

What Contribution Can Surface Water Irrigation Make to Sustainable Crop Intensification in Bangladesh's Feed the Future Zone?

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Background and Objectives

Global food requirements are projected to increase until 2050. In South Asia, average wheat, maize and rice yields have however increased by only 2.2 percent, 1.4 percent and 1.3 percent, respectively, since the 1960s.¹ Rather than raising yield, crop production can be increased by expanding cultivated land area, though this has undesirable environmental outcomes such as biodiversity loss. The potential for agricultural expansion in South Asia is also limited because most arable land is cropped for at least part of the year, usually during the monsoon. Farm area per capita in South Asia has also shrunk by 63 percent since 1961, to approximately 0.1 hectare per person.²

Sustainable intensification (SI) has been proposed as an alternative to area expansion. SI aims to augment land productivity by increasing resource use efficiency while minimizing environmental trade-offs.³ An important SI strategy is increasing the number of crops grown per year on the same land, thereby raising yield per unit of area-time, while minimizing land expansion.⁴ Achieving such 'double cropping' will often require irrigated dry season cropping to overcome moisture constraints to adequate yields.

The Government of Bangladesh (GoB) recently adopted policy calling for investment of over US\$ 7 billion to support agricultural development in southern Bangladesh.⁵ Approximately 1.7 million farm households crop only during the monsoon, contributing to food insecurity.⁵ Of the funds requested by the GoB, US\$ 500 million is to be allocated for surface water irrigation to transition farmers from monsoon rice-fallow or rain fed systems into double cropping. Further emphasis is placed on increasing dry *boro* season rice production,⁵ to offset increasing production and energy subsidy costs in existing *boro* areas reliant on groundwater. The viability of this approach has however been questioned given the southern region's soil salinity constraints and concerns over the long-term effects of climate change.



The Cereal Systems Initiative for South Asia (CSISA) is a regional initiative to sustainably increase the productivity of cereal-based cropping systems, thus improving food security and farmers' livelihoods in Bangladesh, India and Nepal. CSISA works with public and private partners to support the widespread adoption of resource-conserving and climate-resilient farming technologies and practices. The initiative is led by the International Maize and Wheat Improvement Center (CIMMYT), implemented jointly with the International Food Policy Research Institute (IFPRI) and the International Rice Research Institute (IRRI), and is funded by the US Agency for International Development (USAID) and the Bill & Melinda Gates Foundation.

The objectives of this study were therefore to respond to government need and assess the extent of fallow and rain fed cropland that can be brought under cereal production during the dry season using surface water irrigation.

Methodology*

We considered 33,750 km² in Bangladesh's Feed the Future Zone (FtF), encompassing all land to the South and West of the Ganges and Padma rivers, excluding the Sundarbans forest. This study followed a multi-step spatial assessment, followed by crop production potential scenario analysis.

Quantification of Agricultural Land and Surface Water:

Cropland was identified using Landsat 5 scenes acquired in late January, 2010. At that time of the year, crop vegetation cover is generally low and can be separated from other land cover classes, such as forest or settlements. Next, we used Landsat 5 imagery acquired at the end of monsoon to identify rivers, canals and water bodies. Some water bodies dry out during the dry season. We therefore quantified water availability using an Automated Water Extraction Index calculated from monthly Landsat 8 imagery. A 375-meter buffer indicative of potentially irrigable area was then created around polygons of available water in March (when pre-monsoon rains begin).

Spatial Assessment of Current Cropland Productivity:

Enhanced vegetation index (EVI) was used to assess current crop productivity. Geo-referenced fields of lathyrus, lentil, mungbean, fallow land, *boro* rice, wheat, maize and mustard were selected for EVI extraction from Landsat 7 and 8. EVI values for each crop were plotted as a function of the number of days before or after January 1, until the 100th day of the year, corresponding to the period irrigation is needed most. Crops were then grouped into three intensity classes, including (1) fallow land (2) low-intensity crop land with legumes (lathyrus, lentil and mungbean) that are typically not fertilized, weeded, or irrigated and (3) high-intensity crop land, including wheat, *boro* rice, maize and mustard, which are grown with higher fertilizer application, pest management and usually irrigation. Maximum EVI (corresponding to peak productivity) for each group was subjected to an ANOVA for three consecutive dry *rabi* seasons of Landsat observations. Intensity classes were consistently and significantly different. We therefore set thresholds for each crop production intensity group and classified the corresponding EVI values for each pixel of the entire FtF zone.

