2. Review of literature

Various studies have researched water use and yield relationship of specific crops, on specific locations, with specific cultural and water management practices. The present study summarizes the review of studies that have been conducted worldwide over the years on various aspects of improving water productivity through field experiments or modelling approaches.

**2.1 Choice of crops and water productivity**

Water productivity (WP) is the net return for a unit of water used. Improvement of water productivity aims at producing more food, income, better livelihoods and ecosystem services with less water. The agricultural sector faces the challenge to produce more food with less water by increasing Crop Water Productivity (CWP) (Kijne *et al.,* 2003). A higher CWP results in either the same production from less water resources, or a higher production from the same water resources, so this is of direct benefit for other water users.

Choice of crop can induce very large differences in WP. Crop water requirement of all crops is not the same. By selecting a low water-requiring crop, water can be saved and the saved water can be used to irrigate additional land. This, in turn, increases the productivity of water. Where possible (if the land type and the environment permits), low water-requiring crops should be cultivated to increase the WP. Selecting a high value crop can produce more economic return with limited water resources. This, in turn, produces higher return per unit of water. A review of 84 literature sources from last 25 years suggested that the ranges of CWP of wheat, rice, cotton and maize exceed in all cases those reported by FAO earlier. Globally measured average CWP values per unit water depletion are 1.09, 1.09, 0.65, 0.23 and 1.80 kg m-3 for wheat, rice, cottonseed, cotton lint and maize, respectively. The range of CWP is very large (wheat, 0.6–1.7 kg m-3; rice, 0.6–1.6 kg m-3, cottonseed, 0.41–0.95 kg m-3, cotton lint, 0.14–0.33 kg m-3and maize, 1.1–2.7 kg m-3) and thus offers tremendous opportunities for maintaining or increasing agricultural production with 20–40 % less water resources. The variability of CWP can be ascribed to: (i) climate; (ii) irrigation water management and (iii) soil (nutrient) management, among others. The vapour pressure deficit is inversely related to CWP. The most outstanding conclusion is that CWP can be increased significantly if irrigation is reduced and crop water deficit is interdentally induced. (Zwart and Bastiaanssen, 2004).

Considering the productivity of water in more than 40 irrigation systems worldwide, the study conducted by International Water Management Institute (IWMI) demonstrated a 10-fold difference in the gross value of output per unit of water consumed by crops. Some of these differences are due to environment or the price of grain versus high valued crops. But even among grain-producing areas, the differences are large. In many areas, potential productivity of water is not realized partly due to poor irrigation management. Improving performance of irrigated agricultural systems should be a high-priority action (Singh *et al.,* 2010).

Large differences in water productivity of wheat between wet and dry years has been shown by various workers (Choudhury and Kumar, 1980; Singh and Malik, 1983). The water productivity of rice in India ranged from 0.50-1.10 kg m-3 against 1.4-1.6 kg m-3 for wet-seeded rice in the Philippines (Tuong and Bouman, 2002). Oweis and Hachum (2002) analyzed water productivity impact of supplementary irrigation on pulses. Study by Saeed and El-Nadi (1998) in Shambat, Sudan, Utao and Idaho on forage crops showed improvement in physical productivity of water with supplementary irrigation. Rockström *et al*., (2002) provided evidence from Kenya and Burkina Faso to the effect that supplementary irrigation enhances water productivity (kg m-3) of rainfed maize and sorghum, respectively, remarkably with greater effect coming with fertilizer management; and from Tanzania to show that conservation tillage increases water productivity of maize.

Wheat has the largest number of experimental data (*n* = 412) and the CWP range is between 0.6 and 1.7 kg m−3. Doorenbos and Kassam (1979) gave a lower range of 0.8–1.0 kg m−3. The maximum values are found by Jin *et al.* (1999) in China: application of manure led to higher production and straw mulching improved soil water and soil temperature conditions. CWP for the experiment with straw mulching was 2.67 and 2.41 kg m−3 for a combination of straw mulching and manure. CWP of rice ranges between 0.6 and 1.6 kg m−3. Tuong and Bouman (2003) gave a very similar range of 0.4–1.6 kg m−3 for lowland rice conditions. The maximum CWP value of 1.1 kg m−3 for rice given by Doorenbos and Kassam (1979) exceeded in 6 out of 13 data sources. The maximum values went up to 2.20 kg m−3 and were measured in China on alternate wetting and drying rice plots (Dong *et al.,* 2001). CWP values of cotton lint yield range from 0.14 to 0.33 kg m −3. The maximum values exceed 0.35 kg m−3 and are found by Jin et al. (1999) and Saranga *et al.* (1998) in China and Israel, respectively.

Jin *et al. (*1999) conducted experiments in which cotton was planted in furrows and the soil was covered with plastic leaving holes for infiltration near the plants, thus reducing soil evaporation and improving soil water status of the root zone. Howell *et al.* (1984) measured similar values (0.33 kg m−3) in an experiment with high frequency trickle irrigation and reduced water deficits management for narrow row cotton in California (USA). In maize, CWP values ranged from 0.22 kg m−3 up to a maximum of 3.99 kg m−3 which exhibits a large range of variation (CV = 0*.*38). In 67% of the publications, the maximum value of the source exceeds the value of 1.6 kg m−3 provided by FAO 33. The CWP range of 1.1–2.7 kg m−3 for maize, a C4-crop, is significantly higher than wheat, rice and cotton, which are C3-crops. The maximum values were measured by Kang et al. (2000b) in a combination of alternate furrow irrigation and deficit irrigation experiments under Chinese conditions: low amounts of irrigation water were alternately applied to one of the two neighbouring furrows.

The average water productivity of wheat, pearlmillet, gram, groundnut, mustard and cotton in India are 1.24, 0.54, 1.60, 0.50, 0.67 and 0.26 kg m-3, respectively. The range of CWP is very large for gram 0.4–4.02 kg m-3, wheat, 0.58–2.25 kg m-3 and groundnut, 0.20–1.11 kg m-3 (Yadav *et al.,* 2000). Duan and Zhang (2000) investigated the crop WUE from 4422 irrigated sites/seasons located in 22 provinces and indicated that the average WUE of the principal crops was 1.1 kg m-3, and that from 1953 to 1986, the yield of wheat and WUE increased similarly. In an agricultural technical demonstration trial in semiarid northwest part of China, Mu (1999) showed that the WUE of broomcorn millet (*Panicummiliaceum*) was about 0.74 kg m-3.

Ahmad *et al*., (2004) conducted a study on water productivity of rice and wheat in rice-wheat cropping system of Pakistan’s Punjab as a case study and reported that the water productivity per unit of gross inflow ranged from 0.17 to 0.38 kg m-3 for rice and 0.78 to 2.03 kg m-3 for wheat. The economic water productivity measured in terms of gross margins per unit of gross inflow for rice, wheat and rice-wheat rotation ranged from 5 to 51 $/”000" m-3 , 50 to 150 $/ “000” m-3 and 26 to 76 $/ “000” m-3, respectively. Irrigation water productivity was higher than that of gross inflow and the difference was due to the proportion of rainfall in gross water input. The water productivity of rice was lower than wheat when measured in terms gross inflow, irrigation inflow and evapotranspiration. However, in terms of transpiration rice showed almost same physical water productivity as that of wheat.

