Abstract

 Sustainable food production is a key concern across countries in South Asia. Most assessments of sustainable agriculture in this region focus on the availability and affordability of resource inputs. However, studies accounting for environmental footprint of agricultural activities in South Asian countries are limited in the existing literature. This paper analyzed the environmental impact of energy utilization in agriculture in India and Pakistan. More specifically, the study analyzes the trends of fuel and electricity consumption for crop production in these countries during a ten-year period between the years 2002 and 2011. Life cycle impact assessment categories including global warming potential, human toxicity, acidification and eutrophication were used to holistically analyze the end-user impact of energy consumption. Results indicated an increase in these impacts for both countries during the study period. On a per hectare basis, the assessed impacts were relatively greater in India than in Pakistan during the study period. The main reason behind larger impacts in India was its significantly greater use of coal for electricity generation. Overall, this study showed that further electrification of agriculture will not necessarily lead to cleaner environment in these countries. Due to high population growth rates, energy consumption for agriculture is expected to grow in these countries in the future. Unless cleaner sources of electricity are used, further energy intensification in agriculture will be detrimental to ecosystem and human health, which in turn will be counterproductive for sustainable agriculture.

Keywords

South Asia; agriculture; energy consumption; decade; life cycle impact assessment.

1. Introduction

 Today we live in a globalized world where environmental footprint of natural resource consumption cannot be confined within political boundaries of one country only. For instance, carbon emissions in one country can spread across the globe thus representing the tragedy of commons (Raupach et al., 2014), (Ali et al., 2018b). Similarly, human induced climate change can cause droughts, cyclones and floods in different regions across the globe (Milly et al., 2002). Thus, transboundary ecosystem services need to be managed at a multilateral level. A failure to cooperate for an effective & responsible management of these assets can lead to temporary or permanent elimination of the ecosystems themselves or some of their supporting functions.

 South Asia is home to some of the largest national populations in the world numbering over 1.5 billion people and covering a total land area of 5.1 million Km2 (Linoj et al., 2006). Within South Asia, Pakistan with 201 million people is the fifth most populated country in the world while India is the second most populous country in the world, with a population of 1.3 billion people (World Bank, 2010-2014). These populations are projected to increase further in the future owing to the high population growth rates in both countries (Rasul, 2014). This scenario has obvious implications for food and nutritional security in these countries. Currently, 60% of all Pakistanis are food insecure (WFP Pakistan, 2018) and Pakistan is at the 77th position on the Food Security Index, while India is at the 74th position (Economic Intelligence Unit, 2017). Thus, sustainability of natural resource inputs is necessary to maintain adequate agriculture in this region.

 Since their independence in 1947, there have been different studies tracing the trajectory of both India and Pakistan using different economic, social and political parameters. Previous studies have been conducted to compare economic pointers (Shah et al., 2006), nutritional indicators (van den Bold et al., 2015) or productivity factors (Murgai et al., 2001). Relatively few researchers have holistically compared the environmental sustainability of agricultural systems in India and Pakistan (Benbi and Brar, 2009). Given these drawbacks and the paucity of scientific studies gauging the sustainability of crop production in South Asian countries, it is imperative to consider current and future food and water security challenges in the assessment of agricultural sustainability in these countries.

 India and Pakistan need to increase their agricultural outputs, and reduce their environmental and resource footprints simultaneously. However, both countries lack skilled labor and technical capabilities to achieve this. To cope with an increasing food demand, intensive means of agricultural production are taxing natural resources in both countries. This study aims at exploring some of these challenges by comparing the environmental impact of energy utilization for crop production in both India and Pakistan over a decade. This exercise will, compare for the first time, the impact of resource intensification on populations and ecosystems emanating from agriculture in these countries. This can help policy-makers take a holistic view of the situation and make collective decisions in an otherwise hostile geopolitical environment.

