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A REVIEW

Integrated nutrient management in potato

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The literature on integrated nutrient management in potato crop has been well documented. In this article efforts have been made to review the literature available on integrated nutrient management in potato. The effect of integrated nutrient management on growth character, yield attributes, yield, nutrients uptake, quality characters and economics were presented here. Potato is one of the most important tuber crops for high intensity cropping system because of its short duration and very wide regional and seasonal adaptability. It is a highly productive crop, removing huge quantity of nutrients from the soil. Thus, to maintain a soil health, the crop needs to be tested under organic and inorganic nutrient supply system. Hence, the productivity of potato can be increased in sustainable way by the use of organic manure. Today, for the country of India's dimension, with no scope for horizontal expansion and complexity of problems and challenges, there is no alternative but continue to improve productivity without further degrading its natural resources that too in a sustainable manner. In this contest we will have to adopt a rationalist organic farming approach to have an 'Evergreen Revolution'. This has led to the concept of integrated nutrient management (INM) gain momentum in recent years to improve and maintain the soil health. Besides this, with escalating cost of energy based fertilizer material, limited fossil fuels, INM approach combines the use of organic sources along with fertilizers, which would be remunerative for getting higher yields with considerable fertilizer economy (Subbian and Palaniappan, 1992). The organic manures are important agricultural by-products which are regarded as a great value by cultivators and gardeners since organic materials are used to maintain or improve the tilth, fertility and productivity of agricultural soil.

There is no doubt that the application of chemical fertilizers on crop can lead to increase in crop productivity but continuous application of it can pose deleterious effect to soil health as well as loss of some of beneficial micro nutrients and leaving some residual effect to the crop harvest thereby affecting human health too. The nutrient supply is a key factor in crop production, but the global

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crisis of energy and high cost of fertilizer nutrients enforced to economize their use by applying organic sources and chemical fertilizer together.

It is well documented that integration of organic and inorganic nutrient sources is the only possible way to maintain the soil health and meet the total crop nutrient demand in a sustainable way. Organic nutrient sources are known to restore soil physical environment and enhance nutrient use efficiency by a crop, in such a way that they influence growth, yield and quality of a crop.

The research work done in India and elsewhere in recent years on the effect of organic and inorganic sources of nutrients on growth and yield of potato and potato related crops are reviewed in this chapter. The literature collected on these aspects have been presented under the following subheads integrated nutrient management in potato (*Solanum tuberosum* L.).

Growth, yield attributes and yield:

Sanyal *et al.* (1993) have studied the effect of FYM and mineral fertilizer using 50 per cent RDF, 75 per cent RDF, 75 per cent RDF+10 t FYM ha^{-1}. A highest net production value per unit investment was obtained with 75 per cent RDF+10 t FYM ha^{-1}.

Sujatha and Krishnappa (1995) have studied the effect of FYM and chemical fertilizer on yield of potato crop. Among the various combinations of fertilizers and FYM, the highest yield (222.3q ha^{-1}) was obtained with the application of 120:100:120 kg ha^{-1} NPK, respectively and 50 t FYM ha^{-1}. Also the yield of A grade (>75g) and Bgrade (51-75g) tubers found highest in this combination.

Jaggi *et al.* (1995) studied the effect of FYM and phosphorus fertilizer on tuber yield of potato. The highest tuber yield was obtained with the application of 10 tonnes FYM per ha with 60 kg P ha^{-1}.

Meena and Gupta (1996) conducted experiment during winter season atBikaner, Rajasthan. Potato cv. KUFRI CHANDRAMUKHI were supplied with 10 t ha^{-1} of farmyard manure, Gobar gas spent slurry or digested willow dust, or 3 t castor cake or 0-120 kg N ha^{-1}. Highest tuber yield was recorded with castor cake (16.2 t ha^{-1}) and120 kg N (16.3 t ha^{-1}).

Patil *et al.* (1997) studied the effect of vermicompost, FYM and inorganic fertilizers on growth, yield and uptake of nutrients in potato cv. KUFRI CHANDRAMUKHI was conducted in Karnataka and reported combination of VC @ 4 t ha^{-1} + 50 per cent RDF given maximum yield (34 t ha^{-1}).

Ghosh and Das (1998) conducted a field experiment at Sriniketan (West Bengal) in winter with biofertilizers and growth regulators. Treatments included combinations of Buckup (well matured cattle manure containing vesicular arbuscular mycorrhizas and phosphate solubilizing bacteria), Electra (liquid organic manure extracted from marigold plants), Bioplin (liquid suspension of *Azotobacter*), Micrin (liquid organic manure containing humic and fulvic acid), Vitormone (liquid suspension of several dormant *Azotobacter* species) and protein hydrolysate (plant growth regulators containing amino acids). Higher crop growth rate, tuber bulking rate, large and medium sized tubers and total tuber yield were recorded greatest from combinations of both biofertilizers and growth regulators.

Mahendran and Kumar (1998) found that the maximum number of marketable tuber, grade wise yield and tuber yield (25.87 t ha^{-1}) with the application of100 per cent recommended dose of NPK in combination with *Azospirillum* or phosphobacterium.

Saikia and Rajkhowa (1998) reported that the application of 75 per cent of the recommended NPK rate+2.5 t vermicompost produced the highest marketable tuber yield of 14.1 t.

Savita and Abdul (1998) studied the effect of levels and time of potassium application on tuber bulking rate, tuber size and total tuber yield of potatoes cv. HPS1/67. They found that tuber bulking rate at all growth stage was highest with the highest fertilizer rate of 180 kg K_2O ha^{-1}, while between application dates bulking rate in later growth stages was highest when all K was applied as basal dose. Total tuber yield was 11.9, 14.5 and 16.0 t ha^{-1} with 60, 120 and 180 kg K_2O ha^{-1}. Basal application gave a yield of 14.4 t ha^{-1}, split application between basal and 30 days after transplanting gave the highest total yield of 15.2 t ha^{-1}, and applying half of K as basal dose and the rest split between 30 and 50 days after transplanting gave a yield of 12.8 t ha^{-1}.

