Intensive puddling destroys soil structure and creates soil physical conditions that are unfavourable for wheat cultivation after rice. Though, Zhao, (1989) reported that zero- tillage was more suitable for soils under rice -wheat cropping systems.

Since organic matter is known to improve physical conditions including water holding capacity of the soil. Therefore, this property of organic matter should be explored to reduce the negative effects of intensive puddling as well as reduced tillage. Simultaneously organic manuring also supplements the nutrient requirement of the crops and hence it is necessary to study the nitrogen requirement of the crop under improved manuring and different tillage practices. The evidences of organic manures to reduce the adverse effects of intensive or reduced tillage in rice crop and its residual effect to succeeding wheat crop is scanty, inconsistent and inconclusive. In this chapter an attempt has been made to review the available literature on the present topic under the following heads:

2.1 Effect of tillage methods
2.1.1 Growth and development
2.1.2 Yield and yield attributes
2.1.3 Soil physical and chemical properties
2.1.4 Economic studies
2.2 Effect of organic manures
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2.2.2 Yield and yield attributes
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2.3 Effect of nitrogen levels
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2.1 Effect of tillage methods

Cropping sequence that includes rice-wheat system requires special attention towards management practices to become sustainable. Tillage is an integral part of cropping system, aimed at optimizing crop production by solving specific soil related ecological constraints to crop production. Rice is usually grown under lowland conditions where soils are puddled. Puddling as well as no-puddling for growing transplanted and direct seeded rice, respectively, has their advantages as well as disadvantages on the physical condition of the soil and yield of rice (Mohanty et al., 2004).

2.1.1 Growth and development

Puddling is used to prepare soil for irrigated rice (Oryza sativa) throughout south-east Asia creating a soft mud often over a plough pan. Whilst these conditions are favourable for the rice crop, but are less suitable for any dryland crop (Ringrose-Voase et al., 2000). Reddy and Hukkeri (1983) at IARI New Delhi studied four tillage methods: puddling once, puddling twice, and compaction of the soil surface or preparation of the seedbed by conventional ploughing. They
reported that the field puddled twice produced maximum dry matter accumulation, plant height, number of tillers at harvest, panicle length, number of filled grains per panicle, and 1000-grain weight, maximum grain and straw yields of 4.5 and 7.0 t ha\(^{-1}\), respectively, were also obtained by this method.

Transplanting rice seedlings into unpuddled fields depressed establishment of plants/seedlings, early growth, tiller initiation and number of tillers per plant, but at high soil temperature (25\(^{0}\)C) growth was better than in puddled fields. Dry matter production was suppressed initially but accelerated during heading stage, LAI and N absorption showed similar trends. NAR increased at panicle initiation and early to middle ripening stages (Kumano et al., 1985). Bhadoria (1987) from West- Bengal observed less seedling emergence of subsequent wheat crop under puddled soil because of more clods of larger size.

Bajpai and Tripathi (2000) from Uttar Pradesh reported that the puddling in rice enhanced the root length density by 12 per cent but later affected adversely the wheat crop and minimized the root length density by 28 per cent. Singh et al. (2001b) reported that with the increase in puddling intensity from no puddling (P0), two discing + one planking (P2), and four discing + one planking (P4), significantly increased leaf area index and dry matter production. There was no difference in these parameters in P2 and P4. Whereas, Furuhata et al. (2005) in Japan found that the seedling establishment rates of rice two weeks after sowing were lower in over-puddled plots compared to the normally puddled plots, especially when wheat straw was applied.

2.1.2 Yield and yield attributes

The studies by Sharma and De-Datta (1985) revealed that bulk density and soil strength were the main factors affecting grain yield of rice crop. Sharma et al.
(1988) at IRRI Phillipine found the negative correlation of grain yield with bulk density and soil penetration resistance. Yield components and paddy yields of rice grown in a puddled black cotton soil were significantly increased compared with a non-puddled soil, yields obtained in soils puddled to a depth of 10 cm were higher than in soils puddled to depths of 20 or 30 cm (Bhalerao and Nimkar, 1985). Whereas in plots where puddling was not practiced, grain number per panicle and percentage of productive tillers increased and panicles per hill decreased, grain: straw ratio was higher but percentage of ripened grains was low. Average brown rice yield was 645 g m\(^{-2}\) and decreased by 1-10% and 2-3% compared with puddled fields in soils with low and high permeability, respectively (Kumano et al., 1985). Ali et al. (1992) compared four tillage treatments and reported that complete puddling gave the highest 1000-grain weight, total and head rice recoveries as compared to partial puddling.

Singh et al. (1984) reported that the rice transplanted on a puddled soil gave significantly higher paddy yields than when transplanted on an unpuddled soil. Das and choudhary (1985) found that puddling thrice at 7 days interval, puddling twice or puddling twice after preliminary tillage (local practice) gave yields of 3.66, 3.43, and 3.05 t ha\(^{-1}\), respectively. Singh et al. (1995) in a field trial at Ludhiana compared 3 levels of puddling for rice cultivation viz., no puddling, 2 runs of a tractor-drawn cultivator in standing water, each followed by planking, and 4 cultivations and 4 plankings. He found that the yield averaged 2.22, 2.54 and 3.26 t ha\(^{-1}\) with 0, 2 and 4 puddlings, respectively.

Conversely Utomo and his co-workers (1993) reported that rice yield was not significantly affected by degree of puddling. Growth and yield of subsequent crop was increased by decreasing puddling intensity. Similarly, Kirchhof and So
(1995) has shown that soil puddling intensity had no effect on rice yields except on coarse textured soils. In an another study Kirchhof and So, (1996) reported that puddling could be reduced without affecting rice yields, except on sandy soils. Further he reported that compaction decreased percolation rates, except on clay soils, and tended to reduce rice yields. Compaction was likely to be beneficial for rice on coarse-textured soils, he further suggested that compaction should be avoided on clay soils. Parihar (2004) reported that conventional (3 passes with cultivator+2 plankings) and reduced (through rice puddler) puddling had not much significant difference in paddy yields.