 In this study, we focused on the countries of India and Pakistan because there the agricultural land is rapidly being converted into urban settlements and the scope of future agricultural expansion in these countries is limited (Baloch, 2011), (Pandey and Seto, 2015). Overexploitation of ecosystem services might threaten future agricultural productivity in these countries. Thus, future intensification of crop production should be carried out in a way that avoids detrimental environmental impacts. This can help ensure sustainability of future food production for both countries. This is important because India and Pakistan are also two of the largest producers in the world of major food crops such as wheat, rice, cotton, sugarcane, etc., thus ranking among the top 10 countries in terms of agricultural output (Ray et al., 2013). Agriculture is one of the main assets of Pakistan’s economy contributing more than 25% to the national GDP and employing more than 50% of the labour workforce (Pakistan Bureau of Statistics, 2011). Similarly, the share of agriculture to the national GDP in India is 18.1% and this sector employs 48.8% of the total labour force (Directorate of Economics & Statistics, 2016). Thus improving agricultural sustainability in the Indo-Pak region is primordial for the local population as well as the rest of the world that relies on food imports from these countries.

1. Material & Methods

 Life cycle assessment (LCA) analyzes the environmental impacts of a product or process throughout its life cycle (Ali et al., 2016). It consists of different steps including need & scope definition, establishment of boundary conditions & functional unit, collection of raw data to develop a life cycle inventory, and Life Cycle Impact Assessment (LCIA) followed by interpretation of results (Campion et al., 2012). LCIA is the stage in which the inventory data are translated into impact categories (e.g. ecotoxicity and global warming potential) (Esnouf et al., 2018). The case study involves LCIA of direct and indirect fuel inputs required to grow crops in Pakistan and India between years 2002 and 2011. LCIA is a standardized procedure to assess different environmental impacts across production and process chains. The benefits of using LCIA to compare resource use intensity in agriculture include (i) a common scale to measure impacts at different levels of resource consumption, (ii) identification of tradeoffs between different technologies, e.g., direct fuel use vs electricity consumption and (iii) recognition of appropriate impact mitigation strategies (Henriksson et al., 2018). The central question that we attempt to answer through LCIA is how does changing energy use intensity in crop production in the Indo-Pak region affect ecosystems and human health on a local scale? this will help policy-makers realize their stake in introducing better environmental controls in crop production activities.

 In this paper, we only focus on the environmental impacts of direct energy use in Indian and Pakistani agriculture. Direct energy consumption in agriculture in the Indo-Pak region mainly involves electricity and fuel use for operating agricultural machinery, tube wells and transportation vehicles used during irrigation, harvesting and other field operations. Indirect energy inputs include energy used for production of material inputs such as machinery, seeds, fertilizers & pesticides, etc. Here, the temporal system boundary consisted of 1 year to produce all crop varieties in a given hectare of farmland. This year consisted of the period from July 1 to June 30 next year, as reported in the government issued national statistical reports for both India and Pakistan. The spatial boundary included total sown area in each country consuming direct energy inputs such as fuel and electricity. As discussed earlier, forward and backward linkages in the agricultural supply chain such as seed & fertilizer production, storage, etc., were excluded from the present analysis.

 To study the local impacts we will examine impact categories including human toxicity to measure the direct impact on human health and acidification & eutrophication to measure the impact on local ecosystems. The impacts of Eu and GWP correspond closely to the main planetary boundaries for which food production is a major driver and together, these impacts can provide a comprehensive picture of the studied environmental impact (Henriksson et al., 2018). Additionally, global warming potential of energy use in agriculture will also be determined. The functional units used in this paper are given below

1. Fuel consumption: electricity - MWh/ha, fossil fuel - GJ/ha.
2. Human toxicity (HT): grams 1,4 dichlorobenzene eq./ha.
3. Eutrophication (Eu): grams PO4 equivalent/ha.
4. Global warming Potential (GWP): grams CO2 equivalent/ha.
5. Acidification (Ac): grams g SO2 equivalent/ha.

