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Study on the Effect of Film Mulching on Broad Bean Germination and Moisture Conservation

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Abstract Broad bean (*Vicia faba* L.) is a vital leguminous crop widely cultivated for its nutritional and agronomic value; however, its successful germination and moisture retention remain challenging under conventional cultivation practices. In this study, we investigated the effects of film mulching on broad bean germination, soil moisture conservation, and subsequent plant growth by modifying the microclimate and reducing water evaporation. The research explored the mechanisms through which film mulching enhances soil temperature stability, moisture retention in the root zone, and seedling emergence while also reducing irrigation frequency and weed competition. A field experiment comparing mulched and non-mulched plots over two seasons demonstrated higher germination rates, better moisture metrics, and increased yield in the mulched plots. Additionally, we assessed the impact of different mulch materials on plant performance and analyzed environmental and economic implications, including residue management and sustainability of biodegradable films. These findings suggest that film mulching significantly improves the germination and moisture status of broad bean crops, offering practical insights for sustainable legume production in moisture-limited regions and promoting its broader application in climate-smart agriculture.

Keywords Broad bean; Film mulching; Germination rate; Soil moisture conservation; Sustainable agriculture

1 Introduction

To be honest: in the arid areas south of the Sahara, people often have no choice, and only crops that can survive are good crops. *Vicia faba* happens to belong to this category. Not only because it is high in protein - many farmers are looking for the ability to "improve the soil by themselves": *Vicia faba* rhizobia can fix nitrogen, allowing the fields to "fertilize" themselves. Therefore, it is natural that many developing countries use it as a staple food (Zhao et al., 2022).

But then again, growing broad beans is not so worry-free. If the soil leaks seriously, the seeds will not germinate, and the yield will immediately drop; once the rain comes at an untimely time, it may even wash away the little water, making it even more difficult to see the harvest in the field (Han et al., 2024). The situation will be even worse if there are years of drought or soil degradation. At this time, people really realize that "a drop of water is worth a few cents of grain" is not an exaggeration (Valens et al., 2021).

So, mulching was brought to the field. Some people first use plastic film to test the water, while others use biodegradable film or hay to cover the ground. The purpose is the same - to prevent water from escaping and keep the seeds warm (Zhang et al., 2024). Many experimental results are quite encouraging: the soil is more moist, the root system is more developed, the broad beans grow stronger, and other legumes also benefit (Jasim & Al-Amiri et al., 2020). This study does not intend to repeat the old conclusions of "whether the film is good or not", but to sort out the existing data to see how much the ground film can help broad beans in germination and water retention, and whether these practices can really make sustainable planting a reality.

2 Mechanisms of Film Mulching

2.1 Microclimate modification: effects on temperature, humidity, and radiation

Remember stepping into the film-covered fields in the early morning? The soles of your feet were noticeably

warmer. The temperature gun also gave the numbers: the new film can raise the surface temperature by 18.4%, and the old film by about 11.4% (Zhao et al., 2022). However, when it is extremely hot at noon, it is not good to keep the film on all the time. Many farmers will lift a corner to ventilate as an "escape window". In addition to temperature, the film also locks in moisture, and the ground often feels a little damp; some of the strong light is reflected, so the seedlings will not be wilted by the sun (Han et al., 2024).

2.2 Soil moisture conservation: reduction in evaporation and improved infiltration

When exposed to the scorching sun, bare land will be dried up by a gust of wind; the film is like a pot cover, which first blocks evaporation and then allows rainwater to slowly seep in. Field comparisons have shown that the soil moisture content of the soil covered with film is about 11% higher (Valens et al., 2021). This 11% is life-saving water in the dry season. Even better, the water stays next to the roots, so crops can drink it anytime they are thirsty - farmers in water-scarce areas have used this trick time and again (Wang et al., 2024).

2.3 Weed and pest suppression: physical barrier reducing competition and pest exposure

Mulch can also block weeds, which is equivalent to a barrier. It can make weeds grow less, thereby reducing their competition for water and nutrients. Some studies have also used biodegradable mulch with herbicides, which can effectively control broadleaf weeds, but when using it, it should be noted that too much herbicide may harm broad beans (Figure 1) (Khan et al., 2020). In addition to suppressing weeds, mulch can also make it more difficult for pests to approach broad beans, so that the crop can use more nutrients for its own growth and yield, thereby improving overall performance.