Assessing Salinity Dynamics and Relative Landscape Elevation:

We assembled surface water salinity readings ($n = 4,821$) from the Bangladesh Water Development Board (BWDB) from 2002-2012 and analyzed the first 14 weeks of each year, extracting the 90th percentile of observations as a conservative index for water salinity. The temporal progression of saltwater intrusion was next interpolated by Kriging. Considering soil quality and to identify cropping suitability, maximum soil salinity measurements at the end of the dry season before precipitation were utilized. The SRDI coastal salinity map⁶ was selected as the most methodologically robust data source. Data were reclassified into three classes using the highest reported value for each spatial unit as the basis for reclassification. In order to limit analytical complexity for soil and water salinity given

the range of potential *rabi* season crop species, we created three irrigation water and soil salinity classes including 0–2, 2.1–4, and > 4.1 deciSiemens per meter (dS/m) bins, which we labeled as high- and medium-quality, and low-quality water or soil, with the latter bin considered as poorly suitable for high-yielding rice, wheat, or maize growth (Table 1).

Table 1. Analytical matrix to land potential for cropping using surface water irrigation.

Soil (dS/M)	Water (dS/M)		
	0 – 2	2.1 – 4	> 4
0 – 2	High potential	Medium potential	Marginal potential
2.1 – 4	Medium potential	Low potential	Marginal potential
> 4	Marginal potential	Marginal potential	Marginal potential

Note: Land identified as marginal was excluded and not considered in the analysis.

In Bangladesh, monsoon season flood inundation classes provide an indicator of relative landscape elevation, which also influences dry *rabi* season crop species suitability. Inundation class shapefiles were therefore collected from BARC⁷ and overlaid on the preceding datasets. Lowland and very lowland, which are poorly suited for *rabi* cropping, were removed from further analysis.

Cereal Production Scenario Analysis:

Yields and profits achieved by 510 irrigated wheat, 550 irrigated maize, and 553 irrigated *boro* rice farmers in the FtF zone were measured over the three study seasons. Georeferenced yields and profits were categorized by land potential following Table 1, with each crop's cumulative distribution function (CDF) plotted to identify yields and gross margins in high and medium potential index classes at the 25th, 50th and 75th percentiles (equivalent to $P = 0.75$, $P = 0.50$, and $P = 0.25$, respectively, Figure 1 Top). As noted above, the land upon which dry *rabi* season crops can be grown in Bangladesh is partially governed by monsoon flood inundation classes indicative of relative landscape elevation.⁷ Wheat is generally suited to Medium-Highland-1 and -2 and higher classes.⁴ Maize is usually established on the same elevation classes. As per the study's database, maize or wheat farmers never established crops on elevation classes lower than these. Observations of *Boro* rice farmers indicated that classes higher than Medium-Lowland were used, while lower elevations were not.

Assuming that some land that could be irrigated and double cropped will remain in rain fed low-intensity

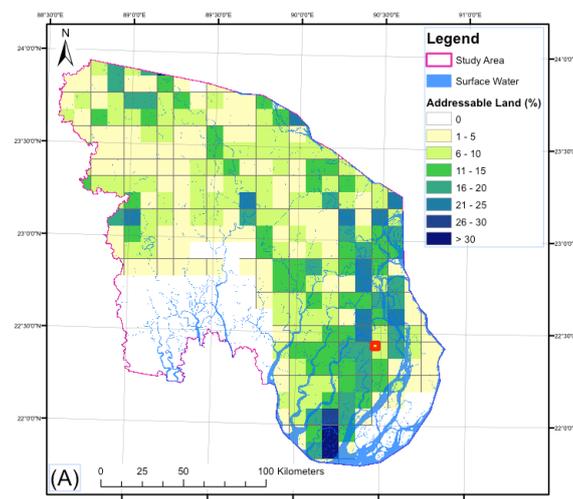
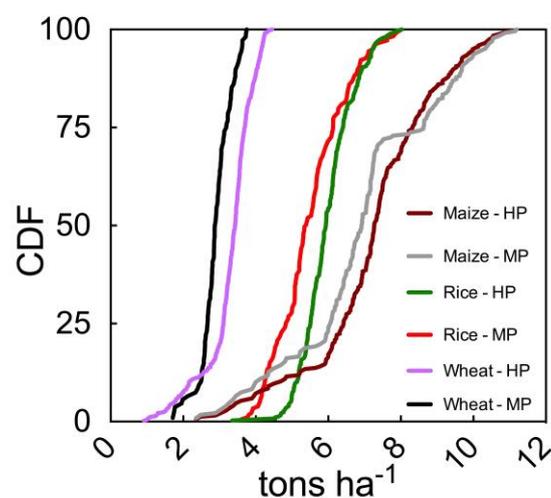


