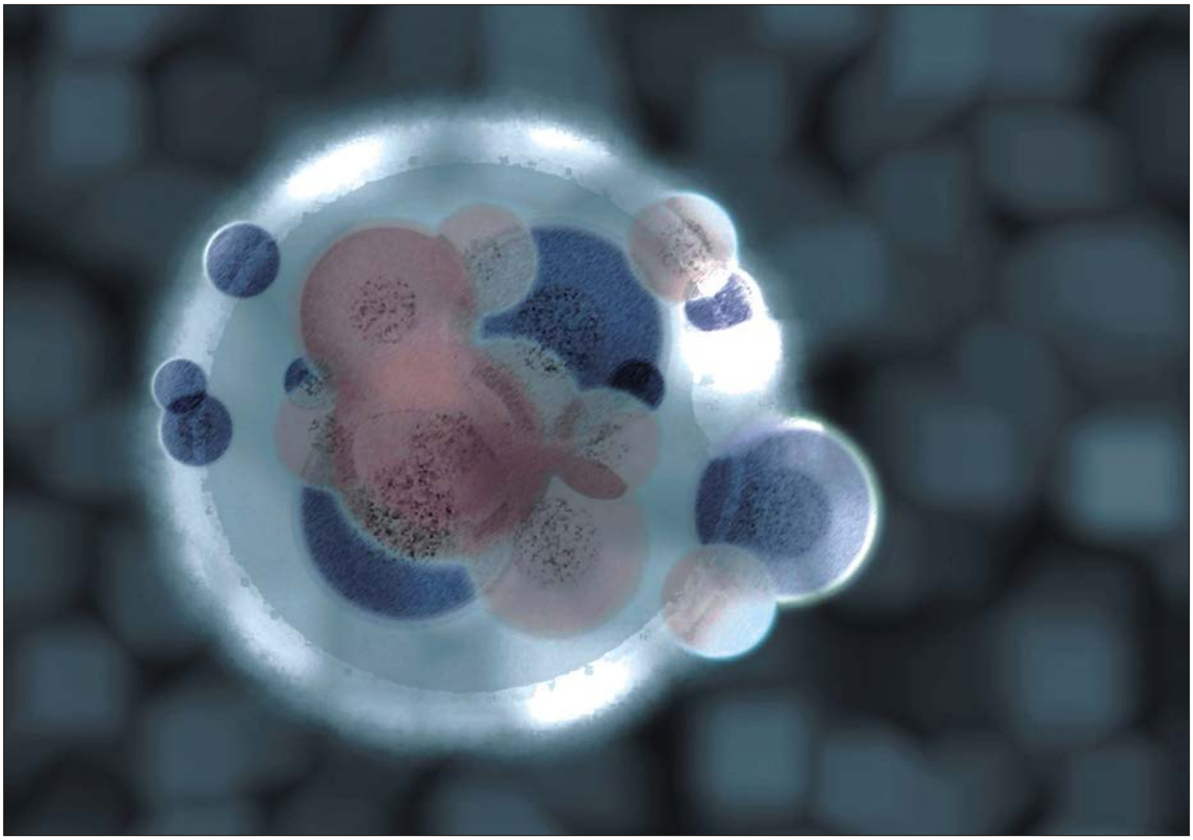

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Application of Radioisotopes and Radiation in the Field of Agriculture: Review

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Abstract: Nuclear radiation and radioisotopes are proving very helpful in several fields including agriculture. To the world today , these tools are unlocking the secrets of many agricultural problems, which could never have been possible by conventional means. Till now radioisotope and radiation are being more widely used in the field of agriculture than any other field of science and their application is leading us to the solution of agricultural problems in a shorter time and more precisely. Radioisotope and radiation give us the opportunity to clear the events that once were mysterious in the growth and nutrition of plants and evolution of new varieties by creating genetic variability. In addition to this, radioactive tracers and radiation sources have become indispensable to all the agricultural research problems. In agriculture, radiation and radioisotopes are also used in the nutritional studies of trace elements, mechanism of photosynthesis, plant protection including action of insecticides, metabolisms in plant, uptake of fertilizers, ions mobility in soils and plants and food preservation. Thus, radioisotopes and radiation have contributed tremendously to fulfil the need of mankind such as food and agriculture, health and medicine, energy production, environmental protection etc. The role of radioisotopes and radiation in the cause of human being has been well -established. However, their application in some other fields have not been fully realized. This article briefly describes the role of radioisotopes and radiation in the field of agriculture.