Figure 1 Plant image showing reduction in plant growth particularly at higher concentrations of MCPA in the bioactive mulch films in six-week-old fava bean plants. MCPA concentrations from 10 to 0% (left to right) in comparison with control treatment (extreme right) (Adopted from Khan et al., 2020)

3 Effects of Film Mulching on Broad Bean Germination

3.1 Enhanced germination rates due to stable soil temperatures

In the first few days after sowing the seeds, whether the surface temperature can be stable is actually quite critical. Can the mulch help? Experimental data shows that it can. New mulch can increase the surface temperature by 18.4%, and old mulch can also increase it by 11.4% (Zhao et al., 2022). It doesn't sound like much, but in cold weather or at the beginning of spring, this temperature difference may be the "watershed" that determines whether or not the seeds will germinate. However, the hotter the better, and local overheating may damage the roots. Therefore, the temperature increase should be just right, which will help germination without being "suffocated".

3.2 Reduction in seedling mortality by maintaining adequate soil moisture

The difference between covering with film and not covering with film can be seen quickly. After a few days of exposure to the sun, the water evaporates quickly, and the seedlings fall to the ground without absorbing any water. The film acts like a blanket covering the soil, which reduces water evaporation and makes the area around the roots more moist. According to data, the water content of covered soil is about 11% higher than that of uncovered soil (Jasim & Alghrebawi, 2020). This amount of water is particularly critical in the seedling stage, not only for survival, but also for rapid growth and nutrient absorption.

3.3 Influence of mulch color and transparency on germination efficiency

Film is not just about covering it. Different colors and transparency are really important. Some people used semi-transparent film and found that broad beans grew better than before. It is not a coincidence. The main reason is that this film allows sunlight to penetrate while preventing the surface from getting too hot, which is a good balance (Yuan et al., 2010). Although there are not many comparative studies on different colors, from experience, semi-transparent and ordinary plastic films have significantly improved germination rates and early growth. So when choosing a film, you really can't just look at whether it is cheap or not. You also have to look at the weather and soil quality. Whether it is suitable is the key.

4 Impact on Soil Moisture Conservation

4.1 Prolonged retention of soil water content in root zones

After laying a film (whether plastic or biodegradable), evaporation will be much less, and the soil's water storage capacity will be stronger, so the root zone is wetter, and the upper layer of 0-20 cm is most obvious (Chen et al., 2019). The experiment found that the moisture content of the plots covered with white film was higher than that of bare land in the soil layer up to 10 meters deep, which can retain water longer and extend the water supply time of crops (Wang et al., 2022). This effect is most prominent in the early and middle stages of crop growth, which can ensure that broad bean roots always have water to absorb (Li et al., 2022).

4.2 Reduced frequency of irrigation and water input

Because water is not easy to escape, there is no need to water frequently after laying the film. Studies have shown that fields with film use less water, and some treatments save up to 41.86% of water compared to those without film (El-Shafie et al., 2024). In addition, the film can also reduce soil evaporation and evapotranspiration by 60.7% and 10.1% respectively, further saving water, while maintaining or even improving yield and water use efficiency.

4.3 Prevention of soil crusting and enhancement of soil structure

The ground film can also block direct rainwater erosion and reduce strong evaporation, so the soil surface is not easy to form lumps, not easy to be compacted, and water can seep in more easily. Under the conditions of film laying, infiltration is enhanced, soil structure is improved, and the dry soil layer recovers faster; among them, the white film has the most outstanding rain storage efficiency and water recovery effect. After the structure becomes loose, the roots are easier to stretch and the soil is healthier (Mao et al., 2020).

5 Influence on Plant Growth and Yield

5.1 Improvement in early plant vigor and root development

Mulching can increase soil temperature and make humidity more stable, which helps plants grow more vigorously

in the early stage and allows roots to grow better. Studies have found that in plots covered with plastic film, the root dry weight and root length in the upper soil layer increased, and the root vitality was stronger at maturity, which is important for early development and nutrient absorption (Pei et al., 2024). Plants are more likely to survive and more resistant to environmental stress when roots grow more vigorously, especially when there is less water or low temperature (Zhao et al., 2023).

5.2 Increased pod formation and biomass accumulation

After covering the ground with mulch, the photosynthesis and transpiration of plants will become stronger, so that plants can accumulate more biomass and grow pods more easily. Because the mulch improves the water and heat conditions and increases the utilization rate of nutrients, key factors of yield such as the number of pods and particle weight will increase (Zhao et al., 2020). Some studies have also found that compared with land without mulch, mulch can increase biomass by more than 20% on average (Han et al., 2020).

