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Review Article

A review of the potentials of cover crops and ways in which they can enhance cereal crop productivity

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ABSTRACT: Sole cropping of cereals for consecutive cropping seasons exhausts soil nutrients more excessively compared to other cropping systems. The use of leguminous cover crops in cereal crop production in an intercropping manner is important for controlling weeds and improving soil properties to enhance soil fertility, soil moisture retention, and manage pests to increase crop yield. Weed infestation has been a threat to crop production for decades which costs farm operations hence reducing the output. Integrating leguminous cover crops with cereal crops and crop allelopathy have been reviewed as strategies to suppress weeds, and some types of pests, and improve soil structure and soil fertility by nitrogen fixation which boosts crop productivity. In addition, legumes have a direct impact on improving soil fertility from the decomposition of soil organic matter and circulating nutrients for cereal growth. Therefore, the purpose of this review is to discuss the potential of cover crops in cereal crop production.

Keywords: Allelopathy, cereal crops, intercropping, leguminous cover crops, soil fertility, weed infestation.

INTRODUCTION

Leguminous cover crops also referred to as dicotyledonous are shorter, annual crops with relatively large canopies and broad leaves (Al-Tawaha *et al*., 2020). Some of the common leguminous cover crops include common beans, soybeans, cowpeas, groundnuts, Bambara nuts, lablab, and most pulses. These crops are used as vegetables for human consumption and forages for livestock (Pinotti *et al*., 2020). However, lablab has a low market value unlike other legumes since it lacks human preference (Nord *et al*., 2020). On the other hand, Sah *et al*. (2022) stated that "cereal crops are monocotyledonous, annual crops with parallel veins in leaves that produce grains that are rich in carbohydrates for instance maize, sorghum, finger millet, pearl millet, and rice". Weed infestation, crop pests, diseases, and high rate of evapotranspiration have been a threat to crop farming due to their detrimental effects on crop quality and quantity up to 50% where high farm operation costs have been stated (Ghaffar *et al.,* 2022). Weeds and pests usually compete for limited natural resources, such as water, sunlight, nutrients, and space (Zhang *et al*., 2020). Characteristically as a means of survival, weeds grow faster than cultivated crops because of their deep root system which enables plants to absorb nutrients and water, resist drought, and have water use efficiency (Kubiaak *et al.,* 2022). Studies have shown that the chemical weed management approach alone is no longer effective. Sabbagh *et al.* (2020) stated that, in Tennessee, cover crop adoption rates have been increasing as a result of the many advantages, for instance, they provide nutrients to the soil, keep moisture, and suppress weeds thus favouring crop growth and sustainable vegetation.

Table 1. Plant spacing for cereal-legume intercropping.

Legume intercropped with cereal	Alternate row (cereal-legume)	Double rows	Strip cropping 4/6 row of cereal-legume	Relay cropping
Velvet bean	80-90 cm X 30 cm	40-45 cm X30 cm	45cm X 30cm	80-90 cm X 30 cm
Pegion pea	80/90 cm X 100 cm	N/A	N/A	80/90 cm X 100 cm
Soybean	80-90 cm X 5 cm	30-40 cm X 5 cm	40-45 cm X 5cm	N/A
Common bean	80-90 cm X 15 cm	40-45 cm X 15 cm	45 cm X 15cm	80-90 cm X 10 cm
Cow pea	80-90 cm X 10 cm	40-45 cm X 10 cm	45 cm X 10cm	80-90 cm X 10 cm
Ground nuts	80-90 cm X 30 cm	40-45 cm X 30 cm	45 cm X 30cm	N/A
Bambara nuts	50-60 cm X 50 cm	40-50 cm X 25 cm	40 cm X 25cm	N/A
Lablab	N/A	N/A	N/A	70-75 cm X 25 cm

Key: N/A – Not applicable, *- that means intercropping under that pattern is not applied (Source: Adopted from (Baijukya *et al.,* 2016).

Water is vital for plant growth; however, evapotranspiration is high especially in semi-arid areas which receive low and poor distributed rainfall causing wilting of plants (Chebbi *et al*., 2018). The use of leguminous cover crops as a mulch helps to reduce the rate of evapotranspiration by retaining soil moisture content, soil organic matter, and nutrient circulation which enhances cereal crops growth and production (Yuvaraj *et al*., 2020; Toler *et al.,* 2019). Growing two or more crops concurrently on the same land is known as intercropping agriculture. Increasing yield on a specific area of land by utilizing resources or biological processes that a single crop would not use is the main objective of intercropping (Yin *et al*., 2020). According to Bagheri Bodaghabadi *et al*., 2015 land equivalent ratio refers to the area under intercropping divided by the area under sole cropping that should be present to produce the same yield levels at the same level of management. It is calculated by dividing the total fraction of intercropped yields by the yields from sole crops.

