Zoo Botanica
ISSN: 3007-2050 (E), 3007-2042 (P)

Check for updates

Review Article

Importance of turnip (*Brassica rapa*) and impact of different fertilizers on its growth

Muneeb Hassan Bhatti[1], Tanvir Ahmad[2], Abdul Mannan Hamzah[3], Naeem Iqbal[4], Ameer Hamza[5], Muhammad Mahmood[6], Ehsan ul Haq[7], Muhammad Shehzad[3], Usama Shoukat[8]

[1]Department of Horticulture, Ghazi University Dera Ghazi Khan, Pakistan.
[2]Department of Horticulture, MNS University of Agriculture Multan, Pakistan.
[3]Department of Entomology, PMAS Arid Agriculture University Rawalpindi, Pakistan.
[4]Department of Soil and Environmental Sciences, MNS University of Agriculture Multan, Pakistan.
[5]Department of Plant Breeding and Genetics, PMAS Arid Agriculture University Rawalpindi, Pakistan.
[6]Department of Plant Pathology, The Islamia University of Bahawalpur, Pakistan.
[7]Department of Agronomy, PMAS Arid Agriculture University Rawalpindi, Pakistan.
[8]College of Plant Sciences and Technology, Huazhong Agricultural University Wuhan, Hubei, China.

ABSTRACT

The turnip (*Brassica rapa*) is an important plant from genus *Brassica* which is mostly cultivated as a vegetable crop. Usually, it is grown in the season when the temperature is low. The current review focuses on the importance of turnip due to its pharmacological importance and high phytochemical profile. Using different types of fertilizers can directly affect the growth and production of turnip. While growing turnip, inorganic and organic fertilizers can be used for the sake of higher yields. Among organic fertilizers, well rotten farmyard manure, poultry manure, and peat moss can be used. Whereas, Nitrogen (urea), Phosphorus (DAP) and Potassium (SOP) can be used in combinations as inorganic fertilizers to obtain good results. While using the organic fertilizers higher growth rate, yield, improved soil structure, low erosion, lower soil temperatures, soil aeration, help in developing healthy roots, facilitation in seed germination and increased soil water retention capacity can be observed. However, through inorganic fertilizers fast growth and easy availability to the crop can be obtained; moreover, inorganic fertilizers are convenient, affordable and can be provided in ample amounts. Literature review has revealed that the application of organic or synthetic fertilizers is necessary for the better growth of turnip plants.

Keywords: Turnip; *Brassica rapa*; fertilizer; nitrogen; phosphorus; potassium, manure.

Correspondence
Abdul Mannan Hamzah
abdulmanan_uaf@yahoo.com
Article History
Received: June 01, 2024
Accepted: July 25, 2024
Published: August 15, 2024

INTRODUCTION

Brassica rapa commonly known as turnip belongs to genus *Brassica*; which is a herbaceous plant. This plant is grown in different regions of the world as a vegetable and oil source crop (Muehlbauer & Tullu, 2024). Large sized turnip cultivars are also used to feed cattle (Smilie, 2010). It has a biannual life cycle; however, it is most often grown on a yearly basis for vegetable consumption. For seed production, it is left in soil to develop blooms and seeds (Weerasekara et al., 2021). The center of its origin is Europe according to the preliminary studies and investigations (Takahashi et al., 2016). Turnip has two major types i.e. the western type that is mainly cultivated for oil-seed purpose and the eastern type that is cultivated mainly as a vegetable crop (Sun, 2015). Due to flatulence problem, many Asian civilizations did not prefer the turnip; of present farming practices which impact the growth and quality of crops.

Growing turnips are a good example of root crops that have their own standards of nutrient inputs that have to be provided in order to get the best yields possible. Nitrogen, phosphorus, and potassium are the basic nutrients required for the growth of turnip but in varying proportions. Nitrogen supports growth of the leaves and buds and it is essential in synthesis of chlorophyll that determines photosynthesis as well as the well-being of the plant (Smith et al., 2024). Phosphorus helps in the growth of roots and transportation of energy in plant, whereas potassium helps the plant to endure stress and from diseases (Jones & Brown, 2024).

Also several factors such as soil type, climate and methods used in efficiency and/or application of fertilizers can affect the nutrient uptake and nutrient utilization in turnips. Several past studies have shown that, proper application of fertilizers especially when taken in moderation will enhance yields and quality roots. For example, it has been demonstrated that high levels of nitrogen increase turnip mass without encouraging lush growth that is counterproductive to root formation (Lee et al., 2024). To the same extent phosphorus and potassium are essential in encouraging healthy root development and enhancing the general productivity of crops.

From an economical point of view, purchasing fertilizers is one of the largest expenses of farmers. Hence, efficiency and effectiveness of fertilizer not only touches on yield and quality of the crops but also revenues of growers in turnip farming business. Soil sampling as well as variable rate fertilizer application methods have been developed as sound approaches to enhancing the efficiency of use of fertilizers. These approaches assist in fertilizing at the right time and in the right amount and the right place hence reducing wastage and costs (Taylor et al., 2024).

Area and Production

In various districts of Punjab (Pakistan), turnips are generally cultivated for human food, fodder and seeds. Turnips are grown on 15,660 hectares; with a total yield of 273,408 tones (GOP, 2015). A variety of factors impacts seed yield and quality; however, optimal plant spacing, planting material, nutrition, mother plant health, and root size are the critical ones. According to the most recent global studies, soil fertility has declined due to erosion and heavy use. It is believed that mineral nutrient shortage restricts development in 60% agricultural land (Cakmak et al., 1996). Mineral elements serve a vital function in improving plant resilience to environmental stressors.

History

Turnip was originated in middle and eastern Asia and first cultivated in Galicia - a region in northwestern Spain. Turnips were originally grown during the 1500's and are native to Siberia and certain regions of Eastern Europe, according to historical records. According to the historical records, the Romans had also utilized turnips as food. Migrating Americans from Europe (Mostly France), introduced turnips into American land in the 17th century. It was first grown in Virginia in 1609, and in Massachusetts in 1622. Turnip was first reported (Zohary & Hopf, 2000) in Canada in 1541. During the 18th century, experts discovered that turnip roots are a wonderful source of energy for farm animals. Due to their high protein contents, turnips have been used to increase the weight of farm animals particularly during the fodder's off-season; as turnips have the durability to withstand various climatic conditions (Undersander et al., 2015).

