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Integrated nitrogen and irrigation management strategies for sustainable wheat production: Enhancing yield and environmental efficiency

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Abstract
This review critically examines the interplay between nitrogen management and irrigation techniques in enhancing the sustainability and productivity of wheat farming. Wheat, as a fundamental global staple, requires efficient management strategies due to its extensive cultivation under diverse environmental conditions. The optimal application of nitrogen is pivotal for improving grain yield and quality while preventing environmental impacts such as eutrophication and greenhouse gas emissions. This paper synthesizes findings from various studies highlighting that strategic nitrogen application can significantly boost plant growth and yield, particularly under water-limited conditions. However, excess nitrogen can lead to negative environmental consequences, necessitating balanced and precise application strategies. Equally important is the role of effective irrigation practices in wheat production. Innovative irrigation techniques, including deficit irrigation and tailored scheduling, are crucial in semi-arid regions where water scarcity is a persistent challenge. These methods help in maximizing water use efficiency (WUE) and adapting to variable rainfall patterns, thus ensuring crop productivity during critical growth phases. The review emphasizes the necessity of integrating nitrogen and water management to optimize wheat yield and sustainability. Such integration not only addresses the crop's physiological needs but also mitigates the adverse environmental impacts associated with agricultural inputs. The findings suggest that a coordinated approach, involving controlled nitrogen application and efficient irrigation, can lead to significant improvements in wheat productivity and resource use efficiency. This approach is particularly relevant in regions facing environmental constraints and aiming to enhance food security without compromising ecological balance.

Keywords: Wheat Production, nitrogen management, irrigation techniques, water use efficiency, sustainable agriculture, nutrient use efficiency

Introduction
Wheat is most ancient and important cultivated crop. In 2018-19 worldwide production of wheat was 734.74 million metric tonnes. In our country wheat is cultivated on an area of 8,678 thousand hectares with production of 24,349 thousand tonnes having average yield of 2,806 kg ha^{-1} (Government of Pakistan, 2019-20) [40]. Wheat mainly used as staple food that provides more nutrition (Protein) than any other cereal. Wheat straw is consumed as animal feed and also in paper industry. To meet increasing food demands for rapidly increasing population, it is very important to achieve the required wheat production potential. Potential yield of our wheat varieties is higher than its actual production under varying environments. Some of causes of lower grain yield of wheat in Pakistan are inadequate irrigation regimes, fertilizer rates and lack of site specific and innovative production technologies. So, it is a need of time to optimize the irrigation regimes and fertilizer rates for maximum grain yield (Baloch *et al.*, 2014) [20]. Water is a vital component for effective nutrient uptake and better crop growth and development. Yield is adversely affected if water shortage occurs particularly at critical stages of growth. Irrigation is indeed most important input for maximum productivity of crops. The water deficit, deciding crop growth and production, is a major bottleneck limiting sustainable agriculture progress the farmers face significant risk when it comes to sustaining agricultural production under conditions of environmental hardship and drought. To preserve the infrastructure and prevent floods, management of agricultural water should be paired with other water saving practises (Abbas *et al.*, 2015) [3].

Wheat grain yield and crop water response to irrigation are both influenced by soil extractable water capacity. Excessive irrigation raises evapotranspiration, lowers water quality that lowers crop yield. In arid and semi-arid climates, limited irrigation is a major restriction to wheat production. Nitrogen has important role in living tissues of plant. Efficiency in use of nitrogen may be enhanced by integrating soil, fertilizer, water and other management practices (Shirazi *et al.*, 2014).

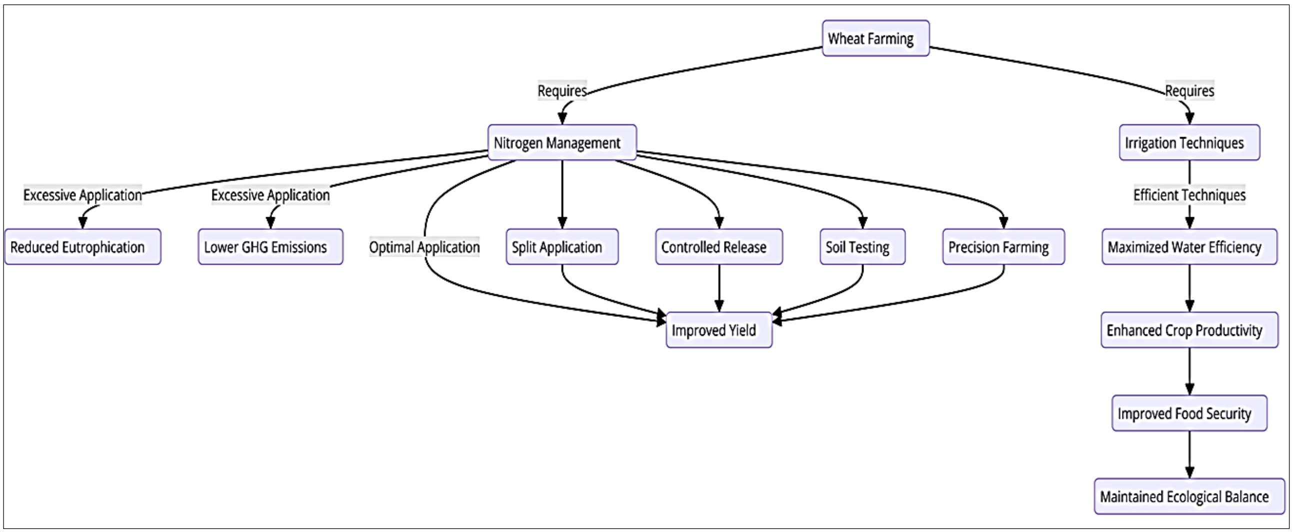

Fig 1: Balancing Nitrogen Use and Irrigation Techniques for Sustainable Wheat Farming

Nitrogen is needed during the whole growing period of wheat. It is important for synthesis of protein. In case of a nitrogen shortage, leaves are dried and burned, low growth is obtained, grains are poorly filled and yield is significantly compressed. On the other hand, too much nitrogen, in particular, is also not ideal for wheat crop it causes a rapid depletion in soil moisture, promotes lodging, decrease leaf disease tolerance and delays the maturity (Ali *et al.*, 2011) [7]. Given the significant impact of irrigation and nitrogen management on wheat yield, this review aims to explore comprehensive strategies that balance these key factors to enhance agricultural productivity sustainably. As global demands for food increase and resources become more strained, optimizing these agricultural inputs becomes crucial. Effective management not only promises to elevate yield and quality in wheat production but also aims to minimize adverse environmental impacts and resource wastage. By synthesizing current research and emerging techniques, this review seeks to provide a foundation for future innovations in wheat cultivation, especially under the challenging conditions of water scarcity and nutrient management. Thus, the goal is to contribute to a more sustainable agronomic future by detailing how integrated approaches can resolve the complexities of wheat production in diverse environments

Optimizing Nitrogen Management for Enhanced Winter Wheat Production and Environmental Sustainability

Nitrogen is most important macronutrient for winter wheat production, quality and harvest index (Fageria and Baligar, 2005) [34]. Nitrogen residing in the soil surface layer results in excessive risks for farmers and deterioration of the environment associated with groundwater runoff by nitrate leaching, river and lake eutrophication from excess nitrogen, as well as global warming caused by N2O emissions is linked with soil bacteria denitrification of nitrate and ammonium nitrification. Wheat (*Triticum aestivum* L.) belongs to Hordeae class of the family Poaceae. Wheat is Pakistan's most valuable winter crop. It is mainly utilized as a staple food and provides larger amount of protein as compared to any other crop of cereals. It is eaten in a number of ways, such as pizza, cookies, pancakes, baking goods, and many pastries. The straw is also consumed as feed for livestock and used for paper making. N plays very important function in the plant's every living tissue. No other factor has such an impact on the encouraging of significant growth of plant. Readily available protein significantly increases the leaves' size, resulting in an improvement in the synthesis of carbohydrates. Nitrogen (N) is an important part of plant nutrition. Although the usage of nitrogen, phosphorus and other management activities enhance the wheat yield, in certain instances they have detrimental consequences as irrigation is heavily limited (Rusan *et al.*, 2005) [53].

Productivity through the usage of nitrogen can be enhanced through mixing nutrients, land, water and management. Use of nitrogen during growing season have improved by two major approaches and the lack of nitrogen can be minimized by applying appropriate doses (Cui *et al.*, 2010) [28]. Main limiting factors for yield include early sowing, plant infestation and water insufficiency at critical growth stages and insufficient fertilizer use. Among fertilizers, nitrogen fertilizer usage usually affects production costs above all other inputs. (Ahmad *et al.*, 2008) [4]. Nitrogen (N) is most important plant nutrient of all fertilizers for growth of wheat and quality grain production (Fageria and Baligar 2005) [34]. Nitrogen existing in the top soil profile results in excessive costs for farmers and detrimental environmental effects associated with groundwater runoff by nitrate leaching, river and lake eutrophication from excess nitrogen, as well as anthropogenic global warming due to N2O pollution attributable to nitrate denitrification of soil bacteria and ammonium nitrification.

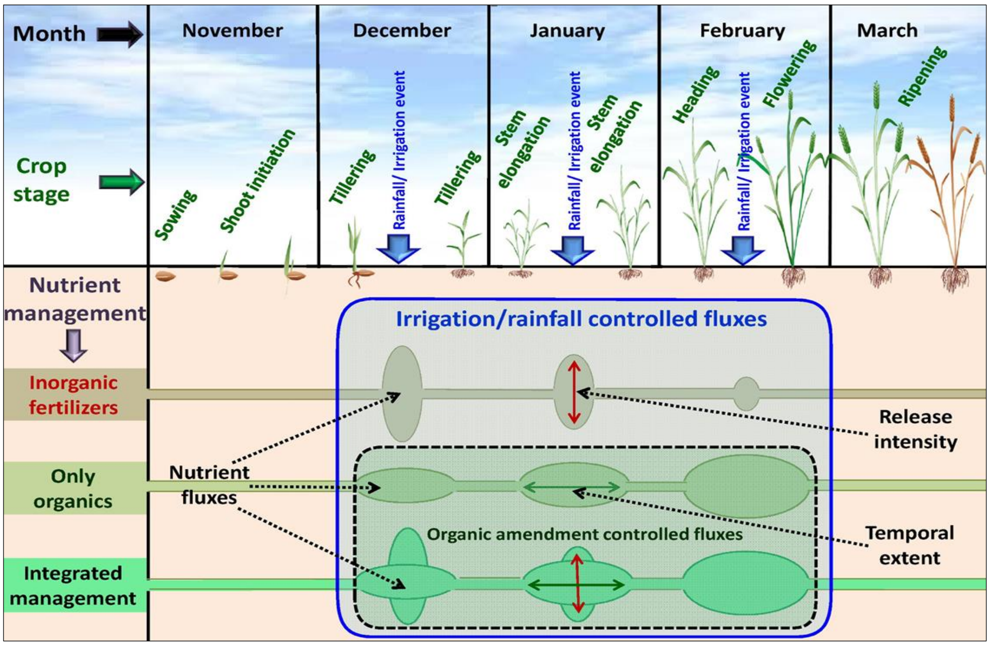

Fig 2: General nitrogen (N) availability scenarios under organic, inorganic, and integrated fertilization during wheat (*Triticum aestivum*) growing period (Bhardwaj *et al*., 2021) [25].

