Review on advances of airjection irrigation

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Abstract: Air is squeezed out of the soil in the process of traditional irrigation. Hypoxia stress of the root zone is harmful to the yield and quality of crops. It was found that the improvement of the soil oxygen condition can increase the crop yield and quality in the root zone. In recent years, a number of studies showed that hypoxia stress has bad influence on root zone, and the ventilation technologies have some positive effects on crop yield and quality. This paper introduces and analyzes the mechanism of hypoxia stress in root zone, and provides an overview about characteristics and application on airjection irrigation. Simultaneously, the advantages and disadvantages of different airjection irrigation technologies were investigated, the achievements that have been made in this filed were summarized, and some existed problems were discussed. Based on the previous studies, the research trends of the airjection irrigation technology were proposed, which can provide a reference for the further research in the research field.

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1 Introduction

For the crop, traditional irrigation methods provide moisture while driving hypoxia stress on roots. Irrigation in heavy clay soil[1-3] or under unreasonable management will worsen the anoxic condition of the soil. If the root stays in the anaerobic environment or cannot get enough oxygen for a long time, it would be declined for the water and nutrients absorption of root. Also, it will change the hormone levels and enzyme activities of the plant, block the photosynthesis, limit the function of vegetative organs, and eventually lead to the decline of crop yield and quality[4]. The healthy growth crops are hindered by the traditional irrigation. According to the research, it made a difference from root respiration and soil respiration[5]. Air in the soil sustains root respirations, soil microbes and soil animals[6]. Therefore, lack of oxygen in the root zone may produce compromise to soil microbes, soil animals and plant itself. Improving the oxygen level of the crop root zone has a great significance in increasing crop yield and quality. As early as 1940s, Melsted et al.[7] began the experiment

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about ventilation in the crop root zone. In recent years, a variety of airjection technologies in the root zone have been developed, and the experimental studies on crops have been done in different regions and soil. However, the present study lacks systematization, it is necessary to summarize and analyze the problems on airjection technology recently. In this review, we will introduce the achievements, and discuss the existing problems in this field, as well as summarize the research trends to provide a reference for further in-depth study.

2 Effects of soil hypoxia

2.1 Harm of root zone hypoxia stress on crops

Root respiration is the process of absorbing oxygen and releasing carbon dioxide in the live root[8]. The broad sense of root respiration refers to the root respiration and its derivatives. The process includes the root respiration, symbiotic bacteria respiration, and the microbial respiration which participates in the decomposition process on exudates and tissues of dead roots[9,10]. Oxygen in soil supplies root system and various microorganisms. If the permeability of soil decline in the root zone, it may cause oxygen deficiency. Furthermore, the root will be in the state of oxygen stress.

Oxygen, as electron acceptor in the terminal respiratory chain, the hydrogen atom in reduced nicotinamide adenine dinucleotide (NADH) and flavin adenine dinucleotide ($FADH_2$) after being activated by dehydrogenase and separated from NADH and $FADH_2$. Then hydrogen atoms combine with activated oxygen generated water, oxidation state of NAD, FAD accompany with the phosphorylation of ADP to ATP. When the soil is lack of oxygen in the root zone, the electrons in NADH, $FADH_2$ is lack of receptor and cannot be transformed into NAD and FAD, so tricarboxylic acid cycle (TCA) restrained, ADP cannot be phosphorylated and that lead to cell energy supply shortage[11]. The study by Fukao et al.[12] suggested that the hypoxia stress on crops suffocated the transportation of oxidative phosphorylation electrons, decreased the generation of ATP and $NADP(H)^+$, and caused ATP in the root cell in short supply.

If the rhizosphere is lack of oxygen, cells cannot get enough energy. It results in a decreased absorption ability of nutrients and moisture; there are not sufficient nutrients can be transported to the aboveground parts of plants, and will weaken photosynthesis[13]. Gibbs et al.[14] found that the content of photosynthetic pigments in leaves declined and photosynthesis inhibited, if there was hypoxia stress in crop root. Munns et al.[15,16] discovered that hypoxia stress increased leaf abscisic acid (ABA) concentration. The accumulation of ABA led to the reduction about stoma density, opening degree, and reduction in chlorophyll content, inhibited the growth of stems, leaves, and at the same time, resulted in reducing the net photosynthesis rates.

