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RESEARCH ARTICLE

A REVIEW ON THE TOXIC EFFECT OF NICKEL INDUCED STRESS ON GROWTH AND DEVELOPMENT IN RICE SEEDLING (*Oryza sativa* L.)

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Abstract

Rice (*Oryza sativa* L.) is the main food of different countries in the world. Currently, the demand for food is increasing along with the increase in population in the world; therefore, the demand for rice is constantly increasing due to rice being the staple food of various countries. As the population and human need increase, the environment is continuously polluted. In order to grow good crops, we mix various chemicals in the soil, besides, many harmful heavy metals mixed in the soil from various factories and household waste. One of the most harmful heavy metals is nickel. Nickel comes into contact with rice plants and plant seeds. A certain amount of nickel is good for plant growth but above this level it causes physiological and chemical process changes as well as morphology of the plant, like germination rate; plant root and shoot height, weight all decrease, the activity of various enzymes required for growth cycle of rice plant is inhibited. For this increasing nickel concentration level nitrogen metabolism may not function properly because the changes of amount of nitrate, nitrite, and ammonium. Elevated levels of Nickel cause damage the biological and chemical pathway of rice plants which are very harmful for them lifecycle. This review aims to summarize the different responses of rice like physiological, morphological, molecular and biochemical changes when nickel concentration increased rapidly.

Introduction:-

A heavy metal is a substance that induces the toxicity level in the environment when its concentration becomes severely increased. One of the main causes of environmental pollution is heavy metals, which are exposed from anthropogenic, municipal, agricultural and industrial sources (1). Incorporation of heavy metals into the soil leads to complete loss of soil microbial activity and also the soil fertility, resulting in reduced crop yields, and we will compare such heavy metals with xenobiotic compounds (2). A Swedish Chemist Axel Crostedt in 1751, was first isolated Nickel from the mineral niccolite and this name "Nickel" was derived from the term 'Kupfenickel' which means "Old Nick's Copper" that the German miners gave to niccolite because of its emission of toxic fumes when it become heated (3). Nickel is one such heavy metal that is found in very small amounts in the environment. Nickel (Ni), chemical element, ferromagnetic metal of Group 10 (VIII b) in the periodic table and atomic number 28 (4). It

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may exist in the several oxidative states (from −1 to +4); nevertheless, the +2 oxidation state (Ni^{2+}) is the most widespread in the environment and the biological systems. Mainly Nickel is bound with the oxygen and sulfur in the environment as an oxides or sulfides forms. It is essential for plant growth up to optimum concentration but on the other hand when Nickel concentration exceeds the optimum level it interferes with various key enzymes in the plant and thereby inhibits various biochemical and physiological processes like metabolic pathways and developmental processes of the plant (5). Approximately eight billion tons of Nickel is present in the sea area (6). Based on the Nickel concentration dose and length of exposure time, and as a type of immune toxic and carcinogenic agent, Nickel has the harmful effects of plant as well as human body are noticeable like allergy, cardiovascular and kidney diseases, lung fibrosis, lung and nasal cancer etc. (7). In this review, we discuss about the effect of nickel on the rice plant. Rice is consumed by more than half of the people in the world as a staple food in their daily life, mainly Asia and Africa and it get third rank after wheat and maize (8). We get a lot of important things from rice for a good health, that's described in figure 2 (9). In the world several countries are severely affected by nickel such as the United States of America, Netherlands, Germany, Canada, Japan, Australia, South Africa, china and India (10). In India, Orissa, Jharkhand and Andha are the most Nickel affected areas in which paddy cultivation is severely affected, and that also affects the human body (11). The content of nickel is mixed with soil; they are different in different places. The range is 3 to 1000 ppm. Jinchang city of Gansu province is a famous "Nickel City" in China (12). The presence and absence of Nickel highly affect the plant life cycle especially the rice plant. Nickel is present in rice in both of the vegetative part and seed in nickel affected area and so it is act as a source for the primary and secondary consumer (2).

