西北农林科技大学

硕 士 学 位 论 文

农艺措施对黄土区雨养旱地冬小麦水分利用效率的影响

专业学位类型 水土保持与荒漠化防治

领 域 名 称 农业高效用水

论 文 作 者 黄杨（Gantsetseg Gantumur）

指 导 教 师 田霄鸿 教授

联合指导教师

论文提交时间 2019.05

Thesis Submitted to Northwest A & F University

in Partial Fulfillment of the Requirements

for Degree of

Master of Agriculture Science

EFFECT OF AGRONOMIC PRACTICES ON WATER USE EFFICIENCY OF WINTER WHEAT IN RAINFED DRYLAND OF LOESS PLATEAU

Major: Soil and Water Conservation and Desertification Control

Research Field: Water Use in Agriculture

Candidate: Gantsetseg Gantumur

Supervisor: Tian Xiaohong

Date of submission: May, 2019

Institute of Soil and Water Conservation

Northwest A & F University

分类号：S157.1　　　　　　　　　　　　　　　　　　学校代码：10712
U D C：631.43　　　　　　　　　　　　　　　　　　研究生学号: 2017071030
密　级：公开

西北农林科技大学硕士学位论文

农艺措施对黄土区雨养旱地冬小麦水分利用效率的影响

论文作者:黄杨（Gantsetseg Gantumur）

指导教师:田霄鸿教授

答辩委员会：

西北农林科技大学大学	教授	（主席）
西北农林科技大学大学	教授	
西北农林科技大学大学	教授	
西北农林科技大学大学	教授	
西北农林科技大学大学	教授	

答辩日期：

本研究得到 国家重点研发计划课题 基金

（编号：2016YFD0200308）资助。

Supported by the National Key R&D Program

(Grant no. 2016YFD0200308)

研究生学位论文的独创性声明

本人声明：所呈交的学位论文是我个人在导师指导下独立进行的研究工作及取得的研究结果；论文中的研究数据及结果的获得完全符合学校《关于规范西北农林科技大学研究生学术道德的暂行规定》，如果违反此规定，一切后果与法律责任均由本人承担。

尽我所知，除了文中特别加以标注和致谢的地方外，论文中不包含其他人已经发表或撰写过的研究结果，也不包含其他人和自己本人已获得西北农林科技大学或其它教育机构的学位或证书而使用过的材料。与我一同工作的同事对本研究所做的任何贡献均已在论文的致谢中作了明确的说明并表示了谢意。

研究生签名：　　　　　　　　　　　时间：　　　年　　　月　　　日

导师指导研究生学位论文的承诺

本人承诺：我的研究生　　　　　　　所呈交的学位论文是在我指导下独立开展研究工作及取得的研究结果，属于我现岗职务工作的结果，并严格按照学校《关于规范西北农林科技大学研究生学术道德的暂行规定》而获得的研究结果。如果违反学校《关于规范西北农林科技大学研究生学术道德的暂行规定》，我愿接受按学校有关规定的处罚处理并承担相应导师连带责任。

导师签名：　　　　　　　　　　时间：　　　年　　　月　　　日

关于研究生学位论文使用授权的说明

本学位论文的知识产权归属西北农林科技大学。本人同意西北农林科技大学保存或向国家有关部门或机构送交论文的纸质版和电子版，允许论文被查阅和借阅；同意西北农林科技大学将本学位论文的全部或部分内容授权汇编录入《中国博士/硕士学位论文全文数据库》和《中国学位论文全文数据库》进行出版，并享受相关权益。

本人保证，在毕业离开（或者工作调离）西北农林科技大学后，发表或者使用本学位论文及其相关的工作成果时，将以西北农林科技大学为第一署名单位，否则，愿意按《中华人民共和国著作权法》等有关规定接受处理并承担法律责任。

任何收存和保管本论文各种版本的其他单位和个人(包括研究生本人)未经本论文作者的导师同意，不得有对本论文进行复制、修改、发行、出租、改编等侵犯著作权的行为，否则，按违背《中华人民共和国著作权法》等有关规定处理并追究法律责任。

（保密的学位论文在保密期限内，不得以任何方式发表、借阅、复印、缩印或扫描复制手段保存、汇编论文）

研究生签名：　　　　　时间：　　　年　　月　　日

导 师 签名：　　　　　时间：　　　年　　月　　日

ABSTRACT

The imbalance between water supply and demand leads to water shortage, which has become one of the most pressing problems in the world. For the agriculture sector especially in the rainfed region, water is a more valuable resource. The Loess Plateau is one of the main areas of wheat production in China. In this region, the groundwater level is very deep and it is impossible to be used for irrigation in agriculture sector. The agriculture water fully depends on precipitation; the main precipitation comes from July to September, which occupies 60% of annual precipitation, while the precipitation during the crop growing season is only close to 40%. Another problem is that evaporation process is higher than precipitation in rainfed area. Therefore, the objective of this work was to investigate and compare the effects of different agronomic practices on soil moisture, grain yield, water use efficiency and soil temperature of winter wheat (*Triticum aestivum* L.) in dryland.

The data in this article was based on a three-year field experiment of the Key Lab of Plant Nutrition and Agri-environment in Northwest China, which was conducted from September 2007 to July 2010 at tableland and terrace field in Loess Plateau. Soil texture was dark loessial soil and soil type was silt loam according to the USDA textural classification system. This long-term field trial consisted of seven treatments included (1) CK (no mulch and fertilization), (2) NP (nitrogen and phosphorus fertilization), (3) NP+PF (plastic film mulch with fertilizers), (4) NP+S (straw mulch with fertilizers), (5) NP+PF+S (plastic film combined with straw mulch plus fertilizers), (6) N1P1 (farmers are used to fertilizing), and (7) NP+M (Recommended fertilization plus organic fertilizer). Each treatment was replicated seven times, replicated twice in the tableland and five times in the terraces, using a randomized complete block design.

The results showed that the amount of precipitation in the experiment period (2007-2009) was 280%, 374% and 298% lower than the pan evaporation respectively. In the 2007, the soil water storage was 10% higher under NP+PF+S and 13% higher under NP+PF than CK in the tableland and NP+PF+S was 7.5% higher than CK in the terrace field. According to the results, NP + PF in the tableland and NP + PF + S in the terrace field were more conducive to soil water storage. Both NP+PF and NP+PF+S treatments improved the grain yield, but N1P1, NP and NPM treatments had no effects on it. The lowest soil temperatures (ranged from -1℃ to -1.5℃ from the end of January to mid-February) in both fields were obtained by NP+S treatment. NP+PF+S and NP+PF treatments enhanced the soil temperature, soil moisture, and grain yield. Irrespective of the treatments, the soil water storage, WUE, and grain yield were lower in terrace fields than tablelands.

So the technology which recommended fertilization plus plastic mulch was suitable for rainfed agriculture. If farmers use that method for their planting, they will receive a plenteous harvest and favorable economic benefits.

KEYWORDS: Water use efficiency; Plastic mulch; Straw mulch; Yield; Rainfed dryland

摘要

供需不平衡导致的水资源短缺已成为当今世界最紧迫的问题之一。在雨养农业区，旱地水资源显得更为宝贵，水分亏缺成为限制作物产量及水分利用效率的关键因素。黄土高原是中国小麦的主要产区，该地区用于农业生产中的水分主要来源于天然降水，但降雨量低且季节分布极不均匀，其中7-9月的降水占全年降水量的60%，而小麦生长季的降雨量只占到全年降雨量的40%。此外，在雨养旱区，其蒸发量远大于降水量。由于作物生长季节降水太少，提高当地降水的利用效率或找到合适的农艺措施是提高作物产量、改善作物品质的重要措施。因此，本试验旨在探究推荐施肥与覆盖（秸秆和地膜覆盖）对旱地土壤水分和温度，冬小麦产量及水分利用效率的影响。

本研究数据基于农业部西北植物营养与农业环境研究重点实验室于2007年9月至2010年7月在黄土高原塬面和梯田进行的为期三年的田间试验，通过对其试验数据的分析，系统地探究了不同农艺措施对雨养旱地冬小麦产量及其水分利用效率的影响。试验区主要轮作制度为冬小麦-夏休闲，土壤类型为黑垆土，土壤质地为粘壤土。试验共设置七个处理包括CK（不施肥且不覆盖）、NP（推荐施肥）、NP+PF（推荐施肥配合垄上覆膜）、NP+S（推荐施肥配合麦草覆盖）、NP+PF+S（推荐施肥配合垄上覆膜沟内覆草）、N1P1（农民习惯施肥）和NP+M（推荐施肥配合有机肥），每个处理重复七次，其中在塬面重复2次，梯田重复5次，采用完全随机区组设计。

结果表明，三年试验（2007-2009）的降水量比潜在蒸发量分别低280%，374%和298%。在2007年，在塬面，推荐施肥配合垄上覆膜沟内覆草处理（NP + PF + S）和推荐施肥配合垄上覆膜处理（NP + PF）的土壤蓄水量分别比CK高10%和13%，而在梯田中，推荐施肥配合垄上覆膜沟内覆草处理（NP + PF + S）的土壤蓄水量比CK高7.5%。结果表明，塬面的推荐施肥配合垄上覆膜处理（NP + PF）和梯田的推荐施肥配合垄上覆膜沟内覆草处理（NP + PF + S）更有利于土壤蓄水。推荐施肥配合垄上覆膜处理（NP + PF）和梯田的推荐施肥配合垄上覆膜沟内覆草处理（NP + PF + S）提高了籽粒产量，但农民习惯施肥处理（N1P1），推荐施肥处理（NP）和推荐施肥配合有机肥处理（NP + M）对其无影响。通过推荐施肥配合麦草覆盖处理（NP + S）可获得两种田地土壤的最低温度(1月底至2月中旬，-1℃~ -1.5℃)。推荐施肥配合垄上覆膜处理（NP + PF）和梯田的推荐施肥配合垄上覆膜沟内覆草处理（NP + PF + S）提高了土壤温度，土壤水分和粮食产量。无论采用何种处理方法，梯田的土壤储水量、水分利用效率和粮食产量均低于塬面田。

因此，推荐施肥加地膜覆盖的技术适合于雨养农业。如果农民采用这种方法进行种植，他们将会获得很好的收成和经济效益。

关键词：水分利用效率; 地膜覆盖; 秸秆覆盖; 雨养旱地

Acknowledgments

First, I would like to thank China and Asian Pacific Forestry Forestry Network (APFNet) for offering the opportunity to study a Master's degree in China. It was a great chance not just for improving my understanding of science, but it was also a unique chance to experience the long history, extended culture, and artistic language of China.

I would like to express my heartfelt gratitude to my superviser Prof. Tian Xiaohong for his continuous support, guidance, and for widening my vision toward new and advanced ideas in science through my study in his lab.

I would like to thank Assoc. Prof. Shi and Ning and all of my labmates (Yang Long Chen, Jin Jin, PeiPei, Miao Miao, Ying Ying, Yuhan and Shar) for their continued help and suggestions.

I would like to thank Wang and Li Yu for their generous support and for helping me to fulfill the graduation requirements.

Finally, I would like to thank my friends and my family especially my husband Khuderbat.O for their love, support, and encouragement.

Content

ABSTRACT..I
摘要..错误！未定义书签。
Chapter 1 Literature review...1
1.1 literature review...1
1.2 Overview of mulch...3
1.3 Research status of plastic film mulching...5
1.3.1 Problems with film mulching..8
1.3.2 Effect of plastic film mulching on soil microclimate...9
1.4 Research progress on straw mulch...10
1.4.1 Increase soil organic matter and maintain soil fertility.....................................11
1.4.2 Problems with straw returning to the field..12
1.5 Fertilization (nitrogen and phosphorus)...12
2.1 Water utilization efficiency of wheat at the field scale...14
2.1.1 Description of research site...14
2.2 Experiment design and process..15
2.3 Data determination..17
2.3.1 Determination of moisture...17
2.3.2 Determination and analysis of temperature...17
2.4 Data Processing...17
2.4.1 WUE calculation method...17
Chapter 3 Results & Analysis..19
3.1 Precipitation and surface evaporation in the area during the test..........................19
3.2 Soil water storage during the experiment period...20
3.2.1 Soil water storage change during the growth period of wheat (Δ W).....................21
3.3 The temperature of the soil in different treatments..22
3.4 Winter wheat yield under different cultivation modes..24
3.5 Water use efficiency of winter wheat in two seasons under different treatments...25
Chapter 4 Discussion & Conclusion..28
4.1 Discussion..28
4.2 Conclusions..31
Reference..32
Appendix...41

Chapter 1   Literature review

1.1 Literature review

Water is one of the world's most valuable resources. In recent decades, the world's population has increased substantially and at present, the world's population is about 7.6 billion, and it is expected to reach 10 billion by 2040, based on the current annual growth rate of 1.5% (PRB. 2018). The tentatively increase in population calls the significant increase in food production to meet the growing need and demand and also for rational use and protection of the natural resources, especially soil and water, for agriculture sustainability (Alexander. 1998). Water usage in agriculture is at the main of any debate of water and food security. Totally agriculture accounts for, on average, 70 percent of all water withdrawals globally but rainfed agriculture does not depend on irrigation. For rainfed agriculture precipitation is the only source of water (Jiang et al. 2015; Liu et al. 2014).

China's is one of the largest countries in the world, also the population growth rate progressive in the last several decades. In 2019, China's population was 1.42 billion; due to limited supply, uneven distribution, population growth, and economic development, China is facing a serious shortage of water resources. In China, the arid and semi-arid regions account for 53% of the land area. The total area of arable land is 128 million hectares, of which about 60% is rainfed. Rainfed agriculture is divided along the boundary of the Kunlun Mountain and Huai River into ten zones, see the appendix (Table 1) for more details. Rainfed farming systems are the main agricultural practices in the north part of China (Ling et al. 2014), the northern rainfed farming regions include arid, semi-arid and semi-humid areas, cover 16 provinces with a total cultivated area of 33 million hectares (Li et al. 2003) and regions properties are low temperatures in winter and spring, severe water deficits result from low total rainfall, (with about 60% falling between June and September), uneven distribution, and high rates of evaporation in summer (Liu et al. 2015).

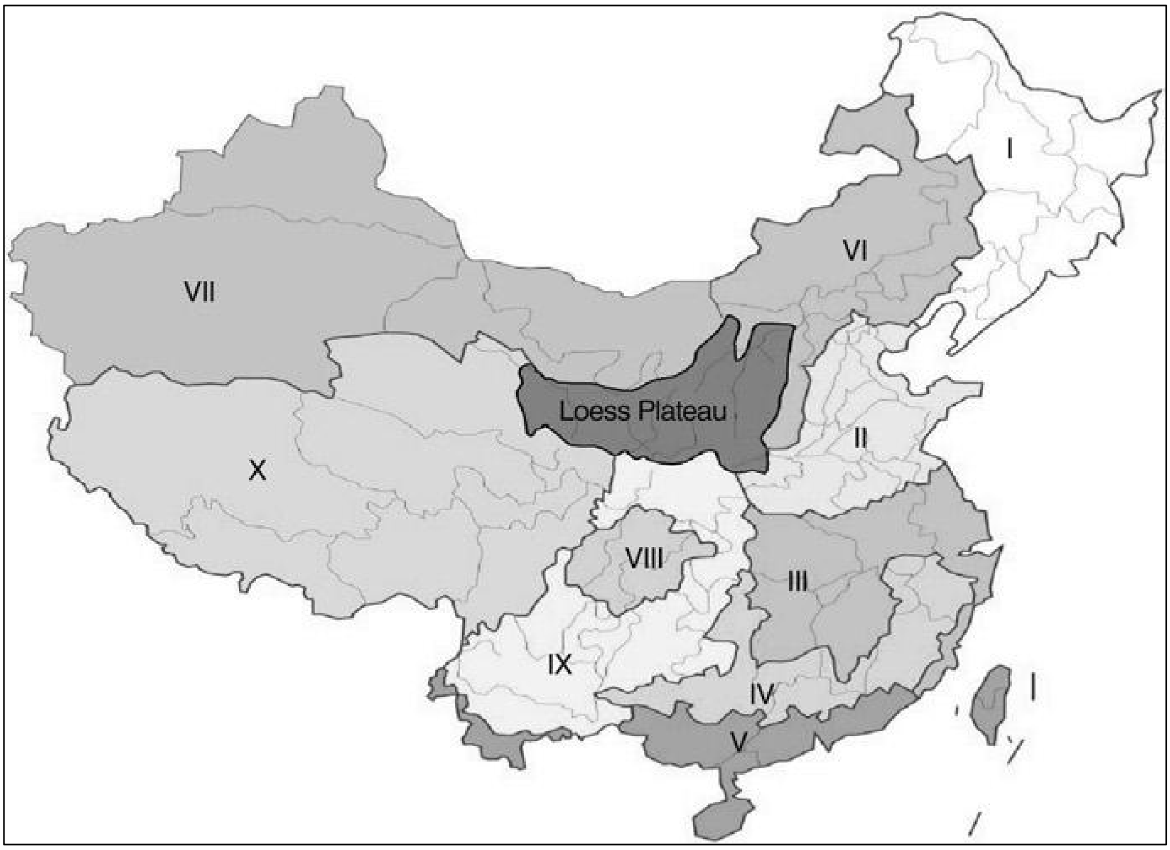

Figure 1.1 Map of agricultural regions in China (Liu and Chen 2005)

The Loess Plateau is one of the areas with the most serious water shortage in China. The moisture source the regions come from precipitation. The annual average precipitation is 382 mm, mainly received in from July to September. Loess Plateau is a main agricultural zone especially for crop production in the northern Shaanxi. Xue (2017) noted the 40 million ha in Loess Plateau of China is a vital cereal production area. Winter wheat (*Triticum aestivum* L.) is cultivated on 44% of the Loess Plateau cropland. The Loess Plateau covers an area of about 64 million hectares and supports about 100 million people. It is the main dryland agricultural region in China (Heerdt et al. 2017; Chen et al. 2015).