Zheng et al.[17] studied the cucumber growth on the condition of hypoxia stress. Under the soil compaction stress, the activities of root pyruvate decarboxylase, alcohol dehydrogenase, lactate dehydrogenase and the contents of root anaerobic respiration products: alcohol, acetaldehyde, and lactate increased significantly, the aerobic respiration of cucumber root is inhibited. In addition, under hypoxia stress, start-up anaerobic respiration also made some negative impact on crops. Anaerobic respiration produced cytoplasmic acidification and led to the mass accumulation of Fe^{2+} and Cu^{2+}, damage to the internal environment. The ethanol or lactic acid that plants produced could not be completely oxidized. When the accumulation of these harmful materials reached a certain degree, it would produce significant toxic effects on crops, and even destroyed the entire environment in the cell[18].

The study also found that plants got $NAD(P)^+$ and ATP at the expense of dry matter accumulation which would inevitably affect the output of crops[19], due to the shortage of energy supply, when cells were in hypoxia stress. Sun Yanjun’s research[20] showed muskmelon seedling under the stress of root-zone hypoxia, height, root length, fresh weight and dry weight decreased to some extent.

2.2 Influence on soil microbes, soil animals under the condition of insufficient oxygen supply

Participants in the decomposition process of soil organic matter are mainly fungi and bacteria. Fungi secrete hydrolytic enzymes into organic matters and use their nutrients for growth and reproduction. Bacteria can survive in the gaps which produced by fungi activities. Macromolecules organic matters translate into small molecules for crops under the common action of fungi and bacteria[21]. If oxygen is lacked in the soil, the quantity and activity of soil microorganism will decline as well as organic matters decomposition. It cannot provide enough N, P and K for crops.

The main contribution of soil fauna to field ecosystem is that accelerates the process of organic decomposition and promotes microbial activities. On the one hand, large particles which are difficult to break down and transform into labile substances through soil animals' feed and excrete. On the other hand, soil animals' activities promote the contact of organic matter and microorganisms, and soil animals' bodies also can be used as nutrients of soil microorganisms[22]. If the concentration of soil oxygen is too low, aerobic respiration of soil animals cannot be carried out smoothly. So the normal physiological activities are limited, large particles of organic matter decomposition slows down and has adverse impact on microbial activities.

3 Techniques of airjection irrigation

Air Permeability is one of the composite indicators of soil fertility. It can reflect the soil texture, structure, compactness, dry and wet conditions comprehensively[23]. Firstly, Air permeability has significant effect on soil oxygen content, and it is also affected by the soil texture and bulk density. Secondly, irrigation may affect the permeability of the soil. Lower oxygen content in the soil restricts plants' growth and yield. Disturbed samples from two kinds of soils in China, Brown Forest soil (sandy loam) and Lou soil (silty clay loam) were repacked to construct soil columns with various bulk densities (1.3 g/cm^3, 1.4 g/cm^{3}and 1.5 g/cm^3). For the brown forest soil, soil air permeability was reduced by 88.2%, 70.1%, and 42.5%, with a bulk density of 1.3 g/cm^3, 1.4 g/cm^3, and 1.5 g/cm^3 after irrigation. Respectively, 71.2%, 65.4%, and 54.3% for the Lou soil. The air permeability level was 3.7, 2.0 and 1.5 times after 10 min aeration, as before, the Lou soil with a bulk density of 1.3 g/cm^3, 1.4 g/cm^3, and 1.5 g/cm^3, respectively, 3.0, 2.5 and 2.0 times, for the Brown Forest soil[24].

Airjection irrigation can efficiently improve soil air permeability and oxygen content. This technique has great significance in improving soil environment about water, fertilizer, gas and heat in the crop root zone[25]. The O_2 concentration increases by 2.4%-32.6% in the crop root zone when using Mazzei air injector. For oxygation, the soil respiration ability increases by 42%-100%[26]. Sufficient oxygen supply ensures the normal growth of root system and improves the efficiency of aerobic respiration and root vitality, and enhances the root absorption of mineral elements and soil water that be used efficiently. Efficiently physiological activity of root sustains the normal operation of the aerial parts of the plant. Thereby, it improves numbers of physiological indicators. Bhattarai et al.[3] put forward a new irrigation technique which installed venturi air injector in the first portion of the irrigation system, using it to achieve the aeration through subsurface drip irrigation. The study found that the technique could alleviate effectively the shortage of oxygen in the soil during irrigation, and unlock yield potentials of crops. This technique has positive effect especially on heavy clay and saline soils[4,27,28].