Performance in absorption of nitrogen represents the ability of nitrogen to recovery from fertilizer, soils and nitrogen conservation capacity in plants is greatly affected by root length density, and primary nitrogen assimilation enzyme activities. As a measure of grain production per unit of nitrogen intake above ground, the efficiency of nitrogen consumption can be determined by ratio of nitrogen harvest index (HI) to the grain nitrogen concentration and it is positively affected by the N harvested index but negatively by grain nitrogen concentration (Foulkes *et al.*, 2009) [37]. The association between Nitrogen Usage Efficiency, N intake efficiency, N consumption efficiency, above ground N intake, root length duration, N extracted index and grain N concentration was studied by previous investigators suggested that efficiency in absorption of nitrogen was the most significant aspect of nitrogen use efficiency. Barraclough *et al.,* (2010) [21] observed a semi-functional inverse relation between productivity in the usage of nitrogen and concentration of grain nitrogen, assuming a constant index of the extracted nitrogen. Sadras and Lawson (2013) [54] suggested that the concentration of grain nitrogen constituted 85 percent of the difference in the efficiency of nitrogen usage across cultivars and ecosystems. Nutrient management offers a chance to increase growth, development, yield and composition of nutrients. By playing significant role in crop production, it is a crucial driver for high yields and maximum economic returns. Deficiency of N is the key element reducing production yields of cereal crops. A number of recent soil fertility surveys have shown that soils in Pakistan are largely lacking in nitrogen by 100 percent and phosphorous by 90 percent among essential nutrient elements. In another study it was determined that the optimum amount of nitrogen fertilizer for durum wheat was about 100±20-kilogram N ha^{-1} from both an optimistic and economical viewpoint. From this research, this was revealed that implementation of N break was half at planting of seeds and half at stage of stem extension, resulting in the best management practices (Rinaldi, 2004) [50].

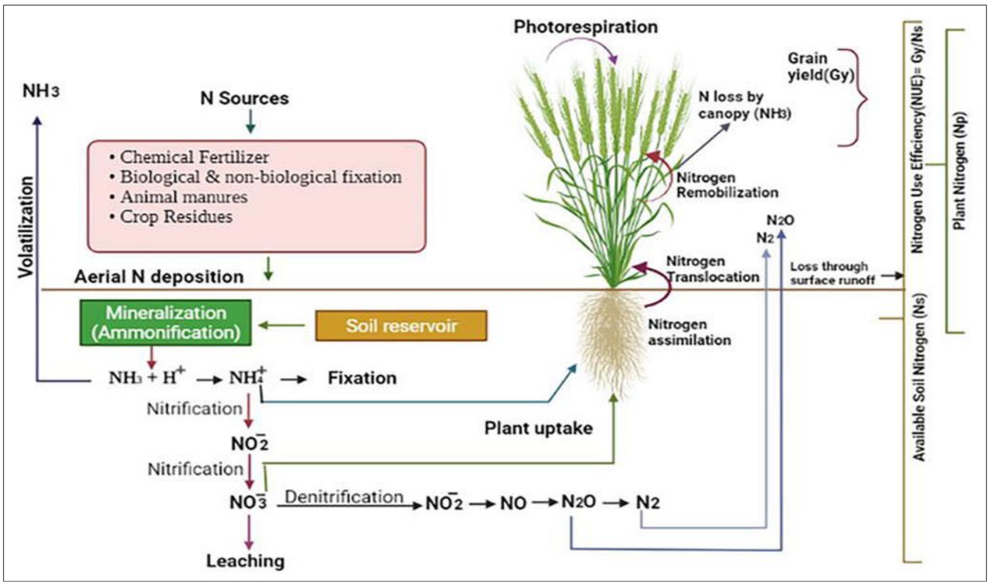

Fig 3: Schematic representation of the relationship between the nitrogen sources, uptake, utilization, and conversion to the wheat grain yield (Raigar *et al.*, 2022).

Influence of NPK Levels on Growth, Yield, and Protein Content in Winter Wheat

Different levels of NPK greatly influenced height of plant, No. of productive tillers, weight of 1000 grains, wheat grain yield alon gwith wheat protein content. Highest yield of grains (4.99 tonnes ha^{-1}) was reported sing a 105-75-75 kilograms $NPKha^{-1}$ method. A substantial rise in number of per unit fertile tillers, spike weight, plant height, grain yield of high yielding cultivars with an increase in N intensity has been investigated. At the rates of 100, 150 and 200 kg ha^{-1}, impact of nitrogen added was measured. Data about several parameters of yield and quality were published. Nitrogen was shown to provide the maximum grain yield of 3385 kg ha^{-1} with 12.26 percent protein content and highest harvest index (HI) among all N concentrations when added at a rate of 150 $kgha^{-1}$ at the time of planting. For seed growth and grain yield, nitrogen is a major component necessary. Except legumes, all crop plants exhibit significant reactions to nitrogen fertilization. Nitrogen increases the consistency and volume of dry matter production and proteins of leafy vegetables in cereal crops (Silva and Uchida, 2000) [58]. Increases in vegetative production, LAI, intercepted light segment and economic yield have been reported as the dosage of nitrogen applied has increased. In order to study impacts of irrigation water and to apply N to wheat growth and development crop studies were conducted for two consecutive years. It was studied that increasing irrigation increased vegetative growth, LAI and CGR, with 120 kg N/ha generating maximum amount of $unit^{-1}$ productive tillers, an increased leaf area and a high rate of crop growth among the various nitrogen levels. They said that only by adding nitrogen and irrigation water at its optimum level can optimum yield be achieved (Pandey *et al.*, 2001).

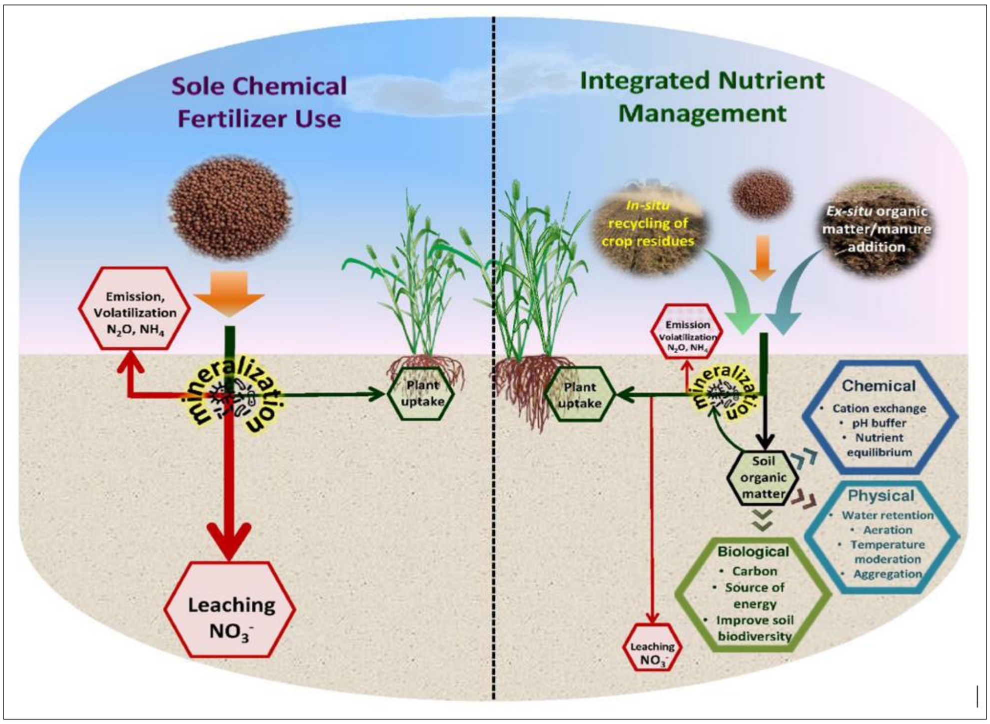

Fig 4: Contrasting influences of sole chemical fertilizer vs. integrated nutrient management on the nitrogen pools, mineralization, leaching, and volatilization fluxes (Bhardwaj *et al*., 2023) [24].

Near-flowering nitrogen application is found to be helpful in the post-flowering, dry matter production, and even wheat grain total protein uptake of can N (Wool folk *et al.*, 2002) [65]. As N application improved the source-sink relationship, nitrogen application increased total dry matter production and photosynthates were directed to economic parts. When fertilized 180 kg Nha^{-1}, number of fertile tillers, spike weight, straw and grain yield was substantially high. With N fertilization @ 175 $kgha^{-1}$ and maximum plant height @ 200 kg Nha^{-1}, a substantial increase in amount of fertile tillers per unit area was investigated. However, when nitrogen fertilizer was applied, the maximum weight of grains and maximum grain yield were obtained at the rate of 150 kg/ha. Increased wheat protein content was observed by increased N levels, while phosphorus application decreased protein content. In nitrogen fertilizer plots, the germination count was high, and germination time with N application was also reduced. Nitrogen application was proposed at a rate of 120 $kgha^{-1}$ as increased grain yield was integrated relative to other measured nitrogen (N) levels. When fertilized with 120 kg of Nha^{-1}, significant increases in grain production and wheat yield components were investigated. The amount of nitrogen administered has a direct relationship with the plant's height.

Wheat grain protein concentration is regulated by genotype and also by many environmental conditions including nitrogen fertilizer application, humidity and temperature during various stages of growth and development. Among plant nutrients, nitrogen has a distinctive function, as it is needed in much more quantities than other vital elements. It also encourages the synthesis, root growth and crop production of other plant nutrients. Therefore, except for legumes capable of fixing nitrogen from the rhizosphere, all crop plants show a rapid reaction to nitrogen fertilization (Hofman and Cleemput, 2004) [42]. An experiment was conducted out in order to see influence of different amounts of nitrogen (N) on wheat grain yield. The substantial difference in the yield components reported at each level of nitrogen is. At the maximum nitrogen application level, the highest per unit area and grain yield values for fertile tillers were recorded (Ali *et al.*, 2005) [8].

