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Analysis

Nutrients Metabolism of Agricultural Production in Argentina: NPK Input and Output Flows from 1961 to 2015

D.A. Díaz de Astarloa*, W.A. Pengue

Instituto del Conurbano, Área Ecología, Universidad Nacional de General Sarmiento, J. M. Gutiérrez 1150, Los Polvorines 1613, Argentina

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ABSTRACT

Argentina has historically collected large amounts of nutrients in harvested products for worldwide consumption, relying on the high productivity of its soils. We estimated NPK nutrient flows and partial balance based on historical data for biomass production and fertilizer use, from 1961 to 2015, to better understand intensity and temporal variability of nutrient dynamics in Argentina. Estimated NPK output accumulated 113.6 Mt. (78.4 Mt. N, 10.8 Mt. P, 24.4 Mt. K), or an annual average of 67 kg N, 9 kg P and 21 kg K per harvested hectare. Cumulate NPK supplied in fertilizers explained 15% N, 44% P and 4% K total extraction. Nutrient balance shows 53% (60 Mt) of total NPK outputs came from sources other than fertilizer, fixation or deposition, implying soil depletion. Nutrient deficits cumulate − 30 Mt. N, − 6 Mt. P and − 24 Mt. K, equal to − 26 kg N, − 5 kg P and − 20 kg K per harvested hectare each year. Soybean was the most extractive crop, with 54% of accumulated NPK removed. The estimation approach is robust because it focuses on NPK major sinks and sources from long and reliable data sets, as an indirect way to assess soil nutrient use and stock tendency.

1. Introduction

Argentina has been a large food and biomass supplier to the world for more than a century. It stands as the world leading exporter of protein meals (OECD and FAO, 2015), second world exporter of maize, second top supplier of dietary energy as food available for human use, with more than 3500 of kcal/cap/day (FAO, 2015a), and holds top-ten producing and exporting positions for soybean, sunflower and wheat products, amongst others (BCR, 2016). With a territory of more than 2.7 million km^2, it is positioned fourth in arable land per capita and represents the second largest producer and exporter of agri-food products in Latin America and the Caribbean (FAO, 2014). It also accounts a large agricultural region, the Pampas, one of the most important agricultural areas of the world (Satorre and Slater, 1999), with fertile soils and a favorable climate, surge of commodity flows to the rest of the world over the last 40 years (Pérez-Manrique et al., 2013).

By most of its farming history, the pampas of Argentina represented a large scale, long-term, and non-controlled experiment in low input farming (Viglizzo et al., 2001), referring to systems that use reduced quantities of inputs such as fertilizers, agro-chemicals, irrigation, machinery, etc. (Matson et al., 1997). Until the 1980s production was in fact increased through expansion on natural lands, though intensification of external inputs, technology and management started to spread (Viglizzo et al., 1995). In the 1990s, a new process of 'reprimarization' took place with emphasis on the extractive industries, led by biomass production, fostering the expansion of crops onto newly cultivated lands (Giarracca and Teubal, 2013). Millions of hectares in agricultural-cattle rotation were allocated to permanent crops, turning livestock increasingly dependent on feed crops like cereals and soymeal (Santarcángelo and Fal, 2009). In the past decades, the country has experienced a boosting growth of biomass production, as agro-industry and agri-business spread. Cereals and oilseeds underwent a process of productive and commercial expansion, making Argentina an important player in the world grain and oil market. Pork meat production has continuously grown since 2004, whereas poultry, eggs and derived industrial activities showed great development. Meanwhile, a considerable investment flow has been directed towards bioenergy production, pushing Argentina as a dominant exporter of biodiesel (OECD and FAO, 2015).

Biomass production requires large amounts of N, P and K, amongst other nutrients, to provide the building blocks of all plant and animal life. Countries with substantial farming activities tend to increase the use of NPK inputs in fertilizers as an effort to meet food demands and maintain a competitive presence in the world agricultural market. Latin America shows a negative fertilizer supply/demand balance for N, P and K (FAO, 2015b), evidencing the region's dependence on imported nitrogen, phosphate and potassium. Within Latin America, Argentina positions in the lower end of the range of fertilizer application (Austin

* Corresponding author.
E-mail address: diegoastarloa@gmail.com (D.A. Díaz de Astarloa).

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et al., 2006), with net loss of N, P and K in all major crops due to export in grain and seed (García et al., 2005). Agricultural produce removes nutrients from the soil and these must be replenished. If nutrients are not replaced, soils become depleted and plant growth is restricted. This soil exhaustion represents a 'hidden cost' (Zazo et al., 2011; Trossero et al., 2012), externality or environmental intangible (Pengue, 2009), since nutrients exported from soils as natural capital remain unaccounted for. In Argentina, low fertilizer input and intensive use of soils have lead the way to nutrient capital export as embodied material in harvested products, or 'virtual soil' (Pengue et al., 2014; Pengue et al., 2015a). The reduction of nutrient capital is suggested when assessing the impact of agricultural production over the past century (Viglizzo et al., 2001).

In this study, an original approach to long-term assessment of nutrient flows is proposed to evaluate the performance of agricultural production in terms of nutrients and assess the magnitude of the depletion process. The construction of nutrient balances at large-scales by assessing long time-span inputs and outputs constitutes a powerful approach to explain nutrient flow patterns (Liu et al., 2010; Bouwman et al., 2013), avoiding constraints associated with scaling-up from location-specific measurements (Ladha et al., 2016), and focusing on historical nutrient quantities in sources and sinks that are easier to estimate. Here, we construct a national cumulative nutrient flow analysis for biomass production from 1961 to 2015, assessing data on crop production area, dry matter collected and nutrient contents of harvested products of seventy-two crops and NPK fertilizer inputs. The study strength is supported by the relatively accurate crop production and fertilizer databases consulted from both national and international sources and the long-term period of analysis, and yet challenged by the large spatial and temporal variability of nutrient flows. Our main objectives constitute (a) estimating magnitudes of NPK inputs and outputs to devise long-term nutrient balance (b) analyzing the long-term NPK input and output dynamics and (c) identifying the patterns, trends and drivers of biomass production in Argentina for the last 55 years.

