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Monitoring agricultural productivity for sustainable production and R&D planning

David Laborde and Valeria Piñeiro

Abstract
Argentina's G20 presidency has emphasized the needs to improve soil management and increase agricultural productivity in a sustainable way to achieve an inclusive and resilient food future. While increases in agricultural productivity improve economic welfare and can help address food security problems by benefiting both consumers and producers simultaneously, it has to address the depletion of scarce natural resources. In the context of changing climate, achieving sustainable and resilient agricultural production is a major corner stone in both adaptation and mitigation strategies. The global community needs to have the proper tools to monitor sustainable agricultural productivity gains, identifying countries and sectors lagging behind, and committing R&D efforts accordingly to the challenges ahead. As such, it is suggested that 1) an international consortium should monitor Agricultural Total Factor Productivity to provide international comparisons and track performance over time; 2) the G20 should acknowledge and address the issue of sustainable productivity measurement, and; 3) support more in depth research on the relation between Agricultural TFP and Agricultural R&D.

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1   The Challenge

The relationship between agricultural productivity and agricultural R&D is at the core of long term sustainable agricultural development strategy. Only a combination of the right set of innovations to protect soil, water and other natural resources will deliver the increase in production required to feed the growing and richer population in all countries while achieving the Sustainable Development Goals (SDG).

1.1   What do we know about TFP and how we measure it?

"Total Factor Productivity (TFP) is the portion of output not explained by the amount of inputs used in production. As such, its level is determined by how efficiently and intensely the inputs are utilized in production." Comin (2008)

Applied to agriculture, and in its broader sense, TFP refers to increases in agricultural output owing to an overall increase of efficiency of production processes, rather than through the intensification of input use[1]. TFP is the ratio of agricultural outputs (gross crop and livestock output) to factors of production used to generate those outputs (land, labor, machinery, feed and fertilizers and livestock), see Figure 1. To be closer to the economy-wide concept, agricultural TFP could be defined as the ratio between value added in agriculture and the factors of production used in the production process.

Figure 1 Schematic representation of Agricultural Total Factor Productivity

Source: 2015 GAP report
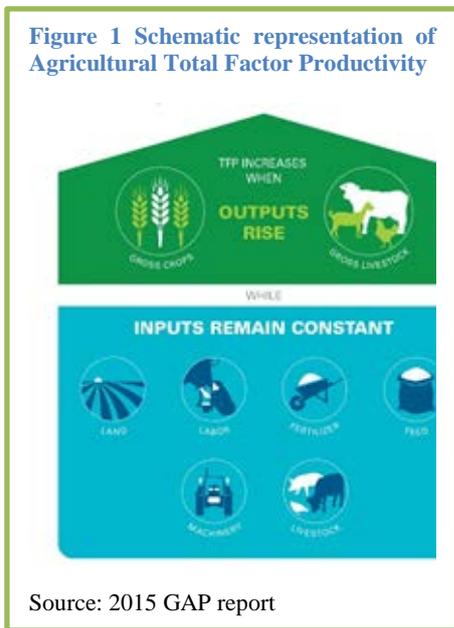
Since total factor productivity in agriculture is strongly influenced by policies, institutions, socio-economic forces, and environmental conditions, having a proper estimate of TFP can help policy makers, researchers and farmers to have a better understanding of the effect of those variables on the level of production.

TFP growth is usually measured by the Solow residual. As shown in the landmark article by Robert Solow (1956), long-run growth in income per capita in an economy with an aggregate neoclassical production function must be driven by growth in TFP. However, it has been also recognized that it is a "measure of our ignorance" (Abramovitz, 1956), since it is a residue: the part of growth we could not explain through increase in inputs use.

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[1] Partial productivity measures such as growth in labor productivity or land productivity (yields per hectare) are a misleading indicator in this respect, as an increase in these partial productivity measures can be achieved by increasing the intensity of use of other inputs (for example, crop yields can be increased by applying greater amounts of fertilizer or using more labor).

Trying to explain this residual, in addition to the role of institutions, technological innovation has been used as a key explanation. However, R&D, if fully capture in the value of inputs, should not appear in the residuals except when there is a wedge between social and private rates of return of this activity. By linking the TFP growth rate to innovation, Romer (1990) and Aghion and Howitt (1992), endogenous growth models shed light on the determinants of TFP growth. R&D subsidies and an abundance of skilled labor reduce the marginal cost of conducting R&D and increase the rate of innovation development and therefore, the TFP growth rate.