3.1 Methods of airjection irrigation

Airjection irrigation is adding air to the process of irrigation or aeration following irrigation. Usually, we use air pump, super micro bubble generating system or venturi injector to deal with irrigation water. These methods are also named oxygation, subsurface oxygation, aeration subsurface drip irrigation or aerated irrigation[1,4]. The followings analyze the airjection irrigation for current conventional ways of root zone.

3.1.1 Method of ventilation after irrigation

In the soil around the roots, buried drip irrigation belts and the hose with holes connected to the water and air compressor above ground portion of belts. Use compressor to inject pure oxygen or compressed air into the root zone of soil. This method is named the ventilation after irrigation (Figure 1). In hydroponic conditions, using the air pump directly to inject the air to the nutrient solution, and also belongs to the scope of it.

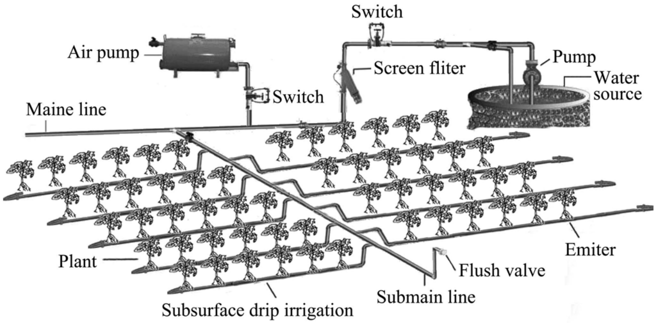


Figure 1 Sketch map of ventilation after irrigation

Firstly, except for adding the air pump, the method of ventilation after irrigation is almost the same as original drip irrigation system. The advantage of this approach is that will have little bad effects on the original soil. Secondly, this method can increase the anti-clogging ability of dripper; therefore, it extends the service life of the drip irrigation belts[29]. Although this method needs an additional cost for electricity, drip facility and etc., these results have some comprehensive benefits. Research shows ventilation once a day, or once two days, the production of muskmelon in greenhouse can get more economic benefit[30]. The research about rhizosphere ventilation of potted maize suggests that this technique can enhance root activity efficiently and improve plant height, leaf area, chlorophyll content, root-shoot ratio, dry matter accumulation[31]. Cultivate rice in hydroponic study of the influence with rhizosphere oxygen concentration enhanced by aeration on rice root growth. A hydroponic study was conducted on the root growth of rice. The results display that aeration significantly increases the oxygen concentration of hydroponic solution during the whole plant growth stage. Rice plant has the highest oxygen absorption ability at heading stage. Compared to control group, length of single root and the longest root of rice planted in higher oxygen concentration solution is longer, and the number of roots per plant is less. In the early rice booting and heading stage, it points out that rice cannot meet normal physiological needs if only relies on the oxygen dissolved in water, So aerated irrigation is necessary[32].

3.1.2 Method of irrigation water and air simultaneously

Before irrigation, it is disposing the water by super micro bubble generating system, so that the water enriched with bubble whose diameter is less than 3 μm. This is the method of irrigation water and air simultaneous. Under the aerated irrigation, the result manifests that it increases the content of chlorophyll, soluble protein, stomatal conductance and activity of super oxide dismutase significantly, but decrease the content of malondialdehyde in leaves. Aerated irrigation delays the leaf senescence effectively and prolongs leaf functional period. Thus, it improves the efficiency of Photosynthesis and promotes grain filling[33].

3.1.3 Method of mixing gases irrigation

At the entrance of underground irrigation system, use venturi injector to inject a certain amount of air, which is transported to the soil in crop root zone by water. This method is called mixing gases irrigation. According to Bernoulli's law, when water flows through the Venturi in a certain pressure, the flow velocity will increase, due to the smaller radius of throat. Water pressure energy converts into kinetic energy and it also reduces on side wall. If the side wall pressure is lower than the atmospheric pressure, a negative pressure will be formed, and then air will be sucked into the pipes (Figure 2). Moreover the air accompanies with water flows to the soil in crop root zone[1,34,35].

