

The Effects of Nitrogen and Moisture Stress on Yield and Quality of Wheat: A Review

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Abstract: This review, summaries the exposure of plants to nitrogen and moisture stress in soils, the role of N in plant physiological processes related to yield formation and moisture stress. Nitrogen is one of the key nutrients that limit crop growth of cereals in many production systems, a key factor in achieving optimum grain yield. The importance of N fertilization in increasing wheat production has been well recognized but still it is difficult to determine the quantities to apply under water deficit conditions. Nitrogen is the key element in plant nutrition limiting plant growth and crop yields in many agro ecosystems, rain fed as well as irrigated systems. Water stress is one of the most important abiotic stresses adversely affects crop production in many regions of the world. Moisture deficit differentially and significantly influenced cultivar test weight and yield. Moisture affects nitrogen nutrition through its influence on nitrogen uptake, on mineralization of organic nitrogen, and on nitrogen losses such as denitrification or volatilization. The protein content of wheat is a function of heredity, climate, available moisture and available N. Thus, optimal supply of N is required to improve crop tolerance to various stresses and to increase yield and quality parameters of wheat. Therefore, Nitrogen and moisture stress is the most limiting factor for wheat production that affects the rapid plant growth and improves grain yield, as discussed in detail.

Keywords: moisture stress, nitrogen, protein, wheat

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is an annual plant that belongs to the grass family Poaceae, tribe Triticeae, and sub tribe Triticineae [1]. It has been understood that the world's utmost significant crop is wheat, considering its geographical usage, its composition and nutrient value [2]. It is one of the major cereal crops in the Ethiopian highlands that lie between latitude of 6° and 16°N and longitude of 35° and 42° E and is widely grown from 1500 to 3000 meters above sea level [3]. Wheat is an important staple food crop all over the world [4]. Greater importance of bread wheat can be expected as a main source of food for solving the increasing population of the world [5]. Wheat is one of the most important cereals cultivated in Ethiopia [6]. Ethiopia is the second largest producer of wheat in sub-Saharan Africa following South Africa and about 1.61 million hectare of land is cultivated for both bread and durum wheat production under rain fed conditions [7]. Water and N are the most limiting factors in agricultural production in most parts of the world, especially in arid and semiarid zones [8].

Nitrogen is one of the key nutrients that limit crop growth of cereals in many production systems [9], a key factor in achieving optimum grain yield [10], a mobile nutrient in soil, and its application in large quantities at sowing may result in loss due to leaching or denitrification [11], is the nutrient with the highest extraction by crops of economic interest. The increase of grain yield in wheat in recent decades was largely due to the supply and use of nitrogen fertilizer [12]. Nitrogen application timing is important for improving crop yields and N use efficiency. Further, if the entire N is applied in the beginning, plant roots are not well developed and cannot absorb all the applied nitrogen. For these reasons, split application of N is generally recommended. The most important factor influencing grain yield of wheat was fertilizer N while soil moisture stress was the least important; Nitrogen increased grain yield primarily by increasing the number of mature spikes [13]. The importance of N fertilization in increasing wheat production has been well recognized but still it is difficult to determine the quantities to apply under water deficit conditions [14]. Increasing environmental stress on wheat production associated with climate change will affect both the yield and quality of wheat production [15]. The key to increased crop yield lies to a large extent, in the increase of usable water [16]. High yielding, good

quality wheat, regardless of its intended end use, requires there be no moisture stress induced by limited water availability [17].

Soil moisture level was the most important factor controlling plant and grain yields while nitrogen fertilizer had the greatest influence on protein content and sedimentation value [18]. Common wheat (*Triticum aestivum* L.) is one of the most important staple crops with potential sensitivity to water stress, especially in the reproductive stage [19]. Water stress can be defined as the lack of adequate moisture necessary for a plant to grow normally and complete its life cycle [20]. Water stress is one of the most important abiotic stresses adversely affects crop production in many regions of the world [21]. Moisture deficit differentially and significantly influenced cultivar test weight and yield. The overall moisture-deficit-induced reduction in grain yield was due primarily to reduction in thousand kernel weight; effects of moisture deficit on yield of specific cultivars were due largely to effects on kernels per spike [22]. Water stress could decrease the photosynthetic rate, leaf area, tuber number per stem and average tuber weight, thereby reducing the yield [23, 24]. Nitrogen could influence leaf area, active life span, chlorophyll content, tuber size and tuber bulking time to affect yield [25, 26]. The exposure of plants to water and nitrogen stress lead to noticeable decrease in leaf water potential, osmotic potential and relative water content [27]. In situations where water availability cannot be assured, a plant can be subjected to a water deficit that may diminish growth. Under water scarcity, N demand by plants is reduced, as growth rate is diminished. The relative impacts of N and water stress on wheat yield and dough quality are not well understood [28]. Therefore, it is very important to review the work done on the effect of moisture stress and Nitrogen on yield and Quality of wheat.