Elevated concentrations of Nickel inhibited rice plant root growth more than plants shoot because shortage of carbohydrate metabolism that inhibit the root respiration system. Carbohydrate, sucrose level and other soluble minarets are also reduced due to increasing the nickel concentration (13). Due to increasing the nickel concentration Nickel affects on the germination percentage, plant's length and natural coloration of the crop plants by affecting the pigments contents like chlorophyll, xanthophylls and carotene (14). Nickel is a non-redox metal and therefore it cannot directly generate active oxygen, so it is used as a catalyst for oxidation and causes oxidative stress increases in plants due to increasing the nickel concentration (9). Seed germination is a most complex process including activation of respiration, repair of macromolecules, reserve mobilization etc. RNA and proteins are synthesized during seed development and maturation step that are deposited in the specific type of storage tissue that we call the building blocks of embryonic access. At the beginning of germination some hydrolytic enzymes are secreted for the mobilization of storage reserves such as ribonuclease, protease etc (15). This ribonucleolytic and proteolytic events are most important for seed germination and rice growth (16).Under stressful condition (increasing the nickel concentration) these hydrolytic enzymes are reduced and for this reason RNA, protein and other biomolecules become increased (17). So, the current review concentrated on the effect of Ni on the rice plant.

Figure 1:- Rice plant (18).

Figure 2:- The importance of rice.

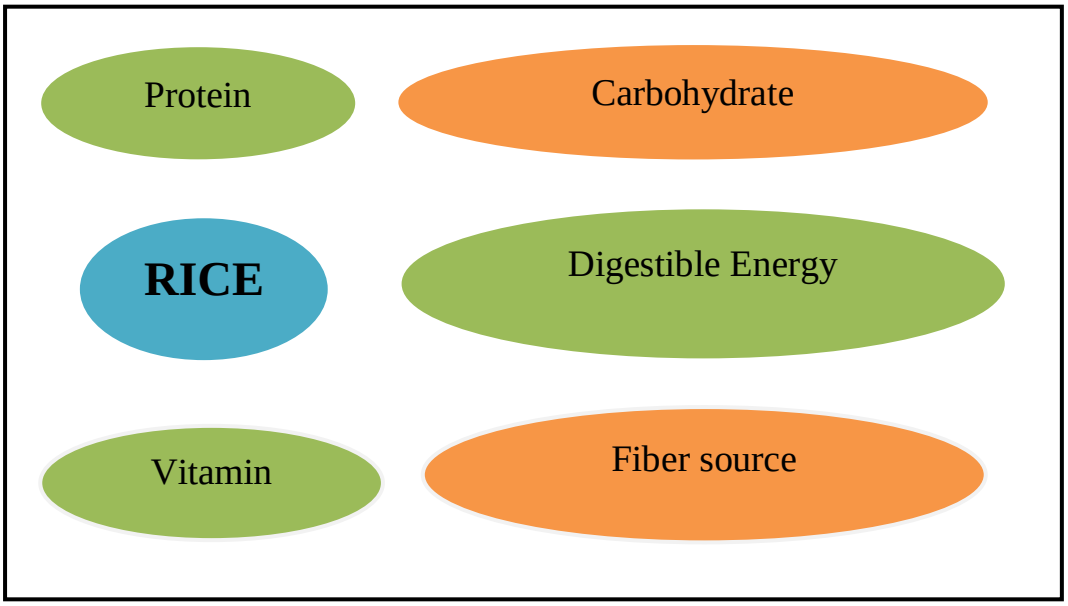

Figure 3:- Atomic structure of Nickel (5).

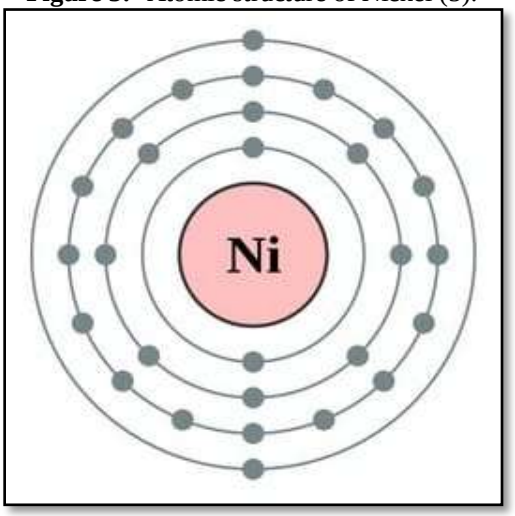

Table 1:- Physical properties of nickel (12).

