Discussion

The integration of aquaculture with livestock and crop farming offers great efficiency in resource utilization, reduces risk by diversifying crop, and provides additional food and income. This system involves recycling of wastes or by-products of one farming system as an input for another system and efficient utilisation of available farming space for maximum production. The livestock waste was used as source of nutrients in aquaculture which enters food-web in several ways namely, as food, as a source of mineral required for autotrophic production, and as organic substrates and minerals for heterotrophic microorganisms which are generally consumed directly by fish or by zooplankton. The bottom dwelling fishes, namely, common carp and mrigal directly utilises bacteria-coated organic particles in manure. In this era of technology, researchers from different corners of the world realize that intensive agriculture with indiscriminate use of agricultural inputs in the irrigated areas and cultivation of highly fragile lands in the rain fed areas have caused serious problems to sustainability of the agriculture. Judicious utilisation of natural resources, proper recycling of agricultural waste and reduction of production costs through different farming systems became the most important towards the sustainability in agriculture and environment. Hence, Integrated Farming System (IFS) can be considered as an important tool to increase farm productivity and sustainability of marginal farmers who have scarce resource in respect to land, finance and knowledge.

Suitable bottom soil condition and high quality water are essential ingredients for successful IFS. Higher amount of nutrients and organic matter as a result of excessive organic manuring and feed wastage often lead to poor water quality and bottom soil conditions. Therefore, the soil and water quality problems are common in aquaculture ponds under IFS.

Livestocks are an integrated and important part of most marginal farmers. About 84% of total draught power used in agriculture throughout the world is still provided by animals (Smith, 1979) and traditionally, animal wastes are used for fertilizer and fuel. With the increase in the demand of protein, the integrated aquaculture has been considered to be relevant and befitting to the rural poor. The use of large amount of wastes by aquaculture is often found to be more reliable, acceptable and profitable than the alternatives of removal and use in terrestrial cropping, or disposal by dumping.

The carp culture mainly involves two groups, such as, the three Indian Major Carps as Catla (*Catla catla*), Rohu (*Labeo rohita*) and Mrigal (*Cirrhinus mrigala*), and three domesticated exotic carps such as Silver Carp (*Hypophthalmichthys molitrix*), Grass Carp (*Ctenopharyngodon idella*) and Common Carp (*Cyprinus carpio*) . Carp culture in India was restricted only to a homestead backyard pond activity in Eastern Indian states of West Bengal and Orissa until late 1950s, with seed procured from riverine sources as the only input, resulting in very low levels of production. Though importance of fish culture as an economically promising enterprise was gradually realized, non-availability of quality fish seed and lack of scientific culture know-how constrained development of carp farming (ICAR, 2006).

In India, pond dykes are usually not used, but in China these are being used for multipurpose production. The top, inner and outer dykes of ponds as well as adjoining areas can be best utilised for horticulture crops. The success of the system depends on the selection of plants. Pond water is used for irrigation and silt, which is high-quality manure and contains several nutritive elements, as base manure for crops, vegetables and fruit bearing plants.

The results from the IFS vary as per the agro-climatic condition of the location where it is practised. Hence, proper assessment and refinement of this technology through different adaptive research can help in developing the location specific IFS packages, which can increase the overall farm productivity.

A typical marginal farmer of the Terai region of West Bengal, generally possesses a unit of small pond, a small unit of livestock such as cow and buffalo, duck and poultry, pig, sheep and goat along with less then 1-2 ha of land for crop production. Keeping in view the limited resources of the marginal farmers of the Terai region of West Bengal, three experiments were executed namely, Experiment-I, II and III. Out of these, as observed in Table-2, Experiment-I was considered to be Control (C), where Non Integrated Farming System (NIFS) was considered. Experiment-II and III were the different Integrated Farming Systems (IFS) followed in the farmer's field. The observations regarding the pond water quality, pond bottom soil quality, zooplankton production, fish growth and production and the economics of the different farming systems are discussed below.

5.1 Physico-Chemical Parameters of Pond Water and Pond Soil

5.1.1 Pond Water

In Integrated Fish Farming System, water is an important natural resource which should be utilised judiciously in order to conserve the same for future. It has been reported that conventional aquaculture consumes 5m^3 of water to produce 1 kg of fish (Avnimelech *et al.*, 2008). Water quality attributes like water temperature, light penetration, dissolved oxygen, total alkalinity and total hardness are the representatives of the seasonal fluctuation (Tepe *et al.*, 2005). The limiting factor in waste fed pond is the unstable quality of the water itself. Certain types of wastes are more likely to adversely overload or underload the pond system, causing a reduction in the fish yield. Boyd (1982) emphasised, that the goal of water quality management is to regulate environmental conditions so that they are within desirable range for survival and growth of fish. The waste-fed eutrophic pond was found to be more productive than a natural pond, but at the same time was less stable. This instability can be reduced by judicious management. It was evident that a balanced variety of fish species reduced the volatile and undesirable changes in water utilizing the different pond food organisms which typically triggered large changes in water quality (Little and Muir, 1987). As a result of deterioration in water quality, the fish become "stressed" and vulnerable to diseases. Therefore, it is very important to know about water quality parameters and their influence on growth and survival of fishes.

The water quality parameters like water temperature, pH, dissolved oxygen, total alkalinity and total hardness remain within the suitable range under the influence of organic manure (Rahman *et al.*, 2004). But the higher doses of manure more than 100kg DM (Dry Manure) ha $^{-1}$d $^{-1}$ deteriorate the water quality like water colour, total suspended solids that inhibit the light penetration and planktonic biomass productivity (Shevgoor *et al.*, 1994). However, Parvez *et al.*, (2006) reported non-significant difference among the physico-chemical parameters of pond water manured with organic waste and with and without inorganic fertilizers (Sayeed *et al.*, 2007).

In the present study, significant variation was observed regarding the different water quality parameters of the pond water in Experiment-I, II and III. It has been observed, that within Experiment-I (NIFS), Experiment-II(IFS-I) and Experiment-III(IFS-I), the values of all water quality parameters of pond waters were significantly different ($p \leq 0.05$) indicating that ponds manured with cowdung in IFS-I and additional duck grazing with cowdung manuring in IFS-II significantly changed all the studied water quality properties of the pond water.