There are two main approaches for measuring TFP: parametric and non-parametric (Griliches 1996).[2] The parametric approach involves econometric modeling of production functions and estimates the relationships between total output and inputs. The residual (unexplained) output from these regressions can be used as a measure of TFP. The non-parametric approach, widely used by national statistical agencies, is a "growth accounting" measure, in which output and input prices are used to aggregate quantities to form a ratio of total output to total input, which is defined as TFP (Caves et al. 1982, Diewert 1992). Because of its strong theoretical properties Diewert (1976) and empirical robustness, the Törnqvist is probably the most popular method for measuring TFP.

Since the TFP measurement[3] is intertwined with the issue of capital valuation, it could not be separated from the Cambridge controversies.[4] However, in the context of agriculture, other challenges arise, given that the key to sustainable growth is having more efficient use of land, labor and other inputs through technological progress. Agricultural productivity estimates should include the use of environmental goods and services in agricultural production to represent the long term sustainability of agricultural productivity growth while they are excluded from traditional accounting approaches (see Figure 1).

While the topic of agricultural productivity was emphasized in a specific white paper (Fuglie and al., 2016) for the G20 Meeting of Agricultural Chief Scientists (MACS) during the Turkey G20 presidency, no significant actions have taken place. Indeed, the MACS white paper mentioned the need to extend the measure of TFP to include the non-market goods and services (i.e. environmental inputs and by-product pollutants). However, current methodologies do not

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[2] Laborde (2017) proposed a mixed-approach when relying on a multisectoral computable general equilibrium model, it uses back casting techniques on a set of time series, as in the accounting approach, to identify TFP drivers for various sectors of the economy, including various agricultural activities. Therefore, the parametric structure of the model and sectoral production functions are combined with market clearing conditions to deduct unobservable breakdown of factor of production across activities.

[3] We focus on TFP measurement at the country level. Still, more detailed analysis capturing farm heterogeneity may be needed. It is important to keep in mind that methodology should consider the fact that farmers are not always on the production frontier. Indeed, theoretically changes in TFP capture how the production frontier shifts over time with technical progress. Observed productivity gains capture both the displacement of the frontier and how producers get closer to their production function.

[4] The Cambridge controversies took place over 20 years, from the mid 50's, between prominent economists from Cambridge, England, and Cambridge, Massachusetts, and was focused on the measurement of capital in aggregate production function models.

properly account for non-marketed, or poorly marketed, factors of production, like water and soil.

Finally, while agricultural TFP indices have been estimated for most countries, it is difficult to make cross-country comparisons as a direct consequence of data limitations and also difference in methodologies. This issue is illustrated by Figure 2 where we compare two widely used sources of TFP estimates for agriculture: ERS-USDA and IFPRI. These two approaches rely on similar growth accounting methodology and have significant overlap regarding data used. However, even though they appeared to be positively correlated, they provide significant different pictures for specific countries, and for relative performance between pairwise of countries.

This can be also seen in the following illustration done by Matthews (2014). Figure 3 shows TFP growth in EU countries over the period 2001-2010 done by DG-AGRI and USDA. Even though the two figures are for the same set of countries and over the same period, the two sources tell a different story about agricultural productivity growth in the EU when looking at specific countries and the comparison between them. The first set of estimates present the new EU members with the highest TFP growth for that period while the second set of estimates has the new EU member states as having a lower TFP growth than the old member states. More striking is the case of Italy, were in the first figure it is shown with a negative TFP growth of around 0.5 percent while the second one has Italy as the country with the highest TFP growth rate for that period in around 4.5 percent growth rate.

