**Enhancing Agricultural Water Productivity of Crops at Field Scale**

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**Abstract**

Increasing water productivity is an important element in improved water management for sustainable agriculture, food security and healthy ecosystem functioning. Agricultural water productivity is defined as the agricultural output, in physical or monetary terms, generated per unit of water consumed or applied. Plants take up water primarily from soil. Thus, judicious water management in field starts with real-time assessment of soil moisture content *via* *in-situ* or remote sensing-based methods. This chapter reviews opportunities for improving field-scale water productivity by the use of precision agronomic and water management technologies. In field scale, water productivity, or water use efficiency of crops, can be improved by seed priming, maintaining proper row-direction of crops, following prudent nutrient management practices to harness synergy of water-nutrient interaction, minimizing water application *via* drip and sprinkler irrigation or optimizing the same *via* precision irrigation approaches, reducing unproductive water losses through conservation agricultural practices or application of antitranspirants, and increasing the water retention capacity of soils by applying soil conditioners *etc*. Identifying the most promising combination of options for improving water productivity is complex and largely determined by the economic capacity of the stakeholders.

Keywords- Antitranspirants (AT); Agricultural water productivity (AWP)

# **INTRODUCTION**

Agricultural water productivity (AWP) signifies the benefit obtained from crop production in expense of water resources utilized to fetch those benefits. The effort should be consolidated to generate more farm income in expense of per unit of water used, for attaining secure daily livelihood and environmental benefits. In conventional crop physiological perspective, agricultural water use efficiency is defined as the total quantity of biomass or marketable output produced per unit of water used for either transpiration or evapotranspiration [1]. However, irrigation engineers defined the same as the relative proportion of irrigation water transpired by standing crops in any irrigation unit or command area during crop growth period [2]. However, both these definitions are silent about economic benefit and efficiency of water application through field scale irrigation. AWP includes the perspective to grow more food, fetch higher farm income, and sustain livelihood security and support ecological benefit at far less social and environmental cost per unit of water consumed [3]; [4]; [5]. There are three different perspectives for defining AWP which are as follows:

**Table 1: Types of Agricultural water productivity**

|  |  |  |  |
| --- | --- | --- | --- |
| **Sl no.** | **Types of AWP** | **Definitions** | **Units** |
| 1. | Physical water productivity (PWP) | Crop output / Amount of water consumed | kg m-3 |
| 2. | Irrigation water productivity (IWP) | Crop output / Amount of irrigation water applied | kg m-3 |
| 3. | Economic water productivity (EWP) | Value earned after selling crop output/ Amount of water consumed (or irrigation water applied) | Rs. m-3 |

AWP is most preferably expressed in terms of either depleted water from soil profile during the entire Plant Growth Period (PWP) or the net amount supplied water (IWP; *via* surface canals, tank, pond or the well and tube well) to grow crop. For high water demanding crops (viz. rice, sugarcane and wheat) PWP fails to present the actual field condition as farmers apply excess amount of irrigation water than the actual crop requirement. The external source of water supplementation through irrigation often includes the contribution from the seasonal rainfall as ‘green’ water and applied irrigation water *i.e.* ‘blue’ water (from natural or artificial water systems); evapotranspiration (ET) bears a major contribution for the profile moisture depletion for determining the agricultural water productivity during the crop growth period. It takes into account the contribution of surface run off and limited reuse of polluted water generated within the crop production system [6]. Globally, more than 70% of total water withdrawals are used for irrigation that covers more than 90% of total consumptive water use [7] ; [8]. To sustain our water safety and food security, the wider adaptation of ‘more crop per drop’ approach for increasing the AWP is an inevitable option [9]; [10]; [11] and, at the same time, critical for bringing economic development in the arid and semi-arid regions of India [12]. Proper dissemination of the social benefits of higher AWP will encourage the adaptation of process-based AWP simulations for investigating and predicting system-crop-productivity under variable irrigation management practices in diverse agro-ecosystem models [13]. Agronomic measures and efficient management of irrigation water has the potential to increase land productivity as well as the water productivity of agro-ecosystems in many developing countries. The fundamental approach are mostly relied on either increase in crop productivity with stabilized net crop water use or securing stabilized yield with limited or reduced (conjunctive use) crop water use**.** In this chapter, we discuss some solutions for improving AWP which could be feasible for the farmers of developing countries like India.