5.1.1.1 Temperature

It is known, that water temperature sets the pace of fish metabolism by controlling molecular dynamics (diffusibility, solubility, fluidity) and biochemical reaction rates. It was reported, that the optimum temperature range for several coldwater and warm water fishes were 14° to18°C and 24° to 30°C, respectively. The optimum temperature required for growth of carp was reported to be 27-32°C (ICAR, 2006). In this study, the temperatures were found to be within the range from 23.7° C to 32.2°C in NIFS (Control), 24° C to32.6°C in Experiment-II and 25.0° to 32.0°C in Experiment-III, maintaining more or less the favourable condition for fish growth (Jana *et al.*, 2012).

In Experiment-I (NIFS) the average temperature was found to be significantly lower than Experiment-II (IFS-I) and Experiment-III (IFS-I) indicating that ponds under IFS-I and IFS-II had significantly higher mean water temperature. The process of decomposition, accumulation of different metabolites and increased biomass may be indicative for such increasing trend of temperature (Boyd, 1990 and 1995). The increased rate of biochemical activity of micro biota during increased temperature was found to be very significant (Rath, 2011). Sheri *et al.*, (1987) in his studies reported that the best growth of Major Carps can be achieved at water temperature ranging from 26°C to 29°C. Oyugi *et al.*, (2012) also revealed maximum growth in common carp when the temperature was between 24°C to 28°C. It was also reported by Rath (2000) that Grass Carp can withstand temperature up to 40°C and IMC can thrive well in the temperature range of 18.3°C to 37.8°C.

As the experiment progressed, the temperature of the pond varied with climate charge under NIFS, IFS-I and IFS-II and an increasing trend was observed in summer followed by pre-monsoon and monsoon. This result might be due to the influence of the environmental temperature as in summer and rainy seasons. Ahmad and Garnett (2011) also observed that water temperature follow the air temperature. Similar findings of Lashari *et al.*, (2009) and Tidame and Shinde (2012) supported the present study that water temperature in the monsoon season was higher than the summer season due to the climatic changes.

5.1.1.2 pH of the pond water

pH is a measure of hydrogen ion concentration in water and indicates level of is acidity. Lopes *et al.*, (2001) realised water pH as an important factor to ensure good fish production. Water pH affects metabolism and physiological processes of fish. It also exerts considerable influence on toxicity of ammonia as well as solubility of nutrients and thereby water fertility (ICAR, 2006). According to Wurts and Durborow (1992), the recommended pH range for aquaculture farming is 6.5 to 9.0. Again, Heydarnejad (2012) found that the best range of pH for carp production was 7.5 to 8.0.

In the present study, the pH of the pond water in Experiment I, II and III were found to in the range of 5.8 to 8.2 maintaining favourable environment for fish production. This corroborates with the report given by ICAR, (2006) on the optimum pH for carp growth as 7.5 to 8.3. The pond water pH was found to be significantly lower in the present study when the manure was applied to the ponds under IFS-I and IFS-II than the Control. This result was supported by similar findings of Jha *et al.*, (2008) that utilisation manure lowered the pH of the pond water.

Seasonal variation of the pH observed in this study (Fig- 8) was found to be decreased in the monsoon season than in the summer. A similar result was observed by Shiddamallayya and Pratima (2008).

5.1.1.3 Dissolved Oxygen

Variation in water quality, especially in dissolved oxygen concentration, may be harmful to fish growth, or even cause acute mortalities. In this study Experiment-I had significantly higher dissolved oxygen concentration (Table-4) followed by Experiment-III and Experiment-II reflecting, that manuring decreases the dissolved oxygen in IFS-I whereas duck grazing in the ponds under IFI-II increases the same (Little and Muir, 1987). Dissolved oxygen is removed from the water through decomposition of organic matter that enters into the pond through cowdung (Jana and Sarkar, 2005). Grazing ducks in IFS-II had aerated the pond water and helped in maintaining more favourable condition in the pre-monsoon and monsoon season.

In Experiment-I (NIFS), the dissolved oxygen concentration ranged from 5.2 to 7.2 mgl^{-1}, whereas, in Experiment-II (IFS-I), where cow dung was used to fertilise the ponds the dissolved oxygen concentration was lowered and ranged from 4.7 to 6.9 mgl^{-1}. In Experiment-III (IFS-II), the higher range of dissolved oxygen concentration was found (5.2 to 7.1 mgl^{-1}) as the duck was allowed to graze and swim in the pond along with the cow dung fertilisation. The optimum dissolved oxygen concentration in fish pond was reported to be more than 4 mgl^{-1} by ICAR (2006). Rath (2011) also expressed that decrease in dissolved oxygen is directly related to increase in temperature.

It was also revealed from Table-5 that manuring decreased the dissolved oxygen concentration thereby maintaining the optimum level for fish farming in IFS-I and IFS-II. High doses of cow dung and poultry manuring were found to reduce the value of dissolved oxygen (DO), while optimum dose that is, 0.26 kg m^{-3} maintained the better water quality and abundance of planktonic biomass, which improved the growth of carps species (Jha *et al.*, 2004).

It was also known that low dissolved oxygen concentration enhanced the toxic effect of ammonium-N in fish pond. Hence, duck rearing on the ponds under IFS-II helped to reduce the toxicity of increased ammonium-N by increasing the dissolved oxygen concentration. Sharma *et al.,* (2005) obtained similar result in his study on duck-cum-fish in IFS where the value of dissolved oxygen increased and ranged from 8.2 to 9.20 mgl^{-1} .

A decreasing trend of dissolved oxygen was observed from the month of April (summer season) to September (monsoon season) in the experimental ponds of IFS-I and NIFS as presented in Fig-9. However, the ponds under IFS-II showed decreasing trend in the summer season but; by introduction of ducks to swim in the ponds, the dissolved oxygen concentration was found to be increased and was maintained stable till the month of September (Fig-10). In the monsoon it was found that IFS-II had dissolved oxygen more than the Control and IFS-I. This result might be due to the fact that grazing ducks had aerated the pond water and helped in maintaining more favourable condition in the month of July, August and September (pre-monsoon and monsoon season). Mustapha (2008) in his study also found dissolved oxygen to be the maximum in wet season than in dry season.

