Research article

Spatial Analysis of Yield Gaps Variability of Black Gram Based on GIS and Geostatistics

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Abstract Black gram, a pulse, is one of the major export crops in Myanmar. Because of a decline in the maximum possible yield of this crop in farmers' fields, a yield gap exists between potential and farmers' actual yields. Reducing the gap between actual and potential yields is critical for increasing crop production. This study was carried out to generate yield gap mapping, and to investigate the reasons responsible for this yield gap in black gram production. An annual survey was carried out to determine farmers' actual yield at Kyee Inn Village, Pyinmana Township during October 2017 and 2018. Drone photos were consolidated and prepared for digitizing and analyzed with Pix4D software. ArcGIS 10.7 software was used to map the spatial distribution of the yield gap of black gram in the selected area. Yield gaps of black gram with a range of 0.02 t ha^{-1} to 2.70 t ha^{-1} in the two consecutive years were observed. The yield gap between potential and farmers' actual yields (Yield Gap I) was greater in 2018 compared to the 2017 season. The gap between the yield obtained through an organized farm trials and the yield harvested by the farmers (Yield Gap II) was also larger in 2018 than that for the 2017 crop season. A technology gap for the variety Yezin-6 (0.68 t ha^{-1}) was observed in 2018 whereas there were no gaps for Yezin-2 and Yezin-5 in 2017 and non for these varieties in the 2018 post-monsoon season. The reasons these large yield gaps may exist, is probably due to differences in crop management practices used at the experimental stations and those by farmers. The results of this study should provide useful information for policymakers, researchers, extension agents, and other stakeholders to upgrade a location-specific package of practices and increase crop yield by supporting technological solutions and training for the farmers.

Keywords black gram, yield gap, mapping, spatial, potential yield

INTRODUCTION

In Myanmar, black gram (*Vigna mungo* L.) is one of the major exportable pulses and widely sown as a second crop after monsoon rice. The total sown area of black gram was 0.98 million hectares, with a production of 1.38 million tons from 2016 to 2018. Depending on the varieties, the average potential yield of black gram recorded by the Department of Agricultural Research (DAR) is 2.40 t ha^{-1}, whereas the average actual yield of black gram is 1.44 t ha^{-1}(MOALI, 2018). Consequently, a large yield gap exists between the farmers' actual yield and the potential yield as demonstrated at the research station.

Expansion of cropland farmed is probably not a sustainable option to increase crop production so there is a need to increase crop yield on existing cropland, providing sustainable intensification of the current crop production (Forland, 2015). Presently, spatial and temporal variability of crop yields exist across regions, even within the same climatic zones due to different levels of knowledge, different farming practices, technologies, supply chains, and policies in that area (Licker et al., 2010). This has resulted in a spatial variability of the yield gap in black gram production in Myanmar. Additionally, farmers were still facing diverse technological gap in cultivation though there were agricultural modernization in pulse crops.

Analyzing the yield gap using Geographic Information System (GIS) can provide graphic information demonstrating the variability of crop yields and possibly allow for the assessment of the underlying causes of this yield gap, which would then assist in identifying strategies for narrowing these yield gaps (Tran and Nguyen, 2006). Yield gap analysis can help to develop changes in methods of crop production to bridge the gaps between the potential yield of crop variety obtained through an organized farm demonstration during its development in research stations and the yield harvested by the farmers (Jopir and Bera, 2017). It also provides valuable information for decision makers and researchers allowing the development of strategies or action plans for minimizing yield gaps and improving production sustainability.

OBJECTIVE

The objectives of this research were to develop mapping showing the spatial variation of yield gaps of black gram in selected areas to provide information that allows the generation of good production practices for black gram production.

METHODOLOGY

Study Site

The research was conducted over two consecutive years of post-monsoon season, in 2017 and 2018, at Kyee Inn Village, Pyinmana Township, Nay Pyi Taw Union Territory, which lies between 19°70'66"- 19°72'62" N and 96°22'43"- 96°25'73" E (Fig 1.). The total study area was 483 ha. The major pulse was black gram which is grown as a second crop after the harvest of monsoon rice. The study area was characterized by low content of organic matter, it has (mostly) low to high levels of total nitrogen and low to medium ranges of total phosphorus, while the level of the CEC is very low to low (Moe et al., 2019).

