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Review on Nitrogen: Forms, Functions and Effects on Potato Growth Performance

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ABSTRACT

Nitrogen has greater influence on growth and yield of crop plants than any other essential plant nutrient. Nitrogen is usually the element that is of primary importance in the determination of crop yields and quality. Potato is a sensitive crop to application management of nitrogen and amounts less or more than its requirements. The main objective of this review was to assess the forms, functions and effects in plant growth (in case of potato). Original source of nitrogen is atmosphere it is also found in soil pore spaces as dinitrogen gas and both organic and inorganic forms in the soil. Nitrogen commonly loses through leaching, volatilization, crop removal, denitrification, soil erosion and runoff. Biological fixation and commercial production are main sources of nitrogen and shortage of nitrogen shows different symptoms on different morphological parts and low nutrient content on tissues and grains (tubers) of crops. Generally nitrogen is one of essential nutrient for complete life cycle of plants. It is the first most important nutrient required relatively in large amounts by plants while soils generally contain relatively small amounts of this element.

***Keywords*:** Nitrogen, Nitrogen loses, Potato, Growth, Function

1. INTRODUCTION

Nitrogen plays a pivotal role in many physiological and biochemical processes in plants. Nitrogen is a component of many important organic compounds ranging from proteins to

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nucleic acids. It is a constituent of the chlorophyll molecule, which plays an important role in plant photosynthesis. Many enzymes are proteinaceous; hence, N plays a key role in many metabolic reactions. Nitrogen is also a structural constituent of cell walls (Fageria and Baligar, 2005a).

Crop yields are commonly limited more by an inadequate supply of nitrogen than of any other element and hence this element occupies a unique economic, as well as metabolic, position. Not only is it needed in comparatively large amounts for plant growth, but it is fairly expensive to supply and easily lost from the soil by leaching or in gaseous forms. The nitrogen in storage organs and mature tissues is likely to be there chiefly as protein but in actively growing tissues the percentage that is present as protein is usually much less (Huber and Thompson, 2007).

About 5% of soil organic matter or humus consists, on the average, of nitrogen combined with the other elements that are essential for crop growth. It is usually the element that is of primary importance in the determination of crop yields and quality. It is required in comparatively large amounts and is likely to be deficient in soils unless the best farm management practices are used. It is a transient element, and an understanding of the factors that affect it is highly important in attempting to secure maximum efficiency in its use**.** Since inadequate nitrogen leads to low yields and poor quality, whereas too much can occasionally be harmful, the proper management of this element often prevents problems. Potato is a sensitive crop to application management of nitrogen and amounts less or more than its requirements or early and late application of nitrogen will affect quantitative and qualitative yield of tuber (Rezaei and Soltani, 1996). Sufficient use of nitrogen fertilizers in early growth season will expand leaf area and increase photo assimilates. Deficiency of nitrogen will decrease tuber yield via affecting the tuber production. To prevent harmful accumulation of nitrate in potato tubers, nitrogen must be used considering production potentials of cultivar and farm. Higher amounts of nitrogen fertilizers will increase nitrate concentration in tubers (Mohammad V. and Mohammadreza N., 2012).

2. NATURE AND FORMS OF NITROGEN

Nitrogen is one of the most yield-limiting nutrients for crop production in the world. It is also the nutrient element applied in the largest quantity for most annual crops (Huber and Thompson, 2007). In addition to nitrogen occurring as atmospheric dinitrogen gas in soil pore spaces, nitrogen occurs in both organic and inorganic forms in the soil.

2. 1. Organic Nitrogen

Several organic compounds compose the organic fraction of nitrogen in soil. Soil organic matter exists as decomposing plant and animal residues, relatively stable products of decomposition-resistant compounds and humus. Nitrogen has accumulated in these various organic fractions during soil development.

