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# Modelling impacts of chemical fertilizer on agricultural production: a case study on Hooghly district, West Bengal, India

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**Abstract** In the context of changing farming practices, particularly with increasing use of chemical fertilizers, the present paper attempts to statistically model the implications of such input intensification for growth of agricultural production and yield and crop diversification in Hooghly district of the Indian state of West Bengal. Understanding the issue is very important for sustainable growth of the sector in the long-run. The paper uses secondary data collected from the Bureau of Applied Economics and Statistics of the Government of West Bengal for the period 1989–2010. The paper shows that greater use of chemical fertilizers has no strong correlation with growth of agricultural production and yield. It is also found that agricultural production has fluctuated during this period possibly due to improper use of N–P–K over the years exceeding the assimilative capacity of soil. Further, excessive use of chemical fertilizers has also resulted in over extraction of ground water in the area. It is, therefore, suggested that efforts should be made towards deeper understanding of inherent potentials as well as limitations of soil and designing the farming strategies accordingly. In addition, formation of farming groups and promotion of organic farming should be explored to facilitate sustainable growth of the sector. Decentralized participatory planning can play a crucial role in this regard.

**Keywords** Chemical fertilizers · N–P–K composition ratio · Agricultural production · Sustainability · Crop diversification

## Introduction

Sustainable development of a society in general and its economy in particular is contingent upon judicious use of its natural resources (Flint 2013; Muthoo 1990). One of the greatest challenges in contemporary development initiatives is to maintain ecological balance for the present as well as the future generation (Ospina 2000; United Nations Sustainable Development 2012). This is so because the decisions on development strategies often favour achieving economic goals with less importance to the environment (Brundtland 1987; Strange and Bayley 2008). Causing anthropogenic and ecological damage, including injudicious use of natural resources, and lack of their proper management are evident during the course of development in many of the countries. More specifically, over exploitation of natural resources is a common practice in contemporary development initiatives (Diamond 1999). Hence, the approaches to development need to be interdisciplinary and holistic (Donaldson et al. 2005), particularly considering that environmental aspects cannot be seen in isolation of the socio-economic conditions (O'Brien et al. 2009).

The problem is more critical in India as the country supports approximately 16 percent of world's total human population with nearly 2.5 percent of the total geographical area (UNEP 2001) causing considerable pressure on natural resources. Steady population growth coupled with

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widespread incidence of poverty and inappropriate policies and management of natural resources is expected to result in excessive pressure on the country's stock of natural resources. Such pressure is estimated to be the maximum in the world by 2020 (World Bank 2008). Increasing emphasis on input intensive agricultural practices with high yielding variety seeds appear to be a critical problem in this regard as these seeds require large-scale use of chemical fertilizers and water [1]. Constraints to bringing in more area under cultivation and deficiency of various macro and micro nutrients in soils have forced Indian farmers to use more chemical fertilizers to increase yield (Planning Commission of India 2011). This a matter of serious concern as sustained growth agricultural production and yield requires use of essential plant nutrients in *right quantity*, in *appropriate proportion* and at *right time* following the *right methods* (Jaga and Patel 2012).

Although the 'Green Revolution' technologies had considerable positive impact initially, excessive use of chemical fertilizer in the states like Punjab and Haryana has caused destruction of useful microorganisms, insects and worms in soil. This has not only disturbed soil texture and its physicochemical properties, but also caused serious damage to the sector in respect of both quantity and quality of production. For example, growth of agriculture sector in Punjab has stagnated since the 1990s (Kumar and Singh 2010) largely due to improper combination of various inputs like chemical fertilizers. There was huge demand for foods in one hand and the farmers' aspiration for high profit on the other. As a result, the farmers used unlimited ground water as well as excessive chemical fertilizers and pesticides to increase production and yield. Positive effects of chemical fertilizers on production and yield motivated the farmers further towards greater use of these inputs. The consequence of such excessive use of chemicals beyond the limit of consumption of the plants has been absorption of the same by the soil causing secondary effects to the soil itself and the plants. As it is recognized in the literature, the harmful effects of excessive application of chemical fertilizers are likely to be the following:

1. Waterways and nearby water bodies can be adversely affected by use of excessive chemical fertilizers from chemical run off through rain water. As a result, the amount of oxygen is reduced in the water leading to hypertrophication to the aquatic system. The living organisms existing in the water use up the oxygen. Such depletion of oxygen can cause death of majority of aquatic organisms including fish (Harrison et al. 2002).
2. Carbon dioxide and nitrous oxide, greenhouse gases, can be released in the atmosphere by over and repetitive application of nitrogenous fertilizer beyond the crop's assimilation capacity contributing to global warming and erratic climatic conditions (Doll and Baranski 2011).
3. Acidification of soil can take place due to decrease of organic matter in the soil by excessive use of chemical fertilizers causing threats to survival of plants (Velthof et al. 2011).
4. Application of chemical fertilizers in imbalanced ratio consumes the indispensable part of the nutrients in soil reducing the amount of minerals and vitamins in the food items (Das et al. 2009).

During the last 50 years, there has been two remarkable landmarks relating to paradigm shift in agriculture sector in West Bengal—(1) successful implementation of the land reforms programmes, and (2) a very high growth rate of the population. Potentials of land reforms towards promoting growth of the agriculture sector and simultaneous reduction of poverty has been observed in many developing countries. Since large farms are less productive and productivity is low in tenant farms (Bardhan and Mookherjee 2007), it was expected that redistribution of land would increase production in the sector. Considerable increase in agricultural yields has been marked through protection of sharecroppers against their eviction and regulation of sharecropping contracts in West Bengal in the late 1970s (Banerjee et al. 2002). However, growing population in the state created additional demand for foods and hence excessive pressure on land, especially in the central alluvium plain of Bengal delta. Thus, high population growth and implementation of land reform, were two facts that were the basic drivers of paradigm shift (i.e., from traditional to intensive input based farming practices) in agriculture sector of West Bengal (Fig. 1).

Modern agricultural practices came into West Bengal in the late 1970s. While only 26 per cent of the total agricultural area of the state used high yielding varieties (HYV) technology in 1977–78, this increased to nearly 90 per cent in 1998–99 (Kar 2011). There was a rapid acceleration in agricultural growth that resulted in food security in the state (Boyce 1987; Saha and Swaminathan 1994). However, intensive farming practices, particularly with rice and wheat in west Bengal, have virtually mined nutrients from the soil resulting in deficiencies in zinc, boron, manganese, and copper. Most of these areas have not been applying organic manures with the spread of green revolution technology. To cater for the gradual increase in food demand more and more intensive

[1] Use of chemical fertilizers for increasing agricultural production is a common practice, particularly in developing countries. In Asia, chemical fertilizers contribute as much as 50 percent growth of yield (Hopper 1993; FAO 1998). Further, use of chemical fertilizers was considered as important as that seeds in the Green Revolution (Tomich et al. 1995).