2. Methods and Data

The long-term performance of agricultural biomass production in Argentina was analyzed from a biophysical perspective, used to investigate the physical base of socioeconomic systems in the fields of ecological economics and industrial ecology (Schandl and Schulz, 2002). Here, we devised a simplified mass balance approach considering those major and most relevant nitrogen (N), phosphorus (P) and potassium (K) input and output fluxes from agricultural production, for which reliable and long-term data sets were available, compiled with data from official national and international statistics. For nutrient inputs, NPK fertilizer consumption (NF), N biological fixation (BNF) and atmospheric deposition (NA) were considered, excluding nutrients in livestock manure and municipal waste, for which no reliable long-term data were available. Inputs from non-biological fixation were considered negligible. Nutrient outputs comprise instead NPK harvested in crops (NH) and nutrient losses from fertilizer source (NL). For each variable, the annual amount in tons of nutrient was estimated, over the 55-year period.

2.1. Inputs

2.1.1. Nutrient in Fertilizers (NF)

Nutrient input from fertilizers was estimated by compounding national fertilizer use of N, P and K for the period 1961–2015. Consumption data for the three nutrients were obtained from the International Fertilizer Association's fertilizer use database for Argentina (IFA, 2016), adopting the grand total N, P_2O_5 and K_2O statistical data in thousands of tons. We converted tons of P_2O_5 and K_2O in the IFA database to tons of P and K by multiplying by the ratio 0.437 and 0.83, respectively.

2.1.2. Biological Nitrogen Fixation (BNF)

We determined the N input from BNF for pulse crops grown in Argentina between 1961 and 2015 for which published evidence of fixation was available. The pulse crops considered were: beans (*Phaseolus vulgaris*), chick peas (*Cicer arietinum*), peas (*Pisum sativum*), lentils (*Lens culinaris*), groundnuts (*Arachis hypogaea*) and soybeans (*Glycine* max). N fixation coefficients, as the proportion of N in the harvested legumes of the pulse crops attributed to BNF, were: 0.49; 0.45; 0.48 and 0.63 (Perticari et al., 2007); 0.43 (Bricchi et al., 1996; Castro et al., 2006) and 0.6 (Perticari et al., 2007; Salvagiotti et al., 2008; Collino et al., 2015) for each crop, respectively. The amount of N biologically fixed was then determined annually for each legume by multiplying the above BNF coefficients by the N content of products yearly harvested by these crops.

2.1.3. Atmospheric Deposition (NA)

Only N was considered for this input source, while P deposition was assumed scarce and not considered. No deposition data were found for K. N input from atmospheric deposition or NH3 adsortion can vary from negligible quantities to as much as 20 kg N ha^{-1} yr^{-1}, though it is generally considered to be of little relevance to agricultural production systems (Echeverría and García, 2014). These authors state a reference range of N contribution through precipitation for the Pampas region of 3 to 10 kg N ha^{-1} yr^{-1}. We used the average of this range, 6.5 kg N ha^{-1} yr^{-1}, as a proxy to estimate annual N contribution from this source per harvested area at a national level, between 1961 and 2015.

2.2. Outputs

2.2.1. Nutrients Harvested in Biomass Products (NH)

Nutrients harvested indicate the amount of NPK removed by biomass crop production between 1961 and 2015, compiled using harvest data in tons of harvested products from several statistics sources (CAA, 2016; FAO, 2016; Federcitrus, 2016; and MinAgri, 2016), for a list of seventy-two crops comprising ten cereals (barley, canary seed, maize, millets, oats, rice, rye, sorghum, wheat and durum wheat); seven oilseeds (groundnuts, linseed, olives, rapeseed, safflower, soybeans and sunflower); five pulses (beans, broad beans, chick peas, lentils and peas); seven leafy-stem vegetables (artichoke, asparagus, beet, celery, lettuce, parsley and radish), four fruit-bearing vegetables (pumpkin, melon, tomato and watermelon); three root/bulb/tuberous vegetables (carrot, garlic and onion); three root/tuber crops with high starch or inulin content (cassava, potato and sweet potato); six tropical and subtropical fruits (avocado, banana, fig, mango, papaya and pineapple); four Citrus fruits (grapefruit, lemon, mandarin and orange); seven pome and stone fruits (apple, apricot, cherry, peach, pear, plum and quince); two nuts (almond and walnut); eight beverage and spice crops (anise, coriander, cumin, fennel, maté, chilli, peppermint and tea), two industrial crops (cotton and tobacco); one sugar crop (sugar cane) and three other crops (grapes, jojoba and strawberries). NPK harvest output was calculated yearly based on crops' annual harvested dry matter and their NPK concentration. Nutrient content data for harvested products for the seventy-two crops were obtained from IPNI (García and Correndo, 2016), USDA, 2016 and Ciampitti and García, 2007, 2011. Since NPK concentrations are presented in a dry matter basis (kg of NPK per dry matter ton of harvested product), the water content was deducted from every product's harvest figure, using water content coefficients obtained from cited IPNI and USDA sources. Output harvested nutrients from livestock products, fodder crops and forestry extraction were excluded from analysis.

2.2.2. Nutrient Losses from Fertilizer Use(NL)

Nutrient losses represent an estimate of the nutrient amount that escaped the soil matrix after applied as fertilizer. Only N was considered for analysis, since N losses can be rather high and significant