Bajpai and Tripathi (2000) reported that both puddling and non-puddling was equally effective for getting higher grain yield of rice. However, non-puddling of rice produced a significantly higher wheat grain yield than that of wheat followed by puddled rice. Kukal and Aggarwal, (2003a) also found that puddling, even though reduces percolation losses of irrigation water in rice production, it also results in yield decline of wheat (*Triticum aestivum* L.) that follows the rice crop in the cropping sequence because of subsurface compaction. Similarly, Singh *et al.* (2004) reported that rice transplanted after puddling by four passes of rotary puddler increased rice yield by 9.3 per cent compared to direct sowing without puddling but wheat yield was recorded highest under direct sowing without puddling treatment. Tripathi *et al.* (2005) at Pantnagar conducted a study to optimize tillage in rice-wheat system. Tillage treatments for rice were puddling by four passes of rotary puddler (PR), reduced puddling (ReP), conventional puddling (CP) and direct seeding without puddling (DSWP). They found that rice yield in the rotary puddler (PR) plots was highest and statistically equal to that in the reduced puddling (ReP) plots but wheat yield was highest in the direct seeding without
puddling (DSWP) plots and was statistically equal to that in reduced puddling (ReP) plots.

2.1.3 Soil physical and chemical properties

Puddling decreased the bulk density of soil in the top 10 cm layer by about 30%, but the differences in bulk density between puddled and non puddled soil narrowed with time (Sharma and De-Datta, 1985). Puddling significantly reduced the bulk density of the surface (0-0.06 m) soil at the tillering stage of rice, compared to non-puddling, whereas it was significantly higher after crop harvest (Bajpai and Tripathi, 2000). In another study puddling reduced the bulk density of soil and decreased the hydraulic conductivity in the upper layers (Chandel et al., 2002). Three puddling intensities i.e. no-puddling (P₀) and puddling by four (P₁) and eight (P₂) passes of 5 hp power tiller were evaluated by Mohanty et al. (2004). They observed that the soil bulk density and penetration resistance (PR) increased significantly from transplanting to harvest in puddled soil, but in unpuddled soil penetration resistance significant increased only at the surface 0-7 cm layer.

Lal (1986) from Nigeria reported that the mean bulk densities of no-tillage and puddled soils were 0.96 and 1.24 t m⁻³ for the 0-10 cm layer and 0.91 and 1.07 t m⁻³ for the 10-20 cm layer. Puddling is reported to increase the soil bulk density and penetrometer resistance (Saroch and Thakur, 1991). Bulk density increased and water stable aggregate decreased as a result of puddling. Bulk density values showed the development of a hard pan at 0.15 m depth from the surface (Rawat et al., 1996). Kirchhof et al. (2000) reported that increase in puddling intensity from medium to intensive, significantly increased the bulk density.
Increase in puddling intensity from medium to intensive significantly increased bulk density from 1.63 to 1.67 Mg m\(^{-3}\) in 16-18 cm and from 1.61 to 1.66 g cm\(^{-3}\) in 18-20 cm soil layers. In normal-puddled plots, the average bulk density of 14-20 cm soil layers was significantly higher (1.74 g cm\(^{-3}\)) than that of shallow puddled plots (1.57 g cm\(^{-3}\)) at the end of 3 years of study. Similar trends were observed in case of soil penetration resistance (Kukal and Aggarwal, 2003a).

The above cited literature indicates that soil bulk density decreases at the time of intensive puddling but with the settling of soil particles it goes on increasing till the maturity of the crop and hence soil bulk density after the harvest of the rice crop is more in conventional tillage than reduced tillage.

Rahman (1991) observed that a combined effect of tillage and puddling during long-term wheat and rice cultivation produces a dense layer below the surface of the soil. Formation of this dense layer enables the topsoil to store more water. Aggarwal et al. (1995) reported that the coarse-textured soils are puddled to reduce high percolation losses of irrigation water under rice field. Utomo et al. (1996) in Indonesia also found that the puddling is necessary in course texture soils to reduce percolation rate and ensure that submerged conditions can be maintained whereas, on the other hand, in finer textured soils, puddling is not necessary, and minimum disturbance/ cultivation may result in a significant saving of energy to the farmer.

Increase in puddling intensity significantly increased depth of puddle and decreased saturated hydraulic conductivity (Ks) of the puddled layer (Singh et al., 2001a). Sandhu and Singh (2001) also showed that puddling decreased the percolation rate of water by up to 92% depending on the depth and intensity of puddling and soil texture. Soils with higher organic matter content responded more
to puddling in terms of reduction in percolation rate. A puddling depth of 10 cm at high intensity of puddling was more effective in reducing the rate of settling of suspended particles and percolation rate of water. Similarly, Mishra et al. (2003) found the average rate of water loss (1.90 mm hour\(^{-1}\)) was reduced significantly under puddled conditions compared with no-tillage conditions (2.78 mm hour\(^{-1}\)). The magnitude of reduction in water loss was greatest (1.72 mm hour\(^{-1}\)) under medium tillage at PAU Ludhiana.

The process of water percolation was studied by Kukal and Aggarwal (2002) in a puddled sandy loam rice field with three puddling intensities. Percolation losses of water decreased with medium-puddling by 54-58%, but it remained unaffected by increased puddling intensity as well as puddling depth. Percolation rate (PR) decreased with time with both medium and high puddling intensity but it increased with increased depth of ponding water.