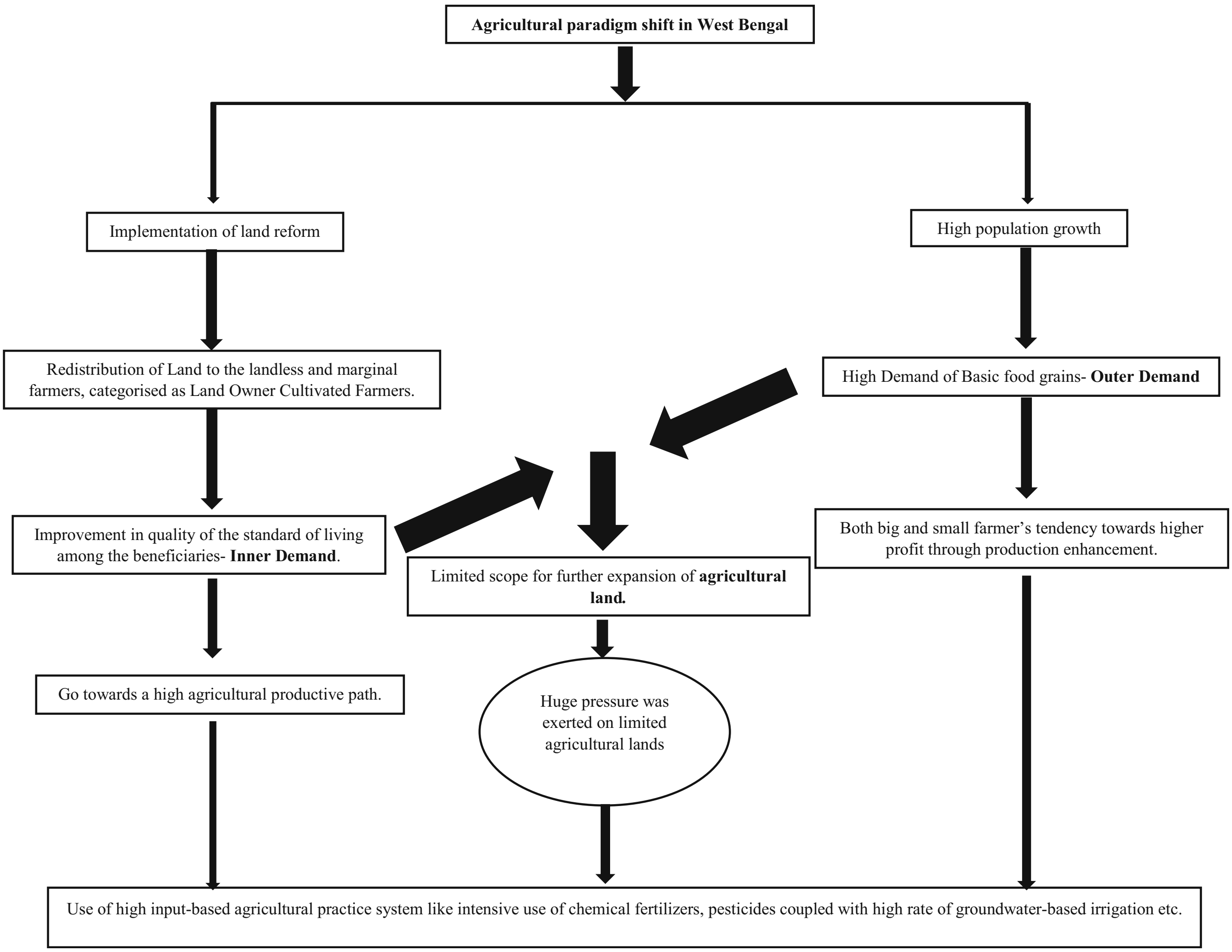


**Fig. 1** Shift mechanism in agricultural paradigm in West Bengal

agriculture often leads to exceeding the land's natural capabilities (Sarkar and Chakrabarti 2007). Extraction of ground water more than its rate of recharge in a year (Moench 2003), rampant and unwise use of chemical fertilizers within a short time period exceeding the soil assimilative capacity are examples of exerting pressure beyond capabilities of the natural resources. Short term development goals are pursued at the expense of long term environmental sustainability that reinforces the hypothesis that high population growth rates can lead to increased pressure on the environment.

In this perspective, the present study is an attempt to investigate impact of chemical fertilizers on growth of agricultural production and yield and its implications for crop diversification through statistical modelling in Hooghly district of the Indian state of West Bengal during 1989–2010. The Hooghly district, being a river deposited plain land, is one of the regions of intense agricultural practice in West Bengal. The entire district comes under Bengal delta of the state. It is the largest fluvio-deltaic sedimentary system in Earth (Mukherjee et al. 2009). The Central Alluvial Plain regions (covering the districts of Murshidabad, Nadia, Bardhaman, Hooghly, Howrah and Medinipur) of the state is well-known for its intensive agricultural practice. The Agro-Climatic Regional Planning Unit has identified this zone as having the most potential of growth in the State. However, fluctuation in groundwater level, and deterioration in soil quality in major part of the region have been the subject of serious attention. Efforts towards understanding impact of chemical fertilizers on agricultural production and its implications for crop diversification in Hooghly district can provide useful insights in designing policies for sustainable growth in the agriculture sector.