Organic matter formation and stability is largely related to long-term moisture and temperature trends. With higher average temperatures, soil organic matter decreases. As moisture increases, soil organic matter increases (Silvia *et al*., 2006). Higher temperatures lead to more rapid and complete organic matter decomposition to soluble products which can leach from soil. Increasing moisture causes more plant growth, resulting in more organic residue. Yet, organic matter levels have declined due to the cultivation of virgin soils. This has increased organic matter oxidation and decreased soil organic matter nitrogen for crop uptake. Soils that once contained 4 to 5 % organic matter may contain only 1 to 2 % after 50 years of cultivation. Reduced tillage techniques in combination with legume rotations and judicious fertilizer use may help maintain or slightly increase organic matter levels with time (Alam *et al*., 2007).

2. 2. Inorganic Nitrogen

Ammonium (NH_4^+) and nitrate (NO_3^-) are pre dominate inorganic forms of nitrogen in soils and urea, ammonium salts, anhydrous ammonia, Cyanamid, urea-ammonium nitrate solutions and various nitrate salts can be produced in factory (Schmied *et al*., 2000).

3. SOURCES OF NITROGEN

The original source of all nitrogen that enters into life processes was long considered to be the atmosphere. Stevenson (1957) has, however, presented evidence that perhaps 20 times as much nitrogen is held as ammonium within the lattice structures of silicate minerals as is present as elemental nitrogen in the atmosphere. Only a negligible amount of the ammonium of rocks is utilizable by plants, and hence the agriculturalist must depend upon other sources of nitrogen. These are: (1) soil nitrogen that originally came almost exclusively from the air; (2) nitrogen constantly being fixed from the air by microorganisms and in a minor way by electric discharges in the air; and (3) nitrogen of commercial fertilizers derived chiefly from the air by industrial processes.

3. 1. Soil nitrogen

Until quite recent times, and even today in many localities, organic matter is the chief and often the only important source of nitrogen for crop production. This supply of nitrogen was often so large in soils first brought under cultivation that there was no need for supplemental nitrogen. As crop yields decreased, animal manures and other outside sources of nitrogen were given increasing attention. In the present age of abundant fertilizers, soil nitrogen is still important but in a somewhat different sense than formerly (John A. Lamb *et al*, 2014).

The soil is no longer serving as a mine but more as a reservoir to which nitrogen is both added and removed. As a result of biological immobilization and mineralization, mineral nitrogen may at one time be decreased and at other times be increased. Ideally, the aim is always to have adequate available nitrogen present to meet the needs of the crop but to avoid excesses that may be subject to loss via leaching or as gases. Of course this ideal can seldom be realized, but nevertheless the soil organic matter does go a long way toward the attainment of this goal.

3. 2. Biological nitrogen fixation

The chief channel by which atmospheric nitrogen is added naturally to soils and to plants is via symbiotic bacteria living chiefly, but not exclusively, on legume roots. A few non legumes also fix nitrogen symbiotically, but since these plants are chiefly shrubs and trees their importance in general agriculture is minor. Fixation of nitrogen by free-living bacteria has undoubtedly been a major factor in the building up of soil nitrogen in undisturbed soils over the centuries, but is of minor importance in any one year in cultivated soils. Under many conditions a considerable portion of this newly-fixed nitrogen is left in the soil or is returned to it in the form of crop residues or manures. Many legumes with deep roots are of considerable benefit in opening up impermeable subsoil's. They were also prized as animal feeds, and the extent to which they were grown was often dependent upon whether they were needed for this purpose (Walker *et al*., 1954; Walker, 1956**).**

The presence of inorganic nitrogen reduces fixation more or less in proportion to the amount present. Under a pasture system of farming the constant removal of the nitrogenous herbage, if properly regulated, results in high fixation of nitrogen at comparatively low cost. Under such conditions, where land and labor charges are low, it is obvious that commercially fixed nitrogen cannot compete satisfactorily with nature's method (Whitehead, 1970).