Colour	Silver white
Texture	hard , lustrous, but powdery
Density	8.9 gcm^{-3}
Melting point	1455°C approx
Boiling point	2732°C
Atomic mass	58.71
Atomic number	28

Nickel in soil:-

Soil Effect depends mainly on nickel concentration. The figure 4 shows how the concentration of nickel is increasing or decreasing in soil and can be divided into two parts. Low concentrations of nickel are found in sedimentary rocks such as limestone, clay etc and more abundant in igneous rock (19). The content of nickel is mixed with soil; they are different in different places. The range is 3 to 1000 ppm (12). Adsorption of the nickel in soils involves two main

mechanisms. The first one is non-selective adsorption, where the metallic cations act as counter-ions in the diffuse layer and the other one is selective adsorption, where surface complexes are formed. The importance of each of these mechanisms depends on the metal and the type of the different type of soil (20).

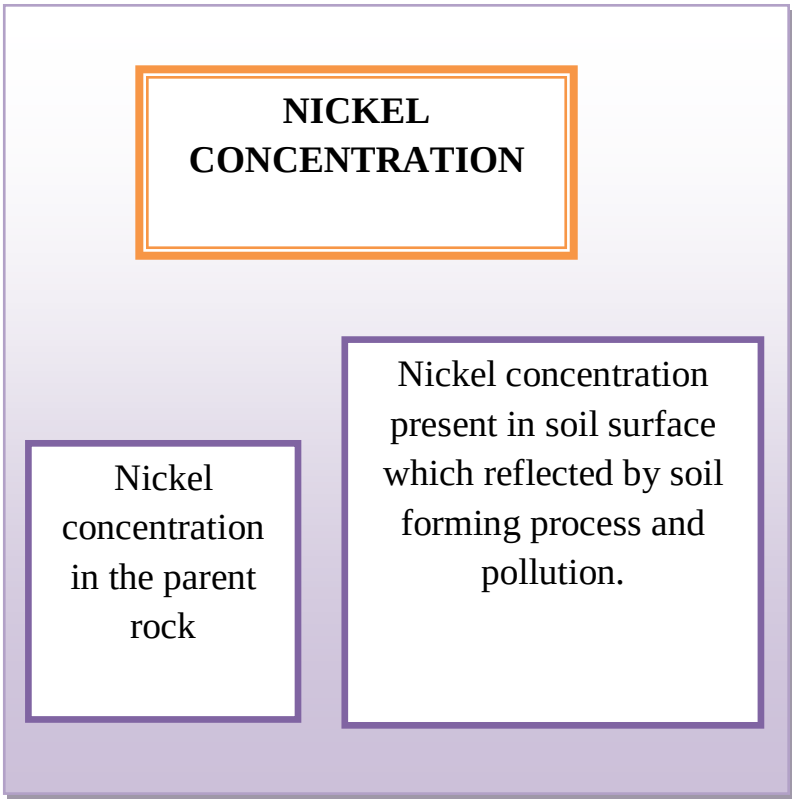

Figure 4:- Nickel concentration in different soil and factors.

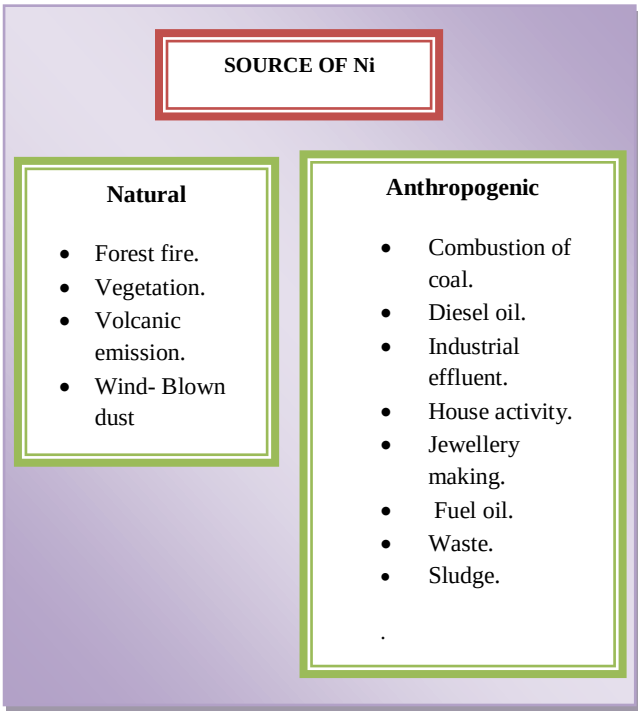

Figure 5:- The sources of Nickel.

