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Supplementary information

Phosphorus for Sustainable Development Goal target of doubling smallholder productivity

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Supplementary information for "Phosphorus for Sustainable Development Goal target of doubling smallholder productivity"

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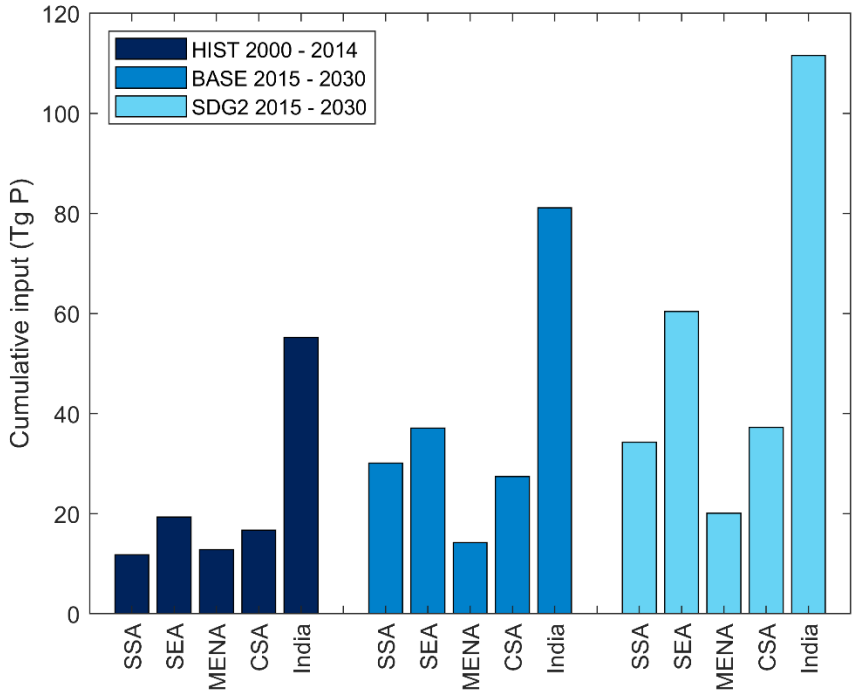
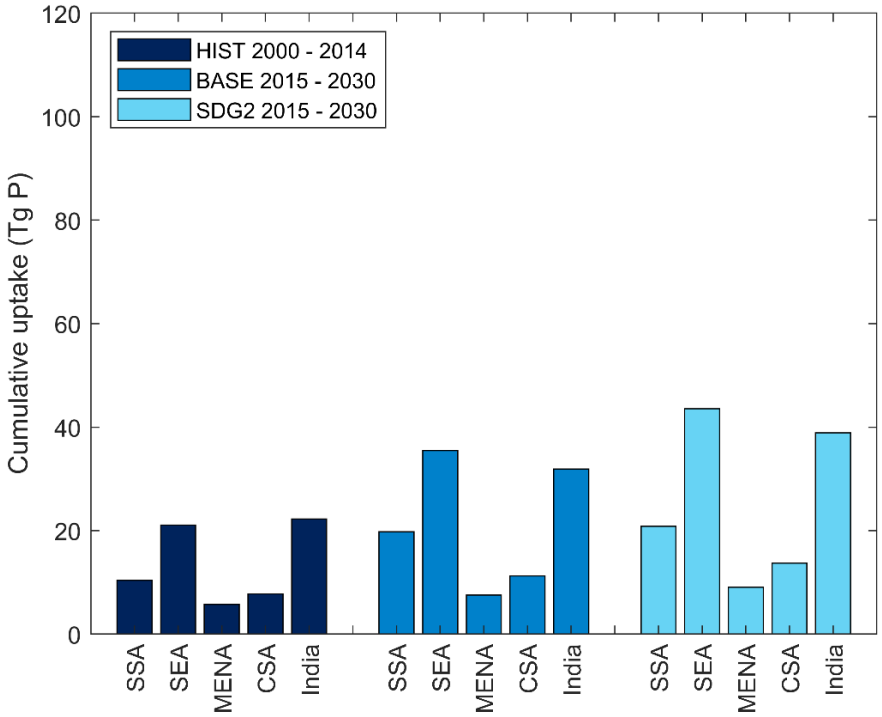
SI 1: Supplementary figures and tables

(a)



(b)



(c)