5.1.1.4 Free Carbon dioxide

Significantly higher values of Free carbon dioxide concentration in the treated ponds were observed in Experiment-III (IFS-I) followed by Experiment-II (IFS-II) and Experiment-I (NIFS) and ranged between 0.5 to 4.5mgl^{-1}, respectively (Table-5). Decomposition of the organic manure and respiration of the aquatic organisms in the IFS-I and IFS-II may be the cause of this increased value of average free carbon dioxide (2.87mgl^{-1} and 3.14mgl^{-1}, respectively) than the Control (1.80 mgl^{-1}). Wurts and Durborow (1992) similarly reported, that carbon dioxide concentrations can become high as a result of respiration. In the present study, the value of free carbon dioxide concentration was below 8 mgl^{-1}. As mentioned by ICAR (2006), that fresh water fish ponds should contain low concentration of free carbon dioxide, that is, less than 8 mgl^{-1}.

Carbon dioxide rarely causes direct toxicity to fish. However, a high concentration of carbon dioxide lowers the pond pH and affects the fish production. There was a negative correlation ($r = -0.796$; $p \leq 0.01$) observed between free carbon dioxide and pH in this study. Aeration and pH of water by hydrated lime (calcium hydroxide) can control high free carbon dioxide concentration.

In the pre-monsoon and monsoon season higher level of free carbon dioxide concentration was observed than the summer season. It may be perceived that the increased temperature in the month of July, August and September enhanced the decomposition of the waste in pond and the respiration of the growing aquatic organisms including fishes resulted in the increased value of free carbon dioxide. In this present study, positive correlation ($r=0.652$; $p \leq 0.01$) was found between the water temperature and free carbon dioxide concentration. On the contrary, the lowest amount of free carbon-dioxide was recorded by Narayan *et al.*, (2007) in monsoon and the highest in summer suggesting that the decomposition of organic matter was fast during summer whereas it was low during monsoon.

5.1.1.5 Total alkalinity

Murad and Boyd (1991) stated that ponds should have at least 20 mgl^{-1} of total alkalinity for good fish production. Pond water with a low alkalinity (less than 20 mgl^{-1}) has a very low buffering capacity and consequently is much vulnerable to fluctuations in pH, especially during rainfall when phytoplankton blooms. In the present study, the mean total alkalinity was found to be more than 20 mgl^{-1} in the three treatments throughout the experiment. However, Experiment-III ($73.29 \pm 0.72 mgl^{-1}$) had significantly higher total alkalinity than Experiment-II (68.54 ± 0.77 mgl^{-1}) and Experiment-I (30.64 ± 0.59 mgl^{-1}). The ideal range of total alkalinity of water for freshwater fish pond is reported to be 60-300 mgl^{-1} (ICAR, 2006). Hence, it is observed that use of organic inputs increased the total alkalinity at higher levels and even resulted in increase in alkalinity compared to use of inorganic inputs (Knud Hansen *et al.*, 1991; Teichert-Coddington *et al.*, 1992; Diana *et al.*, 1994a).

It was observed that alkalinity potentially limited primary production and fish yield, since inorganic carbon was necessary for photosynthesis (Diana *et al.*, 1997). Boyd (1990) showed that alkalinity below 30mgl^{-1}, as $CaCO_3$, limited primary production in well-fertilized ponds, while in unfertilized ponds alkalinities below 120mgl^{-1} could reduce primary production. Diana *et al.*, (1997) also mentioned that use of organic inputs probably reverses the trend of carbon extraction during photosynthesis because of added CO_2 inputs and decomposition of manure in pond soils.

In the pre-monsoon and monsoon season the trend of alkalinity was found to be increased (Fig-12), which may be due to the increased rate of decomposition of organic matter in water body. This result was supported by the findings of

Shiddamallayya and Pratima (2008) and Tidame and Shinde (2012) that the decomposition of organic matter increased the value of alkalinity in water.

5.1.1.6 Total Hardness

The ponds under IFS-II showed significantly higher total hardness (82.47±0.58 mgl^{-1}) in this study followed by IFS-I (77.70±0.66 mgl^{-1}) and the NIFS (51.47±0.69 mgl^{-1}). This result revealed that organic loads like cowdung and duck droppings increased the pond water hardness in the IFS-II and IFS-I. Similar result was achieved by Jha *et al.*, (2008). Rajagopal *et al.*, (2010) in their study mentioned that the increase in total hardness can be attributed to the decrease in water volume and increase in the rate of evaporation at high temperature, high loading organic substances, detergents, chlorides and other pollutants.

NIFS showed slightly increasing trend of mean Total hardness in the pond water (Fig-13) after the summer season. On the other hand, in IFS-I and IFS-II increasing trend was followed from the month of April onwards when temperature were high ($r= 0.389$; $p\leq0.01$). Kaur and Sharma (2001) and Tidame and Shinde (2012) also reported highest total hardness in summer and lowest in winter.

5.1.1.7 Chloride

Ponds under Experiment-III were found to have significantly higher Chloride content (29.18±0.67 mgl^{-1}) than that under Experiment-II (24.17±0.70 mgl^{-1}) and Experiment-I (17.14±0.54 mgl^{-1}); indicating that the animal excreta used in this study increased the chloride level of the pond water. It is known, that the most important source of chloride in the water is considered to be from the discharge of the domestic sewage and animal excreta. Man and other animals excrete very high quantities of chlorides together with nitrogenous compounds (Trivedy and Goel, 1984). Therefore, in this study chloride content can be considered as an indicator of pollution occurring due to the animal excreta being utilised in the pond water. However, its concentration up to 1500 mgl^{-1} is harmless (Trivedy and Goel, 1984). In this study, Experiment- III had higher chloride content indicating that the excreta of cow and ducks together increased the chloride content of the pond water. However, the range of chloride concentration remained within optimum level 5 to 40 mgl^{-1} in all the experiment and 5 to -28 mgl^{-1} for NIFS, 10 to 40 mgl^{-1} for IFS-I and 18 to 40 mgl^{-1} for IFS-II throughout the study period.