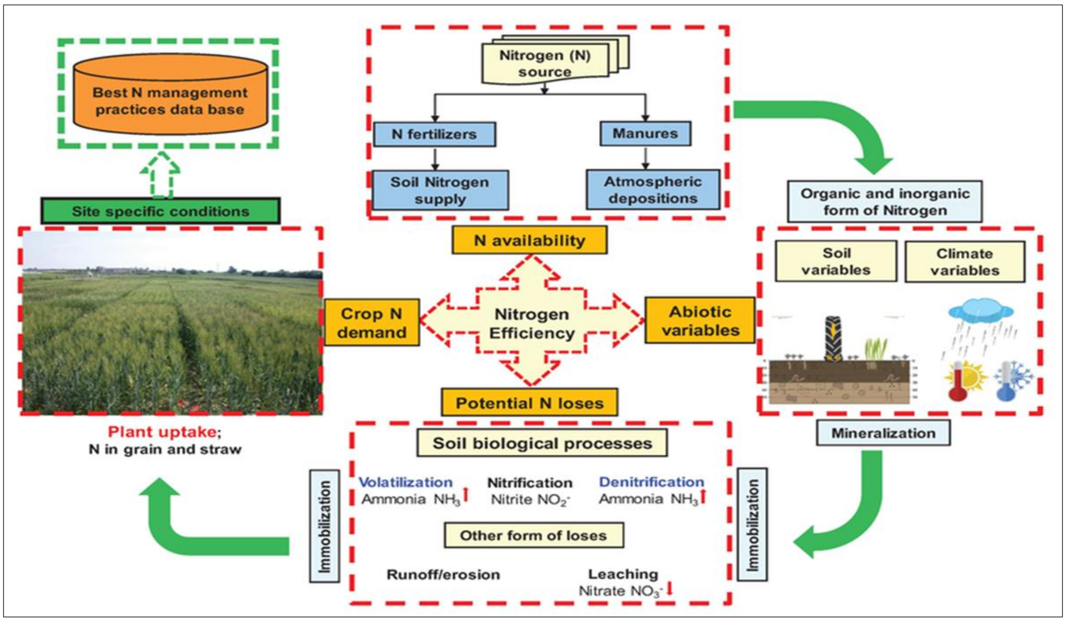

Fig 5: Potential fate of nitrogen in the agricultural system (in the case of durum wheat) (Tedone *et al*., 2017) [62].

The effects of nitrogen treatment on several cultivars of wheat was investigated, it was discovered that the fertile tillers, spike length, spike weight, number of grains per spike, plant height, biological yield, economic yield (EY), harvest index (HI), and days taken to booting, heading and anthesis all influenced nitrogen application favorably. The effect of the relationship between cultivars of N and wheat, however, was not important. The availability of nitrogen also increases the division and rate of expansion photosynthesis and development of leaf. In addition, N fertilization increases production of dry matter along with deposition of N and partitioning to different sections of crops for growth, development and all processes (Fageria and Baligar 2005) [34]. Integrated nitrogen use, i.e. 75 kgha^{-1} added soil and 2-2.5 percent foliar nitrogen use, investigated a tremendous increase in seed growth, yield, grain protein content and nutrient absorption. The introduction of nitrogen in different doses contributes to an increased quality of wheat protein in crops.

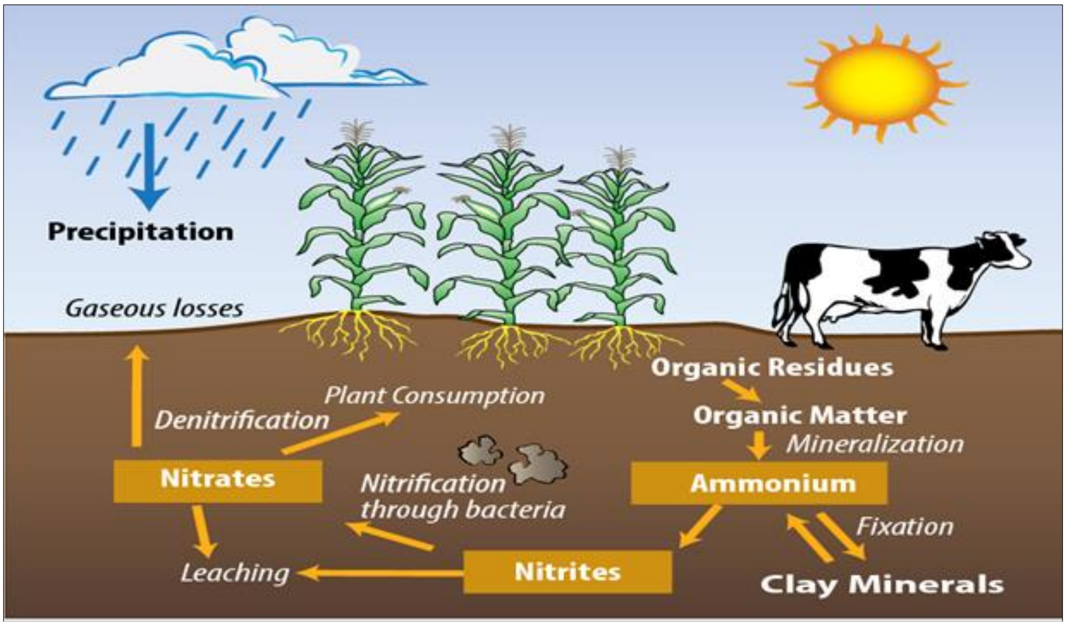

Fig 6: Nitrogen use efficiency and optimization of nitrogen fertilization in conservation agriculture (Grahmann *et al.*, 2014) [41].

The effectiveness of the use of nitrogen (NUE) was also increased by the split-dose treatment of nitrogen. When crop fertilization was observed at a rate of 200 kgha^{-1}, the highest value for the number of tillers, fertile tillers, number of grains per spike, plant height and grain yield was observed. The yield of grain and straw from fertilized crops at a rate of 150 kg Nha^{-1} was equivalent to that obtained from fertilized crops at 200 kg Nha^{-1}. The amount of grain protein in fertilized packets, however, was higher at 200 kg Nha^{-1}.

Impact of Nitrogen Application on Water Use Efficiency, Wheat Yield, and Grain Quality Under Various Conditions

With the introduction of nitrogen, a beneficial effect on the efficiency of water use has been established. Usage of nitrogen in wheat crops under rain-fed conditions was found to be effective for the conservation of groundwater. The yield of crops was greatly improved by application of N. A research was carried out to assess the impacts of N volume, time of application, mode of application and source of nitrogen on wheat growth and yield, it was discovered that nitrogen had positive impacts on all parameters of wheat growth, yield and quality and that nitrogen application also enhanced nitrogen usage efficiency. A field study conceived to chart effect on wheat grain yield of the application of fertilizer. Treatments consisted of 4 levels of nitrogen and 3 levels of phosphorus. Increasing pattern in wheat yield was observed with an improvement in rate of application of nitrogen (Girma *et al.*, 2007) [39]. Protein contents in grains of wheat altered by the application of nitrogen. In addition to weight of grain, form and scale were also impacted with the N fertilizer application. The effects of differing nitrogen (N) levels on various wheat cultivars was observed (Option and Riband).

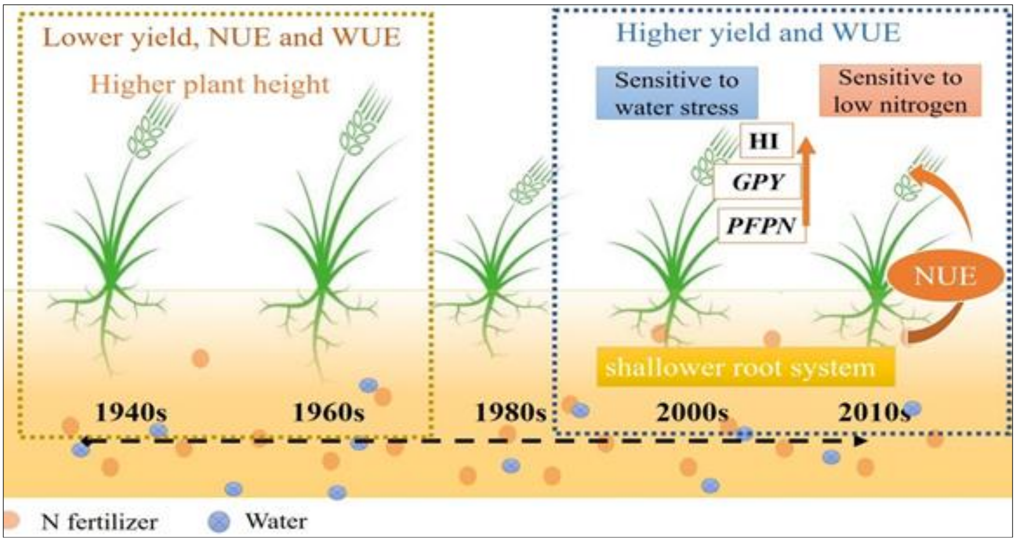

Fig 7: A synergistic increase in water and nitrogen use efficiencies in winter wheat cultivars (Grahmann *et al.*, 2014) [41].

The yield of both cultivars was not substantially different, the grain consistency, however, was significantly affected by the use of nitrogen with respect to protein content. Wheat cultivar Choice demonstrated susceptibility to higher nitrogen concentrations and reduced grain yields were seen by higher nitrogen rate accommodation. N has been shown to be the most potent component in the biological and economic production of wheat crop (Rizwan *et al.*, 2007) [51]. To explore the effect of nitrogen on the Kohdasht wheat variety a field experiment was performed. Four quantities of N were used. Nitrogen application has been shown to have a beneficial impact on yield of wheat grains and portion determinant yield. However, yield observed from 60 and 90 kgha^{-1} fertilized parcels were not substantially different (Fallahi *et al.*, 2008) [35]. A research was conducted to study effects of N on the yield and its components of wheat varieties Behar-2006 and Shafaq-2006 respectively. Various nitrogen levels were used and the results concluded that by adding nitrogen at a rate of 120 kgha^{-1} the full grain yield of both varieties was obtained. Nitrogen is most important nutrient component for plant growth, production and also most significant limiting factor (Kant *et al.*, 2018) [44]. Despite the fact that it is an efficient strategy to assure good crop yields, over use of nitrogenous fertilizers has become a prevalent concern in agricultural production. As a result of the asynchrony between Nutrient availability and N requirements, excessive basal N application can be major cause of lower nitrogen use efficiency, and deferring basal nitrogen application after three leaf level can decrease nitrogen application rates while increasing wheat yield and nitrogen use efficiency. The effects of delaying basal N fertilizer in winter wheat due to N deficiency on grain production, recovery quality and its primary fates are still unknown. Despite reduced grain yield or protein content, nitrogen deficiency may tolerate during vegetative development, and 'non-detrimental' shortfalls can have economic and environmental advantages by raising NUE.