Key words: Radioisotopes, radiation, phosphorus ,nutrients, isotopes technique, crop protection, pests

Introduction

Never in the annals of history has a scientific discovery so profoundly affected the course of human destiny as the discovery of atomic energy. Its potential for destruction is enormous and its use for economic development unlimited. It is this co-existence of fear of annihilation and hope for the progress of human welfare through its application, that has ushered us into the present era rightly known as the "Atomic Age". The emission of radiation in the form of particles or rays is known as radioactivity. The discovery of artificial radioactivity by Henri Becquerel in 1896 has greatly enlarged and expanded extensively to study the roots of the various problems, and the subsequent availability of radioisotopes in large quantity for research work, made it easy to bring to light many complicated functions of daily life ,which could hardly be solved by conventional means.

By radioisotopes or radiation, we generally mean some extraordinary type of energy or rays, which is emitted by radioactive isotopes. Such rays are alpha (α), beta (β) and gamma (γ), which are invisible, spontaneous and penetrating. These rays are generally harmful for all living beings and their presence can be easily detected with the help of the some latest monitoring devices such as Geiger Muller or Scintillation Counters and Gamma Survey Meter etc. These instruments are used for the detection of even the minutest quantity of radioactive elements present anywhere on the earth surface. Thus, this new tiny tool (radioactivity) is proving very helpful in several fields including agriculture. At present, the radioactive isotopes and radiation that have become available as by-product of nuclear reactors are of greater importance to agriculture. Their contributions to food and agriculture is indirect, but nevertheless of immense potential.

The use of isotopes as tracer tools is unquestionably one of the most significant peacetime applications of atom, on which we will have particular and continuing utility in agricultural and biological research. To the world today, these new tools are unlocking the secrets of many agricultural problems which could never have been possible by conventional means. Scientific research is being conducted all over the world putting radioisotope and radiation into use with successful scientific achievements. Till now, radioisotopes are being more widely used in the field of agriculture than in any other field of science and their application is leading us to the solution of agricultural problems in a shorter time and more precisely.

The value of radioisotopes and radiation in agriculture arises from the ease and accuracy with which they can be identified and measured in extremely minute amounts, which makes it possible to use them as highly refined research tools in so-called tracer studies in a wide range of nutritional, metabolic, developmental and pathological investigations in plants, animals and man. In this way, they are giving information which at the present time could be obtained in no other way or only at much greater expense in terms of time and money. Thus, by giving a clearer insight into basic biological processes that have hitherto been obscure, the use of radioisotope and radiation in tracer studies is already leading to greater efficiency and economy in the production and utilization of agricultural products. Bearing in mind that it was only unfettered scientific investigation of the nature of the atom- the pursuit of knowledge for its own sake- that made nuclear energy available to mankind, the potential value of the contributions which radioactive tracer studies can make to food and agriculture may similarly be almost unlimited.

Radioisotopes and radiation give us the opportunity to clear the events that once were mysterious in the nutrition and growth of plants and evolution of new varieties. They help us to clear the causal factors which produce ill-effects to the plants in different ways. Thus radioisotope has become a very important aid to scientists dealing with the solution of agricultural problems. In addition to this, radioactive tracers and radiation sources have become indispensable to all the intricate agricultural research problems. Because of their availability, X-rays, thermal neutrons, fast neutrons and cobalt-60- gamma rays are employed as radiation sources for irradiation of seeds.