1. **Approaches for real time soil moisture monitoring**

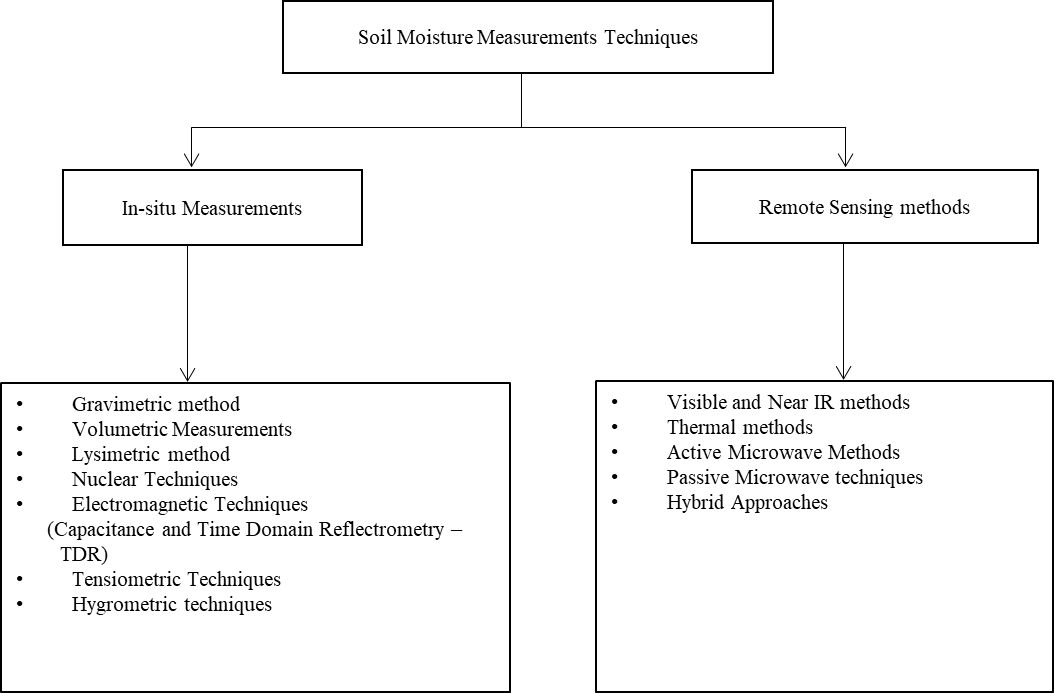
Soil moisture (SM) is an important factor in irrigation schedule. Because of the complexity of SM, exact and real-time measurement is difficult. The vertical profile of SM readings is quite complex and is influenced by several elements, including soil texture, irrigation, and environmental conditions, and it varies dramatically with depth. Increasing the demand per unit of water, especially the opportunities for employment, income generation and nutrition; for that near real time soil moisture monitor need to be done for water productivity analysis.

1. **Gravimetric method**

The gravimetric method is the simplest and most widely used one for the determination of soil water content. Soil samples are collected from field by auger or any other sampling tools and samples are placed in the aluminium cans and sealed to prevent moisture loss during transit to the laboratory. The moisture samples are first weighed and then dried to a constant weight in an oven at 105 to 110˚C. The difference between moist and dry weight gives the water content in the soil samples. In general, the water content is expressed as percentage of dry weight of the soil. For irrigation purposes it is much more useful to express the water content on a volume basis. The volumetric water content θ, are calculated by the following equation:

|  |  |  |
| --- | --- | --- |
|  |  | **(1)** |

Where, = density of water g.cm-3 ; = bulk density of the soil samples, g.cm-3



**Figure 1: Soil moisture measurement techniques**

1. **Lysimetricmethod**

Lysimeter have been used for long time for evaluating agricultural hydrology. By the use of weighing Lysimeters it is possible to measure the water content continuously in the same mass of soil without destructive sampling. Lysimeter are accurate and commonly used for evapotranspiration measurements.

