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Water, Nutrients, Radiation and CO_2 Use Efficiency of Bulb Crops: A Review

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Review Article

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ABSTRACT

World's natural resource will be pressured by population increment that is to achieve high food production through intensive farming. Bulb crops are among largely produced which are characterized by a shallow root system and underground vertical shoots. They are also cool season crops, and their growth and production are influenced by water, nutrients, radiation and carbon-dioxide. Factors that determine their water use efficiency are tillage, stage of the crop, evapotranspiration, irrigation, soil types and elevated CO_2. Nutrient use efficiency of bulbs also influenced by factors like soil factors, fertilizer factors, plant factors, agronomic consideration, biological consideration and climate factors. Nitrogen, phosphorus and potassium are the major consumed nutrients of bulbs. Radiation use efficiency of the bulbs also the key determinant of photosynthesis, photorespiration and respiration. Indicators of radiation use efficiency of bulbs are dry matter production, leaf area index and specific leaf area, ground cover, radiation interception and absorption, maintenance respiration of bulbs and dry matter partitioning. Another essential substrate for photosynthesis of bulb crops is CO_2 and the main factors that determine CO_2 use efficiency of bulbs are temperature and light. So as different studies indicated that for best production of bulb crops water, nutrient, radiation and CO_2 use efficiency of them and the respective determinant factors should be considered and optimized.

INTRODUCTION

An increase in population growth will intensify pressure on the world's natural resource base (land, water, and air) to achieve higher food production through intensive farming. Indeed bulb crops produced are a part of this and cultivated world widely for centuries (www.harvestwizard.com/bulb_vegetables/; www.sopib.com).

Bulb crops are belonging to the Aliaceae family. They are characterized by a shallow root system, and underground vertical shoots that have modified leaves (or thickened leaf bases) used as food storage organs by the dormant plants. Bulb vegetables include chives, garlic, leeks, onions, scallions, shallots and water chestnuts (www.harvestwizard.com/bulb_vegetables/; www.sopib.com).

Bulb crops are cool season crops which grow well in a wide range of temperatures (optimal temperatures are 13 to 29 °C). Better perform when cool during the early stages and warm towards the end of the growth period. Most can grow in all types of soil but most prefer deeply cultivated sandy loam, alluvial clay soils, friable, fertile soils well supplied with humus and well drained with a high level of organic matter. Basic factors which determine high and quality yielding ability of bulb crops are water, nutrients, radiation and carbon-dioxide.

Water is a grower's second most important resource next to land. When it scarce, we need to rethink some practices to obtain maximum benefit from available water. It makes sense to exchange management and labor for water use efficiency (WUE) [1].

Nutrients (bulbs and others) of many agricultural soils in the world are deficient in one or more of the essential nutrients to support healthy and productive plant growth. These are compelling reasons of the need to increase nutrient use efficiency (NUE) [2].

In addition to water and nutrients crops (bulb crops) net primary production has often been found to be linearly related to the photosynthetically active radiation (PAR) absorbed or intercepted by crops. The slope of this relationship is the radiation use efficiency (RUE) [3,4].

At last linked to water, nutrient and radiation CO_2 is a key for crops (bulb crops) production. Linearity CO_2 assimilation of canopies, integrated over one day (`daily' assimilation), and daily absorbed or intercepted photosynthetically active radiation (PAR), implying constant photosynthetic RUE (PhRUE) on a daily basis. However, instantaneous (i.e. hour or minute) canopy photosynthesis tends to saturate at high PAR, and instantaneous PhRUE varies with time of the day [5,6].

As indicated above there are ample problems studied and indicated on different literatures related to bulb crops production. Those problems are associated with water, nutrients, radiation and CO_2 use efficiency of bulb crops. So the basic objectives of this review are:

- To show water use efficiency of bulb crops and contributing factors,
- To show nutrients use efficiency of bulb crops and contributing factors,
- To show radiation use efficiency of bulb crops and contributing factors,
- To show CO_2 use efficiency of bulb crops and contributing factors and
- To indicate or show gaps for further studies or researches

WATER, NUTRIENTS, RADIATION AND CO_2 USE EFFICIENCY OF BULB CROPS

Water Use Efficiency of Bulb Crops

Even when water is more plentiful, there are compelling reasons to use less. Excessive water use can waste soil and fertilizer in water runoff. For example, excessive irrigation results in deep percolation and leaching of nitrates, nitrites, and other farm chemicals. These contaminants contribute to the total daily load of chemicals carried by aquifers. The efficient use of water in any sector of human activity has become an increasingly important need in our daily lives, especially in arid and / or semi-arid regions where water resources have become increasingly scarce [7].