Nickel in plant and its toxicity:-

Nickel is not important for all plant species but important for higher plants as a micronutrient. The plant uptake of Nickel from soil depends on soil pH, organic matter, iron, manganese oxide, etc (21). A document from the Environment Agency (2009) suggests that anthropogenic sources of nickel are more toxic than naturally occurring sources. If the toxicity of Nickel exceeds a certain limit, it can be seen directly effect on the plant, such as inhibition of growth, chlorosis, necrosis, etc (22; 23).

The effect of toxic levels of Nickel on the plant growth has been reported by many authors in many articles. As the concentration of Ni increases, the amount of plant nutrients decreases. The imbalance of Nickel has a detrimental effect on the metabolic processes like photosynthesis and transport of photoassimilates from leaves of the plant growth (24). Increasing the amount of Nickel and for its toxicity results in damage to the water balance of the plant (22). For high affinity, Nickel readily binds to oxygen, nitrogen and sulfur atoms to form sulfhydryl groups and disulfide bond that damage the secondary structure of proteins and enzymes that are associated with various metabolic activities in plants (19).Another effect is the production of reactive oxygen species (ROS) such as O_2 and H_2O_2 indirectly by inhibition of photosynthesis due to the high concentrations of Ni toxicity in plants. (23).

Nickel Uptake, Transport and Distribution in Plants:-

Passive Diffusion and active transport are two methods of uptake the Nickel directly to the plant root from the soil (24). There are some metals that act as inhibitory effects on the adsorption and translocation of nickel in the plant, that's $Fe^{3+}>Co^{2+}>Ca^{2+}>Mg^{2+}>NH^{4+}>K^{+}>Na^{+}$ (25). Nickel is transported from the root to shoot and from there diffuse into various cellular compartments in the plant (26). Nickel may be present as either soluble compounds, like chlorides and nitrates forms, or insoluble compounds, like oxides and sulfides forms. Soluble Ni compounds tend to exhibit greater mobility than the insoluble Ni compounds do, and the concentration of Ni in plants and other soil organisms is generally more closely related to the soluble forms of Ni in to the soil (27). According to the water solubility and plant uptake, soil Nickel can be divided into three category. They are describing in figure 6 (28). The steps and factors of Ni uptake and hyperaccumulation from soil to rice plant describe in the table 2 (29).

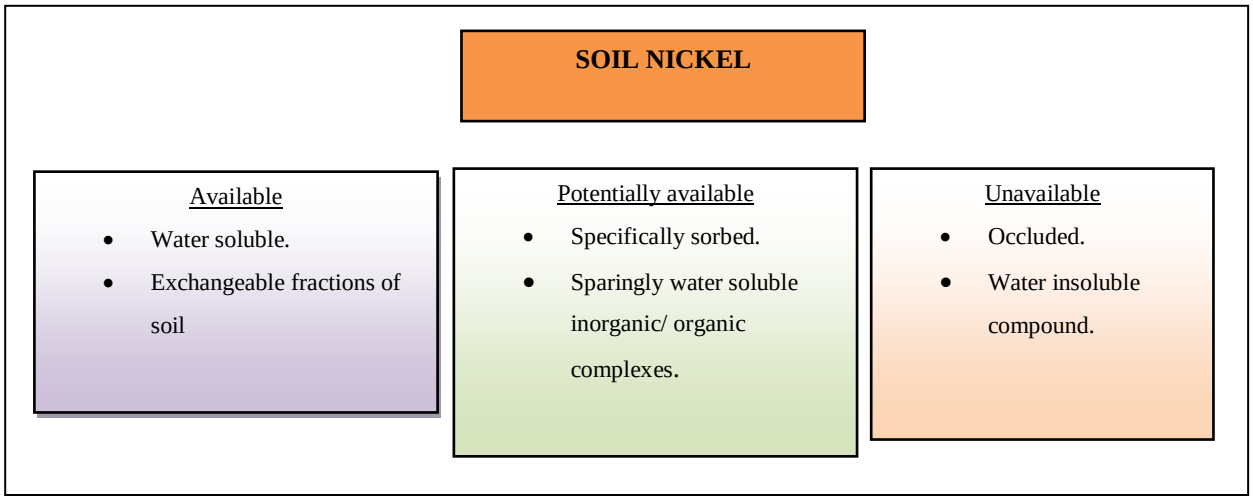

Figure 6:- The three division of soil Nickel (29).

