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Research Article

Fast-Growing Desert Protected Horticulture around Taklimakan Desert: Current Status and Technological Challenges for Sustainable Development

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ABSTRACT

With the rapid development of continuous population growth, urbanization and industrialization, increasing pressure for oasis agriculture aggravated around some deserts (e.g. Taklimakan desert etc.) in Xinjiang province and inner Mongolia provinces of China. Nowadays, agricultural land resource has become limited seriously and agro-environment tends to be fragile and adverse for oasis agriculture. In recent years, scaled Desert Protected Horticulture (DPH) in some cities located in Xinjiang has fast developed successfully in the suburbs of five prefecture-level cities and more than thirty county-level cities around Taklimakan desert on land obtained through desert reclamation, which provided substantial economic output and labor employment for local residents. Nowadays, many eco-environmental problems, such as nutrient leaching (e.g. nitrate and phosphate etc.) and water loss in desert sandy soil under conventional agronomic management like plain area of North China will occur more strongly, which results in seriously environmental pollution and resources waste. Thus, DPH around Taklimakan desert overcome harsh desert soil and climatic conditions and performed increased energy, water and nutrient use efficiencies with aids of modern agricultural technologies to potentially realize sustainable development characterized with high productivity, clean and environmentally-friendly production. In China, some novel soilless cultivation methods had been developed. Currently, higher use efficiencies of agro-resources (land, water, nutrients and labor, as well as light and heat resources) without environmental pollution are more urgent issues for DPH sustainable development. In this paper, current status, benefits, favorable and adverse factors, technological problems and coping strategies for DPH development were collected, also differences and similarities of DPH, Gobi protected horticulture and conventional protected horticulture were compared, highlighting the technology strategies for DPH sustainable development around Taklimakan desert. Finally, DPH, as a feasible and successful agriculture pattern, can be used in many countries worldwide where with similar eco-environment and social developmental problems.

Keywords: Desert protected horticulture; Oasis agriculture; Non-arable land; Eco environment; Soilless culture

INTRODUCTION

As one of crucial staple agricultural product, vegetables are needed daily for everybody to maintain health by providing sufficient vitamins, minerals, crude fiber and carbohydrates etc. In cold winter and spring, fresh vegetable products had to be cultivated in facilities (e.g. all kinds of greenhouses, plant factory with artificial light and so on), called as protected horticulture or environmentally-controlled horticulture. In China, vegetable production in facilities originated from 1980's in Liaoning province and the planting acreage climbed fast in past several decades for its higher economic efficiency. It was reported that the total area of greenhouse horticulture of China has increased to 4 million hectares at the end of 2015 and will reach 5 million hectares in 2020 nationwide (report data from Tianlai Li Academician, Chinese academy of engineering), ranking always first worldwide. Today, protected vegetable mainly cultivated in Chinese Solar Greenhouse (CSG) in north China and plastic-

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covered tunnel in south China, while plant factory with LED light and multi-span greenhouse account for small percent. Nowadays, Chinese people can consume sufficient fresh vegetables all year around, which benefits from the sustainable development of the facility vegetable industry. However, the productivity of Chinese protected horticulture is low in terms of yield and quality due to soil cultivation with heavy fertilization and poor environmental factor control level [1-3]. Thus, in order to afford local market requirement, vegetable products are mainly produced and sold locally avoiding producing extra carbon footprint caused by transportation. For this reason, cultivated area of protected vegetables in China distributed sporadically, covering the substantial land proportion of whole country, even the arid land area, e.g. northwest China. Protected vegetable production has become an economical, cost-efficient and promising industry both past, present and future for China farmers for the heavy consumption in winter as important cash crops, so more and more grain field was transformed into protected vegetable field. Taking advantage of the protective function of the facility, combined with local natural conditions, many prosperous modified models of protected vegetable production have been developed on non-arable land in northwest arid area, e.g. Xinjiang and Inner Mongolia provinces.

MATERIALS AND METHODS

Developmental background of Desert Protected Horticulture (DPH) in Northwest China

Resource and environmental pressures for oasis agriculture in Northwest China: Traditional Agriculture (TA), *i.e.,* open-field farming, is facing great developmental dilemma, including resources limitation and environmental protection pressure with the continuous growth of population, urbanization and industrialization. For traditional agriculture, arable land resources are the most important necessary resources, following by proper climate, water, nutrient, labor and electric energy etc. In the past decades, with the rapid urbanization, industrialization, some arable land resources were gradually converted from agricultural use to industrial or residential us [4-6]. As a result, too limited food can be produced and provided due to lack of arable land to afford the increasing dietary needs of urban and rural residents through TA systems. Today, arable land shortage is a hot potato in China even worldwide, especially in some arid regions, e.g. Xinjiang, Gansu and Inner Mongolia provinces and so on. More seriously, oasis agriculture system where desert and Gobi borders upon or surrounds are confronted with gravely multiple agricultural resources problems (e.g. water, climate etc.) beside arable land shortage. It is well-known that arid desert or Gobi is unsuitable for open-field agricultural production, so restricted arable land is the major limiting factor for modern oasis agriculture development. Meanwhile, arable land shortage is also a worldwide issue in African and Asia countries. So, it is a crucial issue that an integrated technological and policy strategy should be established to deal with arable land shortage for future agriculture sustainable development in these areas.

Oases are special landscapes under arid climate and are modified by human activity, especially agricultural activity. Oasis is not only the most concentrated area of human activities in arid region but also the largest area where artificial disturbances occur at the regional scale. Owing to the increasing population pressure on the oasis agricultural environment, the degradation of the eco-environment in oasis is still continuous, thus arousing attention of the local government on the issue in regional sustainable development. As a typical oasis city, Hotan is distributed on more than 300 oases divided by desert. In the past 20a, population of Hetan city has grown greatly, from 1.5 million at 1995 to 2.26 million at 2014. Moreover, the population density has arrived at 12.23 people per km^2, which has exceeded the international standard of population density limitation of semi-arid area (12 people per km^2). More seriously, 95% population concentrated on less than 0.06 million km^2 oasis area. Therefore, population density of the oasis area has reached at 300 people per km^2. Population of Xinjiang province has grown greatly, from 4.33 million at 1949 to 20.1 million at 2005. Qi and Li pointed out that the agricultural landscape and environment have obviously changed with the population growing in this Jinta Oasis, resulting in transformation of agricultural landscape and serious land pollution. The reason is attributed to the fact that oasis usually takes up only 4%-5% of the total area of the region, over 90% of the population and over 95% of social wealth (e.g., farming products and rich in natural resources) are concentrated within the oases. Recent years, the increasing amount of fertilizer application caused severe degradation of agricultural environment (e.g., deteriorated the groundwater in the oasis) and environmental hazards for oasis derived truly from the population pressure and land-use changes. Long-term intensive farming under population pressure for oasis agriculture, arable land pollution became more and more serious by agrochemicals, industrial wastes and the derivatives. Wei et al., suggested that excessive irrigation and nitrogen applications resulted in substantial nitrate leaching into groundwater in intensively cropped oases in desert areas of Alxa, Inner Mongolia. Hu et al., developed an integrated modeling approach to compare policy incentives to reduce nitrate leaching. The modeling results show that there are "win–win" opportunities for improving farm profitability and reducing nitrate leaching. Hu et al., suggested that water scarcity and nitrate contamination in groundwater are serious problems in desert oases in Northwest China [7]. It is imperative to improve the water and nitrogen management in the desert oasis even through governmental policy. Liang et al., indicated that nitrate leaching decreased from 179 kg N/hm^2 to 86 kg N/hm^2 when irrigation quantity was reduced from traditional 830 mm to the recommended 625 mm [8].