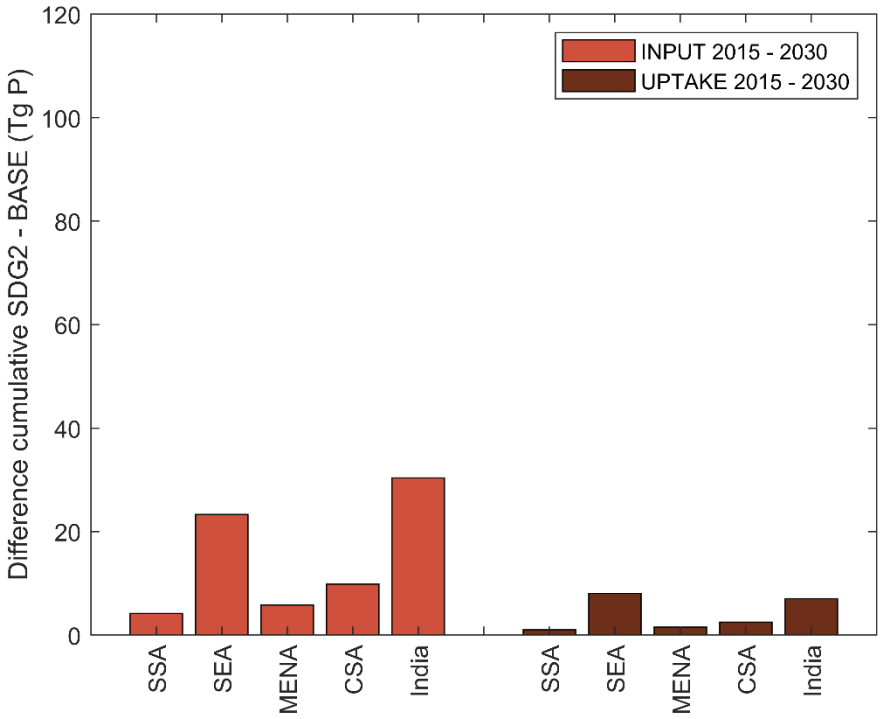


Figure SI1: (a) cumulative P input and (b) cumulative P uptake, in Tg P, for the years 2000-2014 (BASE) and 2015-2030 (BASE and SDG2). (c) Difference (SDG2 – BASE) for input and uptake in 2030. Acronym description: SSA: Sub-Saharan Africa, SEA: South East Asia, MENA: Middle East and North Africa, CSA: Central and South Asia

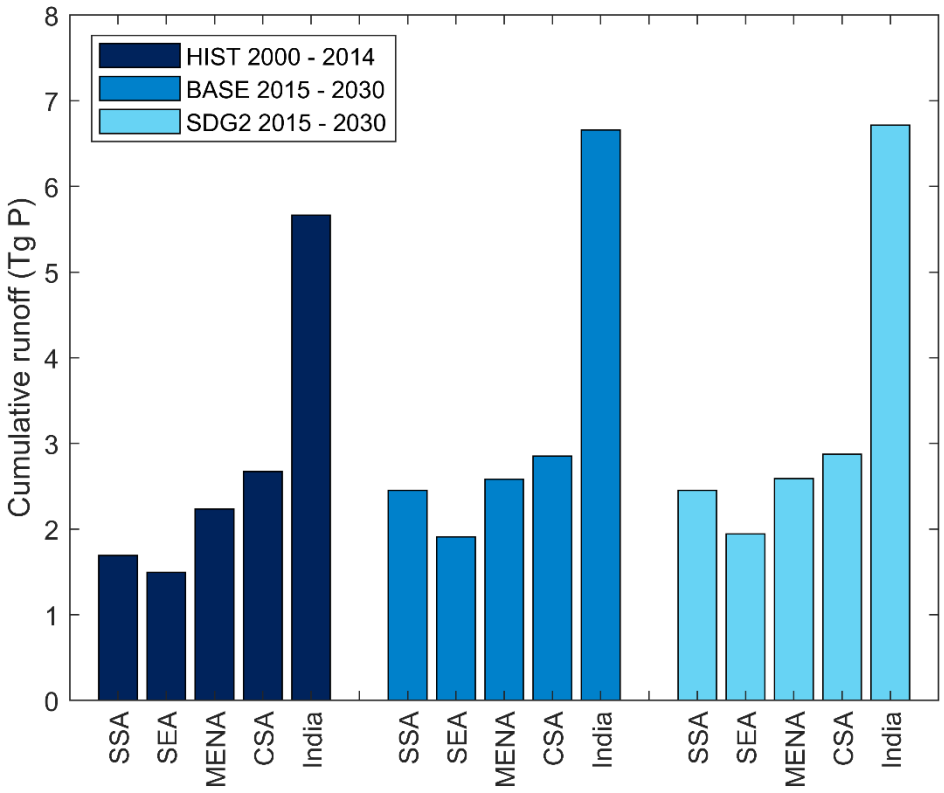
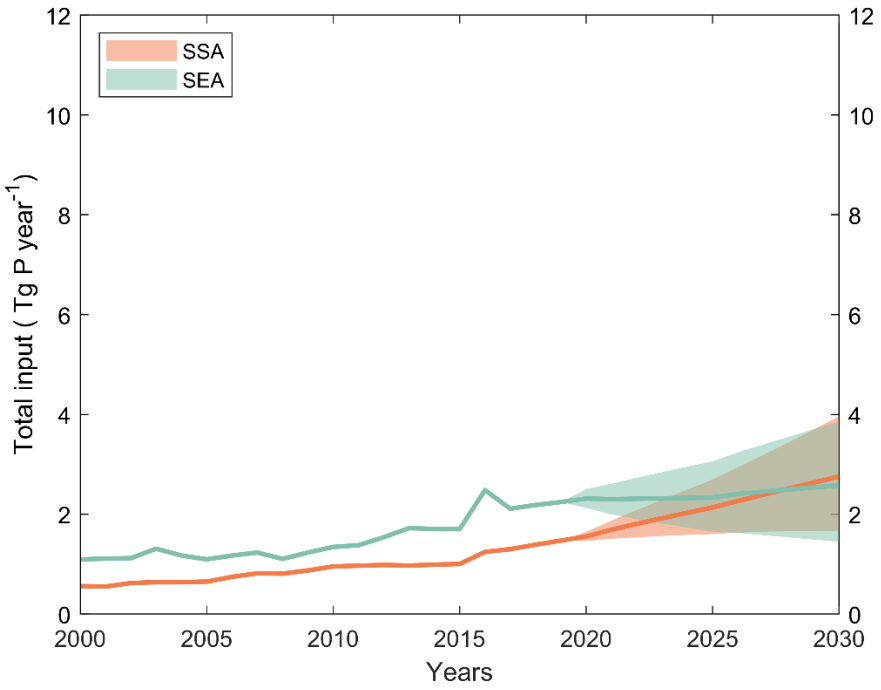


