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Historical changes in land requirements for food in India

KEYWORDS: LRF, food consumption, diet, population growth

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ABSTRACT *Population growth, diet diversification, urbanization and economic growth in India exerts great pressure on land resources of the country. Here we investigate the dynamics of land requirement for food (LRF) in India from 1961 to 2009. LRF of a country is a function of population, diet and technology. Using a sensitivity analysis, we investigate the roles of the individual drivers i.e. technology, population and dietary pattern change on total LRF. Our results show that the total LRF increases by 43%, whereas per capita LRF decreases significantly by 45% from 1961 to 2009. Population growth is responsible for most of the increase in total LRF, as it drives the major increase in consumption of food items. Therefore, increase in cropping yield is an urgent need to ensure the food security of India. We also discussed the adverse effect of excessive technology dissemination on soil pollution; land degradation, ground water depletion etc. and focus on wider agricultural, environmental and policy dimensions of the changes in the light of political economy and sustainable agricultural policies.*

Introduction
Presently, India ranks the second largest populated country (1.2 billion, figure 1, left panel) in the world after China, but it is projected to surpass the population of China by 2030 with the capacity of 1.53 billion. On the other hand, the Gross Domestic Product (hereafter GDP) and per capita income rises steadily since the mid-1980s, and hence in the recent years Indiaemerges as a major developing nation with significant influence over the Asian economic zone. In India agriculture and allied sectors accounted for 19% of the GDP in 2011 (FAOSTAT 2012) and 57% of the total geographic landmass (328.73 million hectare (MHa)) of the country (FAO 2010) is agricultural. The tabular data for population, GDP and arable land are presented in supplementary table 1. Per capita income growth and globalization plays important roles in the transformation of food consumption patterns of Indian households (Pingali, 2007; Mittal, 2008), particularly evident in the urban areas. In 2011, the urban population of India is 377.1 million (31.16% of total). The change in consumer tastes and demand has critical implications on the whole food supply system. Although, per capita staple food consumption declines significantly (Oldiges, 2012), the total consumption increases due to rapid population growth. The diet pattern has transformed from cereal based foodgrains to high value nutritional foods like animal products and fruits and vegetables (Kumar *et al*., 2007; Mittal, 2007; Hubacek*et al*., 2007). Such an inclination of the dietary pattern towards more affluent animal origin food products led to an increase in the demand of foodgrains as feed. Along with population growth, India is currently undergoing tremendous transformations due to reform and globalization, which substantially affect income distribution and inequality (HengQuan, 2006). Moreover, urbanization influences food preferences because urban dwellers have higher average incomes and different food consumption patterns than the rural counterpart (VanGinkel, 2008). Urban populations consume more livestock-based food than rural populations due to higher income, especially in low-income countries (Gandhi and Zhou, 2010). These affluent food items exert more pressure on the arable land demand of the country. Therefore, along with population growth, the changes in the dietary pattern, demands higher foodgrain production to ensure the food security of India and thereby the food self-sufficiency need to be improved.

Demand and supply prospects of food items are the important indicators to the country's food security concerns. Although demand increases significantly but the land requirement for food production is limited. Focusing on a rapidly developing nation like India, per capita annual production of foodgrains increases from 183 kg during 1970 to 207 kg by the mid-1990s, but a declining trend in total production is noticed due to deceleration in the total factor productivity growth (Kumar *et al*., 2004; Kumar and Mittal, 2006). This rapidly changing scenario of production and consumption will have a notable influence on the supply and demand prospects of food. According to FAOSTAT Food Balance Sheets, about 82% of food supply in India originates from the arable land. But there are relatively few studies deal-

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ing with the temporal dynamics of arable LRF. Being, one of the most challenging aspects of global environmental change, several authors tried to quantify the role of different drivers and establish scenarios for future LRF (Penning de Vrieset *al.*, 1997 on a global scale; Rounsevellet *al.*, 2005 for Europe; Kastner and Nonhebel, 2010 (KN10) for the Philippines). Over the Indian subcontinent, still now we didn't come across any statistical study which deals with the historical changes in the land requirement for food.

The LRF of a country depends mainly on the population, dietary pattern, andtechnology implementation (KN10), and each of them have different dynamics over time. Moreover, the scale of impact on LRF is different for the developing and developed nations. For the countries with lower and higher levels of income, the impact of population growth and diet pattern change overrides each other, respectively (Gerbens-Leenes and Nonhebel, 2002). Most of the studies reveal that dietary pattern aligns towards more affluent food items wherever economic growth occurs and thereby requires more arable land to ensure the food security (Gerbens-Leeneset *al.*, 2010; Godfrayet *al.*, 2010). In general, several global outlook studies consider grain equivalents as the proxy for agricultural production (Penning de Vrieset *al.*, 1997).

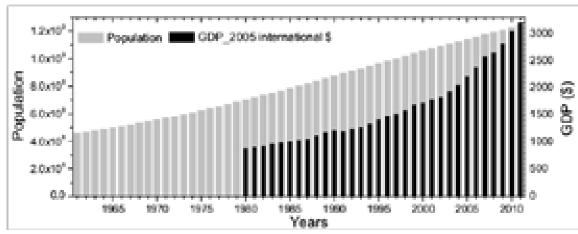
Due to the impact of green revolution, India has made satisfactory progress in the development of cropping yield (Kumar and Mittal, 2006) and thereby the self-sufficiency touches almost 100% marked limit during the 1990s. However, the green revolution technology may not reduce the instability of agriculture in India over the last few decades (Larson *et al.*, 2004). The increase in yield differs remarkably between cropswith cereals at the high end of the yield spectrum, which reflects the agro-economic growth of the country. In a separate study, Gulati (2009) discussed the emerging trends in Indian agriculture and the increasing role of the corporate sectors in agriculture by infusing new technologies and accessing new markets.

The present study is an attempt to provide credible estimates of historical land requirement for food in India from 1961 to 2009 by incorporating the impact of population, technology, dietary pattern changes, and tried to discuss our results in a framework which links consumption of different groups of food items to calories;then to cropping yield and finally to the total land requirement for food in a scenario when population is growing rapidly and diet diversification and urbanization impose excessive pressure on food security of the country. We also elaborate the role of green revolution technology and government policies towards agricultural sector to improve the yield of different crops. Finally, we also tried to emphasize our discussion on wider agricultural, environmental and policy dimensions of these changes in the light of political economy and have estimated the share of import on net LRF of the entire country.