Grain yield is favorably associated with N application in particular range and nitrogen is a significant factor influencing wheat grain yield and NUE. Reduced nitrogen application may result in a substantial reduction of grain yield. The time of application of N is also significant in deciding yield and NUE (Zhongwei *et al.*, 2020) [69]. Nitrogen is regarded as a core factor of plant nutrition, as it involved in all physiological growth processes as plant growth enhancement, yield, and chemical constituents in various plants. However, there were significant variations in how different species responded to different N fertilizer types. Amino acids (proteins) nucleic acids, phytohormones, and variety of enzymes, coenzymes are all nitrogen-containing biomolecules. Nitrogen is primarily involved in the initial development mechanisms, such as chromosome replication, deoxyribonucleic acid synthesis, and nuclear protein synthesis. Studies have shown that nitrogen applications can help reduce negative effects of salinity by partially replacing NO3 with NH4+. On sandy calcareous soils, increasing nitrogen fertilization levels greatly improved plant height, yield, and yield traits of wheat. Plant height, grain weight, straw and grain yields all were influenced by several amounts of nitrogen. With 120 kg N/ha, plant height, grain weight and grain yields were observed, while with 00, 80, and 100 kg ha^{-1}, minimum of these traits were observed (Shirazi *et al.*, 2014a).

Effects of Nitrogen Application on Soil Properties and Wheat Growth Dynamics

The second internode's breaking power was greatly reduced as more nitrogen was used. By raising both stem diameter and wall thickness, it was proposed that decreasing spring nitrogen could lower height of gravity and increase stem power. Furthermore, nitrogen application has a direct effect on soil physiochemical properties and their associations, all of these influence crop growth by influencing plant nutrition, water potential, salinity, soil reaction, crop nutrition requirements, absorption, growth control and microbial culture in soil (Arevalo-Gardini *et al.*, 2015) [11]. According to previous research nitrogen application improved dry matter and yield production by enhancing growth of roots and photosynthetic activity. Furthermore, soil properties have been shown to affect plant phenology by their impacts on soil structure, availability and uptake of nutrients, water capacity and its uptake, fertilizer response, microbial population, nutritional status of crop and root development. On other hand, major effects of N application on soil properties have previously been described (Ata-Ul-Karim *et al.*, 2020) [19].

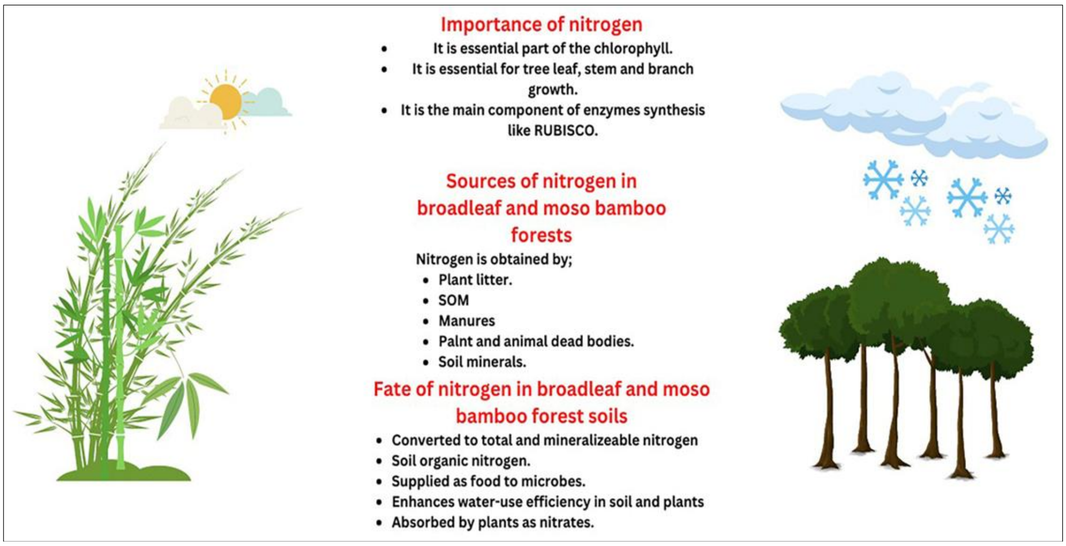

Fig 8: Importance of nitrogen in the soil and its role in soil and plant health (Sardar *et al*., 2023) [55].

Nitrogen (an important macronutrient) for crop growth and grain yield (GY), has a direct impact on dry matter (DM) development by affecting leaf photosynthetic performance. The NUE can be improved by improving fertilizer production and implementing N management techniques. Breeding new cultivars that achieve both high yield and high NUE is an additional successful solution. The productive tillers, height of plants, spike length, number of spikelets, number of grains, 1000 crop weight, grain yield and all increased dramatically when nitrogen fertilizer was applied at 120 and 150 kgha^{-1}. The use of nitrogen fertilizer was found to be the most effective way to improve wheat's quantitative and qualitative development (Kousar *et al.*, 2015) [46]. Nitrogen (N) is regarded as most important factor in optimizing wheat production. Nitrogen application at the optimal rate improves economic production, spikes plant^{-1}, spike volume, grains spike^{-1}, biomass production and disease and pest outbreak (Ghimire *et al.*, 2019) [38].

Optimizing Nitrogen Fertilizer Application for Enhanced Wheat Yield and Quality

Application of N fertilizer at proper rate regarded as primary mean of growing wheat grain production, boosting N uptake, usage quality and as a result, the nitrogen harvest index (Belete *et al.*, 2018) [23]. With each rise in nitrogen dose to 165 kg ha^{-1}, total nitrogen uptake significantly increased. This was mostly due to increased N levels, which led to an improvement in yields. Nitrogen is needed for chlorophyll synthesis since it is a component of all amino acids and proteins and is involved in photosynthesis. It is also a component of all amino acids and proteins, which are thought to be responsible for wheat consistency. The rate and timing of N application are crucial for wheat yield and its quality. Different cultivars' yield responses vary greatly depending on nitrogen control. The availability of nitrogen to wheat at several stages of its growth, development and production has a significant impact on yield and grain quality (Yousaf *et al.*, 2015) [68]. Increased nitrogen levels not only increased 1000 grain weight but also increased straw yield, viable leaves, growth and net assimilation rate at all stages of growth. Nitrogen doses differ by genotype and management scheme; however, an average of 120 kg ha^{-1} N is recommended in order to maximize yield while preserving soil quality (Chaudhari *et al.*, 2019) [27]. Grain spike^{-1} may be genetic influence in general while nitrogen has significant impact on spike duration in controlled systems (Bielski *et al.*, 2020) [26]. Inappropriate nitrogen fertilizer management can result in nutrient losses due to leaching, runoff, volatilization, or denitrification, as well as a reduction in wheat yield. As a result, maximizing the usage of nitrogen fertilizers is critical because it assures the economic viability of cropping systems and adequate plant production while also reducing the environmental risks posed by the nitrogen added (Tabak *et al.*, 2020) [60]. Nitrogen (N) is important structural component of amino acids, rubisco, chlorophyll, certain hormones and its use as fertilizer is an important agronomic management strategy for improving crop efficiency.

In any crop production system, nitrogen (N) is the most important nutrient factor. Asplund *et al.*, (2016) [17] found a connection between nitrogen usage efficiency and spring wheat growth and production. Mineral fertilization can contribute in maximizing crop production, but with the rapidly increasing prices of chemical fertilizer, especially nitrogen fertilizer, and the contamination problems of soil and water, it is becoming less common. Nitrogen (N) influences wheat production, NUE, and WUE. In order to maximize grain yields, proper irrigation and N application are considered critical. Rise in plant height was also because of nitrogen increasing leaf area, which results in a higher rate of photosynthesis assimilate yield, and plant dry matter.

Hence nitrogen is main input among the various nutrients to achieve higher output. Wheat requires nitrogen all along its growth time. Protein synthesis requires this. In the event of a nitrogen shortage, leaves are dried and shot, low growth is attained, grain is poorly drained, and yield is significantly impacted. In particular, excess nitrogen is not ideal for wheat crops; it induces early loss of soil precipitation, encourages accommodation, enhances the resistance to leaf disease and delays maturity.

Strategies for Enhancing Wheat Yield Under Irrigation Deficit Conditions

Irrigation is an important component that ensures maximum productivity of crops. The water deficit, deciding crop growth and production, is a major bottleneck limiting sustainable agriculture progress. Drought has been a human plague, cause war and violence. The farmers face significant risk when it comes to sustaining agricultural production under conditions of environmental hardship and drought. To preserve the infrastructure and prevent floods, irrigated agricultural management of water should be paired with other available water saving practices. We must rely on non-traditional capital, otherwise (desalinated water). There is less than 1000 m3 / capita / year of water available in heavily inhabited arid areas, reflecting its shortage (Rijsberman 2006) [49]. There is an immediate need for advanced and green research and technology in water-constrained areas to use water effectively (such as on-farm water storage and filtered water usage). Supplementary irrigation and irrigation shortages are valuable tools for Improved Water Quality opportunities (Pereira *et al.*, 2002). One potential solution to face the drought problem is irrigation by deficit. Deficit irrigation can be converted into terms of decreased water consumption thus reducing its detrimental impacts on crop production.