## Study area

Hooghly is one of the central districts of West Bengal extending between 20°30′32″ and 23°1′20″ of N and between 87°30′20″ and 88°30′15″ E. This district has a

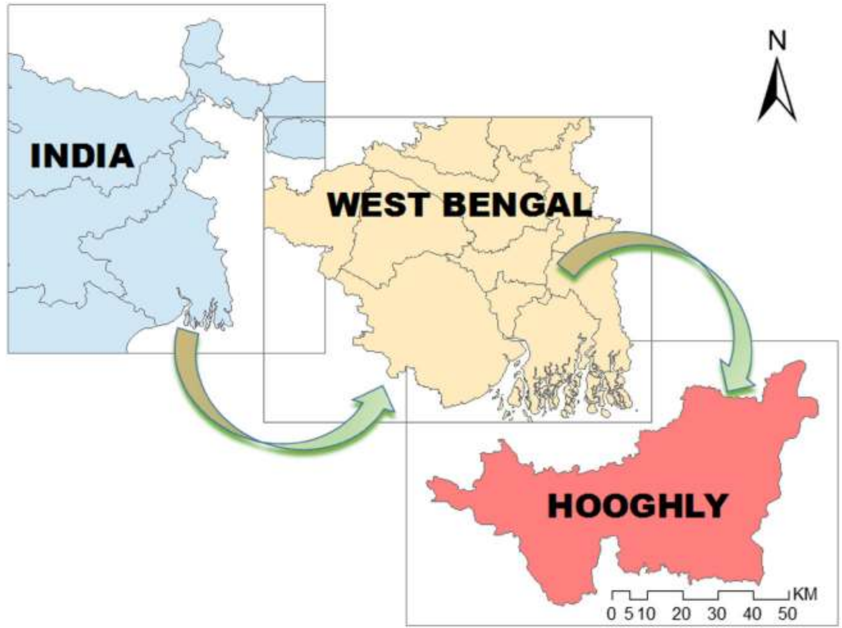


**Fig. 2** The study area

total area of 3149 $km^2$, which is about 3.55 per cent of total geographical area of the State. The district has 18 community development (CD) blocks (Fig. 2) with the headquarter being located in Chinsurah. It is surrounded by the district of Bankura and Burdwan in the north, Nadia and 24-Parganas in the east, Howrah in the south, and Paschim Medinipur in the west. The district is mostly bounded by its principal rivers such as the Bhagirathi (also known as Hooghly), the Damodar and the Rupnarayan. The river Hooghly flows along the eastern boundary of the district, whereas the Rupnarayan flows from Bankura district under the name of the Dhalkisor or Dwarakeswar.

The district forms a part of the flat plains of the lower Gangetic delta and there is a remarkable topographical homogeneity. It is broadly divided into two main natural divisions, the plains and the uplands, and the river Dwarakeswar forming the dividing line between the two. The flat alluvial plains may again be sub-divided into three regions, namely (1) the Dwarkeswar-Damodar interriverine plain, (2) the Damodar-Bhagirathi interriverine plain and (3) the Char lands (HDRCC 2011). The district is well watered by its principal rivers as well as by the smaller streams like the Behula, the Kananadi, the Saraswati, and the Mundeswari among others. The climate of the district is hot moist sub-humid with mean annual rainfall of 1350 mm. The soil moisture and temperature regimes in the district are Ustic and Hyperthermic respectively (Sarkar et al. 2001). Major portion (58.5 percent) of the district is under very gently sloping (1–3 percent) lands and remaining 41.5 percent is under nearly level (0–1 percent) lands. Flooding is one of the major problems of the district. Nearly 30.7 percent area of the district is affected by the occasional floods, while 69.3 percent of the area is affected by moderate to severe flooding (Sarkar et al. 2001). The soils of the district are dominantly loam in texture (53.9 percent) followed by silty clay (23.3 percent), silty clay loam (22.1 percent) and sandy loam (0.71 percent) (Fig. 3). Agriculture is the mainstay of the people of the district with rice being the prime crop. The agricultural economy of the district is largely dependent on potato, jute, vegetables and horticultural crops as well.

## Data and methodology

The study is based on secondary data collected from District Statistical Handbook of Hooghly District (1990–2010) published by the Bureau of applied Economics and Statistics, Government of West Bengal. Data on the variables like net cropped area (NCA), gross cropped area (GCA), consumption of fertilizers, production across crops, annual growth rate of fertiliser consumption (kg $ha^{-1}$) and yield (kg $ha^{-1}$), The nitrogen-phosphorous-potassium composition (N–P–K ratio) of applied chemical fertiliser are sourced from this database.

To address the research objective statistical techniques particularly Pearson's product moment correlation coefficient (R), regression analysis and Coefficient of Determination ($R^2$) were applied to analyse the statistical data. Pearson's correlation coefficient was used to examine the level of correspondence between bivariate variables, whereas regression and coefficient of determination were deployed to investigate the level of dependency of response variable, i.e., agricultural production over predictor

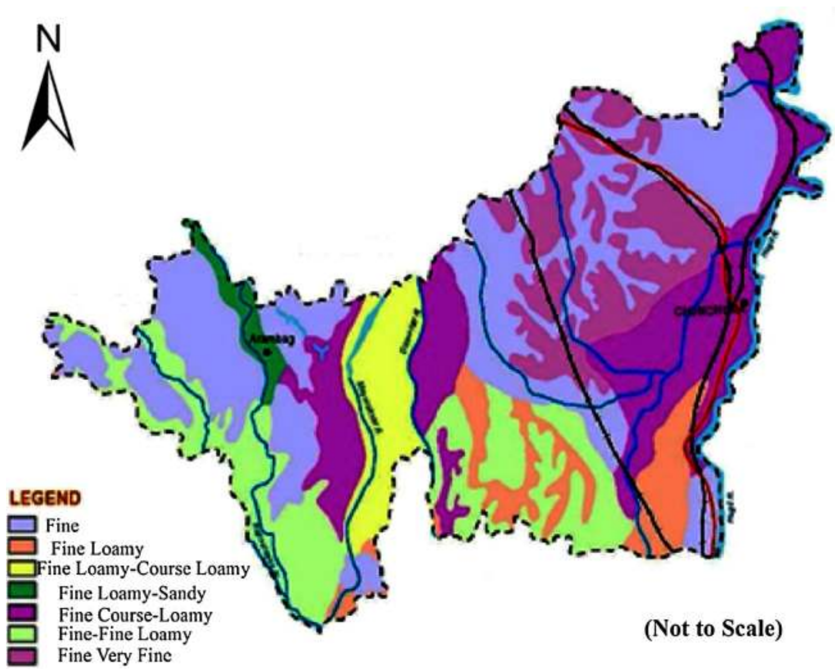


**Fig. 3** Soil map of Hooghly district (Source: NBSS & LUP Regional Centre, Kolkata)

variables like chemical fertiliser consumption and area under agricultural production. In case of statistical regression, polynomial regression was found to be fitting better than linear one. In addition, standard deviation is also computed to examine the temporal variability in yield of various crops.