Kukal and Aggarwal, (2003b) recorded the 14-16% decrease in percolation losses with the increase in puddling intensity. Whereas the requirement of irrigation water decreased by 10-25% with increased intensity of puddling. Puddling depth did not affect percolation losses or the amount of irrigation water applied. Mohanty and Painuli (2003) evaluated three tillage treatments viz., No puddling (P0), puddling with four (P1) and eight (P2) passes of power tiller under the same nutrient management practice and concluded that puddling, on an average, reduced seepage plus percolation to 5.6, 2.8 and 2.4 mm h\(^{-1}\) in P0, P1 and P2, respectively.

Thus puddling reduces percolation losses of water in rice fields, the extent of reduction being a function of intensity and depth of puddling. Course textured soils and soils with high organic matter respond more to puddling in terms of
reducing percolation losses of water. Therefore, Parihar, (2004) reported that rice grown under unpuddled condition required more irrigations without the additional advantage in grain yield over puddled condition.

Increased puddling leads to leaching out of fertilizers and increased soil reduction (Tateno and Kikuchi, 1981). Reddy and Hukkeri (1983) suggested that tillage practices may affect the efficiency of the use of soil and applied nutrients by the rice crop. Sharma and De Datta (1985) reported the concentration of NO$_3$-N in puddled soil was either comparable to or lower than that in non puddled soil. In the first soil, puddling significantly decreased leaching losses of NO$_3$-N, but it decreased leaching losses of NO$_3$-N, NH$_4$-N, P, K, and Zn in the other soil. Whereas continuous flooding and intense puddling greatly reduce permeability of the soil, allow accumulation of reducing substances in the rhizosphere, and retard mineralization and N uptake in some soils (Kundu and Ladha, 1999). The change in the nutrient status has been reported due to repeated transitions from anaerobic to aerobic growing conditions (Timsina and Connor, 2001). Thus the nutrient availability due to different tillage methods is influenced by its impact on nutrient losses mainly through leaching with irrigation water.

2.1.4 Economic Studies

Acceptance of any technology depends on its profitability. Tillage is one of the important factors for increasing crop production as well as cost to crop production. Wet tillage (puddling) done for transplanting of rice seedlings is a labour intensive practice which increases the cost of cultivation and hence decreases the profitability of rice cultivation.

In a field experiment Singh et al. (1994) at Pantnagar recorded the highest rice yield and net returns with Sesbania green manuring + puddling as compared
to conventional puddling, reduced puddling and direct sowing of rice. Sharma *et al.* (1995) reported that owing to the substantial reduction in labour requirements under direct sown, puddled conditions, a higher net returns of RS. 14,741 ha\(^{-1}\) was obtained as compared to Rs. 13,498 ha\(^{-1}\) obtained under direct sown, dry conditions and Rs. 12,981 ha\(^{-1}\) under transplanting. Similarly Singh *et al.* (2004) at Pantnagar also obtained highest net returns (Rs.18,560 ha\(^{-1}\)) from rice crop transplanted after reduced puddling, followed by direct sowing without puddling, puddling by rotavator and conventional puddling. The net returns from wheat was greatest (Rs. 11,820 ha\(^{-1}\)) when followed by direct sowing of rice and lowest (Rs. 7,090/ha) under conditions of rice transplanted after puddling with a rotavator.

### 2.2 Effect of Organic Manures

The continuous depletion of nutrients due to intensive cropping system is posing a serious threat to sustainable agriculture, simultaneously the farmers can not afford to supply all the essential nutrients through chemical fertilizers. Therefore it is necessary to find out suitable organic sources of nutrients which are easily available to the farmers. Organic sources of the nutrients will also help to conserve soil heath. Effect of two different types of organic materials, *viz.*, FYM, and *Sesbania* green manures have been studied in this section.

#### 2.2.1 Growth and development

Application of organic manures has significant effects on growth and development of crop plants. (Sharma, 1983; Thakur 1985. Saha, 1986; Park *et al.*, 1986). Sood (1987) reported that rice crop receiving nitrogen through combination of urea and organic manures resulted in higher dry matter production than receiving N through urea alone. Sharma and Mittra (1988) also reported
improvement in plant growth of rice and wheat crops in terms of plant height, dry matter production and number of tillers with application of various organics.

Sharma (1992) at Palampur reported a significant increase in the plant height, number of shoots m\(^{-2}\) and dry matter accumulation of rice and wheat crops with the application of FYM @ 10 t ha\(^{-1}\) to each crop in a rice wheat sequence. In the same study residual effect of FYM applied to preceding crop @ 10 t ha\(^{-1}\) also showed significant improvement in plant growth of succeeding crop compared to no FYM treatment. Similar findings were also reported by Kumar (1996). Application of 5 t ha\(^{-1}\) castor cake or 15 t ha\(^{-1}\) FYM with recommended NPK (90N:60P\(_2\)O\(_5\):40K\(_2\)O), significantly increased the plant growth and yield of wheat, and remained at par with application of 5 t ha\(^{-1}\) castor cake with 50 per cent of recommended NPK (Dudhat et al., 1997). Singh and Mandal (1997) reported that application of organic materials like Ipomoea sp., water hyacinth, Pistia sp., blue green algae (BGA) and FYM with inorganic nutrition resulted in significant increase in dry mater accumulation, leaf area index, grain and straw yield of rice over control treatment. Suresh et al. (2000) while studying the effect of application of enriched FYM with single superphosphate and phospho bacteria in rice found significant improvement in crop emergence, plant height, leaf area index and panicle m\(^{-2}\).