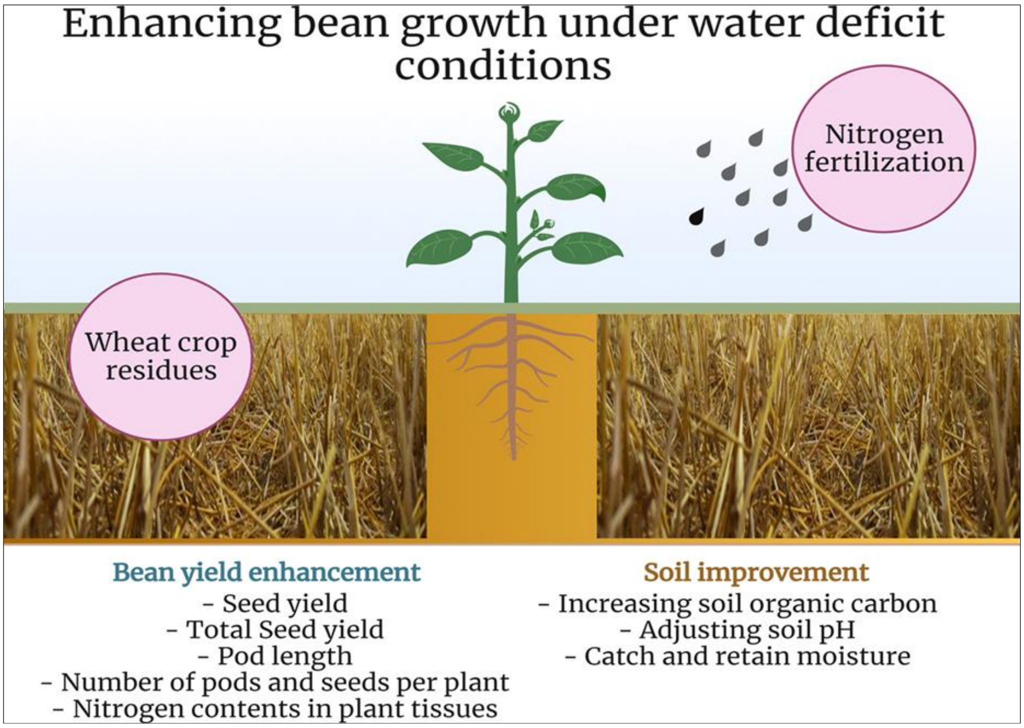

Fig 9: Yield and yield components of common bean as influenced by wheat residue and nitrogen rates under water deficit conditions (Sardar *et al.*, 2023) [55].

Answer of the various stages of the crop to the degree of water deficit as well as its duration and the monetary advantages is fundamental criteria for applying this strategy. The advantage of deficit irrigation can be expressed by following factors: improved WUE, minimum cost of irrigation and opportunity cost of irrigated water. Water conserved from irrigation deficits can be utilized to irrigate surplus land to boost productivity and compensate for decreased yields, especially in water-scarce areas. Du *et al.*, (2010) observed that in semi-arid and arid winter wheat conditions the method of water-saving irrigation, temporal (regular deficit) irrigation, for four years. Owing to alternate irrigation of the furrow, they found comparable photosynthetic levels maintained but reduced transpiration rate. The feasible irrigation period is seven days, in highly arid conditions. For grain yield it is easier to use high irrigation frequency with less water. The magnitude and timing of the water deficiency should be prepared considering the stress resistance potential of the crop variety. Ali *et al.*, (2007) [9] performed another analysis which emphasis on irrigation water scheduling focused on irrigation deficit on various stages of wheat growth and its impacts on crop production. Yield 22 attributes is significantly affected by drought stress. Compared to other therapies full irrigation (no deficit) yielded higher. Grain yield at Crown Root Initiation was reduced in decreasing order, with deficit irrigation, tillering, booting to heading, and light dough flowering level. Substitute irrigation performed well at the crown root initiation and booting-heading period. as comparing tension with two deficit techniques. They proposed that irrigation should prepared first at CRI under a small supply of water. Fang *et al.*, (2006) [36] discovered that photosynthetic material developed after heading stage leads to winter wheat yields of around 70-80 percent. The mean light detection fraction (90 per cent) was higher while the overall LAI in the fully irrigated plot was greater than 5.0. As the mean LAI value in drought treatments drops to 4-5, this fraction of light decreased to 80 percent. This decline in LAI is related to water demand, which eventually decreased biomass production (Rehman *et al.*, 2021) [48].

Optimizing Irrigation Scheduling for Maximized Wheat Yield and Water Use Efficiency

By supplying unfixed volumes of water at the stage of seeding, joining and dry matter production, the impacts of irrigation scheduling on yield and water use efficiency of wheat. No irrigation has resulted in lowest dry matter concentration at maturity during growing season. The highest amount of TDM at the anthesis stage was found while the crop was irrigated. In anthesis irrigation, then in joint and anthesis irrigation, then in sowing, joining and anthesis irrigation and, at least, in no irrigation during the whole season, the partitioning of dry matter into grain was largest. Increased TDM concentration and rate of conversion into grain mass resulted from the comparatively high net photosynthesis rate and rate of grain filling. In order to improve the irrigation plan for grain output and WUE of wheat, they performed three consecutive years of research. They observed that the grain yield and water use efficiency were optimal at evapotranspiration values. The average use of SWU (soil water) in two-meters deep soil profiles differed from 263.9-135.6 mm during the growing season, relative to no irrigation with irrigation during raising, jointing and planting. Due to the absence of signs of water shortage, they recommended halting irrigation after sowing, before or after joining. Water absorption from deeper soil layers is encouraged by irrigation after seeding, leading in root development. Based on the supply of water, second irrigation at flowering should be applied

23 to prevent the burden of drought on milking. Under insufficient water supplies, initial irrigation should be deferred until booting. No. of grains/spike is determined by growth cycle from jointing to flowering. In order to achieve high yield, second irrigation is advised at the joint stage with Flowering. The average yield over three consecutive years was 6659, 6914 and 7384 kg ha^{-1} Irrigation for the very first 2 years at jointing, flowering and milking, and Irrigation for the third at jointing and flowering (Li *et al.,* 2005; Abbas *et al.,* 2021) [47,]. Ram *et al.*, (2013)'s study of measuring wheat production in various irrigation schedules based on essential growth stages for consecutive three years was comparable, and observed that with rise in the No. of irrigations in growing season, WUE decreases. 5 irrigation numbers are no promise of greater production. Four irrigations will rarely yield more. As the amount of irrigation rose from one to four, Tariq *et al.,* (2012) [61] recorded a substantial increase in biomass, although growth in the number of irrigation rates from four to five indicated no considerable rise in biomass. In comparison to the completely irrigated plot, reduction in wheat production under drought stress plots due to a substantial reduction in yield, especially thousands of grain weight and active tillers. Spent two consecutive years researching the impact of daily deficit irrigation on crop production and the WUE. In daily irrigation with the shortfall, they found higher yield and yield components in relation to no stress therapy. The grain production rose from 16.6-25 percent along with water savings of 14-22.9 percent with standard deficit irrigation water levels relative to complete irrigation treatments suggesting over application of irrigation as opposed to need. At booting, 50-60 percent of FWC, 65 to 70 percent of water holding capacity at booting and leaf development, and 50 to 60 percent of field water capacity at grain filling time, recorded the optimum soil moisture content level. Xue *et al.,* (2003) [67] have published another analysis to assess the wheat rain fed, shortfall, and full irrigation system. Leading to the reduced soil water supply from booting to the extent of grain filling, lowest shoot dry weight was observed at rainfed plots. In the deficit irrigation system, crop irrigation had accrued more biomass only at the vegetative stage relative to crops receiving irrigation at the level of reproduction. Due to higher water intake compared to rainfed crops, higher grain yields were recorded in the complete irrigation system and deficit irrigation regime with reproductive water application. On the other hand, large decrease in grain production with various soil water deficits care in 24 light soil water deficit care and no substantial improvement in yield and WUE as compared to no stressful treatment in 24 light soil water deficit treatment. They concluded that with no substantial reduction in grain production, evapotranspiration can be limited to any extant. A decline in biomass due to drought stress due to lower LAI, reduced number of leaves and increased physiological maturation has been observed. Higher ET isn't a guarantee of high yields in terms of high soil moisture. In plots with moderate stress during seedling or early vegetative stage, higher yield, HI, and WUE values were attained. Under restricted water conditions, WUE is linearly linked to HI. Can HI will help to enhance the WUE. For four growing seasons, based on pan evapotranspiration, Liu *et al.,* (2013) used the simple and efficient irrigation scheduling method. The relation between crop yield and ET was quadratic, they observed. The response factor was proportional to ET for the crops. The association among grain production, quantity of irrigation, WUE and ET has been studied. They indicated that 300 mm of irrigation water with an ET value of 426 mm would be appropriate for the optimum yield to be obtained. With increased ET, the need for crop water has increased, but grain yields have decreased, particularly in the case of excessive irrigation, with a definite decrease in WUE. For both grain yield and TDM, a maximal RUE of 50 mm PSMD. Water scarcity and erratic precipitation/rainfall are major threats to agricultural sustainability, particularly for wheat (*Triticum aestivum* L.). Plant development is hampered by too much or little water. As a result, crop production is negatively affected. Extra moisture in the field during the critical growth cycle damages the crop in a variety of ways including reducing yield, inviting pests, causing diseases and deteriorating quality, which cannot command a premium price due to low market demand (Arshad *et al.*, 2024a) [12]. Irrigation at the right time is crucial for wheat growth and has a major impact on grain yield particularly during crown root initiation stage (Islam *et al.,* 2018) [43].

Impact of Water Management and Irrigation Practices on Wheat Growth and Yield

Water is most important factor for proper crop growth, healthy production, and increased yield. Water scarcity affects plant development and grain output in wheat and many cereals as a result of a range of contributing and linked components (Arshad *et al*., 2024b) [13]. Wheat cultivars had a major impact on days to heading and maturity, plant height, number of spike/m^{-2}, number of grain/spike, 1000-grain weight, straw yield and HI. This was evident from the experiment means, which revealed that as number of irrigations grew, the number of spikes/unit area increased as well. Irrigation improved wheat yield at various growth stages, according to this report. Meanwhile, irrigating wheat three times and missing the watering during flowering could result in a yield of 91 percent of the limit (Elhag and Dalia 2017) [33]. Wheat crop needs enough soil moisture to expand and mature properly. Wheat grain production and water productivity to irrigation are both influenced by the soil's extractable water capability. During the dry season, the moisture content of the soil steadily declines as the soil moisture stress rises. Excessive irrigation increases evapotranspiration and reduces water quality, as well as potentially lowering crop yields (Ali *et al.*, 2018) [10].

