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Improving Oilseed Flax Productivity: The Role of Agronomic Management

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Abstract: -

Oilseed flax is a crucial oil crop in China, with its economic value and demand steadily rising due to increasing awareness of its nutritional benefits and improving living standards. Consequently, its cultivated area is expanding. However, oilseed flax yields remain lower than those of other oil crops and are highly variable from year to year. Additionally, the limited mechanization in flax farming has significantly hindered the industry's sustainable growth. This paper reviews the impact of various agronomic practices on the productivity and water use efficiency of oilseed flax. Key strategies for improving yield include optimizing fertilization, adjusting plant density, implementing effective irrigation methods, adopting suitable cropping patterns, and enhancing weed control. Future research should focus on understanding the role of silicon and potassium fertilizers in improving lodging resistance in oilseed flax. Additionally, exploring diversified cropping systems such as strip intercropping and crop rotation could contribute to achieving higher, more stable yields and better resource utilization.

Introduction

Oilseed flax (*Linum usitatissimum* L.), commonly known as flax or linseed, is a fibrous dicotyledonous plant from the Linaceae family with significant economic value. It has been cultivated worldwide for centuries and serves multiple commercial and medicinal purposes. In addition to its use as animal fodder, flax fiber-three times stronger than cotton-is widely utilized in the textile industry for producing linen due to its natural strength, softness, durability, and high water absorption capacity. It is also used to manufacture decorative fabrics, solid yarn,

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cordage, and even tires, making it the first biological fiber adopted in textile production. Because of its affordability, biodegradability, and favorable chemical properties, flax fiber has gained popularity in the production of clothing, table linen, linoleum, rag-based bags, and printing inks, as demand continues to rise. In recent years, the growing interest in value-added products derived from oilseed flax has driven up its market prices, leading to an expansion in its global cultivation area. Between 2018 and 2019, the worldwide cultivated area of oilseed flax reached approximately 3.04 million hectares, with a production of 2.61 million tons-representing increases of 6.15% and 1.95%, respectively, compared to the previous year.

Flaxseed is a valuable source of industrial vegetable oil, rich in essential fatty acids beneficial to human health. It contains omega-3 fatty acids, vitamin E, dietary fiber, lignans, and other functional nutrients that help lower cholesterol and protect against cancer. Additionally, it has been linked to improved cardiovascular health and is used in treating conditions such as carpal tunnel syndrome and ulcers. With a composition of 20%–25% protein and 40%–45% fatty acids, flaxseed is both edible and highly nutritious, aiding in the prevention of heart disease, strokes, diabetes, and certain cancers. It is also incorporated into animal feed to enhance reproductive performance and overall health. Flaxseed oil, commonly known as linseed oil, is one of the oldest commercial oils and plays a crucial role in human health. It has been shown to support cognitive function, brain development, and cardiovascular health while also helping regulate blood pressure, rheumatoid arthritis, and cholesterol levels. Beyond its nutritional value, flaxseed oil is widely used across various industries, including medicine, food additives, cosmetics, paints, printing, tanning, and more. With economic growth and increasing global demand for high-quality food and industrial products, flaxseed consumption has surged, particularly as a functional food rich in omega-3 fatty acids. However, constraints such as limited planting areas and low grain yields continue to hinder the development of the oilseed flax industry. Efforts to enhance flaxseed yield focus on breeding improved varieties and optimizing cultivation techniques. Key challenges in arid agricultural regions include water scarcity, soil nutrient depletion, mismatched rainfall and growth cycles, poor soil fertility, planting structure inefficiencies, and suboptimal plant density. Additionally, diseases, insect pests, and weed infestations pose significant threats to production. This paper reviews advancements in cultivation methods and agronomic strategies aimed at optimizing high-efficiency oilseed flax production.

