Wheat Sensitivity to Nitrogen Supply under Different Climatic Conditions

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Abstract

With the projection of the Earth’s population reaching eight billion in coming years and nine billion by 2050 which means increasing demand for food. Wheat (Triticum aestivum L.) is the main important and strategic cereal crop for feeding the majority of world’s populations. Scientific forecasts predict that wheat production in the future will be affected by climate change and will decrease on the global level. To reduce these risks, the impact of climate change mitigation strategies and management systems for crop adaptation to climate change conditions should be considered. Demand for increases in food production will have to occur on less available arable land, which can only be accomplished by intensifying production. Chemical fertilisers are responsible for 40–60% of the world’s food production. Because nonlegume plants generally require 20–50 g of nitrogen to produce 1 kg dry biomass, the natural supply of soil nitrogen usually restricts plants yield in most agricultural cropping system. The goal of ecological intensification is to increase yield per unit of land, intensify production, while meeting acceptable standards of environmental quality. This chapter discusses some aspects of connection between nitrogen supply and different abiotic conditions.

Keywords: wheat, nitrogen, drought, salinisation, climate

1. Introduction

The global wheat consumption has escalated at a faster rate than all other cereals. This growth is accounted for by the increase in developing countries, mainly in China and India, and based on the future projection, the growth of wheat consumption will continue [1]. In these two countries, the use of production inputs, primarily nitrogen fertiliser and irrigation water, has risen dramatically as well. Wheat is an important staple crop, providing 20% of all calories
consumed by people worldwide. It is the leading source of non-animal protein in human food and also makes a significant contribution to animal feed. Increasing global demand for wheat is also based on the ability to make several food products and the increasing consumption of these with industrialisation. In particular, the properties of the gluten protein fraction allow the processing of wheat to produce bread, other baked goods, noodles and pasta, and a range of functional ingredients [2].

Beside the food demand sustainable nutrient supply and climatic effect on plant productivity are two crucial topics of agricultural development. Applying adequate amount of nutrients based on genotype requirements is hard under potential conditions, especially under different abiotic loads. Nitrogen (N) is an important nutrient, which determines the amount of yield and throughout the proteins the quality as well. The increased crop productivity has been associated with a 20-fold increase in the global use of nitrogen fertiliser during the 50 years [3], and this is expected to increase by threefold by the year 2050 [4]. Inadequate application of N—deficiency and excess—can cause environmental and ecological problems. Climatic factors can improve and deteriorate crop nutrient use efficiency and yield. Drought occurs in all climatic regions and drought-induced crop yield reduction is among the greatest losses in agriculture. About 32% of wheat production areas in developing countries experience serious drought stress in different growth stages [5]. Lobell et al. [6] published that climate trends were large enough in some countries to offset a significant portion of the increases in average yields that arose from technology, fertilisation, and other improving factors. High and low temperature [7–9], irrigation [10–12], salinisation [13, 14], agrotechnology [15–17], and other nutrients [18] also have an effect on N use of wheat. These effects are depending on the adaptation and acclimatisation strategies of different wheat genotypes, the current climatic conditions and its combinations and biotic effects as well [19]. To know more about and improve nitrogen use efficiency of wheat means a way towards the sustainability. Wheat being the basic food plant and the global demand for qualitative perfect food is increasing we have no other alternatives, than step forward to smart-wheat, which will be able to survive unfavourable conditions.

2. Nitrogen requirement and NUE

Nitrogen is one of the nutrients plants need in high quantity [20], as it is a core constituent of a plant’s nucleic acid, proteins, enzymes, and cell wall and pigment system [21]. The availability of nitrogen for plants is complex, and depending on different processes in connection with nitrogen cycle in the environment (Figure 1). Through the different way of nutrition supply and agrotechnology processes, the agriculture has a main impact on global and local nitrogen cycle. Plants also can have an effect on your own nitrogen supply by connecting different bacteria or releasing different extracts, like nitrification inhibitors. Biological nitrification inhibition (BNI) is the natural ability of certain plant species to release nitrification inhibitors from their roots that suppress nitrifier activity, thus reducing soil nitrification and N₂O emission (Figure 1). Among the tropical pasture grasses, the BNI function is the strongest in Brachiaria sp. [22].
Nitrogen availability and using capacity are crucial in plant life. The chlorophyll content of wheat leaves and leaf N is closely related as the photosynthetic machinery accounts for more than half of the N in a leaf [24]. Nitrogen influences carbohydrate source size by leaf growth and leaf area duration and also the photosynthetic rate per unit leaf area and thereby source activity. The availability of N is of agricultural concern because plant metabolism is differently affected by excess, optimal and deficient levels [25]. The concept of nitrogen-use efficiency (NUE) has been widely used to characterise plant responses to different levels of N availability. Moll et al. [26] defined the most use of NUE, at least among breeders, which computes the grain dry mass divided by the total N available to a plant. It is divided into two components: NUE = NUpE × NutE, where NUpE is the N-uptake efficiency calculated as the total amount of N in above-ground plant at harvest divided by the available N in soil, and NutE is the utilisation efficiency calculated as the grain dry mass divided by the total amount of N in above-ground plant at harvest. Based on several authors, establishment N remobilisation efficiency (NRE) is also a main component of NUE [27]. The NRE—the proportion of N in the crop or crop component at anthesis which is not present in the crop or crop component at harvest—is the ability of plants to translocate the N after anthesis from the shoot to the grains. Nitrogen is the most limiting nutrient for the production of wheat [28]. Cultivars with higher NRE tend to accelerate the senescence process and increase N levels in grains [29]. It is widely understood that N accumulated before anthesis provides the major source of grain N. In wheat, around 50–95% of the grain N at harvest comes from the remobilisation of N stored in shoots and roots before anthesis [30–32]. In wheat between anthesis and maturity, the leaves had a higher
NRE than the stem and the roots [33]. About 70–80% of nitrogen, which is needed for grain development in cereals, is gained from vegetative organs before flowering stage [34]. Nitrogen use efficiency (NUE) plays a fundamental role in sustainable grain production [35, 36]. Based on several physiological parameters of doubled-haploid mapping wheat populations can lead to identification of specific loci that might be useful in marker-assisted breeding for increased N-use efficiency [35, 37, 38].