Singh (2004) analyzed composite farming system in north Gujarat consisting of crops and dairying and estimated productivity of applied well water in dairy farming. Kumar (2007) analyzed the composite farming system in north Gujarat, to analyze the applied water productivity in dairy production. It also analyzed the extent to which groundwater use in the region can be reduced without compromising on the farm economy and milk production through efficient irrigation water use technologies using a simulation model based on linear programming.

**2.2 Cultural practices for improving water productivity**

The term ‘increasing or improving water productivity’ implies how we can most effectively improve the outcome or yield of a crop with the water currently in use. The answer lies in three main pathways (Passioura, 2006): (i) transpire most of the supplied water (minimization of unwanted loss), (ii) exchange transpired water for CO2 more effectively in producing biomass, and (iii) convert most of the biomass into grain or other form of harvestable product.Recent forecasts warn of impending global problems unless appropriate action is taken to improve water management and increase water productivity (Rosegrant *et al*., 2005). Without increase in productivity, an additional 5000 km3 water will be required for crop production to meet future food demands (De Fraiture *et al.,* 2007). Globally there are sufficient land and water resources to produce food over the next 50 years, but only if water for agriculture is better managed (Molden, 2007).

Traditional approaches of yield maximization were based on (i) increase in area under cultivation, (ii) high intensity of external inputs (fertilizer, irrigation) and (iii) breeding for high yield potential in high input agro-ecosystems (Richards 2004; Waines and Ehdaie 2007). With decreasing land and water resources, for the future these ways offer limited possibilities to satisfy the increasing food demand. Improved agricultural production systems are required that ensure high yield via an efficient and sustainable use of available natural resources. Improvements in agricultural water use can be achieved at several points along the production chain, such as (1) the irrigation system, (2) the proportion of water attributed to plants use, and (3) the conversion of crop water consumption into yield (Hsiao *et al*. 2007). Gravity driven irrigation systems can have efficiencies as low as 40%, being a main limiting factor for a productive water management (Howell 2001). Better water use efficiency in field crop production can be achieved by adequate soil and crop management measures. Wallace and Batchelor (1997) resumed four options (agronomic, engineering, management and institutional) for enhancing water use efficiency in irrigated agriculture and pointed out that focusing on only one category will likely be unsuccessful.

Kijne *et al.,* (2003) provide several strategies for enhancement of crop water productivity by integrating varietal improvement and better resources management at plant level, field level and agro-climatic level. Examples of options and practices that can be taken are: increasing the harvest index, improving drought tolerance and salinity tolerance (plant level), applying deficit irrigation, adjusting the planting dates and tillage to reduce evaporation and to increase infiltration (field level), water reuse and spatial analysis for maximum production and minimum ETact (agro-ecological level), to mention a few.

Ambast *et al*., (2002) on the rice-wheat crop rotation emphasized that canal water delivery is not a limiting factor during the *rabi*season (wheat) due to the low water requirement and high salt tolerance of the crop and the availability of groundwater. However,during *kharif*(rice) canal water is critical. From a series of scenarios they concluded that reducing the existing differences in canal water supply between head and tail farmers could increase average crop yields by 240 to 580 kg ha-1.

Agricultural water productivity depends on soil and crop management practices. Water depletion occurs when water evaporates from moist soil, from puddles between rows and before crop establishment. All cultural and agronomic practices that reduce these losses, such as different row spacing, and application of mulches, improve water productivity. Similarly, drip irrigation has high water productivity as it causes much less soil wetting and less soil water loss than sprinkler irrigation systems. In agriculture, many ways of conserving water have been investigated and techniques such as partial irrigation, deficit irrigation or drip irrigation have shown that WP can be enhanced (Ali *et al.,* 1997, 2007; Jalota*et al.*, 2006; Zhang *et al.,* 2004; Oweis*et al.,* 2000, 1998; Talukder*et al.,* 1987, 1999; Oweis, 1997). In general, these techniques are a trade-off: a lower yield for a higher WP. Recent research has shown that in some irrigated situations, grain yield can be improved while reducing the amount of water applied to the crop (Yang *et al.,* 2000, 2001, 2002), mainly via improved harvest index which has been shown as a key component to improve WP (Ehdaie and Waines, 1993).

In the northern part of China, Xu and Zhao (2001) investigated the long-term crop yields, precipitation, and the amount of irrigation water applied. Their results showed that from 1949 to 1996, the water productivity increased from 0.23 to 0.90 kg m-3, mainly caused by the establishment of water conservation facilities, better soil management, extension of new crop varieties and a continuous increase in the use of nitrogenous and phosphatic fertilizers.

Dam*et al.,* (2003) showed that water is the main limiting factor to increase the crop yields. In order to identify the main water losses, an extensive water productivity study (WATPRO) has been performed in Sirsa district. The main conclusion from the remote sensing analysis is that WP is good and rather uniform for wheat, and moderate for rice and cotton. The wider range in WP for rice suggests that by narrowing the variability and increasing the WP for rice if water resources in Sirsa can be improved substantially.

Agronomic factors which can affect WP are timeliness of sowing, evenness of establishment, use of herbicides, and the role of previous crop. Water productivity depends not only on how the crop is managed during its life, but also on how it is fitted into the management of a farm, both in space and time (Ali *et al.,* 2005).

Surge irrigation, the application of irrigation water in a series of pulses, rather than the conventional continuous flow system of furrow irrigation, has been proposed as a measure of improving the WP of surface irrigation methods (Stringham, 1988). Mintesinot*et al*. (2007) compared traditional irrigation management (without scheduling) and surge/intermittent irrigation (with scheduling) on a vertisol in Ethiopia using maize as an indicator crop. They found that surge irrigation resulted in a yield of 2.3 times that of traditional irrigation, and the WP and income using surge management were 2.7 and 2.8 times that of traditional management. Horst et al. (2007) concluded that surge flow on alternate furrows was the best technique for water saving and increased WP in cotton.

Kang *et al.* (2002) reported that the high soil moisture treatment caused the highest evapotranspiration (ET) and so the biomass did not produce the highest grain yield and WPET. Water productivity increased linearly with HI and improvement in the latter gave better water productivity under limited irrigation condition.