Effects of fertilizer on grain yield of oilseed flax

Effects of inorganic fertilizer on grain yield

The use of chemical fertilizers, particularly nitrogen (N), phosphorus (P), and potassium (K), is widely recognized as an effective agronomic approach to enhance crop productivity. Among these, nitrogen fertilization plays a crucial role in flaxseed cultivation due to the plant's positive response to N application. However, its overall effect is less pronounced compared to wheat, barley, or canola. N fertilization improves N uptake and protein content in leaves, enhances the contribution of leaves and capsule peel to grain development, and increases both N use efficiency and grain yield. Despite these benefits, excessive nitrogen supply surpasses plant uptake capacity, leading to resource wastage and environmental pollution. To promote sustainable agriculture, research suggests reducing early-stage N application while maintaining the total N input. Studies indicate that topdressing at the flowering stage can optimize N use and boost assimilate accumulation. For example, in Dingxi, Gansu Province, China, reducing the traditional N application rate by 40% maintained grain yield while improving nitrogen use efficiency. Thus, adjusting nitrogen application timing and quantity can enhance oilseed flax productivity. Phosphorus is another essential macronutrient necessary for plant growth and root development. P fertilization is a common agricultural practice worldwide, as it increases chlorophyll content, biomass growth rate, and economic yield in oilseed flax. Research shows that P application boosts P uptake efficiency, enhances dry matter accumulation, and improves nutrient remobilization from vegetative tissue to grain. Additionally, higher P levels have been linked to increased linolenic acid content, which influences the fatty acid profile of oilseed flax oil. However, the efficiency of phosphorus utilization remains low, with apparent utilization rates ranging between 15.42% and 23.58%. Due to P fixation in soil, crops absorb only a limited amount during the growing season, while residual P may be lost through leaching, leading to environmental concerns. Therefore, optimizing P fertilization strategies is critical for maximizing productivity and minimizing ecological impacts. Potassium is absorbed by field crops at a faster rate than nitrogen or phosphorus and plays a key role in enhancing N utilization efficiency. It is vital for the growth and development of flax, as K deficiency can result in stunted growth, yellowing leaves, reduced biomass, and poor root development. Studies indicate that K application significantly boosts dry matter accumulation, with moderate K levels (37.50 kg/hm^2) being more effective than higher rates

(56.25 kg/hm²). Additionally, K fertilization has been shown to increase grain yield by 14.90%–30.11% compared to no K application. The highest efficiency in agronomic productivity and nutrient utilization was observed at a K application rate of 37.5 kg K_2O/hm². As a single fertilizer application no longer meets the needs of modern agricultural production, interest in diversified fertilization approaches has grown. Studies have demonstrated that combining N and P fertilization enhances nutrient uptake by promoting root growth and reducing nitrate accumulation in soil. The synergistic effect of N and P application has been found to significantly increase seed yield in crops such as sesame and maize. In oilseed flax, N and P fertilization improves chlorophyll content, soluble sugar (SS) concentration in stems and leaves, and facilitates the translocation of nonstructural carbohydrates (NSC) into seeds. This, in turn, enhances dry matter accumulation, increasing aboveground biomass production by 11.90%–59.29% compared to no fertilization. Furthermore, the combined application of N and P has been shown to improve fertilizer utilization efficiency, soil moisture absorption, and water use efficiency (WUE). It also enhances important yield components, such as the number of capsules per plant, seeds per capsule, and 1000-seed weight, while improving nitrogen recovery and agronomic efficiency. In summary, balanced fertilization strategies—including optimized N, P, and K application rates and the integration of N and P fertilization—are crucial for improving oilseed flax productivity, resource use efficiency, and sustainable agricultural development.

