Sustainable Nitrogen Management Index (SNMI): methodology

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The agricultural Sustainable Nitrogen Management Index (SNMI) is defined to provide a more comprehensive measurement of the environmental performance of the agricultural production. Here, the SNMI is defined based on two important efficiency terms in crop production, namely Nitrogen Use Efficiency (NUE) and land use efficiency (crop yield). As more data become available, the SNMI could be reviewed and improved by including more efficiency terms in crop production, such as water use efficiency.

NUE measures the efficiency of nitrogen (N) use in agricultural production, and it is usually considered to be positively related to the environmental performance of agricultural production. However, directly using only NUE to rank countries' performance under the Sustainable Development Goal 2 (SDG2) could be problematic for the following two reasons.

1) NUE is defined as the fraction of all nitrogen inputs (fertilizers, manures, N fixation, N deposition) that is harvested as crop products (Zhang et al., 2015). Usually, NUE should be between 0~1, with values between 0.5 and 0.9 indicating efficient N use and low N losses. But NUE may become greater than 1 when the crop system is mining the soil nitrogen (i.e., more N is being removed from the soil at harvest than is being returned) which degrades soil fertility and lowers crop yield in the long term.
2) NUE is usually very high when both N inputs and crop yields are low, which is not compatible with achieving the first part of the SDG2 of reducing hunger.

Therefore, we defined SNMI so that it considers both types of efficiencies in crop production, namely NUE (NUE_{co}) and land use efficiency (crop yield, $NYield_{co}$), in a one-dimensional ranking score.

More specifically, SNMI calculates geometrically how far a country's current position in the normalized NUE (NUE_{co}^*) and yield ($NYield_{co}^*$) is from the reference point in a two dimensional graphic (Figure 1). Here the normalized NUE is defined as NUE divided by 1, except that NUE values >1 are adjusted downward to avoid rewarding soil mining of N; the normalized crop yield is defined as the crop yield divided by a reference level of crop yield ($NYield_{ref}$).

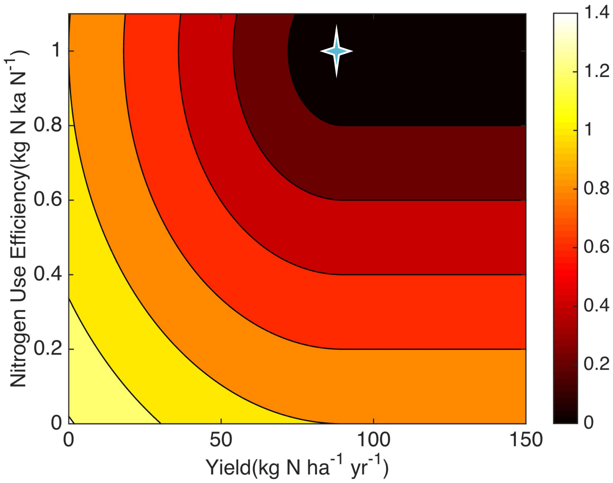

Figure 1. The definition of SNMI based on NUE and N yield. The color bar shows the value of SNMI. The reference points are noted as stars in the figure. The low values (dark shading) in the upper right are the best scores (highest ranking).

The reference yield level is defined to measure a country's progress toward achieving a certain yield target, which addresses land use efficiency and food security. Here we use reference yield level as 90 kg N ha^{-1} yr^{-1}, which is approximately the required nitrogen yield, averaged globally, to meet 2050 crop production targets without expanding the current crop land (FAO, 2012). We acknowledge that there could be some disagreement in how to define the reference yield level, e.g. whether to use a universal value (and which value to use) or a variable value for different countries according to their ecological and socioeconomic conditions. We consider this reference point could be decided according to countries' (or experts') agreement. Regardless of the reference yield target chosen, the ranking approach using SNMI credits countries with both high yield and high NUE (upper right hand corners of Figure 2, adapted from Zhang et al., 2015) with the best ranking scores, and it is consistent with our evaluation in Zhang et al. (2015).

We note that countries can receive the same score for very different reasons. For example, a country with a relatively good normalized yield of 0.8 but a normalized NUE of only 0.2 would have about the same score as a country with a normalized yield of only 0.2 and a normalized NUE of 0.8. The former would be producing more food (high land use efficiency) but would have a low SNMI score because of high pollution (low NUE), while the latter would have low pollution (high NUE) but have a low SNMI score because it is not meeting food production targets (low land use efficiency). Therefore, understanding comparisons of SNMI scores across countries may require disaggregating the one-dimensional SNMI score. Nevertheless, the SNMI score provides a useful metric for each country to track its trajectory of progress toward the dual goals of increasing agricultural land use and nutrient use efficiencies.