A steady increased trend of chloride concentration was observed from the month of April to September in IFS-II and IFS-I than the Control (NIFS) suggesting increased level of chloride concentration in monsoon season. Shiddamallayya and Pratima(2008); Venkatesharaju *et al.*, (2010) and Tidame and Shinde (2012) also observed highest concentrations of chloride in monsoon.

5.1.1.8 Ammonium-N

The means of Ammonium-N concentration was observed to be significantly ($p \leq 0.05$) different in the three experiments conducted. The Mean±S.E of the ammonium-N concentration in the treated ponds under IFS-II (0.36±0.002 mgl^{-1}) was found to be significantly higher followed by IFS-I (0.29±0.018 mgl^{-1}) and then NIFS (0.16±0.013 mgl^{-1}). Biswas, *et al.* (2006) expressed three different concentration levels of ammonium (a) favourable concentration range : 0.262 to 0.294 mgl^{-1}, (b) growth-inhibiting concentration range : 0.313 to 0.322 mgl^{-1} and (c) lethal concentration range : 0.323 to 0.422 mgl^{-1}. All the average values of ammonium-N concentration in the ponds under IFS-I and NIFS remained lower than the value of threshold concentration ammonium-N (0.313 mgl^{-1}) but in IFS-II the value was found to be slightly above the threshold concentration. This might be due to the utilization of both cow and duck waste in the ponds under IFS-II. Lloyd and Herbert (1960) showed that the toxicity of ammonia decreases with increasing carbon dioxide concentration. In the present study, the average value of free carbon dioxide (mg l^{-1}) in IFS-II was also higher which might have managed the toxicity of ammonia and created desirable environment for aquatic production. High dissolved oxygen, high carbon dioxide and high phytoplankton concentrations reduce the toxicity of the ammonia (ICAR, 2006). In the present study, it was observed that duck swimming in the ponds treated with IFS-II increased the concentration of the dissolved oxygen and the free carbon dioxide and as a result the toxicity of the ammonia might have reduced to maintain favourable condition for fish growth.

A sharp increasing trend of ammonium-N concentration was observed from the month of April to September in all the three experiment (Fig-15) indicating that in the pre- monsoon and monsoon ammonium-N concentration increased considerable than summer season. This may be due to low photosynthesis and high organic waste decomposition during the period of experiment.

5.1.1.9 Nitrite-N

Nitrite-N represents the intermediate form of nitrification and denitrification reactions in nitrogen cycle. Under normal conditions, well-oxygenated ponds have negligible concentration of nitrite. Nitrite-N is a very unstable ion and gets converted into either ammonia or nitrate depending on the prevailing situation in the water (Trivedy and Goel, 1984). Boyd (1982) observed, that regardless the source; ponds occasionally contain nitrite-N of 0.5 to 5.0 mgl^{-1}. Again, concentrations of nitrite-N as low as 0.5 mgl^{-1} were found to be toxic to certain cold water fish (Crawford and Allen, 1977). In the present study, average nitrite-N content was observed to be significantly higher ($p \leq 0.05$) in Experiment-III (0.036 mgl^{-1}) followed by

Experiment-II (0.024 mgl^{-1}) and Experiment-I (0.02 mgl^{-1}). The concentration of the nitrite-N was found to be higher in the IFS-I and IFS-II experimented ponds but, maintaining the favourable condition for fish growth. Effective removal of organic wastes, adequate aeration and correct application of fertilizers are the methods to prevent accumulation of nitrite to a toxic level in pond culture (ICAR, 2006). Hence, periodical pond manuring with cow dung and ducks swimming on the ponds maintained the nitrite-N below the toxic level in the integrated farming system.

5.1.1.10 Nitrate-N

Nitrate represents the highest oxidised form of nitrogen. The most important source of the nitrate is the biological oxidation of the organic nitrogenous substances which comes from the livestock waste in this study. High amount of nitrate denotes the aerobic conditions and high stability of the waste (Trivedy and Goel, 1984). In the present study, nitrate-N concentration ranges from 0.01 to 0.79 mgl^{-1} with an average value of 0.459 mgl^{-1} in IFS-II, 0.368 mgl^{-1} in IFS-I and 0.22 mgl^{-1}NIFS. It was observed in this study that utilisation of manure significantly increased the nitrate-N concentration of the pond water in IFS-I and IFS-II.

As the experiment proceeded, sharp increasing trend of nitrate-N concentration was observed from summer to rainy season. The increased oxidation of the nitrogenous compounds of animal waste associated with the increased temperature from April to September may be the indication of present result (Fig-17).

5.1.1.11 Phosphate-P

Phosphorus is commonly considered the major limiting nutrient in freshwater, and additions of phosphorus often result in increased primary production, whether in natural (Vallentyne, 1974) or in aquaculture systems (Boyd, 1990; Diana *et al.*, 1991).

Phosphorus is mainly available to plants as orthophosphate (Diana *et al.*, 1997) and its concentration increases almost immediately after ponds are fertilized (Boyd,1982).The orthophosphate present in water immediately after fertilization may be absorbed by bacteria, phytoplankton and macrophytes (Rigler,1956 and 1964; Hayes and Phillips, 1958). However, phosphorus that is not absorbed by plants is rapidly absorbed by mud (Hepher, 1958). Combined inputs of both nitrogen and phosphorus are necessary to drive high levels of primary production (Diana *et al.*, 1997). In this study, Experiment-III had significantly the highest ($p \leq 0.5$) Phosphate- P concentration (0.59 ± 0.02 mgl^{-1}), indicating that duck grazing might have affected the Phosphate-P concentration in pond water. Kang'ombe *et al.*, (2006) also observed that poultry manure mainly donates nitrogen and phosphates to pond water, which boosts the pond productivity (natural food of fish) and in turn enhances the weight increment in fish. In IFS-II of this study, it showed a stable value of phosphate-P concentration in the month of July, August and September in comparison to IFS-I indicating that duck manuring maintained the phosphate-P level (Fig-17).

5.1.2 Pond Bottom Soil

The productivity of a fish pond depends on the physical, chemical and biological properties of the pond soil. Pond bottom acts as the laboratory, where process of mineralization of organic matter takes place and nutrients are released to overlying water column. Physical properties of soil, like texture and water retention ability, and chemical properties like pH, organic carbon, available nitrogen and available phosphorus are important parameters, which require considerable attention for effective pond management (Boyd, 2008).