1. **Nuclear techniques**

Among the recent advancement of nuclear techniques for soil moisture estimation, which are non-destructive in nature, two methods have been used with success, one is neutron scattering method and another is gamma radiation method. In the former, measurement is made of the number of hydrogen nuclei that are present per unit volume of soil and therefore, the water content by volume is measured. The attenuation of a broad, near parallel beam of gamma radiation is used to characterize the water status of soil. This method has been successfully used in the laboratory to make continuous measurements of the water content of soil layers in fixed columns.

1. **Electromagnetic Techniques**

Since the late 1980s, technological advances have made SM measurements more robust, particularly dielectric approaches. Various electromagnetic (EM) approaches have been used to measure SM on a commercial scale, which has gained appeal because to the lower cost and training requirements. The electrical signal response of the EM sensors is used to monitor SM. Sensors are commonly made up of plastic access tubes that are put vertically into the soil to measure the moisture level. The capacitance sensors operate on frequency signals that are influenced by the dielectric constant of the soil components. Capacitance and time domain reflectometry (TDR) are two sensors that are commonly employed for SM monitoring.

1. **Precision Agriculture techniques to enhance agricultural water productivity**

The major interventions that can substantially increases the AWP are discussed below:

1. **Priming**

Priming is the process of supplementing the initial period of germination by delivering a limited amount of water. Seed priming has been practised for centuries, with reported growth benefits for a range of crops. To improve seed viability and performance in the field, a variety of priming procedures have been used. Advancing is a simple technique that involves imbibition with a restricted amount of water to lower the amount of water required for the germination process later on, with a reported 2-3% increase in germination rate for carrot seeds monitoring[14]; [15]. Hydropriming is the process of partially hydrating (10-20 % of complete) seed with distilled water to improve its tolerance to salinity or drought [16]; [17]. Osmotic solutions are used in osmo-priming to lessen the impact of reactive oxygen species by reducing oxidative damage[18]; [19]. As a result, priming has various advantages, particularly in stressful situations. [20]; [17]; [21]. Primed seeds are rapidly dehydrated before storage to return the moisture content to its original level [22].

1. **Row direction**

Plant geometry influences crop productivity through influencing Intercepted Photosynthetically Active Radiation (IPAR), biomass production, Leaf Area Index (LAI), profile soil moisture storage, radiation use efficiency (RUE), water usage efficiency (WUE), and so on. Water scarcity is one of the major abiotic stresses impacting agriculturally important crops growth, development, and production [23]. The actual loss of water under north-south (N-S) canopy orientation is closely regulated by the combination of sun position, canopy geometry, and leaf distribution. Some research found that canopy water loss along the N-S row direction was linearly related to estimated intercepted light, implying that water use is driven by both light intensity and crop geometry. Water Use Efficiency varied owing to crop performance under various planting patterns. It was higher in the N-S orientation as compared to the east-west (E-W) directional sowing [24]. Leaf growth and development following planting is critical to crop growth and output. Pearl millet grain yield was found to be higher in the N-S direction than in the E-W direction, and yield was found to be connected with highest LAI and light interception in the N-S direction [25].