3. Temperature influence on nitrogen nutrition

Wheat growth can be impaired by heat stress at any developmental stage, and modelling scenarios predict even warmer temperatures in the future [39]. Production of wheat is affected markedly by high temperature [40, 41]. Elevated temperature alters uptake and allocation of N, thus intensifying N deficiency in plants [42]. Wheat shows enormous diversity in canopy architecture, and it has long been proposed that optimised light distribution could improve radiation use efficiency as well as light interception [43]. In heat tolerance, the activity of enzymes has crucial role. Rubisco’s affinity for CO$_2$ decreases with temperatures [44]. Therefore, increasing affinity would simultaneously improve adaptation to warmer conditions, the proof of concept coming from C$_4$ species, in which it is achieved by concentrating CO$_2$ [45]. High temperature not only degrades Rubisco but also accelerates its inactivation by addition of inhibitory sugars to its active site. Moreover, Rubisco has a relatively low turnover number as compared with the other Calvin cycle enzymes. Activity of Rubisco is mainly regulated by a catalytic chaperone—Rubisco activase— which catalyses removal of inhibitory sugars from its active site, switching the enzyme to active mode [46]. Among cereals wheat’s Rubisco has one of the best CO$_2$ affinities. Models where wheat’s substrate specificity factor of Rubisco is replaced from L. gibertii predicted increases of 12% in net assimilation [47].

Combined stress of high temperature and low nitrogen affected both the abundance and mode of regulation of Rubisco, which catalyses CO$_2$ fixation and is one of the primary determinants of photosynthetic rate [48].

4. Effect of drought on wheat nutrition

According to the most recent assessment report of the Inter-governmental Panel on Climate Change, published in 2014, levels of anthropogenic emissions of greenhouse gases are now at their highest in history [49]. Agricultural production and its effect on land use are major sources of these emissions by sharing methane and nitrous oxide gases. Greenhouse gases causing air temperatures increase, thus more moisture evaporates from land and water bodies. Warmer temperatures also increase evaporation and evapotranspiration in plants, soils, and on other hand, they will also escalate the water stress frequency and intensity with a rise from 1 to 30% in acute drought land area by 2100 [50].

Under dry conditions in the field, 75–100% of the grain yield could be attributed to stored assimilates, compared with 37–39% under high-rainfall conditions. Drought stress severely
influenced plant water status by reducing the water potential and the relative water content in wheat [51]. Optimal nutrition levels have also alleviated drought stress damage by sustaining metabolic activities under reduced tissue water potential [52]. Nitrogen supply also has a crucial role in combating drought [53]. Efficiency of nitrogen supply declined with increasing of drought stress [54]. Morgan [55], Arun et al. [56] and Binghua et al. [57] who showed that with an application of nitrogen, plants show positive influence in terms of growth and development under drought stress. Although Li et al. [58] mentioned that different grass species under drought stress did not modify physiological functions under varying N application. Water limitation reduces diffusive conductivity which in turn affects other physiological process such as energy and N metabolism. It is concluded that N uptake and its diffusion depend on environmental condition especially to water supply as also indicated by Abreu et al. [59]. Under water deficiency, roots are unable to get optimal amounts of nitrogen from soil, which has general negative effects on plant metabolisms [60]. The main effect of water restriction is certainly a reduction in N demand due to the marked sensitivity of leaf area expansion [61]. Fewer results have about light reaction affected by genotypic and nitrogen supply variations, mainly under stress conditions. By measuring the yield of chlorophyll fluorescence (Chl-fl), information about changes in the efficiency of photochemistry and heat dissipation can be obtained [62]. Under extreme drought stress when the stomatal resistance just around 0.1 mol H₂O m⁻² s⁻¹, poor performance of photosystem II (Fₐ/Fₘ) and downregulated activities of CO₂ assimilating enzymes such as Rubisco become the dominant limitations to reduced photosynthesis [63]. The optimal photochemical activity (Fᵥ/Fₘ) values were sensitive for the investigated two environmental factors, and genotype differences were established in tolerance [64]. Chl-fl parameter’s sensitivity for detecting nitrogen deficiency is different, but some of them are really applicable for describing nitrogen lack [65]. Previous drought stress studies have reported that photosynthetic rate of the leaf under drought stress is closely related to the leaf chlorophyll contents, N concentrations and stay-green characteristics of the leaf, which in turn increases the grain yield by increasing the photosynthetic process [66]. Palta et al. [67] and Hosenlou et al. [54] reported induction of N remobilisation under drought stress. Application of the high amounts of N under drought resulted to the lowest NUE [68]. Critical, sufficient concentration of nitrogen in leaf is 15–40 mg g⁻¹ DM [69]. Based on Pepó [16] and Zsombik and Seres [70] results, the dry weight production was mainly influenced by environmental factors and modified by fertilisers and genotypes. Water deprivation means higher strain than nitrogen lack with genotype difference based on dry weight value [65]. Plant responses to drought stress vary at different growth stages of the crop [71]. In wheat, tillering capacity of the crop is a major constituent of the final grain yield [72], but has been reported to be highly vulnerable to drought stress [73].

5. Salinisation and impact to wheat production

Salinisation or increased concentration of dissolved cations/anions in soil solution and/or water resources (e.g. capillary rising of saline groundwater, salinised waters used for irrigation) [74] across the (agro)ecosystems is the principal cause of most widespread abiotic constraint to glycophytes (i.e. the majority of cultivated crops, including wheat) known as salt
stress. Salt stress encompasses wide range of physiological dysfunctions as a consequence of primary salinity effects, that is, osmotic and ionic disorder. Primary salinity effects, depending on the salinity level/duration, crop/genotype type, development stage, and so on, very often cause different secondary salinity-induced effects such as reduced cell expansion and assimilate production (i.e. growth and yield reduction), production of reactive oxygen metabolites and even plant mortality [75]. The general salinity effects are quite visible and assume reduce biomass growth (shoot/root height and weight, leaf area) and changes in root and shoots colour (e.g. presence of leaf tip burns, scorching/firing of leaves) [76]. The extent to which growth and yield will be reduced under salt stress mostly depends on the salinity level and plant (crop) species (Figure 2).

