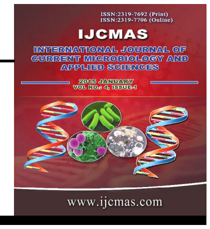
Int.J.Curr.Microbiol.App.Sci (2015) 4(3): 841-853

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 4 Number 3 (2015) pp. 841-853**
http://www.ijcmas.com



Review Article

Increasing Quantity and Quality of Wheat through Deficit Irrigation, Straw Mulch and Zinc Biofortification: A Review

Lawate Pramod. U*, Prasad S. K and Singh R. K

Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi- 221005, India
**Corresponding author*

Keywords

Wheat, Deficit Irrigation, Zinc Biofortification, Mulch, Water productivity, Yield

A B S T R A C T

Wheat yield and quality is affected by many factors but moreover, excess or deficit water conditions are most responsible and these mainly arises due to lack of water availability during its life cycle, being it is mostly grown on residual moisture previous season or degraded soil conditions due to excess water make enforce to follow it. Out of these, deficit water is most important. Due to shrinkage of water resources, wheat is being mostly cultivated in rainfed conditions where deficit irrigation plays an important role. Deficit water is an important constraint for wheat yield, especially in the dry environment and it unavoidable phenomenon hence, it is better to accept it an opportunity through deficit irrigation rather than constraint or challenge in agriculture crop production. Deficit irrigation generally means application of limited water at more growth sensitive stages of crop on the basis of soil moisture status or by measuring quantitative basis. But, alone deficit irrigation is not enough to fulfill need of water to crop and to produce yield to complete the need of ever increasing demand. Hence, if deficit irrigation is combined with any straw as mulch, it will give additive effect over alone it. Straw mulch not only checks the evaporation but also control weed, add organic matter and increase the soil fertility through nutrient recycling, results in to increase in water use efficiency (WUE), economic yield, water productivity and harvest index (HI) of crop. Simultaneously, with quality, also necessary to increase the quantity in hand to hand through biofortification of Zinc, a micronutrient, whose deficiency is raised and is reflecting either through soil, plant or human disorders. Zinc biofortification can be done either agronomical or plant breeding methods.

Introduction

Wheat is the world's most important crop in terms of area, production and its consumption, cultivated largely due to its wider adaptability to different climatic and edaphic conditions. It is also most basic source of calorie and protein and one of the most important crop in the world. About 33 million ha of the world's wheat-cultivated lands, is facing drought damage of which is considerable at global level (Rajaram *et al.*, 1995). In India, wheat is the main cereal crop and occupies the second position, in respect of area and production, next to rice. During 2011–12, total production of wheat of India was 94.88 million tonnes from an area of 29.9 million hectares (FAOSTAT 2012).

More than 90% area of the Rice-Wheat (RW) cropping system is irrigated which is facing the problem of yield stagnation, soil degradation, declining ground water table (Hira, 2009), and air pollution (Singh *et al*., 2008). Hence to minimize these dark impacts or maintain environment health, it is necessary to turn towards deficit irrigation. Here one more thing that everyone should keep in mind that turning towards deficit irrigation right from excess or optimum is not our weakness but necessity under both plenty and scarcity water condition. Water is an important input for realizing high wheat productivity; however, it is becoming curse in arid and irrigated areas either through its less availability or its excess use. Mostly, it is becoming limiting due to scarcity and shrinkage of its resources for crop production in most of the north western parts of India where Rice–Wheat (RW) is predominant cropping system (Hira, 2009). Besides this, out of total water resources on earth about 97% of water is ocean and sea water which is considered as non useful for agriculture purpose and thus only in 2-3% of water is useful for agricultural and industrial purposes in which agriculture sector contributes more water consumption. It is, therefore, essential to improve irrigation water productivity and decrease irrigation supply with improving or maintaining the crop productivity and production and under such critical condition, deficit irrigation can be considered as a possible alternative aspect of irrigated wheat crop production.