Legumes-cereals intercropping system

Cereal-legume intercropping system has been a widespread practice among farmers worldwide for years and is more beneficial than a monocropping system of either sole cereals or cereal-legume rotations season after season (Alsherif, 2020). It is useful for crop diversity, food security, soil fertility, human nutrition, soil water retention, and climate adaptation (Di Bella *et al*., 2021). However, cereal crops out-compete while intercropped with legumes for growth resources, such as light, space, water, and nutrients resulting in a low yield of legumes (Zhang *et al*., 2020). The right crop species selection should be considered to achieve a high yield of legumes comparable to cereals for achieving the economic importance of the intercropping system (Jensen *et al.,* 2020). Patterns used to intercrop are different depending on cereal-legume crop intended to be intercropped. Also, planting spacing is to be kept into consideration to ensure potential productivity. Table 1 indicates intercropping pattern in relation to suggested cropping space to be used. There are a number of intercropping systems according to farmers' preference and crop choice, one being monocropping of cereal followed by legumes cultivation in crop rotation system season after season, secondly, double row system where by single row of cereal is followed by single row of legume in alternated manner, thirdly stripped system is likely same as alternate cereal-legume row configuration but for stripped involved 4-6 alternate cereal-legume rows that is four-six consecutive cereal rows are followed by four-six legume rows in alternated manner, and fourth is relay intercropping system means legume crop relay on cereal crop for support, most legume intercropped in this system are creeping types such as velvet bean, cowpea, Mucuna prubens that should be intercropped five to six weeks later after cereal has been sown to avoid auto-competition as the legume used in this system are like velvet bean, cowpeas, common beans that do creep upward on cereals since are non-self-supporting (Baijukya *et al.,* 2016). The common legume used for intercropping comprises common beans, soybeans, groundnuts, lablab, cowpea, velvet beans and pigeon peas. These legumes are integrated with cereals such as maize, sorghum, and millet but, with the right crop choice based on ecological factors (Baijukya *et al.,* 2016). In addition, growing long-duration (10 months) pigeon pea varieties in maize-pigeon pea intercropping produce the same yield for maize as has been recorded in maize sole crop (Nyagumbo *et al*., 2020). This indicates that the pigeon pea does not compete with maize for resources because of different growth patterns thus, increasing the productivity of pigeon pea while keeping maize productivity the same as sole maize (Kinyua *et al*., 2023).

POTENTIALS OF LEGUMINOUS COVER CROP IN AN INTERCROPPING SYSTEM

Between cropping seasons, leguminous cover crops can be cultivated primarily to cover the ground (Delgado *et al*., 2021). Cover crops are typically sown following the harvest of an early and main crop to promote soil health, this reduces weed invasion, surface runoff, and soil erosion (Chapagain *et al*., 2020). It also plays an important role in food diversification and human nutritional benefits (Stagnari *et al*., 2017). Cover crops are alternatively used as livestock feed (Higgins, 2017). In addition, leguminous cover crops can reduce the pest burden on the primary cereal crop cultivated (Bowers *et al*., 2020). Thus, some of the potentials of leguminous cover crops in an intercropping system are itemized below.

Weed suppression

Weeds that affect cereal crop productivity are both annual, perennial, and biannual with different life cycles (Mishra and Gautam, 2021). Legumes can be used to minimize the effect of weeds, such legumes are velvet bean *(Mucuna pruensis),* common bean (*Phaseolus vulgaris L*), pigeon pea (*Cajanus cajana*), and cowpea (*Vigna unguiculata*) are among the leguminous cover crops with high efficiency of weed suppression in the intercropping (Monteiro and Santos, 2022). Leguminous cover crops have a weed suppression effect because of their competitive nature between the grown cereal and leguminous cover crops which reduces weed biomass (Toler *et al*., 2019). Such interactions have a direct impact on weed suppression that occurs during the actively growing phase of legumes, or at the senescence phase when legume cover crops die and are left on the surface as mulches (Gerhards and Schappert, 2020). The suppression of weeds by legume-cereal crops' intercrop is governed by direct competition for growth resources, allelopathy, and indirect interactions (Homulle *et al*., 2021). According to the plant competition principle, cover crops and weeds may share specific niches in certain cropping systems, causing competition, species in a shared niche will influence the environment and cause a negative reaction in the other species (Ullah *et al*., 2019; Fernando and Shrestha, 2023).

Direct competition

Direct competition involves competition of growth resources such as space, light, water, nutrients and minerals between leguminous cover crops and weed species (Homulle *et al*., 2021). Competition for nutrients and water in a crop–weed situation can be defined as an increase in nutrients and water stress of the crop due to the presence of weeds (Phophi *et al*., 2017; Sardana *et al*., 2017). Therefore, direct competition involves controlling weeds by adjusting the sowing rate of legume cover crops (Fernando and Shrestha, 2023). Plant traits, such as plant height, canopy area, and leaf shape also affect plant competition if spacing and sowing rate are poorly estimated depending on the types of cereals and legumes intercrops (Salonen and Ketoja, 2020). The biomass produced by cover crops is used as an indicator of suppressive impact which affects light transmittance by creating shaded areas, reduced moisture availability, and reduced soil temperature (Vincent-Caboud *et al.,* 2019). Root length impacts nutrient competition by preventing nutrient supplies from coming into contact with neighbouring plants competing for nutrients, which entails maximizing root length (Korav *et al*., 2018). Whereas biomass and leaf area affect competition for light, the growth of the below-ground roots directly influences the development of the above-ground plant components, thus, plants that quickly colonize their root zones and expand their roots are more competitive (Kumar and Dubey, 2020). Cover crops may out-compete weeds and lessen weed pressure in agricultural production systems by altering the soil microclimate (Rosa *et al*., 2021). In addition, the physiological features of legume cover crops can affect the weed population as they contain large canopies that cover large soil surfaces (Sharma *et al*., 2018).