Figure SI2: Cumulative P runoff in Tg P for the years 2000-2014 (BASE) and 2015-2030 (BASE and SDG2). Acronym description: SSA: Sub-Saharan Africa, SEA: South East Asia, MENA: Middle East and North Africa, CSA: Central and South Asia

(a)



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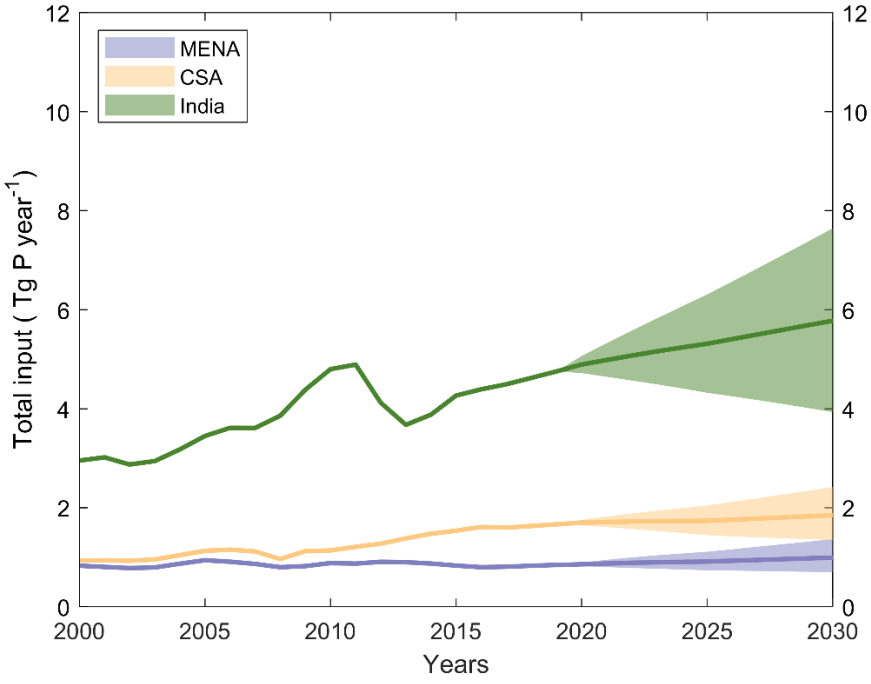

Figure SI3: Sensitivity of total P input to the target P uptake in the BASE scenario, (a) for Sub-Saharan Africa (SSA), South East Asia (SEA), (b) for Middle East and North Africa (MENA), Central and South Asia (CSA), and India. Target P uptake was varied by +/- 20%.