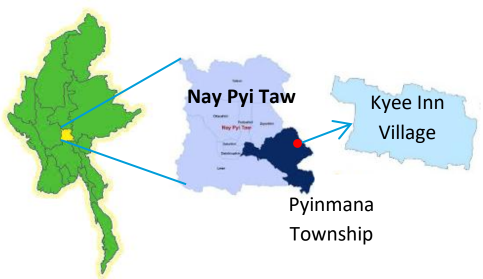

Fig. 1 The study area at Kyee Inn Village, Pyinmana Township

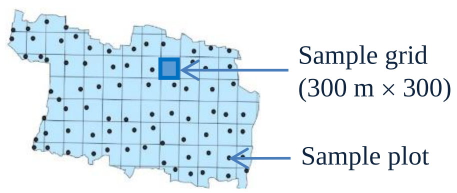

Fig. 2 Sample grids and sample plots taken in Kyee Inn Village

Source: https://myanmar.unfpa.org/.../union-report- volume-3o-nay-pyi-taw-union-territory-re www.dop.gov.mm/sites/dop.gov.mm/files/publication _docs/pyinmana_0.pdf

Preparation of Sample Plots and Data Collection

The base-map preparation enabling use of ArcGIS 10.7 software was accomplished by data obtained from a DJI Phantom 4 drone, with this processed using Litchi software. The photos were consolidated and processed for digitizing using Pix4D software and incorporated onto the digital base map. The study area was divided into 300 m × 300 m geographic grids. The 92 sample grids were encompassed and 78 of these sample grids were under black gram cultivation (Fig 2).

The 70 farmers cultivating the 78 sample plots were selected as respondents and interviews were conducted to identify variation in average yield and crop management practices in the sample area. The potential yield (Y_P- irrigated conditions) of black gram was provided by the Oilseeds and Pulses Crops Division, Department of Agricultural Research (DAR), Yezin, Nay Pyi Taw. The potential yield (Y_W- rainfed conditions) of black gram was obtained from on farm trials conducted by

Department of Agronomy, at Kyee Inn Village, Pyinmana Township in the 2017 and 2018 (Oo et. al., 2019). The farmers' actual yield (Y_A) was recorded from the respondents in the study area for the 2017 and 2018 crop seasons.

Preparation for Mapping

The polygon boundary shapefiles and merged polygon shapefiles were created using the ArcGIS 10.7 software. According to yield gap calculation, point shapefiles of Yield gap I and Yield gap II were prepared for the study area for the two consecutive years. Because of limited number of sample points, the spatial interpolation was conducted by Kriging, it is a geostatistical interpolation method (Karydas et al., 2009). Maps of the spatial distribution of Yield gap I and Yield gap II was generate through ArcToolbox (Spatial Analyst > Interpolation > Kriging).

Calculations

Yield gap I is the difference between potential yield (Y_P- irrigated conditions) and farmers' actual yield (Y_A) and Yield gap II is the difference between water-limited potential yield (Y_W- rainfed conditions) and farmers' actual yield (Y_A) (Equations 1 and 2).

$$\text{Yield gap I} = \text{Potential yield } (Y_P) - \text{Farmers' actual yield } (Y_A) \quad (1)$$

$$\text{Yield gap II} = \text{Water-limited potential yield } (Y_W) - \text{Farmers' actual yield } (Y_A) \quad (2)$$

The technology gap (Y_{TG}) was determined as the difference between the water-limited potential yield (Y_W) and the highest farmers' yield (Y_{HF}) (Equation 3). The highest farmers' yield (Y_{HF}) is an empirical concept intended to define the maximum Y_A achieved. Y_{HF} was estimated by calculating the mean of actual yields above the 90th percentile (Silva et al., 2017).

$$\text{Technology gap } (Y_{TG}) = \text{Water-limited Potential yield } (Y_W) - \text{Highest farmers' yield } (Y_{HF}) \quad (3)$$

RESULTS AND DISCUSSION

Survey Result of Yield and Crop Management Practices

In this study area, the farmers' actual yield (Y_A) was in the range of 0.08 to 1.97 t ha^{-1}, for the 2017 and 2018 post-monsoon seasons (Table 1.). Most of the respondents (85%) do not retain residues of black gram after harvesting. About 32% of respondents use optimum seeding rate recommended by DOA. Only 18% of respondents applied urea and compound fertilizers as basally at planting time. There was no evidence of the application of phosphorus and potash fertilizers for black gram production. The most common type of chemical sprayings used by respondents for black gram cultivation were foliar and fungicides and about 12% of respondents follow optimum spraying frequency (4 times for whole season) recommended by DOA. Seed sowing method was broadcasting so that weeding was not done for black gram cultivation in the study area.