Today, some of important radioisotopes, such as P^{32} ($t_{1/2}$ 14.3 days, β 1.7 mev, γ 0), C^{14}($t_{1/2}$ 5570 yrs,, β 0.155 mev, γ 0), Ca^{45}($t_{1/2}$ 165 days, β 0.254 mev, γ 0), H^3 ($t_{1/2}$ 12.46 yrs, β 0.018 mev, γ 0), Na^{22}($t_{1/2}$ 2.58 days, β 0.54 mev, γ 1.28 mev), Na^{24}($t_{1/2}$ 15.05 hrs, β 1.39 mev, γ 1.368 to 2.754 mev), Co^{60}($t_{1/2}$ 5.24 yrs, β 0.31 mev, γ 1.17 to 1.33 mev), Cu^{64}($t_{1/2}$ 12.9 hrs, β 0.57 mev, γ 1.34 mev), Fe^{55} ($t_{1/2}$ 2.94 yrs, β 0, γ

0), Fe^{59}($t_{1/2}$ 44..3 days, β 0.271 mev, γ 1.30 mev), Mn^{54}($t_{1/2}$ 314 days, β 0, γ 0.84 mev), K^{42}($t_{1/2}$ 12.47 hrs, β 3.58 mev, γ 1.51 mev), Rb^{86}($t_{1/2}$ 18.68 days, β 1.82 mev, γ 1.08 mev), S^{35}($t_{1/2}$ 89 days, β 0.168 mev, γ 0), Zn^{65}($t_{1/2}$ 246 days, β 0.325 mev, γ 1.12 mev[none1]), are available in sufficient quantity and have been widely used to investigate a number of problems of interest to agriculture and other fields.

In agriculture, radioisotopes are used in the nutritional studies of trace elements, diet additives, dairy chemistry and milk productions, mechanism of photosynthesis, plant pathology, plant protection including action of insecticides, metabolism in plants, uptake of fertilizers, ions mobility in soils and plants and food preservation (Alam, 1982; Alam and Khan, 1966; Khan *et al.,* 1970; Spinks and Barber, 1948). Radioisotopes have significant application in plant nutrition. Like other living organisms, plants can grow strong and healthy if grown under proper nutritional condition, while with insufficient nutrition, their growth gets stunted with limited low yield.

The principle underlying the use of radioisotopes is that the radiation (i.e. rays- alpha, beta, gamma etc.) emitted by them can easily be detected by sensitive electronic instruments and can also be recorded on a photographic plate so that even where they are present in minute quantities i.e. one in a million , they can be "traced". In order to determine the correct nutrition for a plant we need to know the exact soil-plant relationship and the factors involved therein. In recent years many different conventional methods have been proposed and tried to determine this very complicated relation but few of them have given satisfactory information on the soil-plant relationships. Although, the investigations with radioisotopes are quite limited, the results obtained by using this new method are very satisfactory, reliable and helpful.

Tracer Techniques: Tracer techniques are now being widely used in almost all the fields of plant physiology, soil chemistry and plant biochemistry. In applying the tracer technique, a minute quantity of radioisotope element is usually mixed with ordinary element of the same kind and the whole batch then becomes "tagged" and may be followed through complicated chemical reactions. Application of radioisotopes and radiation sources in agricultural research has especially the following advantages:

1. With the help of radioisotopes we can easily locate the presence of a single atom and molecule and their movement. Hence, they give research workers the opportunity to follow up step by step all kinds of processes that are related to the nutrition of plant from germination to maturity
2. Very small quantities of labeled nutrients can be accurately measured in presence of large quantities of other nutrients
3. The location of materials can be identified by radio-autography
4. Tracer technique enables one in tracing those elements taken by the plants accurately and precisely.
5. It also helps to study accurately the effect of one element upon the absorption of another and their interaction by plants and now it has become very easy to study properly the phenomenon of interaction among the mineral nutrients

The production of radioisotopes by nuclear reactors and other atomic installations have increased the use of radioisotopes in the field of agriculture. In order to clarify the basic knowledge related to nutrition of plants by using radioactive elements and radiation sources, investigations have been made on soil fertility, nutrient absorption by plants, speed of absorption and regional accumulation of nutrients inside the plants, relationship between fertilization and plant growth, soil moisture content and micro nutrients and their functions in plant.