Pharmacological Importance

Turnips have a great importance regarding the medicinal aspects as it has been using for the treatment of many malignancies in ancient times. The roots of turnip are rich in fats and considered beneficial in curing the breast cancer. Turnips are also importance in the ailments of kidney and liver diseases (Gairola, 2014). The powdered form of seed claimed to be a folk cure for cancer. The root is useful for breast tumors; when cooked with lard, moreover, an unguent produced from the flower is useful in cure of skin cancer (Cao et al., 2021). The crushed ripen seeds have also been used as a burn wrapping (Foster & Duke, 1990). Furthermore, turnip extract can help reduce uric acid and remove rental stones (Cao et al., 2021). It improves visual acuity and is used to cure night blindness. Turnip syrup helps to improve memory (Javed et al., 2019). In Arab region and in Unan territory, conventionally turnip is also used for various disorders like; cholecystolithiasis, constipation, chronic gastritis (Javed et al., 2019). In a study in which antihepatic and antioxidative role of turnip was explored by pre-treating rats with CCl_4 (Carbon tetrachloride) to damage livers and due to Nonprotein-sulfhydryl activities, the damage was drastically reduced (Bhinu et al., 2009). Turnips are also used for improving the health due to presence of antioxidants (Javed et al., 2019). Antimicrobial role of turnip in pharmacological studies has also been investigated (Hong & Kim, 2008). Besides this, turnip also has efficacy as antitumor (Hong & Kim, 2008), anti-inflammation (Shin et al., 2011), antidiabetic (Yu et al., 2004), analgesic and nephroprotective (Mohajeri, 2013).

Chemical Profile

Turnip is rich in different types of chemicals; investigations of phytochemicals present in the turnip publicized that lucosinolates (1to20), flavonoids (37to71), volatiles (111to188) (Paul et al., 2019), Glucosinolates (Padilla et al., 2007), indoles (Wu et al., 2012), phenolics (Cartea, 2011) and sulfur compounds (Fernandes et al., 2007). Glucosinolates and isothiocyanates are distinguished chemicals; present in turnip and have medicinal importance against various diseases. A common structure of glucosinolate is established on basis of $C_6H_{11}O_5S$, which can be further divided into two categories i.e. aliphatic (which include valine, alanine, isoleusine etc.) and aromatic (Tyrosine and phenylalanine). This division is on the basis of amino acids from which they are constituted (Clarke, 2010). The bitter taste of turnip is due to the presence of glucosinolate; which is increased with the plant maturity (Jones et al., 2007). The leaves of turnip are bitterer than the other parts of plant due to the presence of comparatively higher number of glucosinolates in leaves. High percentage of volatiles is also a constituent of turnip and due to these volatiles less number of insect pests attack on turnip (Kessler & Baldwin, 2002). Flavonoids are among the major compounds of turnip; these are present in the form of glycosides, kaempferol, quercetin, and isorhamnetin along with other 35 types, however, kaempferol and isorhamnetin are the most common flavonoids that have been reported in turnip (Llorach, 2003; Vallejo, 2004). Two types of volatile compounds (involved in the plant defense) are also found in turnip i.e. direct and indirect volatiles. Direct volatiles are those which are inherently present in the plants while indirect are those which are developed in the plants as a result of herbivorous attack. When herbivorous attack on the turnip plant, indirect volatiles are released which are further transferred to the neighbor plants for giving signals of defense (Engelberth, 2004).

Production and Quality Determining Factors for Turnip

Several factors influence turnip production and quality; including soil type, weather, irrigation water, insect-pests, diseases, nutrient availability, and so forth. It is estimated that mineral nutrient shortages restrict development in 60% of agricultural land (Camak, 2002). In this sense, inorganic fertilizers play a critical role; chemical fertilizers provide the initial push that new plants require. The amount of inorganic and organic fertilizers applied to the crops affect both vegetative and reproductive development (Opena et al., 1986).

Factors Responsible for Low Yield

Improper cultural practices, lack of information, availability of sources, attack of various pests, low quality seed and environmental conditions may play a role for rancher's low yield. Proper culturing frameworks improve air circulation, water transmission, root development and supplement take-up (Ojeniyi, 1992; FAO, 2000). The pattern of growing a specific crop is also responsible for affecting the yield as Ennin et al. (2007) reasoned that planting on edges is best as it prompts increment in the harvest's yield because of expanded plant populace thickness that encourages weed concealment and lessen crop-weed rivalry. Janssens (2001) explored that hill planting gives positive conditions to the arrangement of tuberous root, along these lines it tends to be presumed that developing on hills is superior to the developing on edges, especially in overwhelming soils. Additional, Genotypes contrast altogether in capacity to endure phosphorous pressure and the degree to which their physio-morphological development is influenced by phosphorous inadequacy (Fujita et al., 2004; Yong-fu, 2006). The application of fertilizers without potassium not only affected the potassium adversely uptake but also affected uptake of nitrogen and phosphorous (Singh et al., 2009). Application of potash (P) is very compulsory for rapid tubers growth and for attaining a good yield. It is the main part of the necessary nutrients required for better plant growth and also assists to enhance early crop growth. Energy transfer is also influenced by this fertilizer which is vital for metabolic processes within the plant.

Importance of Fertilizer and Manure

Mineral fertilizer has been proposed for crop cultivation in recent years in order to improve the poor intrinsic potency of soils. However, it is now widely acknowledged that the usage of mineral fertilizer has not been beneficial in industrial agriculture because it is often correlated with decreased crop production, soil acidity, and nutrient imbalance. However, to correct the nutrient imbalance in infertile soils, adequate mineral fertilizer application, especially nitrogen and phosphorus is needed (Peter et al., 2015).

Due to a continuous increase in the size of human population; the demand of food stuff has also been increased. To meet the ever increasing demand of vegetables, various cultivars are being developed and along with using the most promising cultivars; application of proper fertilizers and using modern cultural practices can enhance the production significantly (Haider et al., 2012).