1. **Nitrogen × water interaction**

Nitrogen (N) is one of the most significant fertilisers for crop productivity. The sensitivity of wheat crops to deficit watering and the combined use of N and phosphorus fertilizer remains unknown. Several research have been conducted to determine the best N application rates and timings for increased crop yield and grain quality [26]; [27]. Because of the greater mobility of N in soil, this nutrient is critical in soil fertility management [28]. Mineral fertiliser application is critical to resolving this issue. [29]. In some circumstances, the application of mineral fertilisers may have little influence on production when water is scarce [30]. Now-a-days the alternative approaches like Decision Support System (DSS) can take more practical implication under different environment. The Crop Simulation Model (CSM) studies can provide the optimum crop N and water requirements under varied soil- and climatic conditions. The losses of both N and water can happen in many ways if the management is not done properly. So, there is a for developing technologies that enhance Nitrogen Use Efficiency (NUE) and productive use of applied irrigation water leading to increased productivity. Crop Simulation Models (CSM) are capable of simulating the intricate relationships between weather, soil, and integrated management elements (water and N) that influence crop performance. As a result, these models can assist in synthesising much of the information gathered from the numerous experimental locations and providing this trustworthy knowledge to other places of interest with distinct soil-climatic features [31]. [32] reported that the growth and development of wheat crop was affected by various levels of water and N application which they simulated by CERES (Crop Environment Resource Synthesis). The flood irrigation system wastes both irrigation water and applied nitrogen. Similarly, bed planting maize and wheat crops not only saves water but also increases NUE and grain output. [33] shown that wheat planting on beds yielded 15.1% more grain than flat planting at the same N rate. Water savings and increases in wheat yield and water productivity have been recorded while using drip irrigation [34]; [35]. Drip fertigation enhanced the usage efficiency of applied nutrients in maize compared to flood irrigation [36].

The presence of enough plant nutrients and water in the root zone promotes leaf area expansion and growth [37], which improves light and CO2 capture. According to several experimental research, wheat with the ideal levels of N treatment produce relatively higher LAI and intercept more radiation, resulting in more biomass and grain yield [38]. It has been claimed that irrigation water applied at water-sensitive times (stem elongation, booting, anthesis, and early grain filling) in conjunction with appropriate fertilisation could result in increased production [39]; [40]. Higher intake fertilizers, on the other hand, results in reduced yield under rainfed (water starved) conditions. This could be attributed to rapid canopy development during the rainy season, followed by rapid senescence, reduced translocation, grain formation, and grain filling during the extended dry spells that follow the cessation of rain [41]. Increasing water availability at low fertilizer levels, has been proven to result in low LAI and yield [42]. Recent studies showed that, Irrigation water was not efficiently used by wheat plants under little or no nitrogen fertiliser treatment due to poor LAI, low canopy cover, reduced radiation interception, and increased evaporation [38]. When enough water and nitrogen were available, the yield per unit water applied rose. This suggests that fertiliser (nutrient) supply has an effect on water productivity [43]; [44]; [38]; [45]. Understanding the appropriate interplay of fertilizers and water may thus be critical for higher IWP and yield. [46] found that a high N fertiliser rate combined with moderate watering boosts IWP. IWP could be improved by reducing irrigation and increasing N supply. [45] underlined that prudent management measures in this sector are essential for better output and water productivity**.**

1. **Irrigation techniques**

The major sector of using fresh water is agriculture and utilizes almost 70%, i.e., out of 2500 billion m3 1500 billion m3 being utilized every year [47]; [48]; [49]; [50]. In most developing countries, this fresh water is used in agriculture and loses up to 40% through evaporation, spills, and deep layer soil adsorption beyond the reach of roots. Today, it is commonly acknowledged that managing agricultural water is a significant challenge that is frequently correlated with problems related to development. Researchers have paid a lot of attention to water use efficiency as water scarcity continues to vary globally through time and geography as a result of climate change [51]. For the distribution of fresh water in agricultural fields, irrigation is only one method that has been practiced for more than 6000 years [52], but in the past 100 years, with the use of more advanced technology, it has become competent at meeting all demands for water productivity. Irrigation scheduling is a technique that provides an idea of when to irrigate, how much water to apply, and what method should be used for enhancing irrigation use efficiency, thorough understanding the pattern of plant water use, which is influenced by elements including weather, growth stage, and canopy moisture. Irrigation scheduling significantly affects water productivity since it controls the crop's water use and affects its yield [53]. The most commonly used irrigation scheduling is based on assessing soil-water harmony, which requires estimating crop evapotranspiration (ETC). ETC is generally determined by integrating potential (or) evapotranspiration (ET0) measurements from meteorological data with crop coefficients. Previously, irrigation methods used gravity to apply and distribute water, however, improved methods such as drip irrigation, sprinkler irrigation, and smart irrigation methods are being used to minimize water losses [54];[55]. With the use of precision agriculture, in particular smart irrigation, farmers may conserve valuable resources without endangering plant health [56]. The description above makes it evident that in order to increase irrigation water use efficiency (WUE), losses throughout conveyance and distribution systems must be reduced, and the timing and quantity of water applied (or irrigation schedule) must be optimized. When water is the primary constraint on productivity, improving the irrigation WUE may result in water savings that may be used to irrigate more areas.