Fertility Status: For the last 50 years, the radioisotopes have provided an invaluable tool for investigating the availability of plant nutrients under field conditions. While a number of different isotopes have been used, the economic importance of phosphate fertilizer and the relative ease of handling P^{32} have resulted in particular attention being paid to phosphorus. Quantitative soil and plant studies using radioactive phosphorus (P^{32}) began in 1936 and were followed ten years later by quantitative field studies of phosphate fertilizer uptake by wheat plants (Stout and Hoagland, 1939). Radioisotope of phosphorus as a tracer has a wide application in the field of plant physiology and soil chemistry. Works have also been done on the mechanism of nutrient uptake by using radioisotope of phosphorus. The use of P^{32} in short term plant physiological studies has been reported by Stout and Hoagland (1939), Balock *et al.* (1963) and Biddulph (1948) worked with P^{32} in bean plant. He studied its uptake and movement after absorption period of one, two, and four hours. The plants were removed from culture solution, harvested and dried and P^{32} was determined by Geiger- Muller counting. At the end of one hour, the tracer was found only in the roots, after two hours

it was present in hypocotyl and stem. Radio-autographs have demonstrated the movement of P^{32} from older leaves to younger expanded leaves and meristemetic areas. By combing the radioactive measurement of fertilizer uptake with the measurement by ordinary chemical methods of total phosphorus uptake, the uptake of soil phosphorus could be determined by difference. In the past, the recovery of phosphate fertilizer by a crop was determined by difference of the uptake of phosphorus by crops grown with and without fertilizer. The extra phosphorus in the fertilized crop was taken as the quantity coming from the fertilizer. This method assumed that fertilized and unfertilized crops take up the same amount of soil phosphorus, but tracer experiments indicate that this is often far from being the case. By using radioactive phosphorus research workers have succeeded to distinguish between soil phosphorus and the fertilizer phosphorus, taken by the plants (Blume 1952; Burditt 1994; Bustos *et al.*, 1992; Caldwell *et al.*, 1954).

Numerous experiments have been reported during the last four decades, covering such diverse topics as utilization of various phosphatic fertilizer by different types of crops at various stages of growth, grown on different types of soils, using different methods of placement and different rates of application. In the first field experiment, 1 milli-curie P^{32} was used. Four years later, 30 curies was used in the United States alone, and now the labeled phosphate fertilizers are made by the ton (Chanasyk and Naeth, 1996). In order to obtain an increased yield from the soils by applying fertilizers, one has to determine the fertility status of the soils. Several problems can be solved by this study such as comparison of various fertilizers, soil density, and soil moisture content, influence of particle size, placement, time of application, doses, absorption by plants and the reaction of the applied fertilizer in the soil (Dean *et al.*,1948; Frissel, 1996; Gheorghe and Burloi, 1993; Hall, 1953).

Absorption of Nutrients: Recent studies with radioisotopes have also shown that with many crops supply of plant nutrients through the leaves is more quick and effective that the application in soil. For example, it has been found that a nutrient which is hardly absorbed upto 10% by root can be absorbed upto 90% when applied on the leaves. Experimentally it has been found that the absorption of nutrients by leaves takes place not only during the day time but also at night time. Using rice as a test crop, studies are being made on the absorption, translocation and distribution of phosphate, carbon and nitrogen with the help of super phosphate, urea and ammonium sulphate labeled with P^{32}, C^{14} and N^{15} which were applied both in soils and on leaves as spray (Alam, 1982; Hady, 1996; Hallman and Worley, 1999).