3. 3. Commercial nitrogen

Abundant supplies of nitrogen are now available at reasonable prices in various reduced and oxidized forms. These include urea, ammonium salts, anhydrous ammonia, Cyanamid, urea-ammonium nitrate solutions and various nitrate salts. The organic materials that were so important in fertilizer mixtures at the beginning of this century have essentially disappeared from the market. Because of the increasing interest in the disposal of city wastes, it is expected that in the future there will be an increase in the use of processed sewage and garbage (Fageria *et al*., 2003b).

These materials, when properly prepared, are good sources of nitrogen and are somewhat less readily available than is most of the nitrogen compounds now in common use. Urea formaldehyde products, and other slowly available materials, are used to a limited extent for special purposes. These materials are satisfactory sources of nitrogen, but are not of equal value under all conditions, and for all crops. All of these materials, when added to soil, are transformed into ammonia and nitrates and this tends to minimize the differences in their effects on plants.

4. NITROGEN LOSS AND AVAILABLE FORM

4. 1. Nitrogen loss

Leaching: In contrast to the biological transformations, loss of nitrate by leaching is a physical event. Leaching is the loss of soluble NO_3^- as it moves with soil water, generally excess water, below the root zone. Nitrate-N that moves below the root zone has the potential to enter either groundwater or surface water through tile drainage systems. Coarse-textured soils have a lower water holding capacity and, therefore, a greater potential to lose nitrate from leaching when compared with fine-textured soils. Some sandy soils, for instance, may retain only 1/2 inch of water per foot of soil while some silt loam or clay loam soils may retain up to 2 inches of water per foot. Nitrate-N can be leached from any soil if rainfall or irrigation moves water through the root zone (wyffels.com, 2013).

Denitrification: Denitrification can be a major loss mechanism of NO_3^- when soils are saturated with water for 2 or 3 days. Nitrogen in the NH_4^+ form is not subject to this loss.

Management alternatives are available if denitrification losses are a potential problem (wyffels.com, 2013).

Volatilization: Significant losses from some surface-applied N sources can occur through the process of volatilization. In this process, N is lost as ammonia (NH_3) gas. Nitrogen can be lost in this way from manure and fertilizer products containing urea. Ammonia is an intermediate form of N during the process in which urea is transformed to NH_4^+. Incorporation of these N sources will virtually eliminate volatilization losses. Loss of N from volatilization is greater when soil pH is >7.3, the air temperature is high, the soil surface is moist, and there is a lot of residue on the soil (wyffels.com, 2013).

Crop removal: Substantial amounts of N are lost from the soil system through crop removal. Crop removal accounts for a majority of the N that leaves the soil system (wyffels.com, 2013).

Soil erosion and runoff: Nitrogen can be lost from agricultural lands through soil erosion and runoff. Losses through these events do not normally account for a large portion of the soil N budget, but should be considered for surface water quality issues. Incorporation or injection of manure and fertilizer can help to protect against N low through erosion or runoff. Where soils are highly erodible, conservation tillage can reduce soil erosion and runoff, resulting in less surface low of N (wyffels.com, 2013).

4. 2. Nitrogen available form

Atmospheric N is the major reservoir for N in the N cycle (air is 79% N_2 gas). Although unavailable to most plants, large amounts of N_2 can be used by leguminous plants via biological N fixation. In this biological process, nodule-forming *Rhizobium* bacteria inhabit the roots of leguminous plants and through a symbiotic relationship convert atmospheric N_2 to a form the plant can use. Any portion of a legume crop that is left after harvest, including roots and nodules, can supply N to the soil system when the plant material is decomposed. Several non symbiotic organisms exist that fix N, but N additions from these organisms are quite low. In addition, small amounts of N are added to soil from precipitation (Jensen, Dr. Thomas L., 2010)

Commercial N fertilizers are also derived from the atmospheric N pool and major step is combining N_2 with hydrogen (H_2) to form ammonia (NH_3). Anhydrous ammonia is then used as a starting point in the manufacture of other nitrogen fertilizers. Anhydrous ammonia or other N products derived from NH_3 can then supplement other N sources for crop nutrition. Nitrogen can also become available for plant use from organic N sources. But first these organic sources must be converted to inorganic forms before they are available to plants.