Electrical conductivity (EC) is commonly used as an expression of the total dissolved salt concentration in an aqueous sample (e.g. water, soil solution) and usually express soil salinity level based on measured EC of saturated soil paste extracts (ECe) (e.g. Rhoades et al. [77]). Therefore, ECe threshold level (i.e. ECt), as a numeric value at which crop growth and yield start to decline (more or less intensive under certain slope) can be very useful for categorisation of plants from salt tolerant (halophytes) to salt-sensitive (glycophytes) (Figure 2). In general, wheat is categorised as moderately tolerant to soil salinity (e.g. a threshold EC of 6.0 dS/m) [78] although existing significant differences among genotypes that it is difficult to make a categorical statement [79]. The relative effects of salt stress on wheat vegetative

![Figure 2](image)

**Figure 2.** Simplified presence of salt tolerance in some cereals (adapted according to Maas [81]). ECt represents the threshold in soil EC that is expected to cause the initial significant reduction in the maximum expected yield, whereas the slope is the percentage of yield expected to be reduced for each soil salinity unit above the ECt [82].
growth parameters and grain yield can vary significantly among genotypes (Figure 2) and with the developmental stage at which salt stress occurs [75] as well under specific environmental conditions given that the interaction of crop (genotype) and environment is not completely understood but is likely to be significant [80].

5.1. Salinisation and wider (agro)ecological impact

Environmental salinisation process represents an increasing environmental issue especially in intensive agroecosystems such as (fert)irrigated areas [83] but also in less intensive rain feed (semi)arid regions [84]. Salt-affected areas are often overlapping with numerous other physical, chemical and/or biological pedosphere constrains such as sandy soils with low water retention capacity, non-structured/dispersed (waterlogged) soils, organically depleted soils with diminished microbial activity/diversity and excessive alkalinity, specific ionic (Al, B) toxicity, and many other [84, 85] (Figure 2). Saline or alkaline (sodic) soils due to increased concentration of particular slats (Na⁺, Cl⁻, Ca²⁺, Mg²⁺ etc) and ionic interrelations (e.g. Na⁺/Ca²⁺; Na⁺/Mg²⁺) can be recognised and visually by crystallised (precipitated) salts on the soil surface (forming a brighter salt forms on the soil surface; Figure 3a) or at later (developed) stages by topsoil crusting, as a consequence of dispersed clay minerals and soil aggregates (Figure 3b).

A constitute of structurally dispersed soils (e.g. clay particles, minerals, organics) undergo leaching through the soil profile, accumulating and blocking deeper macro/micro pores, especially in textured-heavier soil layers, and finally causing waterlogging (e.g. Burrow et al. [86]. Thus, salt-affected soils (profiles) depleted in adsorption matrices (organic matter and clay content notably) might be more prone to mobility and transfer of certain pollutants (e.g. toxic trace elements) on the soil/crop/groundwater routes, although certain genotypic differences have to be considered.

For instance, it was shown that raised soil solution salinity can significantly impact mobility of toxic Cd in the rhizosphere and enhance its uptake and root/shoot accumulation in different wheat cultivars [87, 88]. Also, sublimating the results of studies conducted by Norvell et al. [89], Khoshgoftarmanesh et al. [88] and Ozkutlu et al. [90] their outcomes suggest that

Figure 3. Topsoil (a) crystallisation of soluble salts (dotted brighter areas) in a wheat paddock, depleted with soil organic matter, and (b) crusting in an adjacent saline plot with disturbed soil structure (Esperance area, Western Australia).
durum vs. bread wheat genotypes could be more effective, not only in Cd root extraction, but also in Cd root to shoot (leaf/grain) translocation and deposition under excessive Cl salinity. Such genotypic differences should be considered also in wheat breeding programs related to salt resistance (next section).

5.2. Sustainable management practices and perspectives for wheat cropping under salinised conditions

Some of the widely used and most promising perspectives and strategies against soil salinity are listed in Table 1, and some of them are explained in the next section in more detail. Beside excessive ECe in saline soils, it is of great importance and interrelated concentrations of particular ions (notably portion of exchangeable Na⁺; ESP) as well as soil pH reaction. According to some of chemical parameters, salt-affected soils generally can be categorised as: saline (ECe > 4 dS/m, ESP < 15 and pH <8.5), saline-sodic (ECe > 4 dS/m, ESP > 15 and pH <8.5) and sodic/alkaline (ECe >4 dS/m, ESP >15 and pH >8.5), and usually require specific strategy for reclamation often with low benefit/cost ratio for crops (Ondrasek et al. [85] and references therein). Sustainable agricultural management in saline/sodic conditions usually is combination of certain preventive actions (aiming to control salinity/alkalinity level) and/or remediate of saline/alkaline areas. For instance, saline soils might be easier for reclamation than sodic soils because the former often requires only salt leaching while the latter requires addition and certain Ca-/Mg-based soil amendments (e.g. gypsum) to replace excess ESP in addition to leaching (e.g. [91]).

| Perspective                              | Description                                                                                                                                                                                                 |
|------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Species/varieties selection              | Cropping of more salt resistant wheat varieties (genotypes), although genotypic differences related to efficiency of mineral uptake and accumulation (e.g. trace elements) should be considered (explained above)         |
| Amelioration of soil water management    | Implementation of subsurface drainage system may be useful approach for: (i) prevention of salt accumulation in sub/surface horizons as a consequence of seasonal sea water intrusion and/or capillary rising and/or (ii) salt leaching from the surface soil layers (e.g. [109]). Implementation of irrigation can decline vegetative growth of wheat cropped on salt-affected soils but without evident yield reductions (e.g. [75]) |
| Soil amelioration by microbes            | It was shown that exploitation of certain microbial populations can be a promising alternative to alleviate crops stress under excessive root zone salinity [96]. Thus for instance, inoculation of wheat seeds prior sowing by salt-tolerant microbe colonies might be beneficial strategy for wheat cropping in salt-affected environment (e.g. [97]) |
| Application of inorganic amendments     | Addition of natural or synthetic Ca-/Mg-/Zn based sources can ameliorate soil salinity/sodicity [110] and related pedosphere constrains (e.g. Zn-deficiency; see above)                                                |
| Conservation and increasing of soil organic matter | Over conservation land management (e.g. reduced/minimal/no tillage) is possible to preserve and/or enhance soil–plant water relations, soil organic matter content and rhizosphere biodiversity across the saline paddocks (e.g. [85]) |
| Genetic improvement                     | Genetic improvement of wheat genomes for salt-tolerance has a great potential of acquiring some halophytic traits such as Na⁺ and/or Cl⁻ exclusion by crossing cultivars of Triticum aestivum L. with genetically related (non)halophytes (e.g. [80]) |