Food and Agriculture: Proper and sufficient food is the basic requirement of all human beings. Still at present, and unfortunately millions of the world population is suffering from hunger and malnutrition. Solving food problems on the other hand, are not easy. Apart from appropriate policy measure, better means of food preservation and stronger efforts to increase agriculture productivity are called for to augment global food availability. However, nuclear techniques have been employed to solve this problem

Use of Atoms in Pakistan Agriculture: Agriculture is the most important segment of our economy . In spite of having great potential in the form of favourable climatic and soil conditions suitable for producing a variety of crops, our agriculture suffers from low yield per acre, wastage on account of insects and pests and the post harvest losses. The use of nuclear radiation and radio isotopes in agriculture provides powerful techniques which have already been successfully applied for solving some basic problems like low agricultural productivity and pre and post harvest losses. PAEC has chosen such areas for research and development where the use of nuclear and other modern techniques would give an added advantage by increasing agricultural productivity and finding better methods of the conservation of the produce and the inputs.

The commission has established three well equipped and integrated nuclear agricultural research centres . Nuclear Institute of Agriculture, (NIA),Tandojam (1961), Nuclear Institute of Agriculture and Biology (NIAB) Faisalabad, (1972), and Nuclear Institute for Food and Agriculture (NIFA) Peshawer (1982). In addition National Institute for biotechnology and Genetic Engineering (NIBGE) was established at Faisalabad (1994). These Institutes have been setup in distinct agro-ecological zones in the country. The research activities are focussed on applications of nuclear techniques using P^{32} labeled super phosphate showed that surface application of super phosphate was superior to deep placement under waterlogged condition. During the same period Coordinated programmes with IAEA on the application of radioisotopes and radiation in rice cultivation were also carried out. The main objects were to study the method of placement of super phosphate, the time and rate of application of nitrogenous fertilizer and its effect on the phosphorus uptake and yield. It was observed that placement of super phosphate at a depth of 10 cm beneath the hills give better dry matter yield and significantly higher uptake of phosphorus than by other placements under non-flooded condition. and other biotechnological and genetic engineering approaches to enhance production by evolving improved varieties of crops, better methods of conservation optimum utilization of lands effected by salinity and water logging, etc. The scientific endeavours are envisaged in developing the higher yielding, disease and insect resistant varieties of important crops like cotton, rice, wheat, chickpea, mungbean, lentil, etc., by using induced mutations through gamma radiation plant molecular breeding and plant biotechnology. Uptill now 35 new varieties of different (i.e. Cotton NIAB-78, NIAB-88, NIAB-26, CHANDI(NIA), NIAB-KARISHMA, in rice, KASHMIR BASMATI, NIAB-IRRI-9, SHADAB(NIA), SHUA(NIA), KHUSHBOO(NIA), in wheat, JAUHAR-78,SINDH-81, SARSABZ, SOUGHAT-90,KIRAN(NIA) BUKHTAWAR TATARA, NISHTAR ,FAKHR-E-SARHAD(NIFA) in chickpea CM-72, CM-88, CM-98 (NIAB), NIFA-88, NIFA-98, in mungbean, NIAB-MUNG-28, NIAB-MUNG-121-25, NIAB-MUNG-19-19, NIAB-MUNG-20-21, NIAB-MUNG-13-1, NIAB-MUNG-51, NIAB-MUNG-54, NIAB-MUNG-92, NIAB-MUNG-98, and in rapeseed ABASIN from NIFA have been introduced making valuable contributions towards the economy of Pakistan.

Salinity and water-logging of arable land is a serious problem of agriculture in the country. NIA and NIAB have been pursuing research to develop some screening techniques for wheat and rice crops and biotechnological methods to deal with salinity problems. The emphasis has been to economically utilize the waste saline lands and brackish water for growing salt tolerant plants. At Nuclear Institute of Food and Agriculture (NIFA), Peshawer special emphasis is laid on food preservation through nuclear radiation. Besides wheat mutants other crop varieties of chickpea soybean etc, have been introduced. The National Institute for Biotechnology and Genetic Engineering (NIBGE), Faisalabad has been established to create an infrastructure to do research in biotechnology and its applications in agriculture biofertilizers industry energy health and environment (Heather *et al.*, 1991).