Both estimates use information on the growth of agricultural outputs and inputs over the 2001-2010 period which are then weighted to form the aggregate total output and total input indices from which TFP growth is derived as the change in the ratio over time. The differences can be

Figure 2 Alternative measurements of annual growth rate of TFP for the 1993-2014 period between two main sources (USDA and IFPRI)
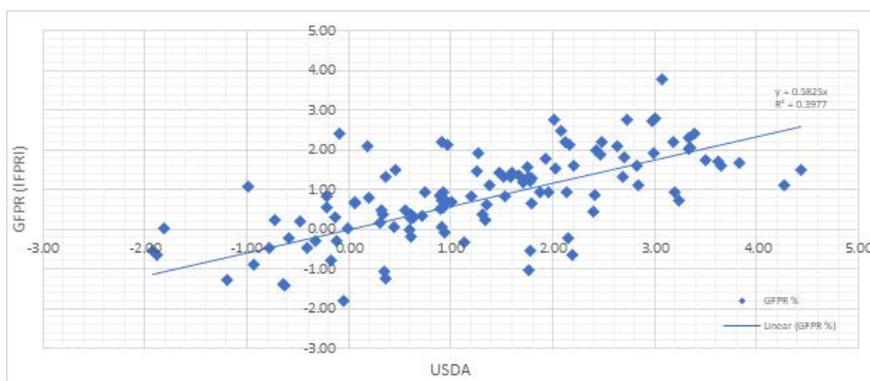

Note: Each data point represents the annual average TFP growth rate estimated by each source of a given country.
Source: Authors' computation based on USDA Agricultural total factor productivity dataset https://www.ers.usda.gov/data-products/international-agricultural-productivity/ and IFPRI Global Food Policy Report (GFPR) 2018 http://www.ifpri.org/publication/2018-global-food-policy-report.

due to differences in the volume measures for the individual outputs and inputs, to differences in the weights used for aggregation, and to differences in the index number methodology adopted to create the TFP index.

Therefore, the issue of measuring sustainable agricultural productivity in a comprehendsive and comparable way between countries has not benefited from a strong and significant impetus while the issues are growing and many sustainable targets have been identified at the country, G20 and global level. For agriculture in particular, a proper measurement of productivity performance should be a key metric to track progress towards the various sustainable goals in a consistent framework (see Appendix).

Figure 3: Agricultural TFP growth EU countries, 2001-2010

Source: DG-AGRI. Matthews 2014.	Source: USDA estimates. Matthews 2014.
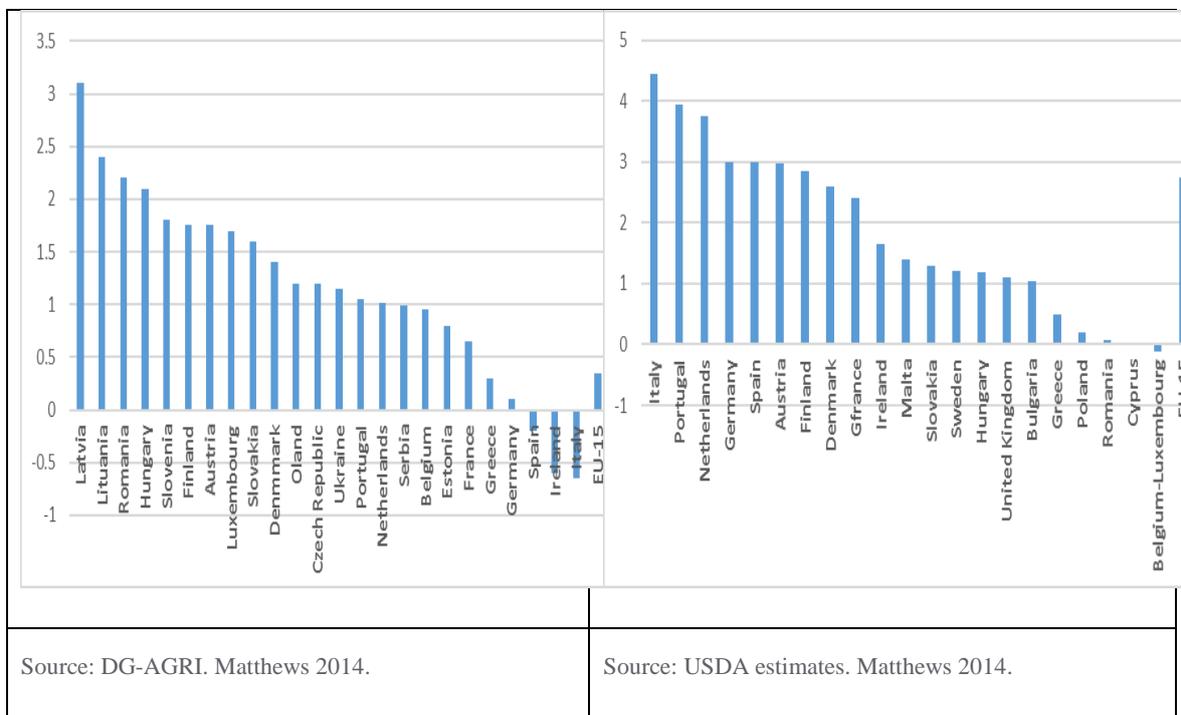
2   Proposals

2.1   What should we know? Assessing the knowledge gaps

There are still some issues to be studied and improved related to the measurement of TFP. We list below some of the major issues and challenges that should require a collective response.