Table 1. Some perspectives for improving wheat cropping in salt-affected agroecosystems.
Application of (in)organic soil amendments, such as mineral/organic fertilisers, lime, gypsum phospho-gypsum, and so on to salt-affected pedosphere has multi-beneficial impact [75]. Introduction of Ca-/Mg-enriched amendments enhances to maintain soil micro-aggregate structure in the soil profile, and consequently improves physical pedovariables such as improved flocculation, reduced spontaneous dispersion (air-dry aggregates) and dispersion of remoulded aggregates, increased hydraulic conductivity and soil aeration [92]. Furthermore, it was confirmed that soil salinity/alkalinity is frequently associated with microelement Zn deficiency, and that under such conditions, application of certain inorganic Zn-based fertilisers is able to improve salt tolerance but also and nutritional value of wheat. Namely, ~40% of the soils used for wheat production in Iran are Zn-deficient [93] and comparing to some other widely cropped cereals, wheat genotypes are especially very sensitive to Zn deficiency which markedly reduce wheat grain yield [94]. However, one of the biggest issues with soil amendments (Ca-/Mg-/Zn-based) application and their beneficial impact to crops in saline conditions is often lacking of their dissolution (i.e. phytoavailability of specific element/substance) due to (semi)arid conditions and/or not implemented irrigation practice.

Another promising strategy to enhance wheat salt tolerance might be introduction of salt more tolerant root-associated microbes that enhance plant growth under excessive salinity. Namely, it was widely discussed how spatial rhizosphere adaptation of plants is also driven by genetic differentiation in closely associated microbe populations such as: (i) arbuscular mycorrhizal fungi (whose hyphal networks ramify throughout the soil and within the plant cells) then (ii) ectomycorrhizal fungi (over a fungal layer around the root system and root intercellular spaces) and (iii) root-associated plant growth-promoting rhizobacteria (see reviews by Rodriguez and Redman [95]; Dodd and Perez-Alfocea [96]). Alleviation of salt stress on yield and mineral nutrition (e.g. increased K/Na ratio) exploiting the arbuscular mycorrhizal fungi was confirmed in certain wheat varieties under field saline conditions [97]. For instance, the mycorrhizal colonisation enhanced grain wheat yield up to >31% in Kavir (spring cultivar), up to >32% in Roshan (spring and semi-early maturing cultivar) and even up to >38% in Tabasi (mutated salt tolerant line) [97]. Furthermore, Sadeghi et al. [76] applying the isolate of Streptomyces in cultivated soil with wheat (cul. Chamran) observed: (i) increased the growth/development and shoot concentration of N, P, Fe and Mn in both saline and non-saline conditions and (ii) significant increases in germination rate, percentage and uniformity, shoot length and dry weight of salt-exposed plant (vs. non saline control). Also, studying the effect of inoculation of the five halotolerant bacterial strains in alleviation of NaCl-induced stress (80–320 mM) in wheat (var. HD 2733) Ramadoss et al. [98] observed an increase in root elongation (by >90%) and root dry weight (by >17%) in comparison with control (uninoculated) plants. Such beneficial effects of salt-tolerant microbes to (wheat) crops exposed to salinity are explained by improved plant water relations (e.g. due to enhanced accumulation of specific osmolytes), then regulating plant homeostasis and improved phytonutrients (e.g. N, P, K, Zn, Cu, Mn, Fe) uptake as well by enhanced germination rate [96, 97, 99].

Breeding programs to salt tolerance (as relatively long-term approach) are expecting that might have crucial role in (wheat) cropping under saline conditions in the near future (see down). Relatively little work has been done on breeding programs of wheat cultivars for saline conditions [80] given on polygenic character of salt tolerance, but continuous progress
is evident. Namely, hexaploid bread wheat (Triticum aestivum L.) has one of the most complex (ABD) genomes (e.g. six copies of each chromosome, numerous of near-identical sequences scattered throughout, overall haploid size of >15 billion bases) [100], thus making wheat highly challenging for genome sequencing and detection of salt-tolerant genes and quantitative trait loci. Also, the huge amount of repetitive sequences poses a big challenge for sequencing the wheat genome [101]. For instance, first assembly of the wheat genome from 2012 was represented by only ~33% (5.42 billion bases) [102], another assembly from 2014 by ~66% (10.2 billion bases) [103] whereas assemblies from 2017 were extended to 78% (12.7 billion bases) [104] and recent assembly was almost completed with >15.3 billion bases [100]. Hence, the genomic complexity and its uncomplete assembly makes the wheat crop additionally extremely difficult for improvement to salt tolerance over conventional (e.g. traditional breeding) and/or modern genetic (e.g. molecular and transgenic breeding) approaches.

Genetic improvement of wheat for salt-tolerance has also a great potential of acquiring some halophytic traits (genes) such as Na+/Cl− exclusion and/or compartmentation by crossing wheat genotypes with genetically related halophytic plant species (e.g. Lophopyrum elongatum) [105]. In wheat salt resistance is associated with low rates of the root-to-shoot transport of Na+ with high selectivity for K+ over Na+ [106]. Bread wheat genotypes have a low rate of Na+ accumulation and enhanced K+/Na+ discrimination which is controlled by a locus (Kna1) on chromosome 4D [107]. Contrary, durum wheat (tetraploid, AB genomes) have higher rates of Na+ accumulation and weaker K+/Na+ discrimination [80] and is consequently less salt resistant vs. bread wheat (Figure 2). It was confirmed that salt-/draught-tolerant genes and quantitative trait loci identified in T. dicoccoides and H. spontaneum have great potential in wheat improvement also [108]. Finally, improvement in salt resistance of modern wheat genotypes will be generated from introducing new gene(s) by (i) crossing with new donor germplasm or (ii) transformation with single genes, and after the progeny has to be back-crossed into adapted cultivars before the donor genes are ready for cultivation [80].

6. Conclusion

Sustainable plant production has three main goals: environmental health, economic profitability, and social and economic equity. It needs to achieve higher and higher amount of quality food by using less stock and energy under actual environmental conditions. Nitrogen is one of the most important nutrients for plants because of the yield quality and quantity as well. Applying adequate amount of nutrients based on genotype requirements is hard under potential conditions, especially under different abiotic loads. About 70% of all fertilisers are used on wheat and rice. Wheat is an important staple crop and crucial source of non-animal protein in human food and also makes a significant contribution to animal feed. The problem is that the utilisation efficiency of nitrogenous fertilisers under field conditions is relatively low, thus the production may become dangerous for the environment, economically inadequate and can result in poor quality. Finding of ‘smart’ wheat genotypes with high NUE does not mean a solution for the problem of being sustainable. Several environmental conditions have effect on NUE and/or the components of NUE, thus we need more knowledge to locate the final answer our global challenge.
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Conflict of interest

We have no conflict of interest declare.