Effects of organic fertilizer on seed yield

In recent years, the quality of cultivated land in China has deteriorated. The application of organic fertilizer is recognized as a crucial method for enhancing soil quality. Organic fertilizers contribute to increasing soil organic matter (SOM), improving soil's physical and chemical properties, and enhancing soil enzyme and microbial activity, ultimately supporting long-term sustainable land use. Organic fertilizer application plays a key role in balancing plant growth with soil nutrients, significantly improving the efficiency of nitrogen and phosphorus (NP) fertilizers while simultaneously increasing grain yield and seed quality. Combining organic manure with inorganic fertilizers is a widely adopted strategy to maintain soil fertility and optimize fertilizer use efficiency. Research has shown that the long-term application of both organic and chemical fertilizers can regulate nitrogen runoff, boost soil microbial biomass carbon (SMBC), and reduce nitrogen leaching and groundwater contamination. Therefore, investigating the effects of combined organic and inorganic fertilizer use on oilseed flax nutrient uptake is essential. Studies indicate that organic fertilizers enhance dry matter accumulation in oilseed flax compared to no fertilizer application. Bio-organic fertilizers have been found to increase the biological yield of oilseed flax by 2.03%–8.79%. The combination of inorganic and organic fertilizers is more effective in promoting dry matter accumulation than inorganic fertilizers alone, with an increase of 11.69%–16.44% observed in the mid-to-late vegetative growth stages. Specifically, a fertilizer mix of 30% organic and 70% chemical fertilizer significantly boosts dry matter accumulation. Additionally, integrating organic and inorganic fertilizers enhances soil water utilization, particularly by improving access to deep soil water reservoirs, which is crucial for meeting oilseed flax's water needs after the budding stage.

As a slow-release nutrient source, organic fertilizer ensures a steady supply of nutrients during the reproductive growth phase of oilseed flax. Studies reveal that oilseed flax grown under organic fertilization produces 9.92% more residue compared to chemical fertilization. The application of farmyard manure (5 t/hm²) has been shown to promote plant growth, increase yield, and improve yield components when compared to fields without manure application. These findings suggest that the primary benefit of organic fertilization is grain yield improvement through increased dry matter accumulation. Organic fertilizers also significantly enhance flaxseed quality. The linolenic acid content is higher under 60% organic fertilizer application than with chemical fertilizers alone. Additionally, soybean meal quality improves by 3.78% when organic fertilizers are used instead of chemical fertilizers, while fat content increases by 1.24% under organic fertilization. In summary, organic fertilizers positively impact the quality of oilseed flax grains but have a limited effect on overall grain yield. In practical agricultural production, the choice between organic, chemical, or combined fertilizers should be based on specific cultivation objectives.

Effect of irrigation

Flood irrigation is one of the oldest and most commonly used irrigation methods worldwide. Despite its widespread application, water losses due to evaporation and leaching remain a concern. In arid regions, where agricultural production is constrained by water availability, enhancing water-use efficiency is crucial for improving grain yield. Consequently, recent water-saving initiatives have led to the development of alternative irrigation techniques aimed at replacing traditional flood irrigation to achieve more efficient water use in crop production. Several studies have examined the impact of irrigation on oilseed flax. Increased irrigation water supply raises total water consumption while reducing the proportion of soil water and rainfall contribution. Irrigation enhances dry matter accumulation after anthesis and boosts dry matter contribution to oilseed flax grains. Additionally, using lower water volumes with multiple irrigation events improves soil water storage (SWS), optimizes water uptake, reduces overall water usage, and significantly increases irrigation water use efficiency (IWUE). On average, irrigated fields produce higher grain yields compared to non-irrigated fields. Research indicates that the highest grain yield and water-use efficiency (WUE) in oilseed flax occur when irrigation is applied at 60 mm during the budding stage and 40 mm at anthesis. While many studies confirm that irrigation significantly improves oilseed flax grain yield, some findings suggest that irrigation has little to no impact on yield. Furthermore, excessive irrigation can lead to a decline in photosynthate production and grain yield. Therefore, determining the appropriate irrigation volume and timing is essential for maximizing grain yield and ensuring efficient water use in oilseed flax cultivation.