In rain fed, coastal, arid, and semi-arid areas, limited irrigation is a major restriction to wheat production. When rainfall is low and irrigation is minimal, the optimal management method for N and irrigation levels is to sustain maize-wheat cropping series and mix restricted irrigation water with nitrogen fertilizer to maximize wheat productivities. In comparison to the rainfed treatment, supplemental irrigation greatly improved wheat yield (Rathore *et al.*, 2017). Irrigated plants' tillers formed 94 percent of the ears, compared to 79 percent for stressed plants. When compared to irrigated plants yield was decreased by 65 percent in plants under stress. Irrigating the wheat crop at all definable growth stages resulted in the maximum grain yield. Increased yield per unit area is needed for productive input usage, and irrigation water is the most useful input that is rapidly depleting. Since the need for food and safe water is the, the importance of effective water usage is unavoidable. It was determined that four irrigations had the ability to produce good yields, perform well, and be cost-effective. While the three irrigations had an average production and output, as well as an average profit, the two irrigations had a negative impact on plant growth and efficiency, as well as a decline in yield. The lowest yield values were found in one irrigation (kanwal *et al.*, 2020) [45]. Improving water productivity for irrigation and lowering irrigation demands while retaining productivity is critical. As compared to two irrigations at CRI and late tillering levels, a larger number of irrigations resulted in higher yield due to rise in the number of active tillers and photosynthates accumulation. Increased water supply may have resulted in increased development of wheat leaves under well-irrigated conditions due to increased uptake of water and nutrients from soil. Lack of optimal water requirements, balanced nitrogen fertilizer usage, optimum seeding density, strong seed of high yielding varieties, and proper cultural practices are all factors that contribute to Pakistan's low wheat yield. Increased grain protein content is also linked to water shortages.

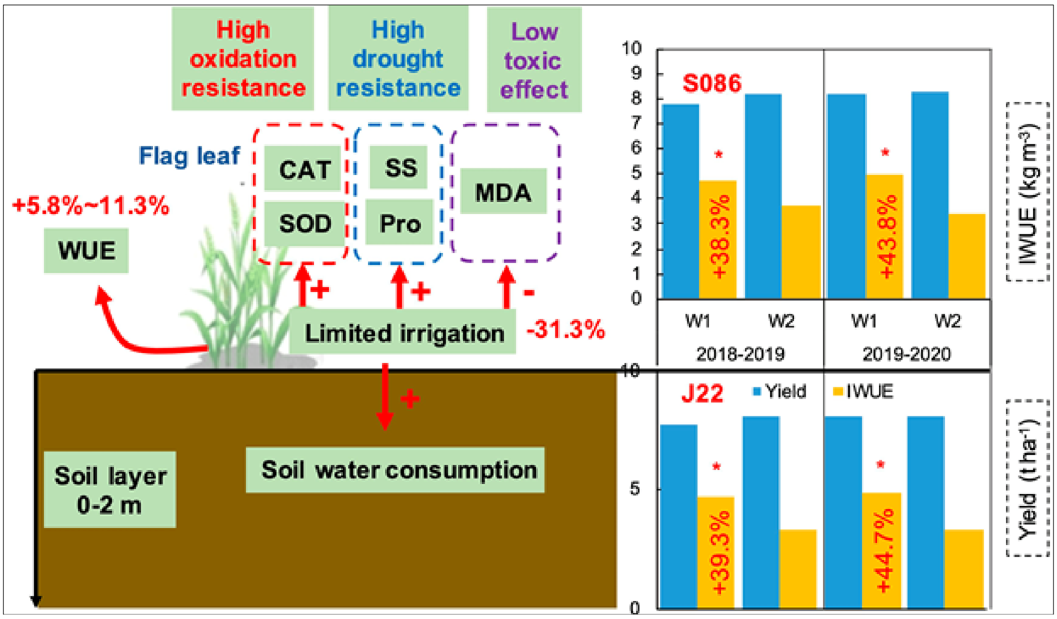

Fig 10: Improving Wheat Yield and Water-Use Efficiency by Optimizing Irrigations in Northern China (Zhang *et al.*, 2023).

If nitrogen supply is not increased in combination with irrigation or any other cultural activity that increases yield capacity, grain protein content may be reduced due to dilution with carbohydrates. Irrigation at an excessive rate, or irrigation in the absence of a yield increase, reduced grain protein levels. Irrigation, on the other hand, improved grain protein content in some situations, and it can also mobilize surface-applied fertilizer. Plant density is most important considerations in assessing ability of crop to capture resources. It's especially important in wheat production because most cropping systems put it under the farmer's thumb. Plant densities that are optimal for a given area differ significantly depending on climatic conditions, soil, sowing time, and variety. The improvement in tillers m^{-2} and leaf area tiller-1 with irrigation leads to an increase in leaf area index. Increased water supply, which affects cell division and cell enlargement, may have increased all of these characters, as well as the leaf area index (Shah *et al.*, 2016; Abbas *et al.*, 2021a) [57, 1]. Since farmers are involved in straw in addition to grain, biological yield is a significant parameter. It can be deduced from the data that different irrigation levels had a major impact on biological yield (Rafeeq *et al.*, 2020). Water is a critical input among all the inputs, but water for irrigation is a limited supply, so effective irrigation water use is critical. The most efficient use of water for irrigation allows all other input variables to be properly used, resulting in improved yield per unit area and time. A detailed examination of the plant-water relationship, environment, agronomic practices, and economic evaluation is needed for effective water management. Since the weather stays relatively dry throughout the growing season, irrigation is more important in the cultivation of high yielding wheat varieties. The judicious application of water necessitates urgent treatment, which can only be achieved by adhering to any empirical rationale for water application to crops. Critical crop growth stage approach for irrigation scheduling is one such scientific approach, especially in the area of water scarcity (Arshad *et al.*, 2024c) [14]. Bedarkar *et al.*, (2017) [22] demonstrated an increase in number of grains per ear as a result of increased irrigation levels.

Interactive Effects of Water and Nitrogen on Wheat Growth and Productivity: Water access and nitrogen supply to crops are intertwined factors that influence plant growth and productivity. Appropriate nitrogen fertilization facilitates the expansion of leaf area and canopy cover, increasing plant evapotranspiration performance. Supplementary irrigation at the jointing stage combined with application of 100 kg nitrogen ha^{-1} plays a vital role in increasing yield and water productivity of Sardari wheat cultivar in semi-arid regions (Tomaz *et al.*, 2017) [63]. Wheat yield and growth parameters are also influenced by irrigation regimes. The best treatment for wheat cultivation is a blend of irrigation (200 mm) and nitrogen (120 kg ha^{-1}). At any critical growth stage of wheat, from germination to plant maturity, irrigation is critical. Moisture stress to wheat crops at the spike emergence and antithesis stages has been shown to decrease yield from 3.3 to 7 tons per hectare in previous studies. Irrigation at a critical point will be a beneficial management method for will yield (Rummana *et al.*, 2018; Arshad *et al.*, 2021) [52, 15]. Because of stomata closure and early senescence, water stress and nitrogen deficiency decrease photosynthates yield, which affects grain growth processes (Liu *et al.*, 2016). The impact of water and nitrogen on wheat physiological responses suggests that high concentrations of spring added nitrogen require supplementary water to improve the rate and duration of leaf photosynthesis during grain filling cycle. Nitrogen is essential in all of the plant's living tissues. Protein, in which nitrogen is an important component, is involved in all crucial processes in the plant. Proteins, sugars, coenzymes, nucleic acids and chlorophyll all contain nitrogen. It has a significant role in plant's biochemical processes. As a result, it has become one of the most significant nutrients for wheat crop (Akhter *et al.*, 2017; Pervaiz *et al.*, 2024) [5,]. As a result, nitrogen fertilization in the form of chemical fertilizer is needed to increase crop yield. With rising nitrogen levels, high yielding varieties' yield and yield components typically increased. The application of the right amount of nitrogen is critical for a bumper wheat harvest. The application of spilt nitrogen had minimal impact on yield but it did reduce lodging and spike density while grain weight increased (Abbas *et al.*, 2021a) [1]. Wheat production is limited by poor nitrogen fertilization control, its non-use, soil type, water, temperature, and crop management. Water usage along with fertilizer application are two most limiting factors in deciding wheat crop production, With a high nitrogen level, spike numbers and grain weight were recorded to increase. A rise in nitrogen level as a result of which grain yields have increased. Nitrogen deficiency has an effect on the plant's biomass production and solar radiation usage quality, as well as grain yield and its components (Yousaf *et al.*, 2014) [68]. Root morphology and physiology are also closely linked to above–ground growth and development, which is dependent on nutrient and water uptake in the soil (Ju *et al.*, 2015). Nitrogen (N) is important nutrient that influences wheat production, NUE, and WUE. In order to maximize grain yields, proper irrigation and nitrogen application are critical (Li *et al.*, 2015; Aleem *et al.*, 2024) [6]. The two most important factors impacting wheat yield are water and fertilizer. Furthermore, in order to achieve high crop yields, farmers rely on high rates of nitrogen fertilization (Sui *et al.*, 2015) [59]. Excess nitrogen fertilization, on the other hand, does not result in a large rise in crop grain yields (Sui *et al.*, 2015) [59]. Furthermore, past studies' optimum levels of irrigation and nitrogen may not have the same results as those currently used at local level, particularly in case of cumulative soil fertility as a result of improper fertilizer usage. It has already been demonstrated that a shortage of water reduces nitrogen fertilizer effectiveness.

Influence of Increased Irrigation and Nitrogen Application on Wheat Growth, Yield, and Water Use Efficiency

Increased irrigation and nitrogen application significantly increased real evapo- transpiration, leaf area index (LAI), biomass, crop yield and water usage efficiency of wheat, according to the findings. Nitrogen (N) application rate greater than 240 kg/ha, on the other hand, these had not effect on growth, yield and WUE of wheat. A high level of agricultural productivity requires irrigation, in this area due to inadequate rainfall. Due to the varying lengths of flood irrigation borders, irrigation volumes are greater than 150 mm/irrigation occurrence (Xu *et al.*, 2019) [66]. Furthermore, in the field, long term high nitrogen application surpass crop demand for wheat and maize. Precipitation, irrigation, and nitrogen application rate are the most important elements regulating water and solute movement below root zone into deep soils. Besides that, due to the system's complexities and extremely nonlinear material properties, specifically studying solute and water movement at deep soil depth is difficult. Water and nitrogen are also essential for crop production and yield. Increased nitrogen application rates will boost crop yields significantly. Quadratic (linear plus-plateau) models accurately explain the relation between yield and N application. When total N application was reduced, crop yield seemed to be influenced by N application timing in addition to overall N application. Crop yields were improved because some of the nitrogen was added later in the growing season, preventing the rapid development that occurs when there is a lot of available nitrogen early in season. Increasing number of nitrogen applications from 1 to 3 improved maize and wheat yields upto 1.6 percent and 4.6 percent, respectively, for given N rate. The length of the boundary determines the amount of irrigation used for the border flood irrigation system (Xu *et al.*, 2019) [66]. Multiple applications of nitrogen and rising the rate of N operation at later growth stages may increase NUE and production. Increased N application resulted in increased water intake, organic matter absorption in, and water storage in soil resulting reduction in DPW for maize and wheat. The maximizing the N fertilizer increased WUE significantly. When N levels approached critical level, maize WUE decreased, as a result of greater biomass and crop canopy inducing excessive transpiration. When it comes to improving efficiency and minimizing nitrogen leaching failure, the timing of N application is critical. When compared to no irrigation, studies showed that irrigation at jointing and anthesis stage increased grain yield. In every cropping season, however, various irrigation regimes had no major impact on protein contents of grain. And compared to no N procedure, grain yield improved dramatically when 180, 240 and 300 kg ha^{-1} N was applied. With higher nitrogen application, grain protein and amino acid concentration increased considerably. When opposed to no irrigation, irrigation greatly increased the essential amino acid index (EAAI) and protein- digestibility-corrected amino acid score (PDCAAS). EAAI and PDCAAS had positive correlation, but yield and grain protein content was strongly negatively correlated.