Research at the International Centre for Agricultural Research in the Dry Areas (ICARDA) has shown that application of only 50% of full supplemental irrigation (SI) requirements causes a yield reduction of only 10–15% (Zhang and Oweis, 1999). Assuming that under limited water resource only 50% of the full irrigation required by the farm would be available (i.e., 4440 m3 for a 4 ha field), Zhang and Oweis (1999) compared the deficit irrigation with other options. They showed that a farmer with 4 ha would, on average, produce 33% more grain if deficit irrigation was applied over the whole area compared to full irrigation over part of the area. The deficit irrigation increased the benefit with more than 50% compared with that of farmers’ usual practice of over-irrigation. The association of high WP values with high yields has important implications on the crop management for achieving efficient use of water resources in water scarce areas (Oweis*et al.,* 1998). Guidelines for recommending irrigation schedules under normal water availability (Allen *et al.,* 1998) may need to be revised when applied in water scarce areas. In rice cultivation, instead of maintaining 3–5 cm standing water in the field, application of irrigation after 3–4 days of disappearance of ponded water (irrigation is applied until 5 cm of water is ponded, permit to disappear the ponded water, wait 3–4 days from the day of disappearance, and then field is irrigated again with 5 cm of water) (also termed as alternate wetting (ponding) and drying (to field capacity)) leads to 20– 30% water saving without significant yield reduction (Sandhu*et al.*, 1980; Pandey*et al.,* 1989; Sarkar*et al.,* 2002). Such practices certainly increase IWP. Deficit irrigation facilitates in using applied and stored (within root zone) water more efficiently, and increases WP (Ali *et al.,* 2007).

Buttar*et al*. (2012) indicated that with increase in temperature from 28 to 32oC, cotton seed yield was reduced to half (from 4 700 to 2 300 kg ha-1) following a linear relation with high coefficient of determination (0.97), and the reduction was more with increased temperature during sowing to flowering stage than other pheno-phases. Total evapo-transpiration (ET) during crop period and crop water productivity was also decreased with increased temperature.

In many dry-area soils having inherent low fertility, judicious use of fertilizer is particularly important. Under such condition, organic sources of nitrogenous fertilizer such as farmyard manure and bio-fertilizer are more appropriate (Sushila and Giri, 2000; Azad *et al.,* 1998). A legume based cropping system can enhance the fertility status through addition of atmospheric nitrogen. Increasing the organic matter (OM) of soil has long been recognized as an effective way of improving their physical and chemical conditions, and water-holding capacity. Increase of OM content of fine-textured soil does not increase the available water-storage capacity as much as it does for sandy soils.

The OM also results in more efficient water use, releases water slowly, facilitating proper crop growth and thus increases yield and water productivity (Kumar and Wadood, 1995; Mbagwu, 1992; Piccolo et al., 1996; Mapa et al., 1994; Leinweber et al., 1993).

Liu et al. (1998) indicated that maximum yield and the highest WP could be achieved under the optimum fertilizer input in the semi-arid field conditions of the hilly loess area in Ningxia, China. They found that increased soil fertility was positively correlated with grain yield and WP of spring wheat. The fertilizer improved the extension of the root system. The ameliorated root system was able to improve crop water use and nutrient absorption and hence, crop yield and WP were increased. Their study highlighted the effects of improved nutrition on the efficient use of limited water in dry land wheat production. Deng et al. (2003) demonstrated that the contribution of nutrients can improve WP and biological water saving. In some soil, nitrogen up to 100 kg N ha-1 is effective, after which no benefits were obtained. This rate of N greatly improves WP. It is also important that there is adequate available phosphorus (P) in the soil so that response to N and applied irrigation is not constrained (Ryan, 2000). Hatfield *et al.* (2001) showed that the addition of N and P have an indirect effect on water use through the physiological efficiency of the plant. The study conducted on wheat in Niger, Syria and Uruguay emphasised that. CWP increases when nitrogen is applied and reaches an optimum at a rate of approximately 150 kg ha−1. On the other hand Corbeels*et al. (*1998) and Fernández*et al.* (1996) did not measure significant differences when N fertilization was applied. Combined nutrient and irrigation supply levels are more commonly researched (e.g. Li *et al.,* 2001; Pandey*et al.,* 2001; Oweis*et al.,* 2000; Zima Szalokine and Szaloki, 2002). Optimum values for amount nutrient and irrigation water application can be found to maximize CWP.

In most crops (especially in cereals), we are interested to produce higher grain yield, but not the straw yield. Harvest index has been shown as a variable factor in crop production, especially in cases where the whole plant senescence (rice and wheat) is unfavourably delayed. Such delayed senescence can delay the remobilization of pre-stored carbon reserves in the straw and results in lower harvest index. Controlled soil drying can enhance the whole plant senescence and, therefore, improves the remobilization of pre-stored carbon reserve. Gains from the improved harvest index may outweigh any possible biomass loss due to shortened photosynthetic period in grain filling. The early senescence induced by water deficit does not necessarily reduce grain yield even when plants are grown under normal N conditions (Yang et al., 2001). Zhang et al. (1998) found in field grown wheat that a soil drying during the grain filling period enhance early senescence. They found that while the grain filling was shortened by 10 days (from 41 to 31 days) in unwatered (during this period) plots, a faster rate of grain-filling and enhanced mobilization of stored carbohydrate minimized the effect on yield. Zhang and Yang (2004) showed that WPmay be enhanced through an improved harvest index (HI). Ali (2006) found the highest HI, harvest ratio and IWP with alternate deficit treatment, having water shortage during the grain filling stage.

Tillage roughens the soil surface, breaks soil crust and improves water storage by increased infiltration. Musick*et al.* (1994) found that wheat yield was positively and linearly related to soil water stored at planting and this relationship was more significant than that to seasonal water use. Sub-soiling or deep tillage facilitate root expansion and soil moisture abstraction. Normally, the roots do access sub-soil at the mid- or late-season, after the anthesis, when the products of the photosynthesis go almost entirely towards the grain filling (with little respiratory or other losses). Thus, a minor gain in photosynthetic activity at this stage contributes to an accelerated rate of grain yield.

Chahal*et al.* (2007) observed that with the shifting of transplanting datesof riceatPunjab,India, fromhigher(midMay)tolower (end of June onwards) evaporative demand, therewas an increase in grainyieldwhiletherewasareductioninETandirrigationwater applied. As a consequence, crop WP was enhanced. Mulching with crop residues during the summer fallow can increase soil water retention (Feng, 1999). Sauer *et al.* (1996) found that the presence of crop residue on the surface reduced soil water evaporation by 34–50%. Oweis and Hachum (2006) demonstrated that substantial and sustainable improvement in WP can only be achieved through integrated farm resource management.

The influence of irrigation and nitrogen on WPET and transpiration ratio was investigated by Zhang *et al*., (1998). The fertilized crops consistently had significantly higher WPET than unfertilized crops under both rainfed and irrigated conditions. Application of N significantly increased transpiration (by improved plant growth) and reduce evaporation (by mean of shading the soil surface) and the variation in soil evaporation among season was smaller for the fertilized crops than for unfertilized crops. Irrigation increased WPET due to high HI and transpiration ratio was significantly increased by the addition of N under irrigated and rainfed conditions.