Disinfestation of stored foodgrains: For improving productivity as well as for protection of crop plants against various diseases , different types of agro-chemicals and other sources are used. In these days, radiation from radioisotopes are employed in crop protection. Ionizing radiations are inestimatable value for obtaining an insight into ecological habits of insects. With the aid of radioisotopes we can find out population density, the maturity rate during different stages of the life cycle, modes of dispersal, movement and migration, flight range hibernating places, egg laying sites, relation to predators.

Reducing loss in growing crops: Every year a large part of the potential harvest is destroyed by diseases, pests and virus which attack the growing crops. Potential food supplies and other agricultural products are subject to heavy losses in all phases of production, distribution, and storage through fungal and bacterial infection and the ravages of insect pests, and it is by combatting those that the most immediate and spectacular improvements in supplies can be achieved. No valid estimate of total world losses is possible, but they are undoubtedly of immense magnitude. A very conservative estimate that has been brought forward for losses in stored food-grains, largely from the depredations of weevils and other insect pests, about 10%, but the losses are undoubtedly much greater in the hot and humid areas of the world, when the figure of 25 to 50% losses of harvested cereals and pulses which has been estimated for commodities agriculture in Central America is probably generally applicable in most of the less advanced countries. It has been said that even in such relatively developed countries as the United Kingdom the work of over 51,000 skilled farm workers is lost each year, and that in the United States of America losses caused to farm products by insects, weeds and plant diseases are equivalent to millions of dollars per year. Most of these losses can be avoided by the timely application of effect control measures. Gamma rays have also been used to destroy insects and pests which infest stored food grains.

Experiment in many countries have shown that the irradiated wheat and rice do no undergo any significant change in taste or nutritional properties provided the dose of gamma rays is controlled. Gamma -rays do not induce any radioactivity so that irradiated grains are totally harmless (Islam *et al*., 1995; Karim and Alam, 1967; Khan *et al.,* 1965; Larsen, 1952; Mackey, 1952). Modern grain-irradiators using cobalt-60 are therefore, being installed and planned by many countries particularly those with tropical climates, where the spoilage in stored grains is as high as 10 percent One of the great advantages of this method over chemical fumigation is that there is no danger of residual toxicity left by the potent chemicals and the cleaning is so thorough that re-infestation is considerably delayed. This is because the radiation destroy not only the live insects but their eggs and pupae also. The perishable foodstuffs such as fresh fruits, vegetables, meat and fish are particularly subject to spoilage in distribution and storage (Morris and Jessup, 1994). Sprouting in potatoes and onions is inhibited by exposure to gamma rays and certain varieties of oranges, strawberries etc., stay fresh after a light dose to these rays. The shelf life of fresh fish is extended by several days when treated with gamma rays and poultry products remain preserved when exposed to cobalt-60. Similarly, the deterioration resulting from fungal infections and the attacks of various insect pests of major concern in timber utilization.

Evidently there is great scope for the adoption of control measures and these can be applied relatively and easily at a cost which is usually but a small fraction of the value of the returns. Already radioisotopes and radiation show promise of making important contributions to the development of improved control measures which would markedly improve the supply situation. Thus, the destructive power of radiation has been used to eliminate insect infections in grain and cereal products at costs which compare favourably those of the more conventional produces such as fumigation. The sprouting of potatoes has been successfully inhibited as result of the effects of radiation, on the enzyme system, thus permitting transportation under less stringent conditions than are usually required and extending storage life by many months. Much attention has also being given to the possibility of food preservation through cold sterilization by irradiation at normal temperatures.

Evidently, radiation may have a very useful field of application food processing and preservation, although much more exploratory work must be done to evaluate its full potentialities. One of the most attractive features of this application is the wide scope it offers for the useful employment of the radioactive residues arising as a by-products of the operations of nuclear reactors.

Mutation Breeding: Mutation breeding involves the use induced beneficial changes or mutations for practical plant breeding purpose both directly and indirectly. It is a technique to create a new characteristics, such as drought resistance or higher yield of the crops. It has been observed that irradiation of crop with gamma rays from Co^{60} can lead to changes due to its deep penetrating rays in the genetic traits of the plants which are inherited. Radioisotope and radiation are used in mutation induction. Mutation is sudden heritable changes of the hereditary factors on the chromosomes of the organisms. The employment of radiation to induce hereditary variant is an useful tool of potential value in agriculture. We have been able to show conclusively that with radiation, changes can be brought about in the organization and general morphological changes that are useful in plant improvement.