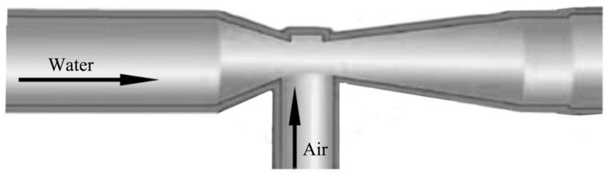


Figure 2 working principle of the venturi injector[52]

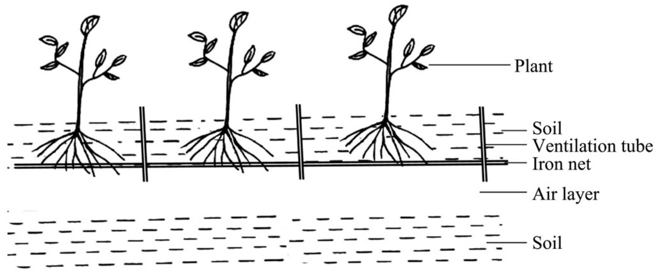
A venturi injects air into irrigated water streams. It results in positive benefits of alleviating hypoxia. Subsurface irrigation with aerated water (12% air in water) stimulates above-ground growth, and enhances the reproductive performance through earliness for flowering and fruiting compared to the control group. Compared to the control, fruit yield of tomatoes with aeration in the experiment increases by 21% and 38% in saline soil, due to aeration contrasted to the non-aerated control[1]. Employing an in-line air injector (Mazzei venturi) to introduce 12% air by volume of water on fruit yield that is with oxygation increases from 14.5 t/hm^2 to 24.6 t/hm^2, and 26.3 t/hm^2 to 28.9 t/hm^2, for watermelon and pumpkin, respectively. The total soluble solids increases by 19% with oxygation, but internal fruit crack decreases for watermelon and pumpkin. And the fruit dry matter increases by 4%, besides total soluble solids increases by 7%[36].

3.1.4 Method of using chemical materials to increase oxygen

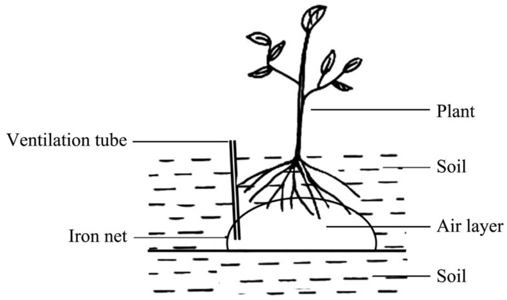
Use urea and calcium peroxide as fertilizer and add low concentration hydrogen peroxide (HP) to the water in the irrigation. These substances will release oxygen to add oxygen to the root zone soils lowly. This method is named using chemical materials to increase oxygen[3,37,38]. In the 1940s, Melsted used HP to improve oxygen concentration in the root zone soil[7]. In the end of each irrigation cycle, Bhattarai used HP, which is at the rate of 5 L/hm^2 and to inject in subsurface drip irrigation (SDI) tape to a field-grown zucchini (*courgette*) crop on a saturated heavy clay soil in Queensland, Australia. Due to HP treatment compared to the control, fruit yield, number and shoot weight increased by 25%, 29% and 24% respectively. Compared to the control, two pots experiments on potted soybean (*Glycine max*) and cotton (*Gossypium hirsutum*) for HP treatment, fresh pod yield of potted soybean increased by 82%-96% in aeration treatments. The yield increasing was associated with more pods per plant and greater average pod weights. Significantly, above ground biomass was higher and light interceptions were evident with aeration. HP affected above ground biomass and has an increasing in root mass, root length and soil respiration, and also brought an enhancement of water using efficiency (WUE) for pod and lint yield as well as increased leaf photosynthetic rate, but had little effect on transpiration rate and stomatal conductance per unit leaf area[3].