The option to use water pricing as a means to improve water productivity was explored byHellegers(2003). The hypothesis tested was whether a mechanism of water pricing would bea feasible management tool to minimize seepage and percolation in saline, waterlogged areasand to minimize groundwater pumping in the declining groundwater areas. She concludedthat since returns on water are on average about 100 times the price of delivery, a sociopoliticalunacceptable increase in water price is required to achieve this. A solution proposedis to have reliable canal water supply in saline areas and, as a price, less reliable supply infresh water areas.

Economic value of water in agriculture is much lower than that in other sectors (Barker *etal.,* 2003), including manufacturing (Xie*etal.,* 1993). Growing physical shortage of water on the one hand, and scarcity ofeconomically accessible water owing to increasing cost of production and supply of the resource on the other,had preoccupied researchers with increasing productivity of water use in agriculture in order to get maximum production or value from every unit of water used (Kijne*et al.,* 2003b).

**2.3 Soil-water-crop relationship**

Water is the most crucial input for agricultural production. Globally, agriculture accounts for more than 80% of all freshwater used by humans, most of that is for crop production (Morison *et al.,* 2008). Currently most of the water used to grow crops is derived from rainfed soil moisture, with non-irrigated agriculture accounting for about 60% of production in developing countries. Though irrigation provides only 10% of agricultural water use and covers just around 20% of the cropland, it can vastly increase crop yields, improve food security and contribute about 40% of total food production since productivity of irrigated land is almost three times higher than that of rainfed land. The Food and Agriculture Organization has predicted a net expansion of irrigated land of about 45 million hectares in 93 developing countries (for a total of 242 million hectares in 2030) and projected that water withdrawals by the agriculture sector will increase by about 14% during 2000–2030 to meet food demand (FAO, 2006). Scenario analysis shows that approximately 7100 km3 year-1 are consumed globally to produce food, of which 5500 km3/year are used in rainfed agriculture and 1600 km3/year in irrigated agriculture (De Fraiture*et al.,* 2007). The analysis also describes large increases in the amount of water needed to produce food by 2050, ranging from 8500 to 11,000 km3 year-1 depending on assumptions regarding improvements in rainfed and irrigated agricultural systems.

The scope for increasing water-use efficiency in agriculture is large-simply because agriculture uses the largest volumes of water. Efficient use of limited water resources, especially for agricultural irrigation, will both enhance producer’s yield per unit of water and hinder such negative effects on environment as drainage, salinity and increase in the level of underground water, resulting from overuse of water. Efficient use of water will result in an opportunity to benefit adequately from water schemes. Whether the expected efficiency from the schemes has been obtained should be checked at regular intervals or continuously, and after these controls, it should be determined if water, a considerably limited resource, is used efficiently at scheme level (Ucar*et al*., 2010).

Many examples from literature describe the influence of irrigation water management on CWP (Oktem*et al.,* 2003; Zhang *et al.,* 1998; Yazar*et al.*, 2002a; Kang *et al.,* 2000a; Sharma *et al.,* 1990). Water stress during different growth stages affects CWP differently; lower CWP was measured in cotton experiments where water stress occurred during vegetative and early bud formation periods. Gentle stress during yield formation did not affect yield production, but reduced vegetative growth and would thus improve CWP (Prieto and Angueira, 1999). The relationship between irrigation and CWP in rice is not the same as found for wheat and maize. In rice cultivation, instead of traditional continuous flooding, other water management strategies, such as alternate wetting and drying (intermittent irrigation) and saturated soil culture, were researched. Analysis of alternate wetting and drying experiments in India by Mishra et al. (1990) showed that, although irrigation water is saved, there is no significant improvement in CWP, which remains between 0.80 and 0.99 kg m−3 (*n* = 24). Dong et al. (2001) found similar results and concluded that there was no significant difference between continuous flooding and alternate wetting and drying experiments. On the other hand, Shi et al. (2003) measured in lysimeter experiments higher CWP values for intermittent irrigation experiments (2.0 kg m−3) compared with continuous flooding (1.6 kg m−3), whereas yields were only 200 kg ha−1 lower).

Deficit irrigation practices have been researched to quantify the effect on yield and to find optimum CWP values. It was found that without irrigation CWP in rainfed systems is low, but that CWP rapidly increases when a little irrigation water is applied. According to the database, optimum values for CWP are reached at approximately 150 and 280mm of irrigation water applied for wheat and maize, respectively (in addition to rainfall). Doorenbos and Kassam (1979) suggest that for many crops, yield is directly related to water consumption *(i.e.,* linear). However, the yield per unit of water consumed for a given crop is dependent both on the crop variety and the climate. For that reason, they express yield per unit of water consumed relative to the maximum yield, and associated maximum water consumption. Solomon (1983) examined various functions to describe yield as a function of available water. These included both the rising portion where yield increases as available water increases, and also the decrease in yield when water was in excess.

Plants require water for photosynthesis, growth, and reproduction. Water used by plants is non-recoverable, because some water becomes a part of the plant chemically and remainder is released into the atmosphere. The processes of carbon dioxide fixation and temperature control require plants to transpire enormous amounts of water. Various crops transpire water at rates between 600 to 2000 liters of water per kilogram of dry matter of crops produced. The average global transfer of water into the atmosphere from the terrestrial ecosystems by vegetation transpiration is estimated to be about 64% of all precipitation that falls to Earth (Schlesinger, 1997).

Increasing competition in water use has spurred the concept of better use and management of water resources so that the needs of all stakeholders can be met properly. The need to study how water can be used efficiently is therefore necessary (Molden, 1997). A strategic point to start with is to answer the question of how much water is really needed to grow crops. But even this question is difficult to answer because of the interrelationship of factors in the soil-plant-atmosphere system.

It is more difficult if the issue expands to how crops are using the applied water in the soil. Simulation models are strong in this regard; they can simulate the processes in the real system and predict the state variables at every stage in the simulation. The role of simulation models in understanding the processes in the soil-plant-atmosphere system has increased significantly in recent years (Ines *et al.*, 2001). This is attributed to increased computing capabilities available today. Mathematical models, be it physically or empirically based, have the promising potential to explore solutions to water management problems. Evaluation of water management scenarios can be easily done, thus facilitating better recommendations for improved water use (MacRobert and Savage 1998; Droogers and Kite 1999; Droogers and Bastianssen 2000; Droogers*et al*., 2000a,b). Comparing model results with field observations, or inter comparing models of different nature will provide information on the performance of the models and will reveal strong and weak points. Simulation models are strong in understanding physical processes and scenario testing. Simulation and optimization make a strong tandem in water resources analysis, and, if used together, they could broaden the capacity to manage available resources. Combining a simulation model with an optimization algorithm is a promising tool for better water resources management.