2. Study area: the India

The Indian peninsula comprises of varied landscape from extreme mountains (Himalayas) in the North to vast oceans (Bay of Bengal, Indian Ocean, and Arabian Sea) in the South. It experiences two types of monsoons, the summer (June-September) and the winter monsoon (October-November), which strongly modulates the agricultural system, development and economy of the whole country. In the field of agriculture, India ranks second worldwide in farm output. As a major developing nation in the South-East Asia, agriculture and allied sectors accounted for 19% of the GDP in 2009, about 50% of the total work force. From the economic development scenario, per capita GDP adjusted for purchasing power parity (PPP) in constant 2005 international dollars increases strikingly from 1000$ in 1980 to 3000$ in 2011(figure 1, right panel). This per capita GDPcan be considered as a proxy for per capita income level of India. The geo-political divisions of Indian states are shown in supplementary table 1.

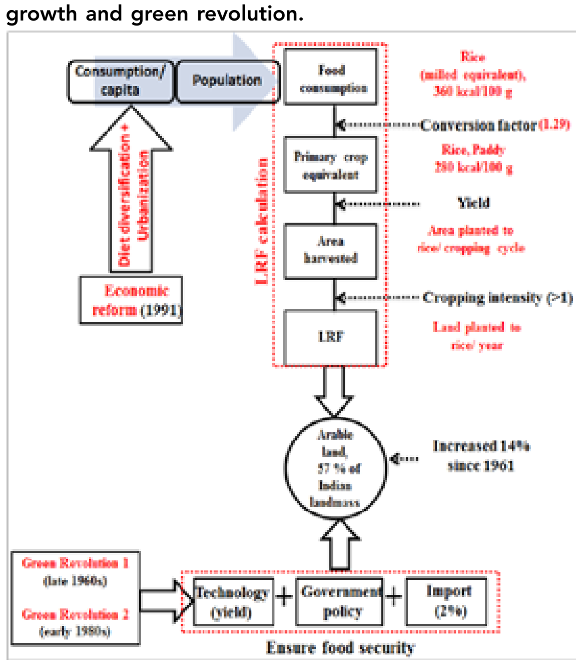
Figure1.Temporal trend in population growth (left panel) and GDP (PPP) per capita at constant 2005 international dollars (right panel) in India.



3. Data and methodology

In the present study, we use the data available on the Food and Agriculture Organization of the United Nations (FAO, 2010) data archival websitefrom 1961 to 2009 including the FAOSTAT (Classic) consumption, production, yield and area harvested data to assess the LRF in India, as listedin supplementary table 2.FAO statistics are mainly provided by the member countries' statistical office (Ministry of Statistics and Program Implementation for India) and they also developed data quality frameworks to ensure its accuracy and consistency (FAO statistical data quality framework report, 2004; FAO, 2006). The GDP data is available from World Bank (http://data.worldbank.org), India database.

Figure 2.Framework to link LRF to consumption to calories, then to cropping yield and impact of economic growth and green revolution.



Source: Kastner and Nonhebel 2010 for LRF calculation flow chart only.

In our study, we adopt the methodology described by KN10, and worked out the changes in historical land requirements for food in India from 1961 to 2009. A flow chart is shown in figure 2 to explain the steps and components involved in LRF calculation. Firstly, the individual processed food items

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(e.g. sugar, rice milled equivalent, etc.) are converted to their primary crop equivalents (e.g. sugarcane, rice-paddy, etc.) and the processing or conversion losses are then adjusted in the LRF calculation by means of the conversion factor (supplementary table 3). The LRF is separated into two parts, the vegetal origin part (LRFvegetal) and the animal origin part (LRFanimal). The LRFvegetal can be computed as follows,

$$LRF_{vegetal} = \sum_{i=1}^{n} \frac{consumption_i \times conversion\ factor_i}{yield_i \times cropping\ intensity} \quad (1)$$

Where i stand for the individual crop items and LRFvegetal is the sum total land requirement for the entire primary crop equivalents. In our analysis, we consider the cropping intensities which are greater than or equal to 1 (KN10). In actual sense, land is commonly fallowed and planted regularly with possible changes and rotations of different crop items. Since the statistics of fallowed land is not readily available and cannot be linked to the single crops, we consider the cropping intensity of the whole country in one year, instead. The yieldi is the crop yield for each crop item and the consumptioniis the total consumption of individual food items by the entire population of the country in one year. The conversion factori is used to connect the individual food items to their primary crop equivalents, i.e. 100 g (351 kcal) of sugar is assumed to be equivalent to 1170 g (30 kcal) of sugarcane, and then the conversion factor is 11.70. The caloric content of the individual food items and their primary crop equivalents are tabulated in supplementary table 3(FAO,2001).

LRFanimal is the land required to feed the livestock products and is calculated as,

$$LRF_{animal} = \frac{consumption_{animal(kcal)} \times LRF_{vegetal}}{consumption_{vegetal(kcal)}} \times 3 \quad (2)$$

Where consumption$_{animal(kcal)}$ and consumption$_{vegetal(kcal)}$ are the total consumption of the animal origin and vegetal origin food items in one year, respectively and both are expressed in the calorie content form. The multiplication factor 3 arrivesin equation 2, based on the assumption that one calorie of animal origin food requires three times the amount of arable land requires for an average calorie of vegetal origin. This rough assumption is based on a number of studies dealing with arable land demand for animal origin food products (Steinfieldet *al.*, 2006; Elferink and Nonhebel, 2007; Galloway *et al.*, 2007; KN10). Nevertheless, it is clear that an average animal calorie requires more arable land than a vegetal calorie.

In this study, we consider the consumption data for about 72 primary food items in 18 FAOSTAT categories (supplementary table 3) and further aggregate into 6 groups: cereals (9 items), sugar and sugarcrops (5 items), vegetal oils and oilcrops (22 items), fruits and vegetables (14 items), other vegetal food items (13 items) and animal products (9 items). Since our research is restricted to arable land we exclude the products originated from the aquatic sources. The Food Balance Sheet consumption data are available both in national annual total (tonnes) and daily per capita (kcal) consumption form (supplementary table 2). The former is used to estimate the LRF and the later to explain the average diet of the country.