5.1.2.1 Soil pH

Slightly acidic to neutral soil, with pH 6.5 to7.0 is considered productive. However, the ideal range for soil pH is 6-8 as reported by ICAR (2006) and 7.5 to 8.5 according to Boyd (2008). In the present study, the average pH value 7.48, 7.60 and 7.47 of the bottom soil was observed to be non-significant ($p \geq 0.05$) amongst the Experiments-I, II and III, respectively maintaining favourable condition for fish production. Silapajarn *et al.*, (2004), in their study, explored that soil pH averaged 7.15, but the minimum value was 5.05 and the maximum was 8.10. However, in the present study, the minimum and maximum value of soil pH was found to be 5.5 to 9.3, 6.2 to 9.4 and 5.7 to 9.6 in Experiment-I, II and III, respectively which corroborates with the findings of Boyd *et al.,* (2002) that pond bottom soil pH can range from less than 4 to more than 9.

Banerjea (1967) mentioned that best pH value for pond soils to be 6.5 to 7.5 and pH value of 5.5 to 8.5 was considered to be acceptable. But, Boyd (1995) argued, that aquaculture pond soil should not have pH below 7.0 and the average value of soil pH in all the treated ponds was observed to be above 7.0. According to Boyd *et al.*, (2002) maximum availability of soil phosphorus usually occurs at about pH 7.0 and most soil microorganisms, and especially soil bacteria, function best at pH 7.0 to 8.0. In this study, the average pH value was within 7.0 to 8.0 in all the three experiments maintaining favourable condition for fish production.

5.1.2.2 Pond Soil Organic-C

The average values of Organic-C, 0.97%, 0.95% and 0.83% were found to be significantly higher ($p \leq 0.05$) in manure fed ponds under Experiment-II followed by III and Experiment-I, respectively. In the present study, Organic- C was found to be in the range from 0.66 to1.11% in Experiment-I (Control), 0.86 to 1.30% in Experiment-II, where cow manuring was done and 0.75 to 1.33% in Experiment-III where the ponds were treated with cow manuring along with the duck manuring indicating that the organic –C range were maintained for the achievement of average or medium fish production.

Banerjea (1967) evaluated the potential of a large number of ponds in India for fish production and found that organic carbon concentrations in soils of less than 0.5 % and greater than 2.5 % resulted in low fish production. Low organic carbon was associated with low productivity of phytoplankton and bottom organisms; whereas high organic carbon caused anaerobic conditions in the pond bottom soils. According to Banerjea (1967), average fish production was achieved in ponds with 0.5 % to 1.5 % organic carbon, and 1.5 % to 2.5 % organic carbon was associated with high fish production. Adhikary (2003) also mentioned in his study that organic carbon acts as a source of energy for bacteria and other microbes that release nutrients through various biochemical processes. Pond soils with less than 0.5% organic carbon was considered unproductive while those in the range of 0.5-1.5% and 1.5-2.5% to have medium and high productivity, respectively (Rath, 2011). Organic carbon content of more than 2.5% may not be suitable for fish production, since it may lead to an excessive bloom of microbes and oxygen depletion in the water.

Boyd *et al.*, (2002) gave a general recommendation that organic carbon concentration in pond bottom soils should be between 1 and 3 percent, but in ponds where fish are fed, organic matter concentrations below 1 percent are acceptable. In the present study, the ponds were treated with organic waste along with fish feed and had average organic-C less than 1% in all the three experiments which was acceptable in aquaculture.

The organic-C content of all the treated pond bottom soil in the present study increased slightly from the month of April to September during the experiment. Boyd (2002) agreed with the fact that organic matter concentrations in pond soils do not continue to increase indefinitely. If aquaculture practices remained about the same, the annual input of organic matter and the rate of organic matter decomposition also remain about the same (Avnimelech *et al.*, 1984 and Boyd, 1995).

New ponds usually have little organic matter in bottom soil, and the labile organic matter added each year will largely decompose, while a considerable proportion of refractory organic matter will accumulate (Boyd, 1995). Every year removal of the desilted pond bottom soil for crop production on the pond dykes might have maintained the favourable organic-C content for fish growth in the present study.

5.1.2.3 Total Pond Soil Nitrogen

It was observed that the total nitrogen percentage ranged from 0.068% to 0.088%, 0.011%-0.130% and 0.081% to 0.133% in Experiment-I (Control), Experiment-II (IFS-I) and Experiment-III (IFS-II), respectively. Again, the average value of total percentage of nitrogen present in the bottom soil of the manure treated pond under Experiment-II and Experiment-III was significantly ($p \leq 0.05$) higher (0.095% and 0.0985%) than Experiment-I (0.078%).

Silapajarn *et al.*, (2004) found in their study that the average concentration of total nitrogen was 0.08 % and were in the range between 0.01 to 0.50 %. They realised that low concentrations of total nitrogen are normal in soils with low organic matter concentrations, because nitrogen is present in pond soil primarily as a component of organic matter.

Banerjea (1967) suggested that 0.05-0.075% of total nitrogen of soil may be taken as relatively more favourable for aquaculture. But, in the present study average value of the total nitrogen was found to be above 0.075% and maintained favourable condition of for aquaculture.

5.1.2.4 Carbon to Nitrogen Ratio (C: N Ratio)

The carbon to nitrogen (C: N) ratio of soil influences the activity of soil microbes to a great extent. This in turn affects the rate of release of nutrients from decomposing organic matter. The rate of breakdown (mineralization) is very fast, moderately fast and slow at C: N in the range of less than 10, 10-20 and more than 20 respectively (Adhikary, 2003). In the present study, the average value of C: N ratio was found to be nonsignificantly higher in IFS-I (11.09±1.13), NIFS (10.61±0.14) and IFS-II (9.68±0.10).

Adhikary (2003) reported that in general, soil C: N ratios between 10-15 were considered favourable for aquaculture and a ratio of 20:1 or narrower gives good results. Banerjea (1967) also reported that fish production was lower in ponds with carbon: nitrogen ratios below 10 than in those with ratios above 10. He also mentioned that the range of C: N ratio between 10-15 was best for fish production. In the present study, the average C: N ratio was found to be approximately around 10-11 in all the treated pond bottom soil which was favourable for aquaculture.