New varieties of crops: When seeds of wheat, rice maize, sugarcane tobacco, cotton or for that matter flowers are exposed to a measured dose of gamma rays, they undergo profound genetic changes with the result that on sowing, the irradiated seeds give a variety of plants, some of which are high yielding and pest resistant. Successful breeding of new varieties of cereals and cash crops have been reported from many countries and there is no doubt that new varieties of crops from radiation-induced mutants promise a revolutionary breakthrough for plant breeders all over the world (Millikan, 1951; PAEC., 1999).

Eradication of insect and pests: There are some insects and pests which mate only once in life. The males of such pests can be reared in the laboratory on a mass scale and sterilized by a dose of gamma rays. When such sterilized males are released in the pest infested area they mate with their females and die. Because of sterility no new generation is born and after some time even the females also die resulting in the ultimate wiping out if the pests. The eradication of the screw worm attacking the cattle in the United States is one of the success stories of the sterile male technique which is being applied in the case of fruit flies and other pests in many parts of the world (Singleton, 1958).

Increasing Animal Production and Health: To enhance livestock productivity, radio-immunoassays of animal steriod hormones have been performed and using the information obtained , feed supplementation strategies for milk producing animals in tropical and subtropical environments have been developed through nuclear and related techniques. The quantity and quantity is the principal determinant of productivity throughout a wide spectrum of animal species and production systems. Studies based on isotopic methods have led to dramatic increases in growth rates, milk production and/or reproductive efficiency by improving the nutrition of ruminant livestock through supplemental feeding with locally available products such as urea, molasses, palm kernel cake, rice polishing and legume tree leaves.

References

Alam, S.M. and A.B. Khan, 1966. Interaction of Fe^{55} and manganese on the uptake of Fe^{55} and yield of rice plants. Proceedings of the Agriculture Symposia, May 13-14, Atomic Energy Centre, Dhaka, pp: 95-99.

Alam, S.M., 1982. Assimilation of $^{14}CO_2$ in the rice plants with and without nitrogen application. Pak. J. Bot., 14: 99-101.

Balock, J.W., A.K. Burditt Jr. and L.D. Christenson, 1963. Effects of Gamma radiation on various stages of three fruit fly species. J. Econ. Entomol., 56: 42-46.

Biddulph, O., 1948. Studies of chlorosis using radioiron and radiophosphorus. Proceedings of the Auburn Conference on the Use of Radioactive Isotopes in Agriculture Research, December 1, 1948, Auburn, Alabama.

Blume, J.M., 1952. Radioisotopes in soil fertilizer research. Plant Food J., 6: 25-30.

Burditt, Jr. A.K., 1994. Irradiation. In: Quarantine Treatments for Pests of Food Plants, Sharp, J.L. and G.J. Hallman (Eds.). Westview Press, USA., ISBN: 9780813387758, pp: 101-117.

Bustos, M.E., W. Enkerlin, J. Toledo, J. Reyes and A. Casimiro, 1992. Irradiation of Mangoes as a Quarantine. In: Use of Irradiation as a Quarantine Treatment of Food and Agricultural Commodities, IAEA (Eds.). International Atomic Energy Agency, Vienna, Austria, ISBN: 9789201029928, pp: 77-90.

Caldwell, A.C., A. Hustrulid, F.L. Hammers and J.M. MacGregor, 1954. The absorption of phosphorus from radioactive phosphate fertilizers applied to established meadows I. Effect of source, rate and time of application. Soil Sci. Soc. Am. J., 18: 440-443.

Chanasyk, D.S. and M.A. Naeth, 1996. Field measurement of soil moisture using neutron probes. Can. J. Soil Sci., 76: 317-323.