Figure 1. Top: Cumulative distribution functions (CDF) for (A) irrigated maize, boro rice and wheat yields (t/ha) obtained by farmers on high (HP) and medium potential (MP) land considering the soil and water salinity index (Table 1) between 2011–2014. Bottom: Agricultural land suitable for surface water irrigation expressed as percentage of total cropland area in 100 km² imposed grids. Low- and marginal-potential lands were excluded.

legume cultivation, we modeled potential intensification scenarios considering wheat, maize and boro rice were they to be grown on 25 percent, 50 percent and 75 percent of the three-season averaged fallow and low-production intensity cropland identified as suitable for surface water irrigation by geospatial analysis, with consideration of relative landscape position.

Results

Out of 1.93 million hectares of agricultural land in the FtF zone, 12 and 45 percent, respectively, were identified as fallowed or under low-production intensity rain fed crops during the *rabi* season. 47,066 and 132,470 hectares were identified as fallow and rain fed low-production intensity cropped land, respectively. According to the soil and water salinity index (Table 1), 21 percent of the observed fallowed land was classified as high and medium potential, with the remainder poorly suited to double cropping and dry *rabi* season surface water irrigation. Conversely, 78 percent of the observed low-production intensity acreage addressable by surface water irrigation was classified as high and medium potential. The largest concentration of fallow land that could be brought under surface water irrigation was located in central southeastern half of the FtF zone (Figure 1 Bottom).

We also analyzed the aggregate production potential of wheat, maize and *boro* rice were they to be established on the combined fallow and low-production intensity cropland identified as suitable for conversion to cropping using surface water irrigation, by applying scenario analysis using observations from the inter-quartile range of yield data from the CDFs. Based on these distributions, the yield data used are reliable at levels equivalent to $P = 0.25$, $P = 0.50$ and $P = 0.75$. The resulting data was applied to one-quarter, one-half and three-quarters of the observed fallow and low-intensity cropland within buffer areas, in order to leave land remaining area for alternative uses.

Considering the more conservative 75th probability level for yield, the estimated aggregate production potential for maize ranged from 166,659 – 499,976 tons within one season, assuming the crop were planted on one- to three-quarters of the buffered land area suitable for surface water irrigation. Were the same areas established with wheat at the same probability level, an estimated 85,671 – 257,012 tons could be produced, while the range of production for boro was 167,659 – 502,977 tons. The least conservative estimate used data from the 25th probability level, resulting in an estimated range of 237,729 – 713,188 tons of maize, 101,648 – 304,994 tons of wheat or 198,126 – 595,381 tons of *boro* rice from one- to three-quarters of the buffered land area, respectively. Modeling the potential economic consequences of surface water irrigation, our data indicates that farmers could generate US\$ 9.07 – US\$ 108.2 million (at $P = 0.25$), using one- to three-quarters of the buffered land, depending on the crop chosen, with the order of profitability ranges following maize > wheat > *boro* rice at all probabilities between 0.25–0.75. Higher yields and profit levels may also be achieved where farmers transition into use of agronomic best management practices.

During the winter of 2011-12, the most recent season for which national level data is available, 1.72 million tons of maize was produced in Bangladesh, from 232,000 hectares. Roughly 0.99 million tons of wheat was produced from 258,000 hectares, while *boro* production was much greater, at 18.76 million tons from 4.81 million hectares.⁸ We next modeled the potential contribution of each crop

grown using surface water irrigation to national cereals aggregate production in Bangladesh. Although 167,659 – 594,381 million tons more *boro* rice could be produced on the land suitable for surface water irrigation in the FtF zone, the potential contribution to national production is unlikely to exceed 3.2 percent unless yield gaps are diminished. Cultivation of maize on one- to three-quarters of the area identified as suitable for surface water irrigation would conversely contribute between 10 – 29 percent more maize nationally at the 75th probability level, or 14 – 42 percent at $P = 0.25$ (Figure 2). Between 9 – 26 percent more wheat could be produced from the same area at $P = 0.75$, or 10 – 31 percent at $P = 0.25$.