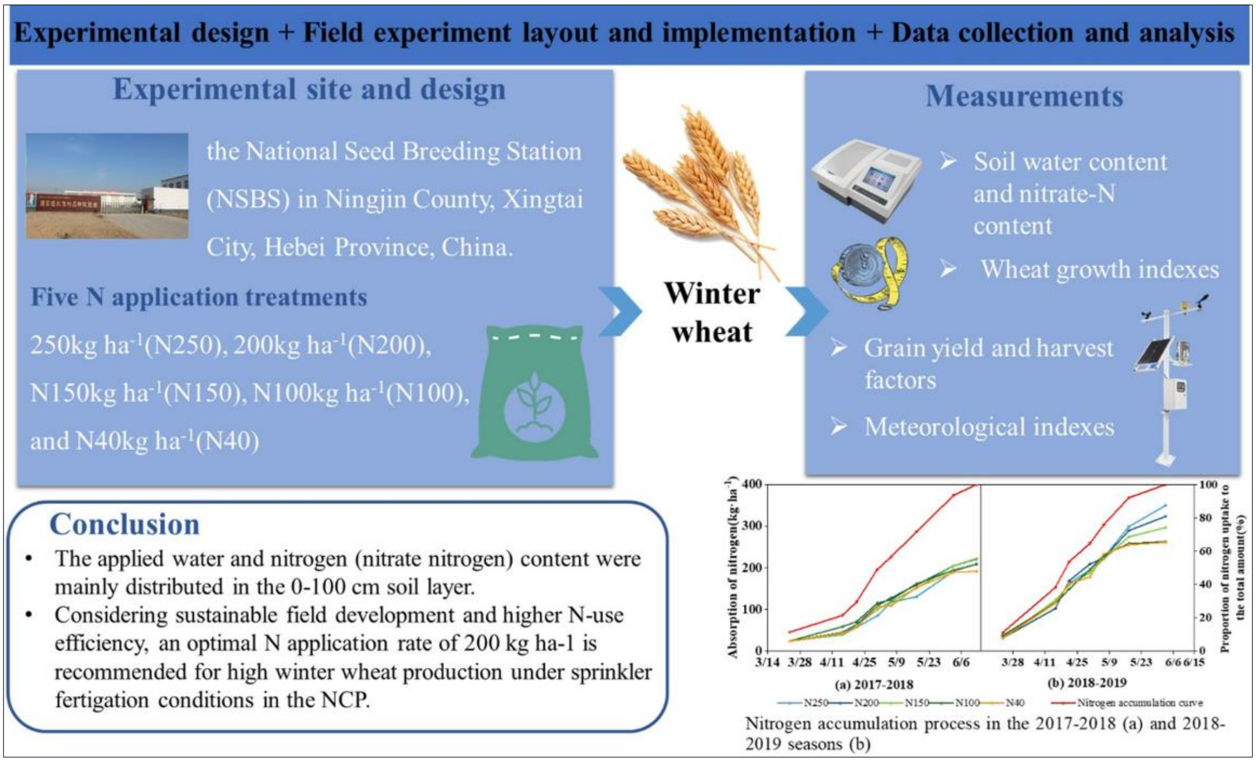

Fig 11: Effects of Nitrogen Application at Different Levels by a Sprinkler Fertigation System on Crop Growth and Nitrogen-Use Efficiency of Winter Wheat in the North China Plain (Wang *et al*., 2024) [64].

Conclusion

The insights gathered from this comprehensive review underline the intricate balance required between nitrogen management and irrigation techniques to optimize wheat farming sustainably. The synthesis of various studies reveals that precise nitrogen application enhances wheat growth and yield, particularly in water-limited scenarios, but also cautions against the environmental risks posed by excessive nitrogen use such as eutrophication and greenhouse gas emissions. On the irrigation front, innovative techniques like deficit irrigation and tailored water scheduling emerge as vital in managing the limited water resources effectively, especially in semi-arid regions where water scarcity is prevalent. It is evident that the integration of nitrogen and water management strategies is not merely beneficial but essential for the sustainable intensification of wheat production. Such integration ensures that crops meet their physiological needs efficiently while mitigating potential negative impacts on the environment. The review strongly advocates for ongoing research into the development of more resilient wheat varieties and the refinement of nitrogen and irrigation practices. This approach will not only sustain agricultural productivity in the face of climatic variability and resource limitations but also enhance food security globally without compromising ecological integrity. Ultimately, the future of sustainable agriculture will rely heavily on our ability to implement these integrated management strategies effectively across different geographic and climatic regions. This will require a concerted effort from researchers, farmers, policymakers, and industry stakeholders to ensure that the advancements in agricultural science translate into practical applications that benefit both the environment and the global population.

References

1. Abbas A, Wang Y, Muhammad U, Fatima A. Efficacy of different insecticides against gram pod borer (*Helicoverpa armigera*) and their safety to the beneficial fauna. International Journal of Biosciences. 2021a;18:82-88.
2. Abbas RN, Arshad MA, Iqbal A, Iqbal MA, Imran M, Raza A. Weeds spectrum, productivity and land-use efficiency in maize-gram intercropping systems under semi-arid environment. Agronomy. 2021b;11(8):1615.
3. Abbas SH, Bhatti AA, Muhammad Asif, Islam Z, Sohail M, Din RU. Effect of supplemental irrigation on wheat water productivity under rainfed ecology of Pothohar, Pakistan. Innovations in Journal of Agricultural Sciences. 2015;3(1):10-13.
4. Ahmad R, Naveed M, Aslam M, Zahir ZA, Arshad M, Jilani G. Economizing the use of nitrogen fertilizer in wheat production through enriched compost. Renewable Agriculture and Food Systems. 2008;23(3):243-249.
5. Akhter MJ, Abbas RN, Waqas MA, Noor MA, Arshad MA, Mahboob WM, Gull UG. Adjuvant improves the efficacy of herbicide for weed management in maize sown under altered sowing methods. Journal of Experimental Biology and Agricultural Sciences. 2017;5(1):22-30.
6. Aleem S. Advancements in Mutation Breeding in Phalsa (*Grewia asiatica* L.) Crop Improvement: A Comprehensive Review of Radiation and Chemical Induced Mutagenesis Studies. Haya: Saudi Journal of Life Sciences. 2024;9(5):158-171.
7. Ali A, Syed AW, Khaliq T, Asif M, Aziz M, Mubeen M. Effects of nitrogen on growth and yield components of wheat. (Report). Journal of Biological Sciences. 2011;3(6):1004-1005.
8. Ali H, Ahmad SH, Ali H, Hassan FS. Impact of nitrogen application on growth and productivity of wheat (*Triticum aestivum* L.). Journal of Agricultural Science. 2005;3:216-218.
9. Ali MA, Amin S. Effect of irrigation frequencies on yield and yield attributes of wheat cultivar (*Triticum aestivum*)

'Shatabdi'. Journal of Food Technology. 2007;2(3):145-147.