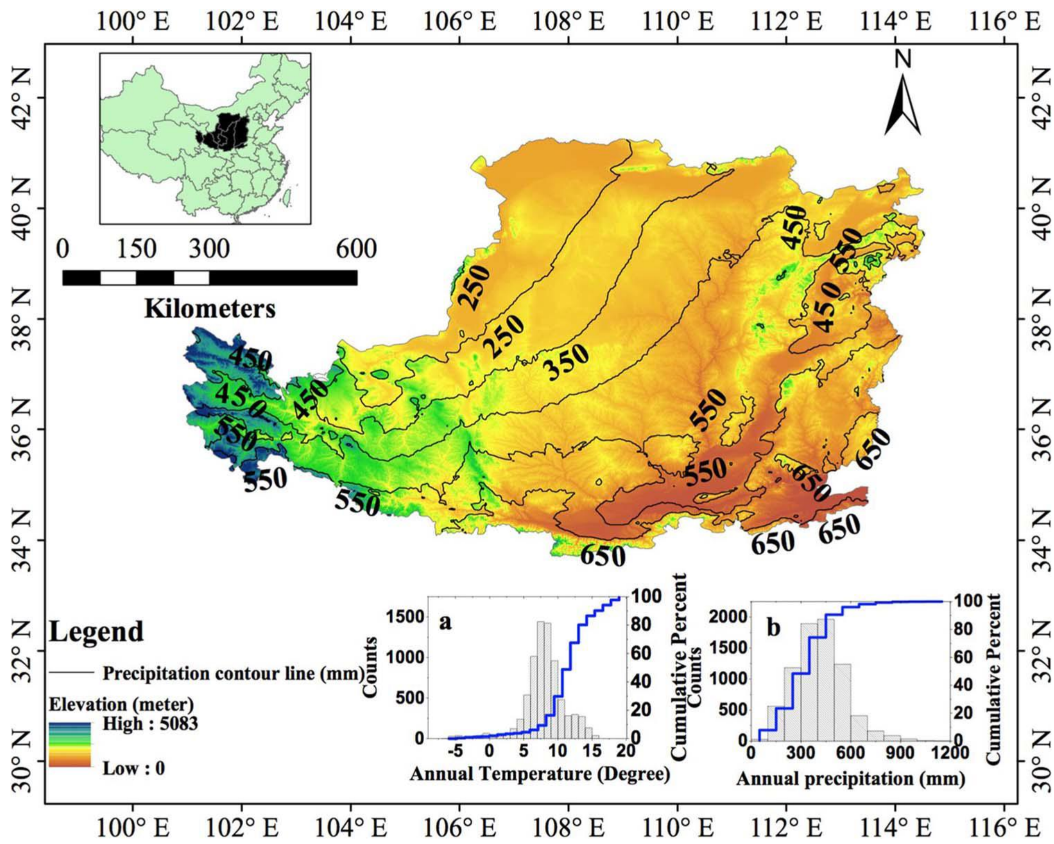

Figure 1.2 Elevation and distribution of precipitation in the Loess Plateau, China

a. annual temperature histogram of Loess Plateau.

b. annual precipitation histogram of Loess Plateau (Zhang et al. 2018)

Winter wheat occupies 35% planting in this region (Liu et al. 2016). Experiment site was semiarid continental climate with an average annual temperature of 9.1°C, pan evaporation of 1500 mm, and precipitation of 542 mm. About 60% of the precipitation is concentrated between July and September (Liu et al. 2015). It means Weibei dryland's agricultural water mainly depends on natural precipitation, which is a typical rain-fed agriculture area. In winter wheat growing season, water deficit is serious, and precipitation generally cannot meet the water demand for crop growth and development (Jin et al. 2018). Even though the natural precipitation's potential not excessive in the region still has to be exploited rainfall.

1.2 Overview of mulch

The word 'mulch' is derived from the German word "molsch", that means soft or beginning to rot. Mulches are described as materials that are applied to the soil surface, it protects the surface of the soil from any external cause (Kader et al. 2017) and reduces evaporation (Adekalu et al. 2007), which directly control to root stress and plant health.

Soil physical properties are affected by the soil environment that is greatly related to soil moisture and soil temperature (Kader et al. 2017).

The mulching materials can be roughly divided into three categories: organic materials (plant products, animal manure), inorganic materials (synthetic materials) and special materials. Organic mulching materials come from organic materials, such as agricultural waste, wood industrial waste, processing residue and animal waste. When decomposed by microorganisms, organic mulches supplement nutrients in the soil to help carbon sequestration and use as fertilizers. Generally, green crops and animal manures, used as mulch, supply nutrients at higher rates than the other mulches like straw, wood chips and bark (Kader et al. 2017).

The inorganic mulching materials included polyethylene plastic films, which are petroleum-based products (Kader et al. 2017), and synthetic polymers (Kyrikou and Briassoulis 2007). There are also several types of organic and inorganic mulching materials. Adhikari (2016) and Yang (2015) described several new types of biodegradable and photodegradable plastic films as ecological materials and proposed sprayable and biodegradable polymer films for easy application and versatility.

Chakraborty (2008) reported mulching is an effective method to direct the crop-growing environment to increase crop yield and improve product quality by controlling soil temperature, retaining soil moisture and reducing soil evaporation. Mulches moderate soil temperature and increase infiltration during intensive rain. Both soil moisture and temperature being substantially influenced by mulching affect soil microbiology (Moreno and Moreno 2008). Many studies have demonstrated that rainwater harvesting and conservation practices are sufficient for improving nutrient use, increasing yield and WUE (Wang et al. 2015).

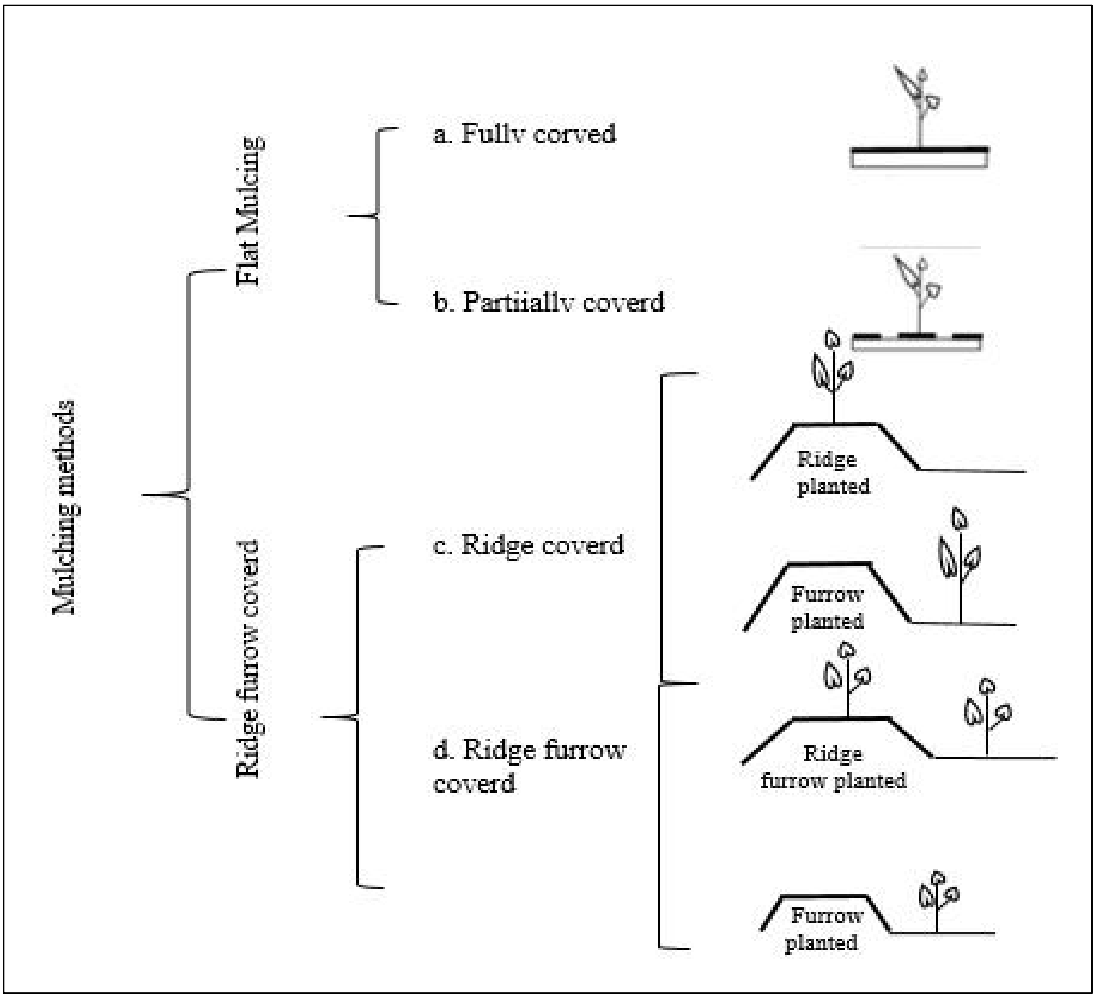

Figure.1.3 A schematic diagram of different mulching methods (line indicates cover by mulch materials) (Kader et al. 2017)

1.3 Research status of plastic film mulching

The plastic used in the agriculture sector from 1948 when polyethylene was first used as a greenhouse film to replace the expensive glass (Adhikari et al. 2016). Nowadays plastic films can be used in agriculture for mostly as mulch films, drip irrigation tape, row covers, low tunnels, high tunnels, silage bags, hay bale wraps, plastic trays and pots used in transplant and bedding plant production (Keith et al. 2016). The plastic film, which is typically made from polyethylene, is applied before crops are planted and removed after the harvest (Kasirajan and Ngouajio 2012).

In 2006, world consumption was approximately 700,000 tonnes/year representing about 10% of the total plastic consumption in Agriculture (Espí et al. 2006). From this research 10 years later (Adhikari et al. 2016) one of the studies reported that approximately 2,250,000 tons/year of plastic mulch used for agriculture sector including fresh market vegetable in the worldwide every year. The use of plastic mulch is on the increase due to new emerging markets in Asian countries dominated by India and China. Xue (2018) found China is the largest consumption country of the mulching film, accounting for 60% of the world agricultural film demand. Dryland agriculture plays a to dominated role in the global food supply. That mulching technology is widely used in arid and semi-arid regions of China (F. Zhang et al. 2019). Most of the inorganic mulching researches done in the Chinese Loess Plateau area described the effects of rainfall on soil moisture storage under different crop productions (Kader et al. 2017).

In rainfed agriculture region need new technology for how to efficiently use precipitation, decreasing evaporation and improve yield. Last several decads researches found that use plastic mulch for cover the grain yield, it is a widely used water management practice, which effectively reduced about 90% of soil surface evaporation (Li et al. 2019b) compare with bare soil (Liu et al. 2014; Chakraborty et al. 2010), increases rainfall retention (Lamont 2005; Kasirajan and Ngouajio 2012) and consequently increases soil water storage (Li et al. 2019b; Zhang et al. 2011; Briassoulis et al. 2015; Huang et al. 2005; Lamont 2005). Also that technology has been reported to remarkably improve crop yields (Luo et al. 2018a; Saglam et al. 2017; Berger et al. 2013; Wang et al. 2016) and increase soil temperature and reported to directly affect the soil microclimate by modifying the surface radiation (Adhikari et al. 2016). Summarized by (Anifantis et al. 2012) all mulches altered soil temperature such that black and clear films warmed soil temperature up to 7◦C while aluminized, leaves and grass clapping slowed the rate at which soils warmed and cooled. Also, (Adhikari et al. 2016) study showed that the mulching plastic films increased the soil temperatures around 2◦C, compared with the un-mulching soil, at 20 cm depth.

Plastic mulching has been used widely for crops and vegetables in China. Wheat is one of the main food in China and therefore, plays a critical role in the food security of China. Xue (2018) found rainfed winter wheat accounts for approximately 60% of the total wheat planting area in southern Shanxi Province on the Loess Plateau. The area of plastic mulching used for winter wheat production accounted for approximately 10% of total sowing area of dryland winter wheat in Shanxi Province in 2013, and the user is still rapidly increasing. Luo (2018b), their experiment plastic mulch compared with no mulch result shown average grain yield was significantly increased by 13.7%, (N. Li et al. 2018) result shown more significantly increased 16.7%-36.8% compared with control. Dong (2018) found the average wheat yields under the plastic mulch and straw mulch treatments were increased by 21.3% and 7.4%, respectively. The average water use efficiencies under the PM and SM treatments were 24.5%, 8.8% in winter wheat. Fig 1.4 showed plastic film mulch on winter wheat crop.

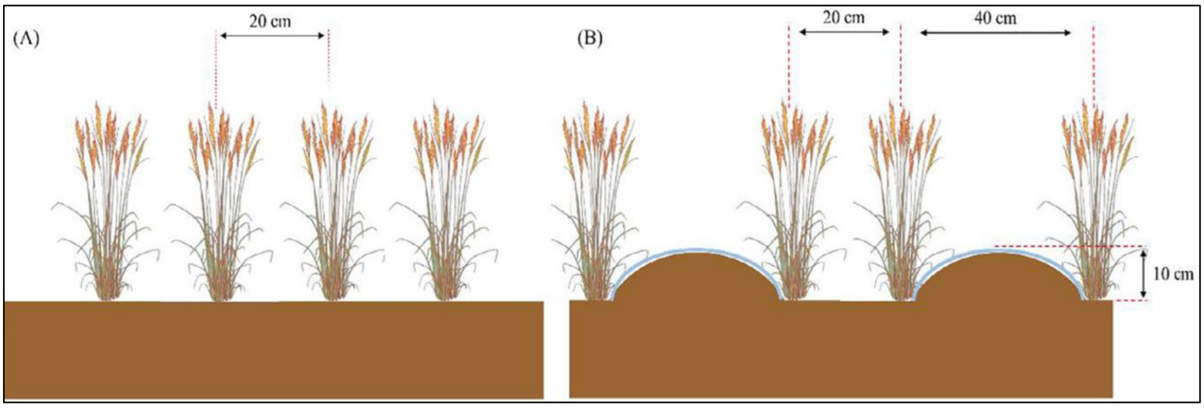

Figure 1.4 A schematic diagram of the different sowing methods
(A) indicate conventional drill sowing (DS), and
(B) indicate drill sowing beside the common plastic film(DSF).
The blue curve indicates the film in the figure (B) (Xue et al. 2018)

Plastic mulch also extends maize planting to the higher altitudes of the western Loess Plateau region, where CK cannot attain grain yield due to sustained low temperatures (Kasirajan and Ngouajio 2012). Covering ridges and furrows with the plastic film is effective for improving maize yields under moderate plant densities of 45,000–52,000 plants ha^{-1} in the Loess Plateau of China (Liu et al. 2012; Wang et al. 2016). F. Zhang (2019) found the plastic mulch treatment increased maize grain yields by more than 300% compared with non-mulched plots planted at the same density. Zhang (2018) and X. Zhang (2019) their result shown plastic film mulching significantly improved soil water content and temperature, thereby enhancing the photosynthetic rate of maize mainly by facilitating stomatal opening. Full mulching enhanced the capacity of maize plants to uptake nutrients, capture soil water, and resulted in increased crop productivity.