Crop diversification indicates the extent of dispersion in distribution of cropped area across different crops at a given point of time and space. In order to measure extent of crop diversification in Hooghly district, the Barry's Index ($DI_B$) based on Berry (1971) was computed (Eq. 1).

$$DI_B = 1 - \sum P^2 it \quad (1)$$

where, Pi stands for proportion of area under the *i*th crop at time point. $DI_B$ is expected to increase with increase in the extent of diversification and vice versa.

## Results and discussions

The study finds that the composition of nitrogen, phosphorous and potassium (i.e., N–P–K ratio) did not follow the optimum consumption ratio of 4.0: 2.0: 1.0 in the area during 1989–2007[2] (Table 1). Instead, a high proportion of nitrogen, phosphorous and potassium has been used in the area over a long period of time. In addition, balanced nutrient supply should also include appropriate timing for use of chemical fertilizers for a particular crop under

**Table 1** Year wise change in the N–P–K composition ratio of applied chemical fertilizers in agriculture in Hooghly district from 1989 to 2009

| Year | N | P | K |
|---|---|---|---|
| 1989 | 6.189152 | 2.40612 | 1.404729 |
| 1990 | 5.835509 | 2.689295 | 1.475196 |
| 1991 | 5.483444 | 2.860927 | 1.655629 |
| 1992 | 5.954301 | 2.930108 | 1.115591 |
| 1993 | 5.957447 | 2.393617 | 1.648936 |
| 1994 | 6.275033 | 2.336449 | 1.388518 |
| 1995 | 6.176837 | 2.366127 | 1.457036 |
| 1996 | 6.040428 | 2.520809 | 1.438763 |
| 1997 | 5.840807 | 2.578475 | 1.580717 |
| 1998 | 5.602837 | 2.806484 | 1.590679 |
| 1999 | 5.433213 | 2.806859 | 1.759928 |
| 2000 | 5.581623 | 2.55132 | 1.867058 |
| 2001 | 5.443511 | 2.586368 | 1.970121 |
| 2002 | 5.366541 | 2.678571 | 1.973684 |
| 2003 | 5.596944 | 2.550143 | 1.852913 |
| 2004 | 5.337423 | 2.524102 | 2.138475 |
| 2005 | 3.466782 | 2.954161 | 2.561859 |
| 2006 | 3.681319 | 3.31044 | 3.008242 |
| 2007 | 3.796232 | 3.265876 | 2.937893 |

specific soil and climatic conditions along with application of right methods of cultivation (Dev 1998). This requires efficient use of different nutrients, maintenance of soil productivity and conservation of precious natural resources. However, due to non-availability of soil and crop specific data, the present paper focuses on aggregate

[2] According to the Fertiliser Association of India (FAI), the optimum nitrogen-phosphorous-potassium (N–P–K) composition is 4.0: 2.0: 1.0.

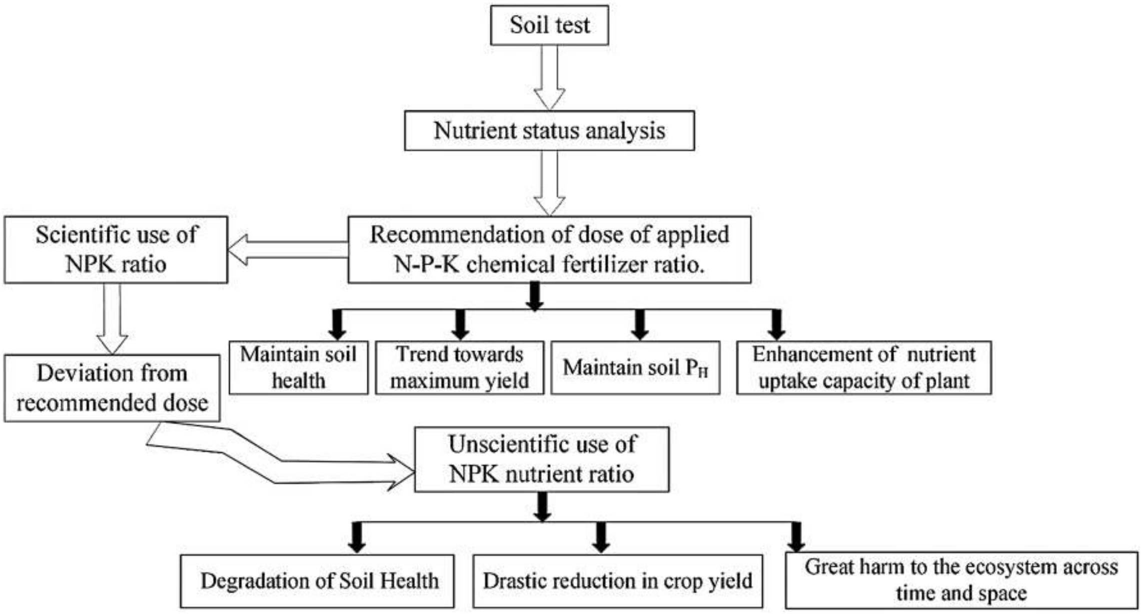


**Fig. 4** Determination of scientific and unscientific ratio of applied N–P–K fertilizer and their impact on agri-environment system

volume of chemical fertilizers used for the agriculture sector as a whole.

The average nitrogen-phosphorous-potassium ratio in the area during 1989–2007 was 5.4: 2.7: 1.8 (Table 1). Further, share of nitrogen has recorded the largest deviation (1.4) followed by potassium (0.8) and phosphorous (0.7). On the other hand, the trends in use of phosphorous and potassium show largely a steady path with deep fluctuations in recent years, whereas consumption of nitrogen depicts a declining trend (Fig. 5a). Although fertilizers should be applied according to the nutrient status of the soil, such a practice has not been followed by the farmers in the area[2] (Fig. 4). This also reflects lack of awareness among farmers about use of appropriate technologies for enhancing crop production.

Furthermore, soil productivity depends on the structure and mineral composition of the soil, depth and drainage facilities, organic matters, intensity of earthworm, and microbial activities. Fairly productive soils in combination with assured irrigation and optimum supply of nutrients can enhance the crop yields by 200–300 percent (Hegde 2000). Since there is a strong relationship between agricultural production and soil productivity, improper N–P–K ratio may cause adverse consequences on soil ecology and productivity and nutrients availability in the long-run. It is observed that injudicious use of chemical fertilisers has made fertile lands barren in many areas. For example, soil in Punjab and Haryana has started showing the signs of exhaustiveness (Maredia and Pingali 2001). Thus, application of fertilisers with improper composition of N–P–K over the years in the study area has resulted in considerable fluctuations in agricultural production, and the issue requires serious attention in future research to facilitate sustainable growth of the sector (Fig. 5b).