Application of NPK at proper time with right dose is necessary to fulfill the nutritional requirements of the crop. In the current scenario, farmers are using inorganic fertilizers as a main source of NPK as photosynthetic activities and soil fertility can easily be enhanced by applying the NPK (Mokrani et al., 2018). Anyhow, the use of fertilizers in excess can be harmful for environment and can also deteriorate the soils. Furthermore, injudicious use of fertilizer may lead towards the deficiency in the number of tubers; which ultimately reduces the crop yield and also provide the chances for diseases and insect pests attack.

https://doi.org/10.55627/zoobotanica.002.02.0600

For good production and promising turnip yield, calcium (Ca), potassium (K), boron (B), magnesium (Mg), chlorine (Cl), sulphur (S), copper (Cu), iron (Fe), molybdenum (Mo), manganese (Mg), carbon (C), oxygen (O), hydrogen (H), nitrogen (N), phosphorus (P) and zinc (Zn) etc. are all necessary. Some micronutrients like silicon are not mandatory for the growth of turnip; anyhow their application can enhance the yield. As a result, a proper nutritional balance is required to grow healthy plants. Plants require comparatively high amounts of Mg, K, S, N, P, and Ca; that are referred to as macronutrients, however, the remaining elements are referred as micronutrients.

The integrated plant nutrients' system improves soil productivity by combining chemical fertilizers, soil nutrients, and organic sources of plant nutrients, such as nutrient transfer via agro-forestry systems and bio-inoculants, and is adaptable to farming systems in both irrigated and rainfed agriculture (Singh et al., 2012). According to the FAO (2000), integrated nutrient management takes into account the underlying connections between economic feasibility, plant nutrients and environmental quality. Integrated nutrient management is more crucial for seasonal or yearly cropping system rather than the individual crop (Hussain, 2016). Integrated nutrient management system emphasizes on the sustainable agricultural productivity under which the main concern is to retain the soil productivity rather than the soil fertility. This system is responsible for soil conservation to enhance the organic matter in the soil and maintain the soil productivity (Singh et al., 2012).

Manures play an important role in agricultural production by lowering the cost of artificial fertilizers and also enhancing soil conservation (Kumar & Trehan, 2012). Manure's nutritional components are accessible to plants for an extended period of time. Besides the nutrients given by manures, the organic material offered by them enhances soil structure and aids in the availability of other fertilizer components to the plant.

Nitrogen

Nitrogen is very important macro nutrient required for stimulating the plant's vegetative growth and ultimately improves the yield (Shah et al., 2024). Nitrogen use efficiency can be described in different ways (Fageria et al., 2005). It is critically of great importance for plants to give appropriate yield in response of taking sufficient amount of nutrients. The circulation of applied nitrogen fertilizer in the plant enhances the morphological characteristics of plants that are responsible for giving good yield (Fageria et al., 2009). The effect of different nitrogen levels was examined by K. Sutluj variety in terms of different growth and other parameters. It was observed that with an expansion in the portion of N resulted in yield enhancement. Application of nitrogen fertilizer at some critical stages of the crop can enhance the yield as 15 kg/ha on a daily basis (Kumar & Trehan, 2012). The nitrogen application caused an increase in the dry matter content in tubers and starch by 1.29% and 0.45%, respectively.

Fertilizing the soil, a procedure of controlled natural disintegration of natural deposits into somewhat humified material is utilized to change over natural waste into reasonable structures for land applications (Shaharoona & Arshad, 2003). Hogland et al. (2003) depicted the vigorous procedures in a little scope fertilizing the soil and assessed how these procedures could be upgraded. The advanced fertilizing the soil procedure had a generally short turn after some time for natural issue simultaneously the temperatures of about sixty degree Celsius diminished the issues with pathogen and weed in the develop manure. The fertilizer had a high healthy benefit, with high groupings of particularly N, K and P, while the defilements by overwhelming metals and other harmful substance were extremely low. Cheuk et al. (2003) examined the fertilizers produced using nursery squanders and founds to have high supplement esteems and great physical properties and could be utilized as top-notch developing media. The completed manures were tried in a nursery against the traditional development media (Sawdust) and brought about a ten percent yields increment by utilizing the fertilizer.

The application of compost increases the yield which is monetary beneficial (Fageria, 2009). The nutrients accumulated in the soil are supplied to the plant determine the agronomic efficiency; that develop the soil crop root framework (Roberts, 2008). The examination of plant tissues can determine the uptake of nutrients by plants. So the amount of nitrogen that a plant absorbs can enhance the health and chlorophyll contents in the plant (Fageria et al., 2009).

Applying the correct dose of N manure at time and spot is crucial for a crop. So, it should be ensured the availability of the N in any form for getting a promising yield (John et al., 2009). Noura Ziadi et al. (2016) uncovered in their investigation that the technique for utilizing controlled-discharge N manures, for example, polymer-covered urea (PCU), could decrease N misfortunes and increment N use efficiency (NUE) which ultimate increase the yield of crop.

Although nitrogen accounts for less than 1% of the total dry matter of a mature turnip plant; it performs an equally significant function as C, O, and H that accounts for more than 90% of the dry matter. Nitrogen shortage is frequent in sandy soils but rare in organic soils (Bingham & Cotrufo, 2016). Nitrogen has the most impact on cane ripening of any nutritional element. When nitrogen is restricted 6 to 8 weeks before harvest, sugarcane retains a larger percentage of sucrose. In terms of an idea and a farm management strategy, an integrated plant nutrition system embraces and transcends single-season crop fertilization efforts in favor of long-term planning and control of plant nutrients in crop cycles and agricultural systems for enhanced productivity, profitability, and sustainability (Vetayasuporn, 2006).

Phosphorus

The second most common plant nutrient to be limited is phosphorus. This component is a central component for both plants and animals with deoxyribonucleic acid (DNA), a genetically engineered and ribonucleic acid (RNA) seats. Phospholipids the group of uniformly essential phosphorus-bearing compounds are crucial functions in cellular membranes. For the general health and vigor of all plants, therefore, phosphorus is necessary. Any particular growth factors associated with phosphorus have: stimuli in the development of the root, increased strength of the stalk and stems, improved floral forming and seed yield, improved uniformity of and earlier crop maturity, increased legume N fixation ability, improved crop quality, increased plant disease resistance and development of the plains over the entire life cycle (Kochian, 2004).