Factors determining water use efficiency of bulb crops

Tillage

Conservation tillage practices such as minimum tillage, no till, and strip till help conserve soil water. The retention of crop residues reduces water loss from the soil to the air and cools the soil. Especially the advantages of no-tillage include reduced machinery traffic, soil structure improvement, increasing infiltration and soil-water retention, water loss reduction by evaporation and runoff, superior crop root system development, improved control of weeds, erosion processes reduction, and increased water use efficiency [8,1].

Stage of the crop

During the early development stage, bulb crops (e.g. onion plants) only cover a fraction of the soil surface, therefore, soil evaporation accounts for most of the crop evapotranspiration. Then, plant water use during this stage is less mainly for crops with lower capability of soil coverage. On the other hand, the transpiration process becomes predominant as plants grow and cover larger fractions of soil surface [9].

Evapotranspiration

Evapotranspiration water use efficiency mostly depends on precipitation amount and distribution, and establishes whether the growing period is favorable for plant production or not. Evapotranspiration water use efficiency generally is highest with less irrigation, implying full use of the applied water and perhaps a tendency to promote deeper soil water extraction to make better use of both the stored soil water and the growing-season precipitation [10].

Irrigation

Irrigation effects and the applied irrigation regime can be determined by irrigation water use efficiency (Iwue) (Sarkar et al.,). If the irrigation regime is not synchronized with water needs of crops, water and physical properties of soil and weather conditions, the effect of irrigation can fail, that is the irrigation water use efficiency values can be below the optimum [10].

Soil types

Soil water-holding capacity of our soils can be determine water use efficiency of bulb and other crops. A sandy loam soil will not hold as much water as a silt loam; thus, it must be irrigated more frequently with less water per irrigation. Extra water is lost to runoff and deep percolation [1].

Elevated CO_2

Elevated CO_2 slows transpiration by inducing the partial closure of leaf stomatal guard cells. Whole-plant transpiration reduction coupled with increased photosynthesis, can contribute to increased water use efficiency (WUE = the ratio of carbon fixed to water transpired) under optimum nutrients (like nitrogen) supply. Although instantaneous WUE is increased, whole-plant water use may be differentially affected as a result of increased plant size and seedlings grown with limited nitrogen (N) did not exhibit a growth response to elevated CO_2, so the increased WUE resulted in decreased whole plant water use and reduced stress [11,12].

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Nutrient Use Efficiency of Bulb Crops

Plants that are efficient in absorption and utilization of nutrients greatly enhance the efficiency of applied fertilizers, reducing cost of inputs, and preventing losses of nutrients to ecosystems. Inter and intra specific variation for plant growth and mineral nutrient use efficiency (NUE) are known to be under genetic and physiological control and are modified by plant interactions with environmental variables. Nutrients can macro or micro and among them the most primary nutrients are nitrogen (N), phosphorus (P) and sulfur (S). Like other crops bulb crops demand those nutrients and have their own nutrient use efficiency (NUE). Bulb crops are characterized by a shallow root system which explains why fertilizers should be banded at 8-10 cm below the seed row [5].

Factors determine bulb crops' nutrient use efficiency (NUE)

Overall NUE in plant is a function of capacity of soil to supply adequate levels of nutrients, and ability of plant to acquire, transport in roots and shoot and to remobilize to other parts of the plant. NUE determinant factors are:

1. Soil factors
2. Fertilizer factors
3. Plant factors
4. Agronomic consideration
5. Biological consideration
6. Climate factors

An improved NUE in plants (bulb crops) can be achieved by careful manipulation of plant, soil, fertilizer, biological, environmental factors and best management practices [5].

Major nutrients of bulb crops

Nitrogen, phosphorus and potassium are often referred to as the primary macronutrients because of the general probability of plants being deficient in these nutrients and because of the large quantities taken up from the soil relative to other essential nutrients (Marschner) Bulb crops such as onions and shallots are more susceptible than most crop plants in extracting nutrients, especially the immobile types, because of their shallow and unbranched root system; hence, they require and often respond well to additional fertilizers [13].

Nitrogen (N)

Nitrogen (N) it is one of the most essential mineral for the plant. It plays an important role in bulb development of bulb crops. This is due in part to the role N plays in controlling leaf growth. Early applications of N accelerate, or have little effect on crop maturity while low N levels can delay maturity. Late season applications of N or high residual N levels in the soil often delay or prevent bulbing under marginal photoperiods but have no influence when photoperiods are ideal. Excessive N applications have also increased leaf blade growth late in the season which delays crop maturity and contributes to increased storage losses [13,14]. As different studies showed that the use of lower N levels for bulb crops like onion should not affect productivity but would increase nitrogen use efficiency (NUE). For example onions can be grown with 150 lbs. N/acre and still achieve high yields. However, further N reductions to 100 lbs/acre will result in yield reductions regardless of the N source used [15,16].