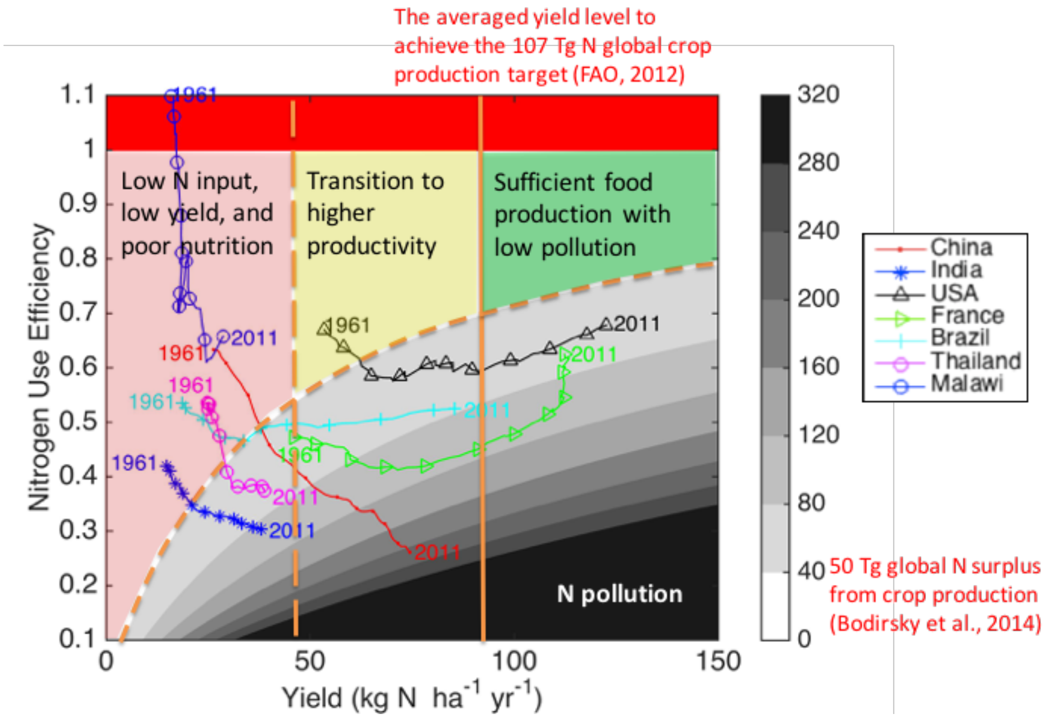

Figure 2. Historical trends of harvested nitrogen (Yield), NUE and nitrogen surplus (Nsur), for a sample of countries examined in this study (Adapted from Zhang et al., 2015). The grey scale shows the level of Nsur. The area covered in red indicates negative Nsur, where the crop production is mining soil N. The data have been smoothed by ten years to limit the impact of year-to-year variation in weather conditions. The vertical solid-orange line denotes the global yield target for 2050 given FAO's estimation and no cropland expansion (FAO, 2012); while the vertical dashed-orange line denotes half of that yield target. The curved dashed-orange line denotes the environmental target for 2050 in order to bring the N pollution back to one estimate of a planetary boundary (Bodirsky et al., 2014). The region highlighted with green color denotes where a country has achieved both the global averaged crop production target and the environmental target.

The mathematical definition of SNMI is derived from Pythagorean's Theorem for calculating the hypotenuse of a triangle, as follows (see Figure 3 for an example)

$$SNMI_{co} = \sqrt{(1 - NYield_{co}^{*})^2 + (1 - NUE_{co}^{*})^2}$$

where,

$$NYield_{co}^{*} = \begin{cases} NYield_{co}/NYield_{ref} & (NYield_{co} \leq NYield_{ref}) \\ 1 & (NYield_{co} > NYield_{ref}) \end{cases}$$

$$NUE_{co}^{*} = \begin{cases} NUE_{co} & (NUE_{co} \leq 1) \\ 1 - (NUE_{co} - 1) & (NYield_{co} > 1) \end{cases}$$

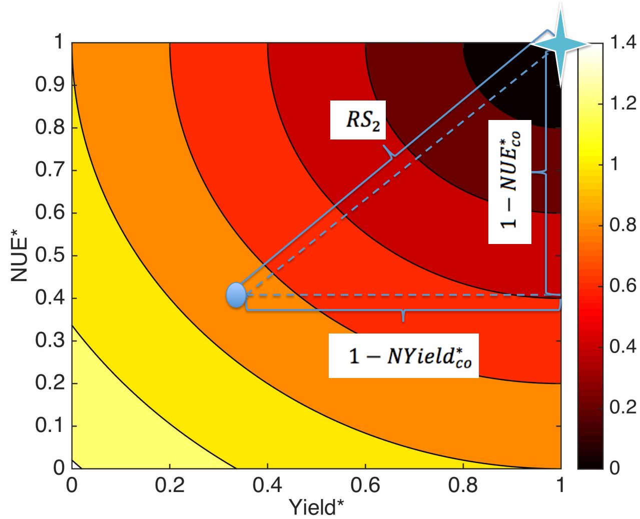

Figure 3. The definition of SNMI based on normalized NUE (NUE^*_{co}) and N yield ($NYield^*_{co}$). The star corresponds to the reference points in Figure 1; while the blue circle is an example of a country that have normalized NUE and N yield level at NUE^*_{co} and $NYield^*_{co}$ respectively.

The SNMI is computed using country-level data published by Zhang et al. (2015).

Reference

Bodirsky, B.L. et al., 2014. Reactive nitrogen requirements to feed the world in 2050 and potential to mitigate nitrogen pollution. Nature communications, 5.

FAO, 2012. World agriculture towards 2030/2050: the 2012 Revision, Rome, Italy.

Zhang, X. et al., 2015. Managing nitrogen for sustainable development. Nature, 528(7580): 51-59.