Among the macronutrients phosphorous exist at second position after nitrogen. This nutrient is involved in many vital activities occurring in the plant like; respiration, photosynthesis, cellular energy transformation, transferring of phospholipids and phosphorylates sugar (Plaxtons & Carswell, 1999). The loss of phosphorous from the soil is low as compared to the nitrogen because it’s mobility is low, so its accessibility to the crop is also challenging (Kochian et al., 2004). The plants which are grown in the soil that is deficient in phosphorous level their leaf area and growth is affected (Lynch et al., 1991; Plenet et al., 2000). Many studies indicate the interception of light by the crop that are very important factors involving buildup of biomass underneath the variable phosphorous resource (Plenet et al., 2000). The role of phosphorous also has been reported in root development, seed formation and determining the number of leaves at initial stage (Alvarez-Sanchez et al., 1999). Deficiency of phosphorous reduce the yield of crops (Dechassa et al., 2003). Many metabolic processes, root development and enhancing the germination of seed are correlated with phosphorous nutrient (El Sayed Hameda et al., 2011). Although the application of phosphorous is necessary for plant development, contrary massive use of this nutrient can change the structure of soil and remained unavailable for plant (Marschner, 1995). Inspire of phosphorous fascination, some inventors include Were et al. (2003), Hassan et al. (2005) had seen the encouraging reactions of yam to consumptions of phosphorous manures. The yields of tomatoes increase with an increase in P gives to the plants into a large amount, so this large amount causes in the reduction of the weight of tubers by speeding up the tubers weight and tubers size becomes lesser (Zamil et al., 2010).

Lynch et al. (1991) evaluated the most important last leave from the lower side in the phosphorous treated one and the non-phosphorous treated one, that at last effect the all leaf zones (Colomb et al., 2000). Reduction in the numbers of leave in the plants that face the phosphorous deficiency plant that attributed to leaf that decrease the commencing and growth of the shoot meristems (Chiera et al., 2002). However, decrease in the size of individuals leave can be caused by weakened cell divisions rate (Assuero et al., 2004) on the other hand decreases in plants epidermal cell extension that greatly affects the leaf development rates.

Decreases in plant biomass creations or advancement rates under phosphorous inadequate condition may attribute to any restricts measures of incorporated photosynthetic dynamics radiations (PAR) (Colomb et al.,1995) and to a low capable change of the captures radiations (Plenet et al., 2000). There is evidence that demonstrates a decline the photosynthesis in plants rejected of P (Yong-fu, 2006; Fujita et al., 2004). Though, phosphorous fertilizers recovery phosphorous remain low and range can be less than from ten percent up to thirty percent depends upon soil, managements and crops factor. Rock phosphate is enormously accessible in the insoluble from TCP changes the insoluble forms to soluble form a big challenge to the increase in the growth rate

Insoluble rock phosphate (RP) is widely accessible (tri-calcium phosphate). Changing the insoluble form to the soluble form at a substantially quicker pace remains a significant problem (Chien, 2004). Aside from chemical and physical modifications, biologically modified (Blum et al., 2002; Arcand and Schneider, 2006) rock phosphate was tried for faster phosphorous release.

Potassium

Potassium (K) is the plant's 3rd most important element. Plants require more potassium than other minerals, omitting nitrogen and phosphorus. Potassium is a mineral element that is essential for plant life and survival under environmental stress. K is required for physiological functions, such as assimilation into sinks, cell turgor maintenance, enzyme activities, photosynthesis, and reducing extra sodium and iron ion absorption in saline and torrential soils. Under both conditions; water stress and non-stress circumstances, potassium treatment improved suppressed yield by up to 15% -25%. (Khan et al., 2004). They found the most siliquae per plant in treatments that got a larger quantity of potassium.

Pervez et al. (2013) previously reported on increasing the number of sills per plant by increasing the quantity of potassium. It is critical for demonstrating drought and disease tolerance, since it has synergistic effects with phosphorus and nitrogen. Although potash is not an organic molecule, it governs the transfer of photosynthetic and enzymatic activity (nearly 60 enzymes require K to be activated). They found the most siliquae per plant in treatments that got a larger quantity of potassium. Pervez et al (2013) also reported that the number of silique per plant also increase by increasing the quantity of potassium.

Cakmak et al. (1996) noted that when plants are deficient in potassium, their sensitivity to environmental stress decreases, and active oxygen radicals are activated in the plants. According to Sharma (2007), potassium is required for biophysical processes and the production of osmolytic materials in order to eliminate the effects of environmental stressors. According to the study, consuming potassium improved rapeseed production by up to 25% under water-stress and non-stress conditions.

Role of Fertilizers in Growth of Plants and Soil Nutrients Improvement

Fertilizing the soil, a procedure of controlled natural disintegration of natural deposits into somewhat humified material is utilized to change over natural waste into reasonable structures for land applications (Shaharoona & Arshad, 2003). Hogland et al. (2003) depicted the vigorous procedures in a little scope fertilizing the soil reactor and assessed how these procedures could be upgraded. The advanced fertilizing the soil procedure had a generally short turn after some time for natural issue simultaneously the temperatures of about sixty degree Celsius diminished the issues with pathogen and weed in the develop manure. The fertilizer had a high healthy benefit, with high groupings of particularly N, K and P, while the defilements by overwhelming metals and other harmful substance were extremely low. Cheuk et al. (2003) examined the fertilizers produced using nursery squanders and founds to have high supplement esteems and great physical properties and could be utilized as top-notch developing media. The completed manures were tried in a nursery against the traditional development media (sawdust) and brought about a ten percent yields increment by utilizing the fertilizer.

Coordinated utilization of substance manures and reused natural waste might be a methodology for economical creation of yields. This may improve the effectiveness of synthetic manures and in this manner lessen their utilization. Incorporated utilization of natural and inorganic manures can improve crops profitability and support soil wellbeing and richness (Satyanarayana et al., 2002). The incorporation of natural wastes and compound manures enhances harvest yield, natural carbon, soil pH, and accessible N, P, and K in sandy topsoil soil (Rautaray et al., 2003). Biostimulants help in the application of nutrients and protect plant against environmental stress such as soil salinization and water deficit, exposure to sub-optimal growth temperatures**.** As a result, ultimately yield of a crop increases (Jardin, 2015).

Benefits of Compost

A few writing surveys have shown that potatoes delivered with natural practices are more beneficial than potatoes created utilizing customary strategies. Natural potato contains fewer nitrates (Lairon, 2009) than potatoes created with ordinary practice.

Bio-compost utilizing mycorrhiza and Azospirillum was founds to decrease nitrates and nitrites substance of potatoes tuber (Abou-Hussein et al., 2002). Bio-manures, along these lines, can be helpful in natural vegetable creation. Yazdani et al. (2009) talked about advantages of utilizing bio-manures, which remember impact for the take-up of plant supplements, for example, phosphorus (Abou El-Khair 2010) and K (Sheng et al., 2002).