In order to investigate the nature of relationship between fertiliser used in agriculture and agricultural production, the standardised values of the variables were used. The scenario of total fertiliser consumption was subdivided into three sequential stages: lower steady stage (before 1998), moderate steady stage (between 1999 and 2004) and higher steady stage (post 2004) (Fig. 6a). The value of Pearson's correlation coefficient (R) between fertiliser consumption and agricultural production is 0.091 which was not statistically significant[3] implying that there was no significant association between the two variables. The regression analysis suggests for 3rd degree polynomial curve (Fig. 6b) with the coefficient of determination ($R^2$) of 0.2251. Such low value of $R^2$ indicates that variations in agricultural production do not depend the magnitude of fertiliser consumption.

The association between annual rate of growth of fertiliser (kg $ha^{-1}$) consumption and yield (kg $ha^{-1}$) for the sector as a whole is shown in Fig. 7a. It is seen that the annual rate of growth of fertiliser consumption has followed a stable path, but that of yield has fluctuated. Possibly, focus of the farmers on enhancing total production rather than yield with poor farm management practices has caused such phenomenon. Further, stable growth of agricultural production and yield depends not only on fertiliser consumption, but also ideal combination of good soil health, proper irrigation, favourable climatic conditions,

[3] The level of significance of the correlation coefficient is as high as 0.70 percent.

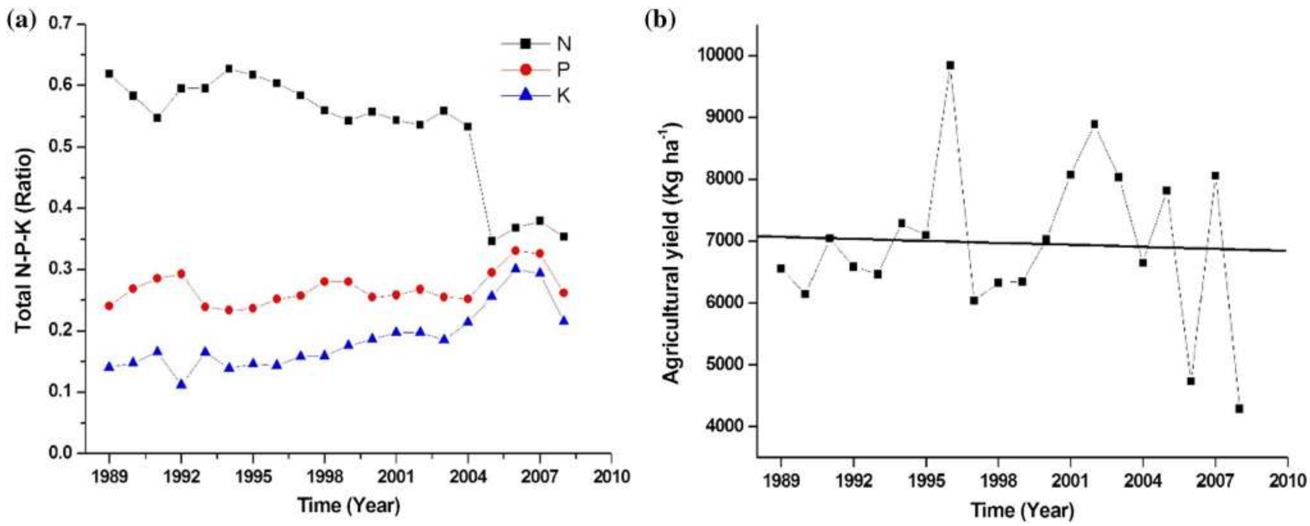


**Fig. 5** **a** Temporal trend of N–P–K ratio of chemical fertilizer, and **b** temporal trend of agricultural yield (kg $ha^{-1}$) in Hooghly district (1989–2009)

etc. Although Pearson's correlation coefficient (r) between the annual rate of growth of fertiliser (kg $ha^{-1}$) consumption and yield (kg $ha^{-1}$) for the period under consideration was 0.62, it is not statistically significant.[4] This means that there is no significant association between fertiliser consumption and agricultural yield. Further, the coefficient of determination of the third degree polynomial function is as low as 0.0728. This means that the function fails to explain variations in growth of agricultural yield in terms of growth of consumption of chemical fertilisers (Fig. 7b).

Table 2 shows the yield variability of the major crops in the study area. The whole study time period was divided into two phases, where the first phase was considered between 1989 and 2000 and the second phase from 2001 to 2009. The variability (standard deviation or SD) in potato yield increased from 2963.45 kg $ha^{-1}$ in the first phase to 5936.6 kg $ha^{-1}$ in the second phase, nearly 100 percent increase. During the same time period, oil seed yield variability also grew from 115.16 to 180.22 kg $ha^{-1}$(about 57 % increase). However, the yield variability in rice yield showed a decline of 24 % from 180.92 kg $ha^{-1}$ in the first phase to 136.9 kg $ha^{-1}$ in the second phase. Increasing variability in yield for many of the crops has raised risks of farming and forced the farmers towards intensification of agricultural practices by raising gross area under cultivation through multiple cropping and greater use of fertilizers and other inputs.

It is important to note that the net area under cultivation Hooghly district has decreased from 221.25 thousand hectares (70.26 percent of total geographic area of the district) in 1988–89 to 214.64 (68.16 percent) in 2008–09 though with some fluctuations (a declining trend) (Fig. 8a). However, with intensification of agriculture, the gross cropped area (GCA) has increased from 376,000 hectares to 471,000 hectares during the same period. Furthermore, the area under *boro* paddy, potato and oilseeds together increased from 37.69 percent of gross cropped area in 1989–90 to 52.39 percent in 2009–10. Such increase in gross cropped area despite decline in net area under cultivation has created extra pressure on land and which has adversely affected the sector.

Table 3 shows that the area under *boro* paddy, potato and oil seeds increased by 111 percent, 45 percent, and 71 percent respectively during 1989–90 to 2009–10 as these crops had adequate demand in the market. It is possible because of high market demand for these crops the farmers might have been motivated to cultivate them increasing the gross cropped area in the district. This effect was also shown in the crop diversification index (CDI) where the value of C.D.I of Berry (Table 4) increased from 0.69 (1989–90) to 0.74 (2009–10). Since these crops require more chemical fertilizers compared to other crops, consumption of these fertilizers has increased considerably in the district.