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References

[1] Kearney J. Food consumption trends and drivers. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences. 2010;365(1554):2793-2807. DOI: 10.1098/rstb.2010.0149

[2] Shewry PR, Hey SJ. The contribution of wheat to human diet and health. Food and Energy Security. 2015;4(3):178-202. DOI: 10.1002/fes3.64

[3] Glass ADM. Nitrogen use efficiency of crop plants, physiological constraints upon nitrogen absorption. Critical Reviews in Plant Sciences. 2003;22:453-470. DOI: 10.1080/07352680390243512

[4] Good AG, Shrawat AK, Muench DG. Can less yield more? Is reducing nutrient input into the environment compatible with maintaining crop production? Trends in Plant Science. 2004;9:597-605. DOI: 10.1016/j.tplants.2004.10.008
[5] Ginckel MV, Calhoun DS, Gebeyehu G, Miranda A, Tian-you C, Lara RP, Trethowan RM, Sayre K, Crossa J, Rajaram S. Plant traits related too yield of wheat in early, late, or continuous drought conditions. Euphytica. 1998; 100:109-121

[6] Lobell DB, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. Science. 2011; 333(6042):616-620

[7] Fahad S, Hussain S, Saud S, Hassan S, Ihsan Z, Shah AN, Wu C, Yousaf M, Nasim W, Alharby H, Alghabari F, Huang J. Exogenously applied plant growth regulators enhance the morphophysiological growth and yield of rice under high temperature. Frontiers in Plant Science. 2016; 7:1250. DOI: 10.3389/fpls.2016.01250

[8] Peerzada YY, Elsayed FAA, Mohd N, Ambreen A, Abeer H, Abdulaziz AA, Altaf A. Responsive proteins in wheat cultivars with contrasting nitrogen efficiencies under the combined stress of high temperature and low nitrogen. Genes. 2017; 8(12):356. DOI: 10.3390/genes8120356

[9] Tahir ISA, Nakata N. Remobilization of nitrogen and carbohydrate from stems of bread wheat in response to heat stress during grain filling. Journal of Agronomy and Crop Science. 2005; 191:106-115

[10] Bandyopadhyay KK, Misra ĆAK, Ghosh ĆPK, Hati ĆKM, Mandal ĆKG, Moahnty ĆM. Effect of irrigation and nitrogen application methods on input use efficiency of wheat under limited water supply in a vertisol of Central India. Irrigation Science. 2008; 28(4). DOI: 10.1007/s00271-009-0190-z

[11] Majeed A, Muhmood A, Niaz A, Javid S, Ahmad ZA, Shah SSH, Shah AH. Bed planting of wheat (Triticum aestivum L.) improves nitrogen use efficiency and grain yield compared to flat planting. The Crop Journal. 2015; 3:118-124 Available from: http://creativecommons.org/licenses/by-nc-nd/4.0/

[12] Pepó P. Role of fertilization and water supply in wheat production. In: Hidvegi SZ, Gyuricza CS, editors. Hungarian Academy of Sciences. Budapest: Akaprint; 2004. pp. 275-279

[13] Abdul-Kadir SM, Paulsen GM. Effect of salinity on nitrogen metabolism in wheat. Journal of Plant Nutrition. 2008; 5(9):1141-1151. DOI: 10.1080/01904168209363047

[14] Soliman SM, Shalabi HG, Campbell WF. Interaction of salinity, nitrogen, and phosphorus fertilization on wheat. Journal of Plant Nutrition. 1994; 17(7):1163-1173. DOI: 10.1080/01904169409364796

[15] Árendás T, Berzsenyi Z, Láng L, Bedő Z. A minőségi búza termesztésének néhány agrotechnikai szempontja a martonvásári kutatási eredmények tükrében. In: Pepó P, editor. Búzavertikum aktuális kérdései. Szaktanácsadási Füzetek 2. Debrecen: Hungarian Academy of Sciences; 2006. pp. 73-83

[16] Pepó P. Efficiency of fertilization in sustainable wheat production. Acta Agraria Debreceniensis. 2002; 1:1-7
[17] Pepó P, Zsombik L, Vad A, Berényi S, Dóka L. Agroecological and management factors with impact on the yield and yield stability of maize (Zea mays L.) in different crop rotation. Analele Universitatii Oradea of Facultatea de Pretectia Mediului. 2007;13:181-187

[18] Duan YH, Shi XJ, LI SL, Sun XF, He XH. Nitrogen use efficiency as affected by phosphorus and potassium in long-term rice and wheat experiments. Journal of Integrative Agriculture. 2014;13(3):588-596. DOI: 10.1016/S2095-3119(13)60716-9

[19] Lehoczky É, Kismányoky A, Kismányoky T. Study on the weediness of winter-wheat in a long-term fertilization field experiment. Communications in Agricultural and Applied Biological Sciences. 2006;71(3a):793-796

[20] Epstein E, Bloom AJ. Mineral Nutrition of Plants: Principles and Perspectives. Sunderland: Sinauer Associates, Inc.; 2005. p. 400

[21] Krapp A. Plant nitrogen assimilation and its regulation: A complex puzzle with missing pieces. Current Opinion in Plant Biology. 2015;25:115-122. DOI: 10.1016/j.pbi.2015.05.010

[22] Subbaro GV, Rao IM, Nakahara K, Sahrawat KL, Ando Y, Kawashima T. Potential for biological nitrification inhibition to reduce nitrification and N₂O emissions in pasture crop-livestock systems. Animal. 2013;7(2):322-332. DOI: 10.1017/S1751731113000761

[23] LaRuffa J, Thomason W, Taylor S, Lees H. Soil-Plant Nutrient cycling and Environmental Quality. Department of Plant and Soil Sciences, Oklahoma State University. Available from: http://slideplayer.com/slide/9941674/

[24] Evans JR. Nitrogen and photosynthesis in the flag leaf of wheat (Triticum aestivum L.). Plant Physiology. 1983;72:297-302. DOI: 10.1104/pp.72.2.297

[25] Iqbal N, Umar S, Khan NA. Nitrogen availability regulates proline and ethylene production and alleviates salinity stress in mustard (Brassica juncea). Journal of Plant Physiology. 2015;178:84-91. DOI: 10.1016/j.jplph.2015.02.006