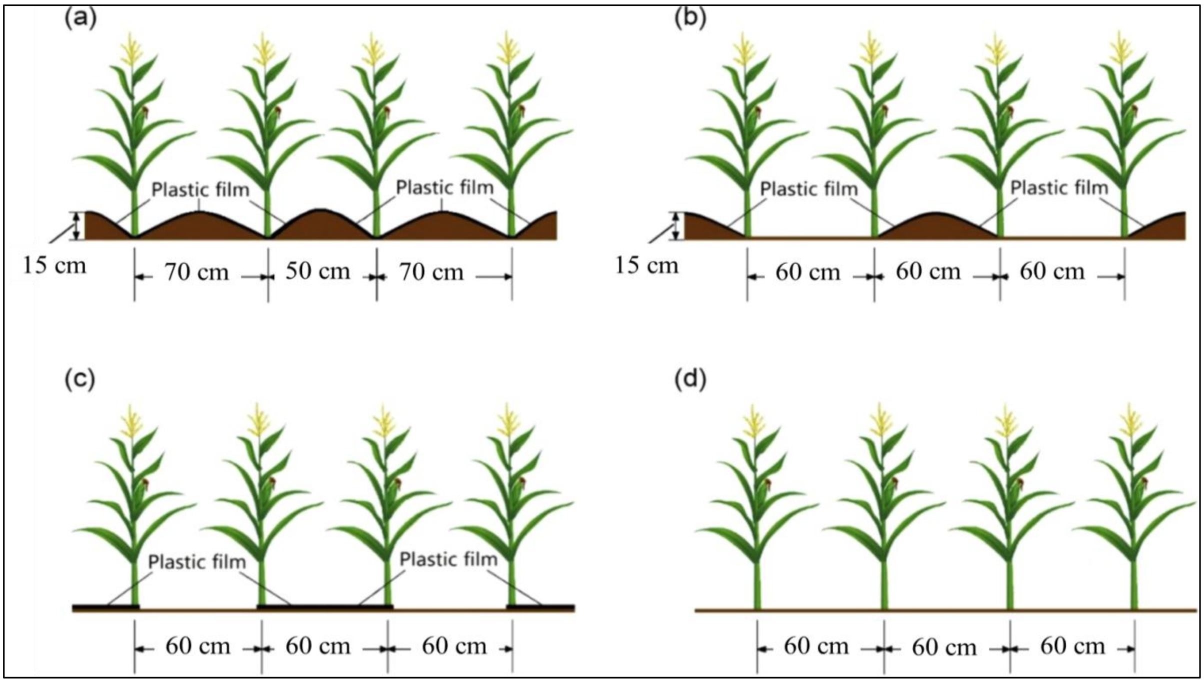

Figure 1.5 Schematic diagram of the different planting treatments in the study

(a) RF, ridge-furrow construction with full plastic film mulch; (b) RH, ridge-furrow construction with half plastic film mulch; (c) FH, flat planting with half plastic film mulch; *(d) CK, flat planting with no mulch (control)* (Zhang et al. 2019).

Another one experiment about vine crops. Also Adhikari (2016) found that vine crops were most responsive to microclimate modification with clear plastic more effective than black plastic mulch. Over the last decade, large tracts of cropland have been cultivated under plastic mulching, reaching about 19% (25million ha) of the total arable and (130million ha) in China by 2014 (Wang et al. 2016a). Plastic mulching has become a leading practice in rainfed farming in the country.

1.3.1 Problems with film mulching

The presence of small plastic particles in the environment reported for the first time in the 1970s, has only recently been recognized as a global issue. Oliveira and Almeida (2019) briefed as world plastics production continues to experience an increase (approximately 335 million tons in 2016). Although plastic mulches offer many benefits, there have also negative impacts on the environment and soil (Saglam et al. 2017). Most of the plastic mulch used in agriculture is made of polyethylene, which is durable and supplies excellent material characteristics for use. However, the plastic has to be removed from the field at the end of the growing season and then disposed of. Because agricultural plastic mulch is usually contaminated with soil and plant debris, which cannot be recycled efficiently and is often stockpiled on-farm, burned, or deposited in landfills (Hayes et al. 2012).

Another one problem is the plastic film mulching significantly reduces soil organic matter and greatly increases greenhouse gas emissions (Cuello et al. 2015). Plastic mulches create difficulties in dumping and emit harmful substances during burning (Lamont 2005). They promote soil degradation, cause soil-water repellency and occur as potential pollutants in the soil (Steinmetz et al. 2016). It becomes problematic in the top dressing of fertilizer when plastic mulches are used. Rochman (2015) and Nizzetto (2016) researchers have paid attention to plastic wastes in the soil media and warned about the dangers of small plastics in the soil and terrestrial ecosystems.

Adhikari and others (2016) found removal of these films is time-consuming (about 16 h/ha) and despite the use of machines, manual hand labor is still required. In an attempt to overcome these limitations, degradable poly-olefins have been designed to provide the required mechanical integrity which can later degrade to ostensibly non-toxic end products. These are typically designed to oxo-degrade undergoing changes in chemical structure due to ether linkages as a result of oxidation in air, thus causing the break-down of the polymer into small fragments that are subsequently bio-assimilated (Ammala et al. 2011).

Chae and An (2018) discussed if plastic wastes are transferred via the food chain and their effects reach the next generations, these impacts could affect populations and communities, and further, affect the entire ecosystem.

1.3.2 Effect of plastic film mulching on soil microclimate

In the study of (Smets et al. 2008), mulching materials at the soil surface improved soil hydrologic characteristics by affecting the soil physical and chemical properties. The soil-water environment is directly related to soil moisture and temperature and has a significant impact on soil physics and soil microbiology. The mulch reduces soil quality deterioration by preventing runoff and reducing soil loss, thereby improving soil aeration, soil structure, organic matter content and physical properties (Jordán et al. 2010). In the study of (Komariah et al. 2011), the combination of rice bran and transparent plastic mulching raised the earthworm populations at 5 cm depth. Soil microbial biomass carbon is a sensitive indicator of microbial activity that reflects soil quality (Benintende et al. 2008).

Kader (2017) described the plastic film residue reduces soil porosity and hence air circulation changes microbial communities and leads to low soil fertility. But (Wang et al. 2016) found the higher soil temperature under plastic film mulch promotes soil microbial activity and speeds up the decomposition of organic matter in the soil. Zhang (2019) found the thermal effect of mulching accelerated maize growth and indirectly promoted water utilization, resulting in marked soil wet-dry alternation.

The addition of polymers to compost to improve soil properties and increase crop yields can also be considered a recognized source of microplasticity in the environment (Hurley and Nizzetto 2018). Under plastic mulching with the ridge-furrow system in India, (Kasirajan and Ngouajio 2012) reported 2, 12 and 12% increased population of soil bacteria, fungi, and actinomycetes, respectively compared to the non-mulched treatment. Plastic mulch, on the other hand, under ridge-furrow systems, improves soil fertility by reducing exhaustion risk of organic carbon and nitrogen of the soil (J. Liu et al. 2015).

1.4 Research progress on straw mulch

Agricultural production generates a large amount of crop residue (straw), approximately 4 billion metric tons per year globally (Lal 2005), 0.8 billion metric tons produced in China (Hu et al. 2016). Straw mulching is widely used to conserve soil water and increase crop yields (Wang et al. 2018) as well as to improve soil fertility and reduce erosion in arid and semiarid regions of Spain, India, USA, and China (Hu et al. 2015). Cereal straw is the most common organic mulching material in almost all climatic areas that have several advantages after applying in the field and is suitable for soil moisture storage (Ji and Unger 2010). Application of straw mulching at 4–6 t ha^{-1} has been found effective in improving soil physical condition, including protection of the topsoil, in tropical environments (Lal et al. 2016). Price and Quinty (1998) found under temperate environments, straw mulching has been reported to intercept 44% of the total rainfall at a typical rate of 2.6 mm day.

Wheat straw mulching is typically used during the summer fallow period or throughout the year to conserve soil water (Zhao et al. 2009; Mulumba and Lal 2008), enhance crop yields (Deng et al. 2006) and water-use efficiency (WUE) were 13–25% increased with straw mulching than without mulch in India (Chakraborty et al. 2010). Another one experiment (Deng et al. 2006; Hu et al. 2018) found straw mulching can improve wheat WUE by 10–20% compared with no mulching. Peng (2015) three years experiment result shown soil water content at the 0–2m soil layer increased by 1–23%, wheat yield by 13–23%, and WUE by 24–33% using wheat straw mulch compared with no mulch in Loess Plateau of China.

Meanwhile, straw mulching can reduce evaporation loss from the soil surface (Agassi et al. 2004; Arora et al. 2011; Ji and Unger 2010), protect the surface from the direct strike of raindrops, enhance soil aggregation, and promote biological activity (Salinas-Garcia et al. 2001). Straw mulching can keep the soil warmer in winter and cooler in summer as well as reduce soil temperature oscillation (Chen et al. 2007). Some researchers have discovered the negative impact of straw mulch. Wang (2018) found straw mulching increased soil water content, but reduced corn (*Zea mays* L.) yield and WUE compared with no mulching in silty clay loam soil in northeastern China. Gao (2009) their research results mulching did not have a significant effect on wheat yield when soil water content at planting was high in the Loess Plateau of China. Also, some researches present that low soil temperature caused by straw mulching froze wheat seedlings and roots during the winter, thereby negatively influenced germination and tillering (Gao et al. 2014). Therefore, straw mulching has not always been shown to increase, but decrease yields (Bonfil et al. 1999). The effect of straw mulching on soil water conservation and crop yield has been highly variable, depending on mulching practices (Cook et al. 2006), climate and soil conditions (Tolk et al. 1999).

1.4.1 Increase soil organic matter and maintain soil fertility

It is well known that microorganisms play an important role in soil quality by releasing soil nutrients through the decomposition of soil organic matter (Li et al. 2004). Straw mulch dampens the influence of environmental factors on the soil by increasing soil temperature and controlling seasonal fluctuations of soil temperature (Li et al. 2013). It also enhances the soil biotic activities of earthworms and other soil fauna that improve the soil structure and quality (Döring et al. 2005). The effect of mulching on soil bulk density varies depending on type and properties of the soil, type of mulch, climate and land use (Mulumba and Lal 2008). Mulching increases soil bulk density in case of conventional tillage (Bottenberg et al. 1999) but reduces it by adding organic matter to the soil (Kader et al. 2017); such increase or decrease in soil bulk density depends on specific situations.

Sarno (2004) found weed as a cover plant in coffee fields to be effective to improve soil chemical properties and maintain soil fertility. For the hilly humid area of Indonesia, (Kader et al. 2017) reported that paspalum conjugatum (buffalo grass), covering the soil surface in coffee fields, improved soil physical conditions with the consequent increase in organic carbon, aggregates stability, porosity and available moisture content of the soil.

Mulching stimulates soil micro-organisms such as algae, mosses, fungi, bacteria and other organisms like earthworms. Bacterial populations increase under organic mulches due to different chemical compositions and decomposition rates of organic materials (Kader et al. 2017). In addition, the functional diversity of both microbial biomass and microbial community plays a role in plant litter decomposition and carbon cycling in forest ecosystems (Carney and Matson 2005). Mulching treatments augment the total soil nitrogen compared to the bare soil; the increased nitrogen is, probably, attributable to an increased nitrogen metabolism by nitrogen-fixing of the organic mulching that stimulates protein production of the bacterial community in nitrogen cycles (Kader et al. 2017).

1.4.2 Problems with straw returning to the field

Sometimes, the natural mulches are not good for weed control (Boyhan et al. 2006). For example, certain types of mulches such as straw, hay, and grass contain seeds, which may become weeds. Organic mulching materials such as wood chips and bark may occur as soil acidifiers (Chalker-Scott et al. 2007). Too much organic mulch can lead to excess moisture, creating new problems such as pests, anaerobic conditions and rotting of the roots that can damage the plants. Straw mulches often contaminate the soil and deplete the seedbed nitrogen due to their high carbon-to-nitrogen (C/N) ratio (Kasirajan and Ngouajio 2012). Moreover, when carbon-rich materials such as straw or stalks are used for mulching, nitrogen from the soil may be used by microorganisms for decomposing those materials.

1.5 Fertilization (nitrogen and phosphorus)

Since the generation of the Haber–Bosch process in the early 20th century, chemical nitrogen (N) fertilizer production has converted a large amount of unreactive N to reactive forms (Galloway et al. 2004). Chemical phosphorus (P) fertilizer production was promoted along with the phosphorus acid. Fertilizer use is one of the important land management practices that has substantially increased crop yield and soil fertility over the past century (Giomaro et al. 1988) in the agriculture sector. A critical part of the “green revolution”, the rate of increase in fertilizer production and application has contributed considerably in increasing agricultural productivity and reducing hunger worldwide (Erisman et al. 2008).

Large spatial and temporal variations exist in chemical fertilizer use across the world. China, the US, and India together accounted for over 50% of fertilizer consumption globally and they demonstrated a contrasting changing trend over the past century due to the status of economic and agricultural development (Lu and Tian 2017).

China has the largest population but limited arable land per capita so need to manage to increase arable land productivity (Hou et al. 2013). Increased application of nitrogen (N) and phosphorus (P) fertilizer has significantly improved crop yields and food security in China over the past several decades (Huang et al. 2017). China's increased application of N and P fertilizer has greatly increased crop yields (Ma et al. 2012). For example, from 1977 to 2005, total annual synthetic N fertilizer application increased from 7 to 26 million tons; during this time, grain production increased from 283 to 484 million tons (Ju et al. 2009).

The enhancing harvest mainly depends on the precipitation in the dryland agricultural. So every country tries to find a good way to improve grain yield and testing new technologies. Therefore, the purpose of this experiment was to study technologies that reduce evaporation and to improve water use efficiency. The experiment was to compare the effects of different treatments and technique on reducing evaporation, improving soil water storage and winter wheat yield. We used plastic film mulch, straw mulch, organic and nonorganic fertilization in our experiment. First, the effects of plastic film straw mulching combined with fertilization on soil water and soil temperature during the growth period, yield and water use efficiency of winter wheat were studied. The research results can study how to effectively utilize evaporation, which is the key to solve the problem of water resources in this area.

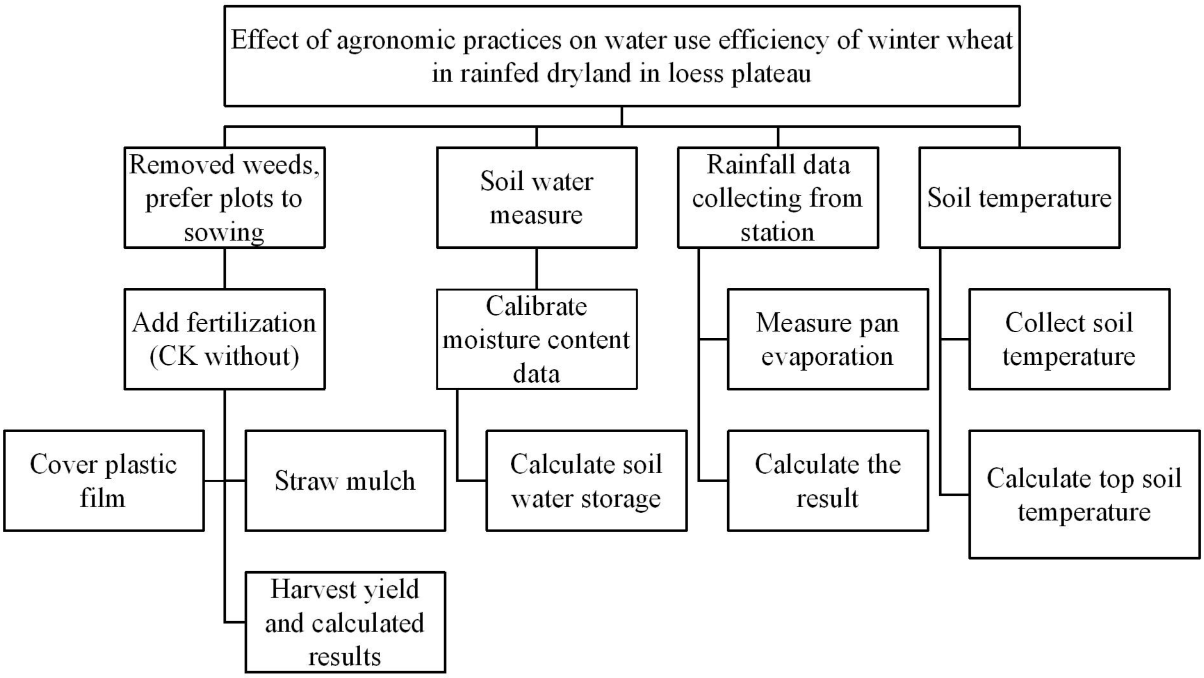

Figure. 1.6 Experiment route map

Chapter 2 Materials & Methods

2.1 Water utilization efficiency of wheat at the field scale

2.1.1 Description of research site

This experiment was a three-year continuous positioning test conducted during the period from 2007 to 2010 in the Wangdong Village Experimental Area of the Changwu Agricultural Ecology Experimental Station of the Chinese Academy of Sciences. The experiment station was located in Changwu County, Weibei District, Shaanxi Province, at an altitude of 1200 m. The annual rainfall is 584 mm, and the rainfall varies greatly from year to year. The rainfall from July to September accounts for 50%-60% of the annual rainfall. The annual average temperature was 9.1°C, the frost-free period is 171 days, and the groundwater level was below 60 m. It has typical characteristics of drought and flood plain on the Loess Plateau (Liu et al. 2005). The tested soil was loessial soil, the soil texture was uniform, the organic matter content was low, and it has a strong calcareous reaction. The soil layer was soft, and the water permeability and cultivability were good. Basic nutrient status of 0-20 cm of plowed soil before the start of the experiment: total nitrogen in the tableland and terraces were 0.67 and 0.41 g/kg, nitrate nitrogen was 1.84 and 1.65 mg/kg, and ammonium nitrogen was 0.49 and 0.59 mg. /kg; available phosphorus is 33 and 31 mg/kg; total potassium is 17.34 and 16.18 g/kg; available potassium is 103.2 and 96.8 mg/kg.

