and N rates need to be economized for optimum wheat production under high WUE and NUE simultaneously [129]. The effect of N and water on the process of photosynthesis is present in literature, claims the positive effect of N rate on photosynthesis. Similarly, with increase in soil moisture the physiological processes are positively influenced and results in optimum wheat production [130]. In fact, there are diminishing return that with the increase of N and water, the photosynthesis rate increases, but the rate of photosynthesis tends to saturate with further increment of water and N resulting in less WUE and NUE for the wheat crop and increasing cost of production [131]. Under certain environments, it is reported that NUE may increase under maximum supply of water and contrary to this N increment may also increase WUE [132]. Therefore, the interaction of N and water is the interplay of management, environment and cultivar collectively [133]. Application of irrigation water at higher rate may cause N losses through leaching resulting in N shortage in the rhizosphere [134], this condition also leads to stomatal closure thereby affecting the crop physiological processes. Under low N availability, photosynthesis process will be less leading to reduction in wheat productivity with less WUE [135]. On the other hand, the crop susceptibility to drought, temperature stress and may increase under high N application. Plant species differs in demand for N and water that affects the photosynthesis process. The studies also suggest that increasing both N and water has positive effect on yield rather than increment in either factor. This increment in both N and water leads to higher production cost, water loss, affecting water quality, aquatic flora and fauna and ultimately causes pollution of water and air as well [136]. It is thought that N input effect will be more efficient at low water input that the higher water supply. Similarly, the NUE decreases with higher N rate and increment in water input may increase NUE at lower N rate.

5. Nitrogen (N)-climate interaction; fix N to fix climate change

The wide spread use of synthetic fertilizers in agriculture [137, 138], fossil fuel use from the industry, leguminous crops cultivation on large scale has therefore increased the reactive nitrogen in the atmosphere in the last five decades [139–141]. Globally, a great threat is there to impair the water and air quality [142], biodiversity and human health due to unpredictable alteration in biogeochemical cycle especially N [143]. The considerable amount of N is lost through leaching in the form of $\text{NO}_3\text{-N}$ [144, 145]. This $\text{NO}_3\text{-N}$ leaching varies due to the N status of the soil and greatly depends on soil properties [146–149]. Thus, the shallow ground water and aquifers are contaminated through the soluble nature of the NO_3 in soil water [150, 151].

Worldwide, $\text{NO}_3\text{-N}$ is considered as the major concern as it deteriorates the ground water and surface water quality since few decades [152–154]. Increment in the $\text{NO}_3\text{-N}$ contents in drinking water have bad effect on human and animals health as well [155, 156], also the aquatic bodies are contaminated through its higher concentration accumulation [157–160] thereby favoring the aquatic plants to grow and nourish well [161, 162] by making a surface layer thereby impeding the solar radiation to reach the aquatic fauna [163–166] and ultimately causing the death of the aquatic fauna [167] which creates eutrophication [168]. Besides this, blue baby syndrome in infants (methemoglobinemia) and human birth defects [169] are the major serious problems linked with NO_3 contamination [170–171]. Therefore, it is of prime importance to estimate the NO_3 leaching from cropland [172] and to evaluate the environmentally compatible and economically suitable agronomic practices [173] that could maintain and/or decrease this phenomenon [174].

The increment in the NO_3 leaching loss is strongly correlated with the rainfall occurrence, intensity and irrigation volume and methods [175]. The excessive fertilization increases the risk of N loss through leaching in agriculture system [176, 177]. To feed the overwhelming population of the world, higher fertilizer application to crop field [178] is under practice have rapidly raised the NO_2 emission of the atmosphere [179, 180] and is expected to increase linearly in coming decades [188], aggravating the environmental quality [181]. Through the anthropogenic rise in NO_2 emission from agriculture sector to atmosphere thereby offset the efforts to decrease the CO_2 sully from other sectors [182].

Global warming is directly affected by NO_2 emission [183] which is considered as a major greenhouse gas [192], having 300 times more potent than CO_2 because of its greater resident time in the atmosphere usually greater than 100 years [184]. The unregulated and increasing trend of the NO_2 defines the global warming [185]. This increment in N availability in atmosphere affects the sinks and sources of NO_2 , CH_4 and CO_2 thereby potential increase in CO_2 sequestration [186].

Climate change will certainly increase the N emission, which in turn will affect the agriculture system, aquatic water bodies, humans and animals' health [187]. Thus, climate N cross talk will expose the crops to elevated O_3 [188]. Greater emission of the N will be observed from livestock and agriculture production systems as well [189]. Drought spell, erratic and unpredictable rainfall, temperature events taken place because of climate change will ultimately affects the farmers decisions and practices thereby enhancing C and N release from agriculture ecosystem [190] when higher N rates are practiced keeping in mind leaching losses [191]. N availability to crops impedes and its losses will increase under drought induction, irregularity in rainfall, high temperature events and flooding [192].

Nitrogen, the essential macronutrient responsible for plant growth and development is fundamental for farming [191]. Climate change impact may be taken under consideration for minimizing N losses [193, 194] and to manage N in better way [195–197]. Perturbation to both N and climate needs to be fixed to reduce its adverse effects environmentally compatible and economically suitable agronomic practices [198]. Firstly, irrigation water availability to field crops is a great question and this the situation become worsen in each passing day. Then the application volume to field crops in higher rates decreasing the WUE on one way and depleting the available nutrients in the soil on other hand because farmers are applying higher fertilizers to harvest maximum yield thereby ultimately increasing their cost of production. Therefore, a gate way for future research is to economize the N rates/levels for the crop growth, yield and quality by monitoring the rhizosphere moisture for irrigation water optimization till moisture allowable depletion (MAD) of the respective crops that may not affect its growth and development but also enhance the availability and utilization of the nutrients in soil solution.

6. Conclusion

This chapter provides the information regarding water and N rates on wheat physiological, morphological, biochemical, qualitative changes and yield traits of wheat crop focusing on the NUE and WUE. Drought stress is the most prominent limiting factor that manipulates the physiological pathway, biochemical traits and hence negatively affects wheat crop productivity. The global nitrogen (N) recovery indicated that about two-fifths of N inputs are lost in the ecosystems through leaching, gaseous emission, denitrification, surface runoff and volatilization. About 50–60% of the applied N fertilizer to the field are lost to environment and thus not available to the plants. These deleterious environmental consequences need to be reduced by efficient management of N and/or water focusing on their intricate relationship. N-availability is often regulated by soil water; hence crop is experiencing N- and water-limitation simultaneously. There is great impetus to optimize their uptake through interconnectedness of water and N for yield determination of wheat because of the water scarcity and N losses for enhancing wheat productivity and thereby reducing the production cost. There is need to optimize the N and water colimitation simultaneously to determine the minimum N and water to harvest optimum yield with better baking quality and hence safeguarding the environment, soil micro fauna and water bodies.

Therefore, a gate way for future research is to economize the N rates/levels for the crop growth, yield and quality by monitoring the rhizosphere moisture for irrigation water optimization till moisture allowable depletion (MAD) of the respective crops that may not affect its growth and development but also enhance the availability and utilization of the nutrients in soil solution.

Conflict of interest

The authors declare no conflict of interest.

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