Hemalatha, et al. (2001) reported that amongst the organic treatments, in-situ incorporation of dhaincha applied @ 12.0 t ha\(^{-1}\) recorded the higher plant height (97.61 cm), number of tillers per hill (19.55), leaf area index (6.85), dry matter production (13 848 kg ha\(^{-1}\)), grain yield (6374 kg ha\(^{-1}\)) and straw yield (8411 kg ha\(^{-1}\)). Vaiyapuri and Sriramachandrasekaran (2002) at Tamilnadu revealed that incorporation of 12.5 t ha\(^{-1}\) of Sesbania aculeata recorded the highest plant height
number of tillers hill\(^{-1}\) (15.4), LAI (7.9). Bhattacharya \textit{et al.} (2003) reported that the plant height at 45 and 90 days after transplanting was greatest in plots treated with 9.0 t FYM (61.5 and 84.3 cm), 7.0 t FYM (61.2 and 83.6 cm) and 1.0 litre humic acid ha\(^{-1}\) (60.9 and 83.4 cm). The application of 7.0 t FYM and 1.0 litre humic acid ha\(^{-1}\) resulted in the highest dry matter accumulation at 45 (327.1 and 319.8 g m\(^{-2}\)) and 90 days after transplanting (648.4 and 651.1 g m\(^{-2}\)). Pramanik \textit{et al.} (2004) showed the best performance of \textit{Sesbania rostrata} in respect of plant height, total number of tillers hill\(^{-1}\).

From the above cited literature it is evident that application various organic manures improved the growth and development of rice and wheat crops.

2.2.2 Yield and yield attributes

According to available data, incorporation of different organic materials in soil before transplanting of rice increased the total productivity of ‘rice-wheat’ cropping on an average by 2.9 to 126.2 per cent over control. The increases in grain yields of rice and wheat was attributed to improvement in soil physical properties, like bulk density, penetration resistance, aggregation, hydraulic conductivity, infiltration and moisture retention (Prasad, 1994; More, 1994; Gupta \textit{et al.}, 1995; Aggarwal \textit{et al.}, 1997; Mishra and Sharma 1997), and chemical properties, like organic carbon, available macro- and micro- nutrients like Zn, Cu, Mn and Fe etc. (Maskina \textit{et al.}, 1988; Bhandari \textit{et al.}, 1992; Prasad, 1994; Aggarwal \textit{et al.}, 1995; Kumar and Yadav, 1995; Mahapatra and Sharma, 1995; Pathak and Sarkar, 1995; Tiwari \textit{et al.}, 1995). Chemical changes increased the nutrient supplying power of rice soils. In case of sodic soils, incorporation of organics decreased pH, EC, and ESP thereby increasing crop yields (More, 1994; Kumar and Yadav, 1995).
Under Palampur conditions, Ganai (1983) and Sharma (1983) reported that application of FYM improved yield attributes and yield of both rice and wheat in rotation. Ganai (1983) further reported significant residual effect of FYM applied in rice on succeeding wheat crop. In another study at Palampur, Verma and Dixit (1989) observed that wheat grain yield increased significantly with the incorporation of paddy straw and had significant residual effect on following rice crop in wheat-rice sequence. Sharma (1992) also reported an improvement in yield and yield attributes of rice and wheat with the use of FYM in rice and wheat crop. The residual effect of FYM application on yield of either of succeeding crop was also observed when it was applied in any of the preceding crop.

The numbers of panicles m$^{-2}$ and spikelets per panicle, percentage of filled grains and 1000-grain weight increased with increasing NPK rates and FYM application (Mondal et al., 1990). Application of FYM to rice increased the grain yield of rice over control and also increased the grain yield of wheat due to marked residual effect in soil fertility at Ludhiana (Brar et al., 1995). A significant increase in grain and straw yields of rice 5.90 and 6.36 per cent and of wheat by 13.73 and 14.06 per cent was obtained with the application of 10 t FYM ha$^{-1}$ to rice crop over control by Singh et al. (1996). Increase in the productivity of rice-wheat cropping system has also been reported by Nair and Gupta (1999) with the use of green manure in rice. Application of various organics in rice significantly increased the rice grain yield. They also exhibited significant residual responses on grain and straw yields of wheat crop (Singh et al., 2001b). Chettri et al. (2003) from Bhutan reported that the farmers' practice of applying seven tonnes farmyard manure per hectare appears adequate to produce stable rice paddy yields of 4-6 t ha$^{-1}$.

Tiwari et al. (1995) observed that the productivity of the rice-wheat system
increased from 62.6 q ha\(^{-1}\) without green manure to 77.7 and 76.7 q ha\(^{-1}\) with *Sesbania rostrata* and *Sesbania cannabina*, respectively. Mehla *et al.* (1998) found that the grain yield increased with increasing nitrogen application up to 80 kg ha\(^{-1}\) in green manure and 120 kg ha\(^{-1}\) FYM treatments. Mann and Ashraf (2000) from Pakistan reported high rate of farmyard manure (20 t ha\(^{-1}\)) in combination with lower N (49 kg ha\(^{-1}\)) also gave significant increase in paddy yield. Mirza *et al.* (2005) reported that green manuring with *Sesbania* improved the paddy and straw yield by 15.4 and 14.5%, respectively. Productive tillers were increased with the application of FYM but differences were not significant between 10 and 20 tonnes ha\(^{-1}\) of FYM application. The increases in paddy yield due to application 5, 10 and 20 tonnes ha\(^{-1}\) FYM were 6.8, 24.4 and 37.6%, respectively over control.

In an experiment conducted by Singh *et al.* (2002) observed that application of 50% of the recommended dose of nitrogen (RDN) through inorganic fertilizer (IF) + dhaincha (*Sesbania aculeata*) at 2.5 tonnes ha\(^{-1}\) to rice gave significantly higher mean grain yield of rice (31.8 q ha\(^{-1}\)) and wheat (28.4 q ha\(^{-1}\)) over the rest of the treatments, except for 50% RDN through chemical fertilizers + pressmud at 5 tonnes ha\(^{-1}\) in rice. The yield of succeeding wheat increased by 43.1-48.9% because of the integrated nutrient management over the control. Premi (2003) reported that green manuring of dhaincha (*Sesbania aculeata*) with 25 per cent of recommended dose of nitrogen (30 kg N ha\(^{-1}\)) produced as much yield as recommended dose (120 kg N ha\(^{-1}\)) of nitrogen. Similarly higher yields of rice as well as succeeding wheat crop in *Sesbania* green manure plots was also recorded by Mandal *et al.* (2003).