Allelopathy

Cover crop plants contain compounds known as allelochemicals, which are allelopathic and have been shown to have a weed-suppressive effect (Robert, 2018). There was a study which reported a linear correlation between the allelochemicals produced by legume cover crops and the percentage of weed inhibition (Hickman *et al*., 2023). Cowpea and velvet beans are some of the common cover crops which suppress weed germination and growth by allelopathic processes (Hussain *et al*., 2021). In allelopathy, the ability of some invasive plant species to produce biochemical substances poisonous to native species is regarded to be one of the reasons for their success when introduced to a novel range (Schandry and Becker, 2020). Legumes like velvet beans, which might be a case of physical rather than allelopathic suppression, are also known to have suppressive effects on weeds when mixed with maize (Fernando and Shrestha, 2023). Plant allelopathy is considered a viable alternative to herbicides for controlling weeds and a way to reduce reliance on agrochemicals with allelopathic potential, hence, reducing the pressure for herbicide resistance (Abbas *et al*., 2018).

Indirect interaction

Indirect interaction with weed suppression occurs when leguminous plants have completed their life cycle (Iqbal *et al*., 2020), i.e., when leguminous plants die; it then becomes a mulching material and acts as a physical barrier for weed seed emergence (Gerhards and Schappert, 2020). Mulches suppress weeds in different ways including blocking weed-seed germination stimuli by intercepting light, minimizing soil temperature, and fluctuating day-night temperature which limits weed-seed germination (Phophi *et al.,* 2017). Moreover, mulches hinder the emergence of germinated weeds, mulch with dense cover enough to prevent light from reaching the trapped seedlings results in weed death. According to Iqbal *et al*. (2020), mulch can enhance crop growth, competition reduction, and competitiveness against weeds by conserving soil moisture and moderating soil temperature.

Enhancing soil fertility and cereal crops productivity

Leguminous cover crops can significantly improve soil organic matter and levels of soil-produced below-ground biomass in terms of carbon content (Elsalahy *et al*., 2019). Leguminous cover crops frequently lead to higher biomass production; accumulating soil matter also raises soil carbon concentration (McClelland *et al.,* 2021). Microorganisms that fix nitrogen are found in both leguminous and non-leguminous plants. The degree to which leguminous cover crops increase soil organic matter relies heavily on the texture, porosity, tillage, and time. Leguminous cover crops such as living mulch can also indirectly reduce nutrient losses by preventing nutrients from washing down and lessening soil degradation caused by water or wind (Stein *et al*., 2022). As a result, leguminous cover crops advantages are so expressive under loam-silt than other soils (McClelland *et al.,* 2021). In comparison to bare soils, crops minimize soil water erosion by 79%; this may be due to the high production of biomass. Moreover, leguminous cover crops have an impact on the chemical and structural makeup of soil organic matter which affects the movement of soil nutrients and soil fertility (Scavo *et al*., 2020). Leguminous cover crops may affect positively the structure and composition of humus in the soil enhancing soil health (Sahu *et al.,* 2017).

Soil organic matter, together with rhizodeposits released into the rhizosphere by leguminous cover crops, provides energy for soil microbes for their activity (Cavo *et al*., 2022). Soil microorganisms release inorganic nutrients through soil organic matter mineralization by fostering soil enzymatic complex, this influences plant nutrient uptake and allows nutrient cycling (Ibrahim *et al*., 2021). Leguminous cover crops can establish different forms of associations with roots-associated microorganisms that are mainly N-fixing bacteria and various endophytic fungi and bacteria. Examples of associations include symbiosis, mutualism, and commensalism (Coonan *et al*., 2020; Al-Tawaha *et al.,* 2020). On top of that, there are mycorrhizal fungi that drive phosphorous (P) circulation due to the increase of the root area network, which gives room to soils to explore nutrients, therefore. a better absorption of phosphorous. Leguminous cover crops increase the population in the community of mycorrhizal fungi that alter phosphorous fractions by increasing the organic pool in the topsoil compared to fallow, with species-specific effects on phosphorous pools (Delgado *et al*., 2021). For instance, cowpea (*Vigna unguiculata* (L.) discharges P deficiency to stimulate hyphal branches of Arbuscular mycorrhizal fungi (AFM) (Sahu *et al.,* 2017). In addition, legume cover crops can fix the atmospheric N into plant-available ammonium by associations with N-fixing rhizobacteria (Stein and Klotz, 2016). Leguminous cover crops can increase soil organic matter levels from 8% to 114% (SARE 2017). In contrast, non-legume cover crops such as grasses and brassicas increase soil organic matter by 4% to 62% indicating high efficiency in producing organic matter which improves soil properties (SARE 2017; Wooliver and Jagadamma, 2023). Soil organic matter improves soil cation exchange capacity and soil's capacity to store macronutrients namely calcium, magnesium, and potassium (Kocira *et al*., 2020). Micronutrients like iron, zinc, copper, manganese, and molybdenum combine with organic matter to produce complexes that speed the rate of nutrient absorption by plants (Wulanningtyas *et al*., 2021). Organic matter offers carbon as energy for microorganisms that aid in the mineralization processes that increase the availability of many soil nutrients (Yuvaraj *et al.,* 2020). Thus, organic matter improves the soil's ability to retain water and infiltrate most of the clay soil (Lal, 2020). The physical characteristics of the soil are also impacted, soil organic matter helps to improve soil tilth by stabilizing soil structure (Elsalahy *et al*., 2019). Thus, microbes play a vital role in fixing atmospheric nitrogen into five phases starting from fixing nitrogen, nitrification, mineralization, immobilization, and denitrification,

Furthermore, the use of leguminous cover crops has been of great importance in improving soil properties due to its peculiar ability to convert and fix atmospheric nitrogen into available nitrogen for plant growth, however, any other plant type in the absence of leguminous can be used to improve soil fertility.