Deng *et al*., (2000a) reported that both soil water deficit and high VPD simultaneously induced the midday depression in photosynthesis, which was interpreted as both stomatal and non-stomatal limitations being responsible for the decrease in photosynthesis in spring wheat in a semiarid environment.Liang *et al.*, (2002) demonstrated that alternately drying and rewatering had a significant compensatory effect that could reduce transpiration and increase WUE significantly under drought conditions.

Kang *et al*., (2002) found that periods of mild soil water depletion in the early vegetative growth together with severe soil water depletion near maturity was optimal for limited irrigation of winter wheat in 540 mm rainfall region.

Deng *et al*., (2002) showed that a single irrigation of 600 m3ha-1 (equivalent to 30% of the volume of irrigation water required for a full cropping season and the maximum yield) applied at the jointing stage yielded up to 75% of the yield of the fully-irrigated wheat. This amounted to a 2.8 kg increase in grain yield per cubic meter of water. The optimum time for limited irrigation in spring wheat was at the jointing stage, before the water deficit became critical.

Water loss by evapotranspiration is very high during the growing season in the semi arid regions. Therefore, irrigation is needed during the growing season to maintain and enhanced crop growth, yield and quality (Yilmaz*et al.,* 2010). Irrigation is an important factor influencing grain quality in cereals (Seleiman*et al.,* 2011).Researches on corn revealed that 368 L water is needed to produce 1kg of dry matter (House, 1985). The water supply has a significant effect in grain filling period. Smaller grains and consequently decreased dry matter yields results from drought during grain filling period (Andrade *et al*., 2005).

Tyagi*et al.,* (2005) worked on improvement in farmers water management decisions for improving agricultural productivity in a water scarce canal irrigation system of Haryana, India and suggested that the highly inadequate canal water supply and poor quality of groundwater created variation in farmers’ decision in crop choices during summer season while in the winter season wheat was grown as the sole crop. The higher exploitation of groundwater, besides keeping water table under control, to some extent increased crop yields in tail reaches. But water quality being marginal, the yields in the tail water courses was lower by 10–20% in case of wheat and 20–40% in case of rice when compared with the head watercourses. The water productivity can be increased to some extent by resorting to crop diversification and by cultivation of salt tolerant high yielding varieties of crops. Fresh and brackish water aquaculture also offers opportunity to improve both water productivity as well as income of the farming community in the region.

In semi-arid and dry sub-humid regions, major water investments in agriculture are required. In these regions yield gaps are large, not due to lack of water but rather due to inefficient management of water, soils, and crops. An assessment of management options indicates that knowledge exists regarding technologies, management systems, and planning methods. A key strategy is to minimise risk for dry spell induced crop failures, which requires an emphasis on water harvesting systems for supplemental irrigation. Large-scale adoption of water harvesting systems will require a paradigm shift in Integrated Water Resource Management (IWRM), in which rainfall is regarded as the entry point for the governance of freshwater, thus incorporating green water resources (sustaining rainfed agriculture and terrestrial ecosystems) and blue water resources (local runoff). The divide between rainfed and irrigated agriculture needs to be reconsidered in favour of a governance, investment, and management paradigm, which considers all water options in agricultural systems. A new focus is needed on the meso-catchment scale, as opposed to the current focus of IWRM on the basin level and the primary focus of agricultural improvements on the farmer’s field. We argue that the catchment scale offers the best opportunities for water investments to build resilience in small scale agricultural systems and to address trade-offs between water for food and other ecosystem functions and services,(Rockstrom*et al.,* 2010).

Makurira*et al.,* (2011)reported that the innovations resulted in increased maize grain yields of up to 4.8 t/ha compared against current averages of less than 1.0 tha-1. The average productivity of the available water over four seasons was calculated to range between 0.35 and 0.51 kg m-3. For the SIs that were tested, the distribution of yields within a cultivated strip showed variations with better yields obtained on the down slope side of the cultivated strip where ponding effects resulted in higher water availability for infiltration and storage. However, due to the large seasonal climate variability, statistical analysis did not show significant differences in the yields (p < 0.05) between different cultivation techniques. The study showed that there is scope to improve grain yields with the little available rainfall through the adoption of techniques which promote water availability and retention within the field. The repartitioning of water within the field creates mitigation measures against the impact of dry spells and allows alternative cropping in addition to the traditional maize cultivated in the rainfall seasons

Balla*et al.* (2013)conducted experiment for two consecutive seasons to investigate the effect of water stress on seed yield and seed quality of onion (*Allium cepa* L.). Water stress was imposed on the plants at four stages of reproductive growth, namely, bolting, flowering, seed formation and seed maturation stage, respectively. Watering was withheld for an interval of 2 weeks only once for every treatment “growth stage” during the first season, while during the second season, the interval of watering was extended to 3 weeks. Water stress at any stage of reproductive growth significantly reduced seed yield and its effect was variable depending on plant growth stage. Based on 1000 seed weight per seed head, bolting followed by anthesis were the most sensitive growth stages during the first season. Water stress at the time of anthesis significantly decreased the diameter of seed head when compared to control.

**2.4Modelling approach for assessment of crop yield and use of CropSyst model**

The first examples of crop growth models used by the agriculture research community were available during the 1970s (de Wit *et al*., 1970; Arkin*et al*., 1976). In the early 1980s, the applications of modelling oriented to management or field decisionmaking (irrigation scheduling, pest and disease control, etc.) appeared (Wilkerson *et al*., 1983; Swaney*et al*., 1983). Models such as SUCROS and others associated with the ‘School of de Wit’ (Bouman*et al*., 1996) as well as those of the CERES (Ritchie et al., 1998) and CROPGRO (Boote*et al*., 1998) families of models had a significant impact on the crop modelling community. However, the need to simulate crop rotations was felt by the scientific community for analysing cropping systems. Models viz. CROPGRO and CERES, placed under the common umbrella of DSSAT (Jones *et al.,* 1998), can be used in rotation configurations. However, the DSSAT approach has been slow in adopting a more generic simulation platform that would allow users to easily integrate these models and simulate crop rotations (Jones *et al.,* 2001). Williams *et al.* (1984) pointed out that the EPIC model provides a simple but effective generic multi-crop simulation approach suitable for the analysis of crop rotations and cropping system. However, the model has limitations due to simplicity of its crop growth descriptions and related biophysical processes.

CropSyst was designed to draw from the conceptual strengths of EPIC, but including a more process-oriented approach for simulation of crop growth and its interaction with management and the surrounding environment. It shares somewhat common objectives with APSIM (McCown*et al.,* 1996; Keating *et al.,* 2003), a modelling approach that has evolved to place substantial resources in the development of quality software engineering practices.

Monteith (1965) reported that the implementation of the penman-monteith model follows the methodology suggested by FAO (Allen *et al.*1998). This option requires daily maximum and minimum temperature, solar radiation, maximum and minimum relative humidity (or dew-point temperature), wind speed.Stockle*et al.* (1992) pointed out that the implementation in CropSyst relies on experimental evidence of crop growth response to CO2. These experiments report to percent increase of growth under a specified atmospheric CO2 concentration compared to growth at a baseline concentration.