In a study conducted by Silapajarn *et al.*, (2004) it was reflected that Carbon: Nitrogen ratios ranged from 5.4 to 75 with an average of 18.4. Boyd *et al.*, (2002) mentioned, that pond soils with low Carbon: Nitrogen ratios tend to have highly decomposable organic matter, and anaerobic conditions at the soil-water interface may be a common problem.

5.2 Productions of Zooplankton

In the present study, qualitative and quantitative analysis of the zooplankton of the Experimental ponds were done because it was reported by Rahman *et al.*, (2006) that the IMC and Grass Carp prefer to feed on zooplanktons. Similarly, Ekelemu (2010) emphasised, that zooplankton is very important in the food web of open water ecosystem. In the present study, ponds under IFS-II and IFS-I were found to contain significantly higher concentration of zooplanktons (131±12 no l^{-1} and 128±11 no l^{-1}, respectively) than NIFS (27 ± 2 no l^{-1}). However, no significant difference was observed regarding the mean value of zooplankton count found in IFS-II and IFS-I. This result indicated that the organic manuring of the ponds had positive effect on zooplankton production. The present finding is, therefore, in agreement with the findings of Wohlfarth and Schroeder (1979); Delmendo (1980); and Little and Muir (1987) that, manuring enhances the zooplankton production.

Jha *et al.*, (2004) found that application of both cow dung and poultry manure, at the rate of 0.26kg $m^{2\ -1}$ 10 d^{-1}, is most suitable for better growth of Koi Carp in tanks through maintenance of better water quality and greater abundance of plankton in the system. Other workers like, Hickling (1962), Buck and Baur (1980), Motokubo *et al.*, (1988), Jhingran (1991), reported that organic manuring results in higher zooplankton densities in the ponds. Hence, it can be concluded that in the given IFS-I and IFS-II, zooplankton population improved significantly with the application of the manure and maintenance of the water quality was favourable for fish production.

There was also significant difference in the mean zooplankton production under different farming systems throughout the summer and monsoon months. A pattern of sharp increase in the zooplankton production up to May month (2008 -

2011) was observed in all the three treated ponds. This may be due to the fact, that the fingerlings were small and required to graze less on the zooplankton in the month of April. From the month of June onwards the zooplankton count was observed to be decreasing sharply. This may due to the increased intake of zooplanktons by the growing fishes in the pond (Little and Muir, 1987).

Qualitative analysis of zooplanktons were done and identified zooplanktons in this study were under 3 orders namely Copepoda, Rotifera, and Cladocera. Dominant groups of the zooplankton available in all the samples were observed to be Copepoda (*Cyclops sp.* and *Diaptomus sp.*) and Cladocera (*Daphnia sp.*). The population of the same was observed to have increased in the samples of IFS-I and IFS-II indicating, that manure had a favourable effect on the production of Copepoda and Cladocera. In this study it was also observed that organic manure, such as cowdung, significantly increased the production of *Daphnia, Moina*, *Cyclops*, *Brachionus* along with *Diaptomus* and *Keratella* in Experiment-II(IFS-I). In Experiment-III(IFS-II), where combination of cowdung and duck rearing in the pond was followed, significant increase of *Daphnia, Moina*, *Cyclops*, *Brachionus*, *Diaptomus, Keratella* along with *Bosmina* was observed. This result indicated that, in the IFS-II duck grazing along with cowdung application appeared to be more effective when compared to cowdung application alone. This is in agreement with earlier findings by Singh and Sharma (1999) that duck dropping helped to increase the zooplankton population and its diversity.

Okonji and Obi (1999) , agreed that organic fertilizer produced more of the smaller-size zooplanktons (Rotifers, Cladocerons), while inorganic fertilizer favoured the production of larger-sized zooplanktons (Copepods). Rappaport *et al.*, (1977), reported a general increase in the contribution of Rotifers to zooplankton in ponds manured with chicken droppings and cereals manure; but the dominance of Copepods were observed in Control and the ponds receiving liquid cowdung. On the contrary, Dhawan and Kaur (2002a) reported a decrease in Cladoceran population with increased organic manure application. Frequent application of low doses of manure resulted in significantly higher number and biomass of *Daphnia* (Jana and Chakraborti, 1997).

Ekelemu and Nwabueze (2011) revealed that poultry droppings, compared to cow dung and pig dung, produced more zooplanktons. They also observed, that cow dung produced more rotifers, poultry droppings more Cladocera and pig dung more Copepods. In the present study, cowdung produced more Rotifera and Copepoda but duck droppings produced more Cladocera. Sasmal *et al.*, (2008) suggested, that duck excreta was a good source of nutrient as it was easily soluble in water and available for plankton production. Damle and Chari (2011) observed that lack of zooplankton caused poor survival of spawn in nursery ponds. Poultry manures were found to release soluble salts continuously, resulting in high production of zooplankton (Gaur and Chari, 2007). Wurts (2004) reported, that better abundance of planktons supported large population of fish species. This finding was also reflected, in Experiment-III with greater abundance of zooplanktons the production of the fishes was also significantly high as 2778 $\pm$ 50 kg yr^{-1} ha^{-1}.It was also opined that introduction of live zooplankton into a fish culture unit increases the growth rate of carp species (Jha *et al.*, 2006).

Further, was also observed that except water temperature and pond bottom soil pH, zooplankton concentration was found to be significantly correlated ($p \leq 0.01$) with all the physico-chemical parameters of pond water and bottom soil as summarized in Table-12. Negative correlation was observed with water pH and dissolved oxygen concentration in this study. Similar inverse relationship was also observed between zooplankton and dissolved oxygen by Shayestehfar *et al.*, (2010). However, Yamada and Ikeda (1999) observed that zooplankton of freshwater was sensitive to acidic pH. Again, Koli and Muley (2012) observed positive correlation of pH- value with rotifers whereas, a negative correlation of pH-value with copepods.