Mahendran and Kumar (1998) found that the maximum plant emergence, plant height with the application of 100 per cent recommended dose of NPK in combination with *Azospirillum* or *Phosphobacterium.*

Bhukta (2000) reported that the application of 10 t FYM along with150:80:100 kg NPK ha^{-1} produced maximum yield. In case FYM is not available the application of 150 kg N, 100 kg K and 40 kg P blended with cow dung slurry (2:1) proved equally better to that of 150:80:100 kg NPK ha^{-1}. Further it has reported

that75:40:50 kg NPK ha^{-1} can be saved if it is applied along with cow dung @ 7.5 t ha^{-1} collected at once and decomposed for 27 days.

Pervez *et al*. (2000) studied that the effect of organic manure and inorganic fertilizers particularly for increased doses of potash on the yield and quality of potato. Various doses of potassium (K_2O) were 25, 50, 75, 100, 200 and 300 kg along with combined application of five tons rottened farmyard manure per hectare. Nitrogen and phosphorus were applied as a single constant dose *i.e*. 130 kg each per hectare at the time of sowing and at the time of earthing up, respectively. Potash application alone did not show any promising results, although increased levels of potassium, increased the yield to some extent. Combined application of farmyard manure and higher doses f potassium proved best to increase the yield of potato.

Singh *et al*. (2002) studied that effect of phosphate solubilizing bacteria (PSB) in combination with 0, 60, 120 or 180 kg P_2O_5 ha^{-1} applied as di-ammonium phosphate (DAP), single super phosphate (SSP), or rock phosphate on the yield of potato cv. KUFRI MEGHA and cv. KUFRI JYOTI. Crop yield, tuber size and net returns increased with increasing rate of P and were higher with phosphate solubilizing bacteria (PSB) inoculation.

Roy and Sharma (2001) noticed that potato require NPK at 150 per cent of recommended doses for maximum tuber production (*i.e*. 270 kg N, 52 kg P and 150 kg K ha^{-1}). Further, it has reported that application of FYM at 30 t ha^{-1} with 270 kg of inorganic N ha^{-1} (FYM + N) was less effective than the use of NPK at 150 per cent of current recommended rate.

Chettri and Thapa (2002) found highest dry matter production (360.3, 570.4 and 825.3 g/m at 60, 80 and 100 days after planting), tuber bulking rate (12.83 and8.78 g/m per day at 80 and 100 days after planting, respectively) and yield (275.7q ha^{-1}) with 100 per cent NPK + FYM.

Imas and Bansal (2002) conducted a field trial in Shimla and reported that balanced NPK application increased the tuber yield efficiency and maximum yield of40.8 t ha^{-1} was noted under 180 kg N, 100 kg P_2O_5 and 150 kg K_2O ha^{-1}. Kumar *et al.,* (2002) reported that the application of 150 per cent RDF of NPK increase the tuberyield by 8.3 and 3.4 t ha^{-1}, as compared to 50 and 100 per cent RDF of NPK, respectively. The highest tuber yield (29 t ha^{-1}) was recorded with integrated use of FYM with 160 kg inorganic N ha^{-1}.

Praharaj *et al*. (2002) conducted a field experiment to test biofertilizers with potato in sandy clay loam soil in Patna under trans-gangetic plain zone (Bihar, India). The treatments comprised the combinations of three biofertilizer applications and three fertilizer schedules (100, 75 and 50 % of the recommended rate). Soaking of seed tubers prior to planting in solution containing 1 per cent urea and 1 per cent NaHCO₃ for 5 minutes along with biofertilizer inoculation (*Azotobacter* for N and phosphobacter for P) resulted in significantly higher tuber yield than the control + urea + NaHCO₃ soaking treatment.

Hossain *et al.* (2003) found that the highest plant height was 71.2 cm and lowest was 46.2 cm at 100 days after emergence (DAE) when potato was grown with cow dung + Mustard oil cake (MOC) +N + P_2O_5 + K_2O and without manure and fertilizers, respectively.

Abou Hadid *et al*. (2003) studied the effects of cattle manure (60 m^3 $feddan^{-1}$), poultry manure (20 m^3 $feddan^{-1}$), cattle manure (30 m^3 $feddan^{-1}$) + poultry manure (10 m^3 $feddan^{-1}$) and poultry or cattle manure (10 m^3 $feddan^{-1}$) + inorganic fertilizers (150N, 150 P_2O_5 and 175 K_2O kg ha^{-1}) on the tuber yield and quality of potato cv. CARA at Egypt. Greater increase in tuber size, number of stolons, tubers $plant^{-1}$ and tuber weight was obtained with poultry manure along with inorganic fertilizer than other treatments. It is also reported that the application of cattle manure with poultry manure increased dry matter, total carbohydrates and specific gravity, but reduced the contents of reducing and non-reducing sugars. The highest tuber weight (274.55-634.27 g) and yield (16.13 t $feddan^{-1}$) were obtained with cattle manure with poultry manure [1feddan=0.42 ha].

Yadav *et al*. (2003) found that *Azotabacter* inoculation increased potato tuber yield by 5-24 per cent in the absence of N over inoculated control with N. The highest increase was recorded with cv. MXZ-9, produced the highest tuber yield of 321.99kg ha^{-1}, which was 9 per cent more than the tuber yield obtained with the recommended dose of N (100 kg ha^{-1}).

Chettri *et al*. (2004) reported that the application of 125 per cent recommended dose of inorganic fertilizer (NPK) gave the highest potato tuber yield (28.18 t ha^{-1}) followed by 75 per cent recommended dose of inorganic fertilizers + 10 t FYM ha^{-1}.

Chettri and Thapa (2004) found maximum dry matter production, tuber bulking rates and tuber yield (270.8 q ha^{-1}) with 100 per cent recommended dose of NPK coupled with 10 t ha^{-1} FYM at Hooghly (W.B.).

Das *et al.* (2004) found that the highest dry matter accumulation, number of tubers per plant, tuber weight plant^{-1} and tuber yield in the treatment having 60 per cent recommended N as vermicompost + 40 per centre commended dose of N as urea rather than in the treatments using 100 per cent recommended dose of N as urea or farmers' practice or other combinations of vermicompost and urea.

Al-Moshileh *et al*. (2005) observed that the application of 450 kg ha^{-1} potassium and 300 kg ha^{-1} nitrogen split in three equal doses are found in a significant increase in plant height, leaf area, chlorophyll concentration, specific gravity and carbohydrate content. Maximum plant height (43.56 cm), fresh weight of shoot per plant (361.40 g) and dry weight of shoot per plant (23.73 g) were recorded with the application of 100 per cent recommended NPK + 15 t FYM followed by 75 per cent NPK + 15 t poultry manure ha^{-1} (Banafar *et al*., 2005).