3.1.5 Other methods

Dig a groove before planting, and lay an arched iron net at the bottom of the groove that is covering gauze on the iron net. Finally, covering the soil and beneath the iron net, what formed underground air reservoir. Using the underground air layer that will be penetrate the soil and replenish soil air. This method is named aerated by groove or substrate-aeration (Figure 3)[39]. Studies have been shown that aerated by groove and could increase O_2 and reduce CO_2 concentrations in soil root zone significantly. Available nutrition contents heightened significantly, and alkali-hydrolysable nitrogen increased by 12.95%-28.87% and also available phosphorus. Compared to CK, the results also showed that aerated by groove what has a significant increase in the height, stem width, leaf area and the tuber content of potato plant[40,41].



a. Side view



b. Transverse view

Figure 3 Sketch map of aerated by groove

3.2 Benefits of the airjection irrigation

At present, research on the benefits of rhizosphere ventilation mainly concentrated in the soil enzyme activity, morphology and physiological activity of root, leaf and photosynthetic rate of reaction, crop yield and quality, WUE and so on.

3.2.1 Effect of rhizosphere ventilation on soil enzyme activity

Supply gas for potted tomato by air compressor and set three irrigation levels. Each irrigation level has different ventilation volume coefficient with the reference standard as 50% soil porosity. Activities of soil catalase, urease, and dehydrogenase under the ventilation treatment are higher than those of the non-ventilation. When the irrigation level is 80% of the field capacity and the ventilation coefficient is 0.8, besides, the activities of three soil enzyme reach the highest value. The results prove that water (80% of field capacity) and aeration (the coefficient is 0.8) can improve potted tomato root zone environment, accelerate the activity of soil enzyme, promote the plant growth and increase fruit yield. The soil enzyme activity increases by 172.0%, 1718.7%, and

35.2% for the soil catalase, urease and dehydrogenase respectively[42]. Using this method to improve soil oxygen content of the cucumbers, the researchers find that activity of various enzymes in the groove treatment is higher than those of the CK treatments, including: phosphatase (by 18.3%), invertase (by 20.87%), dehydrogenase (by 22.52%), and unease (by 7.67%) respectively. Moreover, obvious increases are found in other indexes, such as the available N and P contents, and the dry matter accumulation of plants[43]. In conclusion, aeration cultivation can boost the enzyme activities, increase nutrient content in the matrix, and promote the growth of plants[44].

3.2.2 Effect of rhizosphere ventilation on the crop root

In order to clarify the effects of aeration on root nitrogen metabolism in rice seedlings, aerator pump continues to fill the root zone with air under hydroponics. Compared to the control group, the results show that rice seedlings grown in oxygenation solutions have higher root dry matter, longer root length, stronger root activity and larger root absorption area. In addition, the contents of soluble sugar, root vigor are higher than those in the control as well as the activities of glutamine synthetase, glutamic acid oxaloacetate transaminase and glutamic acid-pyruvic acid transaminase in the aeration solutions. The results also indicate that the activities of root nitrogen metabolism of Xiushui 09 are enhanced by aeration[45]. The study on potted corn aerated after irrigation finds that tube aeration every four days. Under the irrigation level 600 mL per pot, root vitality will be the highest and significantly higher (66.7%) than that of the control[46]. Using aerated water to drip irrigation can ameliorate hypoxia stress and overcome the negative effects of poor soil aeration. Oxygation of irrigation water by Mazzei air-injector produces significantly higher yields. Data display that it is higher (by 17%) in total root mass per plant significantly, greater (2%) fibrous root mass and larger (26%) taproots per plant than the control especially. The study finds that oxygation stimulates the growth of root. The normal growth of roots protects the canopy development is higher than before, the same as the photosynthetic efficiency and crop yields[27].

3.2.3 Effect of rhizosphere ventilation on leaf and photosynthesis

The research found that the leaf area per plant with air injected was 1.477 times larger than in drip irrigation[47]. Compared to the control treatment, researches on soybean, chickpea, pumpkin and tomato under oxygation treatments, the stomatal conductance and leaf transpiration were higher significantly[1,48]. Aerated irrigation with water treated by super micro bubble generating system that delayed leaf senescence process, prolonged leaf functional activity and led to enhanced grain filling[49].