 Data for all calculations was obtained from government resources. The characterization factors and units for these impacts correspond to CML 2000 baseline (Armines et al., 2010). Despite the availability of useful energy statistics, there was a lack of consistent supplementary agricultural data before 2002 (for India) and beyond the year 2011 (for Pakistan). Hence, the LCIA comparison period was confined to the period between 2002 and 2011. This is significant as this ten-year period roughly coincides with the first decade of the twenty first century. As such, the analysis for this period can act as a benchmark for future decadal studies. IPCC’s default emission factors were used for the year 2006 while making all calculations (Ministry of Climate Change, 2016). Data for fuel and electricity inputs were obtained from the national statistics bureaus and ministries in India and Pakistan (Directorate of Economics & Statistics, 2016; Pakistan Bureau of Statistics, 2011) as well as from the website of the International Energy Agency (IEA) (International Energy Agency, 2016). All calculations for the LCIA have been provided in the Supplementary excel file.

1. Results

 Fig. 1 and 2 given below display the yearly change in fuel and electricity intensity in agriculture for Pakistan and India, respectively. It can be observed that in Pakistan, since 2002, a decrease in fuel consumption per hectare was matched with a corresponding increase in electricity consumption. While the sown area in Pakistan increased by 5.79% between 2002 and 2011, the corresponding fuel use per hectare decreased by 78.29% and electricity use per hectare increased by 51.24%. On the other hand, in India, while electricity consumption increased gradually since 2003, fuel consumption started increasing continuously only after 2008. Overall, while the sown area in India increased by only 0.59% between 2002 and 2011, the fuel and electricity use per hectare increased by 6.91% and 53.83%, respectively. A slight increase in fuel consumption in 2008-2009 was also experienced in crop production sector in Pakistan. This can be partly attributed to external factors such as changing international fuel and food prices. On the whole, Pakistan reduced fuel consumption while increasing electrification for crop production, whereas in India both fuel and electricity consumption increased during the study period.

[Insert Figure 1 here]

[Insert Figure 2 here]

 Fig 3 shows the change in LCIA characterization factors for Pakistani and Indian crop production systems between the years 2002 and 2011 in terms of HT, Ac, Eu, and GWP. On a per hectare basis, Eu for Pakistani crop production system increased by 10.81% with an annual average value of 6.35 E-02 g PO4 eq. HT increased by 17.96% with an annual average value of 7.75 E-01 g 1,4 dichlorobencene eq. Ac increased by 36.26% with an annual average value of 2.65 E+00 g SO2 eq. and GWP increased by 11.34% with an annual average value of 1.82E+02 g CO2 eq. On a per hectare basis, Eu for Indian crop production system increased by 46.84% with an annual average value of 2.03 E-01 g PO4 eq., HT increased by 59.62% with an annual average value of 3.97 E+00 g 1,4 dichlorobencene eq., Ac increased by 33.54% with an annual average value of 2.74 E+01 g SO2 eq., and GWP increased by 41.77% with an annual average value of 7.77E+02 g CO2 eq. Detailed calculations for the measurement of the factors have been provided in the Supplementary file.

[Insert Figure 3 here]

1. Discussion

 There is a need to ascertain the reason behind the differences in results for both countries. In order to do that, we analyzed the fuel mix for electricity production in both countries. It was revealed that the main fuel sources for electricity production in Pakistan were natural gas and furnace oil while for India electricity was mainly produced from coal and natural gas. For the 10-year period the relative share of furnace oil, natural gas and coal for India were 4.69%, 11.10% and 84.21% respectively while those for Pakistan were 42.67%, 56.69% and 0.64% respectively. In absolute terms in India, consumption of coal and natural gas for electricity generation increased while that of furnace oil decreased each year during the study period. On the other hand, in Pakistan, the consumption coal and natural gas for electricity generation decreased while that of furnace oil increased each year during the study period. Fig. 4 and 5 display average share of fossil fuels for electricity consumption in Indian and Pakistani agriculture for the study period.

[Insert Figure 4 here]

[Insert Figure 5 here]

 For the study period, the percentage shares of average indirect emissions from electricity consumption and average direct emissions from fossil fuel consumptions are given for both India and Pakistan in Fig. 6 and 7, respectively. It can be seen that in case of India CO2, SO2 and CH4 emissions from electricity consumption were significantly higher than those from fossil fuel combustion. Whereas in case of Pakistan, fossil fuel combustion generated relatively higher emissions with the exception of CO2 and SO2 emissions. Due to high coal consumption for electricity generation, the rate of increase in HT, Eu and Ac in India was much greater than that in neighboring Pakistan which used relatively negligible amount of coal for electricity generation.