The soil type was silt loam, according to the USDA textural classification system, and the soil properties measured using the recommended methods (Bao et al. 2000) are shown in Table 2.1.

Table 2.1 Soil properties (0-20 cm) prior to planting in 2007

Experiment Locations	SOM (g $kg^{-1)}$	Bulk density (g $cm^{-3)}$	Sand 0.05-2 mm (%)	Silt 0.002-0.05 mm (%)	Clay <0.002 mm (%)
Tableland	18.3	1.20	1.7	75.2	24.1
Terraca	10.0	1.23	10.9	65.1	24.0

(Liu et al. 2016)

Bulk density was measured at 0-20 cm depth. The Particle size distribution was determined for a composite sample collected at the start of the experiment.

2.2 Experiment design and process

The test was carried out from 2007 to 2010 and was carried out simultaneously on the tableland and terraces. The study's treatments included 1. CK (a control that is no mulch and fertilizer), 2. NP (nitrogen and phosphorus fertilizers), 3. NP+PF (plastic film mulch with fertilizers), 4. NP+S (straw mulch with fertilizers), 5. NP+PF+S-(plastic film combined with straw mulch plus fertilizers), 6. N_1P1 (farmers are used to fertilizing) and 7. NP+M (Recommended fertilization with organic fertilizer). There were two replicate in the tableland, and there were five replicate of the terraces. Each plot has an area of 50 m^2 and is designed with a completely random block. The five treatments were N 120 kg/hm^2 and P_2O_5 90 kg/hm^2, which were applied to the soil at one time without topdressing measures. The control treatment is a conventional flat mode without any covering measures (Table.2.2).

Table.2.2 Treatments design

No.	Code	Treatments	Treatment content
1	CK	Control	No fertilization
2	N_1P_1	Farmers' used fertilization methods	N 180, P_2O_5 120 kg ha^{-1}
3	NP	Recommended fertilization	N 120, P_2O_5 90 kg ha^{-1}
4	NP+M	Recommended fertilization + organic fe rtilizer	Organic fertilizer 3000 kg ha^{-1}
5	NP+S	Recommended fertilization + straw cov erage	Covering straw 4500 kg ha^{-1}
6	NP+PF	Recommended fertilization + ridge coat ing	Film width 60 cm
7	NP+PF+S	Recommended fertilization + ridge mul ch + furrow	Membrane width 60 cm +wheat straw in the ditch

Notes: CK- Control, N_1P_1 -Farmers' used fertilization methods, NP- Recommended fertilization, NP+M- Recommended fertilization + organic fertilizer, NP+S- Recommended fertilization + straw coverage, NP+PF- Recommended fertilization + ridge coating, NP+PF+S- Recommended fertilization + ridge mulch + furrow

For the straw mulching treatment, the wheat straw harvested in the previous season was selected. The straw was cut into 10 cm with a sickle before the wheat straw was planted at a height of about 6-10 cm, and the straw coverage was 4500 kg/ha. Half of the field covered with mulch was used for artificial ridges. The width of ridge and furrow was 60 cm, the height of the ridge was 20 cm, the ridge covered with film, and the other half of the area (inside the ditch) was used for planting winter wheat with a groove width of 60 cm. The plastic film was made of an agricultural plastic film with a thickness of 0.05 mm and a width of 80 cm. The operation method of mulching on the ridge and the grass in the furrow was the same as that on the ridge, and the amount of grass is 4500 kg/ha. The two coating treatments cover the entire growth period and repair the damaged film in time. The weeding method uses manual weeding and spraying herbicides. There were no irrigation measure except for natural precipitation during the growth period of wheat, and the groundwater level was as deep as 60 m, so there were no groundwater recharge. The tested varieties of wheat were "Longhan 58", the main planting variety was 150 kg/ha, and the row spacing was 20 cm.

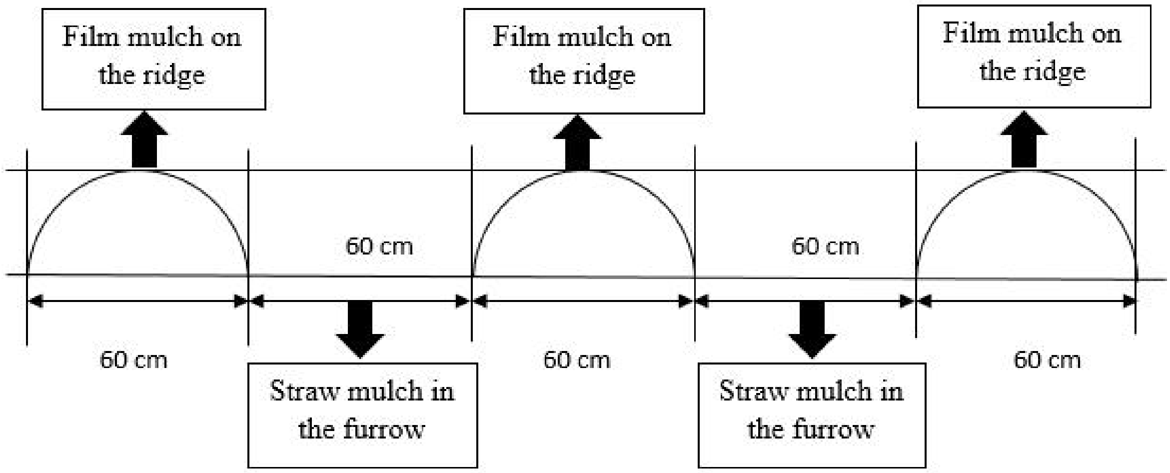

Figure 2.1 Diagram of the ridge-furrow cultivation system

Experimental time schedule shows more detail in Table 2.3. After each season's harvest, the air-dried grain weight was recorded for each plot and used to calculate grain yield in all treatments. During the fallow period, all the plots remained bare until the following season. The cultivar of winter wheat was Changhan 58. The sowing depth, sowing rate, and row spacing were 6 cm, 150 kg ha^{-1}, and 20 cm, respectively. Weeding and herbicide application followed standard field management practices for this region and all field operations were conducted manually.

Table 2.3 Experimental time schedule

Season	Sowing	Straw mulch*	Harvest
2007-2008	Sept 23, 2007	Nov 7, 2007	Jun 16, 2008
2008-2009	Sep 20, 2008	Nov 4, 2008	Jun 19, 2009
2009-2010	Oct 12, 2009	Nov 12, 2009	Jun 25, 2010

**Straw mulch only applied in the furrows of FS treatments.*

2.3 Data determination

2.3.1 Determination of moisture

The moisture was measured using a CNC503B (DR) neutron meter and the depth was measured from 0 to 200 cm. There are 16 neutron tubes in the field and 4 meddlers. Due to the complex terrain of the terraces and the large variation in water, three replicates were set up in the terraces, and the soil water storage was the average of three replicates. The neutron tube in the furrow cultivation mode was set in the furrow, and the non-ditch cultivation mode was set in the central position of each plot. Among them, the 0-60 cm soil layer was measured every 10 cm, and the 60-200 cm soil layer was measured every 20 cm. The measurements were taken every half month from the second season of wheat sowing until the third season of the wheat harvest. Meteorological data related to precipitation and surface evaporation were provided by the Shaanxi Changwu Agricultural Ecology Experimental Station of the Chinese Academy of Sciences.

2.3.2 Determination and analysis of temperature

The temperature data was collected using a StowAway TidbiT pocket automatic temperature gauge. The geothermal instrument was installed at the central position of the terraced field CK and the grass-covered area, where in the furrow cultivation mode was set in the ditch. The temperature measurement began on November 10, 2008, and ended on June 25, 2010. During that period, the soil temperature of 10 cm of the plow layer was automatically recorded every 1 hour. This study mainly analyzes the temperature of 10 cm soil in different growth stages of winter wheat, and randomly selects 8:00 on November 3, 2009, March 6, 2010, April 14, 2010, and June 2, 2010. Key studies were conducted at three-time points, 13:00 and 20:00.

2.4 Data Processing

The processing and statistical analysis of related data used Office 2013 (Microsoft Office programm., 2013), SAS package software (SAS institute Inc., North Caroline, USA) and SPSS 22 software was used to conduct analysis of variance tests (one way ANOVA). Differences between the means of treatments were compared using the least significant difference (LSD) approach. Differences were considered statistically significant when $P \leq 0.05$.

2.4.1 WUE calculation method

Neutron probes (CNC503B, Campbell Scientific, Logan, UT) were used to record the soil moisture of all the plots every 10 cm in the 0-to 60 cm layer and every 20 cm in the 60-to 200-cm layer from sowing in 2007 to harvest in 2010. The neutron tubes were installed in the middle of the CK, NP, and NP+S treatments plots and in the furrow in the middle of the NP+PF and NP+PF+S treatment plots.
Soil moisture data were recorded twice a month and soil water storage in the 200-cm layer was calculated by summing the soil water storage in each layer.

Soil water storage change during the growth period of wheat (W_{Δ}):

W_1 -Soil water storage amount before sowing

W_2 -Soil water storage amount after harvesting

$$W_{\Delta} = W_2 - W_1$$

The consumption of water by wheat (ET):

$$ET = (W_1 + R - W_2)$$

R-Rainfall amount during the whole growth period

Water use efficiency (WUE):

$$WUE = Y / ET$$

Y-Grain yield of winter wheat (kg ha^{-1} mm^{-1})

Potential evaporation: (Potential evaporation=rainfall during growth period +soil water storage change)

$$ET = P + W_{\Delta}$$

The ET was calculated without considering supplements from the underground water supply, surface runoff loss, or deep drainage (Li et al. 1999).

All the data, were analyzed with a one-way ANOVA was applied to check for significant differences between the treatments at each site every year. A comparison of the mean was performed using the LSD method at the 5% level. A correlation analysis was used to assess the relationships among the reported indicators. All the statistical analyses were conducted using the SAS and SPSS 22 software.

Chapter 3 Results & Analysis

3.1 Precipitation and surface evaporation in the area during the test

The Weibei dryland is a semi-humid and drought-prone climate zone, and the natural precipitation is unevenly distributed in time and space. During the winter wheat leisure period (July, August, and September), the precipitation accounts for near to 60% of the annual precipitation, while the growth period was as long as 9 months and the precipitation was less than 40%, and the two seasons of winter wheat have strong evaporation during the growth period (2007-2009), and the water surface evaporation is 550-620 mm. When evaporation compares with precipitation it is much higher than from precipitation (160-215 mm). The result of experiment shown every year from May to September evaporation higher it depends on season's temperature and From October to march evaporation lowest.

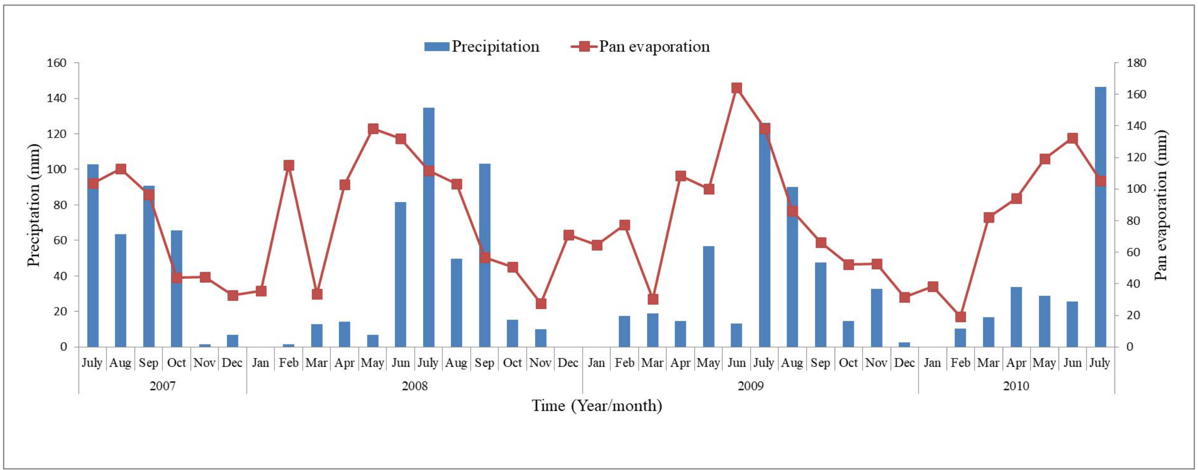

Figure 3.1 Rainfall amount during the experiment period

The monthly potential evaporation during the winter wheat growing season was higher than the monthly precipitation in this region. Those two experiment sites compare with each other Tableland's potential evaporation higher than Terrace field. Actual water losses from land surfaces are strongly influenced by the supply of moisture in the soil. While the highest crop yields are probably consistent with maximum rates of water loss, almost, if not all, plants in their natural environment were subjected to some moisture stress during their growing season (Eagleman 1967).

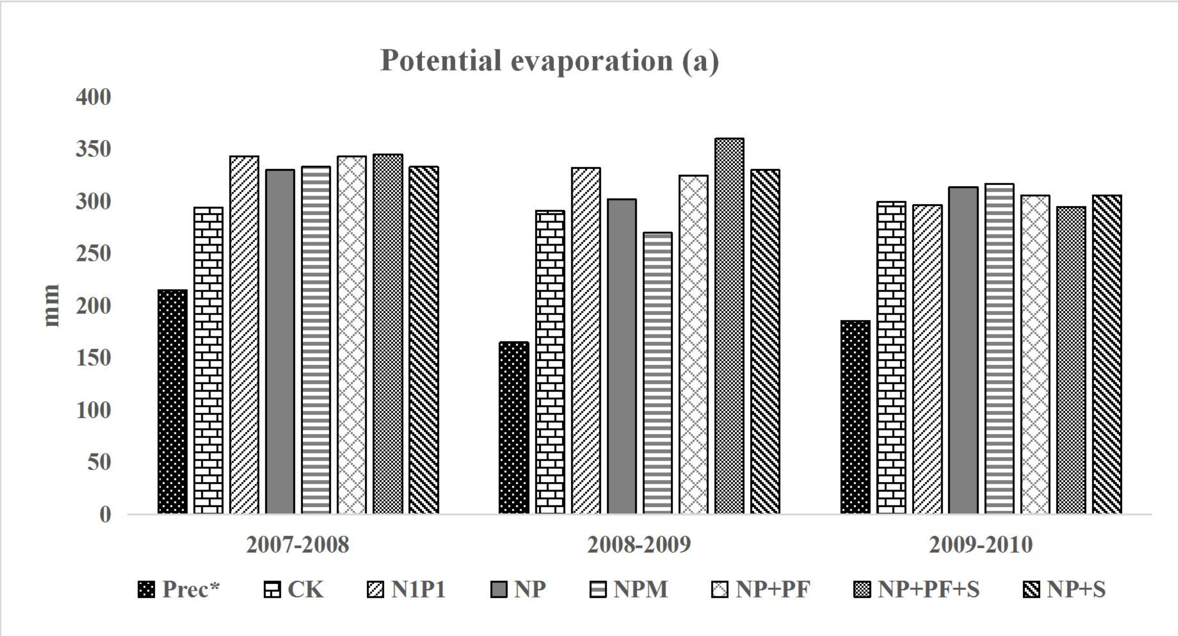

Figure 3.2 Terrace-Potential evaporation (a)*(Prec*-Precipitation)*

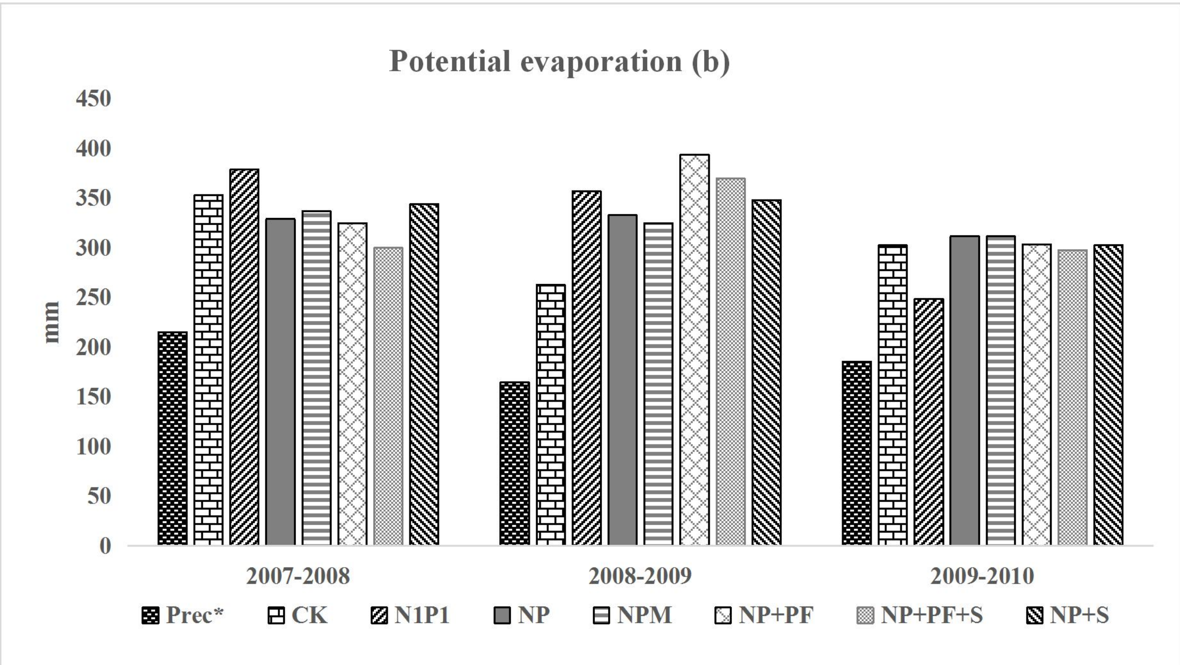

Figure 3.3 Table land-Potential evaporation (b) *(Prec*-Precipitation)*

3.2 Soil water storage during the experiment period

Soil moisture data were recorded twice a month and soil water storage in the 200-cm layer was calculated by summing the soil water storage in each layer. The result indicated first sowing after soil water storage range was from 367 mm to 410 mm in tableland, from 329 mm to 372 mm in terreca site. First year before harvest soil water storage was 272 mm (CK), high was 289 (NP+PF), 305 mm (NP+PF+S) in tableland field. But terrace field's

CK higher than other six treatments and when compared NP+PF 20%, NP+M 25% lowest from CK. Before sowing NP+PF (511mm, 413 mm), NP+PF+S (476 mm, 440 mm) treatments shown high result in tableland field last two years experiment. Also terrace field that two treatments shown high result when compared with other treatments (NP+PF 419 mm, 366 mm, NP+PF+S 477 mm, 404mm).