Spatial Analysis on the Variation in Yield Gap I

The potential yield (Y_P) obtained from the DAR for black gram varieties used in the study area ranged from 1.75 to 2.78 t ha^{-1} while the farmers' actual yield (Y_A) was in the range of 0.08 to 1.97 t ha^{-1}, for the 2017 and 2018 post-monsoon seasons (Table 1). The Yield gap I of black gram was recorded with the range of 0.73 to 2.70 t ha^{-1} in 2017 and 0.28 to 2.62 t ha^{-1} in the 2018 post-monsoon season (Table 2). The results indicate that variations of Yield gap I occurred during these two consecutive years.

A wider Yield gap I of 0.73 to 1.99 t ha^{-1} and 0.81 to 2.70 t ha^{-1} was recorded for the varieties Yezin-2 and Yezin-6, respectively in the 2017 and 2018 post-monsoon seasons (Table 2).

Table 1 Potential yield and farmers' actual yield of black gram varieties in Kyee Inn Village, Pyinmana Township during 2017 and 2018 (post-monsoon seasons)

Variety	Potential yield (Y_P) (t ha^{-1})	Potential yield (Y_W) (t ha^{-1})	Farmers' actual yield (Y_A) (t ha^{-1})	
			2017	2018
Yezin-2	2.15	0.88	0.43-1.42	0.16-1.47
Yezin-5	1.75	0.73	0.16-1.82	0.16-1.47
Yezin-6	2.78	0.93	0.08-1.97	0.16-0.25

Table 2 Yield gap I and Yield gap II of black gram varieties in Kyee Inn Village, Pyinmana Township during 2017 and 2018 (post-monsoon seasons)

Variety	Yield gap I (t ha^{-1})		Yield gap II (t ha^{-1})	
	2017	2018	2017	2018
Yezin-2	0.73-1.72	0.68-1.99	0.21-0.45	0.23-0.47
Yezin-5	0.80-1.59	0.28-1.59	0.02-0.57	0.08-0.32
Yezin-6	0.81-2.70	2.53-2.62	0.10-0.85	0.68-0.77

The spatial variations of Yield gap I appears to be higher and range from 1.26 to 1.60 t ha^{-1} in 2017 whereas most fields displayed a Yield gap I of 0.91 to1.25 t ha^{-1}in 2018 (Fig. 3). The highest Yield gap I (1.61-1.89 t ha^{-1}) happened in both years, but showed a greater and more scattered pattern in 2017 (Fig. 3). These differences may possibly be due to differences in crop and nutrients management practices between the trial station and the farmer's fields.

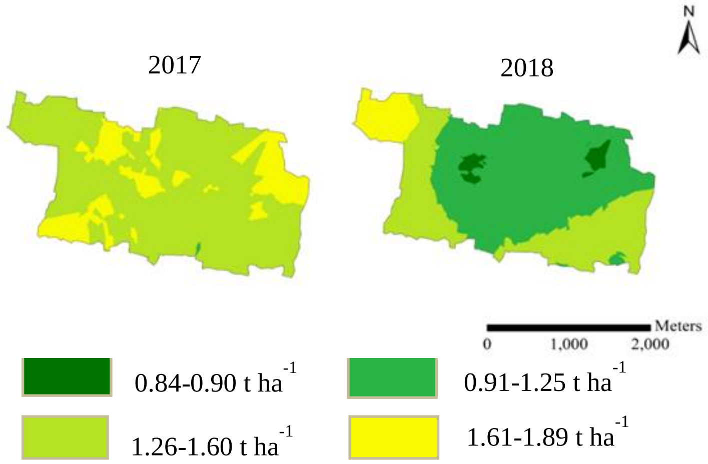

Fig. 3 Spatial variations of Yield gap I of black gram in Kyee Inn Village, Pyinmana Township