Structure transformation of oasis agriculture in Northwest China: Oasis is a specific landscape that exists with deserts in arid regions, where the most concentrated area of human activities and artificial disturbances happen at the regional scale. Under the multiple pressures of population increase, arable land decrease, urbanization and industrialization, some tough agricultural derivative issues, *i.e.,* employment, food security, resource exploitation and efficient utilization and eco-environment protection etc., stand out. Under such circumstances, structure transformation of oasis agriculture is an inexorable trend for planting cash crops for higher benefits. In fact, there is a large amount of land resources (non-arable land) around the oasis which can be used *via* protected agriculture or indoor agriculture instead of open-field agriculture. Crops can be cultivated on land covered under facilities (mainly Chinese solar greenhouse, CSG), taking advantages of beneficial climatic resources (e.g. light, heat and so on), meanwhile eliminating adverse climatic factors (e.g. strong evaporation, infertile sandy soil, low temperature and sand storm etc.). So, in Xinjiang and Inner Mongolia provinces located at northwest China, Desert Protected Horticulture (DPH) and in Gansu province, Gobi Protected Horticulture (GPH) rose in the past decade, respectively. DPH and GPH tended to improve socioeconomic benefits of oasis agriculture and Gobi agriculture, reduce environmental impacts and employment pressure and meet dietary food needs under population growth pressure. In essence, different from open-field farming, land resources instead of arable land are necessary resources for modern agriculture (e.g. protected horticulture or indoor farming, such as plant factory with artificial light) supported by agricultural structures, modern soilless culture technology, environmental control and drip irrigation technologies.

DPH and GPH rising in Northwest China: Oasis agriculture and Gobi agriculture are strictly restricted with the sharp contradiction between arable land shortage and population and food requirement increases. Therefore, DPH and GPH are two effective ways to solve this contradiction. Gobi and desert are non-arable land as potential agricultural land, which is suitable for protected horticulture use instead of open agriculture. Nowadays, structure transformation of oasis agriculture is undergoing inevitably as described in Figure 1, which takes Hotan city of Xinjiang for example. DPH have developed greatly in Xinjiang and Inner Mongolia provinces of China, while GPH in Gansu province mainly. Nowadays, as a key feature, only CSG instead of glass greenhouse can be used in DPH and GPH, since CSG can maintain inner temperature above 8°C through its strong heat storage capacity (*via* thermal absorption of north, east and west walls of CSG, as well as soil and crops) without heating system, meanwhile enhanced heat preservation ability of CSG is realized *via* and insulating coverings.

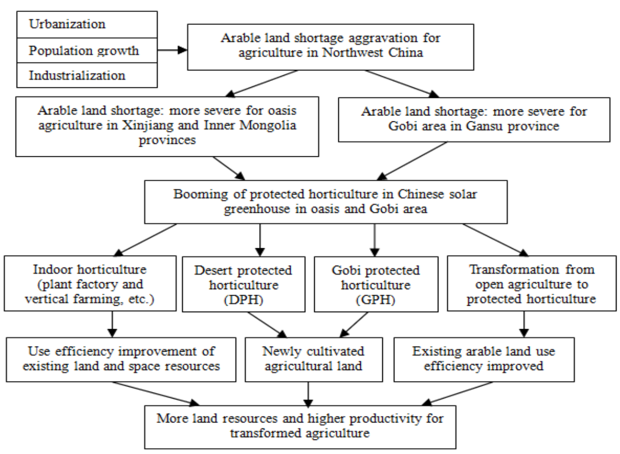

Figure 1: Generation and functions of desert protected horticulture and Gobi protected horticulture for structure transformation in Northwest China.

It is well-known that Taklimakan desert located at the south of Xinjiang province of China, which is the largest desert of China and second only to the Sahara desert in Africa worldwide, covering 337.6 thousand of square kilometers. On the edge of the desert, five prefecture-level cities (*i.e.,* Hotan, Aksu, Kashi, Artux, Korla etc.) and more than thirty county-level cities (*i.e.,* Alar, Hotan, Keriya and so on) are located. In recent years, scaled DPH in these cities has fast developed in their suburbs on land obtained through desert reclamation, which provided substantial economic output and labor employment for local residents. Likewise, GPH achieved great success in Gobi area around many big cities, such as Jiuquan, Wuwei in Gansu province. So DPH and GPH are two kinds of optimal solutions for arid circumstances to develop modern agriculture with limited arable land resource. Surely, no true normal soil but poor soil-like substrate coverings on Gobi and desert land, which is not competent for crop growth directly compared with real fertile soil. Therefore, some attempts and practice for using soilless cultivation were conducted, by which soil-like substrates act as cultivation auxiliary materials.

DPH and GPH emerging played a fundamental role in supporting regional development for a populated area with limited arable land resource, especially important for economically undeveloped Xinjiang and Inner Mongolia provinces. In summary, the fundamental functions for both DPH and GPH included agricultural land extension, employment enhancement and gaining more foods (mainly fruit vegetables). Globally, some agricultural patterns were established on desert or Gobi land in the past decades, also Xie et al., reported that Gobi protected horticulture status in Gansu province of China, highlighting that GPH was an innovative farming system that increases energy and water use efficiencies. In fact, there is a major difference between domestic and foreign models. Chinese systems (*i.e.,* DPH and GPH) depend solely on CSG, a kind of unique greenhouse invented by Chinese farmers.

DPH and GPH, as two feasible and successful agriculture patterns, can be used in many countries worldwide where some regions with similar eco-environment and social developmental problems. DPH and GPH are booming in Xinjiang and Inner Mongolia provinces, which is very meaningful for other provinces nationwide where similar situation exists. Xinjiang and Inner Mongolia provinces cover 1.66 and 118 million square kilometers, ranks the first and third largest provinces of China. Moreover, Xinjiang and Inner Mongolia possesses with the largest distribution of desert area. Truly, desert is potential land resource for human agricultural activity through soil amelioration. Well-established DPH and GPH farming systems could be replicated after certain modifications according to current situation of climate, ecology, social and economic development of target area. Finally, DPH is recommended as a feasible and successful agriculture pattern useful in many countries worldwide where some regions with similar eco-environment and social developmental problems. In this paper, current status, benefits, technological problems and coping strategies for DPH clean and environmentally-friendly production, eventually sustainable development around Taklimakan desert were collected and discussed, also differences and similarities of DPH, GPH and conventional protected horticulture were compared, highlighting the technology strategies for clean production and sustainable development of DPH.