[Insert Figure 6 here]

[Insert Figure 7 here]

Other studies estimating emissions from crop production usually focus on a single crop species such as rice (Koga and Tajima, 2011) or a specific impact category such as GWP (Meisterling et al., 2009). Even so, the results might vary between different studies accounting for same category of impacts for same crop species. For instance a review of six publications found that the annual energy use and GHG emissions associated with corn (*Zea mays* L.) production ranged from 5.72 to 12.06 GJ per ha and  2.44 to 4.20 ton CO2 eq per ha, respectively (Farrell et al., 2006). Most of these variations in results come from differences in data sources, crop management and data modeling techniques (Camargo et al., 2013). This makes it difficult to compare the present analysis with previous studies. Nevertheless, being one of the first studies of its kind for the subject region this study can act as a reference for similar studies in other regions across the world. Moreover, researchers can expand the depth of this study to analyze emissions across the provincial or the district level in South Asia. This study can also be useful for future interdisciplinary research involving topics such as tradeoffs between ecosystem services, agriculture and Circular Economy (Power, 2010), (Ali et al., 2018a).

1. Conclusions

 Agriculture makes significant contributions to the global food system and as such identification of impacts of energy intensification in crop production provides an opportunity to avoid some of its environmental pitfalls. In this paper, our intention was to display the environmental footprint of such intensification by using life cycle impact categories including GWP, Au, Ac and Eu. Policy-makers can use the results of this study to identify strategies that can limit these impacts. Such strategies may vary from innovative farming techniques such as drip or sprinkler farming to greater use of greenhouses. An extensive discussion of such remedies is beyond the scope of this paper as the main objective of this study was to show the environmental effects of current practices and suggest that the situation would grow worse in the absence of corrective actions.

 A limitation of this study is that we only considered the crop-production systems and ignored livestock, poultry and fisheries sectors. Moreover, since crop production can be affected by natural events or adverse weather conditions, this might cause some results to deviate from trend lines. It is also important to note here that both countries might have a different mix/yield of crops on a per hectare basis apart from differences in tillage, fertilizer use, or crop rotations. As such, they might have different direct energy requirements per yield of crops. Such differences might exist even at the province/division levels. In this study, the use of hectares as a unit of references has been done precisely to address this. By taking aggregate sums for the whole country we have attempted to de-link the energy consumed from individual products. A more in-depth analysis could compare, say, LCIA results for Basmati production in Indian and Pakistani Punjab regions. However, since this study has been organized as a short communication, we have mainly focused on how per-hectare emissions have been changing in both countries over time and how the choice of fuel mix is driving these changes.

 Future studies can build on the foundation laid by the present study to analyze crop-wise, location-specific and seasonal resource footprints of crop production within India and Pakistan. Moreover, other countries in South Asia can be included in future assessments for benchmarking and comparison purposes. Finally, comparisons can be made with developed countries to assess strategies for improvement. It is essential to highlight the subject issue through scientific and journalistic outlets to stimulate further research and to attain due attention from the concerned authorities. As such, it is hoped that the present study will gain due attention from policy-makers and practitioners to effect a positive change.

1. Conflict of interest

 The authors declare no conflict of interest.

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Figure Captions

Fig. 1. Change in energy use intensity for Pakistani agriculture.

Fig. 2. Change in energy use intensity for Indian agriculture.

Fig. 3. LCIA categories for Indian and Pakistani agriculture.

Fig. 4. Share of fossil fuels for electricity consumption in Pakistani agriculture.

Fig. 5. Share of fossil fuels for electricity consumption in Indian agriculture.

Fig. 6. Source wise emissions from energy consumption in Indian agriculture.

Fig. 7. Source wise emissions from energy consumption in Pakistani agriculture.