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The Contribution of Improving Phosphorous Use Efficiency to Agricultural Economics: A Case Study in Türkiye

Fethi Şaban Özbek[1,*]

[1]Turkish Statistical Institute, Ankara, Türkiye

HIGHLIGHTS

- Important economic benefit can be gained by improving phosphorous use efficiency
- The economic benefit is gained for all regions in Türkiye by decreasing P mineral fertilizer usage

Abstract

The contribution of improving phosphorous (P) use efficiency (PUE) in agricultural areas of Türkiye to agricultural economics has been measured regionally for the years of 2007-2011 within this study. For this purpose, the economic benefit gained from use of P mineral fertilizers has been presented when improving PUE from 5% to maximum PUE in agricultural areas. PUE values used in this study were estimated by using hyperbolic regression model, which states the relationship between phosphorous input and output in agricultural areas of Türkiye. The results showed that important economic benefit would be gained by improving PUE, even when PUE was improved to maximum level, this benefit would be almost the half of the expenses for purchasing P mineral fertilizers. Yearly average economic benefits gained from purchasing P mineral fertilizers would be 0.22 ($0.15 billion) and 0.82 billion TL ($0.56 billion) by 5% improving of PUE and reaching maximum PUE, respectively over the five years 2007-2011.

Keywords: Agricultural economics; economic benefit; phosphorous mineral fertilizers; phosphorous use efficiency

1. Introduction

Phosphorus (P), a crucial macronutrient for all living cells (Johnston and Dawson 2005; White et al. 2010, Zeng et al. 2022), can limit plant growth if not provided in sufficient quantities by the soil or external sources (MacDonald et al. 2011; Chien et al. 2012; Dhuldhaj and Malik 2022). For this reason, P mineral fertilizer is commonly used in agricultural production in Türkiye as in the world. The application of P mineral fertilizer to agricultural soils increased by 3.2 % annually from 2002 to 2010 in the world (Lun et al. 2018); and increased to 4.4 million tonnes in 2017 from 3.4 million tonnes in 2009 in Türkiye (Turkstat 2018). However, surplus use of P in soil has increased the r isk of P movement from agricultural fields to adjacent water bodies (e.g. Djodjic et al. 2005, Sims et al. 2000). This affects water quality with negative effects on biodiversity, eutrophication, and low oxygen level in waters (Sharpley et al. 1994; Smith 1998; Hansen et al. 2002).

The other negative effects of surplus use of P are specified by Withers et al. (2018) that high global consumption rates of P fertilizer are depleting the finite reserves of good quality rock phosphate, phosphorus

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***Correspondence:** fethiozbek@gmail.com

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fertilizers are also a source of harmful inputs of metals, especially cadmium and uranium, to agricultural soils, the manufacturing process leaves large stockpiles of radioactive phosphogypsum, heavily fertilized soils are ecologically less diverse with loss of soil function (Vries et al. 2013), and excess P in the human diet resulting from increasing meat consumption and use of food additives may be compromising human health (Ellam et al. 2012). It was also emphasized that the manufacture and use of P fertilizers is extremely wasteful and inefficient, and this inefficiency is existing along all parts of the P supply chain, including the field application of the manufactured products (Withers et al. 2018; Cordell and White 2013).

Improving P use efficiency (PUE) is essential because of the above-mentioned negative and positive effects of the use of P in agricultural soils. To improve PUE, it is crucial to quantify PUE accurately. Ozbek et al. (2016) developed a method that allows estimating PUE under conditions of changes in soil P stock (SSC-P). This method ensured to quantify PUE more accurately compared to P budget method estimating PUE by not taking account of the SSC-P. The results of Ozbek et al. (2016) gave a range of regional PUE of 56% and 93% with a mean national PUE of 74% at the level of administrative regions for the period 2007-2011. This indicates that 26% of P is not taken by plants in Türkiye. This percentage is almost 44 % for some regions. To this end, improving PUE in Türkiye agriculture, in other words improving agricultural production by using less P mineral fertilizer is also essential for Türkiye.

Using recycled and recovered P, appropriate fertilizer placement, application time and rate of fertilizer, soil testing, erosion reduction, microbial inoculants, plant selection, utilizing legacy soil P, and improving soil characteristics are the options to improve PUE in agricultural soils (Cordell and White 2013; Withers et al. 2018). By using these methods, the usage of P mineral fertilizers decreases, so significant economic benefits can be gained.