RESULTS AND DISCUSSION

Conception and features of DPH

Conception of DPH: By definition, DPH is a kind of facility agricultural system located on desert adjacent to oasis, which generated from the transformation, extension and development of oasis agriculture under increasing multiple pressures of population, resources, environment and food security. Apparently, DPH was developed and established on desert land (non-arable land) to produce horticultural crops through unique CSG facility, modern cultivation and environmental control technologies. As protected horticulture, DPH has some inherent features listed as below. First, CSG is the major exterior protected construction; secondly, soil or soilless cultivation with drip fertigation is the major cultivation technologies; third, solar energy utilization for temperature regulation or control is key technological problems; fourth, clean production is a critical issue for DPH sustainable development. As a result, DPH system needs a lot of novel technology and governmental policy supports for clean production and sustainable development. That means that DPH is established on uncultivated desert land where traditional crop production is not possible. The negative external factors are screened out *via* CSG shielding, meanwhile novel cultivation technologies made it feasible to grow horticultural crops on desert land taking fully use of light resource. DPH facilities are constructed in "clusters" of individual production units. A typical clustered facility consists of several (up to hundreds even thousands) individual cultivation units (including CSGs and tool houses). Usually, production and living facilities are designed together in an orderly manner, which became a new part of city as new villages around oasis. Totally, as a novel agricultural form, DPH has greatly facilitated the development of oasis agriculture and oasis city together and comprehensively. Social, environmental carrying capacities of oasis cities had been improved, while employment, economic input and vegetable supply are becoming better. To sum up, DPH is beneficial both for farmer, company and government, even social and economic development.

Core facility and technology of DPH: Greenhouse type, environmental control and cultivation technologies are three fundamental and core features for DPH. First, CSG is the ideal facility type for DPH in the context of agricultural development domestic and overseas in terms of inner air temperature performance without exogenous electric input used in heating, cooling and so on. CSG is highly depends on solar energy, which is highly efficient absorbed by soil, north wall and plant biomass, then passive or positive stored and passive or purposely released at night. By above mechanisms, inner air temperature and soil temperature can be kept over 8°C, the lowest temperatures for normal growth of fruit vegetables. Therefore, CSG performs better in terms of solar energy use efficiency through unique north wall design and soil cultivation methods. CSG is very suitable for DPH for highly self-regulation in solar energy utilization, low cost and easy to operation. However, soil function in absorption and utilization of solar energy for DPH is reduced greatly since desert sandy soil is inferior to normal soil significantly in thermal buffer and capacity properties. Second, improved soil cultivation and soilless cultivation is usually adopted in DPH production. Apparently, there are many differences between conventional arable land soil and desert soil in terms of cultivation performance and productivity. Totally, high-efficient production with minimal environmental pollution is a target for DPH sustainable development based on the fragile ecological environment bearing capacity for human activity. Thus, cleaner production is highly required during DPH occurrence and future development. Finally, high-efficient environmental control technology for heating, cooling, lighting, etc. should be developed and used in DPH for sustainable development.

Similarity and difference between DPH, GPH and Conventional Protected Horticulture (CPH): DPH, as an innovative and promising farming system, derived from Taklimakan desert area, shows many differences and part similarities between GPH (distributed in Gobi area) and CPH (located in plain area) in terms of resources utilization, environmental protection, technological and policy requirements for sustainable development strategy. Practically, GPH, DPH and CPH facilities are constructed in "clusters" of individual production units, including mainly CSGs. Similarly, a typical clustered facility consists of several (up to hundreds even thousands) individual cultivation units, e.g. Chinese solar greenhouses and tool houses. Moreover, DPH rather than GPH and CPH, production unit "clusters" usually combines with domestic installation together, such as housing and roads, as well as commercial service facilities (e.g. shops, supermarkets, restaurants, etc.). Totally, the similarities and differences between DPH, GPH and CPH were listed in Table 1.

Table 1: Similarities and differences among desert protected agriculture, conventional protected agriculture and Gobi protected agriculture in China.

Items	Desert protected horticulture	Gobi protected horticulture	Conventional horticulture protected
Geographical distribution	Desert or oasis periphery, distributed in Xinjiang and Inner Mongolia provinces etc.	Gobi area, distributed in Gansu and inner Mongolia provinces etc.	Plain regions, such as Liaoning, Hebei and Shandong provinces etc.
Climatic condition	Large evaporation, small rainfall, good light, large diurnal temperature variation, frequent sandstorm weather	Large evaporation, small rainfall, good light, large diurnal temperature variation, frequent sandstorm weather	Suitable evaporation, rainfall, water retention capacity and diurnal temperature variation, less sandstorm weather
Soil quality	Non-arable land: Infertile sandy soil	Non-arable land: Infertile mixtures of sand and stone	Arable land: Fertile soil
Water supply pattern	Mountain snow melt water, sufficient	Remote water collection, scarce	Well, sufficient
Cultivation method	Sandy soil cultivation or soilless cultivation with drip irrigation	Soilless cultivation with drip irrigation	Soil cultivation with drip irrigation or furrow irrigation
Nutrient application	Fertigation technology and drip irrigation	Fertigation technology and drip irrigation	Solid fertilizer or organic manure plus furrow irrigation or fertigation technology of drip irrigation
Sustainable developmental potential	Moderate	Low	High
Adversity conditions	Low temperature, infertile sandy soil, sand blowing weather	Low temperature, water stress, sand blowing weather	Low temperature, continuous cropping obstacle, overuse of agrochemicals
Electric supply	Adequate	Scarce	Sufficient
Agricultural foundation	Well-developed oasis agriculture	No open-field agriculture	Well-developed open-field agriculture
Distance from city	Close	Far away	Not always
Developmental power	Government planning and funding	Farmer spontaneous	Farmer spontaneous
Developmental target	New village or town with production and living functions	Agricultural production system	Agricultural production system

To meet the food production, protected horticulture instead of traditional agriculture emerged in the past decade located in the desert area extended from suburban areas around Taklimakan desert. Protected horticulture has many advantages over open agriculture, e.g. without strict demands on temperature and arable land *via* greenhouses, high economic income, no suffer from general natural disasters, such as drought, water logging and cold and heat stresses. Desertification plundered arable lands before, nowadays, people are seizing them back from desert and Gobi take advantage of advanced technologies in forms of DPH and GPH production systems. Open field agriculture is not feasible on desert land to grow crops for fluidity of sandy soil under strong wind, also strong evaporation and low temperature in the cold winter. However, the growth situation will become much better under facility coverage (e.g. CSG), because the ecological problems mentioned above are solved and what's more important, vegetables could be produced year-round in CSGs. Generally, more novel soil cultivation technology should be developed to save agro-resources and alleviate environmental release and pollution. Moreover, novel substrate cultivation method was invented to achieve above-mentioned targets. However, establishment and sustainable development of agriculture needs occupied many resources, including arable land, irrigation water, labor and suitable environmental conditions (e.g. light, temperature, etc.). Spatiotemporal utilization efficiency of the existing land or arable land was improved significantly. Meanwhile, extended land developed from desert is high-efficiently used *via* protected horticulture.