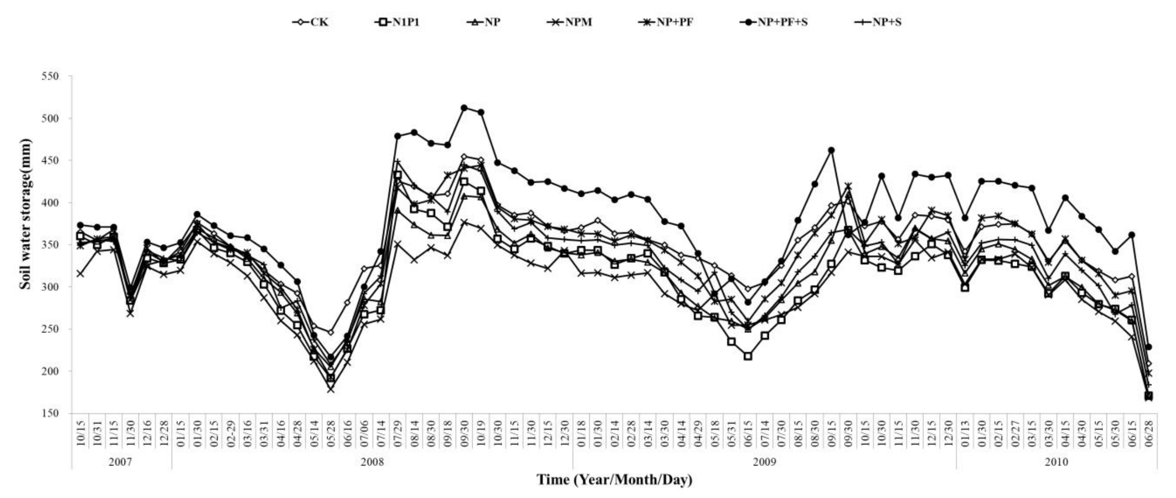

Figure 3.4 Terraced soil water storage

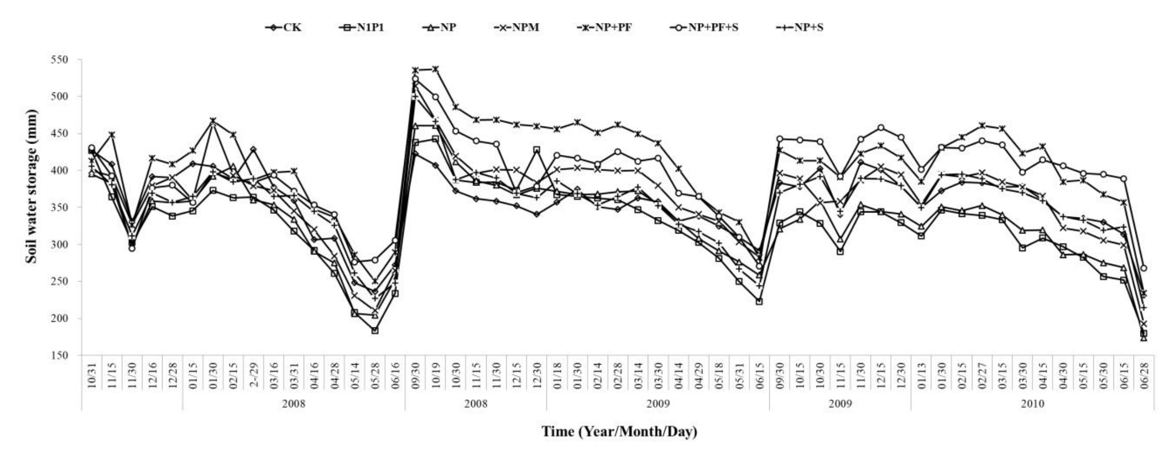

Figure 3.5 Tableland soil water storage

3.2.1 Soil water storage change during the growth period of wheat (Δ W)

When seeing that table soil water storage change during the growth period of wheat all treatments have negative changes. It means soil water storage amount before sowing more higher than after harvesting. During the harvest, there was low soil water storage in all treatments. Tablelands highest and lowest changes were NP+PF+S (85, 229), Terrace field's highest also NP+PF+S (2008-2009) lowest soil water storage changes was CK (79, 2008-2009). Also, soil water storage changes depend on that year's precipitation.

Table 3.1 Soil water storage change (mm) during the growth period in 0-200 cm depth

Experiment site	Treatments	2007-2008	2008-2009	2009-2010
Tableland	CK	138	98	117
	N1P1	164	192	63
	NP	114	178	126
	NPM	122	160	126
	NP+PF	110	229	118
	NP+PF+S	85	205	112
	NP+S	129	183	117
Terrace	CK	79	126	114
	N1P1	128	167	111
	NP	115	137	128
	NPM	118	105	131
	NP+PF	128	160	120
	NP+PF+S	130	195	109
	NP+S	118	165	120

Note: NP+PF recommended fertilization+ridge mulching, NP+PF+S recommended fertilization+ridge mulching +furrow straw mulch, NP+S recommended fertilization+straw mulch, N_1P_1 farmers are used fertilizing, NPM recommended fertilization+organic fertilization, NP recommended fertilization, CK control

3.3 The temperature of the soil in different treatments

Experiment's temperature measurement began on November 10, 2008, and ended on June 25, 2010. During this period, the soil temperature of 10 cm of the plow layer was automatically recorded every 1 hour. This study mainly analyzes the temperature of 10 cm soil in different growth stages of winter wheat. End of winter stage (a) soil temperature was shown negative meaning (-2°C), first two weeks of February soil temperature getting positive meaning shown in 2009. But next year same period soil temperature is shown almost 80 percent was negative meaning all treatments in 2010. During reviving stage (b) soil temperature getting increased at the middle of March (16-18°C), this period changes was not high in 2009 but the same days more changes in 2010. For jointing stage (c) first-year soil temperature a constant increased, second-year soil temperature was changeable. For a term of grain filling stage (d) soil temperature was constant during the experiment period (15-20°C). When the compare that treatments NP+PF+S+R during experiment period soil temperature higher than others, NP+S shown lowest meaning. Chen (2019) found straw mulch practice often lead to a significant decrease in soil temperature, and hence making the wheat, maize and other thermopiles crops seriously reduce production due to the shortage of accumulated temperature. Our experiment also had shown the same result with them.

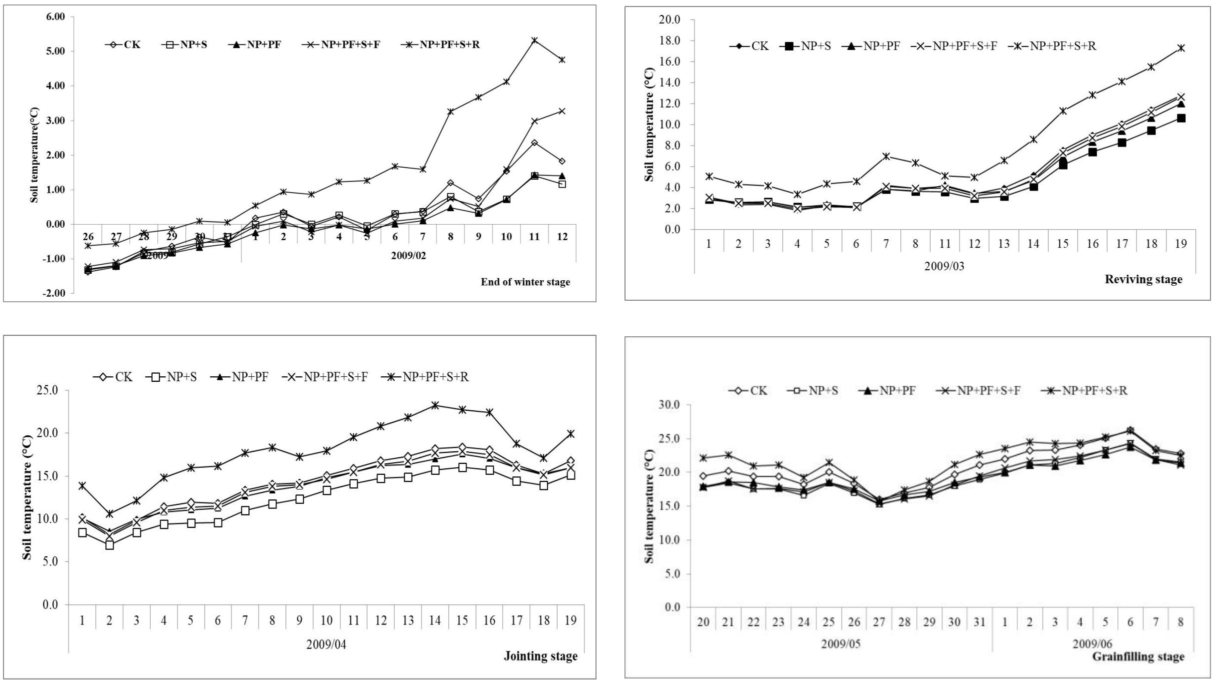

Figure 3.6 The soil temperature measurement in different treatments in 2009

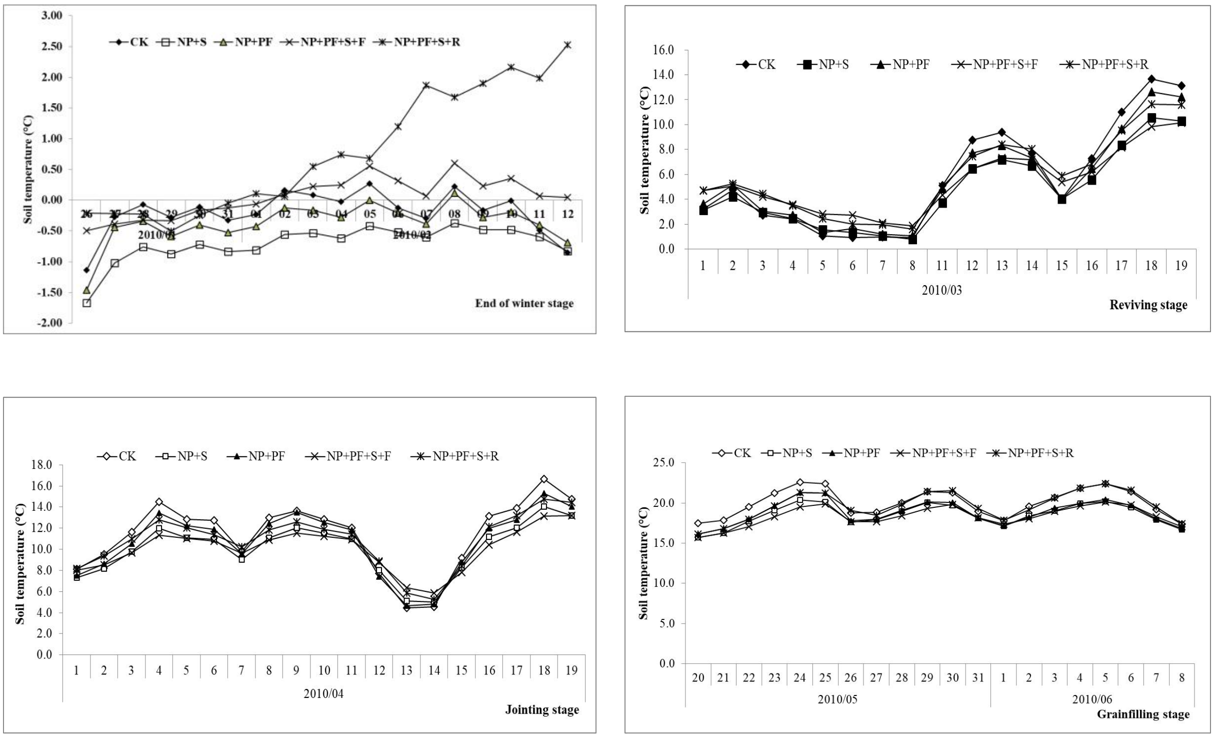

Figure 3.7 The soil temperature measurement in different treatments in 2010

Note: CK as control; NP+S-recommended fertilization+straw mulching; NP+PF is recommended fertilization+ridge mulching; NP+PF+S+F is recommended fertilization+film mulching on ridges+grass mulching in furrows+grass mulching in furrows; NP+PF+S+R is recommended fertilization+film mulching on ridges+grass mulching in furrows+ridges.

3.4 Winter wheat yield under different cultivation modes

Yields result to indicated, NP+PF treatments shown high result compared with other six treatments during two years harvest. CK was 1115 kg/ha, NP+PF (3342 kg/ha), and NP+PF+S (3328 kg/ha) almost similar result shown but NP+S (2764 kg/ha) was low than compared with plastic film mulch at terrace field in 2008-2009. Grain yield was Ck 15%, NP+PF 49%, NP+PF+S 30%, and NP+S 55% increased compared with before year at terrace field. In tableland fields, CK was 3050 kg/ha, NP+PF (6547 kg/ha) and NP+PF+S (6446 kg/ha) shown a similar result, NP+S (6097 kg/ha) grain yield 220% higher than terrace fields CK. All of tablelands treatments result higher than compared with terrace fields in 2008-2009. But grain yield CK 36%, NP+PF 3%, NP+PF+S 13%, NP+S 13% lower than before year in tableland field.

Table 3.2 Effect of different cultivation modes on grain yield in during experiment period

Experiment site	Treatments	Yield (kg/ha)	
		2008-2009	2009-2010
Terrace	NP+PF	3342 a	5010 a
	NP+PF+S	3329 a	4350 b
	NP+S	2764.8 a	4293 b
	N_1P_1	2023.6 b	4014 b
	NPM	2005.4 b	3903 b
	NP	1693.6 bc	3693 c
	CK	1115.6 c	1293 d
Tableland	NP+PF	6547 a	6360 a
	NP+PF+S	6446 a	5663 b
	NP+S	6097 ab	5325 b
	N1P1	5527 b	4770 c
	NPM	5495 b	4005 d
	NP	5155 bc	3555 de
	CK	3050 c	1965 e

Note: NP+PF recommended fertilization+ridge mulching, NP+PF+S recommended fertilization+ridge coating+furrow straw mulch , NP+S recommended fertilization+straw mulch, N_1P_1 farmers are used fertilizing, NPM recommended fertilization+organic fertilization, NP recommended fertilization, CK control. Values followed by different letters within a column and in the same year are significantly different ($P<0.05$) Differences between the means of treatments were compared using the least significant difference (LSD) approach. Differences were considered statistically significant when $P<0.05$(one way ANOVA).

3.5 Water use efficiency of winter wheat in two seasons under different treatments

During the experiment period N_1P_1 (Tableland) lowest water consumption in 2009-2010 harvest year (248.6) but that years precipitation was 215 mm in the growth stage. The highest was NP+PF in 2008-2009 at Tableland site. That years precipitation during growth period was 164.9, pan evaporation 617.7 mm. Two sites all treatments use water during the growth period were higher than rainfall in experiment years. Chen (2015) found that the water consumption of winter wheat was much higher than the precipitation during the growing season in the Loess Plateau. Our study also exhibited their idea (Figure 3.7, Figure 3.8).