Deficit irrigation means the application of water below full crop-water requirements (Fereres and Soriano, 2007). In another way, it is the practice of deliberately under irrigating the crop to reduce water consumption while minimizing adverse effects of extreme water stress on yield (Dag'delen *et al.*, 2006). Deficit irrigation doesn't means total absence of water but the fact is application of water at certain critical growth stages (Kang *et al*., 2002) like crown root initiation (CRI), flowering, grain filling and dough stage of wheat depending upon water availability. The deficit irrigation also becoming more important in recent years as there is continuous decrease in availability of fresh water that can be used by agricultural production (Cai and Rosegrant, 2003). With this support, it is also observed that, deficit irrigation increase water use efficiency (WUE) of wheat (Xue *et al.*, 2006), while in other hand it is also revealed that, deficit irrigation might reduce photosynthesis rate and accelerate leaf senescence if crop was over stressed, which in turn might cause decrease in wheat yield (Wang, 2005).

At the same time, it is also registered that, soils which have more moisture ultimate have more evapotranspiration rate and more accumulation of biomass but produced less economic yield (grain) results in to low WUE and was achieved highest in deficit irrigation (Kang *et al*., 2002). Studies on the effect of deficit irrigation on crop yield and WUE showed that, crop yield can be largely maintained and product quality in some cases can be improved or maintained with substantial reduction of irrigation (Li.1982; Shan 1983; Fapuhunda *et al*., 1984; Sharma and Alonso Neto, 1986; Kang and Dang, 1987). However, the impact of deficit soil moisture on crop yield depends on the particular phenological stage of the crop and the most sensitive stage can vary regionally (Singh *et al*. 1991).

Moreover, application of only deficit or limited irrigation doesn't gives positive results regarding crop production or soil quality and under such crucial condition mulching may be one of the suitable alternatives to maintain optimum moisture and thermal environment in soil, increases water use efficiency through reduction in evaporation and subsequently higher grain yield (Chakraborty *et al.* 2008). Owing to this, it is also observed that, rice straw mulching decreased soil temperature and reduced the weed dry matter, increased yield attributes and yield in wheat, while total water use increased with increase in irrigation levels, mulching decreased the total water use in wheat; nevertheless, highest water use efficiency was recorded with two irrigations applied to wheat under 6 t ha^{-1} of rice straw mulch, besides this, rice straw mulching saved 75 mm (one irrigation) water which is depleting at faster rate (Hari Ram *et al.* 2013). Despite of this, it is also observed that, mulch conserved soil water and delayed the need of water for irrigation and when irrigations were scheduled based on soil matric potential (SMP), mulching reduced the number of irrigations by one in 2 years of contrasting rainfall patterns and amount, while maintaining yield and greatly increasing irrigation water productivity in comparison with the recommended practice of scheduling according to cumulative pan evaporation (Singh *et al*. 2011). By the proper combination of conservation tillage and mulch it has also proved that, the minimum tillage in combination with polythene mulch followed by straw mulch is advantageous in point of view of the economically (cost reduction), ecologically (soil compaction, improve soil physical properties), and organizationally (reducing soil preparation operations) (Sharma *et al.* 2011).

Due development of short statured wheat varieties, adoption of intensive irrigation practices and heavy application of nitrogenous fertilizers which are directly responsible for production green revolution and its effect appeared in terms of extensive production of wheat. But at the same time, the micro nutrient zinc (Zn.) was neglected by most of the farmers being it is not directly responsible for yield expansion hence another burning problem of zinc deficiency in wheat production has been created. Deficiency of micronutrient Zn is the most widespread problem (Wuehler *et al.,* 2005), being soils are low in available Zn are widespread in a number of the major wheat growing regions of the world, including Turkey, India, Pakistan, China and Australia (Alloway, 2004). About one half of Indian soils are low in zinc (Welch *et al.,* 1991) which varied from 54-60% in different states (Nayyar *et al.,* 2001).