Soil surface and water conservation

Climate change is a global challenge caused by human activities which have affected rainfall distribution where some geographical locations have experienced flooding while others have experienced extreme drought which affects agriculture (Cook *et al*., 2018; Huang *et al.*, 2021). Leguminous plants are physically designed to have broad leaves that cover the majority of the soil's surface, which lowers the rate of evapotranspiration (Agarwal *et al*., 2022). Cover crops are therefore essential tools for preventing soil water loss and soil moisture preservation (Delgado *et al*., 2021). In semi-arid regions, climate change has made drought stress worse, which reduces farm yield (Berdugo *et al*., 2020; Wang *et al*., 2020). Effective use of water resources has emerged as a critical issue for the future agricultural science and technology revolution and a major obstacle to the sustainable development of global agriculture to secure food security (Huang *et al*., 2021; Fang *et al*., 2023). To raise yields, the preservation of quality surface and groundwater should be enhanced to prevent soil erosion, absorb atmospheric carbon, improve soil quality, and reduce surface water run-off (Wooliver and Jagadamma, 2023).

Pest management

Natural enemies such as insect pest invasion in farming fields have been reported to contribute to crop loss (Darby and Gupta, 2017). Pests increase the high farm operation costs of pesticides which alone cannot be curative since insect pests develop pesticide resistance, integrated pest management is an important tool for pest management (Desneux *et al*., 2022). Intercropping and the use of cover crops in rotation can also increase the number of natural enemies by giving them food and shelter all year long, which may lessen the pest burden on the primary cereal crop cultivated (Bowers *et al*., 2020). Cover crops are beneficial for controlling a wide range of insect pests in cereals (Nengovhela, 2020). Leguminous cover crops can feed and serve as a home for both beneficial and pest insects, which reduces the population of pests that can harm a primary crop by attracting them away from it (Beaumelle *et al*.,2021). It is crucial to remember, nevertheless, that a rise in beneficial insects does not always correspond to a corresponding decline in insect pest species (Vogelweith and Thiéry, 2017).

Crop diversification

The demand for food is rising worldwide, especially in sub-Saharan Africa (Cakir *et al*., 2019). Crop diversification is a dynamic technique to maintain food security in a sustainable way (Kurdyś-Kujawska *et al*., 2021). Food security is a top concern and necessity for any country. Growing conventional crops as well as introducing new non-conventional crops are both parts of crop diversification (Ijaz *et al*., 2019). Legumes are important source of food for humans which replace numerous food products and livestock feeds. In addition to providing nutrients and increasing biodiversity, legumes also enhance cropping systems by reducing reliance on a sole cropping system (Ferreira *et al*., 2021). In addition, legumes play a significant role in the human diet and are even treated as staple crops in some parts of the world and they are increasingly used as pasture to produce high-quality meat and milk (Ayilara *et al*., 2022). The most effective way to achieve a balance between food production and conserving biodiversity is to increase plant diversity in agricultural systems (Beaumelle *et al*., 2021; Chapagain *et al*., 2020).

Nutritional benefits

Consuming legumes help to reduce cholesterol, decrease blood sugar levels, and increase healthy gut bacteria (Wang *et al*., 2021). Legumes are rich in protein, fibre, vitamin B, iron, folate, calcium, potassium, phosphorous, and zinc nutrients (Kouris-Blazos and Belski, 2016). The high protein in legumes makes them a great option in places where meat and dairy products are limited and vegetarians usually substitute legumes with meat (Mefleh *et al*., 2022). The body uses carbohydrates in legumes slowly, providing steady energy for the body, brain, and nervous system (Kamboj and Nanda, 2018). Eating legumes as part of a healthy diet helps to lower blood sugar and blood pressure (Cakir *et al.,* 2019). Legumes are a good source of antioxidants that help to prevent cell damage and fight disease and ageing. Fibre and other nutrients benefit the digestive system and prevent digestive cancers (Stagnari *et al*., 2017). Nevertheless, legumes contain substances known as antinutrients that may hinder some nutrients from being absorbed by your body (Rahate *et al*., 2021). Also limiting the amount of food consumed at once and consuming a wide variety of nutritious foods each day might help you combat this effect. Lectins as antinutritional compounds, which can hinder the absorption of calcium, iron, phosphorus, and zinc, as well as Phytates (phytic acid), are antinutrients found in legumes that reduce the absorption of calcium, magnesium, iron, and zinc. Another is tannins which may decrease the absorption of iron. Saponins as antinutritive also prevent your body from properly absorbing nutrients (Maphosa and Jideani, 2017). The potential use of cover crops has several positive merits than the negative impacts that can be elaborated in anti-nutritional values when used for human consumption (Rahate *et al*., 2021).

TRENDS OF COVER CROPS ADOPTION IN INTERCROPPING SYSTEM

In most nations, the adoption of cover crops stayed steady. According to Zhou *et al*. (2022), the adoption rate in 2021 was four times greater than that of 2011. However, according to Wallander *et al.* (2021), the Midwest of the United States still has a low adoption rate of cover crops (7.2%). According to American farmers, 15.4 million acres of cover crops were planted in 2017. This is a 50%

increase in the adoption of cover crops compared to 2012 when farmers reported growing them on 10.3 million acres (Cruze *et al*., 2019). From 20 million acres by 2020 to 100 million acres by 2025 are the long-term goals for the introduction of cover crops. The UK is using cover crops more often despite research demonstrating its many benefits for the environment and soil. About how these practices impact farmers, however, not much is known. In 2016, 66% of those surveyed reported using cover crops following harvest. Along with benefits for managing soil erosion and improving soil structure, respondents also reported improvements in water infiltration, decreases in the use of chemical fertilizers and herbicides, and improvements in soil structure (Storr *et al*., 2019). Unfortunately, statistical information regarding the trend of cover crop use in the majority of African countries is not readily available.