* 1. **Sprinkler irrigation**

The scientific irrigation schedule is justified by the sprinkler irrigation approach, which is a comprehensive irrigation method. It’s having some special equipment to use to carry pressurized water through uniform spraying to irrigate the land. Water use efficiency of crop can be improved with great potential by the sprinkler irrigation system because modern technologies use pipe to transport the water which limits conveyance water loss [57]. [58] provided a model to assess the effects of uniformity on agricultural production, which links yield response to evapotranspiration deficiencies at several growth stages. It is generally accepted that creating sprinkler irrigation uniformity is a crucial strategy for increasing crop output in sprinkler-irrigated areas while simultaneously saving water. Sprinkler irrigation systems with poor consistency, according to [59] lead to lower yields owing to water stress and waterlogging, which raises the cost of irrigation and causes other associated problems. Sprinkler irrigation uniformity also makes a significant contribution when taking into account the several elements influencing crop productivity in addition to evapotranspiration deficiencies [60]; [61]. Designing irrigation systems must take into account its impact on agricultural productivity. To ensure that every portion of the irrigated area receives the same quantity of water, an irrigation system should apply water in a consistent way. Sadly, it appears that there is no way to make this happen [59]. Therefore, drip irrigation is more efficient to reduce crop water usage.

* 1. **Drip irrigation**

Subsurface drip irrigation was developed around 1959 in the USA, particularly in California [62] and Hawaii [63]. This drip irrigation, sometimes referred to as trickling irrigation, appears to be a potential solution to assist in resolving the water crisis. Additionally, it has the capacity to raise crop yields even with a lower irrigation water application [64] and to increase yields and water application efficiency to the point where water productivity is doubled or tripled [65]. Using plastic tubing positioned close to the root zone of the plants, drip irrigation is the steady, even distribution of low-pressure water to soil and plants. It serves as an alternative to the sprinkler and furrow irrigation techniques. Crops with high or low water requirements can employ drip irrigation. According to [66], Drip irrigation is a response to the increasing demand for limited freshwater resources, and it plays a significant part in the growth of WUE. Crops including cotton, sugarcane, grapes, tomatoes, and bananas can all achieve output gains of 20–50% and water use reductions of 30–60% with drip irrigation [67]. “Drip irrigation uses 30–50% less water than surface irrigation, reduces salinization and waterlogging, and achieves up to 95% irrigation efficiency”.