Soil organic matter is also a major source of N used by crops. Organic matter is composed primarily of rather stable material called humus that has collected over a long period of time. Easily decomposed portions of organic material disappear relatively quickly, leaving behind residues more resistant to decay. Soils contain approximately 2,000 pounds N in organic forms for each percent of organic matter.

Effect of soil pH on nitrogen availability: Soil pH or soil reaction is an indication of the acidity or alkalinity of soil and is measured in pH units. The availability of some plant nutrients is greatly affected by soil pH. Nitrogen (N), Potassium (K), and Sulfur (S) are major plant nutrients that appear to be less affected directly by soil pH than many others, but still are to some extent.

One of the key soil nutrients is nitrogen (N) and plants can take up N in the ammonium (NH_4^+) or nitrate (NO_3^-) form. At pH is near neutral, the microbial conversion of NH_4^+ to nitrate (nitrification) is rapid, and crops generally take up nitrate. In acid soils (pH < 6), nitrification is slow, and plants with the ability to take up NH_4^+ may have an advantage. Soil pH also plays an important role in volatilization losses. Ammonium in the soil solution exists in equilibrium with ammonia gas (NH_3) and the equilibrium is strongly pH dependent (Sweeney, D. W. and J. L. Moyer. 2004).

The difference between NH3 and NH_4^+ is a H^+. For example, if NH_4^+ were applied to a soil at pH 7, the equilibrium condition would be 99% NH_4^+ and 1% NH_3. At pH 8, approximately 10% would exist as NH_3. This means that a fertilizer like urea (46-0-0) is generally subject to higher losses at higher pH. But it does not mean that losses at pH 7 will be 1% or less. The equilibrium is dynamic. As soon as a molecule of NH_3 escapes the soil, a molecule of NH_4^+ converts to NH_3 to maintain the equilibrium. There are other factors such as soil moisture, temperature, texture and cation exchange capacity that can affect volatilization (Marschner, H. and V. Romheld. 1983).

Soil pH is also an important factor in the nitrogen nutrition of legumes. The survival and activity of rhizobium bacteria responsible for nitrogen fixation in association with legumes, declines as soil acidity increases.

5. DEFICIENCY SYMPTOMS OF NITROGEN IN POTATO PRODUCTION

Nitrogen has greater influence on growth and yield of crop plants than any other essential plant nutrient. It plays a pivotal role in many physiological and biochemical processes in plants. Due to such function its shortage shows different symptoms on different morphological parts and low nutrient content on tissues and grains (tubers) of crops. Nitrogen-deficient plants grow slowly, and their leaves are small. Nitrogen deficiency also decreases leaf area index (LAI), lowers radiation use efficiency, and lowers photosynthesis activity in plants (Fageria and Baligar, 2005a). A significant positive association has been reported between the light saturation rate of photosynthesis of a leaf and its nitrogen content. The reason for this strong relationship is the large amount of leaf organic nitrogen (up to 75%) present in the chloroplasts, most of it in the photosynthetic machinery (Poorter and Evans, 1998). The reduction in yield and quality are directly related to the severity of the N deficiency. Nitrogen deficiency on potato results stunted plant growth, leaves show a uniform yellow coloration, and slow growth rate.