Agronomic nitrogen use efficiency can be calculated by [17].

$$NUE = BY/NP$$

Where NUE is nitrogen-use efficiency (g bulb g N-1), BY is bulb yield (g/m-2), and NP is nitrogen application rate (g N/m-2).

Even as nitrogen uptake efficiency (NUPE) of bulb crops increased, nitrogen utilization efficiency (NUTE) may be decreased. Improved NUPE (e.g. onion) is due to increased root development during the season that allows better uptake but not necessarily better utilization. The decrease in utilization reflects may be due to potential leaching losses a lack of demand as leaf initiation slows and poor recovery of applied N by the shallow, sparse root system [18]. The overall NUE may be lower due to the high fall application of N by the grower [13]. Increasing the applied nitrogen rate may decrease the NUE due to volatilization, denitrification and leaching of nitrogen [19].

Phosphorus (P)

Phosphorus (P) deficiency is one of the largest constraints to crop production in many tropical soils, owing to low native content and high P fixation capacity of the soil. It is essential for root development and when the availability is limited, plant growth is usually reduced. The movement of P in soils is very low and its uptake generally depends on the concentration gradient and diffusion in the soil near roots [20, 21].

In bulb crops such as onions, P deficiencies reduce root and leaf growth, bulb size and yield and can also delay maturation. In soils that are moderately low in P, onion growth and yield can be enhanced by applied P, which mean that enhance p use efficiency. P levels are also known to improve bulb size and the number of marketable bulbs in shallots [13, 22].

Potassium (K)

Bulbs take up potassium (K) in quantities nearly equivalent to N. Moreover, like N, K is easily leached from soils and fertilization may be needed for high yields [13, 20]. For example the K requirement of onion plants increases with yield and its functions are linked to photosynthesis. If K is deficient or not supplied in adequate amounts, onion plants can be stunted, become susceptible to disease and have reduced yields. Yield responses of bulb crops to applied K would be less likely on soils with high cat-ion exchange capacity such as certain types of clay soils, low soil moisture contents and low yielding cultivars [23].

Radiation Use Efficiency of Bulb Crops

The absorbed radiation use efficiency can depend on rates of photosynthesis, photorespiration and respiration, or on a sink demand limitation. In other words, the conversion efficiency is the result of a complex interaction among photochemical and biochemical processes and transport of assimilates. A common way to measure it is to calculate the slope of the linear relationship between cumulative dry matter production and cumulative absorbed radiation by the crop canopy. The quantitative relationships for the allocation of dry matter among the leaves, roots, stems and storage organs are mostly empirical [24]. Those processes are strongly temperature-dependent and the temperature sensitivity of a crop is a species-specific characteristic which should be taken into account [25].

Indicators of radiation use efficiency of bulb crops

Dry matter production

The dry matter yield of a crop, when weeds, pests, diseases and soil conditions are not limiting factors, and when water and nutrients are available in ample supply, is the product of the radiation absorbed by the leaf canopy, the mean efficiency of conversion of the absorbed radiation to dry matter, and the partitioning of this between the harvested parts and the rest of the plant [26, 27].

Leaf area index and specific leaf area

At the beginning leaf area of bulb crops increase leaf area index (for example, in onion, the cessation of appearance of new leaf blades occurs with the onset of bulbing). After this development stage, leaves continued to expand for a while but then started to die and, as consequence, a progressive decrease of leaf area index (LAI) occurred. Specific leaf area also decreased with the time [28]. The extent to which the canopy absorbs the available radiation depends not only upon the leaf area index but also upon the characteristics such as leaf angle and the canopy architecture.

Ground cover

The percentage ground cover of bulb crops describes radiation use efficiency in relation to leaf area index (LAI). For example, onion reached a maximum value of 50 % ground cover at maximum LAI. Species showed the same linear relationship during early growth stages while plants were still isolated (i.e. before the canopy closure) and LAI was low. Canopy closure depends on density, plant architecture and leaf posture: For later growth stages, when leaves overlapped with neighbouring plants, the relationships changed between species [28].