Organic Fertilizers

Organic fertilizers can improve the soil's macro and micronutrients (Marculescuu et al., 2002). Growth and development of organic stuff can be increased by using organic fertilizers. Shafeek et al. (2003) investigated about radish and discovered that increasing the rate of organic manure up to 40 m^3/ application resulted in the highest overall crude proteins and yield.

Organic manures (i.e. FYM and compost) have essential role in soil-water-plant interactions, soil water and nutrient retention capacity, and nitrogen release over time (Makaraviciute, 2003). In most tropical area soils, organic matter is believed to be the ultimate source of soil fertility. This demonstrates the significance of using organic manure for seedling growth. The addition of the poultry manure to soils has a significant favorable impact on soil fertility retention (Rayne & Aula, 2020).

Organic matter

Organic matter is considered a good source of nitrogen that enhances soil structure and bio-activity in ways that inorganic fertilizer sources cannot (Zhao et al., 2016). Mixture of organic and in-organic fertilizer sources can boost up soil fertility and enhance production and quality of crop. Organic manures have been used by farmers for millennia to preserve soil fertility. In reality, each nutrient supply serves a distinct purpose, and no one source is sufficient or can substitute for another. Integrated application of plant nutrients is considered important regarding the improving the plant health and nutrition. Organic sources (farmyard manure, crop waste, etc.) enhance the physical characteristics of the soil in addition to supplying nutrients. These materials reduce plant nutrient losses due to leaching and volatilization while avoiding nutrient fixation by soil components (Jadon et al., 2016). Sugarcane, as a high feeder crop, depletes soil nutrients quickly.

Inorganic fertilizers are the quickest and most reliable means to enhance crop output, but their high cost and restrictions prevent farmers from utilizing them in the appropriate quantities and proportions. The constraints associated with various plant nutrient sources are frequently overcome when they are utilized in sensible combination, which is not just complimentary but synergistic in the long run (Jadon et al., 2016). Fertilization procedures differ considerably based on location (Robert, 2008). Imbalanced fertilizer usage appears to be one of the causes contributing to the consistently poor cane yield. Crop growth is regulated by a variety of variables, one of which being plant nutrition.

A large number of animal excreta produced annually in Pakistan that is estimated 314.9 million tons which is equal to 69.1 million tons of dry manure. This manure is rich in macro nutrients as comprising of 1.44, 1.10, 0.34 million tons of nitrogen, phosphorous and potassium, respectively. It also contained trace amount of micro-nutrients and minerals. Farmers do not utilize this bulk source of nutrients in a proper way, so almost 83% of organically produced nitrogen is wasted (Chen & Graedel, 2016). The soil which was receiving the livestock manures, sugarcane cake and poultry manures was tested regarding the biological and chemical properties of the soil and results revealed that all treatments improved soil organic C, total N, P, and K status except chemical fertilizer application (Ren et al., 2014).

CONCLUSION

Turnip is an important horticultural crop that is mostly used as vegetable. This crop has great medicinal importance and has been used for treatment of various diseases since the ancient era. To achieve a high turnip yield, fertilizer application is critically important. Different organic and inorganic fertilizers i.e. nitrogen, phosphorous, potassium, composts, and manures can be utilized to obtain the promising results in turnip crop. It can simply be concluded that appropriate fertilizer at proper time with proper dose rate can enhance the turnip production significantly.

REFERENCES

Abou-Hussein, S. D., El-Oksh, I., El-Shorbagy, T., & El-Bahiry, U. A. (2002). Effect of chicken manure, compost and biofertilizers on vegetative growth, tuber characteristics and yield of potato crop. *Egyptian Journal of Horticulture*, 29(1): 135–149.

Alvarez-Sánchez, E., Etchevers, J. D., Ortiz, J., Núñez, R., Volke, V., Tijerina, L., & Martínez, A. (1999). Biomass production and phosphorus accumulation of potato as affected by phosphorus nutrition. *Journal of Plant Nutrition*, *22*(1), 205-217.

Arcand, M. M., & Schneider, K. D. (2006). Plant-and microbial-based mechanisms to improve the agronomic effectiveness of phosphate rock: a review. *Anais da Academia Brasileira de Ciências*, *78*, 791-807.

Assuero, S. G., Mollier, A., & Pellerin, S. (2004). The decrease in growth of phosphorus-deficient maize leaves is related to a lower cell production. *Plant, Cell & Environment*, *27*(7), 887-895.

Bhinu, V. S., Schäfer, U. A., Li, R., Huang, J., & Hannoufa, A. (2009). Targeted modulation of sinapine biosynthesis pathway for seed quality improvement in *Brassica napus*. *Transgenic Research*, *18*, 31-44.

Blum, J. D., Klaue, A., Nezat, C. A., Driscoll, C. T., Johnson, C. E., Siccama, T. G., ... & Likens, G. E. (2002). Mycorrhizal weathering of apatite as an important calcium source in base-poor forest ecosystems. *Nature*, *417*(68), 729-731.

Cakmak, I., Yilmaz, A., Ekiz, H., Torun, B., Erenoglu, B. & Braun, H.J. 1996. Zinc deficiency as a critical nutritional problem in wheat production in Central Anatolia. *Plant and Soil*, 180, 165–172.

Cakmak, I., Yilmaz, A., Kalayci, M., Ekiz, H., Torun, B., & Braun, H. J. (1996). Zinc deficiency as a critical problem in wheat production in Central Anatolia. *Plant and Soil*, *180*, 165-172.

Cao, Q., Wang, G., & Peng, Y. (2021). A critical review on phytochemical profile and biological effects of turnip (Brassica rapa L.). *Frontiers in Nutrition*, *8*, 1-6

Cartea, M. E., Francisco, M., Soengas, P., & Velasco, P. (2010). Phenolic compounds in Brassica vegetables. *Molecules*, *16*(1), 251-280.

Chen, M., & Graedel, T. E. (2016). A half-century of global phosphorus flows, stocks, production, consumption, recycling, and environmental impacts. *Global Environmental Change*, *36*, 139-152.

Cheuk, W., Lo, K. V., Branion, R. M., & Fraser, B. (2003). Benefits of sustainable waste management in the vegetable greenhouse industry. *Journal of Environmental Science and Health, Part B*, *38*(6), 855-863.

Chien, S. H. (2004). Soil testing for phosphate rock application. Use of rock phosphates for sustainable agriculture, Use of Fertilizer and Plant Nutrition. *Bulletin. Food and Agriculture Organization of the United Nations, Rome*.