4. Results and Discussions

4.1. Food consumption and average diet pattern

In the present analysis,the food consumption data are usedto estimate the average yearly consumption of food by the entire population (Caballero and Popkin, 2002; Albala *et al.*, 2002). These values refer to the household supply of the food items without accounting for the household level losses. The historical changes in total consumption and daily per capita consumption are shown in figure 3(a) and figure 3(b), respectively. Although the total food consumption (figure 3(a)) increases from 150 million tonnes (MT) in 1961 to 500 MT in 2009, the percentage consumption per year (i.e. the percent share in total food) of each group displays different.For cereals and sugarcrops,it decreases from 45% to 33% and from 9.5% to 7.5%, respectively, whereas, for fruits and vegetables and animal products,it increases from 19.5% to 27% and 12.5% to 18.5%, respectively from 1961 to 2009. While looking at interstate comparison scenario, the food consumption, particularly cereals varies largely. Based on National Sample Survey Organization (NSSO) and National Nutrition Monitoring Bureau (NNMB) report, data from 2004-2005 survey show large interstate differences in types and quantities of food consumed both in rural and urban areas. Both in urban and rural areas, cereals are the major food items, but pulse consumption is relatively low in all the states. There are large variations between states in vegetable, fruit and animal product consumption. In majority of the states' cereal consumption is higher in rural areas, whereas animal product in urban areas(Nutrition foundation of India report). Between 1987-88 and 2008, annual per capita cereal consumption has declined in most of the states (except the north eastern and eastern states), with a compound growth rate of -1.45% and -0.95% per annum in rural and urban areas, respectively (IWMI report).

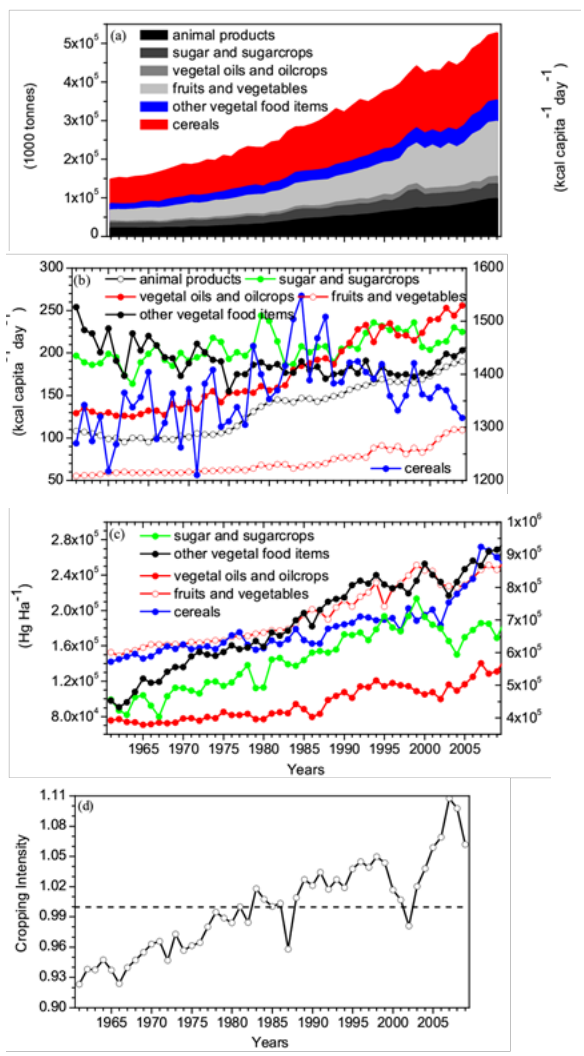

Figure3.(a) Total food consumption trend (1000 tonnes), (b) Daily per capita consumption (kcalcapita-1day-1)

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trend of different groups of food items (only cereals is plotted in the right panel), (c) Cropping yield trend (Hg Ha-1) of different groups of food items (only sugar and sugarcrops and other vegetal food items are plotted in the right panel) , and (d) temporal trend in Cropping intensity of India (the red dotted line indicate cropping intensity=1)

Total food consumption only depicts total demand of food per annum, but daily per capita consumption reflects consumer taste and diet. In national level, daily per capita food consumption increases from 2000 kcal in 1961 to 2300 kcal in 2009. Figure 3(b) shows the daily per capita consumption of individual groups of food items to explain the diet pattern changes in India. The daily per capita consumption of animal products (108 to 190 kcal), vegetal oils and oilcrops (125 to 256 kcal), sugar and sugarcrops (197 to 225 kcal) and fruits and vegetables (55 to 109 kcal) increase significantly, whereas for other vegetal food items (254 to 203 kcal) consumption decreases drastically from 1961 to 2009. In the case of cereals, the daily per capita consumption increases (1270 to 1548 kcal) until 1989, afterwards a declining trend to 1318 kcal in 2009 can be noticed, which may be due to the changes in diet pattern related to the economic development since 1990s. To look further deep inside, we notice that the percentage daily per capita consumption per year (the percent share in daily diet) for cereals decreases sharply from 65% in 1989 to 57% in 2009, whereas for fruits and vegetables and for animal products the percentage increases gradually from 2.75% and 5.5% in 1961 to 4.75% and 8.5% in 2009, respectively. The national level analysis will represent the average diet pattern of the whole country, but it may not reflect the entire complexity of the system, because there is a huge difference in interstate level and also in urban and rural and rural areas. Based on NSSO survey report (1973-2005), in most of the states (mainly the north-western and central part) energy intake in urban region is higher than its rural counterpart. In certain states(e.g. Orissa, Rajasthan, Bihar and UP) higher energy intake is due to higher manual labor (NSSO survey report, 1973-2005). But in general the fat consumption is higher in urban areas as compared to rural. The urban-rural differences in fat intake are very low in some north-western states, because their traditional diets usually containhigh fat. Unlike fat consumption, protein consumption is higher in rural areas of north-western states and is lower in southern and eastern states. Protein intake is comparatively higher in states like Punjab, Rajasthan and Haryana; this might be partly due to the fact that wheat is the staple cereal in these states and partly due to higher intake of animal products with high protein content in these states (nutrition foundation of India report).