In the present study, it can be concluded that ponds under IFS-I and IFS-II the zooplankton diversity and production was significantly higher than NIFS indicating that utilization of cow dung and duck manure for aquaculture can successfully increase the availability of the natural food to support the growing fishes in the integrated fish farming systems followed in the Terai region of West Bengal and thus help to reduce the feed cost. It was also observed, that from April to May there was a sharp increase in the availability of the zooplanktons but after June continuous decreasing trend was followed along with the growing fishes in the cultured ponds. The findings of the present study will thus help to improve the management strategies of the ponds culture under different farming system so that the input cost can be reduced by the utilization of the farm wastes which in turns can control environmental pollution maintaining pond water favourable for aquaculture.

5.3 Growth and production of the Indian Major Carps (IMC) and Exotic Carp

Animal manure is often used in semi-intensive systems to improve the primary production of the ponds and fish growth (Nwachukwu, 1997). Manure input and fish yield are directly related with each other (Diana and Lin, 1998; Ansa and Jiya, 2002). Accordingly, in this study also application of manure in IFS-I and IFS-II showed significantly positive effect on the monthly growth rate of IMC. Jha *et al.*, (2004) found, that application of both cow dung and poultry manure, at the rate of $0.26 kgm^{2}$ $^{-1}10\ d^{-1}$, are most suitable for better growth of Koi Carp in tanks. Significantly higher

($p \leq 0.05$) monthly growth rate of IMC was found in Experiment-III and II than the Control (Experiment-I) as presented in Table-14.

Similarly, Sughra *et al.*, (2003) and Kanwal *et al.*, (2003) observed that cow dung was an effective source of organic fertilization, which positively influenced the growth performance of Major Carps in respect of fish production. As also evident by workers in Israel (Moav *et al.*, 1977), the high fish yields are obtainable using cattle slurry and the cattle waste inputs into the pond.

However, in case of *Ctenopharyngodon idella* (Grass Carp) the monthly growth rate was found to be non-significantly ($p \geq 0.05$) higher in Experiment-III, followed by Experiment-II and then Experiment-I. Similarly, Parvez *et al.*, (2006) found that *Cirrhinus mrigala* and *Cyprinus carpio* responded best in manured ponds with homestead organic wastes while *Ctenopharyngodon idella* did not show any marked response .

Throughout the study period, it was also observed that irrespective of any farming system followed as NIFS, IFS-I and IFS-II, the average monthly growth rate pattern was highest in *Catla catla* followed by *Ctenopharyngodon idella*, *Labeo rohita* and *Cirrhina mrigala*, respectively. This indicated, a quick and high return in *Catla catla* followed by *Ctenopharyngodon idella*, *Labeo rohita* and *Cirrhina mrigala* production under village condition. However, Rahman *et al.*, (2008) observed that Common Carp growth in polyculture with *Labeo rohita* was higher in the presence of artificial feed and negatively correlated with natural food availability. *Cirrhinus cirrhosus* and *Cyprinus carpio* showed maximum growth in manured ponds than control ponds (Dhawan and Kaur, 2002a and 2002b).

High fish yield was also obtained in Israel, @ 30 kg ha $^{-1}$d $^{-1}$ with cattle manure (Schroeder, 1975), @40 kg ha $^{-1}$d $^{-1}$ with duck manure and waste feed (Wohlfarth, 1978) and @20 kg ha $^{-1}$d $^{-1}$ with chicken manure (Milstein *et al.*, 1995). However, in the present study, 17.36 kg ha $^{-1}$d $^{-1}$ was achieved in the IFS-II, having duck rearing on the pond along with cowdung manuring (Experiment-III); 12.86 kg ha $^{-1}$d $^{-1}$ was achieved in the IFS-I having only cowdung manuring (Experiment-II) and 6.67 kg ha $^{-1}$d $^{-1}$ was achieved in the Control (NIFS) with no periodical cowdung manuring (Experiment-I). This may be due to the fact that though cowdung manuring improved the nutritional status of the pond but it also resulted in decreased dissolved oxygen content in the treated ponds. This condition might have been improved by the ducks swimming on the manure fed ponds and as a result positive effect was achieved regarding the monthly growth rate of the fishes.

Buentello *et al.*, (2000) also studied the effect of dissolved oxygen on daily feed consumption, feed utilization and growth of channel catfish. They observed that higher dissolved oxygen levels produced increased feed consumption and as dissolved oxygen declined from 100% to 30% there was a progressive reduction in feed intake.

It was further observed in this study, that the total production of fishes was achieved as 1067kg, 2057 kg and 2778 kg in Experiment-I, II and III within 5 months from 1.0 ha of pond. The total fish production was found to be significantly ($p \leq 0.05$) higher in IFS-II (Experiment-III) followed by IFS-I (Experiment-II) where the organic manure was utilised for aquaculture than NIFS (Experiment-I) as summarised in Table-17. In an experiment conducted by Singh and Sharma (1999) it was revealed that ponds treated with poultry excreta showed higher fish production (2663.50 kg ha $^{-1}$ yr $^{-1}$) as compared to ponds treated with pig dung (2219 kg ha $^{-1}$ yr $^{-1}$) and cow dung (789 kg ha $^{-1}$ yr $^{-1}$). Banerjee *et al.*, (1979) also revealed a net production of fish as 535 kg ha $^{-1}$ 90 d $^{-1}$ when the pond was manured with cow dung and an increased net production of 670 kg ha $^{-1}$ 90 d $^{-1}$ manured with poultry droppings. In another experiment, Dutta and Goswami (1988) showed an average net gain of fish of 781.4 kg ha $^{-1}$ in control, 3013.8 kg ha $^{-1}$ in cow manured and 3030.8 kg ha $^{-1}$ in pig manured ponds.

It was also reported by Schroeder (1978), that manures could achieve75% of the yields by using supplementary feeding of grains and 60% of the yields are possible with protein-rich pellets. Schroeder (1978) admitted that fish yield in properly designed and managed manure loaded ponds can reach 5 to 10 tonnes/ ha /yr, without any supplemental feeding. Patra and Ray (1988) revealed, that the use of organic manures namely pigeon droppings, goat dung and raw cow dung were recommended for increased production of fish in ponds of West Bengal.