Agricultural TFP measurement

Systematic agricultural TFP measurement still face major problems compared to the other sectors of the economy.

First, there are still deficiencies regarding proper data for the agricultural sector and the measurement of capital, labor and land. Indeed, while the issue of measuring capital stock and services is a common issue in growth accounting, existing solutions in the literature, relying mainly on FAOSTAT available time series on machinery inventory has major limitations.[5] Similarly, the issue of agricultural labor, including a large share of family labor or hidden employment (undeclared workers) or unemployment (people staying on farm by default) increases methodological difficulties. Regarding land, while for crops, the situation is acceptable and minor challenges deserve to be addressed (e.g. multi-cropping), accounting of pasture land remains problematic. This can result in very different numbers for TFP growth figures obtained by different institutions using similar approaches but applying different fixes to existing challenges.

Second, most estimates are only available for the whole agricultural sector. In addition, existing methods weakly control for composition effects inside the production bundle. Beyond this methodological issue, the lack of TFP estimates for various agricultural products may limit the capacity to identify which crop is lagging and should require additional efforts in terms of innovation.

Third, a good productivity measure should account for differences in the quality of outputs and inputs and how quality changes over time.[6] While the evolution of output quality is less preeminent in agriculture than in the rest of the economy - but still not totally absent e.g. fortified varieties, animal welfare consideration - the evolution of input qualities (seeds, pesticides, fertilizers, human capital), and how much is captured by their price change, is an important issue, especially if we want to properly study the contribution of R&D.

International comparisons and benchmarks

As a direct consequence of data limitations but also difference in methodologies, while agricultural TFP indices have been estimated for most countries, it is difficult to make cross-country comparisons.

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[5] See Fuglie (2012) for a discussion regarding the limitations on estimate of capital stocks and services and incompleteness of information on input prices.

[6] There have been two approaches to tackle this issue in the literature: one approach accounts for differences in quality by disaggregating the measure into finer and finer units (Ball et al. 2016). The second approach is to determine how the price of input is related to its characteristics (Ball et al. 2010).

For instance, even when comparing two approaches (ESR-USDA and IFPRI[7]) relying on similar growth accounting methodology and have significant overlap regarding data used, we obtain significantly different pictures for specific countries, and for relative performance between pairwise of countries. It also raises a very important concern: some sources may provide a too optimistic situation regarding recent trends in agricultural productivity and may lead to a serious underestimation of the need for sustained efforts and investments, in particular in R&D, to reverse the trend.

Towards a Green TFP measurement for agriculture

The limitations of traditional economic growth measurement were raised as early as 1972 by Nordhaus and Tobin in their improved measure of Economic Welfare (MEW), that was adjusted to consider environmental damages. These authors introduced the notions of sustainable MEW (MEW-S). Still incorporating the use of natural resources with limited market representations in the input side, and the value of production net of environmental damages on the output side have faced various political and analytical challenges.

After 18 years of technical work, the adoption in the 2012 of the System of Integrated Environmental and Economic Accounting by the UN Statistical Commission offers new opportunities. While some challenges remain (see Obst 2015, for a discussion), ongoing works are promising and incorporating the concept of sustainability in the TFP measurement, to move towards a *Green* TFP, or Total Resource Productivity (TRP), appear to be a major gap to address in the incoming years as discussed in the 2016 MACS white paper. Otherwise, existing metrics of TFP will not support the monitoring a sustainable agriculture.

Improving Agricultural TFP through proper R&D investments: quantifying the linkages

Both at an economy-wide level, and in the specific field of agriculture, there is large consensus as to the key role of R&D as an engine for long term sustainable productivity growth. Quantitative evidences regarding the intensity of this linkage are still limited. However, improved information on this mechanism is an important requirement for mobilizing and directing, either in terms of crops or geographical regions, the necessary investments at the national and international levels.