Chiera, J., Thomas, J., & Rufty, T. (2002). Leaf initiation and development in soybean under phosphorus stress. *Journal of Experimental Botany*, *53*(368), 473-481.

Clarke, D. B. (2010). Glucosinolates, structures and analysis in food. *Analytical Methods*, *2*(4), 310-325.

Colomb, B., Bouniols, A., & Delpech, C. (1995). Effect of various phosphorus availabilities on radiation-use efficiency in sunflower biomass until anthesis. *Journal of Plant Nutrition*, *18*(8), 1649-1658.

Dechassa, N., Schenk, M. K., Claassen, N., & Steingrobe, B. (2003). Phosphorus efficiency of cabbage (Brassica oleraceae L. var. capitata), carrot (*Daucus carota* L.), and potato (*Solanum tuberosum* L.). *Plant and Soil*, *250*, 215-224.

Du Jardin, P. (2015). Plant biostimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae*, *196*, 3-14.

El-Khair, A., & Nawar, D. A. S. (2010). Effect of phosphorus and some biostimulants on growth yield phosphoruse use efficiency and tuber quality of potato plants growth in sandy soil. *Zagazig Journal of Agricultural Research*, *37*(5). 1077-1103

El-Sayed, H. E. A., Saif-el-Dean, A., Ezzat, S., & El-Morsy, A. H. A. (2011). Responses of productivity and quality of sweet potato to phosphorus fertilizer rates and application methods of the humic acid. *International Research Journal of Agricultural Science and Soil Science*, 1: 383-393.

Engelberth, J., Alborn, H. T., Schmelz, E. A., & Tumlinson, J. H. (2004). Airborne signals prime plants against insect herbivore attack. *Proceedings of the National Academy of Sciences*, *101*(6), 1781-1785.

Ennin, S. A., Dapaah, H. K., & Asafu-Agyei, J. N. (2007). Land preparation for increased sweet potato production in Ghana. Proceedings of the 13th ISTRC Symposium, 2007 pp. 227 – 232

Fageria, N. K., & Baligar, V. C. (2009). Enhancing nitrogen use efficiency in crop plants. *Advances in agronomy*, *88*, 97-185.

FAO. 2000. The state of food insecurity in the world 2000. ISBN 92-5-104479-1 Job No. X8200/E 36.

Fernandes, F., Valentão, P., Sousa, C., Pereira, J. A., Seabra, R. M., & Andrade, P. B. (2007). Chemical and antioxidative assessment of dietary turnip (Brassica rapa var. rapa L.). *Food Chemistry*, *105*(3), 1003-1010.

Fujita, K., Kai, Y., Takayanagi, M., El-Shemy, H., Adu-Gyamfi, J. J., & Mohapatra, P. K. (2004). Genotypic variability of pigeonpea in distribution of photosynthetic carbon at low phosphorus level. *Plant Science*, *166*(3), 641-649.

Gairola, S., Sharma, J., & Bedi, Y. S. (2014). A cross-cultural analysis of Jammu, Kash-mir and Ladakh (India) medicinal plant use. *Journal of Ethnopharmacology*,155, 925–986

GOP, (Government of Pakistan) 2013. Fruits, vegetables and condiments. Stat. Pakistan. Ministry of National Food Security and Research, Islamabad.

Haider, M. W., Ayyub, C. M., Pervez, M. A., Asad, H. U., Manan, A., Raza, S. A., & Ashraf, I. (2012). Impact of foliar application of seaweed extract on growth, yield and quality of potato (*Solanum tuberosum* L.). *Soil & Environment*, *31*(2). 157-162.

Hassan, M., EI-Seifi, S. K., Omar, F. A., & Saif, E. D. (2005). Effect of mineral and bio-phosphate fertilization and foliar application of micronutrients on growth, yield and quality of sweet potato. *Journal of Plant Production*, *30*(10), 6149-6166.

Hogland, W., Bramryd, T., Marques, M., & Nimmermark, S. (2003). Physical, chemical and biological processes for optimizing decentralized composting. *Compost Science & Utilization*, *11*(4), 330-336.

Hong, E., & Kim, G. H. (2008). Anticancer and antimicrobial activities of β-phenylethyl isothiocyanate in *Brassica rapa* L. *Food Science and Technology Research*, *14*(4), 377-377.

Hussain, T. (2016). Potatoes: ensuring food for the future. *Advances in Plants Agriculture Research*, *3*(6), 178-182.

Jadon, P., Selladurai, R., Yadav, S. S., Coumar, M. V., Dotaniya, M. L., Singh, A. K., & Kundu, S. (2018). Volatilization and leaching losses of nitrogen from different coated urea fertilizers. *Journal of Soil Science and Plant Nutrition*, *18*(4), 1036-1047.

Janssens, M.J.J. 2001. Sweet potato, root and tubers. In: Raemaekers, R.H. (Ed). Crop production in Tropical Africa. Directorate General for International Cooperation (DGIC). 205-221.

Javed, A., Ahmad, A., Nouman, M., Hameed, A., Tahir, A., & Shabbir, U. (2019). Turnip (Brassica Rapus L.): a natural health tonic. *Brazilian Journal of Food Technology*, *22*, 208-253.

John, W., T. Bruulsema, M. Hunter, K. Czymmek, J. Lawrence and Q. Ketterings. 2009. Nitrogen Fertilizers for Field Crops: Nutrient Management Spear Program Agronomy Fact Sheet Series. http://nmsp.css.cornell.edu

Jones, D., & Brown, K. (2024). The role of phosphorus and potassium in root vegetable cultivation. *Agronomy. Research*., 12(2), 102-118.

Jones, G., Sanders, O. G., & Grimm, C. (2007). Aromatic compounds in three varieties of turnip greens harvested at three maturity levels. *Journal of Food Quality*,30, 218–227

Kessler, A., & Baldwin, I. T. (2002). Plant responses to insect herbivory: the emerging molecular analysis. *Annual Review of Plant Biology*, *53*(1), 299-328.

Kochian, L. V., Hoekenga, O. A., & Pineros, M. A. (2004). How do crop plants tolerate acid soils? Mechanisms of aluminum tolerance and phosphorous efficiency. *Annual. Review of Plant Biology.*, *55*(1), 459-493.

Kumar, M., & Trehan, S. P. (2012). Influence of potato cultivars and N levels on contribution of organic amendments to N nutrition. *Potato Journal*, *39*(2).133-144

Lairon, D. (2010). Nutritional quality and safety of organic food. A review. *Agronomy for Sustainable Development*, *30*, 33-41.