Sharma (1974), Jhingran and Sharma (1980), Sharma and Olah (1986) and Sharma *et al.*, (1988) observed, 200 to 300 ducks and 250 to 300 layer poultry birds produced 3 to 4 tonnes and 4 tonnes of fish /year respectively, when recycled in one hectare of water area under the polyculture of Indian and exotic fish. This results is because of the fact that the nutritional value of natural food organisms present in a pond is sufficient to support excellent fish growth (De Silva and Anderson, 1995). Phytoplankton and zooplankton (rich source of protein), often contain 40 per cent to 60 per cent protein on dry matter basis (Pillay, 1995). The high protein content of natural food organisms is efficiently utilized in the early growth stages of semi-intensively cultured fish. Song (1994) reported that common carp utilized about 80 percent to 90 per cent of crude protein content of its important food organisms.

5.4 Economics of NIFS, IFS-I and IFS-II

Cost benefit analysis was done considering the expenditure incurred on the fingerling (@ Rs250/kg), feed (@Rs14/kg) and turmeric seed (@Rs 20/kg), when $1 = Rupees 50. The cost of labour was not taken into consideration as farmers and their family were involved in all the aquaculture and agricultural practices. It has been observed, that Experiment-III (IFS-II) has achieved significantly ($p \leq 0.05$) higher net profit of Rs 28,467 followed by Experiment-II (IFS-I) of Rs 12,907 and Experiment-I (NIFS) of Rs 7,322 .This result indicates, that the undigested fraction in animal waste was eaten by fish which may have reduced the feeding cost in aquaculture. The finding is also in agreement with that of Delmendo (1980) along with the higher zooplankton production which further facilitates the fish growth rate resulting in, maximum profit in Experiment-III followed by Experiment-II and Control.

Studies of Bhakta *et al.*, (2004), Afzal *et al.*, (2007), and Sarkar *et al.*,(2011) on animal wastes, revealed, that fish yield in ponds, fertilised with animal excreta, was 5-7 times higher than normal fish pond. In the present study also, the fish yield was achieved approximately 2 to 3 times higher after application of cowdung and duck swimming on the ponds, indicating good scope of integrated farming system in the Terai region of West Bengal. Panda (2002) also indicated, that the approach of integration of duck farming is profitable and acceptable to the farmers in the developing world for maximum utilization of land and water resources. Sharma *et al.*, (2005) again realized that duck-cum-fish as IFS has become encouraging and economically viable under Indian condition and reduces the chances of environmental pollution. The droppings of ducks act as a substitute to fish feed and pond fertilizer up to 60% of total feed cost resulting more net profit.

Organic manuring proves to benefit the farmer economically as it serves to reduce 50 % cost of inorganic fertilizer and supplementary feed (Yadava and Garg, 1992). Optimum ratio of Nitrogen: Phosphorus (4:1 to 8:1) should be managed in aquacultural practices. Accumulated organic matter and nitrogen fixation can serve as main source of nitrogen. Fertilizers regulate pond ecosystem, through their buffering capacity (Das and Jana, 2003). Over fertilization can lead to poor performance and high mortality rate in fish (Zoccarato *et al.*, 1995; Bhakta *et al.*, 2004). Plankton population is a crucial factor in developing pond ecosystem. It is positively correlated with fish yield (Garg and Bhatnagar, 1999). Water temperature and transparency were significantly higher as in dry season as compared to wet season, whereas a positive and significant relationship was noted among the fish yield and phytoplankton and zooplankton productivities when organic manure was used as fertilizers (Javed *et al.*, 1995; Hayat *et al.*, 1996; Hassan *et al.*, 2000).

It has also been observed that integrated farming system responds well when the number of component or enterprise involved are increased. During the present study, it has been realised that Experiment-III (IFS-II) had ducks as additional component/enterprise which increased the potentiality of the farming system resulting in highest return than Experiment-II and Experiment-I. Oribhabor and Ansa (2006) in his study agreed that manuring is widely practiced in fishponds for natural fish production. It is important for sustainable aquaculture and to minimize expenditure on artificial feeds which form more than 55 percent of the total input cost. As observed by Ansa and Jiya (2002), some carps even feed upon the undigested fraction of these manures directly, which may be low in nutrient value; but the microorganisms adhering to them are of high protein value and thereby resulting in increase in fish production. It was also studied by Fang *et al.*, (1994) that conversion efficiency of organic manure protein (chicken, duck, pig and cow manure) to a fish protein was about 40% on a dry weight basis in the fish ponds. Increased fish production was observed significantly when animal waste was utilised in Terai region of West Bengal (Banerjee and Barat, 2013).

The turmeric production and milk production in Experiment-II and III was found to be significantly higher than the Control (Experiment-I) and achieved additional income. It was also reflected in this study that feeding concentrate in IFS-I and IFS-II to the cow helped to increase the milk production by approximately 2 times than the Control (NIFS). Pond bottom soil is highly fertile and utilization of pond dyke for turmeric production using the pond bottom soil and the pond water also might have increased the turmeric production near about 5-6 t ha^{-1} yr^{-1}. In Experiment-III, due to duck raising additional income was achieved from the selling of 2939 eggs in the market. On the contrary, it was observed that when benefit cost ratio (BC ratio) was calculated, higher value of BC ratio was obtained for IFS-II (8.1) followed by NIFS (6.5) and then IFS-I (5.3). This result suggested, that small and marginal farmers of Terai region could get more benefit provided they increase the number of enterprise to be integrated under IFS.

Sharma *et al.*, (2004) also agreed that the mutual beneficial effect of combined fish cum duck culture showed increased production of both fish and duck and decreased input cost of fish culture considerably. The swimming ducks in the pond in search of food released nutrients from the soil which enhance pond productivity and increase the fish production. Woynarovich (1980), Naidu (1985), Jhingran (1986), Ganesan *et al.*, (1991) and Zheng *et al.*, (1997) also agreed that the integration of fish culture and duck farming has proven to be a profitable venture for small scale rural farmers as well as for commercial entrepreneurs. Therefore, raising ducks in fish ponds has proven viable. Fish-cum-duck culture ponds have very effective nutrient processing and retaining capacity, functioning as natural filters and depositing significant amounts of nitrogen in their bottom sediments (Olah *et al.*, 1992 and Pekar *et al.*, 1993). Therefore, the sediment utilised in this study, increased the production of the turmeric significantly.