Spatial Analysis on Variation of Yield Gap II

The Yield gap II varied from 0.02 to 0.85 t ha^{-1} in 2017, and 0.08-0.77 t ha^{-1} in 2018 (Table 2). The variation in Yield gap II across the fields appears to indicate varied crop management practices among black gram farmers in the study area. The trial plantings, used as a base comparison, usually follow recommended crop management practices, especially regarding basal and foliar fertilizers application, weeding, and plant protection measures. However, the potential yield (Y_W) obtained was lower than that of some farmers' actual yield. The Yield gap II ranged from 0.20 to 0.55 t ha^{-1} in the two consecutive years (Fig. 4). The larger proportion of the fields had a Yield gap II of 0.26-0.35 t ha^{-1} in 2017 and this gap appear to be larger 0.36-0.45 t ha^{-1}in 2018. The greatest Yield gap II of 0.46-0.55 t ha^{-1} was observed in the 2018 crop season, and such a gap was not present in the 2017 crop. The slight increase of Yield gap II in the 2018 season may have been due to a steady decrease in farmers' actual yield during the study period. The study area was characterized by low content of organic matter, it has (mostly) low to high levels of total nitrogen and low to medium ranges of total phosphorus, while the level of the CEC is very low to low (Moe et al., 2019). According to the results of interviews, farmers in the study area did not apply of phosphorus and potash fertilizers for black gram production and thus, the Yield gap II was resulted for two consecutive years.

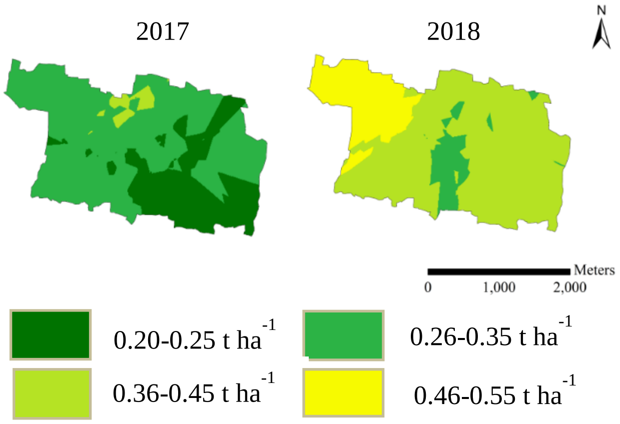

Fig. 4 Spatial variations of Yield gap II of black gram in Kyee Inn Village, Pyinmana Township

Technology Gap of Black Gram in Kyee Inn Village, Pyinmana Township

The technology gap represents the difference between the potential yield (Y_W) and the highest farmers' yield (Y_{HF}). The technology gap was not found in the 2017 post-monsoon seasons (Table 3). It was observed only by the variety of Yezin-6 (0.68 t ha-1) in 2018. From 2017 to 2018 post-monsoon seasons, the technology gap was not recorded by the variety of Yezin-2 and Yezin-5. The results indicated that the recommended crop production practices of a black gram would need to upgrade for increasing crop yield in the study area.

Table 3 Technology gap of black gram varieties in Kyee Inn village, Pyinmana Township during 2017 and 2018 (post-monsoon seasons)

Variety	Potential yield (Y_W) (t ha^{-1})	Highest farmers' yield (Y_{HF}) (t ha^{-1})		Technology gap (t ha^{-1})	
		2017	2018	2017	2018
Yezin-2	0.88	1.42	1.19	-	-
Yezin-5	0.73	0.91	1.23	-	-
Yezin-6	0.93	1.32	0.25	-	0.68

CONCLUSION

A crop yield gap was found in most farmers' fields due to their differences in crop management practices including residue management, basal and foliar fertilizers applications, weeding and plant protection measures. Therefore, it is necessary to introduce an appropriate package of production practices for the study area. Farmers should be encouraged to follow the systematic crop management practices as much as possible to increase crop production. As expected, the spatial variation of Yield gaps exists largely due to the differences in the crop management practices used at the experimental stations and those by farmers. The wide Yield gaps were observed in both years. The reason these large yield gaps may exist, is probably due to not applying phosphorus and potash fertilizers to the black gram. Therefore, the results of the study provide useful information for policy makers, researchers, extension agents, and other stakeholders to upgrade location-specific information packages outlining best practice. This study has shown that the use of new technologies such as GIS and Geostatistics can provide important information for evaluating the status of Yield gap of black gram in the study area.

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