2. EFFECT OF NITROGEN ON YIELD AND YIELD COMPONENTS OF WHEAT UNDER MOISTURE STRESS CONDITION

Wheat grain yield significantly depended on plant nutrition at the beginning of stem elongation stage [29]. Nitrogen is the key element in plant nutrition limiting plant growth and crop yields in many agro ecosystems, rain fed as well as irrigated systems [30], it is part of the protoplasmic structural proteins, cell nuclei, nucleic acids, pigments, vitamins and enzymes [31], is the most limiting nutrient for wheat production that affects the rapid plant growth and improves grain yield. Managing N inputs in wheat production systems is an important issue in order to achieve maximum profitable production, and minimum negative environmental impact [32]. Nitrogen fertilization enhances precipitation or irrigation-water-use efficiency (WUE) [33]. Nitrogen fertilization is one of the most important and effective implements in agriculture, stimulating a lot of vital processes in plants [34]. Nitrogen transformation processes closely depend on water and its mobility in the soil. High amounts of N applied at early vegetative phase could result in more loss due to crop requirements is not high and the crop was unable to assimilate all the N absorbed [35].

In soils deficient in nitrogen but supplied with the other nutrient elements, fertilizer nitrogen, soil moisture and temperature interact in governing the yield and quality of wheat [36]. Nitrogen deficiency can reduce canopy growth and cause premature senescence, and thereby reduce yields [37]. Increased yield and WUE due to application of nitrogen attributed to increase in yield components such as number of tillers, number of grains per spike, 1000-grain weight and harvest index. [38] reported that the kernel weight in general decreased with increasing levels of available moisture in the non-fertilized treatments but showed a reverse trend when nitrogen was applied.

Plant and grain yields were increased by conditions of lower temperature, higher moisture level, and nitrogen fertilization [38]. Moisture affects nitrogen nutrition through its influence on nitrogen uptake, on mineralization of organic nitrogen, and on nitrogen losses such as denitrification or volatilization. Yield is directly related to N and inversely related to temperature and moisture stress, whereas protein concentration is directly related to all three factors. Nitrogen application promotes the absorption of soil moisture and has a beneficial role for promoting WUE, enhances precipitation or irrigation-water-use efficiency (WUE) [39].

3. EFFECTS OF NITROGEN ON WHEAT QUALITY UNDER WATER STRESS CONDITION

Water, the main component of a plant body [40], is the major abiotic limiting factor for plant growth and development [41, 42], adversely affecting crop yield and food grain production [43]. The content of protein in grain is directly connected with the overall available nitrogen, both from mineral fertilizers and from mineralization processes in soil. The protein content of wheat is a function of heredity, climate, available moisture and available N [44]. Different authors have suggested that N fertility is the principal

factor controlling the protein in grain, while soil moisture was more important in controlling yields; but [45] reported that the protein percentage of Thatcher wheat was more strongly influenced by the level of available moisture than available N. Thus there appears to be some conflict of opinion as to the relative effect of N and moisture on protein percentage.

4. EFFECTS MOISTURE STRESS ON YIELD AND YIELD COMPONENTS OF WHEAT

Wheat is grown under irrigated and rain-fed environments in all over the world [46]. Water deficit occurs when water potentials in the rhizosphere are sufficiently negative to reduce water availability to sub-optimal levels for plant growth and development [47]. Growth of wheat grain is reduced depending upon degree of water stress and on the rate of stress development; thereby limiting final wheat yield [48]. These growth restrictions limit the number of kernels that will be produced causing an irreversible reduction in yield potential. Water stress had a significant effect on plant height. Plant height in response to water stress was decreased to 19% compared to well-watered conditions [49]. Yield reduction due to water stress could be as a result of reduction in photosynthesis and translocation resulting to decrease in spikelets per spike, grain per spike and 1000-grain weight.