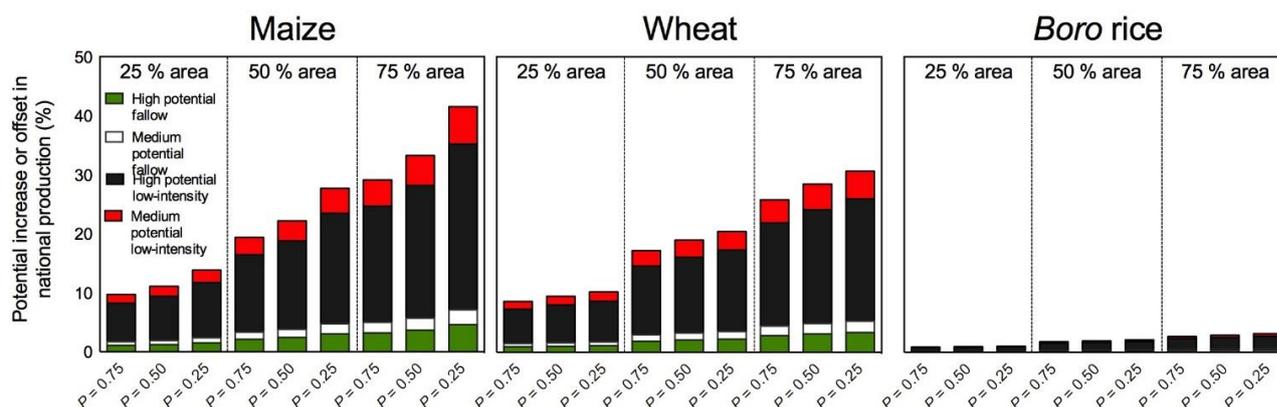


Figure 2: Modeled results describing the potential contribution of surface water irrigated *boro* rice, wheat, and maize to national aggregate production in Bangladesh. Data depict three high and medium suitability land coverage scenarios with respect to the index shown in Table 1, including projections using one-quarter, one-half, and three-quarters of all fallow and low-intensity cropland identified within riparian buffers. Probability values indicate the probability of contribution from surface water irrigated cereals at the probability (P) of 0.25, 0.50, and 0.75 derived from the CDFs (Figure 1 Top).

Discussion and Conclusion

Both the U.S. Agency for International Development (USAID) and GoB have emphasized sustainable intensification in southern Bangladesh. Considerable investments in surface water irrigation are planned by the government to move land under monsoon season '*aman*' rice – dry season fallow crop sequences and *aman* – rain sequences into irrigated rice-rice double cropping and to shift *boro* cultivation from the country's north where production requires costly energy subsidies.

Our findings indicate substantial scope for surface water irrigation to intensify cropping, even in the face of soil and water salinity constraints, although the potential for *boro* production appears to be more limited than anticipated. Dry season cultivation of wheat or maize cropping, however, appears to result in significant production increases, with important implications for national food security. These crops also address income generation constraints while minimizing water pumping and withdrawals and hence, environmental risks. These results should however be interpreted cautiously, as studies into alternative crop and land use options and best-bet policy mechanisms to align risk reduction, finance provision and market access for farmers will be needed, alongside improved water governance measures. Further studies to model crop productivity, salinity and land availability are also needed in consideration of climate change scenarios. Emerging risks such as wheat blast disease, which appeared in 2016, must also be considered in future simulations.

Salinity tolerant crop genotypes are also important, as nearly one-quarter of the observed fallow and low-productivity addressable land fell into the medium-potential category. Additional efforts are thus required to model the most appropriate allocation of surface water irrigation to crops on different land types and salinity levels, in addition to market proximity and value, to advise farmers on the best-bet mixture of farm diversity to reduce risk and provide for food security while increasing incomes. In areas with soil and water salinity >4 dS/m, conversion to aquaculture may be a more viable land use strategy.⁹

In northern Bangladesh, dry season irrigation initially expanded through relatively unrestrained shallow tube well installation, resulting in increased pressure on groundwater in intensively cultivated areas. Proper environmental monitoring and conservation policy was adopted only after resource extraction problems became evident. Learning from these lessons, surface water irrigation and intensification efforts will require measures to manage withdrawal, especially as the ecosystem services of salinity regulation and freshwater provision are reliant on maintaining sufficient southward flow. The aforementioned issues aside, the study's results support the targeted use of surface water irrigation, in partial support of governmental land use policies, though crop diversification options should be seriously considered.

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*All spatial data used in this analysis (exempting crop cut and economic data) can be found online in an interactive tool that can be used to identify specific zones where surface water irrigation has the most potential. For more information, [click here](#).

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