Parihar (2004) reported that grain yields obtained with 80 kg N ha\(^{-1}\) (50% through green manure+50% through urea) were comparable to 80 kg N ha\(^{-1}\) (50%
through FYM+50% through urea), but both were significantly higher than 80 kg N through urea. Integrated sources of nutrients (organic+inorganic) had residual effect on succeeding wheat yield and nutrient uptake of rice-wheat system. Dwivedi et al. (2005) from Lucknow indicated the possibility of saving approximately 90-120 kg chemical N ha\(^{-1}\) with the use of green manures. Combined use of organic and inorganic nutrients increases grain yield by 10 to 20% in rice – wheat cropping system. Similar findings have also been reported by Singh (2006). He also reported that amongst the organic manures the overall performance of green manure was best, followed by FYM and rice straw.

### 2.2.3 Soil Physical and chemical properties

Organic matter is an important soil component influencing the physical, chemical and microbiological properties of soil to a great extent (Gaur, 1984). All physical properties of soil are affected by changes in organic matter levels of soil. Decrease in bulk density with the addition of organic matter has also been reported by other workers (Singh et al., 2000; Ray and Gupta, 2001; Sharma et al., 2001).

Thakur et al. (1995) observed significant decrease in bulk density of a silty clay loam soil at Palampur (H.P.) due to incorporation of dhaincha (Sesbania aculeata) and french bean biomass at an average rate of 18.3 and 1.3 Mg ha\(^{-1}\) year\(^{-1}\) after 3 years. The effect of dhaincha (Sesbania aculeata) was significantly higher than french bean probably because of much higher biomass addition in the first case. Gupta et al. (1995) reported that in a clay loam soil at Kaul (Haryana) incorporation of dhaincha (Sesbania aculeata) @ 33 Mg ha\(^{-1}\) decreased bulk density by 8.1 per cent at 0-15 cm and 2.3 per cent at 15-30 cm depths over the control. The bulk density values in control and treated plots were 1.60 and 1.74 Mg
m$^{-3}$ at 0-15 cm, and 1.75 and 1.71 Mg m$^{-3}$ at 15-30 cm soil depth. Ray and Gupta (2001) showed that incorporation of green manure before puddling for rice improved the soil aggregation and thereby decreased the bulk density. Thus, from above cited literature it is evident that the bulk density decreased with application of FYM and green manures, over a period of 2-7 years. Combined use of organic and inorganic sources of nitrogen have also been reported to decrease the bulk density of the soil (Premi, 2003; Mandal et al., 2003).

According to Kumar and Tripathi (1990), final infiltrability of a silty clay loam soil treated with FYM @ 15 t ha$^{-1}$ for 9 years was 0.36 cm hour$^{-1}$ as compared to 0.20 cm hour$^{-1}$ in untreated control after wheat harvest at Pantnagar (U.P.). Bhagat and Verma (1991) reported that incorporation of FYM @ 5 t ha$^{-1}$ year$^{-1}$ in a silty clay loam soil at Palampur (H.P.) over a period of 5 years increased the cumulative infiltration (observed for 15 h) from 0.48 to 0.56 m. More (1994) reported that incorporation of FYM @ 50 Mg ha$^{-1}$ for 3 years in a soil containing 46 per cent clay at Parbhani (Maharashtra) increased the infiltration rate from $1.4 \times 10.6$ to $3.3 \times 10.6$ m s$^{-1}$; with biogas slurry @ 10 t ha$^{-1}$ the infiltration rate increased to $1.4 \times 10.6$ m s$^{-1}$. Gupta et al. (1995) reported that incorporation of FYM @ 5 Mg ha$^{-1}$ increased the infiltration rate in black clay soil at Jabalpur from 0.50 to 0.89 cm h$^{-1}$. The cumulative infiltration increased from 6.8 to 15.6 cm after 6 hours.

Green manuring with dhaincha (*Sesbania aculeata*) increased cumulative infiltration by 59 mm (in 300 min) over control when used for 3 years in a loamy sand soil at PAU, Ludhiana (Punjab) (Boparai et al., 1992); decreased percolation rate in a sandy loam soil at PAU, Ludhiana from 12.1 to 11.6 mm d$^{-1}$, when used for 6 years (Aggarwal et al., 1995); and increased percolation rate in a clay loam
soil from $0.33 \times 10^{-6}$ to $0.56 \times 10^{-6}$ m s$^{-1}$ when used for 2 years @ 13 Mg ha$^{-1}$ (Aggarwal et al., 1997). Similarly, green manuring with sunhemp (*Crotalaria juncea*) increased water permeability from 0.027 to 0.044 cm hour$^{-1}$ in a clay loam soil at Kota (Rajasthan) (Darra et al., 1968); increased cumulative infiltration in a silty clay loam soil at Palampur (H.P.) when continuously used for 3 years @ 18.3 Mg ha$^{-1}$ (Thakur et al., 1995). Application of green manure was found to improve infiltration rate (Ray and Gupta, 2001). Chaphale et al. (2001) reported the green manuring significantly increased water holding capacity and per cent porosity of the soil.

Thus organic matter accumulated in the soil from long-term application of organic materials improved the physical properties of paddy soils, viz., bulk density and specific gravity mainly by increasing capillary pores and developing water-stable aggregates.