To get a better understanding of this relationship it will be important to identify two methodological challenges. First, due to the problems surrounding the measurement of agricultural TFP discussed above, there is an inherent difficulty to see how R&D efforts, the explanatory variable, impacts agricultural TFP. Addressing previous issues on TFP and sustainable TFP will significantly strengthen the case for improved understanding of the role of

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[7] USDA Agricultural total factor productivity dataset https://www.ers.usda.gov/data-products/international-agricultural-productivity/ and IFPRI Global Food Policy Report (GFPR) 2018 http://www.ifpri.org/publication/2018-global-food-policy-report. Materials available on demand

public R&D.[8] Second, the problems that arise with the way the stock of knowledge is measured in existing literature.

Using lagged flows of expenditures without doing a true perpetual inventory and mixing two separate problems: adoption delays and knowledge depreciation using small weights for early years and for the most recent periods. Using one distribution to mimic two different behavioral issues has clear limitations from a structural point of view and policy recommendations.[9]

This weakness may strongly underestimate the positive contribution of agricultural R&D to productivity and combines with others, may limit the informed decision of policy makers to allocate the right amount of resource to this activity.

2.2   Outstanding issues for the G20

Summarizing, since the Turkey G20 presidency when G20 MACS looked at the agricultural productivity issue, challenges have mainly remained the same.

First, WORLD KLEMS[10] does not have enough information on the agricultural sector, having only one aggregate estimate for the whole agricultural sector (agriculture, hunting, forestry and fishing) as well as not considering land as a factor of production. Of the G20 economies, Saudi Arabia, Indonesia and Turkey are still not covered by the World KLEMS dataset to date.

Second, data and methodological issues previously discussed lead to various and heterogeneous ranking across countries, including among G20 members, and periods leading to significant noise regarding analytical conclusions and policy recommendations. Beyond the broad picture presented in Figure 1, Matthews (2014) pointed out that even though the TFP growth figures for the EU done by USDA and by EC DG AGRI use similar approaches and information on the growth of agricultural outputs and inputs over the same 2001-2010 period, their results differ both in terms of magnitude and country ranking.[11]

Third, there has not been systematic improvement in data and technical specification to be used to calculate TFP for agriculture, especially when aiming to control for environmental impacts.

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[8] We can argue that proper accounting for quality and price effects in terms of marketed inputs while doing TFP accounting can properly capture the role of private R&D. However, public R&D contribution requires additional treatment and analysis.

[9] It also implies that analysts using this method, assume a complete decay of some innovation over time. For instance, the lag assumptions made in most of the literature lead to the implicit conclusion that Dr. Norman Borlaug's work on semi-dwarf wheat varieties have no impact on existing stock of knowledge, and therefore productivity.

[10] The World KLEMS initiative has been set up to promote and facilitate the analysis of growth and productivity patterns around the world, based on a growth accounting framework. See the G20 MACS report (Fuglie et al. 2016, p.15) https://www.oecd.org/tad/events/G20%20MACS%20WP%20Ag%20Productivity%20Metrics%204-26-2016_Final.pdf for a longer introduction to the project, as well as visit their website http://www.worldklems.net/

[11] The differences can be the result of discrepancies in measurement of the variables involved, the volume of the individual inputs and outputs and the weights used for aggregation. The USDA figures are based on FAOSTAT while the DG AGRI are from the Eurostat EAA accounts. Having the latter one a bigger disaggregation (or granularity) particularly for the input use.

In addition, efforts to assess TFP for sub-sets of crops and or livestock products have remained scarce.

Proposal 1. That the G20 gives a mandate to an international consortium of international organizations and national statistical and agricultural research institutions to systematically monitor Agricultural Total Factor Productivity to provide international comparisons and track performance over time. This initiative could be inspired by the World KLEMS project (http://www.worldklems.net/) and the Ag-Incentives Consortium.[12] It will have a high level of complementarity with the AMIS inter-agency platform, initiated by the G20 Ministers of Agriculture following the agricultural price hikes of the last decade. Indeed, while AMIS provide valuable information for short run fluctuations and drivers on world agricultural markets, monitoring sustainable agricultural productivity is a key driver to track long term price dynamics.