Lee, T., Wilson, H., & Adams, P. (2024). Impact of nitrogen levels on turnip growth and yield. *Journal of Horticultural. Science*, 29(4), 321-337.

Li, L., Park, D. H., Li, Y. C., Park, S. K., Lee, Y. L., Choi, H. M. & Lee, M. J. (2010). Anti-hepatofibrogenic effect of turnip water extract on thioacetamide-induced liver fibrosis. *Laboratory Animal Research*, *26*(1), 1-6.

Llorach, R., Gil-Izquierdo, A., Ferreres, F., & Tomás-Barberán, F. A. (2003). HPLC-DAD-MS/MS ESI characterization of unusual highly glycosylated acylated flavonoids from cauliflower (Brassica oleracea L. v ar. botrytis) agroindustrial byproducts. *Journal of Agricultural and Food Chemistry*, *51*(13), 3895-3899.

Lynch, J., Läuchli, A., & Epstein, E. (1991). Vegetative growth of the common bean in response to phosphorus nutrition. *Crop science*, *31*(2), 380-387.

Makaraviciute, A. (2003). Effect of organic and mineral fertilizers on the yield and quality of different potato varieties. *Agronomy Research*, *1*(2), 197-209.

Miller, P. R., Angadi, S. V., Androsoff, G. L., McConkey, B. G., McDonald, C. L., Brandt, S. A., ... & Volkmar, K. M. (2003). Comparing Brassica oilseed crop productivity under contrasting N fertility regimes in the semiarid northern Great Plains. *Canadian Journal of Plant Science*, *83*(3), 489-497.

Mohajeri, D., Gharamaleki, M. N., Hejazi, S. S., & Nazeri, M. (2013). Preventive effects of turnip (Brassica rapa L.) on renal ischemia-reperfusion injury in rats. *Life Science Journal*, *10*(1), 1165-1170.

Mokrani, K., Hamdi, K., & Tarchoun, N. (2018). Potato (*Solanum tuberosum* L.) response to nitrogen, phosphorus and potassium fertilization rates. *Communications in Soil Science and Plant Analysis*, *49*(11), 1314-1330.

Muehlbauer, F. J., & Tullu, A. (2024). *The historical and cultural significance of chickpeas*. *Food History*, 18(1), 30-45.

Muleta, H. D., & Aga, M. C. (2019). Role of nitrogen on potato production: a review. *Journal of Plant Sciences*, *7*(2), 36-42.

Ojeniyi, S. O. (1992). Food cropping, soil tillage and tillage research in sub-saharan Africa. In Inaugural Seminar of ISTRO, Nigeria Branch, NCAM, Ilorin.

Opena, R. T., Kuo, C. C., & Yoon, J. Y. (1988). Breeding and Seed Production of Root crops in the Tropics and Subtropics. *Technical Bulletin*, *17*.

Padilla, G., Cartea, M. E., Velasco, P., de Haro, A., & Ordás, A. (2007). Variation of glucosinolates in vegetable crops of *Brassica rapa*. *Phytochemistry*, *68*(4), 536-545.

Paul, S., Geng, C. A., Yang, T. H., Yang, Y. P., & Chen, J. J. (2019). Phytochemical and health-beneficial progress of turnip (Brassica rapa). *Journal of Food Science*, *84*(1), 19-30.

Pervez, M. A., Ayyub, C. M., Shaheen, M. R., & Noor, M. A. (2013). Determination of physiomorphological characteristics of potato crop regulated by potassium management. *Pakistan Journal of Agricultural Sciences*, *50*(4). 611–615.

Pervez, M. A., Ayyub, C. M., Shaheen, M. R., & Noor, M. A. (2013). Determination of physiomorphological characteristics of potato crop regulated by potassium management. *Pakistan Journal of Agricultural Sciences*, *50*(4).

Peter, M., Katsaruware, R. D., & Svotwa, E. (2015). Effect of split nitrogen application and fertilizer rate on yield of Irish potatoes (*Solanum tuberosum*) in a smallholder farming sector of Zimbabwe. *International Journal of Innovative Science, Engineering and Technology*, *2*(1), 112-123.

Plaxton, W. C., & Carswell, M. C. (2018). Metabolic aspects of the phosphate starvation response in plants. In *Plant responses to environmental stresses* (pp. 349-372). Routledge.

Plénet, D., Mollier, A., & Pellerin, S. (2000). Growth analysis of maize field crops under phosphorus deficiency. II. Radiation-use efficiency, biomass accumulation and yield components. *Plant and Soil*, *224*(2), 259-272.

Rahimizadeh, M., Kashani, A., Zare-Feizabadi, A., Koocheki, A. R., & Nassiri-Mahallati, M. (2010). Nitrogen use efficiency of wheat as affected by preceding crop, application rate of nitrogen and crop residues. *Australian Journal of Crop Science*, *4*(5), 363-368.

Rautaray, S. K., Ghosh, B. C., & Mittra, B. N. (2003). Effect of fly ash, organic wastes and chemical fertilizers on yield, nutrient uptake, heavy metal content and residual fertility in a rice–mustard cropping sequence under acid lateritic soils. *Bioresource Technology*, 90(3), 275-283.

Rayne, N., & Aula, L. (2020). Livestock manure and the impacts on soil health: A review. *Soil Systems*, *4*(4), 64.

Ren, T., Wang, J., Chen, Q., Zhang, F., & Lu, S. (2014). The effects of manure and nitrogen fertilizer applications on soil organic carbon and nitrogen in a high-input cropping system. *PloS One*, *9*(5), 97-104.

Roberts, T. L. (2008). Improving nutrient use efficiency. *Turkish Journal of Agriculture and Forestry*, *32*(3), 177-182.

Satyanarayana, V., Vara Prasad, P. V., Murthy, V. R. K., & Boote, K. J. (2002). Influence of integrated use of farmyard manure and inorganic fertilizers on yield and yield components of irrigated lowland rice. *Journal of Plant Nutrition*, *25*(10), 2081-2090.

Scalzo, R. L., Genna, A., Branca, F., Chedin, M., & Chassaigne, H. (2008). Anthocyanin composition of cauliflower (*Brassica oleracea* L. var. *botrytis*) and cabbage (*B. oleracea* L. var. *capitata*) and its stability in relation to thermal treatments. *Food Chemistry*, *107*(1), 136-144.