3.2.4 Effect of rhizosphere ventilation on crop yield and quality

Pendergast pointed out that Oxygation of SDI contributed to improvements in both yields and water-use efficiency, which may contribute to greater economic feasibility of SDI for broadacre cotton production in vertosols. Over seven seasons (2005-2012), Oxygation of irrigation water by Mazzei air injector produced singularly higher yield and WUE. Averaged over seven years, the yield of oxygated cotton exceeded that of the control by 10%[27]. The effect of oxygation was prominent with increasing emitter depths, due to the alleviation of hypoxia. The effect of oxygation on yield of the shallow-rooted crop vegetable soybean was the greatest (+43%). Moreover, moderate on medium (chickpea+11%) and deep-rooted crops (pumpkin+15%)[48]. Mohamed pointed that in comparison with DI (drip irrigation) and SDI, the air injection treatment achieved significantly higher productivity through the two seasons. Compared to the DI and SDI treatments, yield increase by 37.78% and 12.27% extraordinarily in 2010 and 38.46%, 12.5% extraordinarily in 2011, respectively. If the drip water aerated, data from this study indicated that corn yield could be improved under SDI[47].

3.2.5 Effect of rhizosphere ventilation on water use efficiency

Pot experiments were conducted to evaluate the effects of oxygation (12% air volume/volume of water) on vegetable soybean (moderately salt tolerant) and cotton (salt tolerant) in salinized soil. In vegetable soybean, compared to the control, oxygation increased above ground biomass yield by 13% and WUE by 22% respectively. In cotton, compared to the control, oxygation increased lint yield by 18% and WUE by 16%, especially. Pointed out that oxygation improved yield, WUE performance of salt tolerant, tolerant crops under saline soil environment moderately and rhizosphere ventilation may have significant impact on irrigated agriculture where saline soil posed constraints to crop production[50]. In 2010 and 2011, a field study was conducted to evaluate the effect of air-injection into the irrigation stream in SDI on the performance of corn. Air injection had a highest WUE and IWUE (irrigation water use efficiency) in both growing seasons[47].

4 Main problems of airjection irrigation

Airjection irrigation improves the soil enzyme activity effectively in the root zone, guarantees root aerobic respiration and increases the capacity for mineral elements absorption. Efficient root physiological activities have positive impact on other parts of the crop. Oxygation results in enhancement of leaf chlorophyll concentration, the leaf photo synthesis, and yield and quality rate. However, no matter what kind of technologies compared to the conventional irrigation methods are likely to pay the extra cost of equipment, pipe fittings, electricity, labor, etc. Before the implementation, we need systematic analysis and calculation. Only the additional costs are less than the yield on increase benefit, and airjection irrigation technologies become practical. Moreover, every technology also has some defects or deficiencies, and needs further improvement.

4.1 Method of ventilation after irrigation

The method of ventilation after irrigation is something like the traditional SDI. The emitter usually has submerged in a certain depth. It results in insufficient of soil water for topsoil. Hence, hinders seed germination and seedling emergence. Due to the chimney effect, injection of air alone is expensive and the injected air moves away from the root zone[1,4]. This method cannot control accurately the amount of gas and too much gas will have some negative impact on crop. The research on continuous aeration measured the growth-related parameters and the activity of enzymes related to nitrogen metabolism at tillering stage[51]. Compared to the control, the results were found that lower chlorophyll content in leaves. Under continuous aeration, the dry weights of shoots and roots were decreased by 44% and 40% for “Guodao 1”. Therefore, the nitrate reductase activity in leaves was increased significantly, while under aeration, the glutamine synthetase activity was decreased. Nitrogen metabolism was restrained, but photosynthetic efficiency reduced, the same as dry matter accumulation.

4.2 Method of irrigation water and air simultaneously

Usually, super micro bubble generating system used in the field of sewage treatment. Only a few studies use it to irrigation, just several reports have studied in irrigated rice[49]. The application of this technology can accelerate tillering, increase the leaf area index as well as the effective panicles and maturing rate, dry matter accumulation, and improve rice yield. However, the related research is still at a preliminary stage. There are not any reports in the other crops and this technology is not mature enough. In addition, equipment is relatively expensive, and large area promotion has certain difficulty.