This is reflected in strong correlation between gross cropped area (GCA) and use of chemical fertiliser consumption. The correlation coefficient is found to be as high as 0.809, which was significant at the 0.01 percent. On contrary, the correlation coefficient between annual production and gross cropped area was only 0.367 and that between production and fertiliser consumption was as low as 0.091. This means that increase in gross copped area requires greater use of chemical fertilizers, but such increase in gross cropped area or chemical fertilizers does

[4] The correlation coefficient is significant only at 0.40 percent level.

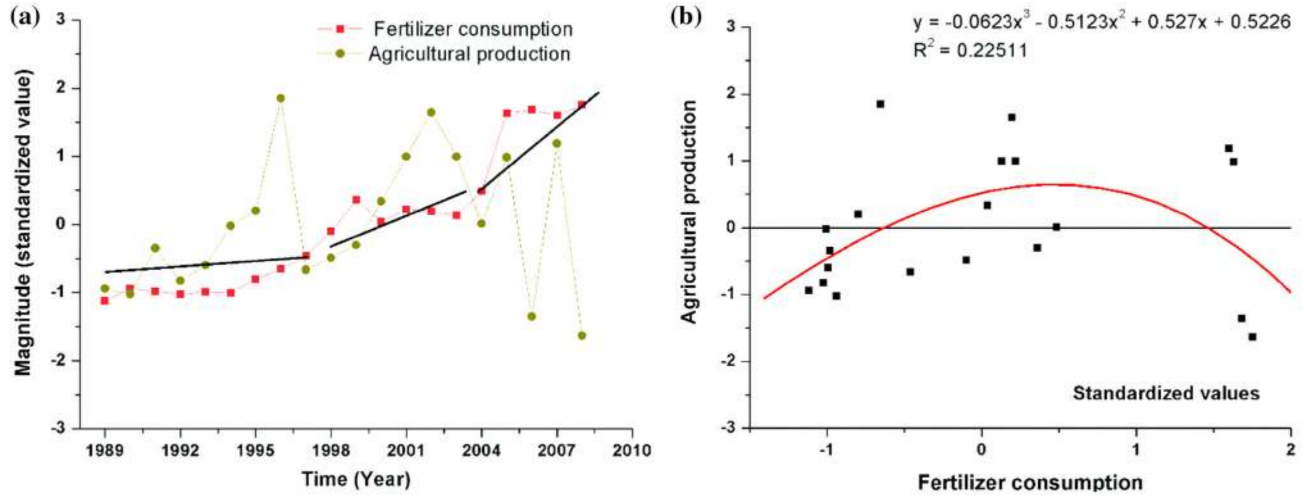


**Fig. 6** **a** Comparison between temporal trend of fertilizer consumption (standardized value) and agricultural production (standardized value), and **b** relationship between fertilizer consumption (standardized value) and agricultural production (standardized value) in Hooghly district (1989–2009)

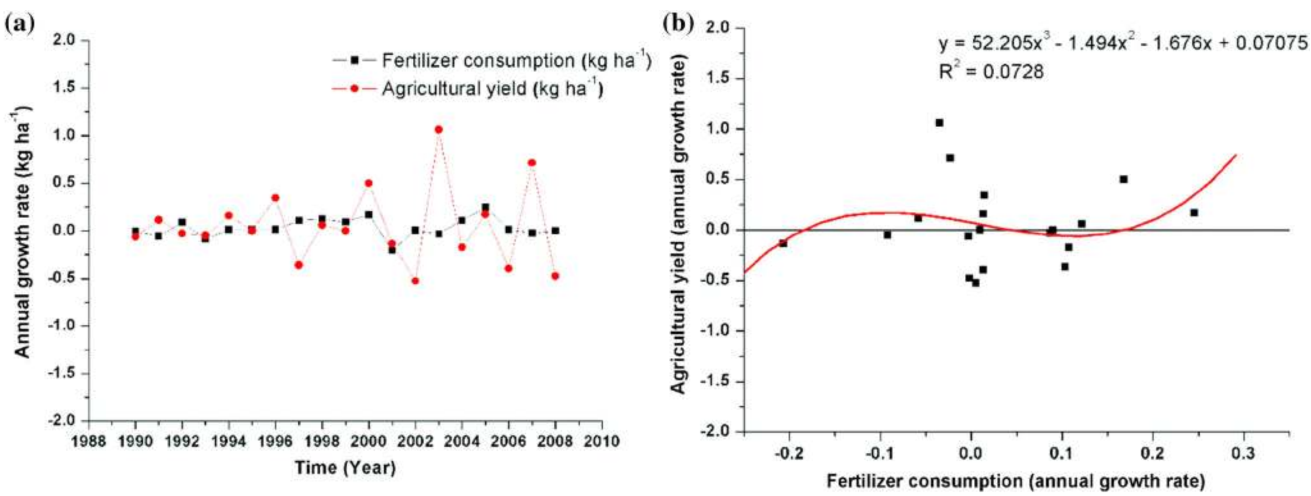


**Fig. 7** **a** Temporal contrast between annual growth rate in fertilizer consumption (kg ha$^{-1}$) and agricultural yield (kg ha$^{-1}$), and **b** nature and degree of relationship between annual growth rate in fertilizer consumption (kg ha$^{-1}$) and agricultural yield (kg ha$^{-1}$) in Hooghly district (1989–2009)

not necessarily result in higher agricultural production. Instead, production shows fluctuations (Fig. 8b).

## Conclusions

With changing farming technologies, farmers are increasingly following input intensive agricultural practices. However, greater use of modern inputs like chemical fertilizers does not necessarily result in sustainable growth of agriculture sector, particularly in respect of production and yield. Empirical evidences from Hooghly district of the Indian state of West Bengal show that greater use of chemical fertilizers, has failed to enhance agricultural production and yield. It is also found that agricultural production has fluctuated in the area possibly due to use of N–P–K in inappropriate composition and application of these chemical fertilizers beyond the assimilative capacity of soil. Improper use of chemical fertilisers seems to have caused environmental degradation and erosion of soil fertility as well. Greater crop diversification in the district has also enhanced use of more chemical fertilizers further.

Hence, appropriate measures are necessary to make growth of agriculture in the district sustainable in the long-run. In addition to designing appropriate policies and institutions towards judicious use of chemical fertilizers and extraction of ground water, there is also a need for collective approach, particularly towards organic farming.