Baishya *et al.* (2005) noticed that the highest tuber yield (229.8q ha^{-1}) was recorded in treatment consisting of 100 per cent NP + phosphobacterium + *Azotobacter* +1 per cent urea +1 per cent sodium bicarbonate solution (233.8 q ha^{-1}) followed by application of 75 per cent NP + *Azotobacter* + phosphobacterium + 1 per cent urea + 1 per cent sodium bicarbonate solutions.

Chettri *et al.* (2005) conducted experiment during winter season at Hooghly (W.B.) to study the effect of organic source (FYM) of nutrient on potato production as compared to inorganic source of nutrients. Maximum number of tubers, Grade wise tuber yield and marketable tuber yield (281.78 q ha^{-1}) of potato were recorded with the application of inorganic source of nutrient (NPK).

Kanbi and Bhatnagar (2005) has conducted a field experiment at Deesa (Gujarat) to study the effect of organic-inorganic sources of nitrogen fertilizers in potato cv. KUFRI BADSHAH. It has reported that organic manure at 25 t ha^{-1} along with 100 per cent recommended dose of nitrogen in inorganic form or more than 50 per cent of recommended dose of nitrogen in inorganic form and remaining parts of nitrogen in castor cake or poultry manure increased the chlorophyll content, other growth parameters, tuber yield and tuber dry matter, minimized storage losses and improved quality of chips.

Kate *et al.* (2005) studied in Maharashtra to determine the response of potato cultivars (HPS-II/67, Kufri Jyoti and S^{-1}) to different nutritional management options. Treatments comprised: 100 per cent recommended dose of fertilizers (RDF; 120:60:120 kg NPK ha^{-1}), 100 per cent RDF + 5 t FYM ha^{-1}, 100 per cent RDF + FYM + biofertilizers (*Azospirillum* and *Azotobacter*), 75 per cent RDF + FYM + biofertilizers, and 50 per cent RDF +FYM + biofertilizers. Among the treatments, 100 per cent RDF + FYM + biofertilizers resulted in the highest total dry matter production plant^{-1} (69.7 g) and tuber weight plant^{-1} (285.6 g).

Khan *et al.* (2005) studied the nutrient management strategy for optimum productivity of maize-potato-wheat cropping system. The yield of individual crop aswell as potato equivalent tuber yield (23.77 t ha^{-1}) was highest in treatment receiving100 per cent NPK through inorganic fertilizer along with secondary nutrients (Zn and S).

Khurana and Bhutani (2005) conducted experiment at Hissar to study the combined effect of FYM, biofertilizer and inorganic fertilizer on potato. Well sprouted tubers of cv. KUFRI BAHAR were planted in the last week of October and haulm cutting was done at 105 days after planting. Treatments were consisted of combinations of 75 and 100 per cent of recommended dose of NPK (N:P:K;150:80:100 kg ha^{-1}) with control, FYM @20 t ha^{-1} and biofertilizers. For biofertilizer, tubers were treated with *Azotobacter* and phophobacteria before planting. Treating of seed tubers with biofertilizer significantly improved total tuber yield, yield of large size tubers and tuber number, during both the years and at both the doses of fertilizers, however, improvement was more at 75 per cent recommended dose of NPK.

Kushwah *et al.* (2005) found the highest tuber yield (321q ha^{-1}) with application of 100 per cent recommended dose of NPK fertilizers and it was significantly higher than all other treatments.

Mondal and Sarkar (2005) conducted an experiment at farmer's field in Nadia (West Bengal) to study the effect of combined application of organic manure and inorganic fertilizers on tuber yield, quality and incidence of late blight disease on the crop. Combined application of organic manure (*Neem* seed powder @1.2 t ha^{-1}, karanj cake @1.0 t ha^{-1}, farmyard manure @ 6 t ha^{-1}, commercial formulation Biomax @ 0.6 t ha^{-1} and Biomas @1.5 t ha^{-1}) along with 75 per cent of recommended dose of NPK fertilizers (RDF) increased the tuber yield by 5.87 per cent to 10.56 per cent over control (100 % RDF). The organic source was observed to be most effective in increasing the tuber yield (10.56 %) and percentage of 'A' (>75g) grade tubers (47.21%).

Application of organics improved specific gravity, total soluble solids and ascorbic acid content of tubers. Organic sources were also effective in decreasing the disease incidence in potato crop.

Sarkar and Mondal (2005) found the highest dry matter accumulation, tuber bulking rate and tuber yield with the application of enmite (a mixture of coarse *Neem* seed powder, karanja, cake and other oil cakes) at 1.65 t ha^{-1} which was at par with FYM at 10 t ha^{-1}.

Singh and Gupta (2005) has studied the effects of biofertilizers, organic fertilizers and inorganic fertilizers on potato tuber yield cv. KUFRI MEGHA and KUFRI JYOTI. The application of farmyard manure (FYM) at 15 t ha^{-1} significantly increased the growth, tuber yield and net return of potato. The application of 100 per cent of the recommended N rate also enhanced the growth and yield of potato. FYM reduced the N fertilizer rate by 60 kg N ha^{-1}. *Azotobacter* was effective in enhancing the growth and tuber yield of potato. The effect of the interaction among FYM, nitrogen and *Azotobacter* was found significant. The highest tuber yield and net return were obtained with FYM at 15 t ha^{-1}+ *Azotobacter* + 100 per cent of the recommended N rate.

Sud *et al*. (2005) observed the positive effect of P and K application through farm yard manure and inorganic fertilizer N (100 %) on dry weight of tubers, total tuber yield (394 q ha^{-1}), yield of large sized tubers as well as nutrient uptake by potato under rainfed condition. It has also reported by them that application of N enhanced protein content while FYM and K improved vitamin C content.