P mineral fertilizer is intensively used for more agricultural production around the world. Above-mentioned studies show that this has a cost both environmentally and economically. However, more agricultural production is required for the food chain to meet better the needs of increasing population. At this point, the crucial question is that "how can we ensure more agricultural production by using less P mineral fertilizer". The answer of this question is to improve PUE (Powers and Thavarajah 2019) by taking above-mentioned necessary measures. Improving PUE reduces the cost of P mineral fertilizer usage both environmentally and economically. To quantify the contribution of improving PUE to agricultural economics is required to evaluate the economic effect of it deeply.

The purpose of this study is to evaluate the contribution of improving PUE to agricultural economics in Türkiye at the regional level for the period from 2007 to 2011. For this purpose, the economic benefit gained from use of P mineral fertilizers has been evaluated when improving PUE from 5% to maximum PUE in agricultural areas.

2. Materials and Methods

Ozbek et al. (2016) presented relationship between P input and P output by developing a model that uses a hyperbolic regression model for Turkish regions for the years of 2007-2011 (Equation 1), where ◎ and ◎ are model parameters. And, they calculated PUE by using this model (Equation 2). In this model, P inputs comprise P from mineral fertilizer, manure production, net manure imports/ exports, withdrawals, stocks, other organic fertilizer, atmospheric deposition, and seed and planting materials. P outputs comprise P from crop and fodder production, crop residues removed, and stock changes of P in soil.

$$P\_output=(\alpha \cdot P\_input)/(\beta+P\_input) \quad (1)$$

$$PUE=P\_output/P\_input \quad (2)$$

Table 1. The average values of P input, output, mineral fertilizer use and change, P use efficiency initial and change values, 2007-2011

Regions	P_{input} (kgP ha^{-1})	P_{output} (kgP ha^{-1})	P_{minfer} (kgP ha^{-1})	$PUE_{initial}$ (%)	ΔP_{minfer} (kgP ha^{-1})							
					ΔPUE=5	ΔPUE=10	ΔPUE=15	ΔPUE=20	ΔPUE=25	ΔPUE=30	ΔPUE=35	$\Delta PUE=PUE_{max}-PUE_{initial}$
TR10	22	14	11	61	1.7	3.2	4.5	5.6	6.6	7.4	8.2	8.9
TR21	17	11	12	68	1.2	2.2	3.0	3.8	4.5	5.1	5.4	5.4
TR22	20	13	7	63	1.5	2.8	3.9	4.9	5.8	6.6	6.8	6.8
TR31	23	14	8	60	1.8	3.3	4.6	5.7	6.7	7.6	7.9	7.9
TR32	15	11	7	70	1.0	1.9	2.7	3.4	4.0	4.6	4.6	4.6
TR33	14	10	7	72	0.9	1.7	2.5	3.1	3.7	4.0	4.0	4.0
TR41	12	9	8	75	0.8	1.4	2.0	2.6	3.1	3.1	3.1	3.1
TR42	27	15	8	56	2.2	4.1	5.7	7.1	8.2	8.2	8.2	8.2
TR51	9	7	6	82	0.5	0.9	1.3	1.5	1.5	1.5	1.5	1.5
TR52	10	8	7	79	0.6	1.2	1.6	2.1	2.2	2.2	2.2	2.2
TR61	14	10	8	72	0.9	1.7	2.5	3.1	3.7	4.0	4.0	4.0
TR62	21	13	16	62	1.6	3.0	4.2	5.2	6.1	7.0	7.7	8.2
TR63	14	10	9	72	0.9	1.7	2.4	3.1	3.6	4.0	4.0	4.0
TR71	8	6	5	84	0.4	0.8	1.1	1.2	1.2	1.2	1.2	1.2
TR72	6	5	3	88	0.3	0.6	0.7	0.7	0.7	0.7	0.7	0.7
TR81	16	11	3	69	1.1	2.0	2.8	2.9	2.9	2.9	2.9	2.9
TR82	11	9	4	77	0.7	1.3	1.8	2.3	2.6	2.6	2.6	2.6
TR83	12	9	6	76	0.7	1.4	2.0	2.5	2.9	2.9	2.9	2.9
TR90	6	5	2	89	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6
TRA1	4	4	1	93	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
TRA2	8	7	1	84	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8
TRB1	6	5	2	89	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6
TRB2	8	7	1	84	0.4	0.8	1.1	1.1	1.1	1.1	1.1	1.1
TRC1	9	8	6	81	0.5	1.0	1.5	1.8	1.8	1.8	1.8	1.8
TRC2	13	10	9	73	0.9	1.6	2.3	2.9	3.4	3.6	3.6	3.6
TRC3	15	11	9	70	1.0	1.9	2.7	3.4	4.0	4.6	4.6	4.6