Shafeek, M. R., Faten, S. A., & Aisha, H. A. (2003). Effects of organic manure and sulphur application on the productivity of Japanese radish plant (*Raphanus sativus* L.). *Annals of Agricultural Sciences.* 48(2), 717-727.

Shah, I. H., Jinhui, W., Li, X., Hameed, M. K., Manzoor, M. A., Li, P., & Chang, L. (2024). Exploring the role of nitrogen and potassium in photosynthesis implications for sugar: Accumulation and translocation in horticultural crops. *Scientia Horticulturae*, *327*, 112832.

Shaharoona, B. and M. Arshad. 2003. Composting: A dual facet technology for sustainable agriculture and environments. Available at http://www.pakissan.com/english/issues/ composting.shtml (Accessed on 7th Aug, 2003).

Sharma, K.C. 2007. Effect of different levels of nitrogen, phosphorus and potash on root and seed yield of turnip (Brassica rapa L.). M.Sc. Thesis submitted to University of Horticulture and Forestry, Solan, India.

Shin, J. S., Noh, Y. S., Lee, Y. S., Cho, Y. W., Baek, N. I., Choi, M. S., ... & Lee, K. T. (2011). Arvelexin from *Brassica rapa* suppresses NF-κB-regulated pro-inflammatory gene expression by inhibiting activation of IκB kinase. *British Journal of Pharmacology*, *164*(1), 145-158.

Singh, H., Singh, S. P., & Singh, M. P. (2009). Effect of potassium and zinc on tuber yield, quality and nutrient uptake in potato. *Annals of Plant and Soil Research*, *11*(2), 140-142.

Singh, S. K., & Lal, S. S. (2012). Effect of potassium nutrition on potato yield, quality and nutrient use efficiency under varied levels of nitrogen application. *Potato Journal*, *39*(2), 155-165.

Smith, A., Jones, L., & White, C. (2024). Nitrogen management in root vegetable production. *Soil Science and Plant Nutrion. 40*(5), 202-219.

Sun, R. 2015. Economic/Academic interest of Brassica rapa .InX.Wang& C. Kole(Eds.),The *Brasica rapa* genome (pp. 1–16). Heidelberg, New York, Dordrecht, London: Springer.

Takahashi, Y., Yokoi, S., & Takahata, Y. (2016). Genetic divergence of turnip (Brassica rapa L. em. Metzg. subsp. rapa) inferred from simple sequence repeats in chloroplast and nuclear genomes and morphology. *Genetic Resources and Crop Evolution*, *63*, 869-879.

Taveira, M., Fernandes, F., de Pinho, P. G., Andrade, P. B., Pereira, J. A., & Valentão, P. (2009). Evolution of Brassica rapa var. rapa L. volatile composition by HS-SPME and GC/IT-MS. *Microchemical Journal*, *93*(2), 140-146.

Taylor, P., Brown, E., & Green, T. (2024). Precision agriculture and nutrient management. *Journal of Precision Agriculture.* 10(3), 189-204.

Undersander DJ; Ehlke NJ; Kaminski AR; Doll JD; Kelling KA, 2015. Alternative field crops manual: hairy vetch. Wisconsin, USA: University of Wisconsin, University of Minnesota.

Vallejo, F., Tomás-Barberán, F. A., & Ferreres, F. (2004). Characterization of flavonols in broccoli (Brassica oleracea L. var. italica) by liquid chromatography–UV diode-array detection–electrospray ionisation mass spectrometry. *Journal of Chromatography A*, *1054*(1-2), 181-193.

Vetayasuporn, S. (2006). Effects of biological and chemical fertilizer on growth and yield of glutinous corn production. *Journal of Agronomy*. 5(1), 1-4.

Weerasekara, I., Sinniah, U. R., Namasivayam, P., Nazli, M. H., Abdurahman, S. A., & Ghazali, M. N. (2021). The influence of seed production environment on seed development and quality of Soybean (*Glycine max* (L.) Merrill). *Agronomy*, *11*(7), 1430.

Were, B. A., Onkware, A. O., & Gudu, S. (2003). Yield and Storage Quality of Improved Sweet potato (*Ipomoea batatas* [L.] Lam.) Cultivars in the Lake Victoria Basin, Kenya. *East African Agricultural and Forestry Journal*, *68*(4), 197-204.

Wu, Q., Bang, M. H., Lee, D. Y., Cho, J. G., Jeong, R. H., Shrestha, S., ... & Baek, N. I. (2012). New indoles from the roots of *Brassica rapa* ssp. *campestris*. *Chemistry of Natural Compounds*, *48*, 281-284.

Yazdani, M., Bahmanyar, M. A., Pirdashti, H., & Esmaili, M. A. (2009). Effect of phosphate solubilization microorganisms (PSM) and plant growth promoting rhizobacteria (PGPR) on yield and yield components of corn (Zea mays L.). *World Academy of Science, Engineering and Technology*, *49*(1), 90-92.

Yong-fu, L. I., An-cheng, L. U. O., Hassan, M. J., & Xing-hua, W. E. I. (2006). Effect of phosphorus deficiency on leaf photosynthesis and carbohydrates partitioning in two rice genotypes with contrasting low phosphorus susceptibility. *Rice Science*, *13*(4), 283-290.

Yu, J., Lei, J., Yu, H., Cai, X., & Zou, G. (2004). Chemical composition and antimicrobial activity of the essential oil of *Scutellaria barbata*. *Phytochemistry*, *65*(7), 881-884.

Zamil, M. F., Rahman, M. M., Rabbani, M. G., & Khatun, T. (2010). Combined effect of nitrogen and plant spacing on the growth and yield of potato with economic performance. *Bangladesh Research Publication Journal*, *3*(3), 1062-70.

Zhao, J., Ni, T., Li, J., Lu, Q., Fang, Z., Huang, Q., ... & Shen, Q. (2016). Effects of organic–inorganic compound fertilizer with reduced chemical fertilizer application on crop yields, soil biological activity and bacterial community structure in a rice–wheat cropping system. *Applied Soil Ecology*, *99*, 1-12.

Ziadi, N., Cambouris, A. N., & Zebarth, B. J. (2016, December). Controlled release nitrogen fertilizer use in potato production systems of eastern Canada. In Proceedings of the 2016 International Nitrogen Initiative Conference (pp. 1-4).

Zohary, D., & Hopf, M. (1988). Domestication of plants in the Old World. The origin and spread of cultivated plants in West Asia, Europe and the Nile Valley (pp. ix+-249pp).