Like per capita consumption, per capita income distribution too hashuge interstate difference, which eventually drives the variability in consumer tasteand diet pattern. In urban areas or relatively developed states like Gujarat, Maharashtra, Himachal Pradesh and Haryana are better off than rest of the country. Northern states have relatively highest household incomes. Punjab and Haryana in the plains doing well in comparison with the hilly states like Himachal Pradesh and Jammu and Kashmir. The states in the central regions like Bihar, Uttar Pradesh and Madhya Pradesh have low household incomes with lowest in Orissa. These state level contributions eventually affect the cumulative growth of the country as a whole. Therefore, we can conclude that per capita income change has most significant impact on the diet pattern of India during the last two decades. Cereals, being the major part of the Indian diet system (especially rice and wheat); although daily per capita consumption decreases, the descent is more attributable tothe change in consumption of barley, millet, maize and sorghum.For rice the trend is relatively flat (although average per capita consumption is maximum ~ 750 kcal) and a sharp ascent in per capita wheat consumptionfrom 250 kcal in 1961 to 500 kcal in 2009 might be related to the increased consumption in the form of bread and other wheat-based products like cakes, cookies, pastries etc.

4.2. Role of Green Revolution and Cropping Yield

Until 1970s India experienced low economic growth due to fluctuations in agriculture affected by seasonal monsoon. Economic liberalization in 1991 not only elevates the agricultural growth but accelerate the Indian economy and GDP to a greater extent. As mentioned before, the first wave of green revolution started in India in the late 1960s which allowed India to attain self-sufficiency by the end of 1970s. However, the technological innovations and high yielding seeds are confined to the wheat cropand in the northwest part India. Therefore, the first wave practically failed to raise the income across the country, in broader sense.

In the second phase of green revolution in the 1980s wider technological disseminations involved range of crops, including rice, coarse cereals, jowar and bajra which elevate the rural income and poverty across the country and thereby fostering India's economic development (Fujita, 2010). Implementation of private tube-wells, improved varieties of fertilizers, pesticides, and irrigation facilities further facilitated the yield of the crops (Kumar and Mittal, 2006). Thus a highly productive double cropping system of high yielding varieties of rice and wheat was established over broad rural areas, especially in the Indo-Gangetic Basin. But the implementation of green revolution technologies is not uniform throughout in India; particularly they were delayed in eastern and northeastern states in comparison with other parts of the country. Despite the fact that, Indian agriculture is boosted by green revolution but excessive technology dissemination has adverse impact on the environmental externalities such as agricultural pollution, land degradation, depletion of ground water level, etc. We have discussed these points with more details in section 5.

However, in the wake of green revolution Indian agriculture boomed up in the last several decades. From the beginning of green revolution in late 1960s the yield increases significantly from 82 MT in 1960-61 to 129 MT in 1980-1981 and 213 MT in 2003-04 (Department of agriculture and cooperation, India report), to satisfy the food demand and increase the self-sufficiency particularly in the production of cereals. In the present manuscript, we use the yield data (Hg Ha-1) available in FAOSTAT (supplementary table 2) from 1961 to 2009. Figure 3(c) shows that except sugarcane the yield of other group of food items has increased by 2-5 times, particularly for cereals. . Although, there is an overall increase in last 50 years, the yield of sugarcane decreases from 76.5 tonnes Ha-1 in 2000 to 64.5 tonnes Ha-1 in 2009, which perhaps related to the insufficient investments in fertilizers and crop protection, and disease prevalence due to genetic uniformity of varieties (Kostka*et al.*, 2009). On the other hand, the yield of cereals increases sharply from 18.3 tonnes Ha-1 in 2002 to 26 tonnes Ha-1 in 2009. Therefore, the cropping yield has a positive impact on the net LRF of the country. In our LRF calculation we too have considered the cropping intensity along with yield. As mentioned before, cropping intensity is the ratio of the total harvested area to the arable land and perma-

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nent crops (Siebert *et al.*, 2010). The net sown area of India increases by nearly 20% since 1947 (Department of agriculture and cooperation, India report) and reaches a point where it is not possible to make any appreciable increase. Cropping intensity physically refers to the raising of a number of harvests from the same area during one agriculture year. Thus, higher cropping intensity means that a higher proportion of the net area being cropped more than once. This also implies higher productivity per unit arable land during one agricultural year. Therefore, by implementing two cropping patterns the overall cropping intensity of the country increases by 11% from 1980 onwards (figure 3(d)). If we look carefully, since early 1980s the cropping intensity is greater than 1 i.e. with the implementation of advanced technology dissemination in the second phase green revolution double or multiple cropping increases the net area being cropped. Due to green revolution the cropping pattern has changed as follows, in dry or rabi season high yielding varieties of wheat and rice was substituted for pulses or the mixed cropping of pulses with local wheat and rice. In the monsoon or kharif season high yield rice was substituted for coarse cereals such as maize, jowar and bajra (Fujita, 2010). The two dips in the cropping intensity around 1987 and 2002 are perhaps due to extreme drought events. More discussion on the impact of drought on crop production is available in section 5. Thus, to a greater extent India needs to rely on cropping intensity to enhance the production and decrease the LRF by increasing the effective area of cropping.

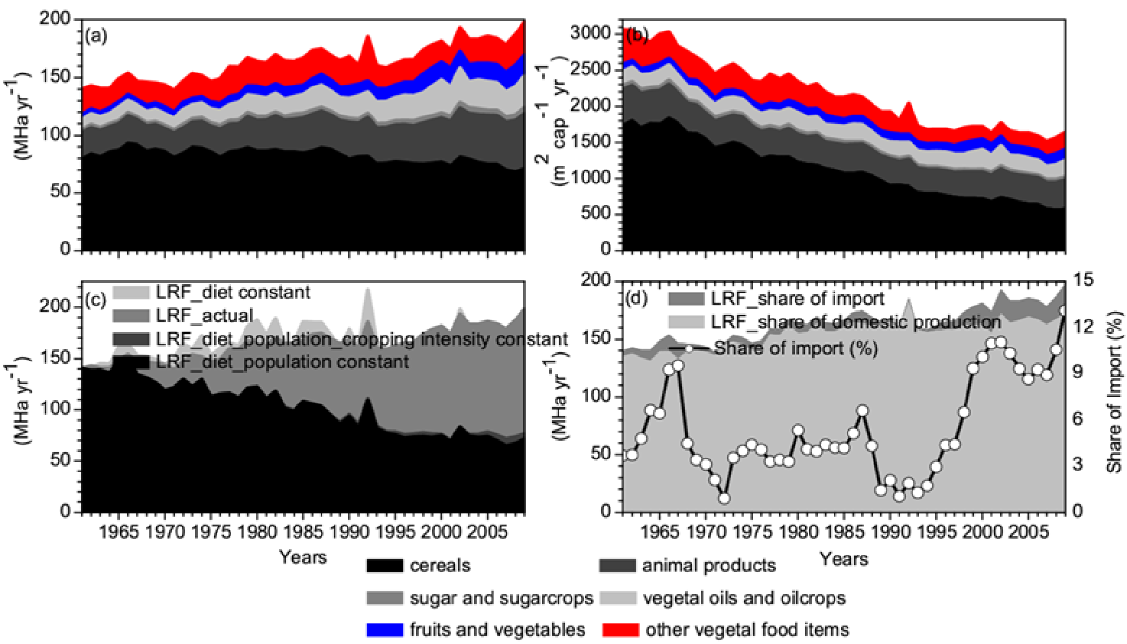

Figure4.(a) Temporal trend in total LRF (MHayear-1) for different groups of food items, (b) Temporal trend in total per capita LRF (m2cap-1year-1) for different groups of food items, (c) Impact of the individual drivers: yield, cropping intensity, population and diet on total national LRF of India, and (d) Share of domestic production and share of import on total LRF of India (left panel) and percentage share of import on total LRF (right panel), in India