Zinc (Zn) is an important micronutrient in biological system and is receiving growing attention worldwide because of increasing reports about Zn deficiencies in human populations and crop plants (Alloway, 2004; Cakmak, 2008; Hotz and Brown, 2004) and this deficiency is reflecting either through soils or humans by causing different disorders and diseases**.** This decrease in grain Zn also reduces its bioavailability in humans and may contribute to Zn deficiency in susceptible human populations (Hussain *et al.*, 2012). Hence there is necessity to be correct this disorder by applying and improving zinc content in to wheat through different methods and it known as biofortification of zinc. Biofortification is a process of increasing the bioavailable (*the amount of an element in a food constituent or a meal that can be absorbed and used by a person eating the meal*) concentrations of an element in edible portions of crop plants through agronomic intervention or genetic selection (Philip *et al*,. 2005). The key tools of the biofortification of zinc are fertilization, breeding, and biotechnology. In China, approximately 100 million people with the majority living in rural areas suffer from Zn deficiency (Ma *et al*., 2008). However, it is also found that, an excessive and monotonous consumption of wheat-based products rapidly results in Zn malnutrition because wheat is inherently low in Zn and rich in compounds such as phytate that limit Zn bioavailability (Cakmak *et al*., 2010a; Welch and Graham, 2004 5Z). Potarzycki and Grzebisz 2009, reported that zinc exerts a great influence on basic plant life processes such as nitrogen metabolism– uptake of nitrogen and protein, quality; photosynthesis– chlorophyll synthesis, carbon anhydrase activity despite of Zn-deficient plants reduce the rate of protein synthesis and protein content drastically.

With reference to above discussed problems and opportunities regarding improvement in wheat production and its quality, we tried to compile some concentrated information from different previous research papers through this paper at better extent with entitled of "Increasing Quantity and Quality of Wheat through Deficit Irrigation, Straw Mulch and Zinc Biofortification".

Effect of deficit irrigation on wheat:

Effect of deficit irrigation could be seen on wheat growth and yield parameters depending upon stage of wheat at which plant is being exposed to water stress. The yield, irrigation amount, irrigation water productivity, relative water savings, relative yield reduction, and net return under limited water resource condition, was found to be maximum when preference given to irrigate first at CRI, followed by heading–flowering, and then at maximum tillering stage of growth of wheat (Ali *et al*., 2007), besides this, harvest ratio and harvest index was also found better over other treatments. But in other, the deficit water was found to be reduces grain yield when applied at any physiological growth stage, but the extent of damage varies from stage to stage (Angadi *et al*., 1991 and Malik, 1993). In other case it is also observed that, evapotranspiration was found highest under continuous high soil moisture conditions, due to above ground biomass, nevertheless, grain yield was not the highest in these conditions, and WUE was relatively low due to inefficient use of the stored soil water; but at the same time, this condition was reverse under deficit condition i.e. deficit irrigation has the advantage of less above ground biomass before flowering, greater net photosynthesis rates during grain filling, and larger grain yield, WUE and harvest index and concluded that, mild soil drying in the early vegetative growth period and severe soil drying in the maturity stage of winter wheat is an optimum limited irrigation regime in the Loess Plateau of China(Kang *et al*. 2002).

Notwithstanding, it is also observed that, yield, harvest index, water use efficiency and evapotranspiration efficiency were affected by deficit irrigation and found that, well-watered treatment produced the highest grain yield, biological yield and harvest index and irrigation only before planting produced the highest water use efficiency and evapotranspiration efficiency and and evapotranspiration efficiency (Galavi and Moghaddam, 2012).

It is observed that in wheat, water productivity may be substantially improved (2.75 kg m^{-3}) as a result of combining the limited supplemental irrigation strategies with N fertilizer appropriate management under climate conditions alike (Montazar and Mohseni 2011). Irrigation applied at the jointing and heading stages of winter wheat to results into a reasonable grain yield and WUE besides increasing root length density due to the changes in the vertical distribution of root length density (Li *et al*., 2010). In winter wheat in semi-arid Haihe River Basin of north China, it was revealed that, if less amount of water applied with more irrigation frequency, is better for both grain yield and WUE in drought years and mild water deficit improved WUE with slight reduction of grain yield in any stage, however, it was also suggested that crop variety is an important influencing factor for the improvement of WUE under temporal and spatial deficit irrigation in those areas (Du *et al*. 2010). Much research on dryland crops have pointed out that, the utilization of deep water is limited by root distribution (McIntyre *et al*., 1995). A mild soil drying at the vegetative stage encourages such a distribution (Jupp and Newman, 1987; Zhang and Davies, 1989a).These works were supported by Zhang *et al*., 1998 and found that, soil drying in the early stage of vegetative growth led to a relatively deeper root system, a smaller leaf area development and shorter basal internodes and these deep root distribution is beneficial for the water-limited culture by making water at depth available to the crop and as stated above, another advantage of usage of the water from depth is that storage capacity is made available for the subsequent summer rains.