Although the lands of desert and Gobi are all called as non-arable land, not suitable for open-field agricultural use, desert land has potential to be converted into arable land with long-term cultivation and high cost. Compared to GPH, DPH has three important inherent advantages. First, desert sand is soil-like medium with similar physicochemical properties, called as desert sandy soil. So, desert sandy soil can be used as cultivation medium for plant growth in greenhouse directly. Second, GPH usually were constructed at the Gobi area which is far away from city, while DPH usually located at the edge of the oasis city. So, some resources, like electric energy, transportation, sales market etc. are more very convenient and closer than GPH. Third, DPH were established in large scales under the guidance and funding of the government, while development of GPH is spontaneous activity by farmers. Therefore, DPH is more meaningful, influential and fruitful in future with powerful executive force, especially in Xinjiang.

Current status, benefits and favorable and adverse factors of DPH development around Taklimakan desert

Current status and benefits of DPH development around Taklimakan desert: DPH is a feasible way to enlarge agricultural size and satisfy food security under increasing pressures from arable land shortage, derived from Taklimakan desert area. Taklimakan desert is the largest desert in China, situated in the south of Xinjiang province. Taklimakan desert coverage is about 330 thousand of square kilometers. Moreover, there are five prefecture-level cities (*i.e.*, Korla, Aksu, Atush, Kashi and Hotan) and more than thirty county-level cities around the edge of the desert with increasing population. These cities are called as oasis cities with limited arable land. However, desert land can be theoretically converted into arable land after many years' soil amelioration and farming. However, DPH can transform desert land into farming land quickly by means of CSG and drip fertigation technology. Take Hotan city as example, it locates on the southern edge of Taklimakan desert. Recent years, DPH has rapidly developed up to thousands of hectares. Meanwhile, a lot of newly built villages were appeared, where many vegetable-growers, both locals and outsiders, settled there and engaged in facility vegetable production.

It is estimated that about 200 thousand DPH units have been constructed up to now around Taklimakan desert and the number is still increasing rapidly. Today, multiple derivative types of CSGs with various materials have been designed, constructed and applied, which performed differently in terms of space, diurnal temperature (particularly night minimum) and eventually productivity. Usually, soil-ridged cultivation in winter and ditch planting in summer with soil or substrate inserted in soil with plastic film are popular in DPH. Naturally, drip irrigation and even drip fertigation technology has been extensively used in DPH. Main fruit vegetable species includes cucumber, tomato, pepper, muskmelon, eggplant, and so on are dominant horticultural plants. The annual maximum yield has climbed to 45 $kg.m^{-2}$, while annual average yield is about 20 $kg.m^{-2}$-30 $kg.m^{-2}$, depends on CSG type, cultivation method, environmental control technology and management level of the growers. Nowadays, only in Hotan city, many specialized villages named as Hexiexin villages, Rongxin villages and Heanxin villages and so on were constructed, engaging in DPH. After years of practice in Hetan city, some mature DPH models have been established gradually, which were used efficiently, promoted continuously. DPH models are extending to more places with similar conditions. However, more novel technologies should be adopted to support sustainable development for DPH.

DPH is an optimal choice for oases agriculture development in Xinjiang and Inner Mongolia provinces and so on, which is a win-win solution under increasing population pressure because vegetables produced off-season from DPH can gained a high selling price. Thus, growers can gain higher economic returns. DPH is highly depended on CSG structure, novel cultivation and irrigation technology and novel environmental control methods and innovations are undergoing. CSG structure is low-cost with efficient heat absorption and storage capacity to afford basic temperature condition. CSG is very suitable for DPH for highly self-regulation in solar energy utilization, low cost and easy to operation. Update, it is postulated that DPH will developed rapidly and vigorously in next decades. Through the facility horticulture industry, the skilled population and company will come and settle in oasis area.

Multiple benefits of DPH development around Taklimakan desert: There are many benefits for DPH development around Taklimakan desert with CSG for oasis city and agriculture in China. These benefits include: (1) Urban expansion, (2) Agricultural land extension, (3) Employment increment, (4) Local food security improvement, (5) Economic development and social stability and (6) Successful structure transformation of oasis agriculture, (7) Increased soil carbon, water and nutrient pool size and use efficiencies. Moreover, DPH effectively improves solar energy utilization efficiency yearly round and made use of abundant desert land resource.

Favorable factors for DPH development around Taklimakan desert: There are many favorable traits for DPH development around Taklimakan desert with CSG for oasis agriculture in China. These favorable traits include: (1) Partly suitable climatic factors (light source and diurnal temperature variation), (2) Abundant desert land without pollutants, (3) Enough mountain snowmelt water resources; (4) Abundant labor resources, (5) Huge vegetable market, (6) CSG production technology maturity, (7) social demand and government support for structure change of oasis agriculture. In addition, DPH development around Taklimakan desert with CSG for oasis agriculture is inevitable trend since open agriculture is not feasible under non-cultivated soil and desert climatic conditions. DPH provides fresh vegetables, as cash crops, can bring higher income than traditional grain crops. Moreover, desert sandy soil is suitable for drip irrigation in CSG for vegetable production with less pollutant, loose and easy to turn and small incidence of continuous cropping disorder and diseases (Figure 2). Taking above advantages into consideration, DPH is currently feasible and promising in realizing clean production without discharging agrochemicals and wastes by precise management, recycle utilization based on clean desert soil and desert environment which contain few pollutants both in species and quantity naturally. Therefore, sustainable development is an achievable via strict control of production processes, *i.e.*, clean production.

Figure 2: Numerous CSGs of DPH in two villages of Hotan city.

Adverse factors for DPH development around Taklimakan desert: Currently, there are some adverse factors faced by DPH development and the most remarkable problems are poor soil quality and water quality. First, CSG construction and vegetable production on desert sandy soil is more difficult than true soil. Infertile and salinization desert sandy soil is not suitable for growing vegetables since poor holding capacity of water and fertilizer. Thus, novel technologies should be adopted to protect ground water from nitrate and phosphorus pollution by leaching. Low temperature problems of root-zone and canopy should be avoided. To summarize, poor physicochemical properties of desert sandy soil is the most prominently adverse problem for DPH development (Figure 3). Generally, drip irrigation is dominantly and popularly used to prevent water and nutrients leaching out root zone into ground water. Second, sandstorm often endangers DPH production severely. Third, bad quality of underground water and low farmers' technical skills are serious shortfalls. Finally, governmental stable policy and financial support is highly depended on and cost-benefit ratio of DPH should be greatly reduced.