The use of organic fertilizers in addition to chemical fertilizer increased soil organic matter and total N, increased the effectiveness of soil P, increased the population of soil organisms, especially some bacteria, and increased the activities of some soil enzymes such as urease. Mann and Ashraf (2000) reported the organic manures increased soil organic matter content and thus total nitrogen. Green manuring has been reported to increase the organic carbon, available nitrogen, phosphorus and potassium status of soil in highly sodic soils (Chaphale et al., 2001). Abeysekerra et al. (2001) revealed that organic manures enhanced the mineral nitrogen contents in the soil irrespective of the source of green manure. Combined application of organic manure and chemical fertilizers recorded more mineral nitrogen than the application of both the sources individually. Pattanayak et al. (2001) reported recycling of K through dhaincha, Azolla and
sunnhemp varied from 10.0 to 17.5, 11.7 to 15.9 and 2.7 to 3.0 kg ha$^{-1}$, respectively.

Organic carbon and available N, P and K contents in soil were also improved with the application of FYM and Kudzu (Pueria thumbergiana) compost in wheat-ragi sequence under Almora conditions (Singh and Chauhan, 2002). The application of farmyard manure @ 7 t ha$^{-1}$ to both the rice and the wheat crops continuously for eight years increased organic carbon levels from 1.4 to 1.6%. Green manuring increased soil total nitrogen and available potassium and decreased base saturation (Chettri et al., 2003). Effective application of farm yard manures in paddy fields provides nutrient recycling (Oh et al., 2004). Mirza et al. (2005) reported that the N and P utilization by rice were also significantly improved with the application of green manure. Nitrogen uptake by rice (grain + straw) was increased by 17.8% and that of P by 21.9% with the application of green manuring.

Above mentioned literature indicates that organic manures not only improve the physical properties of the soils due to higher amount of organic matter additions but also enhance the soil productivity due to improvement in soil chemical properties. Thus, application of organic manures greatly influences the physical and chemical properties of the soil.

2.2.4 Economic studies

The experiment conducted by Choudhary and Thakuria (1996) revealed that green manuring with dhaincha or sunhemp resulted in lower net returns ha$^{-1}$ compared to application of chemical fertilizers alone. The direct, residual and cumulative effects of fertilizers applied alone or in combination with organic manures on productivity of crops grown in rice- wheat and sorghum- wheat
sequence were reported from Jabalpur and Raipur (M.P.) by Dubey et al. (1997). Rathore (1996) reported that increase in rate of fertilizers along with 5 t FYM ha\(^{-1}\) resulted in consistent and significant increase in the net profitability of rice- wheat sequence and maximum net returns were obtained with the application of 100 Kg N + 62.5 Kg P\(_2\)O\(_5\) 37.5 Kg K\(_2\)O ha\(^{-1}\) along with FYM @ 5t ha\(^{-1}\). Combined application of 50% NPK + 50% poultry manure or 50% NPK +50% FYM resulted in higher net returns and benefit: cost as compared to control or application of chemical fertilizers alone (Dubey and Verma, 1999). Another study carried out by Ram and Saha (1999) clearly established that under lowland rice conditions, the combined use of the organic manures like poultry manure, FYM or Sesbania green manure and chemical fertilizer (urea) in 50:50 ratio was found more remunerative in terms of gross returns, net returns and net returns per rupee invested for growing rice compared to use of chemical fertilizers alone (100% NPK). Similarly Singh and Singh, (2000) obtained higher net returns with the application of green manure + 100% N than only 100% N to rice- wheat cropping system. Kalpana et al. (2002) from Coimbatore (Tamilnadu) reported that green manuring with Sesbania reduced the inorganic N requirement by 50 Kg ha\(^{-1}\) and obtained net returns of Rs. 14,802 and benefit: cost ratio 2.63 with Sesbania rostrata in rice cropping.

Bajpai et al. (2002) studied the impact of integrated nutrient supply system in rice-wheat cropping system and found that gross returns, net returns and benefit: cost ratio were significantly higher when 50% nitrogen in rice was substituted through dhaincha green manure and following wheat was fertilized with 100% dose of recommended fertilizer compared with the application of 100% dose of recommended fertilizer to both rice and wheat crops. They, however, reported
that FYM + 50% NPK resulted in lower gross returns, net returns and benefit: cost ratio than 100% NPK application. Mandal et al. (2003) while studying the effect of FYM along with inorganic fertilizers on transplanted rice (cv. IET 4094) found that maximum benefit: cost ratio (1.82) was obtained with 75% NPK through inorganic fertilizers. Singh et al. (2004) reported that 100% recommended NPK through chemical fertilizers + 50% N through FYM (T2), and 75% recommended NPK through chemical fertilizers + 25% N through FYM (T3) in rice-wheat cropping system gave 39.1, 17.5 and 23.1% higher net returns over farmers practice, respectively. Singh (2006) from Agra (U.P.) also reported that green manuring of dhaincha applied with 100 per cent of recommended dose gave highest net returns and benefit: cost ratio.

2.3 Effect of Nitrogen Fertilizer

Modern crop production, where we talk of increasing production to feed ever-increasing population, requires adequate chemical fertilization to meet the requirements of the high yielding crop varieties. Nitrogen is one of the primary plant food required for growth and development of plants. The important role of this nutrient in crop production as reported by various workers have been discussed in following heads.