Ayyub *et al*. (2006) An experiment was conducted at the Research Farm, College of Agriculture, Central Agricultural University, Imphal during *Rabi* season to study the effect of nitrogen integration through different sources *i.e*. FYM, vermicompost and urea at different levels of substitution *i.e.,* 25 per cent, 50 per cent, 75 per cent and 100 per cent to the recommended dose (RD) of nitrogen as urea by the organic sources. Supplementation of 75 per cent RD of nitrogen from Urea *i.e.* 130 kg ha^{-1} and 25 per cent RD of nitrogen from FYM *i.e.* 4 t ha^{-1} exhibited the highest growth, yield attributes and yield, net return per rupee investment and cost benefit ratio.

Nag (2006) observed that the yield parameters like number of tubers, fresh weight of tubers ha-^{1}, dry weight of tubers ha^{-1}, grade wise yield, marketable yield and harvest index were found the highest under the treatment in which crop residues were incorporated and biofertilizers (*Azotobacter* + PSB) were also applied in soil.

Nandekar *et al.* (2006) reported maximum plant height (42.8 cm), number of stems $hill^{-1}$ (5.20) and number of leaves $plant^{-1}$ (68) with application of 120:100:100kg ha^{-1} and seed inoculation with 1 per cent solution of urea + sodium bi-carbonate and biofertilizers over control (no biofertilizers).

Singh and Kushwah (2006) conducted the study on effect of organic and inorganic sources of nutrients on potato (*Solanum tuberosum* L.) production. The treatments included 25, 50, 75 and 100 per cent doses of NPK with and without organic manures (farmyard manure and Nadep compost @ 30t ha^{-1}). Application of 100 per cent NPK+ 30 t FYM ha^{-1} resulted in significantly higher tuber yield of 456 q ha^{-1} than other treatments except 100 per cent NPK + 30 t Nadep ha^{-1} and 75 per cent NPK + 30 t FYM ha^{-1}.

Alam *et al.* (2007) reported that application of T_1-10 t vermicompost and NPKS significantly influenced the growth and produced the highest (25.56 t ha^{-1}) tuber yield of potato. The lowest yield and yield contributing parameters recorded in control (T_0).

Sinha (2007) observed that the application of 225 kg ha^{-1} nitrogen was found optimum to obtained the higher tuberization efficiency and yield of potato per plot (marketable as well as total tuber yield).

Sood (2007) conducted field experiments on integrated nutrient supply and management on sandy loam soil in mid hills of Shimla. The result revealed that combined use of organic and inorganic fertilizers in the ratio of 1:3 significantly increased plant growth parameters, tuber yield and nutrient uptake. The higher tuber yield under integrated use of organic and inorganic fertilizers was mainly due to higher proportion of large and medium size tubers.

Mekonnen *et al.* (2008) obtained highest total tuber yield of 29.59 t ha^{-1} with integration of 10 t ha^{-1} farmyard manure along with 75 per cent of recommended dose of chemical fertilizer compared to the three control treatments. In addition, integrated use of 4 t ha^{-1} vermicompost along with 25 and 50 per cent of recommended dose of fertilizer resulted in higher organic carbon, available P and K content of the soil over the control treatments.

Gayathri *et al.* (2008) reported that the highest potato tuber yield of 56.43 t ha^{-1} was recorded by the

application of 225 kg N, 300 kg P_2O_5 and 300 kg K_2O ha^{-1} along with the application of FYM @15 t ha^{-1} and *Azospirillum* @ 2 kg ha^{-1}.

Kumar *et al*. (2009) reported that the tuber yield of autumn potato was significantly increased with integrated use of 75 or 100 per cent NPK and poultry manure (@ 7.5 t ha^{-1}) or farmyard manure (@ 30 t ha^{-1}) as compared with inorganic fertilizers alone.

Kumar *et al.* (2009) revealed that the tuber yield of autumn potato was significantly increased with integrated use of 75 or 100 per cent NPK and poultry manure (@ 7.5 t ha^{-1}) or farmyard manure (@ 30 t ha^{-1}) as compared with inorganic fertilizers alone. The tuber yield improvement was 22.2 and 20.4 per cent with farmyard manure and 26.8 and 25.7 per cent with poultry manure at 75 per cent and 100 per cent recommended NPK, respectively over application of inorganic fertilizers alone.

Solanke *et al*. (2009) reported that fertilization @ 100 % RDF+ 5t FYM ha^{-1} + Biofertilizers maximized plant height (54.9 cm $plant^{-1}$), number of functional leaves (40.8 $plant^{-1}$), fresh weight of tubers (285.6 g $plant^{-1}$), total dry matter (69.7 g $plant^{-1}$) and tuber yield. Maximum net returns (Rs. 35749 ha^{-1}) and benefit/cost ratio (1.74).

Zelalem *et al*. (2009) results showed that potato dry weight of shoots, LAI and plant height increased linearly and very significantly in response to the application of manure and nitrogen fertilizer. While the interaction between manure and nitrogen fertilizer just on the LAI and plant height was significant, somehow the maximum amount of plant height (73 cm) was obtained by using 150 kg nitrogen + 15 tons of manure per hectare and maximum LAI (5.36) was obtained by using 150 kg nitrogen + 20 tons of manure per hectare. Also maximum tuber yield (36.8 t ha^{-1}) was obtained by the utilization of 150 kg nitrogen per hectare + 20 tons manure.

Najm *et al*. (2010) results showed that potato dry weight of shoots, LAI and plant height increased linearly and very significantly in response to the application of manure and nitrogen fertilizer. While the interaction between manure and nitrogen fertilizer just on shoots, LAI and plant height was significant, somehow the maximum amount of plant height (73 cm) was obtained by using 150 kg nitrogen + 15 t of manure per hectare, and maximum LAI (5.36) was obtained by using 150 kg nitrogen + 20 tons of manure per hectare. Also maximum tuber yield (36.8 t ha^{-1}) was obtained by the utilization of 150 kg nitrogen per hectare + 20 t manure.

Chhonkar *et al*. (2011) found that maximum emergence per cent at 30 days, plant height, number of shoots, fresh and dry weight of shoots were observed with application of 1 per cent urea and Sodium carbonate + *Azotobacter* + Phasphobacteria.

Jaipaul Sharma and Sharma (2011) noticed that chicken manure (7.5 t ha^{-1}) + biofertilizer exhibited highest plant height (70.73 cm) followed by vermicompost (10 t ha^{-1}) + biofertilizer in potato.