Dean, L.A., W.L. Nelson, A.J. MacKenzie, W.H. Armiger and W.L. Hill, 1948. Application of radioactive tracer technique to studies of phosphatic fertilizer utilization by crops. 1. Greenhouse experiments. Soil. Sci. Soc. Am. J., 12: 107-112.

Frissel, M.J., 1996. Transfer Factors of Radionuclides for Paddy Soils to Polished Rice. In: Imprvement of Environmental Transfer Models and Parameters, Brown, R.M. and S. Uchida (Eds.). Little Brown, Boston, pp: 155-164.

Gheorghe, V. and G.H. Burloi, 1993. The behaviour of some winter wheat lines following X-ray treatment in comparative crops. Lucrari Stiintifice, 35: 7-12.

Hady, A., 1996. Determination of moisture content and natural radioactivity in soils using gamma spectroscop. Proceedings of the 3rd Radiation Physics Conference, November 13-17, 1996, Minya, Egypt, pp: 191-198.

Hall, N.S., 1953. The use of P^{32} in plant root studies. Proceedings of the 4th Annual Oak Ridge Summer Symposium, August 25-30, 1952, Oak Ridge, Tennessee, pp: 435-451.

Hallman, G.J. and J.W. Worley, 1999. Gamma radiation doses to prevent adult emergence from immatures of Mexican and West Indian fruit flies (Diptera: Tephritidae).q J. Econ. Entomol., 92: 967-973.

Heather, N.W., R.J. Corcoran and C. Banos, 1991. Disinfestation of mangoes with gamma irradiation against two Australian fruit flies (Diptera: Tephritidae). J. Econ. Entomol., 84: 1304-1307.

Islam, S., R. Rahman and M.A. Khaleque, 1995. Histology of gamma-irradiated adult foregut of the hide beetle, dermestes maculatus degeer (Coleoptera: Dermestidae). Bangladesh J. Zool., 23: 193-198.

Karim, A.Q.M.B. and S.M. Alam, 1967. Use of radioisotpes in the study of interaction between iron and manganese and their effects on the uptake of phosphorus by rice plants. Pak. J. Soil. Sci., 3: 44-51.

Khan, A.B., L. Rehman, A.K.M. Habibullah, S.L. Chowdhary and S.M. Alam, 1965. Application of isotopes and radiation in rice cultivation. Proceedings of the 4h Panel Meeting of IAEA, December 13-17, 1965, Bangkok, Thailand, pp: 1-30.

Khan, A.B., L. Rehman, S.I. Chowdhary, S.M. Alam and Y. Ali, 1970. Studies on the comparative nutrient requirement of low and high yielding varieties of rice. Proc. FAO/IAEA, IAEA HQ, Vienna, Austria, IAEA Technical Report, 120, pp: 29-49.

Larsen, S., 1952. The use of P^{32} in studies on the uptake of phosphorus by plants. Plant Soil, 4: 1-10.

Mackey, J., 1952. The biological action of X-rays and fast neutrons on barley and wheat. Arkiv. Bot., 1: 545-556.

Millikan, C.R., 1951. Radio-autographs of manganese in plants. Aust. J. Biol. Sci., 4: 28-41.

Morris, S.C. and A.J. Jessup, 1994. Irradiation. In: Inset Pests and Fresh Horticultural Products and Responses, Paul, R.E. and J.W. Armstrong (Eds.). CAB International, Wallingford, UK., pp: 163-190.

PAEC., 1999. News letter of the PAEC. Special Issue Youm-I-Takbeer, May 28th, pp: 14.

Singleton, W.R., 1958. Nuclear Radiation in Food and Agriclture. D. Van Nostrand Co. Inc., Princeton, New Jersey.

Spinks, J.W.T. and S.A. Barber, 1948. Study of fertilizer uptake using radioactive phosphorus: II.. Scient. Agric., 28: 79-87.

Stout, P.R. and D.R. Hoagland, 1939. Upward and lateral movement of salt in certain plants as indicated by radioactive isotopes of potassium, sodium, and phosphorus absorbed by roots. Am. J. Bot., 26: 320-324.