Dealing with quality parameters it had found that, Protein content decreased from 12.15–13.04% when irrigation was applied at crown root initiation (CRI) and boot stage. Besides this, it is reported that, wheat grain yield increased in a step-wise manner as additional irrigation was applied but the highest protein content was achieved only with the fewest number of irrigations. (Coventry *et al.*, 2011). While in other also seen that, by increasing irrigation frequency in wheat the grain protein was decreased (Barber and Jessop, 1987).

Table 1. Analysis of variance (Mean squares) for the effects of deficit irrigation conditions on the grain yield and some agronomic traits.

	Mean squares (MS)								
Source of variation d.f Grain yield	d f	Grain yield (Kg ha-1)	Biiomass (kg ha^{-1})	Harvest index (%)	Grain spike	Spike m^{-1}	1000-grain weight(g)	Peduncle Length (mm)	Height(cm)
Replication	3	1256657.5	2985019.8	27.390	143.690	10491.67	7.133	1181.273	39.590
Year	1	21636939 *	176547030.6**	28.056ns	322.056	46785.60*	25.600	272332.51**	1351.406**
Error a	3	1461502.8	4296568.8	18.773	53.156	2123.88	28.467	1757.356	39.323
deficit irrigation	4	3922267 **	264728607.4**	192.616**	434.588**	171313.6**	300.397**	30950.131**	1892.131**
Year× deficit irrigation	4	4337512.9**	30176350.4**	36.072ns	217.838**	56959.08**	51.584**	11179.319**	131.375
Cultivar	3	904812.6ns	925875.4ns	203.99**	264.040**	13269.67	55.933**	30731.540**	283.106**
Year× cultivar	3	215571.3ns	2021542.6ns	64.34ns	23.940	6111.45	34.733**	7956.29**	17.673
deficit irrigation × cultivar	12	68256.2ns	1247955.3ns	22.974ns	12.696	1700.17	4.001	1379.519*	15.440
year× deficit irrigation× cultivar	12	42879.2 ns	1873426.6ns	10.105ns	19.096	2226.04	6.489	1093.123	23.892
Error b	114	389678	3533764.1	40.235	23.809	7318.03	8.370	700455	62.640

Source: Moghaddam *et al*, 2012.

*,*and ns indicate significant at the 0.01, 0.05 probability levels and not significant, respectively.

Effect of Mulch on Wheat:

Organic matter is considered as soul of soil and day by day its content is decreasing at increased rate and to increase this mulch will play important role. Many researchers have reported that, retaining crop residue on soil, can improve several soil characteristics (Ferrero *et al.,* 2005; Karlen *et al*., 1994), reduce soil erosion and runoff (Karlen *et al*., 1994; Sharratt, 1996), affect the quantity of rainwater entering the soil and evaporation (Pabin *et al*., 2003), promote soil stability. Wheat yield increased with increase in level of irrigation with the highest grain yield recorded with irrigation given at CRI, tillering, jointing, boot stage, and milk stage treatment in the absence of straw mulch however; straw mulching decreased soil temperature and reduced the weed dry matter, increased yield attributes and yield in wheat while, total water use increased with increase in irrigation levels and mulching decreased the total water use in wheat (Hari Ram *et al*., 2013). Highest WUE was recorded with two irrigations applied to wheat under 6 t $ha^{-1}$of rice straw mulch and mulching saved 75 mm (one irrigation) water which is depleting at an alarming rate in the northwest India, improved soil organic matter level in the soils and efficient utilization of rice straw can avoid the terrible air pollution occurring due to residue burning however, it was also found that, mulching did not have any significant effect on protein content of wheat grains (Hari Ram *et al*., 2013).