[26] Moll RH, Kamprath EJ, Jackson WA. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilisation. Agronomy. 1982;74:562-564. DOI: 10.2134/agronj1982.00021962007400030037x

[27] Le Gouis J, Beghin D, Heumez E, Pluchard P. Genetic differences for nitrogen uptake and nitrogen utilization efficiencies in winter wheat. European Journal of Agronomy. 2000;12:163-173. DOI: http://dx.doi.org/10.1016/S1161-0301(00)00045-9

[28] Pan J, Zhu Y, Jiang D, Dai T, Li Y, Cao W. Modeling plant nitrogen uptake and grain nitrogen accumulation in wheat. Field Crops Research. 2006;97:322-336. DOI: 10.1016/j.fcr.2005.11.006

[29] Gaju O, Allard V, Martre P, Le Gouis J, Moreau D, Bogard M, Hubbart S, Foulkes MJ. Nitrogen partitioning and remobilization in relation to leaf senescence, grain yield and grain nitrogen concentration in wheat cultivars. Field Crops Research. 2014;155:213-223. DOI: 10.1016/j.fcr.2013.09.003
[30] Palta JA, Fillery IRP. Post-anthesis remobilisation and losses of nitrogen in wheat in relation to applied nitrogen. Plant and Soil. 1993;155:179-181

[31] Kichey T, Hirel B, Heumez E, Dubois F, Le Gouis J. In winter wheat (*Triticum aestivum* L.), post-anthesis nitrogen uptake and remobilisation to the grain correlate with agronomic traits and nitrogen physiological markers. Field Crops Research. 2007;102:22-32. DOI: 10.1016/j.fcr.2007.01.002

[32] Pask AJD, Sylvester-Bradley R, Jameison PD, Foulkes MJ. Quantifying how winter wheat crops accumulate and use nitrogen reserves during growth. Field Crops Research. 2012;126:104-118. DOI: 10.1016/j.fcr.2011.09.021

[33] Zhen-Yuan S, Han BW, Liu SL, Wang HF, Gao RF. Absorption and redistribution of nitrogen during grain-filling period of wheat and their regulation by 6-benzylaminopurine. Acta Phytophysiol Sinica. 1996;22:258-264

[34] Mainard SD, Jeuffroy MH. Partitioning of dry matter and N to the spike throughout the spike growth period in wheat crops subjected to N deficiency. Field Crops Research. 2001;70:153-165

[35] Malik AI, Rengel Z. Physiology of nitrogen-use efficiency. In: Rengel Z, editor. Improving Water and Nutrient-Use Efficiency in Food Production Systems. UK: Wiley-Blackwell Inc.; 2013. pp. 105-121. DOI: 10.1002/9781118517994.ch7

[36] Asplund L, Bergkvist G, Weih M. Proof of concept: Nitrogen use efficiency of contrasting spring wheat varieties grown in greenhouse and field. Plant and Soil. 2014;374:829-842. DOI: 10.1007/s11104-013-1895-6

[37] Malik AI, Veres S, Rengel Z. Differential nitrogen-use efficiency in wheat parents of doubled-haploid mapping populations. Plant and Soil. 2016;408:311-325. DOI: 10.1007/s11104-016-2943-9

[38] Veres S, Malik AI, Rengel Z. Differential nitrogen supply causes large variability in photosynthetic traits in wheat germplasm. Crop & Pasture Science. 2017;68(8):703-712. DOI: 10.1071/CP17126

[39] Easterling DR, Apps M. Assessing the consequences of climate change for food and forest resources: A view from the IPCC. Climatic Change. 2005;70:165-189

[40] Gourdji SM, Sibley AM, Lobell DB. Global crop exposure to critical high temperatures in the reproductive period, historical trends and future projections. Environmental Research Letters. 2013;8:24-41. DOI: 10.1088/1748-9326/8/2/024041

[41] Koehler AK, Challinor AJ, Hawkins E, Asseng S. Influences of increasing temperature on Indian wheat, quantifying limits to predictability. Environmental Research Letters. 2013;8:034016. DOI: 10.1088/1748-9326/8/3/034016

[42] Tjoelker MG, Reich PB, Oleksyn J. Changes in leaf nitrogen and carbohydrates underlie temperature and CO$_2$ acclimation of dark respiration in five boreal tree species. Plant, Cell & Environment. 1999;22:767-778. DOI: 10.1046/j.1365-3040.1999.00435.x
[43] Murchie EH, Pinto M, Horton P. Agriculture and the new challenges for photosynthesis research. The New Phytologist. 2009;181:532-552. DOI: 10.1111/j.1469-8137.2008.02705.x

[44] Jordan DB, Ogren WL. The CO₂/O₂ specificity of ribulose 1,5-bisphosphate carboxylase/oxygenase: Dependence on ribulosebisphosphate concentration, pH and temperature. Planta. 1984;161:308-331. DOI: 10.1007/BF00398720

[45] Sage RF. Variation in the k(cat) of rubisco in C(3) and C(4) plants and some implications for photosynthetic performance at high and low temperature. Journal of Experimental Botany. 2002;53:609-620

[46] Portis AR. Rubisco activase – Rubisco’s catalytic chaperone. Photosynthesis Research. 2003;75:11-27. DOI: 10.1023/A:1022458108678

[47] Parry MAJ, Andralojc P, Khan S, Lea P, Keys AJ. Rubisco activity: Effects of drought stress. Annals of Botany. 2002;89:833-839. DOI: 10.1093/aob/mcf103

[48] Perdomo JA, Capó-Bauçà S, Carmo-Silva E, Galmés J. Rubisco and rubisco activase play an important role in the biochemical limitations of photosynthesis in rice, wheat, and maize under high temperature and water deficit. Frontiers in Plant Science. 2017;8(490). DOI: 10.3389/fpls.2017.00490

[49] Porter JR, Xie L, Challinor AJ, Cochrane K, Howden SM, Iqbal MM, Lobell DB, Travasso MI. Food security and food production systems. In: IPCC. 2014. Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge/New York: Cambridge University Press; 2014. pp. 485-533

[50] Fischlin A, Midgley GF, Price JT, Leemans R, Gopal B, Turley C. Ecosystems, their properties, goods, and services. Climate change 2007: Impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, Hanson CE, editors. Proceedings of the Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; 2007. pp. 211-272

[51] Siddique MRB, Hamid A, Islam MS. Drought stress effects on water relations of wheat. Botanical Bulletin Academia Sinica. 2001;41:35-39