Ni Effect on rice plant growth (height), root and shoot:-

We know that a certain amount of nickel concentration is beneficial for the plant but if the concentration exceeds the limit, it causes various damages to the process of biochemical and physiological to the plant and that inhibited the plant growth (30).When Nickel concentrations exceed certain limits, plant toxicity increases as a result of which the metabolic pathways that necessary for plant growth do not function properly because essential enzymes become out of balance and get inhibited so the plant growth decreases. Germination results in the shortening of the root and subsequent shoot from the rice seed when the rice seed comes into contact with the high level Nickel when rice seed embedded in the soil. But the effect of higher amounts of this nickel is to cause more damage to the root than to the shoot of the rice plant because Nickel inhibits the respiration of the root due to the shortage of the carbohydrate metabolism (31). If the concentration of Nickel increases, the height of the plant will become decreases (32).

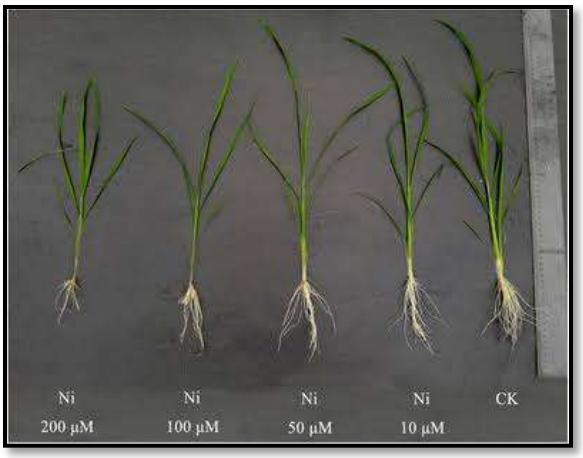

Figure 7:- Increasing nickel concentration reduced plant growth and height. (29).

Table 2:- Nickel uptake and hyperaccumulation from soil to rice plant (29).

Root	Bio-activation process of Nickel in the rhizosphere	Rhizosphere microorganisms: Lowering of the soil pH. Producing some types of compounds (such as antibiotics, antifungals, organic acids, hormones, metal chelating agents etc) Nitrogen fixation Phosphate solubilazation Provision of the nutrients. Simultaneously the other process going on that involve in plant roots: H^+ secretion Organic acid Chelating compounds. Enzymes Phytosiderophopre.
	Root adsorption and the compartmentation	Transporters (helps to accelerate the process) Channels or membrane pump (H^+-ATPase). Chelating compounds. Cytoplasmic chelators.
Shoot	Xylem transport	Passive diffusion and active transport. Symplast loading pump. Cation-proton antiport, cation-ATPase, ion exchange. Chelators (His, NA, MA, citric acid, malate). Proteins (ZIP, NRAMP, YSL, HMA).
	Distribution, Detoxification and the Sequestration	Cell wall binding. Vacuole sequestration. Chelators (His, NA, citric acid, GSH, Cys, SA, OAS etc) Proteins (MTPs, NRAMP, ABC transporters, NtCBP4, RcnA).

Ni Effect on rice plant weight:-

Nickel enters the soil daily through a variety of natural and anthropogenic sources. Various experiments have been conducted by the researchers to see how much damage to the plants is done when the high level toxic nickel mixed in the soil and comes in contact with the rice plants. One of the experiments was to measure the fresh weight of roots and shoots and weight them after drying and take the observe, how much this weight decreased or increased due to increasing Nickel concentration. If the concentration of Nickel increases, the fresh weight and dry weight of the plant will become decreases. (29).

Inhibition of Ribonuclease and Protease activity for increasing nickel concentration:-

Two important events for seed germination and plant growth are ribonucleolytic and proteolytic events (34). RNase is an RNA hydrolyzing enzyme. It is essential for RNA turnover and mobilization (35). Protease on the other hand is an essential enzyme that helps to degrade and recycle the protein to mobilize amino acids. This process is essential for seed germination and other developmental functions of the plant (36), but when the concentration of nickel increases, for its high toxicity the number of different bio-molecules increases and the amount of hydrolyzing enzymes decreases. As a result, protein RNA cannot be the degrade and so their quantity increases, As a result, the level of bio- molecules gradually loses balance, which directly affects seed germination and plant growth.(17).