6. FUNCTION OF NITROGEN IN PLANT GROWTH PERFORMANCE

Nitrogen is the one element above all others that we associate with growth. It is a constituent of proteins, enzymes, chlorophyll, deoxyribonucleic acids that make up the genetic code, amino acids and many intermediates involved in the synthesis of plant substances. It is characteristically present in comparatively large amounts in the growing tips of plants, but it can move about readily from one part of the plant to another to meet the primary needs at the time. Since nitrogen is a constituent of chlorophyll, the appearance of the leaves is a rough measure of the amount present (Ridley and Hedlin, 1980). A very deep green, healthy appearance is an indication of an abundant nitrogen supply. On the other hand, a very light green color, usually associated with stunted growth and possibly dying older leaves, constitutes are a strong indication of nitrogen deficiency, even though occasionally similar symptoms can be due to deficiencies of other elements, or to unfavorable growth conditions. With subnormal amounts of chlorophyll present photosynthesis is greatly reduced and yields are markedly curtailed. (Fageria *et al*., 2005a).

The presence of too much available nitrogen can result in a very succulent plant of excessive height and low sugar content. Tall plants and heavy grain yields may sometimes result in lodging and difficulty in harvesting. Occasionally abundant nitrogen results in delayed maturity, but recent studies show that usually the reverse is true for most crops.

Generally, Except for legumes, which have the ability to fix their own N, N must be supplied to plants for growth. It is usually added as a fertilizer and is required for all types of soils (Clark, 1982). To increase crop yields, growers worldwide apply over 80 million metric tons of nitrogen fertilizers per year (Epstein and Bloom, 2005). Use of inorganic N fertilizers has had its most substantial beneficial effect on human health by increasing the yield of field crops and nutritional quality of foods needed to meet dietary requirements and food preferences for growing world populations (Galloway *et al*., 2002).

7. INTERACTION OF NITROGEN WITH OTHER NUTRIENTS

Balanced supply of essential nutrients is one of the most important factors in increasing yields of annual crops. Hence, knowledge of interaction of N with other nutrients is an important factor in improving efficiency of this element and consequently improving crop yields. Nutrient interaction in crop plants is measured in terms of uptake or yield level. Application of a particular nutrient may increase, decrease, or have no effect on uptake of other essential plant nutrients. Similarly, yield level of a crop may increase, decrease, or experience no change with the increase of two nutrient levels in the growth medium. Hence, nutrient interactions may be positive, negative, or neutral. In mineral nutrition, the nutrient interactions are designated as synergistic (positive), antagonistic (negative), or neutral.

Nutrient interaction can occur at the root surface or within the plant. Interactions at the root surface are due to formation of chemical bonds by ions and precipitation or complexes. One example of this type of interaction is the liming of acid soil, which decreases the concentration of almost all micronutrients except molybdenum (Fageria, 2000). The second type of interaction takes place between ions whose chemical properties are sufficiently similar that they compete for sites of absorption, transport, and function on the plant root surface or within plant tissues. Such interactions are more common between nutrients of similar size, charge, and geometry of coordination and electronic configuration (Robson and Pitman, 1983).

The ratio of the mass of organic carbon to the mass of organic nitrogen in the soil, known as the C/N ratio, controls N availability. A C/N ratio >30/1 generally immobilizes N in soil plant systems and creates the possibility of N deficiency in crop plants (Fixen, 1996). Nitrogen has positive interactions with P and K in crop plants. The increasing N rate increases uptake of P, K, Ca, and Mg in a quadratic fashion in dry bean plants. Wilkinson et al. (2000)

reported that application of N increased uptake of P, K, S, Ca, and Mg, provided that these elements are present in sufficient amounts in the growth medium.

The improvement in uptake of macronutrients with the addition of N is reported to be associated with increase in root hairs, chemical changes in the rhizosphere, and physiological changes stimulated by N, which influence transport of these elements (Baligar *et al*., 2001). Rapid nitrate uptake depends on adequate K in the soil solution. Higher rates of K allowed for the efficient use of more nitrogen, which resulted in better early vegetative growth and higher grain and straw yield as K and N rates increased. In the field, better N uptake and utilization with adequate K means improved N use and higher yields. Crops need more K with higher N rates to take advantage of the extra N. Nitrogen interactions with micronutrients depend on pH changes in the rhizosphere. If N is absorbed in the form of NH_4^+, rhizosphere pH may decrease, and uptake of most micronutrients increases. If N is mainly absorbed as NO_3^-, rhizosphere pH may increase, and uptake of most micronutrients decreases.