CONCLUSION

Leguminous cover crops have been of great advantage to the soil and cereals in an intercropping system. These include reducing the intensity of water and wind erosion, minimising soil compatibility, enhancing water infiltration, soil aggregates build up, soil water holding capacity, improve macronutrient cycling. It also provides a forage for livestock, provides sustenance for plant pollinators, breaks pest cycles, suppresses weeds, and plays a component in the food chain. Thus, integrating legume cover crops in an intercropping system with cereal crops should be emphasized to cultivators. However, it has been observed that in semi-arid areas most farmers do not intercrop cereals and legumes. Most farms remain bare during the off-season meanwhile there is a high evapotranspiration rate. Therefore, awareness needs to be created for farmers to adopt the use of legume cover crops referring to their potential. On the other hand, legume cover crops as a tool alone cannot be sufficient to reduce weed infestation. Therefore, there is a need for cover crops to be integrated with other weed management practices so-called integrated weed management (IWM). IWM practices comprise the use of herbicide, crop rotation, mechanical weeding that involving the use of hand or hoe weeding, deep tillage, and biological control that including allelopathic plant relationships. Nevertheless, cover crops are an important component of the toolbox for integrated weed management.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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REFERENCES

Abbas, T., Zahir, Z. A., Naveed, M., & Kremer, R. J. (2018). Limitations of existing weed control practices necessitate development of alternative techniques based on biological approaches. *Advances in Agronomy*, (*147)* 239-280.

Agarwal, P., Schutte, B. J., Idowu, O. J., Steiner, R. L., & Lehnhoff, E. A. (2022). Weed suppression versus water use: Efficacy of cover crops in water-limited agroecosystems. *Weed Research*, *62*(1), 24-37.

Alsherif, E. A. (2020). Cereal weeds variation in middle Egypt: Role of crop family in weed composition. *Saudi Journal of Biological Sciences*, *27*(9), 2245-2250.

Al-Tawaha, A. R. M., Al-Tawaha, A., Sirajuddin, S. N., McNeil, D., Othman, Y. A., Al-Rawashdeh, I. M., Qaisi, A. M., Jahan, N., Shah, M. A., Khalid, S., & Al-Taey, D. K. A. (2020, April). Ecology and adaptation of legumes crops: A review. In *IOP Conference Series: Earth and Environmental Science* (Vol. 492, No. 1, p. 012085). IOP Publishing.

Ayilara, M. S., Abberton, M., Oyatomi, O. A., Odeyemi, O., & Babalola, O. O. (2022). Potentials of underutilized legumes in food security. *Frontiers in Soil Science*, *2*, Article number 1020193.

Bagheri Bodaghabadi, M., Martínez-Casasnovas, J. A., Khakili, P., Masihabadi, M. H., & Gandomkar, A. (2015). Assessment of the FAO traditional land evaluation methods, A case study: Iranian Land Classification method. *Soil Use and Management*, *31*(3), 384-396.

Baijukya, F. P., Wairegi, L. W. I., Giller, K. E., Zingore, S., Chikowo, R., & Mapfumo, P. (2016). *Maize-legume cropping guide*. Africa Soil Health Consortium, Nairobi. 81p.

Beaumelle, L., Auriol, A., Grasset, M., Pavy, A., Thiéry, D., & Rusch, A. (2021). The benefits of increased cover crop diversity for predators and biological pest control depend on the landscape context. *Ecological Solutions and Evidence*, *2*(3), e12086.

Berdugo, M., Delgado-Baquerizo, M., Soliveres, S., Hernández-Clemente, R., Zhao, Y., Gaitán, J. J., Gross, N., Saiz, H., Maire, V., Lehmann, A., & Maestre, F. T. (2020). Global ecosystem thresholds driven by aridity. *Science*, *367*(6479), 787-790.

Bowers, C., Toews, M., Liu, Y., & Schmidt, J. M. (2020). Cover crops improve early-season natural enemy recruitment and pest management in cotton production. *Biological Control*, (*141*) 104149.

Cakir, Ö., Ucarli, C., TARHAN, Ç., Pekmez, M., & Turgut-Kara, N. (2019). Nutritional and health benefits of legumes and their distinctive genomic properties. *Food Science and Technology*, *39*(1), 1-12.

Cavo, A., Fontanazza, S., Restuccia, A., Pesce, G. R., Abbate, C., & Mauromicale, G. (2022). The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. *Agronomy for Sustainable Development*, *42*(5), Article number 93.

Chapagain, T., Lee, E. A., & Raizada, M. N. (2020). The potential of multi-species mixtures to diversify cover crop benefits. *Sustainability*, *12*(5), 2058.

Chebbi, W., Boulet, G., Le Dantec, V., Chabaane, Z. L., Fanise, P., Mougenot, B., & Ayari, H. (2018). Analysis of evapotranspiration components of a rainfed olive orchard during three contrasting years in a semi-arid climate. *Agricultural and Forest Meteorology*, *256-257*, 159-178.

Cook, B. I., Mankin, J. S., & Anchukaitis, K. J. (2018). Climate change and drought: From past to future. *Current Climate Change Reports*, *4*, 164-179.