**Table 2** Yield variability of various crops for the two different time phases in Hooghly district

| First phase (1989 to 2000) | | | | | Second phase (2001 to 2009) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Yield (kg ha$^{-1}$) | Minimum value | Maximum value | Mean | Standard deviation | Yield (kg ha$^{-1}$) | Minimum value | Maximum value | Mean | Standard deviation |
| Rice | 2210.8 | 2651.36 | 2450.41 | 180.92 | Rice | 2459.58 | 2679.88 | 2679.8800 | 136.9 |
| Potato | 19219 | 29365 | 24686 | **2963.45** | Potato | 11020.00 | 29886.00 | 24629.6667 | **5939.6** |
| Oil seeds | 642 | 996 | 878 | **115.16** | Oil seeds | 609.00 | 1173 | 964.44 | **180.22** |

Bold values indicate that the trend of the yield of potato and oilseeds was highly (significantly) fluctuating from its mean yield over time

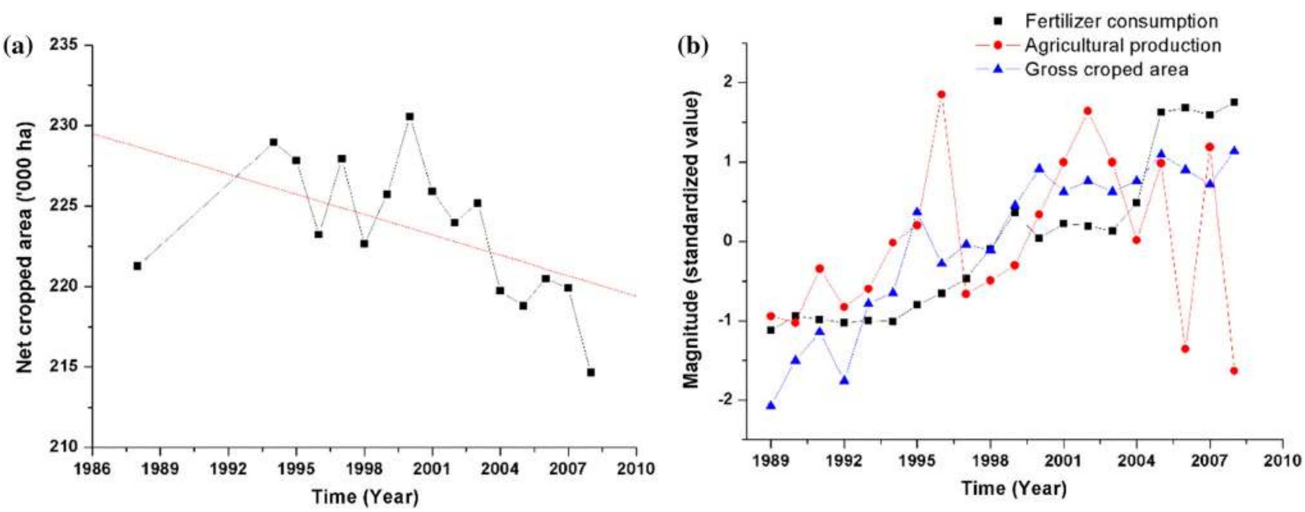


**Fig. 8** **a** Change in net cropped area ('000 ha) over time, and **b** comparison among fertilizer consumption, agricultural production, and gross cropped area over the time periods in Hooghly district (1989–2009)

**Table 3** Gross cropped area (GCA) (in thousand hectares) and percentage of gross cropped area under different crops in Hooghly district

| Crop | 1989–90 | | 1994–95 | | 1999–2000 | | 2005–06 | | 2009–10 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GCA | % | GCA | % | GCA | % | GCA | % | GCA | % |
| Aus | 16.6 | 4.42 | 12.9 | 3.81 | 8.6 | 1.93 | 9.4 | 2.006 | 6.3 | 1.34 |
| Aman | 188.8 | 50.24 | 186.4 | 44.62 | 191.2 | 42.81 | 193.2 | 41.16 | 187.2 | 39.7 |
| Boro | 50.3 | 13.38 | 88.4 | 21.2 | 112 | 25.1 | 107.7 | 22.83 | 106.4 | 22.5 |
| Wheat | 2 | 0.53 | 0.4 | 0.096 | 0.8 | 0.18 | 0.3 | 0.006 | 0.4 | 0.085 |
| Total pulses | 3 | 0.8 | 0.9 | 0.22 | 1.3 | 0.29 | 2.5 | 0.53 | 0.6 | 0.13 |
| Total oilseeds | 28.8 | 7.66 | 32.6 | 7.82 | 26.4 | 5.92 | 31.2 | 3.67 | 49.5 | 10.51 |
| Total fibre | 22.8 | 5.84 | 25 | 6 | 31.6 | 7.08 | 31 | 6.61 | 29 | 6.16 |
| Potato | 62.9 | 16.65 | 69.5 | 16.67 | 73.8 | 16.54 | 92.2 | 19.67 | 91.3 | 19.38 |
| Sugarcane | 0.1 | 0.027 | 0.1 | 0.023 | – | – | 0.1 | 0.021 | 0.1 | 0.0021 |
| chillies (dry) | 0.5 | 0.13 | 0.7 | 0.15 | 0.5 | 0.11 | 1.1 | 0.23 | 0.9 | 0.19 |
| GCA (all crops) | 375.8 | 100 | 416.9 | 100 | 446.2 | 100 | 468.7 | 100 | 471 | 100 |

Integration of markets, policies and institutions and removal of imperfections existing in farming practices can play crucial role in this regard. More specifically, while the policies should be guided towards removing imperfections and creating new opportunities, the institutions should play the role of catalysts to link farming households to both input and output markets. Use of inputs of right quantity and right quality in right time will ensure decline in crop losses and improvement in quality of produces. Interventions of various government agencies are also crucial in this regard. For example, the department of agriculture can guide the farmers in identifying the right combination of crops to cultivate and the right combination of inputs (particularly, chemical fertilizers) to use and take

**Table 4** Temporal trend of crop diversification (Berry's measure) in Hooghly district with 5 year interval

| Year | 1989–90 | 1994–95 | 1999–00 | 2005–06 | 2009–10 |
|---|---|---|---|---|---|
| Berry's measures | 0.69 | 0.72 | 0.72 | 0.73 | 0.74 |

initiatives towards greater use of manures, etc. However, decentralized and participatory planning process is necessary for this purpose.