2.3.1 Growth and Development

Lee et al. (1987) from his experiment conducted at Japan with four cultivars and three nitrogen levels (50, 100 and 150 kg N ha\(^{-1}\)), observed that plant height, length of third internode and lodging intensity increased with increasing levels of nitrogen. Lee and Lee (1987) studied the effect of nitrogen on three rice cultivars in pots. They found that plant height and number of tillers increased with
increasing nitrogen levels. Increase in number of tillers and plant height was also observed, when 50-200 kg N ha\(^{-1}\) was applied to paddy as reported by Rao (1988). Nakazawa et al. (1988) found that increasing rate of nitrogen, increased the plant height and number of stems m\(^{-2}\) of rice crop when it was given 30, 40 and 50 per cent of the total amount of nitrogen at transplanting and rest as 2 or 3 top dressing. Lakshminarayanan et al. (1990) reported increased seedling establishment, water requirements and grain yields as N was increased from 100 to 150 kg ha\(^{-1}\). It was further found that increasing the amount of basal nitrogen fertilizer increased plant height and tiller number, but had no significant effect on grain yield, (Oh et al. 1990). Similar were the findings of Miah et al. (1997) who also reported increase in plant height and dry matter accumulation of rice crop with increase in nitrogen levels. Mendhe et al. (2002) reported that the nitrogen @ 125 kg ha\(^{-1}\) significantly increased plant height (130.09 cm), number of effective tillers per hill (9.29) as compared to application of nitrogen @ 75 and 100 kg/ha, Meena et al. (2003) observed significantly increased plant height (126.8 and 127.9 cm), total number of tillers (16.2 and 16.3), dry matter accumulation (15.6 and 16.3 t ha\(^{-1}\)) with increasing nitrogen application up to 200 kg ha\(^{-1}\). Similarly Sarkar et al. (2004) found that the plant height and leaf area duration increased with the increasing levels of nitrogen up to 80 kg N ha\(^{-1}\) in combination with green manuring crops. Similar increase in growth parameters up to 90 kg N ha\(^{-1}\) were observed by Banwari and Manju (2004).

2.3.2 Yield and yield attributes

Imaizumi and Kitamura (1989) found that application of 60 kg N ha\(^{-1}\) with 40 per cent as a basal dressing and the rest as a side dressing in Koshihikari, increase the grain yield but greater amount of nitrogen increased lodging and gave
poor ripening, with 30 per cent of applied N as a basal dressing, yield increased up to 80 kg ha$^{-1}$ and highest was recorded as 7.1 t ha$^{-1}$ with 80 kg ha$^{-1}$. Balasubramaniyan and Palaniappan (1989) at Coimbatore (Tamilnadu) found that increasing N rates from 0 to 150 kg ha$^{-1}$ increased grain yields from 3.8-4.6 to 5.4-7.0 t ha$^{-1}$. Yields were further increased with 200 kg N ha$^{-1}$ in 2 seasons only. Maeda (1990) reported that the number of culms increased but number of ears and number of grains per ear were decreased with increasing rates of deep placed fertilizer. Peng and Li (1991) found that tiller number, panicles per plant and filled spikelets per panicle were positively and significantly correlated with nitrogen levels. Singh et al. (1992) from IARI, New Delhi indicated that grain yield increased with increasing nitrogen application up to 120 kg N ha$^{-1}$ whereas, plant height, panicle weight and 1000 grain weight were not influenced by treatments.

A mean rice yield increase of 45.8 per cent was observed with 75 kg N ha$^{-1}$ compared with control plots. Split application of N at suboptimal levels was investigated, 40 kg N ha$^{-1}$ applied at active tillering and panicle initiation, resulted in the highest grain yields (Rao et al., 1996). Das and Saharay (1996) conducted a field trial to study the effects of 0-90 kg N ha$^{-1}$ on rice cultivar IET 4094. They found that the highest grain yield was obtained with 90 kg N ha$^{-1}$. Paliwal et al. (1997) reported that when variety IR-50 was given 0, 30, 60 and 90 kg N ha$^{-1}$, grain yield, panicle length, number of grains per panicle and grain weight per panicle were increased significantly up to 90 kg N ha$^{-1}$. The highest net return was also achieved at 60 kg N ha$^{-1}$.

Hari et al. (1997) found that the grain yield increased with increasing rates of nitrogen up to 150 kg ha$^{-1}$. A field experiment was conducted by Sharma (1999) to study the effect of nitrogen on Gayatri rice variety. The nitrogen rates were 0, 20
and 40 kg N ha\(^{-1}\). He found that the mean grain yield (3.61 t ha\(^{-1}\)) response was significant up to 40 kg N ha\(^{-1}\). Lakpale \textit{et al.} (1999) reported that application of 120 kg N ha\(^{-1}\) significantly increased grain yield of rice over 60 kg N ha\(^{-1}\). Effective tillers m\(^{-2}\) row length, spikelets per panicle, weight of panicle and 1000 grain weight increased significantly due to 120 kg N ha\(^{-1}\).

Reddy and Kumar (1999) on the other hand found that the grain yield of rice increased significantly up to 80 kg N ha\(^{-1}\). A field experiment was conducted by Rajarathinam and Balasubramaniyan (1999) to study the response of hybrid CORH 2 rice to nitrogen levels (150, 200 and 250 kg N ha\(^{-1}\)). They found that there was no appreciable change in the yield attributes due to application of higher doses of nitrogen above 150 kg N ha\(^{-1}\). The yield attributes viz., panicles m\(^{-2}\), panicle weight, panicle length and grains per panicle were similar to panicles m\(^{-2}\) obtained with 200 and 150 kg N ha\(^{-1}\). An appreciable production was noticed in important attributes like panicle m\(^{-2}\), filled grains per panicle at 250 kg N ha\(^{-1}\). Highest grain yield recorded in 200 kg N ha\(^{-1}\) which was at par with 150 kg N ha\(^{-1}\). Whereas further increase in nitrogen levels to 250 kg N ha\(^{-1}\) decreased rice yields significantly.