5.3 Yield enhancement under both rainfed and irrigated conditions

Whether in plots that rely solely on rain or in plots that are irrigated, mulching can steadily increase yields. Studies and data analysis have shown that the yield increase brought by mulching is generally between 20% and 50%, and the effect is particularly obvious in arid or semi-arid areas (Li et al., 2019; Zhang et al., 2022). With mulch, water is used more effectively, the root system develops better, and the surrounding microclimate is more suitable for plant growth, all of which increase yields significantly and make them more stable. Therefore, mulch is a very practical solution for broad beans in various planting environments (Shen et al., 2023).

6 Environmental and Agronomic Considerations

6.1 Biodegradable vs. conventional plastic film: sustainability concerns

Traditional plastic mulch works immediately, but over time it leaves a lot of fragments. These fragments slowly turn into tiny plastic particles and can introduce harmful substances such as phthalates (PAE) into the soil (Liu et al., 2023). These substances are difficult to decompose and will remain in the environment for a long time, which may harm soil health, reduce yields, and even enter the human body through the food chain (Rizvi et al., 2022). For farmers who want to farm for a long time, these problems are troublesome. Degradable mulch is a promising alternative. It is designed to decompose after use, so it can reduce long-term pollution. Studies have found that degradable film has similar planting effects as polyethylene film, providing similar yields and insulation effects, and is more environmentally friendly (Flury et al., 2021).

6.2 Residue management and soil health implications

It is difficult to pick up all the plastic film left in the fields, and over time it will accumulate into microplastics. These small particles will change the physical, chemical and biological properties of the soil, and may also slowly reduce yields. As the amount of residual film increases, the field surface will become harder and farming will become more laborious. The residual film can also absorb chemicals in pesticides and fertilizers, further affecting the soil and ecology. Degradable film saves most of the cleaning work, but because it decomposes quickly, it may affect soil microbial activity and nutrient cycling in the later stages of the crop (Feng et al., 2023). Recycling old plastic film is currently the best way to deal with it, which is more environmentally friendly than burning or burying it. Unfortunately, many places do not implement it properly, which also adds extra labor and costs to many farmers (Zheng et al., 2023).

6.3 Economic cost-benefit analysis for broad bean growers

Once plastic film is applied to the fields, the yield increases, the harvest is earlier, and water is saved. At first, everyone will say "it's worth it." This is how the data of Schaefer et al. (2016) came from. But don't forget that there are troubles behind the harvest: the residual film must be picked up, the ground must be cleaned, and the regulations are becoming stricter year by year. In the end, the original profit may be swallowed up by these invisible accounts. So some people turned their attention to degradable film-no need to go to great lengths to clean it, the processing fee is low, and it looks greener. But things are not that simple. Di Mola et al. (2022) mentioned that this type of film degrades quickly, and some plots have to be replaced frequently. If the frequency is high, it

will also cost money. In other words, when choosing which film to choose, you must not only focus on the increase in production in front of you, but also take into account the environmental costs and possible policy changes in the future, and calculate them all according to the actual local conditions. This is considered smart.

7 Case Study in Place

7.1 Study region: climate, soil type, and agronomic background

Let's not talk about the results right away. The location already tells us a lot. The Loess Plateau in northwest China-strong winds and little water, the ground is white all year round; the winter farming belt in Wasit, Iraq-rain comes and goes as it pleases. Such places are perfect for measuring "water retention" (Jasim and Al-Amiri, 2020). However, the soil fertility in the same experimental grid varies greatly: one end is old land that has been worked hard, while the other end still has some base fertilizer. Some farmers simply rotate broad beans and potatoes to make the soil looser and the harvest less likely to drop every year (Figure 2) (Shi et al., 2023).