Coonan, E. C., Kirkby, C. A., Kirkegaard, J. A., Amidy, M. R., Strong, C. L., & Richardson, A. E. (2020). Microorganisms and nutrient stoichiometry as mediators of soil organic matter dynamics. *Nutrient Cycling in Agroecosystems*, *117*(3), 273-298.

Darby, H., & Gupta, A. (2017). Using high glucosinolate mustard as a cover crop to reduce weeds and disease. University of Vermont Extension, Northwest Crops and Soils Program.

Delgado, J. A., Mosquera, V. H. B., Alwang, J. R., Villacis-Aveiga, A., Ayala, Y. E. C., Neer, D., Monar, C., & López, L. O. E. (2021). Potential use of cover crops for soil and water conservation, nutrient management, and climate change adaptation across the tropics. *Advances in Agronomy*, *165*, 175-247.

Desneux, N., Han, P., Mansour, R., Arnó, J., Brévault, T., Campos, M. R., Chailleux, A., Guedes, R. N., Karimi, J., Konan, K. A. J., & Biondi, A. (2022). Integrated pest management of *Tuta absoluta*: practical implementations across different world regions. *Journal of Pest Science*, 95, 17-39.

Di Bella, L., Zahmel, M., van Zwieten, L., & Rose, T. J. (2021). Weed suppression, biomass and nitrogen accumulation in mixed-species and single-species cover crops in a tropical sugarcane fallow. *Agriculture*, *11*(7), 640.

Elsalahy, H., Döring, T., Bellingrath-Kimura, S., & Arends, D. (2019). Weed suppression in only-legume cover crop mixtures. *Agronomy*, *9*(10), 648.

Fang, C., Song, X., Ye, J. S., Yuan, Z. Q., Agathokleous, E., Feng, Z., & Li, F. M. (2023). Enhanced soil water recovery and crop yield following conversion of 9-year-old leguminous pastures into croplands. *Agricultural Water Management*, *279*, 108189.

Fernando, M., & Shrestha, A. (2023). The potential of cover crops for weed management: a sole tool or component of an integrated weed management system? *Plants*, *12*(4), 752.

Ferreira, H., Pinto, E., & Vasconcelos, M. W. (2021). Legumes as a cornerstone of the transition toward more sustainable agri-food systems and diets in Europe. *Frontiers in Sustainable Food Systems*, *5*, Article number 694121.

Gerhards, R., & Schappert, A. (2020). Advancing cover cropping in temperate integrated weed management. *Pest management science*, *76*(1), 42-46.

Ghaffar, A., Rahman, M. H. U., Ahmed, S., Haider, G., Ahmad, I., Khan, M. A., Afzaal, M., Ahmed, S., Fahad, S., Hussain, J., & Ahmed, A. (2022). Adaptations in cropping system and pattern for sustainable crops production under climate change scenarios. In *Improvement of plant production in the era of climate change* (pp. 1-34). CRC Press.

Hickman, D. T., Comont, D., Rasmussen, A., & Birkett, M. A. (2023). Novel and holistic approaches are required to realize allelopathic potential for weed management. *Ecology and Evolution*, *13*(4), e10018.

Higgins, T. R. (2017). *An economic analysis of the value of grazing winter cover crops* (Doctoral dissertation, Kansas State University).

Homulle, Z., George, T. S., & Karley, A. J. (2021). Root traits with team benefits: Understanding belowground interactions in intercropping systems. *Plant and Soil*, 471, 1-26.

Huang, M., Zhai, P., & Piao, S. (2021). Divergent responses of ecosystem water use efficiency to drought timing over Northern Eurasia. *Environmental Research Letters*, *16*(4), 045016.

Hussain, M. I., Abideen, Z., Danish, S., Asghar, M. A., & Iqbal, K. (2021). Integrated weed management for sustainable agriculture. *Sustainable Agriculture Reviews 52*, 367-393.

Ibrahim, M. M., Zhang, H., Guo, L., Chen, Y., Heiling, M., Zhou, B., & Mao, Y. (2021). Biochar interaction with chemical fertilizer regulates soil organic carbon mineralization and the abundance of key C-cycling-related bacteria in rhizosphere soil. *European Journal of Soil Biology*, *106,* 103350.

Ijaz, M., Nawaz, A., Ul-Allah, S., Rizwan, M. S., Ullah, A., Hussain, M., Sher, A., & Ahmad, S. (2019). Crop diversification and food security. *Agronomic Crops: Volume 1: Production Technologies*, Pp. 607-621.

Iqbal, R., Raza, M. A. S., Valipour, M., Saleem, M. F., Zaheer, M. S., Ahmad, S., Toleikiene, M., Haider, I., Aslam, M. U., & Nazar, M. A. (2020). Potential agricultural and environmental benefits of mulches—A review. *Bulletin of the National Research Centre*, *44*, Article number 75.

Jensen, E. S., Carlsson, G., & Hauggaard-Nielsen, H. (2020). Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: A global-scale analysis. *Agronomy for Sustainable Development*, *40*, Article number 5.

Kamboj, R., & Nanda, V. (2018). Proximate composition, nutritional profile and health benefits of legumes-a review. *Legume Research-An International Journal*, *41*(3), 325-332.

Kebede, E. (2021). Contribution, utilization, and improvement of legumes-driven biological nitrogen fixation in agricultural systems. *Front Sustainable Food Systems*, *5*, Article number 767998.

Kinyua, M. W., Kihara, J., Bekunda, M., Bolo, P., Mairura, F. S., Fischer, G., & Mucheru-Muna, M. W. (2023). Agronomic and economic performance of legume-legume and cereal-legume intercropping systems in Northern Tanzania. *Agricultural systems*, *205*, Article number 103589.