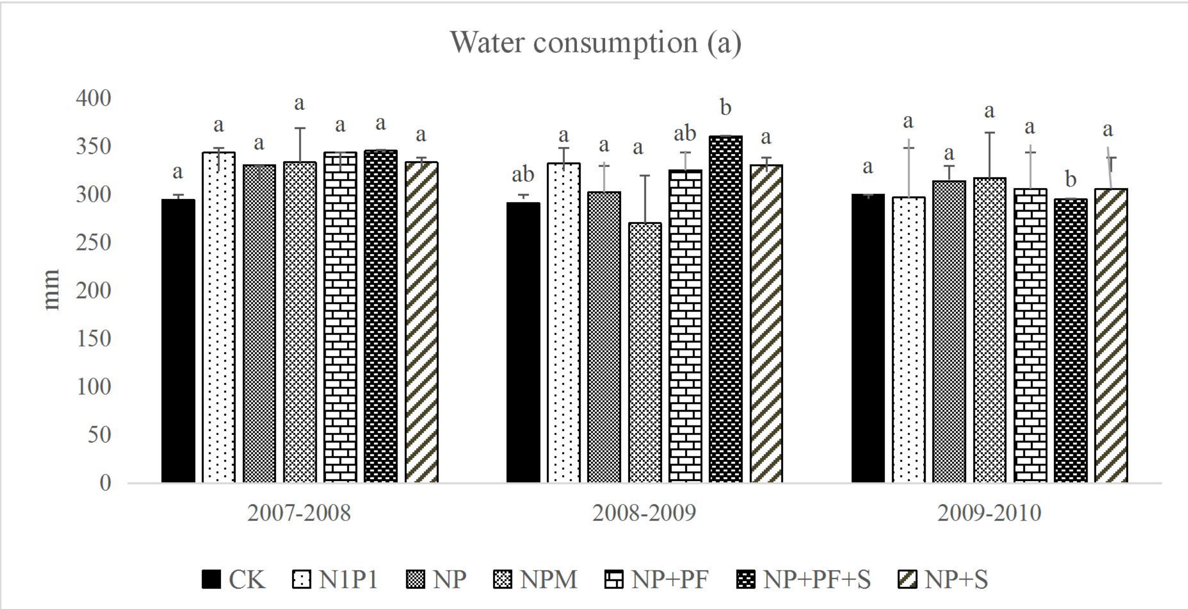

Figure 3.8 Water consumption Terrace(a)

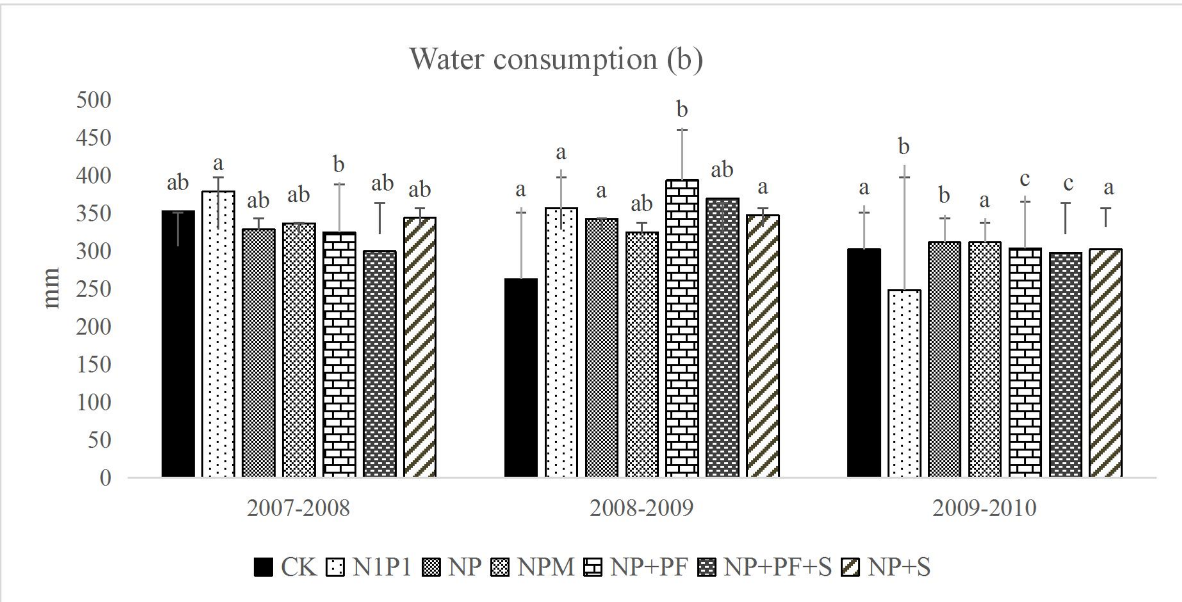

Figure 3.9 Water consumption Tableland(b)

During the experiment period (2007-2010), water use efficiency was from 3.8 kg/mm·ha to 16.4 kg/mm·ha in Terrace field and 6.4-20.9 kg/mm·ha in Tableland site. NP+PF and NP+PF+S are shown the highest result in experimental years both of sites. It means recommended fertilizer combine with mulch is good effect shown for water saving in agriculture. Also water usage of winter wheat difference from soil structure and experimental sites position (Terrace field was slope)

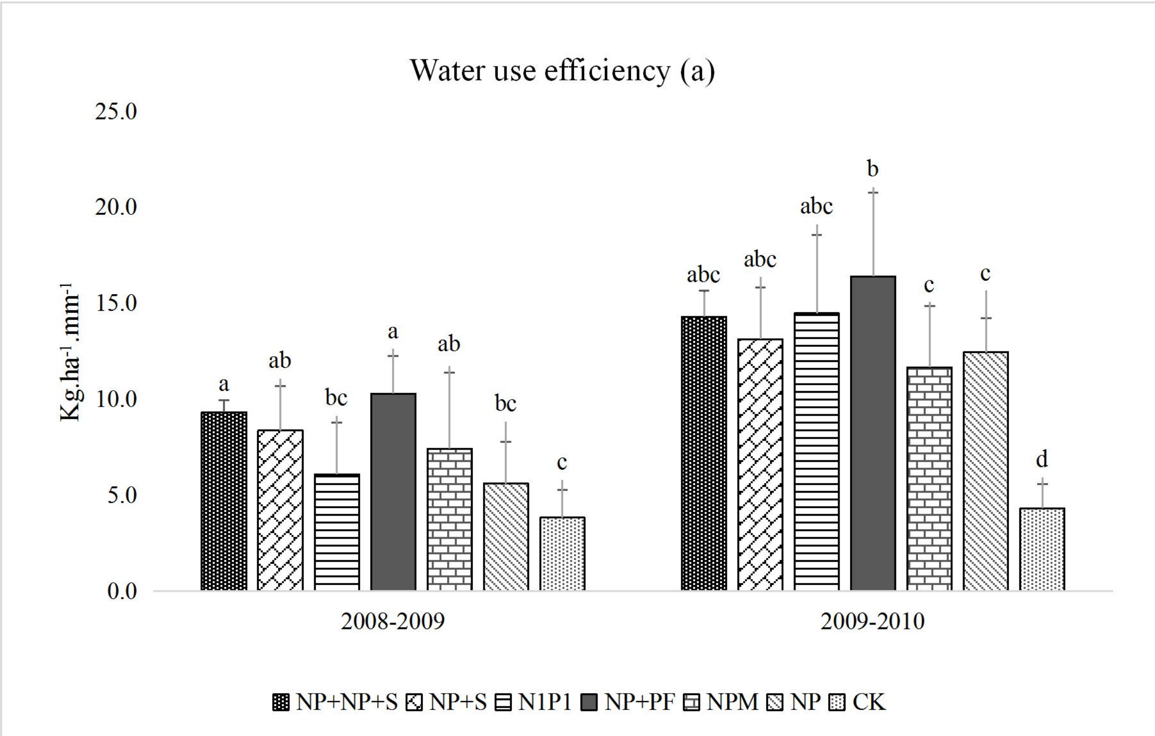

Figure 3.10 WUE-Terrace (a)

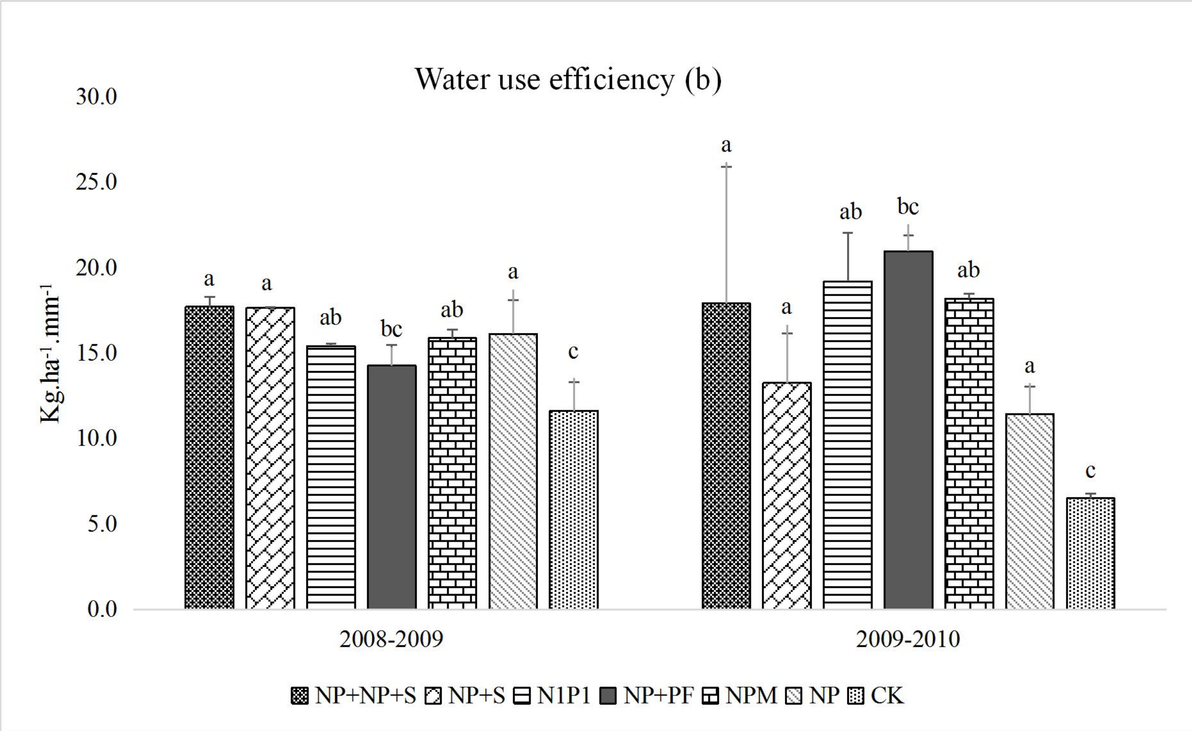

Figure 3.11 WUE-Tableland (b)

Chapter 4 Discussion & Conclusion

4.1 Discussion

Based on a field study on the semi-arid Loess Plateau of China, proposed on those techniques have exhibited positive effects on increasing soil water storage, reducing evaporation, improving crop yield and water use efficiency in dryland. In the Loess Plateau with serious water deficit for agricultural production, thus need to reduce evaporation, as to improve water availability specifically soil water. High yield depends on water also good soil properties in dryland region (Fan et al. 2019). Therefore, many technologies, including straw mulching, plastic film mulching and rainwater harvesting, have been widely used in the world to improve soil quality and crop growth environment, thereby increasing crop yield.

The experiment has seven treatments, all was plus recommended fertilization (N and P, without CK), two treatments with straw mulch, another two of treatments with plastic mulch and one treatment with organic fertilization. Nitrogen (N) and phosphorus (P) are essential elements for living systems. Global N and P consumption are steadily increasing in response to the growing population and increased demand for food crops, non-food crops such as biofuels, and animal-derived food. This has led to the over-use of N and P in a number of agri-food production systems around the world (Huang et al. 2017). Plastic film mulch widely used in worldwide for the agriculture sector to conserve soil moisture, to increase the topsoil temperature, improving the promoted earlier germination for crop growth (Liu et al. 2009), control weeds (Feng et al. 2019) and improve water use efficiency. Straw mulching can increase water infiltration into the soil, reduce evaporation loss from the soil surface, and increase water in the soil profile (Dong et al. 2018), protect the surface from direct strike of raindrops, enhance soil aggregation, and promote biological activity.

1. Precipitation and pan evaporation

Rainfed wheat they are to make full use of natural precipitation to achieve a stable crop yield. The actual evapotranspiration (Eta), yield, and water use efficiency are significantly affected by water management practices (Jin et al. 2018). During the experiment period precipitation was 215 mm (2007-2008) during the growth period, pan evaporation was 280% higher than from precipitation, 2008-2009 was 165 mm, pan evaporation was higher by 374.5%, when compared that three years it was highest, last year precipitation was 186 mm

(2009-2010), pan evaporation 297% higher from precipitation. The annual precipitation affects the yield and soil moisture.

2. Soil water storage in 0-200 cm layer

Soil water is an important factor for crop production in arid and semiarid regions (Li et al. 2018) thus increasing soil water conservation is a crucial approach for improving winter wheat productivity in dryland (He et al. 2016). Soil moisture data were recorded twice a month, started from October of 2007 until June of 2010 and 200-cm layer was calculated by summing the soil water storage. During the experimental years, soil water storage decreased when increasing air temperature and crop growth period but increased as the rainy season (July-Oct) arrived during the fallow period, especially in the NP+PF and NP+PF+S treatments in the tableland. During the winter wheat growing season, the water deficit is severe and precipitation generally cannot meet the water requirement for crop growth and development (Jin et al. 2018). Tableland field's soil water storage during experiment periods on May lowest (N1P1) and from July to October was higher than other months in 2008. Tableland field's seven treatments soil water content was lowest in May during two years (2008, 2009). For Terrace field's lowest month was June (2009, 2010). When the compare that seven treatments, two field's NP+PF+S higher soil water storage than others. Zhang (2019) reported plastic film mulching can significantly improve soil moisture in semi-arid regions by suppressing evaporation and enhancing water infiltration, plastic film has the greatest potential to reduce soil water loss. Experiment result also matched with (Malhi et al. 2014), means plastic mulch and straw mulch both enhanced soil water content. Plastic mulch typically decreases soil water loss by evaporation, increases crop transpiration (He et al. 2016) and straw mulching during the fallow period reduced soil evaporation, augmented the infiltration of rainwater into the soil and enhanced soil water retention (Peng et al. 2015).

3. Soil temperature

Temperature and moisture content of the soil largely determine the germination, blooming, composting, and a variety of other processes (Heerdt et al. 2017) because the growth of biological systems is closely controlled by soil temperature. Soil temperature is influenced by solar radiation, daily and monthly fluctuations of air temperatures as well as vegetation, amount of precipitation (Waring et al. 2007). The topsoil measurements were done in four different phases, at three replicate locations in the 10 cm layer of the terrace plots. End of winter stage soil temperature was -2°C to 5°C in 2009, from -2°C to 2.5°C, NP+PF+S+R (recommended fertilization+film mulching on ridges+grass mulching in furrows+ridges) shown positive result when compared with other treatments. NP+S and

NP+PF+S+R treatments changes was so high. Reviving stage, jointing stage and grain filling stage soil temperature was constant to all treatment but NP+S shown lowest result during that period when compared with other 4 treatments. From that result straw mulch is not good for keep soil temperature, application of straw mulch prevents the soil surface from receiving direct sunlight and reduces soil radiation absorption (Chen et al. 2007) both of which decrease the soil temperature (Zhang et al. 2011). Zhao (2019) mentioned straw mulch adverse effects on soil temperature so have limited use for agricultural.

4. Grain yield and WUE

Experiment period at each site's wheat yield ranged from 1115 to 6360 kg/ha, NP+PF shown higher meaning when compared with other treatments. When Terrace fields NP+PF compare with Ck changes was three times lower in 2008-2009. Table land's Ck was two times lower than NP+PF. Recommended fertilization (NP), NPM, and farmers method (N_1P_1) also shown a low result. That two experiments site's result rate so high, terrace field was approximately 50% lower than tableland. Therefore, the lower grain yield at the terrace was attributed to the natural soil's physical and chemical properties. When compared with the tableland soil, the terrace soil had a higher sand content, which negatively affected the soil water retention capacity. Moreover, the lower soil organic matter may have contributed to poor wheat production. Chen (2015) and Dong (2018) found the effects of mulching practices on crop yields depend on the climate condition, crop type, and soil texture. Plastic mulch combined with recommended fertilization shown high yield this experiment, also nowdays widely used for increasing crop yield in rainfed drylands, such as in China. Owing to plastic mulch applications, spring wheat grain yield was increased by 23% in the west of Loess Plateau (Li et al. 1999) and winter wheat grain yield was increased by 30% in the middle part of Loess Plateau (Zhang et al. 2013).