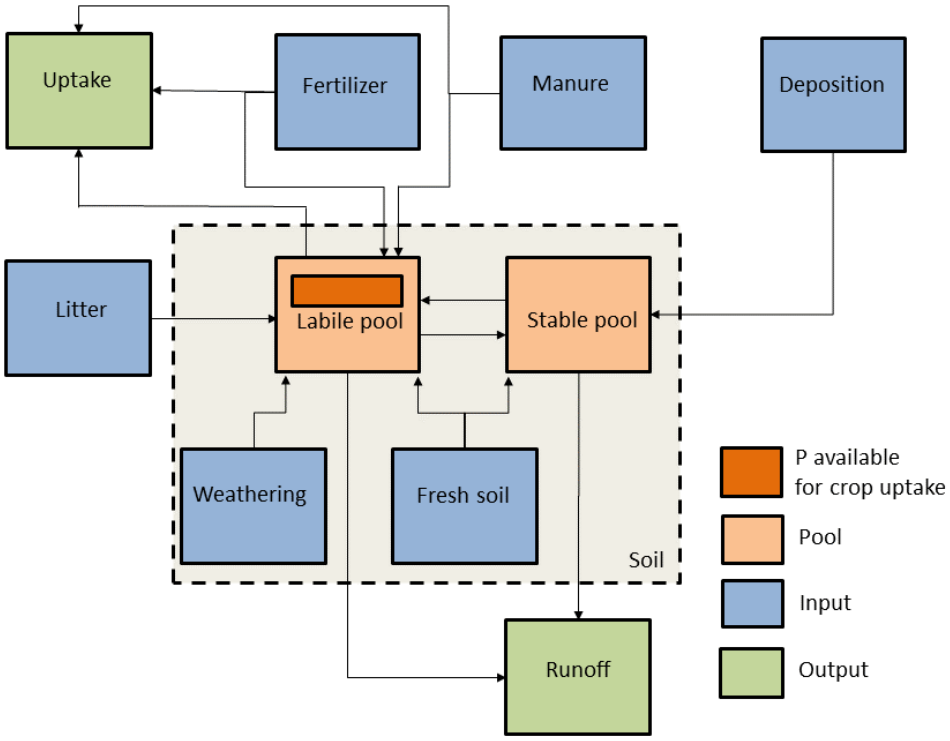

Figure SI4. Simplified scheme of the IMAGE-DPPS model.

Table SI1. Estimated P uptake for the five world regions considered in this study for the year 2015.

	SSA	MENA	CSA	India	SEA
	1000 tons P yr^{-1}				
Cereals	388	208	435	832	642
Pulses	42	7	6	55	20
Oilcrops incl. oilpalm	155	22	29	187	996
Root and tuber crops	192	10	13	28	65
Sugar crops	35	26	44	203	102
Vegetables	43	44	23	80	41
Spices	8	3	3	8	15
Fibre crops	35	10	100	160	6
Biofuels	0	0	0	23	27
Total	898	330	652	1575	1913

48 Table SI2: Countries counted towards the five regions

Region (Acronym)	Countries within region
Sub-Saharan Africa (SSA) *(excluding Republic of South Africa)*	Angola, Botswana, Burundi, Cameroon, Cabo Verde, Central African Republic, Chad, Congo, Democratic Republic of the Congo, Benin, Equatorial Guinea, Ethiopia, Eritrea, Djibouti, Gabon, Gambia, Ghana, Guinea, Côte d'Ivoire, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Guinea-Bissau, Réunion, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, Zimbabwe, Former Sudan, Swaziland, Togo, Uganda, United Republic of Tanzania, Burkina Faso, Zambia
Middle East North Africa (MENA)	Algeria, Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Tunisia, Egypt, Yemen
Central and South Asia (CSA)	Afghanistan, Bangladesh, Bhutan, Sri Lanka, Kazakhstan, Kyrgyzstan, Nepal, Pakistan, Tajikistan, Turkmenistan, Uzbekistan
India	India
South East Asia (SEA)	Myanmar, Cambodia, Indonesia, Lao People's Dem. Rep., Malaysia, Philippines, Timor-Leste, Viet Nam, Thailand, Papua New Guinea

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50 Table SI3: Excretion rates for the different animal categories.