Jaipaul Sharma and Sharma (2011) noticed that numbers of tubers per plant were higher (7.96) in the treatment comprising organic fertilizers + inorganic fertilizers + biofertilizer in comparison to rest of the treatments. Among the organic treatments, chicken manure (7.5 t ha^{-1}) + biofertilizer treatment produced the highest number of tubers per plant followed by vermicompost (10 t ha^{-1}) + biofertilizer treatment.

Matiwos (2011) revealed that most of the yield and yield attributing characters *viz.*, yield per plant (223.33 g), mean tuber weight (65.23 g), tuber girth 914.32 cm), marketable yield (11.91 t ha^{-1}), total tuber yield (12.60 t ha^{-1}) were observed significantly higher with the application of 100 per cent RDF + 25 t FYM ha^{-1} followed by 75 per cent N through RDF + 25 per cent N through sheep manure +25 t FYM ha^{-1}.

Prativa and Bhattarai (2011) study revealed that the integration of organic manures in combination with inorganic fertilizers was found maximum plant height and number of leaves per plant were observed with treatment 16.66 mt ha^{-1} FYM + 8.33 mt ha^{-1} vermicompost + NPK.

Sarkar *et al*. (2011) reported the positive effect of application of nutrients from organic and inorganic source and their combinations on plant height, number of leaves, LAI, dry matter production, number of shoots, number of tubers, number of sprouts, tuber yield of potato and net return was highest in 40 per cent organic + 60 per cent inorganic followed by 50 per cent organic + 50 per cent inorganic than other treatments.

Verma *et al*. (2011) found that the highest plant emergence (%), plant height, number of stems, number of leaves, fresh and dry weight of shoots were recorded intreatment receiving crop residues + *Azotobacter* + phasphobacteria + biodynamic approach + microbial culture.

Balemi (2012) reported that the application of 20 or 30 t ha^{-1} FYM + 66.6 per cent of the recommended inorganic NP fertilizers significantly increased total tuber yield over the application of full dose of inorganic NP fertilizers without FYM.

Kumar *et al*. (2012) results showed that 50 per cent of the recommended dose of NPK through inorganic + 50 per cent recommended dose of nitrogen (RDN) through organic manures (FYM, PM or VC) or 100 per cent recommended dose of NPK through inorganic fertilizers alone favourably influenced the paid higher returns compared to other treatments. Seed treatment with *Azotobactor* + PSB recorded higher returns as compared to sole treatment of either *Azotobactor* or PSB.

Mohammadi *et al*. (2012) the results showed that the factors had significant effects on tuber yield, tuber weight, the number of tuber per plant, biological yield, harvest index and tuber nitrate content of potato were obtained when the tubers were inoculated with nitragin biofertilizer, urea was used and HB-101 was sprayed two times. Moreover, the lowest tuber nitrate content was obtained when HB- 101 was sprayed two times and the tubers were inoculated with nitragin biofertilizer.

Baishya *et al*. (2013) reported that the application of 75 per cent recommended dose of fertilizers (RDF) through chemical fertilizers along with 25 per cent recommended dose of nitrogen (RDN) through farm yard manure (FYM) and/or 100 per cent RDF through chemical fertilizers recorded higher values of the growth parameters like plant height, number of shoots, number of leaves, fresh and dry weight of shoots plant^{-1}.

Congera *et al*.(2013) concluded that application of 50 per cent RDF + 50 per cent FYM+ *Azotobacter* + Phosphobacteria recorded maximum total dry matter production of potato (21.67 %) which was at par with 50 per cent RDF + 50 per cent FYM T_3 (20.53 %).

Islam *et al*. (2013) results showed that addition of organic manure in combination with reduced rate of inorganic fertilizers showed significant effects on the yield parameters and yield of potato. The combination of poultry manure 3 t ha^{-1} + reduced RDF ($N_{135}P_{20}K_{135}S_{10}$ kg ha^{-1}) was found to be best for the cultivation of potato.

Kumar *et al. (*2013) result revealed that integrated application of 50 per cent of recommended NPK through inorganic and 50 per cent RDN through PM recorded significantly highest potato tuber yield (22.73t ha^{-1}) closely followed by 100 per cent recommended NPK through inorganic (22.20t ha^{-1}) which were 228 per cent and 223 per cent, respectively, higher than control.

Najm *et al*. (2013) results showed that potato dry weight of shoots, LAI and plant height increased linearly and very significantly in response to the application of manure and nitrogen fertilizer. While the interaction between manure and nitrogen fertilizer just on the LAI and plant height was significant, somehow the maximum amount of plant height (73 cm) was obtained by using 150 kg nitrogen + 15 tons of manure per hectare and maximum LAI (5.36) was obtained by using 150 kg nitrogen + 20 tons of manure per hectare. Also maximum tuber yield (36.8 t ha^{-1}) was obtained by the utilization of 150 kg nitrogen per hectare + 20 t manure.

Narayan *et al*. (2013) results showed that integrated approach of nutrient management, particularly 75 per cent RDF + 8 t ha^{-1} vermicompost + *Azotobacter* and PSB can be recommended for getting the enhanced yield of potato under temperate condition of Kashmir valley.

Rostami *et al*. (2013) concluded that clover green manure with 75 per cent of recommended N compound increased tuber yield of potato by 33 per cent, where as reduced N demand by 25 per cent.

Shaheen *et al*. (2013) revealed that potato plants which received its nitrogen requirements as chemical (urea 46 % N) if compared with all organic sources with using begasses organic manure gained resulted in the best plant growth, total tubers and total marketable yield as well as the heaviest local marketable tubers yield.

Singh (2013) revealed that the application of 100 per cent recommended dose of nitrogen and phosphorus + *Azotobacter* and Phosphobacteria gave maximum tuber yield closely followed by application of 75 per cent recommended dose of nitrogen and phosphorus + *Azotobacter* and Phosphobacteria.

Balemi (2014) results demonstrated that the application of 10 t ha^{-1} FYM + 66.6 per cent of the recommended inorganic NP fertilizers and 20 or 30 t ha^{-1} FYM + 33.3 per cent of the recommended inorganic NP fertilizers gave a total tuber yield, which was on par with the tuber yield obtained due to the application of full dose of inorganic NP fertilizer alone.