Number of panicles and 1000-grain weight increased with increase in nitrogen levels up to 150 kg N ha\(^{-1}\), yield components such as number of grains per panicle responded quadratically to nitrogen (Garcia and Azevedo, 2000) The nitrogen at 125 kg ha\(^{-1}\) significantly increased number of grains per panicle (130.09), and grain (30.74 q) and straw (45.19 q) yields ha\(^{-1}\), compared to 75 and 100 kg N ha\(^{-1}\). Further increase up to 150 kg N ha\(^{-1}\) significantly increased the yield (Mendhe \textit{et al.}, 2002). Sapatnekar \textit{et al.} (2002) reported that the N application (0, 50, 75, 100, and 125% as urea) increased grain (from 5.7 to 52.8%)
and straw (from 20.1 to 100.3%) yields over the control. Maiti et al. (2003) from West Bengal reported that the application of 140 kg nitrogen ha$^{-1}$ resulted in the highest grain yield (by 76.2%), number of panicles (109 %), number of filled grains per panicle (26.2%) and 1000 grain weight (5.80%) over the control treatments. Similarly Raghuwanshi et al. (2003) and Manjapa (2004) also reported that grain yield, straw yield of rice increased significantly with increased levels of nitrogen. Pandey et al. (2004) in north Bihar recorded significantly higher values of yield attributing characters, grain and straw yield up to 150 kg N ha$^{-1}$.

2.3.3 Soil physical and chemical properties

The chemical fertilizers are applied to meet the nutritional requirement of the crops, however, these materials are known to influence the physical and chemical properties of the soil. A favourable physical effect of combined application of nitrogenous and phosphatic fertilizers in building up organic matter and nitrogen pool in soil was observed by Singh et al. (1980). Ganai (1983) from Palampur (H.P.) reported that various levels of fertilization in wheat crop did not show any considerable effect on physical properties of soil after harvest of rice and wheat crops in rice-wheat system but organic carbon and available N, P and K determined at the end of the experiment were increased significantly with increase in fertilizer levels from 50 to 150 per cent of recommended NPK. Brar et al. (1996) reported an increase in organic carbon, available P and K in soil with increase in fertilizer level. However, improvement in available N status was meager. Increase in organic carbon and available water holding capacity with increase in NPK levels was also reported by Sarkar (1998). Kumar et al. (2000) at PAU, Ludhiana also observed an increase in organic carbon and available N, P and K contents of soil
with increase in fertilizer levels over control in a long term fertilizer experiment on rice-wheat cropping system.

Grewal and Kanwar (1967) reported that ammonical fertilizer increased yield and N uptake of paddy and had a residual effect on the following wheat crop, but not the third (paddy) crop grown on a sandy loam. Broadbent and Reyes, (1971) reported that nitrogen fertilizers had no residual effect on the succeeding crop of wheat. It is well established that percolation losses are very high in rice fields. Higher percolation rates did not improve soil productivity but increased leaching losses of water and plant nutrients (Sharma and De Data 1985). Whereas, Singh and Singh (1986) observed that even modified urea materials on rainfed low land transplanted rice showed no significant residual effect on grain yields of the subsequent wheat crop. Similarly Singh et al. (1995) at PAU Ludhiana found that urea applied to paddy crop had no residual effects. In paddy fields 68.6% of nitrogen was lost by rainfall-runoff approximately, 11% of nitrogen was lost by denitrification and about 20.5% by ammonia volatilization (Cho et al., 2000).

### 2.3.4 Economic aspects

Use of fertilizers in agriculture has substantially increased the food grain production and profitability of the farmers. Sanbagavalli and Kandasamy (2000) revealed that maximum net returns (Rs. 24937 ha\(^{-1}\)) were given by application of highest experimental nitrogen rate of 180 Kg N ha\(^{-1}\). Garcia et al. (2000) in Brazil carried out economic analysis of the cost and returns of the urea application. The greatest returns in relation to costs were obtained with 150 Kg N ha\(^{-1}\). Patra et al. (2000) reported that net monetary returns and benefit: cost ratio of rice-wheat system was highest (Rs. 13,962 ha\(^{-1}\) and 1.64, respectively) with increase in N P K
fertilization up to 100% of recommended dose to each crop. Similarly, Yadav (2001) also reported higher net returns from rice-wheat cropping system with increasing levels of chemical fertilizers. Increase in net returns due to increasing nitrogen levels up to 60 Kg ha\(^{-1}\) have also been reported by Pal \textit{et al.} (2001), Prakash \textit{et al.} (2002) and Katiyar and Uttam (2003). Whereas, Raghuwanshi \textit{et al.} (2003) obtained highest gross monetary returns, net monetary and benefit: cost ratio with 80 kg N ha\(^{-1}\). Maiti \textit{et al.} (2003) obtained highest net profit (Rs. 26,973.64 ha\(^{-1}\)) and cost benefit ratio (3.12) when hybrid rice (Pro-Agro 6111 N) was treated with 140 kg N ha\(^{-1}\). Increase in net returns with increasing nitrogen levels have also been reported by Manjappa, 2004.

Kumar (2001) at Palampur (H.P.) observed an increase in net returns and benefit: cost in rice with increasing levels of nitrogen from 0-90 kg N ha\(^{-1}\). However, further increase in nitrogen level decreased the benefit: cost ration from the crop. Similarly Pandey \textit{et al.} (2004) reported significantly higher values of net returns at 150 Kg N ha\(^{-1}\) than the lower levels of fertilizers. But net returns per rupee of investment and protein content in grain increased significantly only up to 120 Kg N ha\(^{-1}\). Due to increase in cost of fertilizers and stagnation in crop yields, it has become inevitable to go in for integrated use of plant nutrients through organic and chemical fertilizers.

Thus, the above- cited literature indicates that increase in chemical fertilizers increased the gross and net returns from the rice and wheat crops. Though in some studies, higher rate of fertilization resulted in a decrease in benefit: cost ratio of these crops due to higher cost of cultivation. The complementary use of organics and chemical fertilizers is the key to cut down
chemical fertilizer requirement of these crops without impairing the crop yields and resulting in higher profitability.