4. 3. Total and per capita land requirement for food in India

Figure 4(a) shows the development of total LRF in India from 1961 to 2009. The net LRF increases by 43% from 140 MHa in 1961 to 200 MHa in 2009. Looking at the contributions of different groups of food items, in particular for sugarcane, vegetal oils and oilcrops, fruits and vegetables and animal products the average LRF increases from 2.5 MHa, 9 MHa, 4 MHa and 20 MHa in 1961 to 5 MHa, 27.5 MHa, 18 MHa and 46.5 MHa in 2009, respectively, whereas for cereals the average LRF decreases from 85 MHa to 72 MHa. Cereals, particularly rice and wheat being the major part (~60%) of the Indian dietary system, the substantial decline can be attributable to the decrease in net LRF for barley (80%), millet (47%), sorghum (62%) and maize (24%) which perhaps overshadowed the increase in LRF for rice (21%) and wheat (50%).By accounting for population growth, the total LRF increases substantially in the last few decades, whereas for the cereals the decline in LRF might be related to the implementation of improved yield due to green revolution technology. Moreover, consumption of higher amounts of animal products, fruits, vegetal oils is a crucial factor for LRF to increase and is induced by dietary change.

Interestingly, per capita arable land requirement for food in India declines continuously from 1961 to 2009 (figure 4(b)). About 3100 m2 land area was needed to satisfy the average dietper person in 1961, which substantially reduces approximately by 50% to 1600 m2 in 2009. Looking at the contribution of different food items, LRF per capita for cereals, animal products, sugarcane, vegetal oils and oilcrops, fruits and vegetables and other vegetal food items has decreased by 66%, 56%, 55%, 50%, 45% and 47%, respectively. This decrease in per capita LRF, particularly for the cereals is due to the combined effects of the increase in cropping intensity and changes in the dietary pattern towards more affluent food items.

4. 4. Individual impact of yield, population, cropping intensity and diet on LRF

As mentionedbefore, LRF is the function of population, cropping intensity, diet change (per capita consumption) and cropping yields and in the previous section the cumulative

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impacts of these drivers on LRF are presented. Implementing a sensitivity analysis on LRF,based on KN10, it is possible to analyze and quantify the impact of the individual drivers ontotal LRF, by keeping certain input factors as constant in equation 1.Doing this, an assessment of increased yields, changing cropping intensity, population growth and the dietary changes on total LRF can be made and is shown in figure 4(c). To visualize the impacts, firstly, we introduce the time variation of cropping yield only, assumingconstant population, cropping intensity and diet (daily per capita consumption) at 1961 levels. The LRF reduces by 46% (140 MHa to 76 MHa) from 1961 to 2009, due to the impact of yield only.

Consequently, we include the variation of cropping intensity (>=1) along with yield, keeping other two factors i.e. population and diet constant at 1961 levels. This further reduces the LRF to 49% (140 MHa in 1961 to 72 MHa in 2009). Next,we again introduce the actual population growth, still keeping constant 1961 diet,which eventually increases the LRF by 35% from 140 MHa in 1961 to 190 MHa in 2009 (a net increase by 84% (-49% to +35%)). Finally, the average change in diet is added to estimate the total national LRF in India, which accounts for a net increase by 42% from 140 MHa in 1961 to 198 MHa in 2009. The historical changes in population and diet pattern are already discussed in the introduction andsection 4.1, respectively.

From this experiment (figure 4(c)), it becomes clear that due to the implementation of high yield technology and irrigation, the net LRF reduces substantially by 50% from 1961 to 2009, assuming constant population and diet. Adding population growth into account, it can be ensured that it drives the major increases in LRF, especially from 1993 onwards.Until 1992, in few occasions the LRF with a constant diet surplus the actual LRF (net national LRF) and after that actual LRF overshoots significantly. This is due to the combined effect of rapid population growth and income induced dietary pattern change towards more affluent food items, which eventually reduces the average intake of per capita cereal consumption per year (figure 3(b)) from 65% in 1989 to 57% in 2009.

In this context, it is worth to mention that different natural disasters also have significant impact on agriculture (Gbetibouo and Hassan, 2005; Benhin, 2008), especially on crop yields which eventually increases the land requirement of a country (Walker and Schulze, 2008; Blignaut*et al.*, 2009).

4. 5. Share of imports on LRF

While calculating the total national LRF inIndia we consider the net consumption of the food produced in the nation's territory and also imported from outside. Therefore the net LRF is the sum total of the share of import and the share of domestic production and are presented in figure 4(d). Looking at the trends,in the 1960s the share of imports on LRF is about 10%, which eventually decreases to1% in 1990s, butafterwards the share increases steadily to 13% in 2009. Despite, being a self-sufficient nation, agricultural import increases since early 1990s. This is due to alignment of the income induced dietary pattern towards more affluent and imported food products since the 1990s. But still India ranks 16th and 14th in global agricultural import and export sectors, respectively. Usually vegetable oils are a staple food product in India and imports accounted for more than 50% vegetable oil consumption in 2011 (Baldwin and Bonarriva, 2013 (BB13)). India's primary agricultural imports in 2011 are palm oil (40%), pulses (10%) and soybean oil (7%). Additionally, the occurrences of several droughts also have direct impact on the cropping yield, which eventually increases the quantity of import in the last decade. Since our present study primarily focused on the land requirement for food in India, we exclude the share of land required to export large amounts of cash crops from our discussions.