Biruk *et al*. (2014) revealed that application of 75 per cent recommended dose of fertilizers (RDF) through chemical fertilizers along with 25 per cent recommended dose of nitrogen (RDN) through farm yard manure (FYM) and/or 100 per cent RDF through chemical fertilizers recorded higher values of the growth parameters and produced higher potato tuber yield (26.0 and 25.6 t ha^{-1}) than other treatments. Replacement of 50, 75 and 100 per cent RDN through FYM decreased tuber yield by 9.1, 12.6 and 25.6 per cent, respectively.

Chandrakar *et al.* (2014) reported that the maximum yield attributes and total tuber yield of potato crop in the application of 75 per cent N inorganic fertilizer + 25 per cent N organic (Poultry manure) + PSB + *Azotobactor* was found significantly highest yield attributes and total tuber yield.

Dubey *et al.* (2014) observed that application of 75 % NPK through chemical fertilizers along with 5 t ha^{-1} vermicompost gave highest tuber yield of 336 q ha^{-1} with 41.17 per cent higher yield of potato as compared to farmer's practice followed by 75 per cent NPK through chemical fertilizers along with 20 t ha^{-1} nadep compost and FYM.

Ghosh (2015) results showed that 50 per cent of the recommended dose of NPK through inorganic + 50 per cent recommended dose of nitrogen (RDN) through organic manures (FYM, PM or VC) or 100 per cent recommended dose of NPK through inorganic fertilizers alone favourably influenced the tuber yield, nutrient uptake, soil fertility and paid higher returns compared to other treatments.

Boke (2014) results indicated that the highest mean potato tuber yield (41.88 t ha^{-1}) was achieved by NPK (100-100-100 kg ha^{-1}) plus 15 t ha^{-1} FYM application followed by NP plus 15 t ha^{-1} FYM (30.96 t ha^{-1}), NPK (30.28 t ha^{-1}) and FYM (17.73 t ha^{-1}).

Yadav *et al.* (2014) reported that yield of tubers (12.4 t ha^{-1}) were recorded with application of 75 per cent RDF through fertilizers and 25 per cent RDN through FYM which was significantly superior over rest of treatments. However, the lowest tuber numbers (478.3 $\times 10^3$ ha^{-1}) and tuber yield (3.3 t ha^{-1}) were observed in control plot (no application of any nutrients).

Ahmed *et al.* (2015) it could be concluded that using of farmyard manure as organic fertilizer at the level of 20 m^3/fed. integrated with ammonium nitrate as inorganic N fertilizer at the level of 210 N unit/fed. gave the highest values of tubers yield (ton/fed.), tubers number/plant, marketable tubers percentage, N content in the tubers and crude protein percentage of potato tubers while using of farmyard manure at the level of 20 m^3/fed. combined with ammonium nitrate at the level of 120 N unit/fed. gave the highest values of specific gravity, starch percentage, P, K and dry matter percentage in the tubers.

Taheri and Mir (2015) results revealed that the treatment of 40 t ha^{-1} of FYM and 300 kg nitrogen fertilizer resulted in 117.9 (g) of stem dry weight, 70.11 (cm) of plant height, 10.81(cm) of tuber height, nitrogen escape per cent (1.964 %) and 5.8 number of tuber per plant and furthermore, the 40 t ha^{-1} of FYM and 200 kg nitrogen fertilizer resulted in the average yield (40080 kg ha^{-1}).

Quality character:

Hasandokht and Kashi (2000) reported that the applying 3 nitrogen fertilizer levels (120, 160 and 200 kg pure nitrogen per ha) found that in treatment of applying 160 kg derived most nitrogen and protein of tubers. Nitrogen fertilizer consumption can increase the nitrogen percentage of the tuber and convert them to protein, there by improving the nutritional value of the potato's tuber.

Banu *et al.*(2007) indicated that application of nitrogen, potassium and magnesium fertilizers increased the reducing sugars, starch and crude protein content, whereas it decreased the TSS content. Higher N and K levels were found to increase the crude protein content. This might be due to higher N uptake. At N_1K_1, N_2K_2 and N_3K_3, increased level of Mg from 0 to 48 kg ha^{-1} recorded significantly higher crude protein content in potato.

Kandi *et al.* (2011) showed that the application of 100 kg N ha^{-1} had a significant effect on tuber number $plant^{-1}$, fresh tuber yield, starch content and dry matter content in potato.

Matiwos (2011) revealed that with respect to quality parameter the highest crude protein content in potato tuber was recorded with the application of 100 per cent RDF + 25 tonnes of FYM ha^{-1} (8.98 %) followed by 75 per cent N through RDF + 25 per cent N through sheep manure +25 tonnes of FYM ha^{-1}.

Mohammadi *et al.* (2012) concluded that integrated application of natural and biological fertilizers along with urea can be useful to enhance potato yield and quality.

Bashir and Qureshi (2014) reported that the highest carbohydrate (22.92 %), crude protein (2.93) and ascorbic acid (17.20 34 mg 100^{-1}g quality of potato) was obtained in treatment combination of N180F24 which was found superior over all other treatment combination.

Nutrient uptake:

Sud *et al*. (1990) observed the effect of FYM on nutrient uptake by potatoplant. It was found that recovery of nitrogen was 43 per cent and FYM increased theN use efficiency of applied N by 22.4 per cent. The application of FYM @10t ha^{-1} increased the nitrogen uptake by 14 per cent (Sanyal *et al*., 1993).

Similarly, Almazov and Kholuyako (1994) also emphasized the increased uptake of nitrogen due to application of FYM.

Jaggi *et al*. (1995) observed that the application of 60 kg P_2O_5 + 20 t FYM ha^{-1} significantly increased the uptake of nitrogen by potato.

Patil *et al*. (1997) studied the effect of vermicompost, FYM and inorganic fertilizer on growth, yield and uptake of nutrients in potato cv. KUFRI CHANDRAMUKHI and found that combination of vermicompost @ 4 t ha^{-1} + 50 % RDF recorded maximum yield (34 t ha^{-1}) at Karnataka.