Kocira, A., Staniak, M., Tomaszewska, M., Kornas, R., Cymerman, J., Panasiewicz, K., & Lipińska, H. (2020). Legume cover crops as one of the elements of strategic weed management and soil quality improvement. A review. *Agriculture*, *10*(9), 394.

Korav, S., Dhaka, A. K., Singh, R., Premaradhya, N., & Reddy, G. C. (2018). A study on crop weed competition in field crops. *Journal of Pharmacognosy and Phytochemistry*, *7*(4), 3235-3240.

Kouris-Blazos, A., & Belski, R. (2016). Health benefits of legumes and pulses with a focus on Australian sweet lupins. *Asia Pacific Journal of Clinical Nutrition*, *25*(1), 1-17.

Kubiaak, A., Wolna-Maruwka, A., Niewiadomska, A., & Pilarska, A. A. (2022). The problem of weed infestation of agricultural plantations vs. the assumptions of the European biodiversity strategy. *Agronomy*, *12*(8), 1808.

Kumar, A., & Dubey, A. (2020). Rhizosphere microbiome: Engineering bacterial competitiveness for enhancing crop production. *Journal of Advanced Research*, *24*, 337-352.

Kurdyś-Kujawska, A., Strzelecka, A., & Zawadzka, D. (2021). The impact of crop diversification on the economic efficiency of small farms in Poland. *Agriculture*, *11*(3), 250.

Lal, R. (2020). Soil organic matter and water retention. *Agronomy Journal*, *112*(5), 3265-3277.

Maphosa, Y., & Jideani, V. A. (2017). The role of legumes in human nutrition. In: *Functional food-improve health through adequate food*, Pp. 103-120.

McClelland, S. C., Paustian, K., & Schipanski, M. E. (2021). Management of cover crops in temperate climates influences soil organic carbon stocks: a meta-analysis. *Ecological Applications*, *31*(3), e02278.

Mefleh, M., Pasqualone, A., Caponio, F., & Faccia, M. (2022). Legumes as basic ingredients in the production of dairy-free cheese alternatives: a review. *Journal of the Science of Food and Agriculture*, *102*(1), 8-18.

Mishra, A. M., & Gautam, V. (2021, February). Weed species identification in different crops using precision weed management: A review. In *ISIC* (pp. 180-194).

Monteiro, A., & Santos, S. (2022). A sustainable approach to weed management: The role of precision weed management. *Agronomy*, *12*(1), 118.

Nengovhela, N. M. (2020). *The use of cover crops to increase yield and reduce pest pressure in a commercial avocado orchard at Levubu, Limpopo Province* (Doctoral dissertation).

Nord, A., Miller, N. R., Mariki, W., Drinkwater, L., & Snapp, S. (2020). Investigating the diverse potential of a multi-purpose legume, Lablab purpureus (L.) Sweet, for smallholder production in East Africa. *PloS one*, *15*(1), e0227739.

Nyagumbo, I., Mutenje, M., Ghimire, S., & Bloem, E. (2020). Cereal-legume intercropping and rotations in Eastern and Southern Africa: Farmer's Manual. European Union H2020 Research and Innovation programme under the grant agreement number 727201

Phophi, M. M., Mafongoya, P. L., Odindo, A. O., & Magwaza, L. S. (2017). Screening cover crops for weed suppression in conservation agriculture. *Sustainable Agriculture Research*, *6*(4), 124-131.

Pinotti, L., Manoni, M., Fumagalli, F., Rovere, N., Luciano, A., Ottoboni, M., Ferrari, L., Cheli, F., & Djuragic, O. (2020). Reduce, reuse, recycle for food waste: A second life for fresh-cut leafy salad crops in animal diets. *Animals*, *10*(6), 1082.

Rahate, K. A., Madhumita, M., & Prabhakar, P. K. (2021). Nutritional composition, anti-nutritional factors, pretreatments-cum-processing impact and food formulation potential of faba bean (Vicia faba L.): A comprehensive review. *LWT*, *138*, 110796.

Robert, L. Z. (2018). Chapter 9 - Allelopathy, Editor(s): Robert L. Zimdahl, Fundamentals of Weed Science (Fifth Edition), Academic Press. Pp. 253-270,

Rosa, A. T., Creech, C. F., Elmore, R. W., Rudnick, D. R., Lindquist, J. L., Fudolig, M., Butts, L., & Werle, R. (2021). Implications of cover crop planting and termination timing on rainfed maize production in semi-arid cropping systems. *Field Crops Research*, *271*, 108251.

Sabbagh, M. J., Jagadamma, S., Duncan, L. A., Walker, F. R., Lee, J., Essington, M. E., Arelli, P., & Buschermohle, M. J. (2020). Cover crop diversity for weed suppression and crop yield in a corn–soybean production system in Tennessee. *Agrosystems, Geosciences & Environment*, *3*(1), e20112.

Sah, R. P., kumar, A., Rana, M., & Kumar, U. (2022). Maize (Corn). *Forage Crops of the World, 2-volume set: Volume I: Major Forage Crops; Volume II: Minor Forage Crops*, 15.

Sahu, N., Vasu, D., Sahu, A., Lal, N., & Singh, S. K. (2017). Strength of microbes in nutrient cycling: a key to soil health. *Agriculturally Important Microbes for Sustainable Agriculture: Volume I: Plant-soil-microbe nexus*. Pp. 69-86.