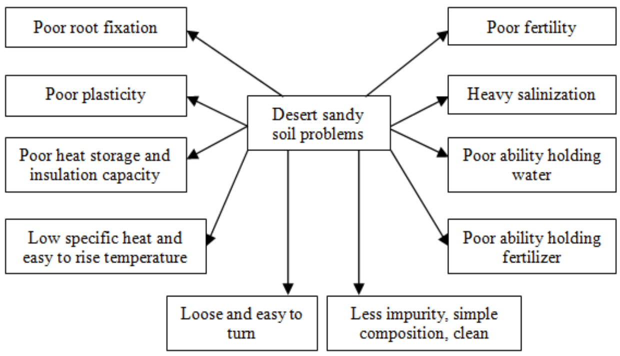

Figure 3: Problems of desert sandy soil properties for vegetable production of DPH.

Resource, eco-environment and environmental control problems for DPH sustainable development around Taklimakan desert

Resource problems for DPH sustainable development: There are serious resource problems for DPH development around Taklimakan desert with CSG for oasis agriculture in China. These problems include (1) Ground water quality problems for high pH and EC, (2) Desert sandy soil fertility problems for poor physicochemical properties, (3) CSG low temperature stress in winter night, (4) Shortage of agricultural production skills of labor force, (5) Timely favorable policy-making by government and (6) Optimized design of CSG for more efficient use in DPH. Truly, as novel agricultural system, DPH is different from traditional facility agriculture in resource utilization. Thus, a series of technologies should be applied to overcome disadvantages and take fully use of advantages in practice. Better performance of DPH systems based on high-efficient utilization of all related resource factors. For example, CSG is very suitable for DPH for highly self-regulation in solar energy utilization, low cost and easy to operation. However, CSG structure design for enlargement, particularly north wall design for high heat absorption and storage is being studied all the time. In addition, how to improve use efficiency of water and nutrient under the premise of high yield is another issue is being worked on.

Environmental pollution problems for DPH sustainable development: Higher pollution risk of soil, ground water and vegetables by pesticides, nitrate, phosphate, antibiotics, heavy metals, antibiotics and so on for DPH in view of long-term practice of traditional protected horticulture in north China due to special soil properties and technology adopted. First, nitrate leaching is the upmost pollution for ground water for DPH because of heavy dose of fertilization, irrigation and higher ground water level. These serious potential environmental pollution problems should be avoided during DPH development around Taklimakan desert (Figure 4). In some areas of China, famous for concentrated vegetable production, ground water and soil were polluted by many pollutants (e.g. nitrate, pesticides, heavy metals etc.), also a large quantity of N_XO gases (e.g. N_2O and NH_3) were released during vegetable cultivation since misuse or overuse fertilizer and water, pesticides and other chemicals. For DPH system, it is cleaner and purer for desert sandy soil than common soil without too much exogenous pollutants. Clean production is one of main target and essential advantages for DPH sustainable development. Clean production means that pollutants should be strictly controlled and forbidden to introduce into greenhouses or to release outside in practice. Therefore, nitrate and phosphate pollution through leaching and runoff, N_XO and NH_3 release for air pollution, also heavy metals and pesticide pollution to vegetables are three aspects for environmental pollution problems.

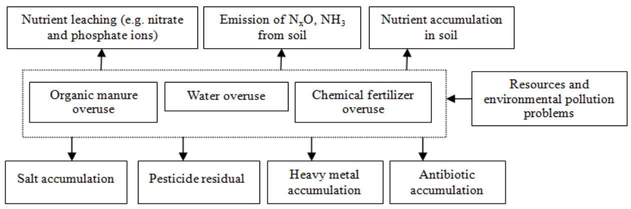

Figure 4: Resources and environmental problems for vegetable production of DPH.

It is a challenge for DPH to prevent ground water pollution due to poor physicochemical properties of desert sandy soil. Two technologies should be developed to alleviate pollutants introduction by reasonable fertilization and irrigation. One is the drip irrigation with suitable frequency and intensity in terms of vegetable growth during different stages to avoid leaching outside root zone. The other is to adopt soil-ridged and Substrate-embedded Cultivation (SSC) and Ditch Substrate-embedded Cultivation (DSC) methods to block leaching of nitrate, phosphorus and water with plastic film [9]. Meantime, pesticide, organic manure should strictly use to control accumulation of pesticides and their derivatives, antibiotics and heavy metals. In addition, reasonable nitrogen fertilization and nitrification inhibitor and biochar should be used to reduce emission factors of N_2O [10,11]. Therefore, the soil N_2O emission from oasis farmland could be reduced by properly prolonging the time interval of drip irrigation and fertilization. Notably, protected vegetable and organic vegetable production systems, as public health closely related agro-ecosystems, are susceptible to antibiotic contamination. Xie et al., found that ciprofloxacin, enrofloxacin and norfloxacin mean concentrations in surface soil were up to 105.8 μg/kg, 18.6 μg/kg and 55.7 μg/kg, respectively. The estimated means and error variances of the three antibiotics changed within soil sub-regions stratified by plant type.

Ecological problems for DPH sustainable development: There are some ecological problems for DPH development around Taklimakan desert with CSG for oasis agriculture in China. These ecological problems include (1) Ecological protection outside greenhouse by planting vegetation and (2) Indoor ecological protection of greenhouse by environmental management. Desert is fragile ecosystem with frequent sandstorm occurrence yearly. Frequency and intensity of sandstorm may tend to strengthen under human disturbance for greenhouse construction of DPH. Sandstorm is very harmful for DPH through damaging greenhouse structure and reducing solar light intensity and film transmittance. Inner greenhouse, fugitive dust from cultivation soil can pollute surface of vegetable leaves and fruits which will sharply decrease photosynthetic capacity and fruit quality (Figure 5). Therefore, ecology problem is very serious and key problem faced by DPH. Dust removal from greenhouse film-covered and leaves and fruits of plants was proposed as an important technology needed in practice. Dust deposition on greenhouse film decreased light transmittance greatly, meanwhile dust deposition on leaf surfaces even fruits impacted the growth and physiological traits of plants, both vegetable and crops [12]. Li and Mu investigated short-term effects of light surface dust on photosynthesis of cotton in the Tarim Basin using chlorophyll fluorescence and gas-exchange techniques. High irradiance at noon reduced actual quantum yield of PSII and increased nonphotochemical quenching for leaves without dust, showing photoinhibition. It suggested that light surface dust alleviated photoinhibition of cotton to high irradiance on a short-term basis. For the leaves without dust, high irradiance induced photoinhibition not only with respect to the photochemistry reactions but the biochemical pathways of CO_2 fixation. Mechanisms such as thermal dissipation and enhanced electron flux to PSI protected the photosynthetic apparatus under high irradiance. Ma et al., investigated the effects of dust retention amount of screw pepper and tomato the leaves on leaf photosynthetic physiological parameters and light response curve, also the correlation between the photosynthetic and physiological characteristics of leaf and leaf dust quantity were also analyzed in Zepu County near Taklimakan desert, Xinjiang. The result showed that photosynthetic parameters of tomatoes and peppers were decreased under the presence of dust and the loss rate of net photosynthetic rate of tomato are greater than that of chili peppers significantly. The tomato leaves the Light Saturation Point (LSP) and Light Compensation Point (LCP) in the influence of dust than that in the clean increased significantly and under the influence of dust, the Light Saturation Point (LSP) of screw pepper leaves increased slightly and the Light Compensation Point (LCP) decreased slightly, indicating that the effects of dust change the ability of tomatoes and peppers to adapt to light. Dust covered leaves can improve the ability of tomatoes and screws to make use of light and reduce the utilization of weak light.