Donatelli*et al*.*,* (1997) reported that the calibration was done through an iterative process using the measured crop growth variables, observed phonological stages, parameters estimated from available data, derived growing coefficients and parameters used in other studies to test CropSyst and the WOFOST model (Eitzinger*et al.,* 2004). Initially, soil, weather, and irrigation files were prepared similarly for all models. Thereafter, measured and estimated crop parameters were inserted in the models. The final phase of calibration consisted in the refinement of other parameters so that simulated values fit well with observed data. In fact, the parameters were changed manually around the default values until the best fitting with measured data achieved.

The performance of the decision support system for agro technology transfer (DSSAT) and the soil water atmosphere plant (SWAP) was studied under an acid sulphate soil. The comparison of these models was done as a prerequisite to the selection of an appropriate model, which is capable of simulating water management scenarios, water balance and crop growth, to be coupled with an adaptive optimization algorithm that can be used to explore water management options. DSSAT was able to predict with good accuracy the leaf area index (LAI) during silking stage; SWAP estimated the same fairly. However, in terms of yield, SWAP simulated the actual yield well. This is strongly influenced by the soil water balance model. The reduction of the potential biomass production has more physical basis in SWAP than in DSSAT. Likewise, the estimate of the potential evapotranspiration was observed to have a significant effect on the actual yield estimate. Along the growth process, DSSAT predicted that there was no water stress while SWAP simulated water and oxygen stress (Ines, 2001).

Jhorar(2002) used the SIWARE model to reduce canal water supply by about 25% during the rainy season in the areas facing rising groundwater levels. In addition he increased the capacity of groundwater extraction by 60 mm y-1. The models results revealed that groundwater of relatively poor quality can be used and that the sustainability of the systemdepends on the rainfall distribution.

Ahmad *et al*., (2002) used Soil Water-Atmosphere-Plant (SWAP) model to estimate water flux in the unsaturated soil profile of groundwater irrigated areas of Pakistan under rice-wheat and cotton-wheatsystem. Singh *et al*. (2003) used the same model to estimate the same for Sirsadistrict of Haryana. Boththe studies quantified the moisture changes in unsaturated soil profile during crop seasons. The studies foundthat the vertical water flux in the unsaturated zone is continuous under rice-wheat system with frequent andintensive irrigation. Though both the studies showed that a significant amount of the water applied is recycled,they also showed significant build up of moisture in the unsaturated zone, which can be lost in soil evaporation.

Stockle*et al.,* (2003) reported that CropSyst is a multi-year, multi-crop, daily time step cropping system simulation model developed to serve as an analytical tool to study the effect of climate, soils, and management on cropping system productivity and the environment.

CropSyst simulates the soil water and nitrogen budget, crop growth and development, crop yield, residue production and decomposition, soil erosion by water and salinity. CropSyst has been applied to perform risk and economic analyses of scenarios involving to model development, evaluation, and application is provided. Richter *et al.,* (1999) found that CropSyst evaluated nitrogen dynamics in Northern Germany in a comparative study with other models. The results indicated that CropSyst is simple and can simulate the nitrogen dynamics better as compared to other models, although the difference among the models in terms of fitting experimental data was small.

Singh *et al.,* (2008) reported that CropSyst has been developed during the last 15yr into a multi-crop, multi-year simulation model with a link to GIS software providing numerous examples of application for different crops and environments (Tubiello*et al.,* 2000; Benli*et al*., 2007). Crop development is simulated on the basis of the accumulated thermal time required to reach each phonological stage. The model accounts for four potential limiting factors to crop growth: radiation interception, water and N uptake, and temperature.

Tingem*et al.*, (2008) suggested that crop simulation model must first be capable of representing the actual performance of crops grown in anyregion before it can be applied for the prediction of climatevariability and change impacts. A cropping systems model (CropSyst) simulations of crop productivity in the sub-Saharan Central African (using Cameroon as the casestudy) region, under the current climate were comparedwith observed yields of maize, sorghum, groundnut and soybean from eight sites. Themodel produced both over-and-under estimates, but with amean percentage difference of only –2.8%, ranging from –0.6% to –4.5%. Based on these results, we judged theCropSyst simulations sufficiently reliable to justify use ofthe model in assessing crop growth vulnerability to climaticchanges in Cameroon and elsewhere.

**Alemie and Kebede (2010)** tested FAO AquaCrop model using independent data sets during the cropping seasons of 2006, 2008 and 2009 at Mekelle site in northern Ethiopia to understand the response of barley to water and to simulate the biomass and grain yield of barley under various water inputs and planting dates. Result should that the model was valid to simulate the barley biomass and grain yield under various planting dates in the study site. AquaCrop model can be used in the evaluation of optimal planting time. Out of the tested planting dates, planting on July 4 (early sowing) was found to maximize barley biomass, grain and water use efficiency. The model can also be used in the evaluation of irrigation strategies. Barley showed slightly lower performance under mild water stress condition compared to full irrigation condition. However, the model has indicated the possibility of obtaining more biomass and grain yield from a relatively larger barley field under (deficit irrigation) mild stress condition.

Montazar and Mohseni (2010) employed validated model to assess interactive effects of irrigation and fertilizer N on grain yield and water productivity indices. Scenario analyses indicated that WPI and WPET (ET water productivity) ranged from 0.16 to 2.07 kg m-3 and from 0.07 to 1.49 kg m-3, respectively. For predicting the best N and water application practices for maximization of water productivity, the best option found by the model was application of water and nitrogenous fertilizer in 70% and 90% of the required values, respectively, for WPI, and equal to the required values (100%) for WPET. The simulations demonstrated that the current wheat productivity of 5.0 Mg ha-1 obtained by the local farmers can be achieved at 140 kg ha-1 fertilizer N and 30% deficit irrigation regime with a WPI of 1.73 kg m-3. The CropSyst model can be applied to derive best management options in terms of N and irrigation application of wheat under arid conditions.

Afandi*et al.*, (2010) used irrigation scheduling to increase water productivity of wheat (*Triticumaestivum* L.)-maize (*Zea mays* L.) rotation under two climate change scenarios. Three wheat varieties and two maize hybrids were planted at in a 2 year field experiment. CropSyst model was calibrated and validated for the collected field data, then was used to assess the impact of two climate change scenarios and three adaptation strategies (early sowing changing, irrigation schedule and the interaction between them) in the year of 2038s. The results revealed that simulation of model resulted in yield variation due to climate change. Changing irrigation schedule was an effective adaptation option for maize, where yield improvement could occur under both climate change scenarios in both growing seasons by up to 9% with less than 3% increase in the applied irrigation water and higher water productivity.