Agriculture is the biggest consumer of water resources in every country. Over the years, agricultural water use efficiency has been widely studied. But efficiency gains are often possible through suitable crop selection, proper irrigation scheduling, effective irrigation techniques, and using alternative sources of water for irrigation (Li et al. 2019a). It should be noted that increasing water efficiency often provides benefits that go far beyond reduced water use (Hewitt et al. 2013). In terrace field, WUE's range was from 7.7 kg/mm·ha (CK) to 13 kg/mm·ha (NP+PF+S) in 2007-2008. Second-year CK 50.1%, NP+PF+S 29%, NP+S 10.6% lower than the first year. The previous year WUE was only CK 4.3 kg/mm·ha other six treatments between from 11.7 kg/mm·ha (NPM) to 16.4 kg/mm·ha (NP+PF) in terrace field. During that period tableland field's WUE higher than Terrace field. The first-year lowest result was CK 6.4 kg/mm·ha, highest was NP+PF 12 kg/mm·ha and NP+PF+S 14.9 kg/mm·ha. NP, NPM and NP+S result was had not much differences. Last year CK result same likes first years, other treatments range was between from 11.6 kg/mm·ha (CK second year) to 20.9 kg/mm·ha (NP+PF last year). When compared two fields tablelands treatments shown high result during that experiment. NP+PF and NP+PF+S treatment's had shown similar result in this experiment. Improving the WUE can be achieved by increasing the production per unit of water consumed or reducing the amount of water consumed per unit yield of production (Jin et al. 2018).

4.2 Conclusions

The experiment focused on how to rainfall effectively use in winter wheat (crop), especially the rainfed area. When the conclusion that three years of field experiment-first factor precipitation is considered the only water source to replenish soil water in this region. From July to the end of September, about 60 percent of the total precipitation fall in this region. So depending on the amount of rainfall, soil water storage was higher when before sowing the winter wheat and the amount of soil water is lower when the harvest month. Two experiment sites soil water storage changes were different.

When we saw the result NP+PF also NP+PF+S was soil water storage higher than others, when compare two field same treatments tableland's higher than Terreca field. The result has shown plastic mulch and straw mulch both enhanced soil water storage. For soil temperature 5 different treatments, four different phases measured NP+PF+S+R shown more positive result during the two years period. (Hu et al. 2015) found generally, soil water storage was higher and soil temperature was lower under straw mulching than under conventional practice. Our result in a similar result shown with them.

Two experiment sites grain yield's changes too high during two years period. Terrace field's grain yield two times lower than from tableland. The main reason was Terrace field's soil dominated sandy so not too much soil organic matter also that sites located slope plate. Both experiment sites NP+PF and NP+PF+S yield higher than other treatments, Ck was lower when compared with others. WUE also tableland more than higher from Terrace field.

Soil water storage, soil temperature, grain yield and WUE NP+PF treatment shown positive result during three years experiment. So recommended fertilization plus plastic mulch technology suitable for rainfed agriculture, farmers use that method for their planting they can receive plenteous harvest it will provide to them for economic significance.

Reference

Adekalu, K. O., I. A. Olorunfemi, and J. A. Osunbitan. 2007. Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in nigeria. *Bioresource Technology* 98(4): 912–17.

Adhikari, Raju, Keith L Bristow, Philip S. Casey, George Freischmidt, John W. Hornbuckle, and Benu Adhikari. 2016. Preformed and sprayable polymeric mulch film to improve agricultural water use efficiency. *Agricultural Water Management* 169:1–13.

Adhikari, Raju, Keith L. Bristow, Philip S. Casey, George Freischmidt, John W. Hornbuckle, and Benu Adhikari. 2016. Preformed and sprayable polymeric mulch film to improve agricultural water use efficiency. *Agricultural Water Management* 169: 1–13.

Agassi, M., G. J. Levy, A. Hadas, Y. Benyamini, H. Zhevelev, E. Fizik, M. Gotessman, and N. Sasson. 2004. Mulching with composted municipal solid wastes in central negev, israel: i. effects on minimizing rainwater losses and on hazards to the environment. *soil and tillage research* 78(1): 103–13.

Ammala, Anne, Stuart Bateman, Katherine Dean, Eustathios Petinakis, Parveen Sangwan, Susan Wong, Qiang Yuan, Long Yu, Colin Patrick, and K. H. Leong. 2011. An overview of degradable and biodegradable polyolefins. Vol. 36. Elsevier Ltd.

Anifantis, A., G. Canzio, G. Cristiano, B. De Lucia, G. Russo, L. Vecchietti, B. Immirzi, M. Malinconico, and G. Santagata. 2012. Influence of the use of drip irrigation systems and different mulching materials on ornamental sunflowers in greenhouse cultivation. *Acta Horticulturae* 952: 385–92.

Arora, V. K., C. B. Singh, A. S. Sidhu, and S. S. Thind. 2011. Irrigation, tillage and mulching effects on soybean yield and water productivity in relation to soil texture. *Agricultural Water Management* 98 (4): 563–68.

Benintende, Silvia M., María C. Benintende, María A. Sterren, and Juan J. De Battista. 2008. Soil microbiological indicators of soil quality in four rice rotations systems. *Ecological Indicators* 8 (5): 704–8.

Berger, Sina, Youngsun Kim, Janine Kettering, and Gerhard Gebauer. 2013. Agriculture , ecosystems and environment plastic mulching in agriculture — friend or foe of N_2O emissions ? *Agriculture, Ecosystems and Environment* 167: 43–51.

Bonfil, David J., I. Mufradi, S. Klitman, and S. Asido. 1999. Wheat grain yield and soil profile water distribution in a no-till arid environment. *Agronomy Journal* 91(3): 368–73.

Bottenberg, Harry, John Masiunas, and Catherine Eastman. 1999. Loss of snapbean planted in rye mulch. 9 (June): 1995–2000.

Boyhan, George E., Ray Hicks, and C. Randell Hill. 2006. Natural mulches art not very effective for weed control in onions. *HortTechnology* 16 (3): 523–26.

Briassoulis, Demetres, Epifaneia Babou, Miltiadis Hiskakis, and Ioanna Kyrikou. 2015. Analysis of long-term degradation behaviour of polyethylene mulching films with pro-oxidants under real cultivation and soil burial conditions. *Environmental Science and Pollution Research* 22 (4): 2584–98.

Carney, Karen M. and Pamela A. Matson. 2005. Plant communities, soil microorganisms, and soil carbon cycling: does altering the world belowground matter to ecosystem functioning? *Ecosystems* 8(8): 928–40.

Chae, Yooeun and Youn Joo An. 2018. Current research trends on plastic pollution and ecological impacts on the soil ecosystem: a review. *Environmental Pollution (Barking, Essex : 1987)* 240: 387–95.

Chakraborty, Debashis, R. N. Garg, R. K. Tomar, Ravender Singh, S. K. Sharma, R. K. Singh, S. M. Trivedi, R. B. Mittal, P. K. Sharma, and K. H. Kamble. 2010. Synthetic and organic mulching and nitrogen effect on winter wheat (Triticum Aestivum L.) in a semi-arid environment. *Agricultural Water Management* 97(5): 738–48.

Chakraborty, Debashis, Shantha Nagarajan, Pramila Aggarwal, V. K. Gupta, R. K. Tomar, R. N. Garg, R. N. Sahoo, A. Sarkar, U. K. Chopra, K. S. Sundar. Sarma, and N. Kalra. 2008. Effect of mulching on soil and plant water status, and the growth and yield of wheat (Triticum Aestivum L.) in a semi-arid environment. *Agricultural Water Management* 95 (12): 1323–34.

Chen, S. Y., X. Y. Zhang, D. Pei, H. Y. Sun, and S. L. Chen. 2007. Effects of straw mulching on soil temperature, evaporation and yield of winter wheat: field experiments on the north china plain. *Annals of Applied Biology* 150(3): 261–68.

Chen, Yanlong, Ting Liu, Xiaohong Tian, Xiaofeng Wang, Meng Li, Shaoxia Wang, and Zhaohui Wang. 2015. Effects of plastic film combined with straw mulch on grain yield and water use efficiency of winter wheat in loess plateau. *Field Crops Research* 172: 53–58.

Chen, Yuzhang, Shouxi Chai, Huihui Tian, Yuwei Chai, Yawei Li, Lei Chang, and Hongbo Cheng. 2019. Straw strips mulch on furrows improves water use efficiency and yield of potato in a rainfed semiarid area. *Agricultural Water Management* 211(July 2018): 142–51.

Cook, Hadrian F., Gerardo S. B. Valdes, and Howard C. Lee. 2006. Mulch effects on rainfall interception, soil physical characteristics and temperature under zea mays l. *Soil and Tillage Research* 91(1–2): 227–35.

Cuello, Jennifer P., Hyun Young Hwang, Jessie Gutierrez, Sang Yoon Kim, and Pil Joo Kim. 2015. Impact of plastic film mulching on increasing greenhouse gas emissions in temperate upland soil during maize cultivation. *Applied Soil Ecology* 91: 48–57.

Deng, Xi Ping, Lun Shan, Heping Zhang, and Neil C. Turner. 2006. Improving agricultural water use efficiency in arid and semiarid areas of China. *Agricultural Water Management* 80 (1-3 SPEC. ISS.): 23–40.

Devkota, M., C. Martius, J. P. A. Lamers, K. D. Sayre, K. P. Devkota, R. K. Gupta, O. Egamberdiev, and P. L. G. Vlek. 2013. Field crops research combining permanent beds and residue retention with nitrogen fertilization improves crop yields and water productivity in irrigated arid lands under cotton , wheat and maize. *Field Crops Research* 149: 105–14.

Dong, Qin'ge, Yuchen Yang, Kun Yu, and Hao Feng. 2018. Effects of straw mulching and plastic film mulching on improving soil organic carbon and nitrogen fractions, crop yield and water use efficiency in the loess plateau, China. *Agricultural Water Management* 201 (August 2017): 133–43.

Döring, Thomas F., Michael Brandt, Jürgen Heß, Maria R. Finckh, and Helmut Saucke. 2005. Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. *Field Crops Research* 94 (2–3): 238–49.

Eagleman, J. O. E. R. 1967. Pan evaporation , potential and actual evapotranspiration." 6: 482–88.

Erisman, Jan Willem, Mark A. Sutton, James Galloway, Zbigniew Klimont, and Wilfried Winiwarter. 2008. How a century of ammonia synthesis changed the world. *nature geoscience* 1(10): 636–39.

Espí, Enrique, Armando Salmerón, Antonio Fontecha, Yolanda García, and Ana Isabel Real. 2006. Plastic films for agricultural applications. *journal of plastic film and sheeting* 22(2): 85–102.

Fan, Tinglu, Shuying Wang, Yongping Li, Xiaomei Yang, Shangzhong Li, and Mingsheng Ma. 2019. Film mulched furrow-ridge water harvesting planting improves agronomic productivity and water use efficiency in rainfed areas. *Agricultural Water Management* 217(February): 1–10.

Feng, Yu, Weiping Hao, Lili Gao, Haoru Li, Daozhi Gong, and Ningbo Cui. 2019. Comparison of maize water consumption at di ff erent scales between mulched and non-mulched croplands. *Agricultural Water Management* 216 (February): 315–24.

Galloway, J. N., F. J. Dentener, D. G. Capone, E. W. Boyer, R. W. Howarth, S. P. Seitzinger, G. P. Asner, C. C. Cleveland, P. A. Green, E. A. Holland, D. M. Karl, A. F. Michaels, J. H. Porter, A. R. Townsend, and C. J. Vo. 2004. *Galloway-et-Al-2004-BioGeoCh*.

Gao, Yajun, Æ. Yun Li, and Æ. Jianchang Zhang. 2014. Effects of mulch , n fertilizer , and plant density on wheat yield , wheat nitrogen uptake , and residual soil nitrate in a dryland area of china effects of mulch , n fertilizer , and plant density on wheat yield , wheat nitrogen uptake , and residual soil. (October 2009).

Gao, Yajun, Yun Li, Jianchang Zhang, Wenguo Liu, Zhanping Dang, Weixian Cao, and Qin Qiang. 2009. Effects of mulch, n fertilizer, and plant density on wheat yield, wheat nitrogen uptake, and residual soil nitrate in a dryland area of China. *Nutrient Cycling in Agroecosystems* 85(2): 109–21.

Giomaro, G., A. Ricci, and P. Scaramella. 1988. Sezione and principal linee di ricerca: considerazioni filogeijetiche da stud1 di process1 di ripara=zioi'je in vivo e in vitro di piante arcaiche a portamento li-anoso. *Giornale Botanico Italiano* 122 (August): 193.

Hayes, Douglas G., Sathiskumar Dharmalingam, Larry C. Wadsworth, Karen K. Leonas, Carol Miles, and Debra a Inglis. 2012. Biopolymers Introduction : The need for biodegradable mulches.

He, Gang, Zhaohui Wang, Fucui Li, Jian Dai, Qiang Li, Cheng Xue, Hanbing Cao, Sen Wang, and Sukhdev S. Malhi. 2016. Soil water storage and winter wheat productivity affected by soil surface management and precipitation in dryland of the Loess Plateau, China. *Agricultural Water Management* 171: 1–9.

Ter Heerdt, Gerard N. J., Ciska G. F. Veen, Wim H. Van der Putten, and Jan P. Bakker. 2017. Effects of temperature, moisture and soil type on seedling emergence and mortality of riparian plant species. *Aquatic Botany* 136: 82–94.

Hewitt, Kelsey. 2013. Cu scholar water efficiency usage in agriculture: evaluating the use of allocated water in food production.

Hou, Y., L. Ma, Z. L. Gao, F. H. Wang, J. T. Sims, W. Q. Ma, and F. S. Zhang. 2013. The driving forces for nitrogen and phosphorus flows in the food chain of china, 1980 to 2010. *Journal of Environment Quality* 42 (4): 962.

Hu, Changlu, Mao Ding, Chao Qu, Victor Sadras, Xueyun Yang, and Shulan Zhang. 2015. Yield and water use efficiency of wheat in the loess plateau: responses to root pruning and defoliation. *Field Crops Research* 179: 6–11.

Hu, Changlu, Cheng Zheng, Victor O. Sadras, Mao Ding, Xueyun Yang, and Shulan Zhang. 2018. Effect of straw mulch and seeding rate on the harvest index, yield and water use efficiency of winter wheat. *Scientific Reports* 8 (1): 1–8.

Hu, Naijuan, Baojun Wang, Zehai Gu, Baorui Tao, Zhengwen Zhang, Shuijin Hu, Liqun Zhu, and Yali Meng. 2016. Effects of different straw returning modes on greenhouse gas emissions and crop yields in a rice-wheat rotation system. *Agriculture, Ecosystems and Environment* 223: 115–22.

Huang, Jing, Chang chun Xu, Bradley G. Ridoutt, Xue chun Wang, and Pin an Ren. 2017. Nitrogen and phosphorus losses and eutrophication potential associated with fertilizer application to cropland in China. *Journal of Cleaner Production* 159: 171–79.

Huang, Yilong, Liding Chen, Bojie Fu, Zhilin Huang, and Jie Gong. 2005. The wheat yields and water-use efficiency in the loess plateau: straw mulch and irrigation effects. *Agricultural Water Management* 72 (3): 209–22.

Hurley, Rachel R. and Luca Nizzetto. 2018. Fate and occurrence of micro(nano)plastics in soils: knowledge gaps and possible risks. *Current Opinion in Environmental Science & Health* 1: 6–11.

Ji, Shangning and Paul W. Unger. 2010. Soil water accumulation under different precipitation, potential evaporation, and straw mulch conditions. *Soil Science Society of America Journal* 65(2): 442.

Jiang, Xiaojin and Xiao Gang Li. 2015. Assessing the effects of plastic film fully mulched ridge-furrow on rainwater distribution in soil using dye tracer and simulated rainfall. *Soil and Tillage Research* 152: 67–73.

Jin, Ning, Wei Ren, Bo Tao, Liang He, Qingfu Ren, Shiqing Li, and Qiang Yu. 2018. Effects of water stress on water use efficiency of irrigated and rainfed wheat in the Loess Plateau, China. *Science of the Total Environment* 642: 1–11.

Jordán, Antonio, Lorena M. Zavala, and Juan Gil. 2010. Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. *Catena* 81(1): 77–85.

Ju, X. T., G. X. Xing, X. P. Chen, S. L. Zhang, L. J. Zhang, X. J. Liu, Z. L. Cui, B. Yin, P. Christie, Z. L. Zhu, and F. S. Zhang. 2009. Reducing environmental risk by improving n management in intensive chinese agricultural systems. *Proceedings of the National Academy of Sciences* 106 (9): 3041–46.

Kader, M. A., M. Senge, M. A. Mojid, and K. Ito. 2017. Recent Advances in Mulching materials and methods for modifying soil environment. *Soil and Tillage Research* 168: 155–66.