1. **Precision Agriculture Technologies**

Precision agriculture was defined as the "application of technologies that integrate sensors, information systems, upgraded machinery, and informed management to optimise productivity by accounting for dynamics within sustainable agricultural systems" by [68]. With the use of precision agriculture, in particular smart irrigation, farmers may conserve valuable resources without endangering plant health [59]. Applying water to a field at the proper time, volume, and location is referred to as smart irrigation [69]. Because of this, it necessitates the employment of monitoring and control systems for the best irrigation schedule while taking into account the variability in soil moisture conditions, shifting weather patterns, and plant physiological requirements. The development and convergence of many new technologies, including GIS (geographic information system), GPS (Global Positioning System), RS (remote sensing), Telecommunication, etc., are found a great potential in natural resource management [70]. The introduction of GPS technology enables precision agriculture that focuses mainly on positioning information in a practical and efficient manner for a few thousand dollar. And modernization of agriculture system with an expensive, high-precision differential GPS (DGPS) systems came out with the advanced features of centimetre accuracies [71] that allows for automated machinery guidance [72] and kinematic mapping of topography [73], and are more relevant in the creation of digital elevation models needed for terrain analysis [74]. This Precision agricultural technology focuses on water use efficiency [75]. Due to increasing water scarcity problems and adverse effects of climate change, water use efficiency with Precision agriculture grabbing the attention of many researchers [51]. For controlling the amount of water based on plant needs, real-time irrigation scheduling is very much important, thus several irrigation scheduling systems have been created to supply water accurately [76]. Smart irrigation is the water application in the field at the appropriate time, volume, and location [69]. Understanding the dynamics of moisture and its relation with the amount of irrigation water supplied to the crop field, the volume of water intake by the plant, and soil moisture available in the root zone area is crucial. It has been shown that using a wireless sensor network (WSN) to manage irrigation has helped conserve water. WSN, as its name suggests, is a network of interconnected sensor nodes that interact with the environment directly and offer real-time data that is useful in detecting farm areas that require attention. It can be used for real-time monitoring as both a data collection device and a decision-making tool [77]. In addition to this prime role, an irrigation controller also plays a very important role in savings labour requirements and increasing efficiency in the use of water, energy, and fertilizer [78]. The following are the three main approaches to precise water management: (i) variable rate irrigation, (ii) drainage, and (iii) matching agronomic inputs to water availability determined by soil and/or landscape characteristics [78]. [79] defines a well-managed irrigation system is one that optimises the spatial and temporal allocation of water resources in order to encourage greater plant development and output and to increase agricultural production's economic efficiency (maximum net return).

* 1. **Conservation agriculture** **(CA)**

Worldwide, there is a hard movement for conservation agriculture, which is the practice of conducting agriculture in a way that does the least amount of environmental harm. The conservation tillage principle calls for zero tillage and low mechanical soil disturbance, which are both necessary to maintain the topsoil cover through crop residue retention. The observed proportionate growth in the number of moderate to micropores brought on by zero-tillage has an impact on the soil's ability to store water. According to [80], who discovered that water content at pF 2 changed more in combination with soil porosity than with organic matter content, water-holding capacity is connected to organic matter content, especially on sandy soils. Because of this, the water content at pF 2 was found to be higher in the top 6 cm of the zero-tilled soil than in the ploughed soil, but the opposite was true in the layer at 11-16 cm. According to [81], tilled plots retain less water than untilled plots. According to [82], reduced tillage increased the soil pore space activity by improving the storage pores (0.5–50 mm) and the quantity of extended conduction pores (50–500 mm). They connected the increased microporosity in soils with minimal tillage to a rise in soil water content and, as a result, a rise in the amount of water that is accessible to plants. The topsoil (0–10 cm) under untilled has been found to have more water-holding capacity or moisture content than soil that has been ploughed [83]. Additionally, non-tillage [84] and decreased tillage [83] systems have been shown to have higher water usage efficiency than Conservation tillage in soils. Therefore, the majority of research have proposed substituting conservation tillage for conventional tillage in order to improve soil water storage and water use efficiency (WUE) [85]; [86].

* 1. **Antitranspirants**

Antitranspirants are substances that, when applied to plant leaves, can lower the rate of transpiration. Antitranspirants are often foliar sprays as water loss typically happens through the stomatal pores in the leaves, while they can occasionally be employed more conveniently as dips for submerging the above-ground plant portions, improving plant water potential [87]. Although ATs increased the water status of plants by slowing transpiration, the products also slowed carbon dioxide (CO2) uptake and, consequently, photosynthesis [88]. Research is ongoing into ATs' ability to "waterproof" the most essential crop growth phases [89] by decreased transpiration and increased water use efficiency (WUE) under dry conditions. There are four types of antitranspirants:

* 1. **Reflective antitranspirants**

Reflective ATs are based on the principle of reflection to lower leaf temperature, which in consequence educes the transpiration rate [90 ]. One of most reflective AT is kaolin, an aluminosilicate [91] particle film kaolin, which has improved reflecting qualities, reduces the heat loading on the surface of the leaf more than unfiltered kaolin because more infrared light and UV light are reflected [92]. In order to decrease the negative effects of higher temperature on crop physiology, drought stress is required. The fact that kaolin is regularly used to protect the fruit from the sun may mean that this isn't always the case.