Animal category	Excretion in kg head^{-1} year^{-1}
	P
1. Beef cattle	10.5[a]/8.7[b]/7.0[c]
2. Dairy cattle	22.7[a]/17.5[b]/10.5[c]
3. Buffaloes	7.9
4. Pigs	1.8
5. Poultry	0.1
6. Sheep and goats	1.5
7. Horses	7.3[d]/6.5[c]
8. Asses	4.4
9. Mules	4.4
10. Camels	8.0

51

52 [a] Canada, USA, Japan;

53 [b] = OECD Europe;

54 [d] = Canada, USA, OECD Europe, Japan;

55 [c] = all other countries.

SI2: supplementary information on methods

SDG2 target definition

The SDG2.3 target to "*… double [by 2030] the agricultural productivity and incomes of small-scale food producers, …*"[1] needed to be specified for the purpose of our study. First and foremost, IMAGE-DPPS does not include productivity or income data on a farm level. As a substitute, we used crop production (as expressed by P uptake) on a country level. While it is clear that the two terms are different, they both aim at the overarching goal of zero hunger (SDG2). Furthermore, while in the past production increases were often achieved through cropland expansion, the expectation is that in developing countries current and future expansion will be 80% attributable to yield increases[2]. Given the difficulty of translating SDG goals into specific indicators that capture the intention of the target comprehensively, we believe that some freedom is allowed in forming indicators for the target, that suit the study purpose.

Selection of world regions

We made use of the study by Lowder et al. [3], which analysed farm size data from a large number of countries worldwide. While there is no widely accepted definition of smallholder farming, relatively small farm size is an indicator which can be compared well between countries. For our study, we chose a threshold of 5ha to count as smallholder farm. We used the 26 world regions of IMAGE[4] to analyse the data set of Lowder et al.[3]. If more than 75% of farms in a region were smaller than 5ha, the region was considered dominated by smallholders. In a second step, the regions qualifying were further aggregated to five world regions which are the geographic unit in which our results are presented (Table SI2). Actually, China was also a region where smallholder farms dominate. However, given that average P input levels are already above 60 kg P $ha^{-1}yr^{-1}$ in China (results not shown), and P limitation in most regions is negligible (Figure 1 a and b), we decided to exclude China from the analysis.

IMAGE-DPPS does not distinguish between farm sizes and therefore P input and uptake calculations for the five regions implicitly include large farms. Smallholder farms do not dominate only in number in these regions[3], but also at least 50% of food production these regions is produced by smallholders, especially cereals and roots and tubers [5,6]. For the chosen regions we assume that the results for all farms will be largely valid for smallholder farms.

Uncertainties and sensitivity

Uncertainty in modelling results stem from the model structure and parameters used, and the data, which is often derived either from country datasets or modelling studies themselves. For example, spatial distribution (allocation) of country level data, such as P fertilizer and manure, on a spatial grid gives rise to uncertainty[2]. Regarding other P inputs in crop production systems (animal manure, weathering, and deposition) there is no statistical information available against which to compare our estimates. A recent study on global nutrient budgets comparing 13 datasets with global coverage[7] showed that estimates of animal manure inputs in crop systems are uncertain for all countries with the largest ranges in estimates for India. Also, P uptake is uncertain due to the uncertainty in estimated P contents for crops. Hence, the uncertainty in P budget terms is caused by different input terms and differs between individual countries.

These uncertainties are not wholly quantifiable, but for model parameters, a sensitivity analysis of IMAGE-DPPS by Mogollón et al.[2] showed that P input requirements are sensitive to fr_{av}, ,the fraction of direct P uptake from fertilizers and manure, and the target P uptake. The strongest sensitivity was to the target uptake of the scenario. These parameters are thus all relevant sources of uncertainty, but given the overriding importance of the P uptake target for P input, the effect of this parameter on P input requirements was visualized here by changing the target uptake +/- 20% (Figure SI 9 a and b).

Another source of uncertainty lies in the construction and interpretation of our scenarios. The translation of the SDG2 target 2.3 into a quantity that can be calculated in our model (P uptake by crops on a country level) and serves the purpose of our study, was discussed above. Furthermore, we focused on crop uptake and not livestock P uptake. This translation and necessary reduction of the SDG target can be unsatisfying for readers viewing the SDGs with different backgrounds. The effect of choosing SSP2 over other SSPs was discussed in the main text. By choosing the middle-of-the-road SSP2 scenario (BASE), we avoid specifically optimistic or pessimistic outlooks on the future as a reference. It is clear, however, that there cannot be a hard justification for choosing one scenario above another. Finally, the COVID19 pandemic, occurred during the time of writing and could not be integrated in any of the analysis or scenarios. The pandemic is likely to affect future scenarios profoundly, and mostly in a negative way, making it even harder for the five regions with smallholder-dominated farms to reach the SDG zero hunger goal[8].

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