Effect of nickel on nitrate and ammonium:-

We know that a certain concentration of Nickel is good for the plant and important for the growth cycle, but if this concentration exceeds this level, various damages are caused to the plant. One of them is the decrease in nitrogen concentration and thereby inhibiting the ability to uptake nitrate (33) even transport from roots. But Nitrogen is a micronutrient that is very important for the plant growth cycle (37). Nitrogen metabolism is also very important for plant growth (38). Nitrate reductase (NR) is an enzyme that catalyzes the reduction of Nitrate (NO_3^-) into Nitrite (NO_2^-). But as the concentration of nickel increases, the activity of NR is inhibited as nitrate content decreases (39). Besides nitrate reductase (NR), nitrite reductase (NiR) is another important enzyme in the reduction of nitrite (NO_2^-) into ammonium (NH_4^+). Similarly, increasing Nickel concentration decreases nitrate reductase as well as nitrite reductase activity (40). Nitrate reductase catalyst nitrite reduction might cause a decrease in nitrite reductase activity primarily because of a reduced availability of nitrite ions (32). Again, if nickel stress increases, protease activity, nitrogen content metabolism and amino acid content decrease and (NH_4^+) content increases (41). But in excess ammonium is very much toxic to the plant cell and causes various damages such as disturbance of osmotic balance, changes in pH, nutrient deficiency, and inhibition of ATP synthesis and restriction of secondary growth (42). Later glutamine synthetase (GS) converts ammonium to glutamine and then to glutamate syntheses (GOGAT) convert glutamine into glutamate (43). Glutamate syntheses (GOGAT) help the initiating process of nitrate but increasing nickel concentration inhibit this process (44).

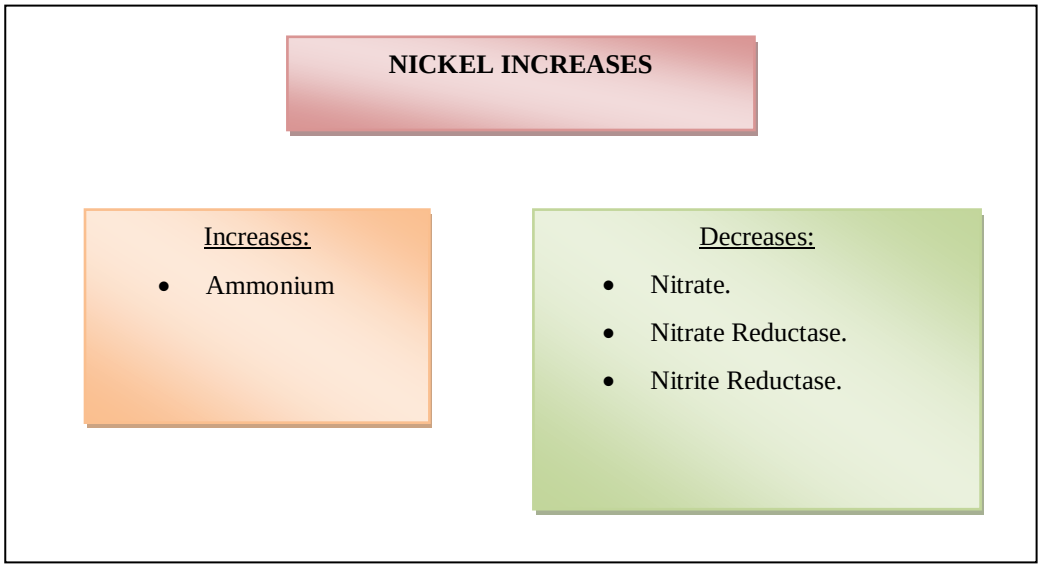

Figure 8:- Effect of nickel on nitrate and ammonium.

Conclusion:-

As the world's population increases, the demand for rice is increasing. But the environment is continuously getting polluted due to various direct and indirect reasons. Through this review we have seen how the heavy metal Nickel mixed in the soil causes various harmful effects on rice plants, as a result, the yield of rice may decrease. Not only the damage to the trees but also the damage to the people is also going on indirectly. Because we eat various foods derived from this rice, our body is indirectly affected by this nickel and it causes various diseases. In addition, due to the addition of Nickel to the yield of rice, there are various changes in the growth cycle of rice, which prevents the proper growth of rice and the amount of protein carbohydrates in various foods made from rice is gradually

decreasing. As a result, along with plants, nutrient deficiency is also appearing in the human body. For future, we should de-pollute the world in such a ways that allow the people to live healthier and meet food demand.

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