Proposal 2. Given the irreversibility of the depletion and degradation of natural resources caused by some activities it is important to go beyond a standard measurement of productivity (Proposal 1). The issue of sustainable productivity measurement should be acknowledged by the G20 countries, and integrated in their monitoring mechanisms as discussed in the G20 Macs white paper "*Metrics of Sustainable Agricultural Productivity*". Such commitment will fully support Argentina's G20 presidency approach of improving soils and increasing agricultural productivity agenda, a key driver to achieve a sustainable food future. Using the G20's umbrella,[13] significant synergies (data, methodologies) can be generated with new initiatives regarding soil quality monitoring and sustainable soil management, and sustainable agricultural productivity measurement.

Proposal 3. While reaffirming the role of investing in agricultural R&D and promoting international cooperation to guarantee benefits for the less advanced economies, the G20 should instruct the MACS to coordinate a white paper on the relation between Agricultural TFP and Agricultural R&D to promote a research agenda on this issue.

2.3   Final comments

•   A proper measure of TFP will help us to understand and link the actions and investments that have a positive impact on agricultural TFP. This measurement will allow us to avoid a too optimistic scenario based on recent trends in agricultural

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[12] While maintaining the autonomy and ensuring the consistency of each International Organization's role with its mandate, the Ag-incentives Consortium (FAO, IDB, IFPRI, OECD, World Bank) organizes further collaboration among IOs to provide a database of well-documented common indicators on agricultural policy monitoring, facilitates the expansion of country and product coverage and to provide a forum for tackling new issues and improving methodologies.

[13] While the priority should focus on primary production sustainable productivity measurement to address the most urgent data gaps, the framework proposed here could be expanded to address the more holistic G20 agenda and provide metrics for the sustainable productivity of the food system, that will capture the effects of the losses and waste along the value chain measurements.

productivity, which may lead to a serious underestimation of the need for sustained efforts and investments, in particular in R&D. In addition, it will allow us to identify countries and regions that are lagging behind and that will need special attention from the international community.

• We need to go beyond a standard measurement of productivity in order to understand the technologies and policies needed to ensure that productivity is not gained through the sacrifice of natural resources. This understanding is a major element in designing strategies and policies for sustainable development in agriculture.

• The global community needs to have the proper tools to monitor sustainable agricultural productivity gains to be able to face the challenges ahead.

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Appendix: Agricultural TFP and SDGs

Table 1 Agricultural TFP and SDGs

Sustainable Development Goals		Specific Targets (simplified)	Relevance of tracking sustainable agricultural TFP
	SDG2 End hunger, achieve food security and improved nutrition and promote sustainable agriculture	2.3 on doubling the agricultural productivity of smallholders, and 2.4 on ensuring sustainable food production	*Monitoring and improving sustainable agricultural productivity is explicitly linked to achieve SDG2.*
	SDG 6 Ensure availability and sustainable management of water and sanitation for all	6.4 regarding the water efficiency across all sectors	*Adjusting the TFP methodology to track the water use contributes to provide a proper metric for agriculture efficiency.*
	SDG 8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	8.1 on sustain per capita economic growth, 8.2 on higher level of productivity through diversification, and 8.4 in improving global resource efficiency and endeavor to decouple economic growth from environmental degradation	*Sustainable TFP gains in agriculture has to be an important component of the income growth strategy and the income diversification opportunities. Environmental considerations have to fully included in TFP accounting.*
	SDG 10 Reduce inequality within and among countries	10.1 on achieving and sustaining income growth of the bottom 40 per cent of the population	*Agriculture remains an important source of income for the lower income segment of the population.*
	SDG 12 Ensure sustainable consumption and production patterns	12.1 on sustainable consumption and production, and 12.2 on achieving the sustainable management and efficient use of natural resources	*Monitoring and improving sustainable agricultural productivity is explicitly linked to achieve SDG12.*
	SDG 13 Take urgent action to combat climate change and its impacts	13.1 on strengthening resilience and adaptive capacity to climate-related hazards	*Climate change contributes to an important slowdown in TFP trend.*
	SDG 15 Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	On ensuring the conservation and sustainable use of freshwater (15.1) and forest (15.2) ecosystems and their services.	*Adjusting the TFP methodology to take into consideration ecosystem services as inputs, and potential damages done to them for output valuation.*

Source: Authors' compilation.

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