Figure 5: Soil cultivation tomato with drip irrigation for DPH in Hotan city, Xinjiang.

Environmental control problems for DPH sustainable development: Environmental control inner CSG is fundamentally important for high-efficient production for vegetables. Currently, there are serious environmental stress problems for DPH production around Taklimakan desert with CSG for oasis agriculture. First, chilling injuries of root and canopy of vegetables resulted from low night temperature occurred frequently in winter since diurnal temperature in CSG and sandy soil varied sharply. CSGs have good heat absorption, storage ability through north wall, soil, crop during daytime and heat insulation capacity *via* heat preservation quilt at nighttime. However, nowadays, almost entire thermal transmission process (heat absorption, storage and release) in CSG system are passive which is beyond human control due to technology and equipment shortage. Thus, Indoor diurnal temperature change of CSG is far away from the optimal requirement for vegetable growth. There are even chilling injury caused by extreme low temperature (below 8°C) at early morning for stored heat dissipated totally. Furthermore, chilling injury tends to be more serious for DPH because sandy soil is poor in heat storage due to smaller specific heat than clay soils of north China. (2) CO_2 concentration shortage is a limitation for high productivity. CSGs are semi or air-tight systems which presented sharp decrease in CO_2 concentration during daytime due to photosynthetic consumption and without in-time supplementation. However, it is not feasible to be supplied inner CO_2 concentration through introduction of outdoor cool air method which will result in temperature sharp decrease of inner air. Usually, soil mineralization of organic matter is an effective method to release and supplement CO_2 gas. However, low organic matter content of desert sandy soil can't afford sufficient CO_2 gas, so it is important to add organic fertilizer to the soil artificially. (3) Weak light and short light are common environmental factors suffered by DPH. In winter, light duration becomes shortened and light intensity becomes weakened, which tends to be more seriously especially when cloudy, snowy and sandstorm weather happen. (4) Low root-zone temperature stress is another environmental deficiency for DPH in practice. Proper root-zone temperature is equally important to or more crucial than canopy temperature (air temperature). In CSG, changes of root-zone temperature and air temperature correlates linearly generally, but the former lags behind the latter temporally. Furthermore, spatiotemporal changes and diurnal fluctuation characteristics of root-zone temperature are strictly influenced by soil type, soil water content, position at ridge or furrow, etc. Nowadays, some root-zone heating methods had been put forward by strengthening utilization of solar energy through innovation design of CSG north wall and invention of novel cultivation method called as SSC and DSC methods. Maybe, large scale CSG will be designed and constructed specially for DPH with well-equipped devices to regulate environmental factors related to growth and yield of vegetables.

Technology strategies for DPH sustainable development around Taklimakan desert

Overall, a lot of novel technologies must be integrated together into CSG unit in order to attain long-term good performance of DPH, *i.e.,* high vegetable productivity without harmful eco-environmental impacts. Totally, novel technologies, including soilless cultivation and drip fertigation, soil fertility promotion, green environmental control, CSG structure innovation, and automatic management etc. should be developed and adopted. Among them, some technologies are problems peculiar to DPH. Surely, these technologies have been researched and developed nationwide in many related institutes and universities during recent years aiming at solving totally the problems of vegetable production in CSG. After perfect application these novel technologies, productivity of vegetables will be promoted greatly with high-efficient resource and energy use efficiencies and high-level environmental control inner CSG according to plant growth requirements. Moreover, agrochemicals input into CSG will be intensively used and pollutants released from CSG will be sharply decreased or disappeared. In summary, an integrated technology strategy for sustainable development of DPH around Taklimakan desert should be developed, which will support the development idea of high efficiency and low pollution. Here, we collected some related novel technologies nationwide in the past decade and summarized how to use them in DPH effectively (Figure 6).

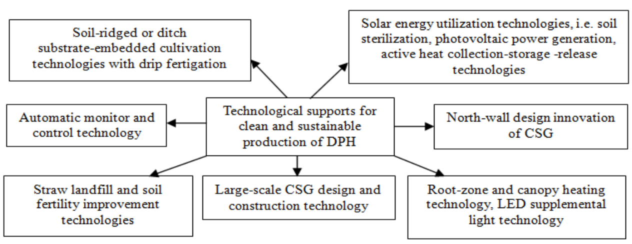

Figure 6: Technological strategies supporting clean production and sustainable development of DPH.

Novel soilless cultivation methods: Two kinds of novel soilless cultivation methods had been put forward, called as SSC and DSC methods (Figure 7). SSC and DSC were regarded as optimal methods for improving fruit vegetable productivity in winter and summer seasons respectively based on their root-zone temperature features regulated by soil-substrate continuum varying heat absorption and storage capacity [13]. Three innovation points can be concluded about SSC and DSC methods apparently. First, leaching of nutrients (particularly phosphate and nitrate) and water out of root zone are effectively blocked by inserting a plastic film into the ditch to separate soil and substrate entirely vertically. Substrate is filled into the plastic film embedded into the ditch and plants are transplanted into substrate. Importantly, two lines of holes (diameter 2 cm, 5 cm-10 cm distance depart from each other) are made along the both sides close to the bottom (3 cm-5 cm distance) of the inserted plastic film to exchange oxygen between soil and substrate. Second, a plastic film is used to cover the soil ridge or ditch entirely to keep the heat and water in the substrate and soil continuum. Third, drip fertigation is used to supply water and nutrient quantitatively according to nutrient and water requirements of vegetables as well as season factor. Totally, SSC and DSC are root-limited and semi-closed substrate culture with precise drip fertigation characterized of three obvious advantages. First, input of water and nutrient are quantitatively by fertigation technology in order to avoid over use and film packed substrate interdicts them leaching out root zone. Thus, ground water pollution resulted from leaching of soil nutrients and pollutants have been solved using SSC and DSC technologies. Second, substrate-soil ridge performs better than soil ridge or single substrate in diurnal heat absorption, storage and release with aid of covered plastic film. Third, clean production and automatic management will be realized after adoption of SSC and DSC methods.

Figure 7: DSC technologies for strawberry and tomato in Hetan city, Xinjiang.