Straw mulch significantly decreased the bulk density from 1.47 g cm^{-3} to 1.37 g cm^{-3} in the surface 0–15 cm soil layer and increased the soil organic carbon content from 0.148% to 0.189% in no mulch treatment to in 6 tone/ha treatments respectively (Hari Ram *et al*.,2013), this fact is also supported by Gła and Kulig (2008) and found that, the bulk density in the upper soil layer (0–10 cm) decreased with mulch residues and reached the similar value as those obtained at conventional tillage (1.25 g cm−3). Straw mulch is an excellent source of carbon, which on decomposition becomes a part of soil organic matter. There are several reports in the literature (Jiafu, 1996; Singh *et al.,* 2007; Singh *et al*., 2009) showing significant increase in soil organic and decrease in bulk density in the surface soil layer. Application of mulch improved the hydrothermal properties of soil and thus helps in decreasing the evapotranspiration (Quanqi *et al*., 2010) and increased WUE (Chakraborty *et al.*, 2008; Singh *et al.*, 2011).

Effect of Zinc on wheat:

Among all micronutrients Zinc is most important nutrient in plants and in human being. Zn is an essential trace element for the growth and development of humans (Jose Brandao-Neto *et al*., 1995; Brown *et al.,* 2001; Salgueiro *et al.,* 2000, 2002), animals, and plants (Broadley *et al*., 2007; Sommer, 1928; Sommer and Lipman, 1926). Zinc participates in the catalytic and regulatory activities of more than 300 enzymes (Jose Brandao-Neto *et al*., 1995). Inadequate Zn intake and status result in growth retardation, immune dysfunction, hypogonadism, and cognitive impairment (Black, 1998).

The studies have been shown that one of the effective and productive ways to improvement in cereal grains is application of Zn fertilizer either to the soil or foliar application (Shaheen *et al*., 2007). It is observed that, Zn-enrichment of urea either with ZnSO4 or ZnO is equally effective for increasing the productivity of wheat and increasing Zn concentrations and uptake by the wheat grain (Shivay *et al*., 2008). Zn-amino acid chelates (ZnAAC) were more effective Zn source to increase yield and grain Zn, Fe and protein concentrations of wheat simultaneously it increases the concentration of Zn in wheat grains and makes it more bioavailable for human (Ghasemi *et al*.,2013). However, Zn application potentially decreased the phosphorus (P) concentration in wheat grain, the phytic acid (PA) concentration in grain, and consequently the PA to Zn molar ratio, which is widely used as an indicator of Zn bioavailability in diets (Cakmak *et al*., 2010a; Erdal *et al*., 2002). Mostly zinc act as quality parameter but in some cases, it has also contributed to yield and its related parameters. The results indicated that the highest number of spikes/m^2 and number of grains/spike and the highest grain and straw yields (kg/fed) were obtained when wheat plants were treated with Zn. Foliar application treatment with Zn surpassed (Zeidan *et al*., 2010), shown as following table.

Table.2 Effect of Zinc on wheat yield parameters

Sr.No.	Characters	Control	Zn Treated
1	Number of spikes/m^2	236.0	362.0
2	Number of grains/spike	36.3	42.4
3	1000 grains weight (g)	28.5	34.7
4	Grain yield (kg/fed***	1968.1	3416.8
5	Straw yield (kg/fed)	2682.7	4173.1

Where - *** fed = one feddan = 4200 m^2

Source: Zeidan *et al*., 2010

Generally, Zn is applied either by foliar or soil application. However, foliar Zn application significantly improved the grain Zn concentration of wheat by 28% and 89% during the first and second growing seasons, respectively and it is also registered that grain yield in the Zn control plots was significantly less than those in the Zn treated plots and application of Zn significantly increased the grain yield of wheat by 0.5 to 1.1 t ha $^{-1}$ over the control; however, this yield response of wheat crop was significant only up to 2.25 kg Zn ha $^{-1}$ and there was no further response to the higher doses of Zn application and continuous application of higher doses of Zn e.g. 18 to 27 kg ha $^{-1}$ to crop did not show any adverse effect on the yield of wheat (Singh and Abrol, 1985).