Other interactions of micronutrients with N may be associated with crop responses to N fertilization. Increase in crop growth with the application of N may increase crop demands for micronutrients, and micronutrient deficiencies may occur (Wilkinson et al., 2000). Chlorine decreases NO_3^- uptake and enhances the uptake of NH_4^+ and ammonium increases the uptake of Mn (Huber and Thompson, 2007).

8. EFFECT OF NITROGEN ON POTATO GROWTH AND TUBER YIELD

The growth, development and yield of potato are mainly governed by availability of major nutrients required for its cultivation. Nitrogen is one of the most important elements needed for growth and yield of potato. Potato is a sensitive crop to application management of nitrogen and amounts less or more than its requirements or early and late application of nitrogen will affect quantitative and qualitative yield of tuber (Rezaei and Soltani, 1996). Sufficient use of nitrogen fertilizers in early growth season will expand leaf area and increase photo assimilates. Deficiency of nitrogen will decrease tuber yield via affecting the tuber production. Nitrogen is one of the essential elements for plant growth and is one of main components of proteins. When plant is in abnormal conditions like over use of nitrogen fertilizer, protein production will decrease and nitrogen will be stored as non-protein form (nitrate). Excess nitrogen also adversely affects the keeping quality of tubers, lowers the specific gravity, and may result in the development of hollow heart disorder. It is the major limiting factor for potato crop which improves vegetative growth and invariably increases yield, tuber per plant, tuber size as well as tuber numbers. Over application of N is a serious problem leading to large nitrogen losses through leaching and enrichment of reactive N constituent in the atmosphere, soil and water with consequent damage to ecosystem. Moreover, excessive nitrogen leads to poor tuber quality and delayed crop maturity, whereas, nitrogen deficiency usually results in poor vegetative growth and low yield.

9. CONCLUSIONS

A good supply of nitrogen stimulates root growth and development, as well as the uptake of other nutrients which results growth and yield. It is commonly available to plants in ammonium and nitrate form and it can be lost by leaching, volatilization, denitrification, crop removal, soil erosion and runoff. Plants deficient in nitrogen become stunted and yellow in color. Balanced supply of essential nutrients is one of the most important factors in increasing yields of annual crops by optimizing interaction with other nutrients. Hence, knowledge of interaction of N with other nutrients is an important factor in improving efficiency of this element and consequently improving crop yields

Nitrogen is one of the most important elements needed for growth and yield of potato. Amount of nitrogen recommended for its high productivity for most agro ecologies of Ethiopia is 81 kg/ha. Deficiency of nitrogen will decrease tuber yield via affecting the tuber production and oversupply of nitrogen also adversely affects the quality of tubers, lowers the specific gravity and decrease dry matter.

References

[1] Alam, M.N., Jahan M.S., Ali M.K., Ashraf M.A. and Islam M.K. Effect of vermicompost and chemical fertilizers on growth, yield and yield components of potato in Barind soils of Bangladesh. *Journal of Applied Sciences Research* 3 (2007) 1879-1888.

[2] Baligar, V. C., N. K. Fageria, and Z. L. He. Nutrient use efficiency in plants: An overview. *Commun. Soil Sci. Plant Anal.* (2001) 32:921–950.

[3] Clark, R. B. Plant response to mineral element toxicity and deficiency. In: *Breeding plants for less favorable environments*, M. N. Christiansen and C. F. Lewis, Eds (1982) 71–142. New York: John Wiley & Sons.

[4] Epstein, M. and A. J. Bloom. *Mineral nutrition of plants: Principles and perspectives*, 2nd edition. Sunderland, MA: Sinauer Associates (2005).