In this study, the relationship between P mineral fertilizer (P_minfer) and PUE was developed by using Equation 2 in order to evaluate the contribution of improving PUE to agricultural economics in Türkiye for the period from 2007 to 2011 (Equation 3). In this formula, P_(other-input) represents other inputs except for P_minfer.

$$P\_minfer=(P\_output*100)/PUE-P\_(other\text{-}input) \quad (3)$$

Change in P_minfer(〖ΔP〗_minfer) was calculated depending on change in PUE (ΔPUE) as follows (Equation 4):

$$〖ΔP〗\_minfer=(ΔPUE*P\_output*100)/(〖PUE〗\_initial*〖PUE〗\_final) \quad (4)$$

Economic benefit (EB) when increasing PUE from 5% to maximum PUE (100%) was calculated according to Equation 5. The values of P input, P output, P_minfer, 〖ΔP〗_minfer, 〖PUE〗_initial, 〖PUE〗_final used in the calculations are given in Table 1.

$$EB=〖ΔP〗\_minfer*p\_minfer \quad (5)$$

Where p_minfer is the average unit price of P mineral fertilizer in TL kgP-1 ha-1. p_minfer was calculated as weighted average of the prices of P mineral fertilizer types according to the amount of P use (Table 2). These types are diammonium phosphate (DAP) (20.1% P), composite fertilizer 20.20.0 (8.7% P), composite fertilizer 20.20.0+Zn (8.7% P), composite fertilizer 15.15.15 (6.5%), and other P mineral fertilizers. Purchasing prices of farmers for these fertilizer types were calculated by increasing average producer and importer prices by 7.5% (BUGEM, 2018a).

Table 2. The amount of P mineral fertilizer and farmer purchaser price, 2007-2011

	2007			2008			2009			2010			2011		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Diammonium phosp. (20.1% P)	428012	779	3882	149098	1797	8954	665435	741	3690	495465	988	4921	386467	1464	7294
Composite fertilizer 20.20.0 (8.7% P)	718200	530	6072	542192	1193	13672	703818	559	6405	701586	663	7599	679739	1036	11873
Composite fertilizer 20.20.0+Zn (8.7% P)	296758	571	6539	247399	1285	14723	241076	602	6897	322864	714	8184	347383	1116	12787
Composite fertilizer 15.15.15 (6.5%)	260201	571	8719	226981	1285	19631	168841	602	9197	189646	714	10912	205891	1116	17049
Other	352721	613	6303	302241	1390	14245	226858	626	6547	258976	770	7904	341353	1183	12251

Source: BUGEM 2018a

a: Fertilizer use amount (ton), b: Fertilizer unit price (TL ton^{-1}), c: P unit price (TL (ton P)$^{-1}$

Average prices of above-mentioned fertilizer types, comprising 87.4% of total P mineral fertilizer usage, were used to estimate the price of other P mineral fertilizer.

NUTS2 (Nomenclature of Territorial Units for Statistics) administrative level, developed by Turkish Statistical Institute, was used in regional analysis (see Figure 1).