Radiation interception and absorption

These can be different between crops due to canopy leaf arrangement. For example, onion always showed lower Photo synthetically active Radiation (PAR) interception and absorption. This crop never intercepted more than 80% or absorbed more than 75% of the incoming PAR. Foliage cover gave a good estimate of the PAR interception only at low values of light interception. Measurements of the proportion of foliage cover (the vertical projection of canopy elements onto the ground surface) and of the fraction of radiation intercepted have some similarities. However, differences arise because solar radiation is incident from a distribution of directions. Indeed, the fraction of radiation intercepted will even depend on the distribution of leaf angles. Moreover, the measurements of cover do not allow for the transmission and reflectance of light by the leaves. PAR is strongly absorbed by leaf tissue, whereas the infra- red radiation (IR), also present in the total solar radiation, is strongly scattered. As a consequence of these effects, the estimates of attenuation coefficient differ and also depend on the waveband of the radiation [28].

Maintenance respiration of bulbs

Maintenance respiration rates measured in a controlled environment, expressed relative to dry weights do not vary significantly with bulb dry weight. Low values of maintenance respiration rate, coupled with the lower production cost could partly explain the high radiation use efficiency as shown by onion [29].

Dry matter partitioning

The fraction of dry matter increase partitioned to the leaves is related to the radiation use efficiency which relate to the developmental stage of the bulb crops (such onion) [29]. For example, in case of onion the relationship shows that at early growth stages the fraction of dry-matter partitioned to the leaves was about 73% of the total (leaves -bulbs -sheaths) amount of the dry-matter produced. At the onset of bulbing the plants still partitioned about 53% to the leaves and at about 85 DAE partitioning was towards the bulbs only [28].

In sum up bulb crops show that a lower early relative growth rate than leafy vegetables and root crops. This was due partly to the low light interception ability of the crop canopy and partly to the low initial radiation use efficiency compared with that of the two crops. On the other hand, there is a more uniform distribution of the radiation inside the canopy, to the cessation of leaf development after the start of bulbing, and to the lower costs of storage and maintenance in the later phase of growth, bulb crops like onion show high radiation use efficiency and was able to produce a large amount of dry matter. Its growth limits seem to be the low light interception due to the leaf posture and to the relatively short duration of a high ground cover compared with the length of bulbing process [30].

CO_2 Use Efficiency of Bulb Crops

Carbon dioxide links the atmosphere to the biosphere and is an essential substrate for photosynthesis. Elevated CO_2 stimulates photosynthesis leading to increased carbon (C) up-take and assimilation, thereby increasing plant growth. However, as a result of differences in CO_2 use during photosynthesis, plants with a C3 photosynthetic pathway (e.g. bulb crops) often exhibit greater growth response relative to those with a C4 pathway [31]. The application of more CO_2 can increase plant water use efficiency and result in less water use. For plants to use a higher level of atmospheric CO_2 (CO_2 use efficiency), they must have a means of storing the additional carbohydrates produced. The increased biomass production under high CO_2 should be advantageous for horticultural plants like bulb crops in that they should attain a marketable size more rapidly [32, 33].

Factors that determine CO_2 use efficiency of bulb crops

Temperature

Leaf temperature increases by 1-2°C in doubled CO_2 due to de-creased evaporational cooling. In turn, vapor pressure of water inside leaves increases and causes a greater leaf-to-air vapor pressure difference, the driving force for transpiration. This effect partially offsets decreased stomata) conductance, and thus whole-crop transpiration is maintained only slightly lower (10%) than would exist at ambient CO_2. Therefore, small increases in temperatures would more than offset the water-saving effect of CO_2 via reduced stomata) conductance [34].

Light

There is obviously a potential for synergism between CO_2 and light. Young plants grown under high light intensities enable to utilize an increase in CO_2 concentration. The light compensation point is lowered by increased CO_2 concentration (Mortensen, 1987). It is more important to achieve optimal light conditions first, and then make use of CO_2 enrichment, which mean that to improve CO_2 use efficiency of the crop [35].

CONCLUSION

In conclusion bulb crops are the most intensive economical crops that can be produce at different agro-ecologies. At different ecological zones there are multiple factors which determine their production. Among them water, nutrients, radiation and CO_2 are primary factors. So to the efficiency of bulb crops regarding to those factors and possible enhancements are summarized as follows:

- To enhance water use efficiency of bulb crops assess and implement some practices to obtain maximum benefit from available water and improve self-regulation by growers typically benefits all parties interested in clean, plentiful water,
- Increased NUE in plants (bulb crops) is vital to enhance the yield and quality of crops, reduce nutrient input cost and improve soil, water and air quality, and best management practices are the best external alternative that can be applied to improve NUE,
- The RUE based on biomass varies during the season for the crop and this variability has been ascribed to both the different metabolic cost of the organic matter produced in different periods of the crop cycle and to different photosynthetic properties of the canopy.
- When CO_2 is elevated, the most limiting resource becomes water or nutrients and from a physiological standpoint, increased WUE may represent one of the most significant plant responses to elevated CO_2.

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