Montazar and Mohseni (2010) evaluated that applicability of the CropSyst model under variable climatic, irrigation, and fertilizer-nitrogen regimes to analyze wheat productivity responses to water and N-application for optimizing water productivity in an arid irrigated environment. Evaluation analysis showed that the model provided very satisfactory estimates for the emergence, flowering and physiological maturity dates. The performance of the model was reasonable as demonstrated by the close correspondence between simulated grain yield, biomass accumulation, seasonal ET and irrigation water productivity (WPI) with measured data. The normalized root mean square error ranged between 5 and 10% for most of the parameters. Overall, the index of agreement between simulated and observed values of grain yield, biomass and seasonal ET were 0.99, 0.98 and 0.97, respectively.

A field experiment was conducted at the research farm, Water Technology Centre, IARI, New Delhi during *kharif*, 2009 and 2010 using AquaCrop model for calibrated and validated *kharif* maize crop (BIO-9681) under varying irrigation and nitrogen regimes. Calibration was done using the data of 2009 and validation with the data of 2010. The model was calibrated for simulating maize grain and biomass yield for all treatment levels with the prediction error statistics 0.95<E<0.99, 0.29<RMSE<0.42, 0.9<R2<0.91 and 0.17<MAE<0.51 t ha-1. Upon validation, Model efficiency between 0.95 and 0.98; Absolute Error between 0.11 and 1.08 and RMSE between 0.1 and 0.75 for grain and biomass yield, respectively The prediction error in simulation of grain yield and biomass under all irrigation and nitrogen levels ranged from a minimum of 0.47% to 5.91% and maximum of 4.36% to 11.05%, respectively. The model prediction error in simulating the water productivity (WP) varied from 2.35% to 27.5% for different irrigation and nitrogen levels Over all, the FAO AquaCrop model predicted maize yield with acceptable accuracy under variable irrigation and nitrogen levels (Abedinpour*et al.,* 2012).

The water balance model was calibrated and verified using 2000 and 2002 weekly irrigation records for the Lakeside and Gulf Coast irrigation districts, and validated using 2001, 2003, and 2004 weekly irrigation records. Tail water recovery offers the largest water saving, followed by adoption of high-yielding cultivars, multiple inlet systems, precision leveling, and conservation tillage. Water saving from lateral improvement varies depending on the extent of existing laterals. Water balance for rice paddies, levees, laterals, fallow fields, tail water recovery. Integration of water conservation measures into water balance components. Model simulation for individual fields, turnouts, irrigation canals, and districts. Dynamic integration with geo-referenced climatic, soil, and rice land databases. Best water saving measure is tail water recovery, followed by water-saving cultivars (Yang *et al.,* 2012).

Sun *et al.,* (2012) used the EU-Rotate N model to simulate the greenhouse cucumber growth, water movement and N fate. Results indicated that the simulated values of cucumber dry weight, N uptake, soil water content and NO3-N concentration in the soil profile all agreed well with the observed values. Also, it was revealed that the irrigation method, amounts of fertilizer input and crop residues had significant effects on nitrate leaching and nitrogen use efficiency (NUE). Compared with that under the FP treatment, the amounts of nitrate leaching under the CN and RI treatments were decreased by 26–32% and 75–80%, respectively, whilst the amount of nitrate leaching under the OPT treatment could be reduced 32-36%. Nitrate leaching under the OPTRI treatment was the least, and the reduction was 79-86%. On the other hand, NUE was increased by 2-3%, 15-18% and 40-43% under the OPT, CN and RI treatments, respectively. The largest NUE occurred under the OPTRI treatment, about 314.5–337.4 kg ha-1. It is concluded that the optimal fertilizer N, drip irrigation and straw incorporation are the effective measures for reducing N leaching and improving NUE. Amongst all the treatments, the OPTRI treatment yielded the lowest N leaching at the expense of a slight decrease in yield of greenhouse cucumber. Therefore, the OPTRI treatment should be recommended to farmers in order to reduce the risk of groundwater pollution and to develop sustainable vegetable production in the area.

Irrigated agriculture faces serious threats of waterlogging and soil salinization in the arid and semi-arid regions of the world. To evaluate different options to solve the problem, the computer based simulation model, Salt Model was applied in a waterlogged area of Haryana State in India. After successful calibration (10 years) and validation (10 years), several alternative water management scenarios were studied for their long-term (15 years) impacts on groundwater levels and salinities. The alternative scenarios revealed that the groundwater levels would continue to rise in the long-run under the existing cropping patterns. Thus, suitable water management strategies such as reduction in rice area by 5-9%, reduction in canal water use by 7-10%, and increase in groundwater use by 6-8%, are suggested to bring the groundwater level down to a safe depth and to prevent further rising of the groundwater level (Singh, 2012).

According to the aggregated accuracy, correlation and pattern analysis (ISWAMP), SWAMP performed well in simulating weekly evapotranspiration (ISWAMP = 70%) and water tale uptake (ISWAMP= 90%) of wheat, peas and maize grown on sand to sandy loam soils. SWAMP was also successful in solving the soil water balance under water table conditions at field level. This was done with easily obtainable inputs, while maximizing in situ field observations, which are vital considering that farmers cannot adopt alternative management practices if their current practices cannot be measured. Due to these strengths SWAMP should therefore be easily adopted by irrigation farmers and agricultural advisers to ensure efficient water use (Barnard *et al.,* 2013).

Arora *et al.,* (2013) reported that irrigation and fertilizer N had significant effects on tuber fresh yield, water use and N uptake. Performance of the SUBSTOR-Potato model was reasonable as indicated by close agreement of simulated crop phenology, biomass, water use, tuber yield and N uptake with the measured data. The normalized root mean square of deviations (RMSD) between simulated and measured values for harvest-time dry biomass and fresh tuber yield was 7.3 and 12.6%, while normalized RSMD for seasonal water use (ET + drainage) and total (tuber + haulm) N uptake was 12.4 and 19%. Simulation of tuber yield for independent data (2008–2009) was as good as for calibration data (2010–2011) giving confidence in the model. Scenario analysis based on historical weather data showed that mean potential tuber yield was 50.8 t ha−1 for October 1 planting that reduced to 41.8 and 37.8 t ha−1 for later (October 16 and October 31) plantings. The analysis also demonstrated that yield and ET-based water productivity (WPET) were greater on a sandy loam than a loamy sand soil for comparable irrigation and N regime. Interaction effects of irrigation and N on yield and ET indicated that irrigation response was greater in the presence of N. Greater initial soil water status reduced irrigation and N needs than with lower initial soil water for comparable tuber yield. Initial soil mineral-N also affected N and irrigation regime to achieve a given yield.

Dechmi and Skhiri (2013) showed that calibrated and validated SWAT-IRRIG model is the first modified SWAT version that reproduces well the irrigation return flows (IRF) when the irrigation source is outside of the watershed. The application of this SWAT version in intensive irrigated systems permits to better evaluate the best management practices (BMPs) in such systems.