In DPH, SSC and DSC methods successfully overcome the disadvantages of desert sandy soil in fertility, holding water and fertilizer capacity and heat storage and insulation capacity etc. Also, the risk of environmental pollution has been sharply reduced through drip irrigation and film block design in SSC and DSC methods. Update, many reports had evidenced that SSC could improve yield of sweet pepper compared with conventional soil ridge cultivation method. In addition, SSC could be used both in winter and summer in CSG through exchange between transparent plastic film and reflective film to increase root-zone temperature nighttime or decrease midday root-zone temperature. By this, root-zone temperature buffer capacity is greatly improved to avoid injuries caused by high or low temperature in summer and winter. More importantly, SSC breakthroughs the long-term limitations that soilless cultivation is unfeasible in CSG due to sharp change in air and root-zone temperature. It is suggested that SSC should be used to deal with current difficulties existing in soil cultivation based protected horticultural production of China. That means soil cultivation will be replaced by soilless cultivation method based on the success experience of Netherland, Japan and Israel in environmentally controlled horticulture. SSC is a crucial technology for realization the transformation of soil cultivation and soilless cultivation without abandoning CSG in current stage. Many works should be conducted to optimize SSC and DSC methods, e.g. substrate composition, N_2O emission, mechanized operation and management strategy and so on.

Soil fertility improvement technology: Poor soil fertility and structure problems of desert sandy soil for DPH are very critical problem in case of soil cultivation vegetables. In order to increase vegetable yield, fertility of desert sandy soil should greatly be improved in many years. First, organic matter content should be increased by using organic manure and straw substantially and consistently. Organic manure, straw and plant root secretes contribute soil organic matter accumulation effectively and proper organic matter content in soil favors the formation of healthy microflora and soil structure. Although soil fertility improvement is a long-term process with heavy investment, soil cultivation for DPH will last many years. Su et al., suggested that after natural desert soil was cultivated for agricultural use, significant changes in element concentrations occurred under tillage, irrigation and fertilization management. Compared to natural soil, the levels of 17 elements increase in agricultural soil from 1.2 to 3.5 times.

Novel north-wall design technology of CSG: North-wall is an important medium for CSG heat buffer through diurnal absorption and release solar energy. In order to improve the CSG night temperature, good heat storage and insulation capacity of north-wall is crucial. In the past decade, based on the effective storage heat thickness of soil-made north wall, the thickness of soil-made north-wall experienced constant attenuation for CSG, which had reduced from several meters to dozens of centimeters. Moreover, material species and structure for north-wall construction became diverse aiming at well heat absorption and storage. The consensus is that three main innovations were put forward and popularly used in north wall design. First, two layers structure from outside to inside north-wall, including heat insulation layer and heat-absorption layer, were designed to improve north wall heat absorption and storage capacity itself. Second, some equipment with active heat absorption and storage capacity were developed to maximize the solar energy quantity stored in CSG when the solar energy arrived the north wall exceeds the heat absorption and storage capacity at noon. Generally, the equipment absorbed and transferred solar energy continuously into heat stored in water medium, then transported and stored in a water tank. During night, the stored heat was released through water reversely flow into the air or soil. In DPH, a kind of efficient and cost-effective equipment was used in CSG as active heat absorption and storage capacity (Figure 8). Third, some novel north wall structures with assembled active heat storage function for Chinese solar greenhouse was developed and they performed better thermal function than traditional one [14].

Figure 8: Interior view of typical CSG for DPH in Hotan city, Xinjiang.

Active heat collection-storage-release technology: Low temperature stress is universal problem for DPH production due to CSG limited heat buffer capacity to exterior extreme low temperature. So, novel green, clean heating technology using solar energy or shallow geothermal energy is urgently developed instead of burning fossil fuels. Heat pump heating system and active heat storage-release system were put forward to utilize ground water heat and solar energy daytime and stored solar energy into water in an insulation water tank, then released the heat when the air temperature is lowest at night. Today, shallow geothermal energy utilization is expensive and unfeasible for DPH rather than multi-span greenhouse. The active heat collection-storage-release technology was purposely invented to heat CSG with low electric energy consumption and high-efficient use efficiency of solar energy. Generally, the active heat collection-storage-release system is composed of four parts, heat collector, ground water pool, air radiator or root-zone radiator, running by sinking pump and controllers.

Different collectors hanging on the north wall of CSG were developed to gather solar energy with different heat collecting efficiency and the collected heat was stored into adiabatic pool *via* water transportation continuously or into the specific-design north wall *via* air transportation during daytime. At night, stored heat could be released through collectors *via* water transportation or release from north wall directly. The former is easy to control the duration of heat collection and release. So, the heating process is active not passive. Three heat transfer modes, heat conduction, heat radiation and heat convection, occur in CSG across the exterior protected constructions. Two kinds of heating modes are using, *i.e.*, air heating and root-zone heating (substrate or soil). It is reported that the latter is more efficient in improve growth and yield of tomato and root-zone temperature compared with air heating in Chinese solar greenhouse [15,16]. Nowadays, cost-benefit of the active heat collection-storage-release technology has greatly improved and active heat collection-storage-release systems had been installed in many CSG for vegetable heating in winter.

LED supplemental lighting and photovoltaic technology: Light environmental factors, for instance, light quality, light intensity, photoperiod and duration determined plant growth, photosynthesis and yield cultivated in both plant factory with artificial light and in greenhouse. For DPH, light condition in CSG is fluctuant and composed of alternating light and dark. Also, light is depended highly on the weather changes and light transmittance of greenhouse coverings. Usually, weak light and short illumination time occurred under cloudy, snowy, rainy and sandstorm weather, as well as haze pollution, which will be more serious when plastic film has been aged or polluted. More seriously, the heat preservation quilt covered on CSG was prohibited to unfold when weather is bad. Darkness in CSG over more than one day will endanger the heath of plants greatly. Therefore, supplemental light is necessary for DPH in winter. It is suggested that LED supplemental lighting and photovoltaic technology should be integrated and used in DPH for high-efficient use of electric energy transformed by photovoltaic power generation. Specially designed LED lamps for supplemental light can emit a specific spectrum containing high-efficient wavelengths (e.g. red light and blue light) for plant photosynthesis and photomorphogenesis. Chen et al [17] showed that light transmittance rate of visible light for glasshouse at October was about 88.0%. Meantime, UV transmittance rate was 15.9% to 21.1%. Therefore supplemental light either visible light or UV light is beneficial for vegetable growth or quality improvement in greenhouses. Du et al., compared the light transmittance of different plastic films of Chinese solar greenhouse of Xinjiang province, finding that new PVC, PE and EVA films showed 68% to 78% transmittance [18]. Photovoltaic technology can integrate with LED supplemental light technology with economic benefits. Solar energy with wide wavelengths will be transformed into electric energy, then LED supplemented the plant in greenhouse with high-efficient light wavelengths, e.g. red light plus blue light. By this, sunlight was transferred temporally *via* LED lamps.