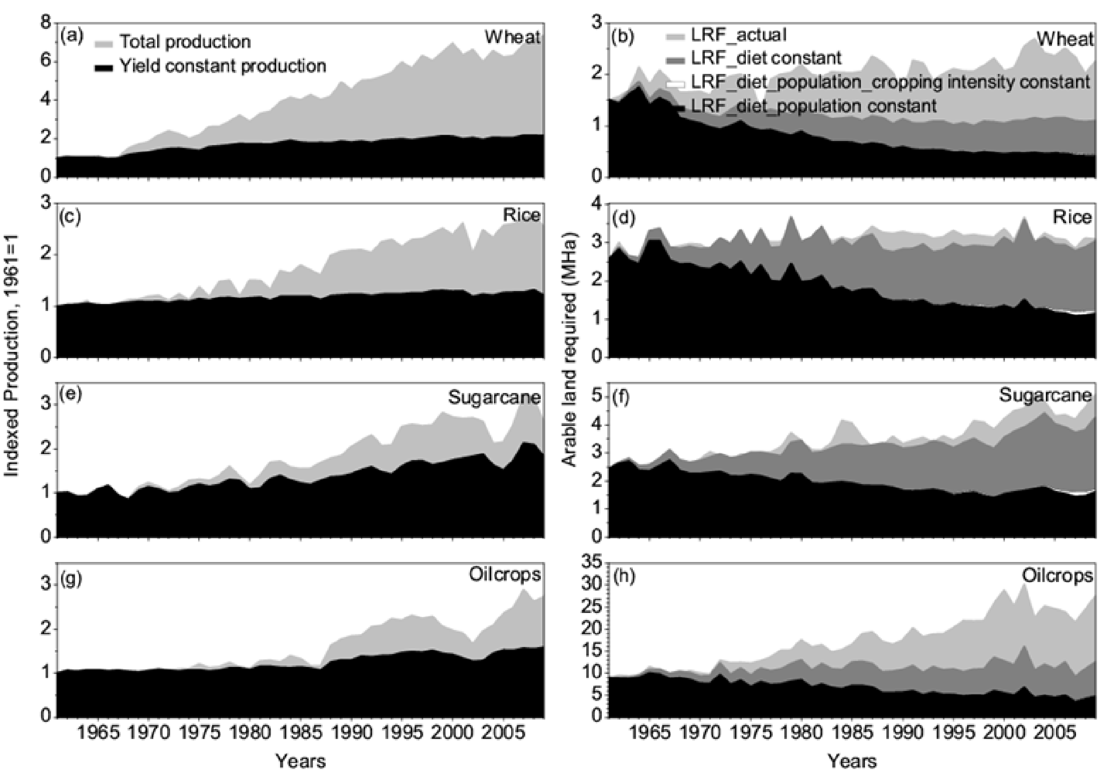

Figure5.Indexed development of total production and yield constant production of (a) Wheat, (c) Rice, (e) Sugarcane and (g) Oilcrops. Individual impact of yield, cropping intensity, population and diet on the total arable land requirement for (b) Wheat, (d) Rice, (f) Sugarcane and (h) Oilcrops in India

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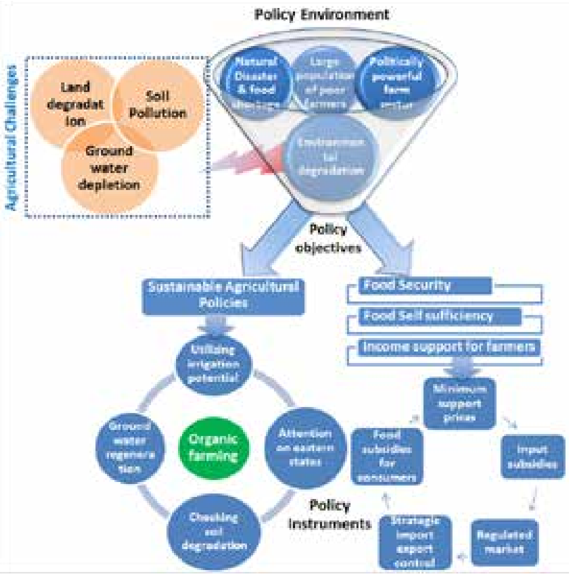
4.6. Temporal changes in production and LRF on four major crop items

So far, we analyze the total consumption trend for all the food items. These include the contributions of various food items, produced from different crops family. Based on the importance and demand in regular Indian diet we have chosen four varieties of primary food crops for further analysis. The available data for population, harvested area, crop yield and productionprovides an opportunity to execute a second sensitivity analysis for wheat, rice, sugarcane and oilcrops. The first two food items are preferred because they represent the largest share in thetraditional Indian diet. Moreover, in the last several decades the net LRF for rice and wheat increases significantly. The latter two crops are chosen, because India is the second largest producer of sugarcane and the daily per capita consumption of oilcrops increases rapidly with time. Assuming,the total production as a function of cropping yield and harvested area,

Production = Yield × Harvested Area (3)

The individual impact of these two drivers on wheat, rice, sugarcane and oilcrops are shown in figure 5(a), 5(c), 5(e) and 5(g), respectively. Firstly, we consider the variation in harvested area only, assuming constant 1961 yield. In all the four crops the yield constant production increases not more than 2 times (or even less for rice and oilcrops) in 2009 from its 1961 level, which only include the expansion in harvested area only.But when weinclude the variation in yield too with harvested area, since 1961the production of wheat increases 8 fold by 2009, whereas almost 3 fold increase is noticed for rice, sugarcane and oilcrops. For wheat and rice the cropping yield has played a significant role to overcome the demand, but for sugarcane and oilcrops the poor yield since 1990 is counteracted by the increase in the harvested area. In section 4.4, we had performed the sensitivity analysis on total LRF, but in this section we perform the analysis on four individual food items to quantify the role of the drivers separately. It is interesting to see that the population growth has significant impact on the land requirement for rice and sugarcane. But inclusion of dietary change along with population growth and technology contributes maximum for wheat and oilcrops.From figure 5(b), 5(d), 5(f) and 5(h), it becomes clear that, thenet LRF for wheat, rice, sugarcane and oilcrops increases from 1.5 MHa, 2.5 MHa, 2.5 MHa and 9 MHa in 1961 to 2.1 MHa, 3 MHa, 5MHa and 27 MHa in 2009, respectively. This is due to the alignment of the Indian diet pattern towards wheat based affluent food items like cake, cookies, pastries and intake of fat based oil products. As discussed in section 4.1, these changes in food demand and taste are induced by economic growth in the last few decades.