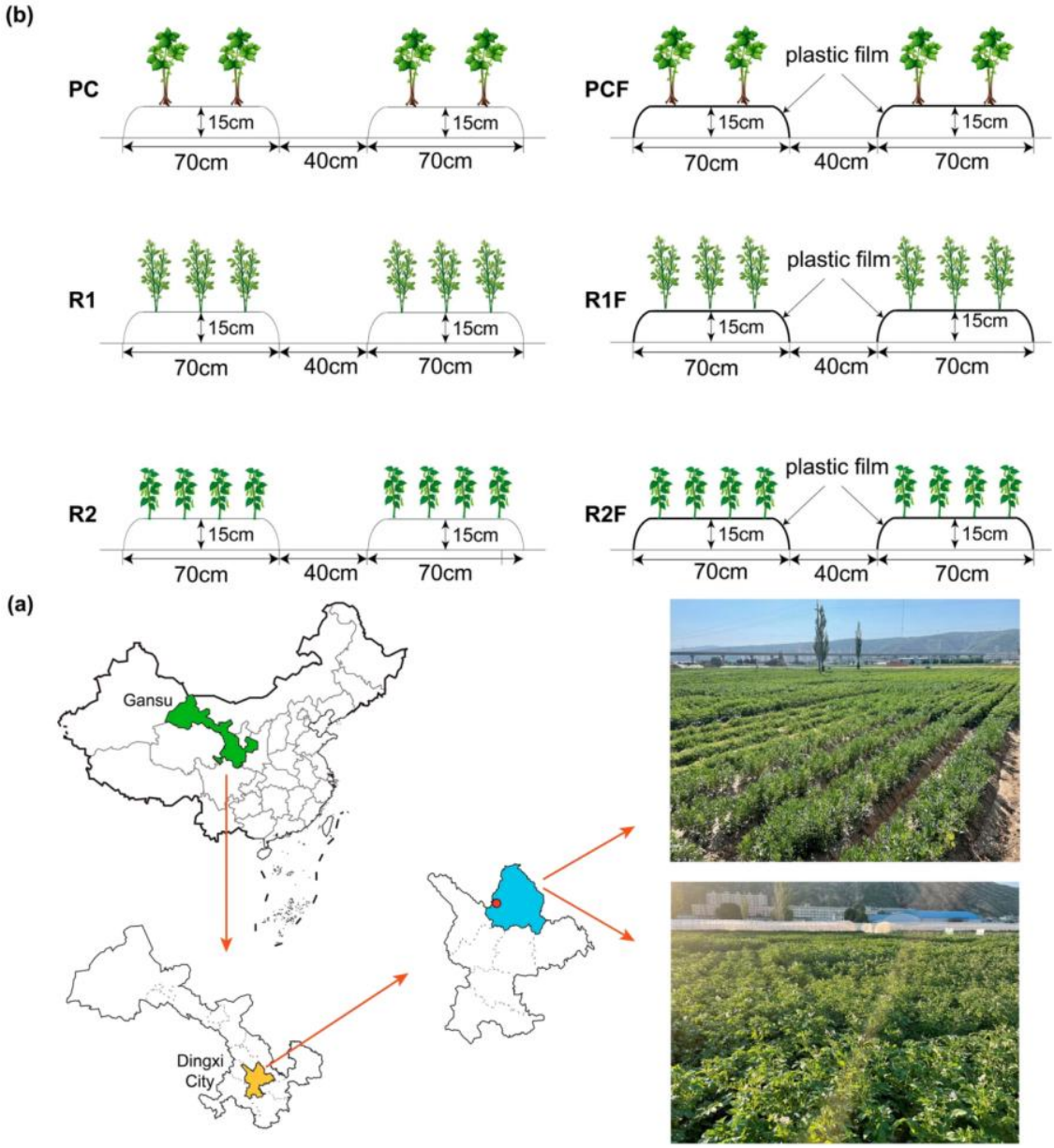

Figure 2 Geographic location of the study site a and experimental design b. PC, potato continuous cropping without film mulching; PCF, potato continuous cropping with film mulching; R1, potato-broad bean rotation without film mulching; R1F, potato-broad bean rotation with film mulching; R2, potato-pea rotation without film mulching; R2F, potato-pea rotation with film mulching (Adopted from Shi et al., 2023)

7.2 Comparison of mulched vs. non-mulched broad bean plots over two seasons

The materials are laid out first: plastic film, wheat straw, field grass clippings - several methods of covering are mixed together. After two growing seasons, the plots with film have high moisture, vigorous seedlings, and the yield is steadily higher than the fields without film. Having said that, there is a ceiling for relying on a single film, so one team also spread some phosphorus fertilizer and added some humic acid to see if the "stacked package" can push it up further (Jasim & Alghrebawi, 2020). The result? It is certain that water retention is more sufficient, but as for which is more cost-effective, investment or increased production, it still needs to be carefully calculated.