Salonen, J., & Ketoja, E. (2020). Undersown cover crops have limited weed suppression potential when reducing tillage intensity in organically grown cereals. *Organic agriculture*, *10*, 107-121.

Sardana, V., Mahajan, G., Jabran, K., & Chauhan, B. S. (2017). Role of competition in managing weeds: An introduction to the special issue. *Crop Protection*, *95*, 1-7.

Scavo, A., Fontanazza, S., Restuccia, A., Pesce, G. R., Abbate, C., & Mauromicale, G. (2022). The role of cover crops in improving soil fertility and plant nutritional status in temperate climates. A review. *Agronomy for Sustainable Development*, *42*, Article number 93.

Schandry, N., & Becker, C. (2020). Allelopathic plants: models for studying plant–interkingdom interactions. *Trends in Plant Science*, *25*(2), 176-185.

Sharma, P., Singh, A., Kahlon, C. S., Brar, A. S., Grover, K. K., Dia, M., & Steiner, R. L. (2018). The role of cover crops towards sustainable soil health and agriculture—A review paper. *American Journal of Plant Sciences*, *9*(9), 1935-1951.

Stagnari, F., Maggio, A., Galieni, A., & Pisante, M. (2017). Multiple benefits of legumes for agriculture sustainability: an overview. *Chemical and Biological Technologies in Agriculture*, *4, Article number 2*.

Stein, L. Y., & Klotz, M. G. (2016). The nitrogen cycle. *Current Biology*, *26*(3), R94-R98.

Stein, S., Hartung, J., Möller, K., & Zikeli, S. (2022). The effects of leguminous living mulch intercropping and its growth management on organic cabbage yield and biological nitrogen fixation. *Agronomy*, *12*(5), 1009.

Storr, T., Simmons, R. W., & Hannam, J. A. (2019). A UK survey of the use and management of cover crops. *Annals of Applied Biology*, *174*(2), 179-189.

Sustainable Agriculture Research and Education (SARE) (2017). Cover crops facts: Cover crop at work increase soil organic matter. Sustainable Agriculture Research and Education Retrieved from https://www.sare.org/

Toler, H. D., Augé, R. M., Benelli, V., Allen, F. L., & Ashworth, A. J. (2019). A global meta-analysis of cotton yield and weed suppression from cover crops. *Crop Science*, *59*(3), 1248-1261.

Ullah, H., Santiago-Arenas, R., Ferdous, Z., Attia, A., & Datta, A. (2019). Improving water use efficiency, nitrogen use efficiency, and radiation use efficiency in field crops under drought stress: A review. *Advances in Agronomy*, *156*, 109-157.

Vincent-Caboud, L., Casagrande, M., David, C., Ryan, M. R., Silva, E. M., & Peigne, J. (2019). Using mulch from cover crops to facilitate organic no-till soybean and maize production. A review. *Agronomy for Sustainable Development*, *39*, Article number 45.

Vogelweith, F., & Thiéry, D. (2017). Cover crop differentially affects arthropods, but not diseases, occurring on grape leaves in vineyards. *Australian Journal of Grape and Wine Research*, *23*(3), 426-431.

Wallander, S., Smith, D., Bowman, M., & Claassen, R. (2021). Cover crop trends, programs, and practices in the United States.

Wang, S., Guo, C., Xing, Z., Li, M., Yang, H., Zhang, Y., Ren, F., Chen, L., & Mi, S. (2021). Dietary intervention with α-amylase inhibitor in white kidney beans added yogurt modulated gut microbiota to adjust blood glucose in mice. *Frontiers in Nutrition*, *8*, 664976.

Wang, X., Zhao, C., Müller, C., Wang, C., Ciais, P., Janssens, I., & Piao, S. (2020). Emergent constraint on crop yield response to warmer temperature from field experiments. *Nature Sustainability*, *3*(11), 908-916.

Wooliver, R., & Jagadamma, S. (2023). Response of soil organic carbon fractions to cover cropping: A meta-analysis of agroecosystems. *Agriculture, Ecosystems & Environment*, *351,* 108497.

Wulanningtyas, H. S., Gong, Y., Li, P., Sakagami, N., Nishiwaki, J., & Komatsuzaki, M. (2021). A cover crop and no-tillage system for enhancing soil health by increasing soil organic matter in soybean cultivation. *Soil and Tillage Research*, *205*, 104749.

Yin, W., Chai, Q., Zhao, C., Yu, A., Fan, Z., Hu, F., Fan, H., Guo, Y., & Coulter, J. A. (2020). Water utilization in intercropping: A review. *Agricultural Water Management*, *241*, 106335.

Yuvaraj, M., Pandiyan, M., & Gayathri, P. (2020). Role of legumes in improving soil fertility status. In: *Legume Crops-Prospects, Production, and Uses* (pp. 17-27). IntechOpen.

Zhang, Z., Sun, J., Liu, M., Xu, M., Wang, Y., Wu, G. L., Zhou, H., Ye, C., Tsechoe, D., & Wei, T. (2020). Don't judge toxic weeds on whether they are native but on their ecological effects. *Ecology and Evolution*, *10*(17), 9014-9025.

Zhou, Q., Guan, K., Wang, S., Jiang, C., Huang, Y., Peng, B., Chen, Z., Wang, S., Hipple, J., Schaefer, D., & Cai, Y. (2022). Recent rapid increase of cover crop adoption across the US Midwest detected by fusing multi-source satellite data. *Geophysical Research Letters*, 49(22), e2022GL100249.