Stress at stem elongation stage had the highest sensitivity than other growth stages [50]. Water stress at flowering and grain filling should be avoided as they are the most critical growth stages in yield determination in wheat, because plants cannot recover, while delay in sowing resulted in reduction in yield and yield components [51]. Water stress during tillering until physiological maturity causes significant reduction of wheat grain yield cultivars. Water stress occurring at any during reproductive growth can result a drastic change in seed yield, the worst time to water stress on many grain crops in during stem elongation and flowering [52]. Water stress caused premature grain desiccation and resulted in a marked decline in grain sucrose and reduced grain weight [53]. Water deficit reduces plant growth and development, leading to the production of smaller organs, and hampered flower production and grain filling [54].

Stress was most critical during and after heading. Stress is likely to occur when the plants appear wilted and the leaves curl. Yield is reduced the most when stress starts during soft dough, flowering or heading [55]. Moisture stress reduces yield potential in the first instance by reducing the capacity to intercept radiation, slowing photosynthesis and therefore decreasing dry matter production [17,54].

Wheat plants produced relatively less vegetation matter under water stress caused by drought and therefore a larger pool of nitrogen was accumulated in grain [29]. Moisture deficit differentially and significantly influenced cultivar test weight and yield [22]. Different authors reported that the kernel weight decreased with increasing levels of available moisture in the non-fertilized treatments but showed a reverse trend when nitrogen was applied. [51] Reported that yield reduction of 16.50%, 34.00% and 25.00% was recorded as a result of water stress at tillering, flowering and grain filling respectively. [14] Reported that the flag leaf area (FLA) decrease under water deficit relative to the well-watered treatment. [56] reported that when comparing the effects of water stress on leaf area, the highest leaf area was found in the control plants of the 80% water regime, followed by the plants under 50% water regime, while leaf area of plants of the 30% had the least leaf area, suggesting that severe water deficit decreases leaf area.

Different levels of water stress have affected the growth of wheat cultivars differently, which indicates that the wheat cultivars differed in their ability to tolerate different levels of water stress. When plants were under water deficit stress, root dry weight was decreased; in contrast mild water deficit had no effect on root dry weight [56]. [57] Reported that moisture stress at different crop growth stages affected Crop growth rate (CGR) differently. The number of tillers per unit area showed that numbers of tillers/m² were significantly affected by different levels of water stress.

5. EFFECTS OF MOISTURE STRESS ON THE QUALITY OF WHEAT

Moisture stress is an environmental factor that may influence end-use quality of wheat (*Triticum aestivum* L.) [55]. Water stress and high temperature are the principle environmental parameters affecting the wheat grain quality under Mediterranean conditions [58, 59]. Wheat quality is controlled not only by genetic factors, but also by environmental conditions, especially the supply of water and fertility in soil that can change wheat quality under normal cropping condition [60]. One of the most effective methods in agricultural management for grain protein increase is water productivity management, because other factors such as nitrogen are under impression of soil moisture [61]. Soil moisture conditions had a greater influence on protein content at higher temperatures, while the largest

responses to nitrogen fertilization were obtained at the medium moisture level [18]. [62] Suggest that grain yield in wheat cultivars under water deficit conditions and photosynthetic inhibition of sources at the beginning of the grain filling period are controlled more by the source than by the sink limitation. Water stress affects both of the storage and mobilization of stem reserves [63]. Stem and spike were found to play important roles in supplying assimilate reserves for the grain filling process under stress conditions. Failing to irrigate frequently enough will put the crop into moisture stress or compound pre grain-fill moisture stress. Quality is immediately affected by reducing kernel weight and increasing screenings [17]. [64] Reported that protein levels can be enhanced by managing an increased, yet non-stress, soil moisture deficit. This enhancement is not exclusive. It requires adequate nitrogen to be available for protein development. Water stress has a significant effect on the physio-chemical properties of wheat [22]. Water stress in the grain filling period was found to affect quality parameters. An increase in protein content, falling number, gluten index, dry gluten and SDS sedimentation volume, consistent with a decrease in grain yield, 1000 grains weight, bread volume and moisture content was observed when a terminal water stress happened [59]. The water stress has played a key role to reduce the moisture percentage and fat, while it increased protein, ash, gluten contents and Zeleny sedimentation test [22]. Soil moisture level was the most important factor controlling plant and grain yields while nitrogen fertilizer had the greatest influence on protein content and sedimentation value [38]. The protein content Thatcher wheat grown in the growth chamber was increased by reduced water supply, nitrogen fertilization, and higher air temperatures [18].