Plastic film mulching (PFM)

Enhancing water-use efficiency (WUE) is crucial for achieving higher grain yields and promoting sustainable agriculture in arid and semi-arid regions. Plastic sheet mulching has gained attention for its ability to reduce soil evaporation and improve soil water retention. When used in conventional flat cropping, it enhances soil moisture content (SMC), promotes root distribution, and increases transpiration rates. Additionally, plastic film mulching (PFM) alters the crop growth environment by influencing soil mineral nitrogen levels, water availability, and root water transport, all of which impact oilseed flax grain yield. PFM has been widely adopted in agricultural practices, particularly in cold and water-limited regions. It aids in soil water storage, boosts biomass production, enhances deep soil moisture utilization during later growth stages, and increases oilseed flax grain yield while minimizing soil moisture loss. Moreover, film mulching raises soil temperatures, accelerates plant growth, promotes earlier emergence, and shortens the growth period by up to seven days. The color of the plastic film also plays a role in soil water conservation and crop productivity. Studies have shown that white film mulch combined with micro-ridge soil covering increases dry matter accumulation (DMA) by 53.0% compared to no mulching and by 7.8% compared to black film mulching. Furthermore, different mulching techniques influence oilseed flax production. Full-film mulch fosters optimal root growth and supports beneficial microbial activity. Methods such as hole sowing with full plastic mulch and ridge plastic mulch with side seeding improve the root microclimate, enhance soil moisture levels, and boost grain yield. A cropping system involving faba bean cultivation followed by oilseed flax, using micro-ridge furrows covered with white plastic film, has been identified as an effective strategy for stable and high-yield production of both crops in dryland farming systems.

Cropping rotation

Crop rotation, the practice of sequentially planting different crops over time, is widely implemented to enhance agricultural sustainability. A well-planned crop rotation system helps mitigate the challenges of continuous monoculture by balancing the plant-soil relationship, reducing the buildup of harmful soil microorganisms, improving soil micro-ecology, and ultimately increasing crop yields. Beyond improving soil health, crop rotation also reduces fertilizer dependency, enhances fertilizer efficiency, increases rainfall storage and water-use efficiency, enriches soil carbon and nitrogen levels, minimizes soil erosion from wind and water, and boosts the productivity of dryland crops. In the case of oilseed flax, factors such as pod number, seed weight, yield, nitrogen content, and nitrogen use efficiency vary depending on crop rotation, farming practices, and seasonal conditions. Compared to continuous flax cropping, crop rotation improves leaf area duration, dry matter accumulation, nitrogen accumulation, and water and nitrogen use efficiency. The wheat-flax-potato-flax (W-P-W-F) rotation system has been identified as particularly effective, yielding the highest grain production for oilseed flax. Conversely, continuous cultivation of oilseed flax has been shown to decrease grain yield. One major reason is the increased presence of *Rhizoctonia solani*, a soilborne pathogen that thrives in monoculture conditions. Additionally, continuous cropping raises toxin levels in soil water, which negatively impacts flaxseed germination and seedling growth. From a soil organic carbon stability perspective, a 25% flax rotation within the W-P-W-F system helps maintain soil aggregate stability and boosts total organic carbon (TOC) and particulate organic carbon (POC) levels. However, grain yield in oilseed flax has been found to have a negative correlation with soil microbial biomass carbon and total phosphorus content. Research indicates that crop rotation is the most influential factor affecting plant grain yield in rotational systems, while the specific placement of each crop within the rotation ranks as the second most significant factor.

Conclusion

As economies grow and residents' incomes rise, there is increasing consumer demand for functional and recreational specialty products derived from oilseeds and vegetable oils, particularly linseed oil. However, the low and unstable yield of oilseed flax, combined with a lower degree of mechanization, has significantly hindered the industry's sustainable development. This review highlights the current state of oilseed flax cultivation and explores key agronomic strategies that influence its productivity. Among the most critical factors affecting yield are fertilization, plant density, planting patterns, and weed control. To enhance fertilizer and water use efficiency while increasing grain yield, several agronomic approaches are recommended. These include optimizing nitrogen and phosphorus application, partially substituting organic fertilizers for chemical ones, implementing water-fertilizer coupling, and diversifying cropping patterns. By integrating these strategies, agricultural practices in dryland regions can be improved, leading to better resource efficiency and more sustainable oilseed flax production.

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