[5] Fageria, N. K. Adequate and toxic levels of zinc for rice, common bean, corn, soybean and wheat production in cerrado soil. *Rev. Bras. Eng. Agri. Ambien* (2000) 4: 390–395.

[6] Fageria, N. K. and V. C. Baligar. Fertility management of tropical acid soils for sustainable crop production. In: *Handbook of soil ac*idity, Z. Rengel, Ed., (2003b) 359–385. New York: Marcel Dekker.

[7] Fageria, N. K. and V. C. Baligar. Enhancing nitrogen use efficiency in crop plants. *Adv. Agron* (2005a) 88: 97–185.

[8] Fageria, N. K., V. C. Baligar, and B. A. Bailey. Role of cover crops in improving soil and row crop productivity. *Commun. Soil Sci. Plant Anal.* (2005) 36: 2733–2757.

[9] Fixen, P. Nutrient management following conservation reserve program. *Better Crops* (1996) 80: 16–19.

[10] Galloway, J. N., E. B. Cowling, S. P. Seitzinger, and R. H. Socolow. Reactive nitrogen: Too much of a good thing? *Ambio* (2002) 31: 60–63.

[11] Akita M, and S Takayama. 1994. Induction and development of potato tubers in a jar fermentor. *Plant Cell Tiss Org Cult* 36: 177–182.

[12] Ali A, SMM Alam, and V Souza Machado. 1995. Potato minituber production from nodal cuttings compared to whole*in vitro* plantlets using low volume media in a greenhouse. *Potato Res* 38:69–76.

[13] Alsadon AA, KW Knutson, and JC Wilkinson. 1988. Relationships between microtuber and minituber production and yield characteristics of six potato cultures. *Am Potato J* 65: 468.

[14] Bizarri M, L Borghi, and P Ranalli. 1995. Effects of activated charcoal effects on induction and development of microtubers in potato (*Solanum tuberosum* L.). *Ann Appl Biol* 127: 175–181

[15] Huber, D. M. and I. A. Thompson. Nitrogen and plant disease. In: *Mineral nutrition and plant disease*, L. E. Datnoff, W. H. Elmer, and D. M. Huber, Eds. (2007) 31–44. St. Paul, MN: The American Phytopathological Society.

[16] Jensen, Dr. Thomas L., Soil pH and the Availability of Plant Nutrients. IPNI Plant Nutrition TODAY, Fall (2010) No. 2, www.ipni.net/pnt

[17] John A. Lamb, Fabian G. Fernandez, and Daniel E. Kaiser: Extension Specialists in Nutrient Management (2014).

[18] Marschner, H. and V. Romheld. In vivo measurement of root-induced pH changes at soil-root interface. Effect of plant species and nitrogen source. *Z. Pflanzenphysiol* (1983) 111: 241–251.

[19] Mohammad Vaezzadeh1 and Mohammadreza Naderidarbaghshahi. The effect of various nitrogen fertilizer amounts on yield and nitrate accumulation in tubers of two potato cultivars in cold regions of Isfahan (Iran) (2012).

[20] Poorter, H. and J. R. Evans. Photosynthetic nitrogen-use efficiency of species that differ inherently in specific leaf area. *Oecologia* (1998) 116: 26–37.

[21] Rezaei A, Soltani A. Potato production. Mashhad University Press.179 pages. Yazdandousthamedani M. The study of nitrogen use effect on yield, yield components and nitrate accumulation of potato cultivars. *J Iran Agri Sci.* (1996) 34: 977-985.

[22] Ridley, A. O. and R. A. Hedlin. Crop yields and soil management on the Canadian Prairies: Past and present. *Can. J. Soil Sci*. (1980) 60: 393–402.

[23] Robson, A.D. and J. B. Pitman. Interactions between nutrients in higher plants. In: *Inorganic plant nutrition: Encyclopedia of plant physiology*, Vol. 1A, A. Lauchli and R. L. Bieleski, Eds.(1983) 147–180. New York: Springer-Verlag.