Sharma and Kumar (2000) studied the effect of nitrogen and FYM on nitrogen use efficiency (NUE), productivity of potato cv. KUFRI JYOTI and uptake of nutrients (N, P and K) at the harvest stage in Himachal Pradesh. The treatments comprised of four N rates (0, 50, 100 and 150 kg ha^{-1}) and three FYM rates (0, 10 and 20 t ha^{-1}). The nutrient use efficiency (NUE) was the highest at the lowest N rate (0 kg ha^{-1}) and decreased with increasing N rates. However, increased N rates upto 10 kg ha^{-1} significantly increased the mean tuber yield of potato (136 %) and also had significant positive effect on uptake of N, P and K. FYM treatment also increased NUE, tuber productivity and uptake of nutrients.

Kumar *et al*. (2009) revealed that nutrient (nitrogen, phosphorus and potassium) uptake of the potato crop significantly increased with integrated use of 75 or 100 per cent NPK and poultry manure (@ 7.5 t ha^{-1}) or farmyard manure (@ 30 t ha^{-1}) as compared with inorganic fertilizers alone (control).

Matiwos (2011) revealed that significantly higher uptake of major nutrients *viz.,* nitrogen (102.95, 62.33 and 165.28kg ha^{-1}), phosphorus (62.73, 62.87 and 125.60 kg ha^{-1}) and potassium (20.20, 131.82 and 152.02 kg ha^{-1}) in tuber, haulms and total, respectively were observed with the application of 100 per cent RDF + 25 t of FYM ha^{-1} and it was also on par with 75 per cent N through RDF + 25 per cent N through sheep manure +25 t of FYM ha^{-1}.

Kumar *et al*. (2012) results showed that 50 per cent of the recommended dose of NPK through inorganic + 50 per cent recommended dose of nitrogen (RDN) through organic manures (FYM, PM or VC) or 100 per cent recommended dose of NPK through inorganic fertilizers alone favourably influenced the nutrient uptake by potato and soil fertility. Seed treatment with *Azotobactor* + PSB proved better in tuber yield, nutrient uptake and recorded higher returns as compared to sole treatment of either *Azotobactor* or PSB.

Islam and Nahar (2012) found that the highest nitrogen (628.68 kg ha^{-1}) uptake by tuber was found in the treatment in which cow dung was applied 30 t ha^{-1} and the lowest uptake was recorded where inorganic fertilizer was used. The nitrogen uptake by potato haulm varied from 13.81 to 39.50 kg ha^{-1}. The maximum nitrogen uptake (39.50 kg ha^{-1}) by haulm was found where poultry manure was used in combination with inorganic fertilizer (NPK) and the lowest (13.81 kg ha^{-1}) was found in the treatment of inorganic fertilizer (NPK).

Islam *et al*. (2013) results showed that the N, P and K uptake by the potato increased significantly due to addition of organic manure and inorganic fertilizers with the highest N, P and K uptake by PM + reduced RDF treatment (N135P20K135S10 kg ha^{-1}).

Economics:

Sasani *et al*. (2003) conducted an experiment with potato cv. KUFRI BADSHAH in Gujarat involving 3 levels of NPK (75, 100 and 125% of the recommended dose, *i.e.* 220:110:220kg NPK ha^{-1}) alone or in combination with farmyard manure (FYM) at 25 t ha^{-1}. Application of organic manure (FYM) along with chemical fertilizer increased the potato yield, net return and B:C ratio at all levels of applied fertilizers. The treatment where the potato crop received 25 per cent more dose of NPK than the recommended dose along with FYM recorded the maximum tuber yield of 533.3 q ha^{-1} and 388.5 q ha^{-1} during 2001-02 and 2002-03, respectively. This treatment also recorded the highest net return of Rs. 69 990 ha^{-1} over the same level of inorganic fertilizers without FYM (Rs. 55 570 ha^{-1}). Application of organic manure (FYM) along with chemical fertilizer increased the potato yield, net return and B:C ratio at all levels of applied fertilizers.

Chettri *et al*. (2005) conducted experiment at Hoogly district of (W.B.) tostudy the economics of different treatment FYM @ 30t ha^{-1}, FYM @ 20t ha^{-1} +biofertilizer (*Azotobacter* and Phosphobacteria), FYM @10 t ha^{-1} + biofertilizer (*Azotobacter* and Phosphobacteria) + crop residue of previous crop, FYM @ 20t ha^{-1} +biodynamic, biodynamic+ biofertilizer (*Azotobacter* and Phosphobacteria), recommended dose of N, P and K and control. They noted that the cost of cultivation from above treatments were about Rs. 43,800/-, 43,400/-,

42,900/-, 43,380/-, 42,480/-, l48,120/- and 42,300/-, respectively. The net return maximized (36,810/-) with the application of FYM @ 30t ha^{-1}. This may be attributed to low input cost as compared to inorganic source of nutrients. It is concluded from the result that organic treatments gave 4 to 20 per cent less tuber yield than recommend fertilization but it was economically profitable than potato produced through inorganic source of nutrients.

Khurana and Bhutani (2005) conducted experiment at Hissar to study the combined effect of FYM, biofertilizer and inorganic fertilizer on potato. Well sprouted tubers of potato cv. KUFRI BAHAR were planted in the last week of October and haulm cutting was done at 105 days after planting. Treatments consisted of combinations of 75 and 100 per cent of recommended dose of NPK (N:P:K;150:80:100kgha^{-1}) with control, FYM @20t ha^{-1} and biofertilizers. Biofertilizers improved net return at both the doses of fertilizers. FYM @ 20t ha^{-1} in addition to inorganic fertilizer significantly improved total tuber yield, yield of large size tubers and tuber number during both the years and at both the doses of fertilizers. FYM also improved the net return at both the doses of fertilizers and during both the years. Reducing the recommended dose of NPK by 25 per cent significantly reduced total tuber yield, yield of large size tubers, tuber number and net return. It may be concluded thatin potato, it is beneficial to treat seed tubers with biofertilizers (*Azotobacter* and *Phosphobacteria*) and add FYM @ 20 t ha^{-1} every year in addition to recommended dose of NPK.

Nag (2006) observed the maximum cost of cultivation in treatment with 125 per cent RDF + organic manure (FYM) @ 20 t ha^{-1} (Rs. 62455 ha^{-1}) followed by 100 per cent RDF + organic manure (FYM) @ 20t ha^{-1} (Rs.56149ha^{-1}) while the lowest cost of cultivation (Rs. 56149 ha^{-1}) was found in treatment 75 per cent + no organic manure. The highest income (both gross and net) was obtained with the application of 125 per cent RDF + crop residue incorporation with biofertilizer (*Azotobacter* + *Phosphobacteria*).