Source: Baldwin and Bonarriva 2013, Hoda and Gulati 2013

Figure 6.Governrnent policy environment, objectives and instruments for food security and sustainable agriculture.

5. Government Policy for sustainable agriculture and food security

While discussing the government policies toward agriculture, it is very essential to realize the environment in which the policies were undertaken. Firstly, India experienced widespread famines and droughts in the recent histories; the goal of attaining self-sufficiency in major food grains is a political issue (BB13). For the countries like India, in which rainfall is seasonal in nature, agriculture often planned with the monsoon season (June-September). Therefore, any deficiency in rainfall, thus have a direct impact on agriculture and the economy of the country.

Secondly, abundance of poor farmers in rural areas with large share of employment based in smallholder agricultureprovides thrust to the policymakers. Thirdly, politically powerful farm sectors deprive the poor farmers in the rural areas economically (BB13). Lastly, environmental degradation due to excessive farmingand irrigation may lead to land degradation, ground water depletion and soil erosion. Additionally, introduction of modern technology, application of excessive chemical fertilizers, pesticides leads to soil toxication and pollution.

Therefore, in the last decade and halfgovernment undertook several policies, schemes and missions with the intent of achieving three overarching goals; stability of supplies, stability of prices and income stability of farmers' incomes (BB13). Government launches several programs like, National Agricultural Insurance Scheme (1999-2000), National Horticulture Mission (2005-2006), National Agricultural Development Plan (2007-2008), National Mission on Micro Irrigation (2007-2008), National Food Security Mission (2007-2008), Weather Based Crop Insurance Scheme (2007-2008) and National Food Security Bill (2011) to ensure the food security and income support to the farmers, as well (Hoda and Gulati, 2013). To achieve these goals policy instruments include minimum support prices, food subsidies for consumers, regulated market, input subsidies in credit

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or bank loan, irrigation, power, high yielding seed, fertilizer etc. and strategic import export control. The agricultural trade policy is consistent with government's long-standing attempts to regulate trade to protect the domestic producers from global competition and international price fluctuations. The agricultural import duties are calibrated carefully with domestic support prices (BB13).

Despite fulfilling the objective of increasing food production consistently, additional effort and policies need to be implemented to foster sustainable agriculture, ensuring sustainable use of land and water resources. Firstly, the investment made by central and state governments in the irrigation projects created gap between irrigation potential created and utilized, due to wastage of water. Secondly, central government had undertaken a massive program for groundwater regeneration through watershed development program, construction of dams for stabilizing ground water level and rain water storage (Ackermann, 2012; Richard, 2012). Thirdly, the farmers in the eastern Indian states rely predominantly on diesel pumps than on electric pump. The diesel pump not increase the cost pressure, it is non eco-friendly too. Lastly, a program is initiated to restrict excessive use of toxic nitrogenous and phosphatic fertilizers and pesticides and promote the use of bio-fertilizers, organic manure, and bio-compost and soil organic carbon (Hoda and Gulati, 2013). Therefore, to address the problems, future policies have laid emphasis on promoting sustainable agriculture and organic farming.

6. Conclusions and discussions

Rapid population growth, economic development, diet diversification and urbanization have significant impacts on Indian society, thereby increase the food consumption and impose excessive pressure on arable land demand. The statistical analysis of arable land requirement for food in India from 1961-2009 shows that the LRF is mainly driven by four primary factors, viz. population growth, per capita consumption (diet), cropping yield and cropping intensity. Sensitivity analysis showed that the total LRF increases by 43%, whereas per capita LRF decreases significantly by 45% from 1961 to 2009. By accounting for population growth the total LRF increases rapidly, but the decline in per capita LRF is due to the implementation of improved yield due to green revolution technology. Moreover, the consumption of higher amount of animal product is a crucial factor for the LRF to increase. Additionally, due to dietary change, the consumption of food items such as fruits, vegetal oils and stimulants, commonly have higher land requirements than cereals.

Our historical assessment reveals that due to rapid population growth the total food consumption of India increases from 150MT in 1961 to 500 MT in 2009, whereas, the daily per capita consumption of oilcrops, fruits and vegetables, animal products and sugarcane increases rapidly but for cereals, it decreases significantly from 1990 onwards. This perhaps related to income, induced dietary pattern change, per capita income growth, globalization and transformation of food consumption patterns of Indian households, especially in the urban areas. The cereal consumption is substituted by the consumption of more affluent food items like fruits, vegetables and animal products. The change in consumer tastes and demand has critical implications for the whole food supply system. Based on the priority and demand we have chosen four major crops like wheat, rice, sugarcane and oilcrops for further sensitivity analysis. The results show that for rice and sugarcane, population played the significant role, but for wheat and oilcrops changing diet pattern contribute maximum to the net LRF. This is due to the alignment of the Indian diet pattern towards wheat based affluent food items like cake, cookies, pastries and intake of fat based oil products.

This increasing demand in food consumption can only be supplemented by improved cropping yield. The waves of green revolution since late 1960s allowed India to attain self-sufficiency in rice and wheat by the end of 1970s and thereby fostering India's economic development. The widespread implementation of tube-wells enabled the farmers to cultivate in two seasons which thereby increases the net area being cropped. Despite the fact that, Indian agriculture is boosted by green revolution but excessive technology dissemination has adverse impact on the environmental externalities such as agricultural pollution, land degradation, depletion of ground water level, etc.

Therefore, to counteract the food demand government undertook several policies, schemes and missions with the intent of achieving three overarching goals; stability of supplies, stability of prices and income stability of farmers. To achieve these, the policy instruments include minimum support prices, food subsidies for consumers, regulated market, input subsidies in credit or bank loan, irrigation, power, high yielding seed, fertilizer etc. and strategic import export control. Despite fulfilling the objectives additional efforts and policies need to be implemented to foster sustainable agriculture, ensuring sustainable use of land and water resources. It is expected that further economic and population growth will exert more pressure on arable land in future, but it remains to be proven, how such targets can be translated into workable policies in a sustainable manner.