Kasirajan, Subrahmaniyan and Mathieu Ngouajio. 2012. Polyethylene and biodegradable mulches for agricultural applications : a review. 501–29.

Komariah, Kengo Ito, Takeo Onishi, and Masateru Senge. 2011. Soil properties affected by combinations of soil solarization and organic amendment. *Paddy and Water Environment* 9(3): 357–66.

Kyrikou, Ioanna and Æ. Demetres Briassoulis. 2007. Biodegradation of agricultural plastic films : A Critical Review. 11855.

Lal, R. 2005. World crop residues production and implications of its use as a biofuel. *Environment International* 31(4): 575–84.

Lal, Ratan. 2016. Soil temperature , soil moisture and maize yield from mulched and unmulched tropical soils : Springer 40 (1): 129–43.

Lamont, William James. 2005. Plastics: modifying the microclimate for the production of vegetable crops. *HortTechnology* 15(3): 477–81.

Li, Feng Min, An Hong Guo, and Hong Wei. 1999. Effects of clear plastic film mulch on yield of spring wheat. *Field Crops Research* 63(1): 79–86.

Li, Feng Min, Qiu Hua Song, Patrick K. Jjemba, and Yuan Chun Shi. 2004. Dynamics of soil microbial biomass c and soil fertility in cropland mulched with plastic film in a semiarid agro-ecosystem. *Soil Biology and Biochemistry* 36 (11): 1893–1902.

Li, Hongchen, Xining Zhao, Xiaodong Gao, Kemeng Ren, and Pute Wu. 2018. Effects of water collection and mulching combinations on water infiltration and consumption in a semiarid rainfed orchard. *Journal of Hydrology* 558: 432–41.

Li, Na, Chunju Zhou, Xiao Sun, Jianyuan Jing, Xiaoxiao Tian, and Linquan Wang. 2018. Effects of ridge tillage and mulching on water availability, grain yield, and water use efficiency in rain-fed winter wheat under different rainfall and nitrogen conditions. *Soil and Tillage Research* 179 (January): 86–95.

Li, S. X., Z. H. Wang, S. Q. Li, Y. J. Gao, and X. H. Tian. 2013. Effect of plastic sheet mulch, wheat straw mulch, and maize growth on water loss by evaporation in dryland areas of China. *Agricultural Water Management* 116: 39–49.

Li, Weiwei, Li Xiong, Changjiang Wang, Yuncheng Liao, and Wei Wu. 2019a. Optimized ridge–furrow with plastic film mulching system to use precipitation efficiently for winter wheat production in dry semi–humid areas. *Agricultural Water Management* 218 (December 2018): 211–21.

Li, Weiwei, Li Xiong, Changjiang Wang, Yuncheng Liao, and Wei Wu. 2019b. Optimized ridge – furrow with plastic fi lm mulching system to use precipitation efficiently for winter wheat production in dry semi – humid areas. *Agricultural Water Management* 218 (March): 211–21.

Li, Zi-Zhen, Wei-De Li, and Wen-Long Li. 2003. Dry-period irrigation and fertilizer application affect water use and yield of spring wheat in semi-arid regions. *Agricultural Water Management* 65 (2): 133–43.

Lingling, Li, Zhang Renzhi, Luo Zhuzhu, Liang Weili, Xie Junhong, and Cai Liqun. 2014. evolution of soil and water conservation in rain-fed areas of China. *International Soil and Water Conservation Research* 2(1): 78–90.

Liu, C. A., S. L. Jin, L. M. Zhou, Y. Jia, F. M. Li, Y. C. Xiong, and X. G. Li. 2009. Effects of plastic film mulch and tillage on maize productivity and soil parameters. *European Journal of Agronomy* 31(4): 241–49.

Liu, Jianliang, Ai Zhan, Huai Chen, Shasha Luo, Lingduo Bu, Xinping Chen, and Shiqing Li. 2015. Response of nitrogen use efficiency and soil nitrate dynamics to soil mulching in dryland maize (Zea Mays L.) Fields. *Nutrient Cycling in Agroecosystems* 101(2): 271–83.

Liu, Jiyuan, Mingliang Liu, Hanqin Tian, Dafang Zhuang, Zengxiang Zhang, Wen Zhang, Xianming Tang, and Xiangzheng Deng. 2005. Spatial and temporal patterns of China's cropland during 1990-2000: An Analysis Based on Landsat TM Data. *Remote Sensing of Environment* 98(4): 442–56.

Liu, Qiaofei, Yu Chen, Weiwei Li, Yang Liu, Juan Han, Xiaoxia Wen, and Yuncheng Liao. 2016. Plastic-film mulching and urea types affect soil co2 emissions and grain yield in spring maize on the Loess Plateau, China. *Scientific Reports* 6: 1–10.

Liu, Ting, Yanlong Chen, Shaoxia Wang, Zhaohui Wang, Xiaofeng Wang, Xiaohong Tian, Huilin Chen, and Meng Li. 2015. Improving winter wheat grain yield and water use efficiency through fertilization and mulch in the Loess Plateau. *Agronomy Journal* 107(6): 2059.

Liu, Xiao-E., Xiao Gang Li, Long Hai, Yong Peng Wang, Tao-Tao Fu, Neil C. Turner, and Feng Min Li. 2014. Film-mulched ridge–furrow management increases maize productivity and sustains soil organic carbon in a dryland cropping system. *Soil Science Society of America Journal* 78(4): 1434.

Liu, Xiao E., Xiao Gang Li, Rui Ying Guo, Yakov Kuzyakov, and Feng Min Li. 2015. The effect of plastic mulch on the fate of urea-n in rain-fed maize production in a semiarid environment as assessed by 15n-labeling. *European Journal of Agronomy* 70: 71–77.

Lu, Chaoqun and Hanqin Tian. 2017. Global nitrogen and phosphorus fertilizer use for agriculture production in the past half century: Shifted hot spots and nutrient imbalance. *Earth System Science Data* 9(1): 181–92.

Luo, Laichao, Zhaohui Wang, Ming Huang, Xiaoli Hui, Sen Wang, Yue Zhao, Hongxia He, Xiang Zhang, Chaopeng Diao, Hanbing Cao, Qingxia Ma, and Jinshan Liu. 2018a. Plastic film mulch increased winter wheat grain yield but reduced its protein content in dryland of northwest China. *Field Crops Research* 218 (July 2017): 69–77.

Luo, Laichao, Zhaohui Wang, Ming Huang, Xiaoli Hui, Sen Wang, Yue Zhao, Hongxia He, Xiang Zhang, Chaopeng Diao, Hanbing Cao, Qingxia Ma, and Jinshan Liu. 2018b. Plastic film mulch increased winter wheat grain yield but reduced its protein content in dryland of northwest China. *Field Crops Research* 218 (January): 69–77.

Ma, L., G. L. Velthof, F. H. Wang, W. Qin, W. F. Zhang, Z. Liu, Y. Zhang, J. Wei, J. P. Lesschen, W. Q. Ma, O. Oenema, and F. S. Zhang. 2012. Nitrogen and phosphorus use efficiencies and losses in the food Chain in China at regional scales in 1980 and 2005. *Science of the Total Environment* 434: 51–61.

Malhi, Sukhdev S., Wang Quanjiu, Fan Jun, Li Yangyang, and Gao Yu. 2014. Mulching effects on water storage in soil and its depletion by alfalfa in the Loess Plateau of northwestern China. *Agricultural Water Management* 138: 10–16.

Moreno, M. M. and A. Moreno. 2008. Effect of different biodegradable and polyethylene mulches on soil properties and production in a tomato crop. *Scientia Horticulturae* 116(3): 256–63.

Mulumba, Lukman Nagaya and Rattan Lal. 2008. Mulching effects on selected soil physical properties. *Soil and Tillage Research* 98 (1): 106–11.

Nizzetto, Luca, Gianbattista Bussi, Martyn N. Futter, Dan Butterfield, and Paul G.

Whitehead. 2016. A theoretical assessment of microplastic transport in river catchments and their retention by soils and river sediments. *Environmental Science: Processes and Impacts* 18 (8): 1050–59.

Oliveira, M. and M. Almeida. 2019. Trends in analytical chemistry the why and how of micro (nano) plastic research. *Trends in Analytical Chemistry* 114: 196–201.

Peng, Zhang, Wei Ting, Wang Haixia, Wang Min, Meng Xiangping, Mou Siwei, Zhang Rui, Jia Zhikuan, and Han Qingfang. 2015. Effects of straw mulch on soil water and winter wheat production in dryland farming. *Scientific Reports* 5: 1–12.

Price, Jonathan, Line Rochefort, and Francois Quinty. 1998. Energy and moisture considerations on cutover peatlands: surface microtopography, mulch cover and sphagnum regeneration. *Ecological Engineering* 10 (4): 293–312.

Rochman, Chelsea M., Sara M. Kross, Jonathan B. Armstrong, Michael T. Bogan, Emily S. Darling, Stephanie J. Green, Ashley R. Smyth, and Diogo Veríssimo. 2015. Scientific evidence supports a ban on microbeads. *Environmental Science and Technology* 49 (18): 10759–61.

Saglam, Mustafa, Henry Y. Sintim, Andy I. Bary, Carol A. Miles, Shuresh Ghimire, Debra A. Inglis, and Markus Flury. 2017. Modeling the effect of biodegradable paper and plastic mulch on soil moisture dynamics. *Agricultural Water Management* 193: 240–50.

Salinas-Garcia, J. R., A. D. Báez-González, M. Tiscareño-López, and E. Rosales-Robles. 2001. Residue removal and tillage interaction effects on soil properties under rain-fed corn production in central Mexico. *Soil and Tillage Research* 59 (1–2): 67–79.

Sarno, Jamalam Lumbanraja, Afandi, Tadashi Adachi, Yoko Oki, Masaharu Senge, and Akira Watanabe. 2004. Effect of weed management in coffee plantation on soil chemical properties. *Nutrient Cycling in Agroecosystems* 69 (1): 1–4.

Smets, T., J. Poesen, and A. Knapen. 2008. Spatial scale effects on the effectiveness of organic mulches in reducing soil erosion by water. *Earth-Science Reviews* 89 (1–2): 1–12.

Steinmetz, Zacharias, Claudia Wollmann, Miriam Schaefer, Christian Buchmann, Jan David, Josephine Tröger, Katherine Muñoz, Oliver Frör, and Gabriele Ellen Schaumann. 2016. Plastic mulching in agriculture. trading short-term agronomic benefits for long-term soil degradation? *Science of the Total Environment* 550: 690–705.

Tolk, J. A., T. A. Howell, and S. R. Evett. 1999. Effect of mulch, irrigation, and soil type on water use and yield of maize. *Soil and Tillage Research* 50 (2): 137–47.

Wang, Hong, Chenbing Wang, Xiumei Zhao, and Falin Wang. 2015. Mulching increases water-use efficiency of peach production on the rainfed semiarid Loess Plateau of China. *Agricultural Water Management* 154: 20–28.

Wang, Jun, Rajan Ghimire, Xin Fu, Upendra M. Sainju, and Wenzhao Liu. 2018. Straw mulching increases precipitation storage rather than water use efficiency and dryland winter wheat yield. *Agricultural Water Management* 206 (1): 95–101.

Wang, Xiaojuan, Zhikuan Jia, Lianyou Liang, Baoping Yang, Ruixia Ding, Junfeng Nie, and Junpeng Wang. 2016. Impacts of manure application on soil environment, rainfall use efficiency and crop biomass under dryland farming. *Scientific Reports* 6 (February): 1-8.

Wang, Yong Peng, Xiao Gang Li, Jing Zhu, Cheng Yun Fan, Xue Jing Kong, Neil C. Turner, Kadambot H. M. Siddique, and Feng Min Li. 2016. Multi-site assessment of the effects of plastic-film mulch on dryland maize productivity in semiarid areas in China. *Agricultural and Forest Meteorology* 220: 160–69.

Waring, Richard H., Steven W. Running, and Ecosystems Third. 2007. Learn more about soil temperature spatial scaling methods for landscape and regional ecosystem analysis environmental physical prop- erties and processes. (1993).

Xue, Jian Fu, Ya Qi Yuan, Hai Lin Zhang, Ai Xia Ren, Wen Lin, Min Sun, Zhi Qiang Gao, and Da Sheng Sun. 2018. Carbon footprint of dryland winter wheat under film mulching during summer-fallow season and sowing method on the Loess Plateau. *Ecological Indicators* 95 (June): 12–20.

Xue, Nai wen, Jian fu Xue, Zhen ping Yang, Min Sun, Ai xia Ren, and Zhi qiang Gao. 2017. Effects of film mulching regime on soil water status and grain yield of rain-fed winter wheat on the Loess Plateau of China. *Journal of Integrative Agriculture* 16 (11): 2612–22.

Yang, Ning, Zhan Xiang Sun, Liang Shan Feng, Mu Zi Zheng, Dao Cai Chi, Wei Zhong Meng, Zhi Yan Hou, Wei Bai, and Kai Yu Li. 2015. Plastic film mulching for water-efficient agricultural applications and degradable films materials development research. *Materials and Manufacturing Processes* 30 (2): 143–54.

Ye, Jiansheng and Changan Liu. 2012. Suitability of mulch and ridge-furrow techniques for maize across the precipitation gradient on the Chinese Loess Plateau. *Journal of Agricultural Science* 4 (10): 182–90.

Zhang, Feng, Ibrahim M. Eldoma, Ming Li, Meng Kong, Kadambot H. M. Siddique, and Feng Min Li. 2019. Integrated model and field experiment to determine the optimum planting density in plastic film mulched rainfed agriculture. *Agricultural and Forest Meteorology* 268 (February 2018): 331–40.

Zhang, Feng, Wenjuan Zhang, Jiaguo Qi, and Feng Min Li. 2018. A regional evaluation of plastic film mulching for improving crop yields on the Loess Plateau of China. *Agricultural and Forest Meteorology* 248 (July 2017): 458–68.

Zhang, Shulan, Pingru Li, Xueyun Yang, Zhaohui Wang, and Xinping Chen. 2011. Effects of tillage and plastic mulch on soil water, growth and yield of spring-sown maize. *Soil and Tillage Research* 112(1): 92–97.

Zhang, Shulan, Victor Sadras, Xinping Chen, and Fusuo Zhang. 2013. Water use efficiency of dryland wheat in the Loess Plateau in response to soil and crop management. *Field Crops Research* 151: 9–18.

Zhang, Xudong, Linchuan Yang, Xuanke Xue, Muhammad Kamran, Irshad Ahmad, Zhaoyun Dong, Tiening Liu, Zhikuan Jia, Peng Zhang, and Qingfang Han. 2019. Plastic film mulching stimulates soil wet-dry alternation and stomatal behavior to improve maize yield and resource use efficiency in a semi-arid region. *Field Crops Research* 233: 101–113.

Zhao, Hubing, Jifei Liu, Xiuwen Chen, and Zhaohui Wang. 2019. Straw mulch as an alternative to plastic film mulch: positive evidence from dryland wheat production on the Loess Plateau. *Science of the Total Environment* 676: 782–91.

Zhao, Yunchen, Ping Wang, Jianlong Li, Yuru Chen, Xianzhi Ying, and Shuying Liu. 2009. “The effects of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat-maize cropping system." *European Journal of Agronomy* 31 (1): 36–42.

Internet link

PRB-2018 (www.prb.org)

Appendix

Table 1 Rainfed agricultural regions in China.

I	Sub-humid, temperate. Annual mono-cropping of cool-season crops in northeast plain and mountain areas.
II	Sub-humid, temperate. Irrigated temperate crops in the Huang, Hai and Huai River Plains
III	Humid, subtropical. Paddy fields, intensive farming and subtropical crops in Changjiang River middle and lower reach Plain and hilly areas.
IV	Humid, subtropical. Paddy fields with double or triple cropping and subtropical crops in the hilly and mountainous regions to the south of Changjiang River.
V	Humid, tropical. Paddy field double or triple cropping with tropical crops on plains and in hilly regions of coastal South China
VI	Semi-arid, temperate. Rainfed farming and pastoral regions with cool-season crops in the northern China's lower and middle plateau including the Loess
VII	Arid, temperate. Irrigated oasis farming and desertified pastoral regions and temperate crops in North-west China.
VIII	Humid, subtropical. Wheat and rice double cropping and subtropical crops in the Sichuan Basin
IX	Humid, subtropical. Extensive rainfed crops and rice double cropping and subtropical crops in the middle plateau of South China.
X	Arid, semi-arid, cold. Alpine pastoral regions and valley mono-cropping in Qingzang Plateau

About the author

Gantsetseg Gantumur, Mongolia, born on 19th May 1990. From 2008 to 2012 she studied bachelor's degree in Environmental and Natural resources management at The University of the Humanities, Ulaanbaatar, Mongolia.

From 2017 to 2019 She studied master's degree in Soil and Water Conservation and Desertification Control at Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Xianyang, Shaanxi, China.