Singh and Kushwah (2006) studied the effect of organic and inorganic sources of nutrients on potato (*Solanum tuberosum* L.) production. The treatments included 25, 50, 75 and 100 per cent doses of NPK with and without organic manures (farm yard manure and Nadep compost @30t ha^{-1}). Maximum net return of Rs. 63,627 ha^{-1} was also obtained from 100 per cent NPK + 30 t FYM ha^{-1}. However, Benefit: Cost ratio was almost same under 75 per cent NPK with 30 t ha^{-1} FYM or Nadep compost and 100 per cent NPK with 30t ha^{-1} FYM or Nadep compost.

Bose *et al.* (2008) found that among different levels of nitrogen application (60, 120 and 180 kg N ha^{-1}), maximum net return of Rs. 56924 was recorded on application of 120 kg N ha^{-1} + 30 t FYM ha^{-1} with Benefit cost ratio of 2.40.

Mekonnen *et al*. (2008) revealed that the economic analysis of integrated use of organic and inorganic fertilizer resulted in higher net return and benefit cost ratio over the control treatments. The study revealed that integrated use of 10 t ha^{-1} farm yard manure along with 75 per cent recommended dose of fertilizer not only resulted in significantly higher tuber yield but also improved the nutrient status of the soil. It could also save 25 per cent inorganic fertilizer for sustainable potato production in potato growing areas.

Kumar *et al.* (2009) revealed that integrated use of 75 or 100 per cent NPK and poultry manure (@ 7.5 t ha^{-1}) or farmyard manure (@ 30 t ha^{-1}) for potato as improving the nutrient uptake, tuber yield and benefit:cost ratio (B:C).

Powon *et al.* (2009) found that at KARI- Kitale season 1 trial, the highest Benefit cost ratio was realized at the application of 100 P kg ha^{-1} (without K and FYM) and the lowest at the application of 83 kg K ha^{-1} + 100 P kg ha^{-1} +10 t FYM ha^{-1}.At the KARI - Kitale season 2, the highest Cost benefit ratio was realized at the application of 166 K kg ha^{-1} + 100 P kg ha^{-1} + 10t FYM ha^{-1} and the lowest benefit cost ratio was realized in the control treatment. At Psigirio, the highest benefit cost ratio was realized at the application of 100 P kg ha^{-1}10 t FYM ha^{-1} with no application of K and the lowest in the control treatment.

Jaipaul Sharma and Sharma (2011) found that the cost of production was highest for chicken manure (7.5 t ha^{-1}) + biofertilizer treatment (Rs. 65,500 ha^{-1}) and lowest (Rs. 28,000 ha^{-1}) for control. The B:C ratio was found highest (4.86) under the treatment using organics and inorganics sources of nutrients followed by chicken manure + biofertilizer treatment (2.30).

Verma *et al*. (2011) found that the combination of crop residues + *Azotobactor*+ Phosphobacteria + biodynamic approach + microbial culture was the best among the all treatments for most of the growth and yield parameters under study and gave highest net return

and B:C ratio. Thus, it can be concluded that the biofertilizers are an advantageous source for sustainable organic agriculture, specially for heavy feeder crops like potato.

Matiwos (2011) revealed that the highest net income (Rs. 70164) and benefit: cost ratio (2.46:1) of potato was found with the application of 100 per cent RDF + 25 t FYM ha^{-1} followed by 75 per cent N through RDF + 25 per cent N through sheep manure +25 t FYM ha^{-1}.

Kumar *et al.* (2012) result revealed that integrated application of inorganic and organic fertilizers and seed treatment with *Azotobactor* + PSB biofertilizers improved tuber yield, nutrient uptake and gave higher return as compared to other treatment combinations to potato.

Baishya *et al*. (2013) observed the highest gross return and net returns from the crop having 75 per cent RDF through chemical fertilizers along with 25 per cent RDN through FYM or 100 per cent RDF through chemical fertilizers and were significantly greater than those of all other fertility treatments during both the consecutive years. The above fertility treatments also paid greater return per rupee invested in potato cultivation than that of crop at 100 per cent RDN through FYM. All the fertility treatments paid higher gross and net returns over that of the control plots that paid the lowest return due to poor growth and low productivity.

Biruk *et al.* (2014) revealed that 75 per cent RDF through chemical fertilizers and 25 per cent RDN through FYM or 100 per cent RDF through chemical fertilizers highest potato tuber yield (27.3 t ha^{-1}) with maximum gross and net returns over others.

Boke (2014)results indicated that the highest net benefit (birr 23982) and maximum marginal rate of return (1060.8) by potato were also achieved with the combined application of FYM and NPK (100-100-100 kg ha^{-1} plus 15 t ha^{-1} FYM) NPK (100-100-100 kg ha^{-1}) plus 15 t ha^{-1} FYM followed by organic amendment but the highest cost benefit ratio (5.59) was achieved by application of FYM alone.

Dubey *et al.* (2014)observed that among different integrated nutrient management treatments of organic sources maximum net return of Rs. 60,990/- and highest B:C ratio of 1:2.6 were recorded from application of 75 per cent NPK through chemical fertilizers + 20 t ha^{-1} nadep compost to potato. The minimum net return of Rs. 34,227/- and lowest B:C ratio of 1:1.7 were noted in farmer's practice along with 75 per cent NPK through chemical fertilizers, vermicompost was found best compared to nadep compost.

Yadav *et al.* (2014) reported that the maximum net returns were with application of 75 per cent RDF and 25 per cent RDN through FYM to potato.

Dash and Jena (2015) resulted in maximum net return (Rs. 55186) and return per rupee investment (2.03) indicating 25 per cent saving of NP over full nutrient application through inorganic sources and biofertilizer treatment (*Azotobacter* + phosphorus solubilizing bacteria) under 75 per cent of recommended NP to potato was significantly higher than that from 100 per cent nutrients from inorganic sources.

Singh *et al.* (2015) evident that maximum net return Rs.168279 as well as benefit: cost ratio (3.07) was obtained under treatments T_8 (FYM @ 5 t ha^{-1} + RDF + 1 t ha^{-1} *Neem* cake) was found to be most remunerative treatment and help in taking decision for successful crop production of potato from farmer's point of view.

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