7.3 Observed outcomes: germination success, moisture metrics, and yield results

The mulched ground has a more stable surface temperature and more moisture in the soil, so the emergence rate is higher and the seedlings grow more vigorously. Mulching can significantly increase the water retention capacity of the soil, reducing irrigation requirements by up to 25%, while reducing salinity and increasing water use efficiency by about 50% (Katab et al., 2008). In some cases, mulching has increased broad bean yields by 70% to 80% compared to unmulched controls (Kang et al., 2020). In addition, mulching can increase pod number, seed weight and total biomass; when this method is used in conjunction with appropriate nutrient management, the benefits are more obvious and the yield increase is more stable.

8 Future Directions and Research Needs

8.1 Development of eco-friendly and cost-effective mulching materials

Traditional plastic films will pollute the soil after long-term use and leave a lot of microplastics. In order to alleviate these problems, people are working hard to develop degradable and renewable mulch films (Feng et al., 2015). New methods include making natural polymers such as lignin into thin films, or degradable films that are light-transmitting and waterproof. However, there are still many difficulties in making these new films easy to use and cheap in the fields, and also widely promoted (Mormile et al., 2019). Next, we need to continue research: first, improve the degradation process, second, measure the toxicity of the decomposed substances, and third, see whether they work well in different soils and climates (Huang et al., 2024).

8.2 Integration with precision irrigation and climate-smart practices

First, farmers complained: the film is a good thing, but water is still tight. So the research team simply added precision drip irrigation to the lineup - sensors monitor soil moisture, valves open and close in seconds, and the goal is to press every drop of water on the roots (Li et al., 2025). However, paper deductions are deductions, and the conditions in the field vary greatly. Zhao et al. (2023) are busy building a coupling model, and how the water, heat, and nutrients in the soil move are all moved to the computer; but in order to prevent the model from "floating", it must be fed with field monitoring and a bunch of big data. When the film, smart irrigation, and weather forecasts are all connected to the same dashboard, farmers may be able to save water and labor by clicking on the screen, and they are not afraid of weather changes.

8.3 Long-term field trials and soil impact monitoring

After one year of testing, the conclusions are often mixed; only after five or ten years of data are accumulated can we know what the film has done to the soil. Jin et al. (2022) mentioned: Don’t just focus on yield, soil health, microplastics, and ecological services must all be accounted for. So, a team buried sensors at different depths and took samples every time the season changed. The data will tell which is better, traditional membrane or degradable membrane (Jin et al., 2024). The difficulty lies in detection: the old method cannot pick up fragmented residual membranes, and microbial changes cannot be accurately grasped. Only by upgrading equipment and changing analytical methods can the details of residues and nutrient cycles be picked out, so that policymakers can have a clear idea when making decisions (Schaefer et al., 2016; Sander, 2019).

9 Concluding Remarks

Film covering can make the ground warmer and wetter, which is particularly helpful for seed germination and early seedling growth, especially in fields with dry, cold or changeable weather. After covering with film, soil moisture is retained for a longer time, the temperature is more stable, the germination rate is high, the root system

is more vigorous, and the survival rate of seedlings is also improved. These benefits can be seen not only in broad beans, but also in other legume crops; and whether it is ordinary plastic film or degradable film, it can generally give similar effects.

Film can keep moisture in the soil and buffer sudden changes in temperature. This is especially critical for legume production in areas with unstable rainfall, drought or cold. Film can extend the growing season of crops and reduce water shortage pressure, ultimately leading to more stable and higher yields. Higher water use efficiency and more survival of seedlings also make the entire legume planting system more risk-resistant and sustainable.

Farmers want to save water and labor on the film in the broad bean field; officials are more concerned about not piling up a pile of white garbage. Therefore, degradable films were pushed to the forefront - not perfect, but at least they can really dissolve without leaving residue. Some people worry whether changing to new materials will affect seedling emergence? After several rounds of trials in the field, germination and yield did not fall behind, and the amount of irrigation also decreased. The problem turns to the other side: the technology cannot keep up, farmers do not know how to use it, and the effect is discounted. Instead of blindly shouting slogans, it is better to spend money on research and development and training: how to make the material more stable, how to lay the film more conveniently, and it is best to compile a manual so that front-line workers can understand it. When monitoring equipment, climate models and precision fertilization are all connected to the same network, the water-saving account, output account, and environmental account of the film can be clearly seen at a glance, so that promotion will not take two steps forward and one step back.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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