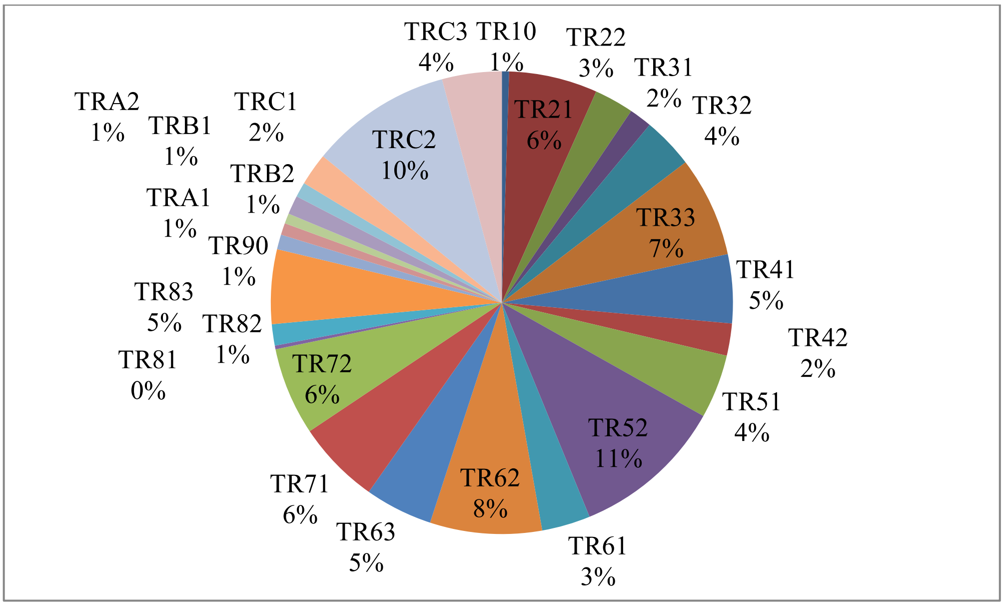

Figure 1. Yearly average expense for purchasing of phosphorous mineral fertilizer by regions, 2007-2011 (Region codes: TR10: Istanbul; TR21, TR22: West Marmara; TR31, TR32, TR33: Aegean; TR41, TR42: East Marmara; TR51, TR52: West Anatolia; TR61, TR62, TR63: Mediterranean; TR71, TR72: Central Anatolia; TR81, TR82, TR83: West Black Sea; TR90: Eastern Black Sea; TRA1, TRA2: Northeast Anatolia; TRB1, TRB2: Central-east Anatolia; TRC1, TRC2, TRC3: Southeast Anatolia)

3. Results

Yearly average expense for purchasing P mineral fertilizers is 1.76 billion TL over the five years 2007-2011. West Anatolia (TR52) has the highest share in total expense in Türkiye for purchasing P mineral fertilizers with a value of 11%. Southeast Anatolia (TRC2) and Mediterranean (TR62) follow this region with the values of 10% and 8% respectively. The lowest share was calculated in West Black Sea (TR81) with a value of 0.3% (Figure 1).

Yearly average economic benefits gained from purchasing P mineral fertilizers would be 0.22 ($0.15 billion) and 0.82 billion TL ($0.56 billion) for the 5% improving of PUE and reaching maximum PUE, respectively over the five years 2007-2011 (Figure 2).

The highest yearly average economic benefit would be in TR62 with a value of 72 million TL by reaching maximum PUE over the five years. Aegean (TR33) and TRC2 follow this region with the values of 70 million TL and 67 million TL respectively. The lowest yearly average economic benefit would be in TR81 with a value of 5 million TL. Northeast Anatolia (TRA1) and Eastern Black Sea (TR90) follow this region with the values of 6 million TL and 7 million TL respectively (Figure 3).

Over the five years 2007-2011, yearly average profit increase per employee in agriculture would be 151 TL yr-1 when PUE reaches maximum level (100%). The highest increase would be in Southeast Anatolia (TRC3) with a value of 510 TL yr-1, and the lowest increase would be in TR90 with a value of 13 TL yr-1 (Figure 4)