By increasing the rates of foliar Zn application around flowering stage is expected to increase the Zn concentration and bioavailability in flour to higher extent. A potential problem is that an increase in Zn concentration in flour may negatively affect its processing traits (Peck *et al.*, 2008), which could affect the acceptance of biofortified flour by consumers (Bouis, 2003; Welch and Graham, 2004). Recent studies showed that adequate N supplied either by soil or foliar application maximized the Zn concentration in wheat grain when the Zn supply is not limited (Cakmak *et al*., 2010b; Kutman *et al*., 2010; Shi *et al*., 2010). Foliar Zn application significantly increased the Zn concentration and the predicted bioavailability in both whole grain and flour of wheat; but, it is also observed that, zinc application through foliar application on wheat with or without urea had little effect on Flour processing traits such as peak viscosity and dough development time (DDT) and taste flour traits including protein concentration are also not affected (Zhang *et al* 2012) and this suggested that biofortified flour with Zn may not affect the acceptance by consumers, likely due to the small quantities of Zn in flour (Bouis, 2003). Increasing the level of available Zn can increase grain protein concentration (Hemantaranjan and Garg, 1988), which may preferentially accumulate in glutenin. Using ^{65}Zn label (Starks and Johnson, 1985) showed that the majority of Zn applied to bread wheat at anthesis was incorporated into grain protein and that the greatest proportion of the ^{65}Zn applied was found in the glutenin which suggests that, Zn is associated with the seed storage proteins of wheat, and is strongly associated with the glutenin fraction. Zinc application play most important role in quality improvement in relation to protein content and other nutrients availability, as shown in table no. 3.

Table.3 Macro and micronutrients concentration in grains as affected by micronutrients fertilization

S.No.	Characters	Control	Zn Treated
1	Grain protein content (%)	9.70	**11.10**
2	Grain P (%)	0.37	**0.41**
3	Grain K (%)	1.27	**2.29**
4	Grain Fe(mg/kg)	33.10	**40.60**
5	Mn (mg/kg)	42.50	**40.90**
6	**Zn (mg/kg)**	**22.00**	**47.10**
7	Cu (mg/kg)	6.30	**6.80**

Source: Zeidan *et al*., 2010.

Gluten is the major component of wheat flour protein that determines processing quality. It is a complex mixture of proteins of different molecular mass whose structure and rheological properties are largely determined by inter and intra molecular disulphide bonds between cysteine residues in the protein (Shewry and Tatham, 1997). The formation of the large polymeric proteins (the SDS-insoluble proteins) occurs late in grain filling and coincides with the oxidation of sulphydryl groups in the storage protein (Daniel and Triboı, 2002; Gobin *et al*., 1997). Zinc also reacts with cysteine residues in proteins (Marschner, 1995). If the levels of Zn in the endosperm alter the redox status of the protein in the grain there may be some effect on the degree of polymerization of the storage proteins. Because of Zinc deficiency, formation of stamen and pollen are damaged and as a result yield are decreased and it is said that, the reason is decrease in Indol Acetic Acid (IAA) and protein (Brown *et al*, 1993; Marschner.1995).

Rice and wheat are major crops in terms of area, production and consumption but water is used abundantly irrespective of their demand for production. But as compared to rice, water requirement to wheat is less hence, there is wide scope to adopt deficit irrigation in wheat crop. Deficit irrigation with mulch is most useful both in regions of plenty water to avoid accelerated land degradation with respect of physical, chemical and biological properties due to excess utilization and in areas of water scarcity to increase water productivity, yield with limited water. Also instead of giving deficit irrigation to wheat irrespective of its phenological stages it is better to give at critical growth stages of wheat, mostly including CRI and flowering stages, which directly contributes yield and quality parameters. Hand to hand inclusion of mulch with deficit irrigation can check evaporation and add organic matter in soil, checks weed population, rather than to be wasted by burning in R-W cropping system areas. While to improve protein, grain composition and quality of wheat in respective of zinc, which is burning problem in RW growing regions, can be improved through its soil application or foliar application and its visible deficiency or hidden hunger can be minimized. In nutshell, it can be concluded that, with the help of deficit irrigation with mulch there is wide scope to increase WUE, water productivity, harvest index, grain yield and through the biofortification of Zn, quality of food and soil can be improved in sustainable way.

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