4.3 Method of mixing gases irrigation

Currently, using venturi throughout the irrigation cycle is the most commonly international aerated technology. The technology is based on the traditional SDI, only added the venturi injection and adjusted the water pressure. At the same time, aeration irrigation can be realized. The cost of this technique is relatively low, and there are a lot of related researches. There are a large number of researches on zucchini, vegetable soybean, cotton and cabbage[3,50]. A number of studies have shown that this technology has significantly increased crop yield and quality in heavy clay and saline soils. Nevertheless, an oxygation experiment carried out on bell peppers. There is evidence on indicating a non-uniform and declining trend of oxygation benefit along the 58 m long oxygen filling pipe. After this, Goorahoo carried out similar experiments and found a similar declining trend over a 300 m long drip tape.

Compared to those located at the downstream (lower yield) of the pipe, the yield of aerated tomato plants has been recorded from the upstream of the lateral (higher yield)[52]. Then Torabi's study confirmed distribution of bubble in a bubbly flow of an air-water system and a horizontal pipe decreased along the pipe line[53]. Bhattarai used a visualization system that based on continuous image capturing that could be used to determine the number and size of bubbles, as well as estimated the void fraction percentage of air in aerated water stream. The research results showed a decline with distance from the Mazzei venturi model 384 air sources, but an offset effect to some extent by adding 2 ppm of surfactant to the irrigation water[54].

4.4 Method of using chemical materials to increase oxygen

Injection of HP in the root zone can effectively improve the oxygen content of the crop rhizosphere. The technique is simple, fast, and some extent alleviates the root zone hypoxia. Therefore, it improved crop physiological indexes and yield. However, limitations of this method is greater, such as HP's easiness can be decomposed, the same as the inconvenience of transportation and storage, strong oxidizing and potential hazards for crop, soil structure and soil organisms[1,25].

4.5 Other methods

By the method of the groove culture, advantages are harmless to the environment, and significantly improved the plant height, stem diameter, biomass, crop yield and quality. However, it needs a large number of costs before planting. People should deal with the soil firstly, due to the high demand for labor. And wide range of application is difficult, so that current researches are mostly in small greenhouses.

5 Conclusions and research prospects

5.1 Conclusions

1) The technology of airjection irrigation can increase crop yield and quality, significantly. Its mechanism is that aeration improves oxygen environment of rhizosphere, and sufficient oxygen guarantees the normal activities of soil microorganisms and root activity, otherwise enhances the ability of water, minerals absorption, canopy light interception rate and photosynthetic efficiency. Therefore, it increases the crop yield and quality.

2) Currently, for a variety of crops, a lot of aerated tests have been done. Long-term experiments show that airjection irrigation can improve the plants' yield and quality. It is obvious on the condition of heavy clay soil and saline soil, and advantage of this technology is also. The technology has good application prospect.

3) The technology of airjection irrigation has been used on a small scale in foreign countries, but still has not been promoted in China. First, the reason is that mainly related aerated technology more or less existed deficiencies. Second, current researches pay more attention on the improvement of crop yield and quality. Third, related experiments are insufficient and lacking of crop growth data in multiple parameters, beside contrast among different technologies is also insufficient.

5.2 Main problems to be solved on airjection irrigation and recommendations

Domestic and foreign scholars on airjection irrigation technology conducted extensive research and made some progress. However, there were still many issues that need to be researched in the further. Thus, we will put forward the following suggestions:

1) In the future, research focus should be shifted from plant apparent morphology, yield, quality to hormonal regulation, the changes of peroxide and antioxidant enzyme system, gene regulation, and cell signal transduction, etc. Further researches should be defined aerated irrigation mechanism of physiological and biochemical mechanisms about improving crop yield and quality. In particular, researches should focus the aerated irrigation on crop root absorption ability of water and fertilizer, and the impact of changes in crop physiology.

2) Develop research on aerated irrigation technology standardization and determine suitable technology, parameters and aerated irrigation standardization to meet the different needs. Using chemical materials to increase oxygen that should be considered of the different needs about oxygen in space, time and hazards of HP on crop. And these considerations determine dosage, concentration, and the timing.

3) On potential hazards of aerated irrigation, the

researches could be conducted, such as for excessive gas, it destructs of the soil microbial community, and is harmful for effect of cavitations on crop root growth.

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