Straw landfill fermentation technology: Straw landfill fermentation technology is feasible for DPH based on its advantages for soil physical environment and soil fertility benefits and CO_2 emission for vegetable high-level photosynthesis. For the high-level air tightness, it was approved that CO_2 deficit occurs in CSG during 10:00 to 16:00 the daytime to different extents. CO_2 deficit will substantially reduce net photosynthetic rate inevitably and yield decrease is the cumulative effect. One of the benefits of straw landfill fermentation technology is to elevate soil temperature during fermentation which could reduce root-zone low temperature damage on vegetable in winter. The second benefit is to improve organic matter content, even microbial abundance and eventually soil fertility. Finally, the other benefit of straw landfill fermentation technology is to produce CO_2 gas during fermentation acting as vegetable carbon fertilizer. Bian et al., [19] studied the effects of the outer type straw reactor on environment factors and tomato photosynthetic performance. The data indicated that the net photosynthetic rate, water use efficiency, the transpiration rate of color turning period and fruit bearing period increased significantly, transpiration rate at seedling stage also reduced significantly. Yield and economic benefits improved 13707 kg/hm^2 and 59310 $yuan/hm^2$. Bian et al. [20], studied the effects of outer type and built-in type straw bio-reactors on the CO_2 concentration, air relative humidity and air vapor pressure deficit in the solar greenhouse during the tomato growth over autumn-delayed cultivation as well as the effects of the bio-reactors on the tomato growth and photosynthetic performance. The results showed that both the outer type and the built-in type straw bio-reactors promoted the tomato plant height growth and early flowering, enhanced the plant net photosynthetic rate and the yield per plant and per unit area significantly, and decreased the plant transpiration rate at the stages of vegetative growth and fruit-bearing significantly.

The combination of straw landfill fermentation and SSC is more valuable in productivity improvement. Yang et al., investigated the effects of mixtures landfill treatments in the furrow of soil-ridged and substrate-embedded cultivation of corn straw and tomato straw with chicken manure at different ratios on root-zone temperature and CO_2 release of tomato. Compared to the control (no straw landfill), tomato straw with chicken manure at 6 and corn straw with chicken manure at 8 were the best for promoting root-zone temperature and CO_2 release dose. Yang et al., investigated the effects of rice, corn, tomato and cowpea straws landfill in the furrow of soil-ridged and substrate-embedded cultivation on root-zone temperature and soil CO_2 release of tomato. Compared to the control (no straw landfill), four kinds of straw landfill improved the root-zone temperature and soil release flux. Among them, tomato straw landfill treatment performed best. Therefore, integration of tomato straw landfill technology and soil-ridged and substrate-embedded cultivation technology is more beneficial for DPH production.

CSG solar smothering technology: Soil continuous cropping obstacles often occur after long-term planting the same vegetable species in CSG, bringing frequent occurrence of insect pests and plant diseases. Thus, a lot of pesticides were overused to reduce the damage caused by biological diseases. However, misuse of pesticides will degrade vegetable quality and pollute soil *via* residuals in the edible parts of vegetables and soil. Nowadays, many pesticide species could be detected in soil, vegetable, groundwater in or around CSG nationwide of China. In view of this, safe, low-cost, green soil disinfection technology with solar energy was developed, called as CSG smothering technology. Generally, CSG smothering technology was conducted in summer during the planting gap when no vegetable were growing due to daytime high temperature. The method is described as below. First, the covering film of CSG should be closed tightly daytime to increase air temperature and the soil should be covered by plastic film and ploughed drying directly. The duration will last several days even a month. High-temperature in CSG and soil body will kill many bad microorganisms and degrade some allelochemicals. CSG smothering technology is physical and environmentally-friend method without harmful impacts on soil fertility and vegetable quality. Meanwhile, CSG smothering technology does not consume electric energy and disturb production. Today, CSG smothering technology has been widely used nationwide, especially in North China.

Root-zone and canopy heating technology: Root-zone heating and canopy heating technologies are effective methods to overcome chilling stress through heating up a specific small space precisely, which is a key way to realize energy-saving during vegetable cultivation in greenhouse. Root-zone heating technology is suitable for DPH due to the sandy soil is loose and easily flipped. Fu et al. [21], found that root zone heating and LED supplemental lighting were beneficial for improving fruit yield of sweet pepper. The interaction of root-zone heating and LED supplemental lighting was more obvious. Also the effect of root-zone heating on the growth and yield of sweet pepper was more obvious than that of LED supplemental lighting.

Automatic monitor and control technology: Microclimatic conditions, such as air temperature and humidity, can be adjusted in some cultivation units, while other monitoring systems allow automatic fertigation. Some advanced technologies such as the internet of objects or internet of things can be installed in the control center to provide more accurate readings of the microclimatic data transmitted from individual cultivation units. More importantly, soil, ground water and substrate properties, such as nutrient content, EC and pH etc., should be monitored to avoid environmental pollution, also to ensure food safety.

Government policy strategies for DPH sustainable development around Taklimakan desert

DPH development around Taklimakan desert is a complex engineering dominated by the government and farmers, even firms which is composed of landscape design, agricultural planning, agricultural structure construction, road and greening design, water pipe system installment, labor resettlement and power supply system etc. In fact, DPH had driven some new village construction on desert around oasis with production and living functions. Governmental policy always plays fundamental roles throughout the formation, development and prosperity of DPH. Government policy supports comprehensively during DPH development *via* land planning, infrastructure construction (Water and electric energy supply), financial support, tax policy, labor policy and so on. A series of consistent governmental favorable policies is precondition for DPH development in large scales. Moreover, sustainable development for DPH in future is closely related to government policy support, particularly in innovation, promotion and application of new technologies. Moreover, governmental policies about infrastructure, communal facilities construction, household registration policy, business policy, land policy, environmental protection and sales marketing development are closely related to DPH development in land, labor, social conditions should be incentive and helpful.

CONCLUSION

DPH is a novel and promising agricultural system with many technology and policy innovations to successfully deal with burgeoning population and arable land shortage in oasis areas in China. This system is playing a vital role in ensuring food security, increasing socio-ecological sustainability and enhancing rural community viability by exploiting desert land surrounding oases. DPH will be sustainable by clean production through adopting specialized technologies and governmental policy to use agrochemicals and energy efficiently. In future, hard works should be continuous for DPH sustainable development in technology research and policy making. Main targets in DPH technology advancement is to increase crop productivity, improve resource use efficiency (water, land, energy, nutrients and labor force etc.), promoting environmental control level with more eco-environmental benefits and rural community stability. Core technological features for DPH include CSG, cultivation and irrigation technology and novel environmental control methods should highly be improved. Policy aspect is a big challenge. Governments should set specific policies for sustainable development in DPH industry. To summary, in spite of there are some restraints (poor land, resources shortage, fragile ecological environments, labor resource constraints and so on), DPH has been highly appreciated and being paid enough attentions both government and farmer and agricultural researcher. In future, after establishment and integration of production technology for clean and efficient production, economic sustainability, product quality and marketing, balance between exploration and protection, perfect food chain, professional farmers training and a sound social service system establishment are becoming more and more important for DPH sustainable development. In conclusion, as original agricultural system, DPH is expected to be sustainable under the aid of innovative technology and policy supports. It is believed that non-cultivated land such as desert land, Gobi land and even urban land will be fully used in facility agriculture. Anyway, there are some challenges during future development of DPH. We believe that sufficient technological support, continued positive policies and high benefit-cost rate will drive sustainable development of DPH industry by attracting more growers and enterprises.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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