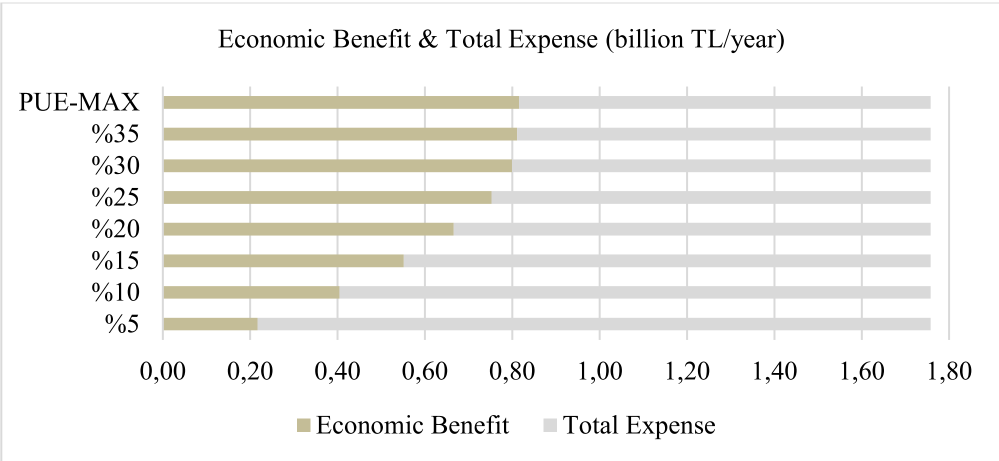

Figure 2. Yearly average economic benefit gained from expense for purchasing of phosphorous fertilizer, 2007-2011

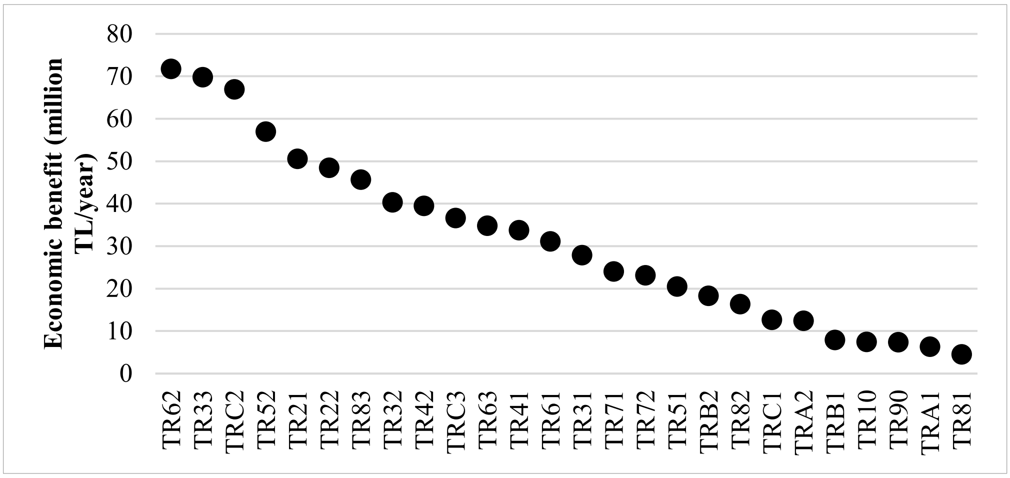

Figure 3. The yearly average economic benefit gained from the expense for purchasing of phosphorous fertilizer by regions when PUE is maximum, 2007-2011