* 1. **Metabolic or stomata-closing antitranspirants**

A class of chemicals known as metabolic ATs work on guard cells to cause partial stomatal closure by having hormone or hormone-like actions [93]. Exogenous abscisic acid (ABA) is prevalent in this class, either in its naturally occurring bioactive form (S)-cis-ABA (s-ABA) or in a commercially accessible combination with the synthetic (R)-cis-ABA [94]. ABA signalling results in an outflow of ions from guard cells and water through osmosis, causing the cells to become flaccid and the stoma to close simultaneously [ 95] (Kim et al., 2015). Fulvic acid is the other biostimulant-antitranspirant of the metabolic AT class. Organic matter breakdown produces fulvic acid, which dissolves in both alkaline and acidic liquids [95]; [96]. [97] found that Fulvic acid was sprayed to maize at the tasselling stage, and while transpiration rate, net photosynthesis, and WUE were all greatly enhanced, stomatal conductance improved only marginally (13%). This suggests that fulvic acid functioned as a biostimulant. Metabolic AT research frequently focused on phenyl ercuric acetate (PMA), which was later discovered to be hazardous [98]. According to [99] and [100], India appears to be the only nation where using PMA as an AT is still permitted.

* 1. **Film-forming antitranspirants**

The majority of the currently accessible film-forming ATs are organic polymers that can be emulsified in water and form films after a spraying treatment has dried [100]. To minimise transpiration water loss, the films function as a physical barrier across the stomata. The oldest film-forming AT is di-1-p-menthene (pinolene), with Williamson being one of the early mentions (1963). [102] examined the drought-relieving effects of di-1-p-menthene and poly-1-p-menthene on oil seed rape in glasshouse settings. Both substances markedly decreased gas exchange, but di-1-pmenthene was superior at suppressing stomatal conductance (by 50% vs 11%) and did so for a longer duration (> 14 days against 9 days). The findings of the yield component were in line with the measurements of stomatal conductance, and di-1-pmenthene had higher values for the number of pods per plant and seed biomass, indicating that the reduced CO2 fixation was offset by enhanced WUE.

* 1. **Soil Conditioners**

In order to produce food, agriculture depends heavily on water. However, water scarcities and droughts have led to soil desiccation and salinization, which pose a threat to both the sustainability of agriculture and the availability of food. Therefore, increasing water consumption efficiency is crucial for agriculture [103]. Superabsorbent polymers (SAPs) can be used to improve water use in agriculture by keeping moisture in the soil and using less irrigation water because of their extremely high-water absorption and retention capacities [104]. The chain of SAPs contains a large number of hydrophilic groups that aid in absorbing water hundreds to thousands of times their own mass. Additionally, three-dimensional networks that are connected chemically or physically ensure SAPs have a significant capacity to retain water even under pressure [105]. Despite the fact that SAPs made of synthetic polymers, including polyacrylic acid (PAA) and polyacrylamide (PAM), have advantages like low cost, extended service life, and high water-absorption rate, their non-degradation characteristics may have a negative impact on the environment and plant growth.

1. **Conclusion**

Seed priming, maintaining proper row-direction of crops, adhering to wise nutrient management practices to leverage the positive water-nutrient interaction, minimising water application via drip and sprinkler irrigation or optimising the same via precision irrigation approaches, reducing unproductive water losses through conservation agricultural practices, or applying antitranspirants can all increase water productivity or crop water use efficiency on a field scale. Finding the best effective combination of choices to increase water productivity is difficult and heavily influenced by the farmers' financial resources.

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