[52] Zhang LX, Li SX, Zhang H, Liang ZS. Nitrogen rates and drought stress effects on production, lipid peroxidation and antioxidative enzyme activities in two maize (Zea mays L.) genotypes. Journal of Agronomy and Crop Science. 2007;193:387-397. DOI: 10.1111/j.1439-037X.2007.00276.x

[53] Marschner H. editor: Mineral Nutrition of Higher Plants. 3rd ed. London: Academic Press; 2011. 672 p. ISBN: 978-0-12-384905-2

[54] Hoseinlou SH, Ebadi A, Ghaffari M, Mostafaei E. Nitrogen use efficiency under water deficit condition in spring barley. International Journal of Agronomy and Plant Production. 2015;4:3681-3687
Morgan JA. The effects of N nutrition on the water relations and gas exchange characteristics of wheat (*Triticum aestivum* L.). Plant Physiology. 1986;80:52-58. DOI: 10.1104/pp.80.1.52

Arun T, Upadhyaya SD, Upadhayay A, Preeti SN. Responses of moisture stress on growth, yield and quality of isabgol (*Plantago ovata* Forsk). Journal of Agricultural Technology. 2012;8:563-570

Binghua L, Liang C, Mingjun L, Dong L, Yangjun Z, Fengwang M. Interactive effects of water and nitrogen supply on growth, biomass partitioning, and water-use efficiency of young apple trees. African Journal of Agricultural Research. 2012;7:978-985. DOI: 10.5897/ajar11.1212

Li P, Chen J, Wu P. Agronomic characteristics and grain yield of 30 spring wheat genotypes under drought stress and nonstress conditions. Agronomy Journal. 2011;103:1619-1628. DOI: 10.2134/agronj2011.0013

Abreau JPD, Folres I, De-Abrea FMG, Medeira MV. Nitrogen uptake in relation to water availability in wheat. Plant and Soil. 1993;154(1):89-96

Waraich EA, Ahmad R, Saifullah U, Ashraf MY, Ehsanullah L. Role of mineral nutrition in alleviation of drought stress in plants. Australian Journal of Crop Science. 2011;5:764-777

Gonzales-Dugo V, Durand JL, Gastal F. Water deficit and nitrogen nutrition of crops. A review. Agronomy for Sustainable Development. 2010;30:529

Maxwell K, Johnson GN. Chlorophyll fluorescence — A practical guide. Journal of Experimental Botany. 2000;51:659-668. DOI: 10.1093/jexbot/51.345.659

Grassi G, Magnani F. Stomatal, mesophyll conductance and biochemical limitations to photosynthesis as affected by drought and leaf ontogeny in ash and oak trees. Plant, Cell & Environment. 2005;28:834-849. DOI: 10.1111/j.1365-3040.2005.01333.x

Sz V, Simkó A, Kiss L, Zsombik L. Wheat genotypes under reduced nitrogen supply: Changes in chlorophyll fluorescence parameters. Columella. 2017;4(1 Suppl):53-58. DOI: 10.18380/SZIE.COLUM.2017.4.1.suppl

Veres S, Marko P, Makleit P, Kiss L, Gáspár S, Frommer D, Rengel Z. Physiological detection of water and nitrogen deprivation. Annals series on agriculture, silviculture and veterinary medicine sciences. 2017;6(1):152-158

Park JH, Lee BW. Photosynthetic characteristics of rice cultivars with depending on leaf senescence during grain filling. Journal of Crop Science. 2003;48:216-223

Palta JA, Kobata T, Turners NC, Fillery IR. Remobilization of carbon and nitrogen in wheat as influenced by post-anthesis water deficits. Crop Science. 1994;334:118-124

Gouarda G, Padovan S, Delougu G. Grain yield, nitrogen use efficiency and baking quality of old and modern Italian bread - wheat cultivars grown at different N levels. European Journal of Agronomy. 2004;21:181-192
[69] White PJ, Brown PH. Plant nutrition for sustainable development and global health. Annals of Botany. 2010;105(7):1073-1080

[70] Zsombik L, Seres E. The effect of genotype and nitrogen supply on the agronomical parameters of winter wheat (Triticum aestivum L.). In: LOTEX 2017, International Conference on Long-Term Field Experiments. 27-28. September; Nyiregyháza: Research Institute of Nyiregyháza; 2017

[71] Shi J, Yasuor H, Yermiyahu U, Zuo Q, Ben-Gal A. Dynamic responses of wheat to drought and nitrogen stresses during re-watering cycles. Agricultural Water Management. 2014;146:163-172. DOI: 10.1016/j.agwat.2014.08.006

[72] Ata-Ul-Karim ST, Nadeem A, Ehsan U. Improvement in wheat crop growth and grain yield under different planting techniques in Faisalabad zone. Journal of Environmental Agricultural Sci. 2015;5:71-79

[73] Blum A, Ramaiah S, Kanemasu ET, Paulsen GM. Wheat recovery from drought stress at the tillering stage of development. Field Crops Research. 1990;24:67-85. DOI: 10.1016/0378-4290(90)90022-4

[74] Muyen Z, Moore GA, Wrigley RJ. Soil salinity and sodicity effects of wastewater irrigation in South East Australia. Agricultural Water Management. 2011;99(1):33-41

[75] Eynard A, Lal R, Wiebe K. Crop response in salt-affected soils. Journal of Sustainable Agriculture. 2005;27(1):5-50

[76] Sadeghi A, Karimi E, Dahaji PA, Javid MG, Dalvand Y, Askari H. Plant growth promoting activity of an auxin and siderophore producing isolate of Streptomyces under saline soil conditions. World Journal of Microbiology and Biotechnology. 2012;28:1503-1509

[77] Rhoades JD, Chanduvi F, Lesch S. Soil salinity assessment-methods and interpretation of electrical conductivity measurements. FAO Irrigation and Drainage Paper 57. Italy, Rome: FAO-UN; 1999. 165 p

[78] Francois LE, Maas EV. Crop response and management on salt-affected soils. In: Pessarakli M, editor. Handbook of Plant and Crop Stress. New York: Marcel Dekker Press Inc.; 1999. pp. 169-201

[79] Munns R, Husain S, Rivelli AR, James RA, Condon AG, Lindsay MP, Lagudah ES, Schachtman D, Hare RA. Avenues for increasing salt tolerance of crops, and the role of physiologicallybased selection traits. Plant and Soil. 2002;247:93-105