6. EFFECT OF WATER STRESS ON THE PHYSIOLOGICAL COMPONENTS OF WHEAT

Water stress usually results in a decrease in leaf transpiration because of the stomatal closure which commonly occurs under water stress. Such a decrease in leaf transpiration results in an increase in leaf temperature [65]. The sensitivity of crop plants such as wheat (*Triticum aestivum* L.) to soil drought is particularly acute during the grain-filling period because the reproductive phase is extremely sensitive to plant water stress [66]. One of the primary injuries caused by water stress is loss in cell compartmentation due to the disruption of membrane stability [47]. Water deficiency stress reduced plumule length from 10.34 to 8.67 cm and radicle length was decrease in the water deficiency stress from 11.27 to 9.22 cm [66]. Most of the abiotic stress factors primarily affect the stability of cell membrane. The water stress activates the reactive oxygen species which ultimately decreases membrane stability caused by lipid peroxidation [67]. Water deficit disturbs normal turgor pressure, and the loss of cell turgidity may stop cell enlargement that causes reduced plant growth and water stress increases root shoot ratio, thickness of cell walls and amount of cutinization and lignifications [68].

The deficiency of water leads to severe decline in yield traits of crop plants probably by disrupting leaf gas exchange properties which not only limited the size of the source and sink tissues but the phloem loading, assimilate translocation and dry matter partitioning are also impaired [54]. A reduced transpiration rate due to water deficit reduces the nutrient absorption and efficiency of their utilization. Post anthesis water stress reduces carbon assimilation and, hence, the availability of current assimilates for grain filling [69]. Grain yield and 1,000-grain-weight reduction under post anthesis water stress reflect a reduction of photo-assimilates supply for grain filling. Photosynthetic rate is reduced by stomatal, non-stomatal, and leaf water status parameters [70]. The severe water stress directly affects photosynthetic capacity of the mesophyll causing decrease in carboxylation as well as electron transport chain activities, and/or induces ultrastructural changes in chloroplasts [71]. A decrease in the rates of photosynthesis and transpiration as well as in intercellular-space CO₂ concentration and stomatal conductance was shown under water deficit conditions relative to the control [72]. Water stress results in stomatal closure and reduced transpiration rates, a decrease in the water potential of plant tissues, decrease in photosynthesis and growth inhibition [73]. Stomatal closure decreases the CO₂ influx which limits photosynthesis under mild water stress and supports photo inhibition under high irradiance. Chlorophyll accumulation play vital role in the crop productivity, as they are the only pigments responsible for CO₂ assimilation. Its destruction as often observed under water stress in deleterious to the crop productivity. Moisture deficit significantly reduced Chl *a* and *b* concentrations and Chl *a/b* ratio in different crops [74].

7. SUMMARY AND CONCLUSIONS

The conclusion drawn from various reviews is that, wherever they grow, plants are subject to stresses, which tend to restrict their growth and development. So that by better understanding the impacts of N

and water on grain yield and quality, it may be possible to optimize water stress and N management. For main crop season, nitrogen can be applied in splits depending on rainfall. Because if the entire N is applied in the beginning, plants roots are not well developed and cannot absorb all the applied nitrogen. Second split may be avoided if the soil moisture is not adequate for top dressing in time. Yield and yield components of wheat are influenced by water stress and the translocation of nitrogen (N) are also impeded by water deficit. Therefore, optimization of N and water management could be an efficient way to attain sustainable agriculture. As nutrient and water requirements are closely related, fertilizer application is likely to increase the efficiency of crops in utilizing available water. Efficient and purposeful utilization of water is, therefore, important under water shortage conditions. It is also concluded that application of nitrogen is important to improve WUE and enables the plants to survive under drought stress conditions.

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