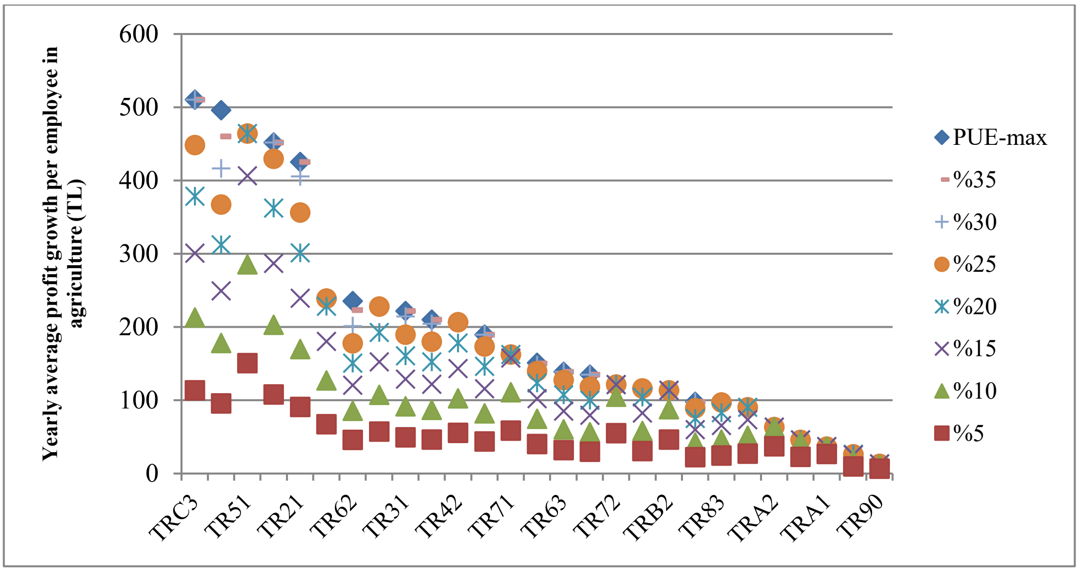

Figure 4. Yearly average profit growth per employee in agriculture by regions when PUE is maximum, 2007-2011

4. Discussion

There are important variations in PUE between regions in Türkiye, PUE vary between %56 and %93 over regions (Ozbek et al. 2016). This implies that economic benefit is gained for all regions by decreasing P mineral fertilizer usage by improving PUE. So, the options to improve PUE e.g. using recycled and recovered P, appropriate fertilizer placement, application time and rate of fertilizer, soil testing, erosion reduction, microbial inoculants, plant selection, utilizing legacy soil P, and improving soil characteristics (Cordell and White 2013; Withers et al. 2018) are crucial for Türkiye agriculture.

Higher P mineral fertilizers are required in agricultural areas because of population increases and dietary changes (Grote et al. 2005; Foley et al. 2011, Bindraban et al. 2020). So, improving PUE, which ensures more agricultural production by using less P mineral fertilizer, is required for the food chain to meet better the needs of 8.5 billion people by 2030, and 9.7 billion people by 2050 (UN 2016), and also to combat negative effects on biodiversity, eutrophication, and low oxygen level in waters.

The results showed that important economic benefit would be gained by improving PUE, even when PUE was improved to maximum level, this benefit would be almost half of the expenses for purchasing P mineral fertilizers. This implies that fertilizer usage can be decreased significantly by taking necessary measures to improve PUE.

The foreign-dependency in using P in Türkiye is high. The share of imported P in total used P in 2015 is 39% (BUGEM 2018b). Decreasing the demand of P mineral fertilizer by improving PUE will decrease foreign-dependency in using P in Türkiye. Additionally, the producers will tend to increase export in order to keep their production levels. This will ensure increase in gross domestic product by increasing net export (export-import) (Ozbek 2018).

Also, so much fossil fuel is used in the production of P mineral fertilizer. Improving PUE will contribute to increase energy efficiency, and decrease production cost of P mineral fertilizer producers. This is crucial when considering the new threat that P fertilizers will become much more expensive in the future as manufacturing (energy) costs increase (Withers et al. 2018). In addition to decreasing indirect energy use by using fewer fertilizers in agricultural sector, direct energy use will also decrease by using less diesel fuel in fertilizing by improving PUE.

The results showed that the yearly average profit increase per employee in agriculture with a value of 151 TL yr^{-1} would be significantly high when PUE reaches the maximum level. It would be close for some regions to yearly average minimum wage per capita with a value of 747 TL yr^{-1} over the years 2007-2011.

In Türkiye, P mineral fertilizers are used for base dressing. Base dressing fertilizers also include nitrogen. When the measures for improving PUE (e.g. appropriate fertilizer placement, application time and rate of fertilizer, soil testing, erosion reduction, microbial inoculants, plant selection, utilizing legacy soil P, improving soil characteristics) are taken NUE would also increase (Ozbek, 2018). It is assumed that this would compensate for N requirements emerging because of decreasing the usage of base dressing fertilizers as the share of N in total P mineral fertilizers is low with a value of 26%. So, the farmers wouldn't make extra payments for these N requirements.

There is no estimation about economic benefit gained by improving PUE for Türkiye at the national and regional level as far as is known. However, Lun et al. (2018) estimated that if Chinese cropland PUE could be increased 20% (to the global average of 46% from 26%) China would save 60 % of its phosphate fertilizer consumption in 2010. This saving is close to saving of Türkiye with a value of 55% calculated within this study if Türkiye agricultural land PUE could be increased 26% (to 100% from 74%).

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