Xinxiang, (2013) reported that AquaCrop model accurately estimated the soil water content of the root zone as well as the biomass and grain yields of winter wheat. When simulating the soil water during the 2008–2009 growing season, the calculated values of r2, RMSE, ME, and the d-index were 0.98, 8.4 mm, 0.98 and 0.99 for no irrigation; 0.95, 14.4 mm, 0.93 and 0.98 for double irrigation; 0.88, 22.9 mm, 0.68,and 0.90 for triple irrigation; and 0.93, 17.5 mm, 0.75, and 0.9 for quadruple irrigation, respectively. For the grain yield, the r2 values for the model’s outputs under the single irrigation, double irrigation, triple irrigation, and quadruple irrigation treatments were 0.80, 0.98, 0.99, and 0.77, respectively. Comparing to no irrigation the highest increases in grain yield were observed for scenarios in which irrigation was applied during the over-wintering and turning green stages. Moreover, the simulations indicated that under double irrigation regimes, water can be withheld during over-wintering and either turning green or stem elongation without greatly reducing yields. The minimum amounts of irrigation water required to achieve high WUE in wet, normal and dry years were 225, 150 and 150 mm, respectively.

Liu *et al.,* (2013) reported that good agreement between simulated and measured yields was achieved for model calibration (normalized Residual Mean Square Error, nRMSE = 9–15%), and “good” to “moderate” agreement was achieved for model evaluation (nRMSE = 12–17%). Simulated volumetric soil water content in the top 20 cm of CT, RT and NT were in “moderate” to “good” agreement with measurements (index of agreement, d = 0.81–0.91, nRMSE = 15.3–20.0%) provided that non-destructive in situ measurements of water content were used. Overall agreement between measured and simulated soil temperature varied from “poor” to “excellent” depending on year and tillage; and the measured soil temperatures were consistently overestimated (mean error, E = 3.2–6.2), possibly due to lack of accounting in DSSAT for the insulating effects of accumulated surface residues, and the shading effects of standing crops. Refinement of the soil temperature algorithm in DSSAT is recommended.

The AquaCrop adequately simulates the daily canopy cover (CC) in control treatments of tomato and corn, and in moderate stress treatment of corn. In the severe stressed treatment of corn, the simulated values of CC were close to the measured values only from sowing to 60 days after sowing, after that the simulated values do not fit the measurements. The AquaCrop model adequately simulates the daily biomass accumulation under all treatments in tomato and under non-stressed and moderate stressed treatments in corn. However, the simulated biomass outputs were generally overestimated during the late stages of the crop cycles and, consequently the yield also exhibited a tendency to be overestimated. Nevertheless, the yield overestimation can be retained as acceptable because the normalised differences (D) between the simulations and measured values were less than 15% on average. An exception was the tomato yield simulated in the severely stressed treatment, for which D was greater than 30%. In contrast, in the case of the severely stressed treatment in corn, AquaCrop did not exhibit any aptitude for simulating the biomass or the grain yield. In fact, the model predicts the absence of any yield production, while 5 t ha−1 of grain were actually measured in the severely stressed treatment (Katerji*etal.,* 2013).

Razaa*et al.,* (2013) reported that CropSyst simulated biomass growth (RMSE 0.58–3.52 t ha−1) and water content in the soil profile (RMSE 20.9–50.6 mm) satisfactorily. Indices of agreement revealed a better model performance for irrigated conditions compared to water-limited growth.

Singh *et al., (*2013) stated that the calibration, validation and sensitivity analysis of CropSyst model was utilized to quantify and verify the interactive effects of different water and nitrogen treatments on the productivity of direct seeded rice–wheat cropping system using the measurements from field experiments. Results showed that for direct seeded rice, the model performed well at lower levels of nitrogen (120 kg ha–1), whereas at higher levels of N treatment (150 kg ha–1) the predicted values under estimated the measured values. The model performed satisfactory at all levels of N in the case of wheat.

Sensitivity analysis of the model for various crop parameters showed that the model is highly sensitive to the parameters like light to above biomass conversion, specific leaf area and phenological degree-days. Thus, more accuracy is required in determination of these parameters in the model. Further the root mean square error for biomass and grain yield was found to be 0.7 and 0.33 Mg ha–1, which was 9% and 13% of the observed mean respectively, in direct seeded rice, whereas for wheat crop it was 0.80 and 0.33 Mg ha–1 respectively, which in turn was 10% and 9%, indicating that the CropSyst model is highly accurate in predicting the grain yield and above-ground biomass of the DSRWCS(Singh *et al.,*2013)

Abdrabbo*et al.*, (2013) reported that CropSystmodel was able to predict wheat yield with high degree of accuracy for both calibration and validationprocedures. The results also indicated that, in general, the yield of both cultivars will be decrease under climatechange; however the reduction was lower for Sakha 93 as compared with Giza 168. The application of the newirrigation schedule under climate change conditions increased water productivity under the two climate changescenarios, compared with irrigation amount resulted from 0.8, 1.0 and 1.2 of ETc, for both wheat cultivars.Moreover, Sakha 93 gave the highest water productivity. Our results suggested that if we want to reduce yieldlosses for wheat under climate change conditions and increase water productivity, Sakha 93 should be cultivatedand BIS model should be used to schedule irrigation.

Jin *et al.,* (2014) conducted an experiment for improving winter wheat water use efficiency in the North China Plain using AquaCrop model to calibrate, and validate winter wheat crop performance under various planting dates and irrigation application rates. The results showed that the simulated canopy cover (CC), biomass yield (BY) and grain yield (GY) were consistent with the measured CC, BY and GY, with corresponding coefficients of determination (R2) of 0.93, 0.91 and 0.93, respectively. In addition, relationships between BY, GY and transpiration (T), (R2 = 0.57 and 0.71, respectively) was observed. These results suggest that frequent irrigation with a small amount of water significantly improved BY and GY. Collectively, these results indicate that the AquaCrop model can be used in the evaluation of various winter wheat irrigation strategies. The AquaCrop model predicted winter wheat CC, BY and GY with acceptable accuracy. Therefore, we concluded that AquaCrop is a useful decision-making tool for use in efforts to optimize wheat winter planting dates, and irrigation strategies.

The coupled model was calibrated and validated with the observed values obtained from melon field experiment conducted at Northwest China. Simulation of total water use, leaf area index, melon yield and soil water dynamics fitted well with the field observations. The calibrated model was then used to predict the yield and water productivity (WP) of melon under different furrow irrigation scenarios. The relative yield and WP for different irrigation depth were considered as the criteria for investigating the appropriate irrigation management practices. Results showed that the relative yield and WP increased and decreased, respectively, as the relative irrigation increased through a quadratic function. The appropriate irrigation amounts for melon in the study area were 209 mm and 218 mm in 2008 and 2009, respectively (Wang *et al.*,2014).