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**Compliance with ethical standards**

**Conflict of interest** The authors declare that there is no conflict of interest.

## References

Banerjee AV, Gertler PJ, Ghatak M (2002) Empowerment and efficiency: tenancy reform in West Bengal. J Polit Econ 110(2):239–280

Bardhan P, Mookherjee D (2007) Land reform and farm productivity in West Bengal. Unpublished manuscript, Boston University

Berry C (1971) Corporate growth and diversification. J Law Econ 14(2):371–383

Boyce JK (1987) Agrarian impasse in Bengal: institutional constraints to technological change. Oxford University Press, Oxford

Brundtland GH (1987). Report of the world commission on environment and development: Our common future. United Nations

Das A, Munda GC, Patel DP (2009) Technological options for improving nutrient and water use efficiency. ICAR Research Complex for NEH Region, Umiam-793103,Meghalaya. Retrieved from http://www.kiran.nic.in/pdf/publications/Water_Use_Efficiency.pdf. Accessed 20 Dec 2014

Dev G (1998) Balanced fertiliser use increases crop yield and profit. Better Crops Int 12(2):25

Diamond JM (1999) Guns, germs and steel: the fate of human societies. Norton, New York

Doll JE, Baranski M (2011) Field crop agriculture and climate change. Climate change and agriculture fact sheet series E3149, Michigan State University Extension, East Lansing

Donaldson A, Heathwaite L, Lane S, Ward N, Whatmore S (2005) Holistic approaches to understanding diffuse land management issues: a framework for interdisciplinary working. Centre for Rural Economy Discussion Paper Series 2, Centre for Rural Economy, University of Newcastle, Tyne, pp 1–14

FAO (1998) Guide to efficient plant nutrition management. Retrieved from ftp://ftp.fao.org/agl/agll/docs/gepnm.pdf. Accessed 22 Mar 2015

Flint RW (2013) Basics of sustainable development. In practice of sustainable community development. Springer, New York, pp 25–54

Harrison P, Bruinsma J, de Haen H, Alexandratos N, Schmidhuber (2002). World agriculture: towards 2015/2030. Retrieved from http://www.fao.org/docrep/004/y3557e/y3557e11.htm. Accessed 11 Jan 2015

HDRCC (2011) District human development report: hooghly, development & planning department, Government of West Bengal. Retrieved from http://www.in.undp.org/content/dam/india/docs/humandevelopment/HDR/DHDR_Hooghly.pdf. Accessed 25 Dec 2014

Hegde NG (2000) Sustainable agriculture for food security. Indian Farming 49(12)

Hopper W (1993) Indian agriculture and fertilizer: an outsider's observations. In keynote address to the FAI seminar on emerging scenario in fertilizer and agriculture: global dimensions. FAI, New Delhi

Jaga PK, Patel Y (2012) An overview of fertilizers consumption in India: determinants and outlook for 2020-a review. Inter J Scienti Eng Technol 1(6):285–291

Kar NB (2011). Changing scenarios of agricultural system and its impact on rural society in West Bengal during the left front regime: a study of two villages (1977–2006). Ph.D. thesis. Netaji Subhas Open University. Retrieved from http://shodhganga.inflibnet.ac.in/bitstream/10603/2970/14/14_chapter%2010.pdf. Accessed 23 Feb 2011

Kumar S, Singh P (2010) Inclusive agricultural growth: district-wise agricultural productivity analysis in Punjab. In: Proceedings of National Workshop on Inclusive Agricultural Growth: Regional Perspective, pp 21–51

Maredia M, Pingali P (2001) Environmental impacts of productivity–enhancing crop research: a critical review. CGIAR Technical Advisory Committee Secretariat, FAO, Rome

Moench M (2003) Groundwater and food security in India. In: Prasad Kamta (ed) Water resources and sustainable development: challenges of 21st century. Shipra, Delhi, pp 148–167

Mukherjee A, Fryar AE, Thomas WA (2009) Geologic, geomorphic and hydrologic framework and evolution of the Bengal basin, India and Bangladesh. J Asian Earth Sci 34(3):227–244

Muthoo MK (1990) Economic considerations and environmental policy implications in the management of renewable natural resources. Unasylva 41(163):50–57

O'Brien K, Hayward B, Berkes F (2009) Rethinking social contracts: building resilience in a changing climate. Ecol Soc 14(2):12

Ospina GL (2000) Education for sustainable development: a local and international challenge. Prospects 30(1):31–40

Planning Commission of India (2011) Crop husbandry, agricultural inputs, demand and supply projections and agricultural statistics for the Twelfth Five Year Plan (2012–2017). Retrieved from http://planningcommission.nic.in/aboutus/committee/wrkgrp12/agri/crop_husbandry.pdf. Accessed 25 Dec 2014

Saha A, Swaminathan M (1994) Agricultural growth in West Bengal in the 1980s: a disaggregation by districts and crops. Econ Political Wkly 29(13):A2–A11

Sarkar R, Chakrabarti B (2007) Rural environment, India infrastructure report, chapt 9. Retrieved from www.iitk.ac.in/3inetwork/html/reports/IIR2007/IIR_2007.html. Accessed 12 Feb 2015

Sarkar D, Das TH, Chattopadhyay T, Velayutham M (2001) Soils of Hooghly district for optimising land use. NBSS and LUP, Nagpur, p 91

Strange T, Bayley A (2008) Sustainable development: linking economy, society, environment. OECD, Paris **OECD Insights**

Tomich T, Kilby P, Johnson B (1995) Transforming agrarian economies: opportunities seized, opportunities missed. Cornell University Press, Ithaca

UNEP (United Nations Environment Program) (2001) State of the environment, India 2001. Retrieved from http://www.envfor.nic.in/sites/default/files/soer/2001/ind_land.pdf. Accessed 26 Jan 2015

United Nations Sustainable Development (2012) The future we want. United Nations General Assembly, Sixty-sixth session, Agenda item 19

Velthof G, Barot S, Bloem J, Butterbach-Bahl K, Vries W, Kros H (2011) Nitrogen as a threat to European soil quality. Eur Nitrogen Assess Sour Eff Policy Perspect Chap 21:495–509

World Bank (2008) India-a new way of cultivating rice. Retrieved from http://web.worldbank.org/archive/website01291/WEB/0__C-712.HTM. Accessed 10 Mar 2015