10. Ali S, Xu Y, Ahmad I, Jia Q, Ma X, Ullah H. Tillage and deficit irrigation strategies to improve winter wheat production through regulating root development under simulated rainfall conditions. Agricultural Water Management. 2018;209:44-54.
11. Arevalo-Gardini E, Canto M, Alegre J, Loli O, Julca A, Baligar V. Changes in soil physical and chemical properties in long-term improved natural and traditional agroforestry management systems of cacao genotypes in Peruvian Amazon. PLOS One; c2015 .p. 10.
12. Arshad MA, Abbas RN, Khaliq A, Ahmed Z. Assessing herbicide efficacy and susceptibility for weed management and enhancing production of non-GMO soybean cultivation. Haya: Saudi Journal of Life Sciences. 2024a;9(5):172-178.
13. Arshad MA, Rouf S, Abbas RN, Aleem K, Sarwar A, Shahbaz Z. Environmental benefits and risks of herbicides use in forestry – Review. Haya: Saudi Journal of Life Sciences. 2024b;9(2):23-35.
14. Arshad MA, Rouf S, Abbas RN, Shahbaz Z, Aleem K, Shahbaz H, *et al*. Navigating synergies: A comprehensive review of agroforestry system and agronomy crops. Haya: Saudi Journal of Life Sciences. 2024c;9(4):97-112.
15. Arshad MA. A review on wheat management, strategies, current problems, and future perspectives. Haya: Saudi Journal of Life Sciences. 2021;6:14-18.
16. Aslam M, Khan MA, Awan IU, Khan EA, Khan AA, Jilani G. Effect of single and combined use of various organic amendments on wheat grown over green manured soil: I. Growth and yield attributes. Pakistan Journal of Nutrition. 2011;10:640-646.
17. Asplund L, Bergkvist G, Weih M. Functional traits associated with nitrogen use efficiency in wheat. Acta Agriculture Scandinavica, Section B—Soil and Plant Science. 2016;66:153-169.
18. Ata-Ul-Karim ST, Cang L, Wang Y, Zhou D. Interactions between nitrogen application and soil properties and their impacts on the transfer of cadmium from soil to wheat (*Triticum aestivum* L.) grain. Geoderma. 2020;357:113923.
19. Ata-Ul-Karim ST, Liu X, Lu Z, Yuan Z, Zhu Y, Cao W. In-season estimation of rice grain yield using critical nitrogen dilution curve. Field Crops Research. 2016;195:1-8.
20. Baloch SU, Li-jun L, Kandhro MN, Fahad S, Sabiel SA, Baloch SK, Badini SA. Effect of different irrigation schedules on the growth and yield performance of wheat (*Triticum aestivum* L.) varieties assessment in District Awaran (Balochistan). Journal of Biological and Agricultural Healthcare. 2014;4:5-17.
21. Barraclough PB, Howarth JR, Jones J, Lopez-Bellido R, Parmar S, Shepherd CE. Nitrogen efficiency of wheat: genotypic and environmental variation and prospects for improvement. European Journal of Agronomy. 2010;33(1):1-11.
22. Bedarkar PB, Sawadhkar SM, Bhale VM, Chore AB. Response of different genotype to restricted irrigation for increasing yield of wheat. International Journal of Scientific Research. 2017;6(1):30-32.
23. Belete F, Dechassa N, Molla A. Effect of nitrogen fertilizer rates on grain yield and nitrogen uptake and use efficiency of bread wheat (*Triticum aestivum* L.) varieties on the Vertisols of central highlands of Ethiopia. Agriculture and Food Security. 2018;7:78.
24. Bhardwaj AK, Malik K, Chejara S, Rajwar D, Narjary B, Chandra P. Integration of organics in nutrient management for rice-wheat system improves nitrogen use efficiency via favourable soil biological and electrochemical responses. Frontiers in Plant Science. 2023;13:1075011.
25. Bhardwaj AK, Rajwar D, Yadav RK, Chaudhari SK, Sharma DK. Nitrogen availability and use efficiency in wheat crop as influenced by the organic-input quality under major integrated nutrient management systems. Frontiers in Plant Science. 2021;12:634448.
26. Bielski S, Romaneckas K, Šarauskis E. Impact of nitrogen and boron fertilization on winter triticale productivity parameters. Agronomy. 2020;10(2):279.
27. Chaudhari D, Vista SP, Ghimire P, Devkota C. Influence of agricultural lime in alleviating acidity level of various acid soils. World Journal of Agricultural Soil Science. 2019;3(3):1-6.
28. Cui Z, Chen X, Zhang F. Current nitrogen management status and measures to improve the intensive wheat–maize system in China. Ambio. 2010;39(5):376-384.
29. Devadas R, Simpfendorfer S, Backhouse D, Lamb DW. Effect of stripe rust on the yield response of wheat to nitrogen. Crop Journal. 2014;2:201-206.
30. Dilshad M, Lone MI, Jilani G, Malik MA, Yousaf M, Khalid R. Sustaining soil productivity by integrated plant nutrient management in wheat based cropping system under rainfed conditions. Biological Sciences- Pakistan Journal of Scientific and Industrial Research. 2011;54(1):9-17.
31. Dilshad MD, Lone MI, Jilani G, Malik MA, Yousaf M, Khalid R. Integrated plant nutrient management (IPNM) on maize under rainfed condition. Pakistan Journal of Nutrition. 2010;9(9):896-901.
32. S, Sun J, Zhang X, Zhang J. An improved water use efficiency of cereals under temporal and spatial deficit irrigation in north China. Agricultural Water Management. 2010;97(1):66-74.
33. Elhag D. Effect of irrigation number on yield and yield components of some bread wheat cultivars in North Nile Delta of Egypt. Egypt Journal of Agronomy. 2017;39(2):137-148.
34. Fageria NK, Baligar VC. Enhancing nitrogen use efficiency in crop plants. Advances in Agronomy. 2005;88:97-185.
35. Fallahi HA, Nasseri A, Siadat A. Wheat yield components are positively influenced by nitrogen application under moisture deficit environments. International Journal of Agriculture and Biology. 2008, 10(6).
36. Fang WB, Sakih MK, Nudi YB. Effect of water stress with physic-development on yield of wheat grown in semi-arid environment. Field Crops Research. 2006;5:55-67.
37. Foulkes MJ, Hawkesford MJ, Barraclough PB, Holdsworth MJ, Kerr S, Kightley S. Identifying traits to improve the nitrogen economy of wheat: recent advances and future prospects. Field Crops Research. 2009;114:329-342.
38. Ghimire P, Giri B, Gautam P, Shrestha P, Shrestha S. Screening of different rice genotypes against rice blast (*Pyricularia oryzae*) at Gokuleshwor, Baitadi.

International Journal of Scientific Research and Publications. 2019;9(6):90117.
39. Girma K, Freeman KW, Teal R, Arnall DB, Tubana B, Holtz S, Raun WR. Analysis of yield variability in winter wheat due to temporal variability. Not Available; c2007.
40. Government of Pakistan. Economic Survey of Pakistan. Government of Pakistan, Finance Division, Economic Advisor’s Wing, Islamabad. 2019;20-21:20-21.
41. Grahmann K, Verhulst N, Buerkert A, Ortiz-Monasterio I, Govaerts B. Nitrogen use efficiency and optimization of nitrogen fertilization in conservation agriculture. CABI Reviews. 2014; (2013):1-19.
42. Hofman G, Van Cleemput O. Soil and Plant Nitrogen. International Fertilizer Industry Association, Paris; c2004.
43. Islam ST, Haque MZ, Hasan MM, Khan AB, Shanta UK. Effect of different irrigation levels on the performance of wheat. Progress in Agriculture. 2018;29(2):99-106.
44. Kant S. Understanding nitrate uptake, signaling and remobilisation for improving plant nitrogen use efficiency. Seminars in Cell & Developmental Biology. 2018;74:89-96.
45. Kanwal T, Haseeba M, Riaz A, Saeed A, Akbar A, Babar H, Wasim TM. Effect of irrigation regimes on growth and yield of wheat (*Triticum aestivum* L.); Economic analysis. Pakistan Journal of Botany. 2020;52(2):753-762.
46. Kousar P, Ali L, Raza A, Maqbool A, Maqbool S, Rasheed S. Effect of different levels of nitrogen on the economic yield of wheat (*Triticum aestivum* L.) variety Aas-11. International Journal of Agronomy and Agricultural Research. 2015;6(3):7-11.
47. Li J, Inanaga S, Li Z, Eneji AE. Optimizing irrigation scheduling for winter wheat in the North China Plain. Agricultural Water Management. 2005;76(1):8-23.
48. Rehman FU, Kalsoom M, Adnan M, Naz N, Ahmad Nasir T, Ali H. Soybean mosaic disease (SMD): A review. Egyptian Journal of Basic and Applied Sciences. 2021;8(1):12-16.
49. Rijsberman F. Water Scarcity: Fact or Fiction? Agricultural Water Management. 2006;80:5-22.
50. Rinaldi M. Water availability at sowing and nitrogen management of durum wheat: A seasonal analysis with the CERES-Wheat model. Field Crops Research. 2004;89(1):27-37.
51. Rizwan AS, Shahzad M, Khalid A, Arshad M, Mahmood MH. Growth and yield response of wheat and maize to nitrogen and *L. tryptophan* enriched compost. Pakistan Journal of Botany. 2007;39(2):541-549.
52. Rummana S, Amin AKMR, Islam MS, Faruk GM. Effect of irrigation and mulch materials on growth and yield of wheat. Bangladesh Agricultural Journal. 2018;21(1):71-76.
53. Rusan MM, Battikhi A, Zuraiqi S. Enhancement of nitrogen and water use efficiency by optimizing the combination of soil, crop and nitrogen management. In: Management of Nutrients and Water in Rainfed Arid and Semi-Arid Areas for Increasing Crop Production. IAEA-TECDOC-1468; c2005 .p. 155-177.
54. Sadras VO, Lawson C. Nitrogen and water-use efficiency of Australian wheat varieties released between 1958 and 2007. European Journal of Agronomy. 2013;46:34-41.
55. Sardar MF, Younas F, Farooqi ZUR, Li Y. Soil nitrogen dynamics in natural forest ecosystem: a review. Frontiers in Forests and Global Change. 2023;6:1144930.
56. Sardo MF, Younas F, Farooqi ZUR, Li Y. Soil nitrogen dynamics in natural forest ecosystem: A review. Frontiers in Forests and Global Change. 2023;6:1144930.
57. Shah WA, Hayat Z, Amin R, Anwar S, Islam M. Effect of irrigation levels and seed rates on wheat production. Pure and Applied Biology. 2016;5(4):1.
58. Silva JA, Uchida RS. Plant nutrient management in Hawaii's soils: Approaches for tropical and subtropical agriculture. University of Hawaii; 2000.
59. Sui J, Wang JD, Gong SH, Xu D, Zhang YQ. Effect of nitrogen and irrigation application on water movement and nitrogen transport for a wheat crop under drip irrigation in the North China Plain. Water. 2015;7:6651-6672.
60. Tabak M, Lepiarczyk A, Filipek-Mazur B, Lisowska A. Efficiency of nitrogen fertilization of winter wheat depending on sulfur fertilization. Agronomy Journal. 2020;10(9):1304.
61. Tariq HAN, Ahmad S, Rasheed M, Chattha TH, Hussain A. Growth and radiation use efficiency of wheat as affected by different irrigation levels and phosphorus application methods. Journal of Animal and Plant Sciences. 2012;22(4):1118-1125.
62. Tedone L, Ali SA, De Mastro G. Optimization of nitrogen in durum wheat in the Mediterranean climate: The agronomical aspect and greenhouse gas (GHG) emissions. Nitrogen Agriculture Updates. 2017;8:131-162.
63. Tomaz A, Ferro Palma J, Guerreiro I, Patanita MI, Penacho J, Dôres J, *et al*. An overview on the use of enhanced efficiency nitrogen fertilizers in irrigated Mediterranean agriculture. Biomedical Journal of Scientific and Technical Research. 2017;1:1938-1940.
64. Wang K, Liu H, Gao Z. Effects of nitrogen application at different levels by a sprinkler fertigation system on crop growth and nitrogen-use efficiency of winter wheat in the North China Plain. Plants. 2024;13(12):1714.
65. Woolfolk CW, Raun WR, Johnson GV, Thomason WE, Mullen RW, Wynn KJ, *et al*. Influence of late-season foliar nitrogen applications on yield and grain nitrogen in winter wheat. Agronomy Journal. 2002;94(3):429-434.
66. Xu J, Cai H, Saddique Q, Wang X, Li L, Ma C, *et al*. Evaluation and optimization of border irrigation in different irrigation seasons based on temporal variation of infiltration and roughness. Agricultural Water Management. 2019;214:64-77.
67. Xue Q, Zhu Z, Musick JT, Stewart BA, Dusek DA. Root growth and water uptake in winter wheat under deficit irrigation. Plant and Soil. 2003;257(1):151-161.
68. Yousaf M, Fahad S, Shah AN, Shaaban M, Khan MJ, Sabiel SAI. The effect of nitrogen application rates and timings of first irrigation on wheat growth and yield. International Journal of Agricultural Innovation and Research. 2014;2(4):645-65.
69. Zhongwei T, Xiaoxue L, Jinhong Y, Shilu G, Lei Z, Dong J. Early nitrogen deficiency favors high nitrogen recovery efficiency by improving deeper soil root growth and reducing nitrogen loss in wheat. Archives of Agronomy and Soil Science. 2020;66(10):1384-1398.