Supplementary Tables

Supplementary table 1.Geo-Political divisions of India

North West India	Haryana
	Himachal Pradesh
	Jammu & Kashmir
	Punjab
	Rajasthan
	Uttar Pradesh
	Uttarakhand
Central India	Chhattisgarh
	Gujarat
	Madhya Pradesh
	Maharashtra
	Orissa
Southern India	Goa
	Andhra Pradesh
	Telengana
	Kerala
	Karnataka
	Tamil Nadu
East and North East India	Assam
	Bihar
	Jharkhand
	Tripura
	West Bengal
	Arunachal Pradesh
	Assam
	Manipur
	Meghalaya
	Mizoram
	Nagaland
	Sikkim

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Supplementary table. 2 Parameter name, FAOSTAT element/items and FAOSTAT category as presented in this paper

Parameter	FAOSTAT element/ item (unit)	FAOSTAT category
Population	Total Population-Both sexes (1000)	Resources/Population/Annual time series
Food production	Production Quantity (tonnes)	Production/(Crops/ Livestock)
Food consumption	Food (1000 tonnes)	Food Balance Sheets/Food Balance Sheets
Daily per capita consumption	Food supply quantity (kcal capita-1 day-1)	Food Balance Sheets/Food Balance Sheets
Crops yield	Yield (Hg Ha-1)	Production/Crops
Area harvested	Area Harvested (Ha)	Production/Crops
Total arable land	Arable land and Permanent crops (1000 Ha)	Resources/Resources/Land
Share of Import/Export	Import/Export Quantity (1000 tonnes)	Food Balance Sheets/Food Balance Sheets

Supplementary table. 3 List of food items as available in FAOSTAT's Food Balance Sheets, with corresponding primary crops; conversion factor from food items to primary crops, based on caloric equivalents (column 7 = column 4/column 6); aggregations according to FAOSTAT India database and as presented in this paper are shown

Aggregation in this paper	FAOSTAT category	Food item	kcal/ 100 g	Primary food item	kcal/ 100 g	Conversion factor
Cereals	Cereals-excluding beer	Wheat	334	Wheat	334	1.00
		Rice (milled equivalent	360	Rice, paddy	280	1.29
		Barley	332	Barley	332	1.00
		Maize	356	Maize	356	1.00
		Millet	340	Millet	340	1.00
		Sorghum	343	Sorghum	343	1.00
		Cereals, other	340	Cereals, other	340	1.00
		Beer	49	Barley	332	0.15
		Beverages, fermented	61	Barley	332	0.18
Sugar and sugarcrops	Sugarcrops	Sugarcane	30	Sugarcane	30	1.00
	Sugar and sweeteners	Sugar, non-centrifugal	351	Sugarcane	30	11.70
		Sugar (raw equivalent)	373	Sugarcane	30	12.43
		Sweeteners, other	318	Sugarcane	30	10.60
		Beverages, alcoholic	295	Sugarcane	30	9.83
Vegetal oils and oilcrops	Oilcrops	Soyabeans	335	Soyabeans	335	1.00
		Groundnuts (shelled Eq)	567	Groundnuts, with shell	414	1.37
		Rape and Mustardseed	494	Rape and Mustardseed	494	1.00
		Coconuts-Incl Copra	184	Coconuts-Incl Copra	184	1.00
		Sesameseed	573	Sesameseed	573	1.00
		Sunflowerseed	308	Sunflowerseed	308	1.00
		Cottonseed	253	Cottonseed	253	1.00
		Olives	175	Olives	175	1.00
		Palmkernels	514	Oil palm fruit	158	3.25
		Oilcrops, other	387	Oilcrops, other	387	1.00
	Vegetable oils	Soyabean oil	884	Soyabeans	335	2.64
		Groundnut oil	884	Groundnuts, with shell	414	2.14
		Sunflowerseed oil	884	Sunflowerseed	308	2.87
		Rape and Mustard oil	884	Rape and mustardseed	494	1.79
		Cottonseed oil	884	Cottonseed	253	3.49
		Coconut oil	884	Coconuts-Incl copra	184	4.80
		Sesameseed oil	884	Sesameseed	573	1.54
		Ricebran oil	884	Rice, paddy	360	2.45
		Maize Germ oil	884	Maize	356	2.48
		Palm oil	884	Oil palm fruit	158	5.59
		Olive oil	884	Olives	175	5.05
		Oilcrops oil, other	884	Oilcrops, other	387	2.28

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Aggregation in this paper	FAOSTAT category	Food item	kcal/ 100 g	Primary food item	kcal/ 100 g	Conversion factor
Fruits and vegetables	Alcoholic beverages	Wine	68	Grapes	53	1.28
	Fruits	Orange	34	Oranges	34	1.00
		Lemons	15	Lemons	15	1.00
		Grapefruit	16	Grapefruit	16	1.00
		Citrus, other	26	Citrus, other	26	1.00
		Bananas	60	Bananas	60	1.00
		Apples	48	Apples	48	1.00
		Pineapples	26	Pineapples	26	1.00
		Grapes	53	Grapes	53	1.00
		Dates	156	Dates	156	1.00
		Fruits, other	45	Fruits, other	45	1.00
	Vegetables	Tomatoes	17	Tomatoes	17	1.00
		Onions	24	Onions	24	1.00
		Vegetables, other	22	Vegetables, other	22	1.00
Other vegetal food items	Starchy roots	Cassava	109	Cassava	109	1.00
		Potatoes	67	Potatoes	67	1.00
		Sweet potatoes	92	Sweet potatoes	92	1.00
	Pulses	Beans	341	Beans	341	1.00
		Peas	346	Peas	346	1.00
		Pulses, other	340	Pulses, other	340	1.00
	Treenuts		262	Treenuts	262	1.00
	Stimulents	Coffee	47	Coffee	47	1.00
		Cocoa beans	414	Cocoa beans	414	1.00
		Tea	40	Tea	40	1.00
	Spices	Pepper	276	Pepper	276	1.00
		Cloves	323	Cloves	323	1.00
		Spices, other	337	Spices, other	337	1.00
Animal products	Meat	Cattle Buffalo	238 77			
		Duck Chicken	291 122			
		Sheep Goat	263 123			
		Pig	220			
		Meat, other	126			
	Offals	Cattle offal	105			
		Buffalo offal	105			
		Duck offal	136			
		Chicken offal	125			
		Sheep offal	117			
		Goat offal	117			
		Pig offal	113			
		Meat offal, other	105			
	Milk-excluding butter	Cow	61			
		Buffalo	97			
		Goat	69			
	Animal fats	Cattle fat	847			
		Buffalo fat	847			
		Duck fat	629			
		Chicken fat	629			
		Sheep fat	902			
		Goat fat	847			
		Pig fat	712			
		Meat fat, other	720			
	Butter	Cow	717			
		Buffalo	717			
		Goat	717			

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