[80] Munns R, James RA, Lauchli A. Approaches to increasing the salt tolerance of wheat and other cereals. Journal of Experimental Botany. 2006;57:1025-1043

[81] Maas EV. Salt tolerance of plants. Applied Agricultural Research. 1986;1:12-26

[82] Shannon MC, Grieve CM. Tolerance of vegetable crops to salinity. Scientia Horticulturae. 1999:78.5-78.7838

[83] Metternicht GI, Zinck JA. Remote sensing of soil salinity: Potentials and constraints. Remote Sensing of Environment. 2003;85:1-20
[84] Shrivastava P, Kumar R. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi Journal of Biological Sciences. 2015;22:123-131

[85] Ondrasek G, Rengel Z, Veres S. Soil salinisation and salt stress in crop production. In: Shanker AK, Venkateswarlu B, editors. Biotic Stress in Plants: Mechanisms and Adaptations. Rijeka: InTechOpen; 2011. pp. 171-190

[86] Burrow DP, Surapaneni A, Rogers ME, Olsson KA. Groundwater use in forage production: The effect of saline–sodic irrigation and subsequent leaching on soil sodicity. Australian Journal of Experimental Agriculture. 2002;42:237-247

[87] Khoshgoftar AH, Shariatmadari H, Karimian N, Khajehpour MR. Responses of wheat genotypes to zinc fertilization under saline soil conditions. Journal of Plant Nutrition. 2006;29:1543-1556

[88] Khoshgoftarmanesh AH, Shariatmadari H, Karimian N, Kalbasi M, van der Zee SEATM. Cadmium and zinc in saline soil solutions and their concentrations in wheat. Soil Science Society of America Journal. 2006;70(2):582-589

[89] Norvell WA, Wu J, Hopkins DG, Welch RM. Association of cadmium in durum wheat grain with soil chloride and chelate extractable soil cadmium. Soil Science Society of America Journal. 2000;64:2162-2168

[90] Ozkutlu F, Ozturk L, Erdem H, McLaughlin MJ, Cakmak I. Leaf-applied sodium chloride promotes cadmium accumulation in durum wheat grain. Plant and Soil. 2007;290:323-331

[91] Tanji KK. Salinity in the soil environment. In: Läuchli A, Lütthe U, editors. Salinity: Environments-Plants-Molecules. Dordrecht: Kluwer; 2002. pp. 21-52

[92] Wheaton AD, McKenzie BM, Tisdall JM. Management of a sodic soil for wine grape production. Australian Journal of Experimental Agriculture. 2002;42:333-339

[93] Balali MR, Malakouti MJ, Mashayekhi H, Khademi Z. The effect of micronutrient on the yield increase of wheat in ten provinces of Iran. Journal of Soil and Water. 1999;12(8):111-119

[94] Broadley MR, White PJ, Hammond JP, Zelko I, Lux A. Zinc in plants. New Phytologist. 2007

[95] Rodriguez R, Redman R. More than 400 million years of evolution and some plants still can’t make it on their own: Plant stress tolerance via fungal symbiosis. Journal of Experimental Botany. 2008;59:1109-1114

[96] Dodd IC, Perez-Alfocea F. Microbial amelioration of crop salinity stress. Journal of Experimental Botany. 2012;63(9):3415-3428

[97] Daei G, Ardekani MR, Rejali F, Teimuri S, Miransari M. Alleviation of salinity stress on wheat yield, yield components, and nutrient uptake using arbuscular mycorrhizal fungi under field conditions. Journal of Plant Physiology. 2009;166:617-625
[98] Ramadoss D, Lakkineni VK, Bose P, Ali S, Annapurna K. Mitigation of salt stress in wheat seedlings by halotolerant bacteria isolated from saline habitats. Springer Plus. 2013;2(6):1-7

[99] Nadeem SM, Zaheer ZA, Naveed M, Nawaz S. Mitigation of salinity-induced negative impact on the growth and yield of wheat by plant growth-promoting rhizobacteria in naturally saline conditions. Annales de Microbiologie. 2013;63(1):225-232

[100] Zimin AV, Puiu D, Hall R, Kingan S, Clavijo BJ, Salzberg SL. The first near-complete assembly of the hexaploid bread wheat genome, *Triticum aestivum*. GigaScience. 2017;6:1-7

[101] Li W, Zhang P, Fellers JP, Friebe B, Gill BS. Sequence composition, organization, and evolution of the core Triticeae genome. The Plant Journal. 2004;40(4):500-511

[102] Brenchley R, Spannagl M, Pfeifer M. Analysis of the bread wheat genome using whole-genome shotgun sequencing. Nature. 2012;491(7426):705-710

[103] International Wheat Genome Sequencing Consortium (IWGSC). A chromosome-based draft sequence of the hexaploid bread wheat (Triticum aestivum) genome. Science. 2014;345(6194):1251788

[104] Clavijo BJ, Venturini L, Schudoma C. An improved assembly and annotation of the allohexaploid wheat genome identifies complete families of agronomic genes and provides genomic evidence for chromosomal translocations. Genome Research. 2017;27(5):885-896

[105] Omielan JA, Epstein E, Dvorak J. Salt tolerance and ionic relation of wheat as affected by individual chromosomes of salt-tolerant *Lophopyrum elongatum*. Genome. 1991;34(6):961-974

[106] Gorham J, Wyn Jones RG, Bristol A. Partial characterization of the trait for enhanced K⁺-Na⁺ discrimination in the D genome of wheat. Planta. 1990;180:590-597

[107] Dubcovsky J, Santa Maria G, Epstein E, Luo MC, Dvorak J. Mapping of the K⁺/Na⁺ discrimination locus Kna1 in wheat. Theoretical and Applied Genetics. 1996;2:448-454

[108] Nevo E, Chen G. Drought and salt tolerances in wild relatives for wheat and barley improvement. Plant, Cell and Environment. 2010;33:670-685

[109] Ondrasek G, Rengel Z, Petosic D, Filipovic V. Land & water management strategies for the improvement of crop production. In: Ahmad P, Rasool S, editors. Emerging Technologies and Management of Crop Stress Tolerance. Vol. 2. A Sustainable Approach. London: Elsevier; 2014. pp. 291-310

[110] Dang YP, Dalal RC, Routley R, Schwenke GD, Daniells I. Subsoil constraints to grain production in the cropping soils of the north-eastern region of Australia. Australian Journal of Experimental Agriculture. 2006;46:19-35