[24] Schmied, B., K. Abbaspour, and R. Schulin. Inverse estimation of parameters in a nitrogen model using field data. *Soil Sci. Soc. Am. J* (2000) 64: 533–542.

[25] Silvia, P.S.L., Silva J., Olivera F.H.T., Sousa A.K.F. and Duda G.P. Residual effects of cattle manure application on green ear yield and corn grain yield. *Horticultura Brasileira* (2006) 24: 166-169.

[26] Stevenson, F.J. *Soil Sci (*1957) 83: 1 1 3 4 2 2.

[27] Sweeney, D. W. and J. L. Moyer. In-season nitrogen uptake by grain sorghum following legume green manures in conservation tillage systems. *Agron. J.* (2004) 96:510–515.

[28] Walker, T.W. Orchiston, H.D. and Adams, A.F.R.J. *Br. Grasshnd Soc. (*1954) 9: 249-274.

[29] Caldiz DO. 1996. Seed potato (*Solanum tuberosum* L.) yield and tuber number increase after foliar applications of cytokinins and gibberellic acid under field and glasshouse conditions. *Plant Growth Reg* 20: 185–188.

[30] Castro G, G Abdala, C Agüero, and R Tizio. 2000. Interaction between jasmonic and gibberellic acids on*in vitro* tuberization of potato plantlets. *Potato Res* 43: 83–88.

[31] Walker, T.W., Adams, A.F.R. andorchiston, H.D. *Soil Sci.* (1956) 81: 339-351.

[32] Whitehead, D.C. The role of nitrogen in grassland productivity. *Commonwealth Bur. Pastures Field Oops Bull* (1970) 48: 202 pp.

[33] Wilkinson, S. R., D. L. Grunes, and M. E. Sumner. Nutrient interactions in soil and plant nutrition. In: *Handbook of soil science*, M. E. Sumner, Ed. (2000) 89–112. Boca Raton, FL: CRC Press.

[34] Danielle J. Donnelly, Warren K. Coleman, Shirlyn E. Coleman. Potato microtuber production and performance: A review. *American Journal of Potato Research* March 2003, Volume 80, Issue 2, pp 103–115

[35] Akita M, and Y Ohta. 1998. A simple method for mass propagation of potato (*Solanum tuberosum* L.) using a bioreactor without forced aeration. *Plant Cell Rep* 18: 284–287

[36] Ahloowalia BS. 1994. Production and performance of potato minitubers. *Euphytica* 75: 163–172

[37] Akita M, and S Takayama. 1988. Mass propagation of potato tubers using jar fermentor techniques. *Acta Hort* 230: 55–61

[38] T. I. N. Ezejiofor, U. E. Enenebeaku, C. K. Enenebeaku, M. U. Nwankwo, C. I. A. Ogbonnaya. Comparative study of bioethanol yield from yam, potato, watermelon, and pineapple peels using different concentrations of hydrochloric acid. *World News of Natural Sciences* 16 (2018) 18-32

[39] Akita M, and S Takayama. 1993. Effects of medium surface level control on the mass propagation of potato tubers using a jar fermentor culture technique. *Plant Tiss Cult Let* 10: 242–248.

[40] Akita M, and S Takayama. 1994. Stimulation of potato (*Solanum tuberosum* L.) tuberization by semicontinuous liquid medium surface level control. *Plant Cell Rep* 3: 184–187.

[41] Boiteau G, LM Moore, and D Wattie. 2000. Comparative analysis of aphid vector behavior in response to potato plants grown from field tubers, minitubers or plantlets. *Am J Potato Res* 77: 71–75.

[42] Chandra R, GJ Randhawa, and DR Chaudhary. 1992. Use of ordinary sugar in*in vitro* production of potato microtubers. *J Indian Pot Assoc* 19: 87–89.