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Authors
Alain Vidal

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Notes académiques de l'Académie d'agriculture de France
Academic Notes from the French Academy of Agriculture
(N3AF)
Point de vue

Retour sur les causes de 25 ans de stagnation des rendements agricoles en Europe

Looking back at the causes of 25-year crop yield stagnation in Europe

Alain Vidal[1]

1 AgroParisTech, Département SIAFEE, 22 place de l'Agronomie, 91120 Palaiseau (France)

Correspondance :
alain.vidal@agroparistech.fr

Résumé
Les rendements des cultures dans le monde, mais surtout en Europe, stagnent depuis le milieu des années 1990, quand sont apparues des inflexions dans l'évolution des rendements du blé, du maïs et de l'orge. Nous revenons ici sur les causes les plus probables de cette stagnation. Si les rendements agricoles avaient suivi la tendance 1950-1990 en Europe, ils seraient aujourd'hui 20 % supérieurs à ceux des années 1990, lorsqu'ils ont commencé à stagner. Le changement climatique explique raisonnablement un tiers de la différence. Des recherches récentes montrent qu'une plus grande diversité des cultures permet de maintenir les rendements plus efficacement que la monoculture, sans estimer dans quelle proportion. Enfin la littérature indique que la fourniture de services écosystémiques pourrait contribuer à stopper cette stagnation, mais sans encore en quantifier le potentiel.

Abstract
Across the world, but especially in Europe, staple crop yields have been stagnating since the mid-1990s, when breakpoints appeared in wheat, maize, and barley yield evolution. We look back here at recent evidence about the most likely causes for crop yield stagnation. If crop yields had followed the 1950-1990 trend in Europe, they would now be 20% higher than in the 1990s, when they started stagnating. Climate change reasonably explains one third of the difference. Recent research shows that increased crop diversity sustains crop yields more effectively than monoculture, but there is to date no estimate in the literature by how much. Finally, the literature suggests that the provision of ecosystem services could help break up crop yield stagnation but to an extent that is not yet quantified.

Mots-clés
stagnation des rendements, Europe, changement climatique, monoculture, services écosystémiques

Keywords
yield stagnation, Europe, climate change, monoculture, ecosystem services

Introduction

All across the world, average staple crop yields have been stagnating or collapsing since the mid-1990s, with a few exceptions (Figure 1), and this started being analyzed and documented in the early 2010s, with variations among regions and crops (Grassini *et al*., 2013; Ray *et al*., 2012).
This was particularly observed in Europe (Brisson *et al*., 2010), with obvious breakpoints in wheat, maize and barley yield evolutions appearing in most European countries in the 1990s (Figure 2) (Wiesmeier *et al*., 2015). It was difficult to identify such breakpoints before, as up to 18 years of stagnation were necessary until a statistically significant yield plateau could be detected (Grassini *et al*., 2013).
The causes of such stagnation have not yet been comprehensively analyzed or understood. A recent literature, strongly calling for further research on causes (Schauberger *et al*., 2018) reviews those and mentions six elements, which we ranked here by decreasing causal impacts (in italics below):
1. further increase in crop yields limited by climate change without adequate adaptation (*most likely for all crops)*,
2. decrease in crop diversity (increasing monoculture) and soil carbon content (*likely*),
3. marginal costs for management interventions reaching a balance where further investment in production is limited (*likely),*
4. physiological yield potential possibly reaching a limit (*likely for wheat),*
5. political decisions (e.g., European Common Agricultural Policy) contributing to lower investment in breeding or a decrease in input use (*unlikely),*
6. increase of relative area share in favor of crops grown under organic or regenerative agriculture (Vidal, 2023), leading to yield stagnation as resulting yields are usually lower than those under conventional agriculture (*unlikely)*.
Simultaneously, a research observing the 20-year crop yield stagnation, by the think tank Institut du développement durable et des relations internationales (IDDRI) argued that such stagnation may be mostly due to the loss of ecosystem services in monoculture systems under conventional agriculture (Poux and Aubert, 2018). A more recent study conducted in Germany on the impact of regenerative agriculture (which has long been associated with lower yields) on winter wheat, barley, and rapeseed even showed yield increases attributed to improved ecosystem services, in addition to avoiding yield losses under drought (Kurth *et al*., 2023).
We therefore explore in this article recent evidence about three of the most likely causes for crop yield stagnation in Europe, namely, climate change, decreases in crop diversity, and loss of ecosystem services (including soil carbon content), to help explore alternative approaches to conventional agriculture, namely those that seek to regenerate ecosystem services (Vidal, 2023).

The role of climate

There are quite consistent figures about global average crop yield decreases as a function of temperature increase, typically: -6% °C^{-1} for wheat, -3% °C^{-1} for rice and soybean, -7% °C^{-1} for maize, with of course regional variations (Anderson *et al*., 2020; Asseng *et al*., 2014; Bassu *et al*., 2014; Iizumi *et al*., 2017; Liu *et al*., 2016; Zhao *et al*., 2017).
Figure 3 illustrates the ranges of temperature impact on average crop yields as estimated with five different models (A) and under four different scenarios for the Intergovernmental Panel on Climate Change (IPCC).
Based on field experiments, it remains unclear whether the main driver is the increase in

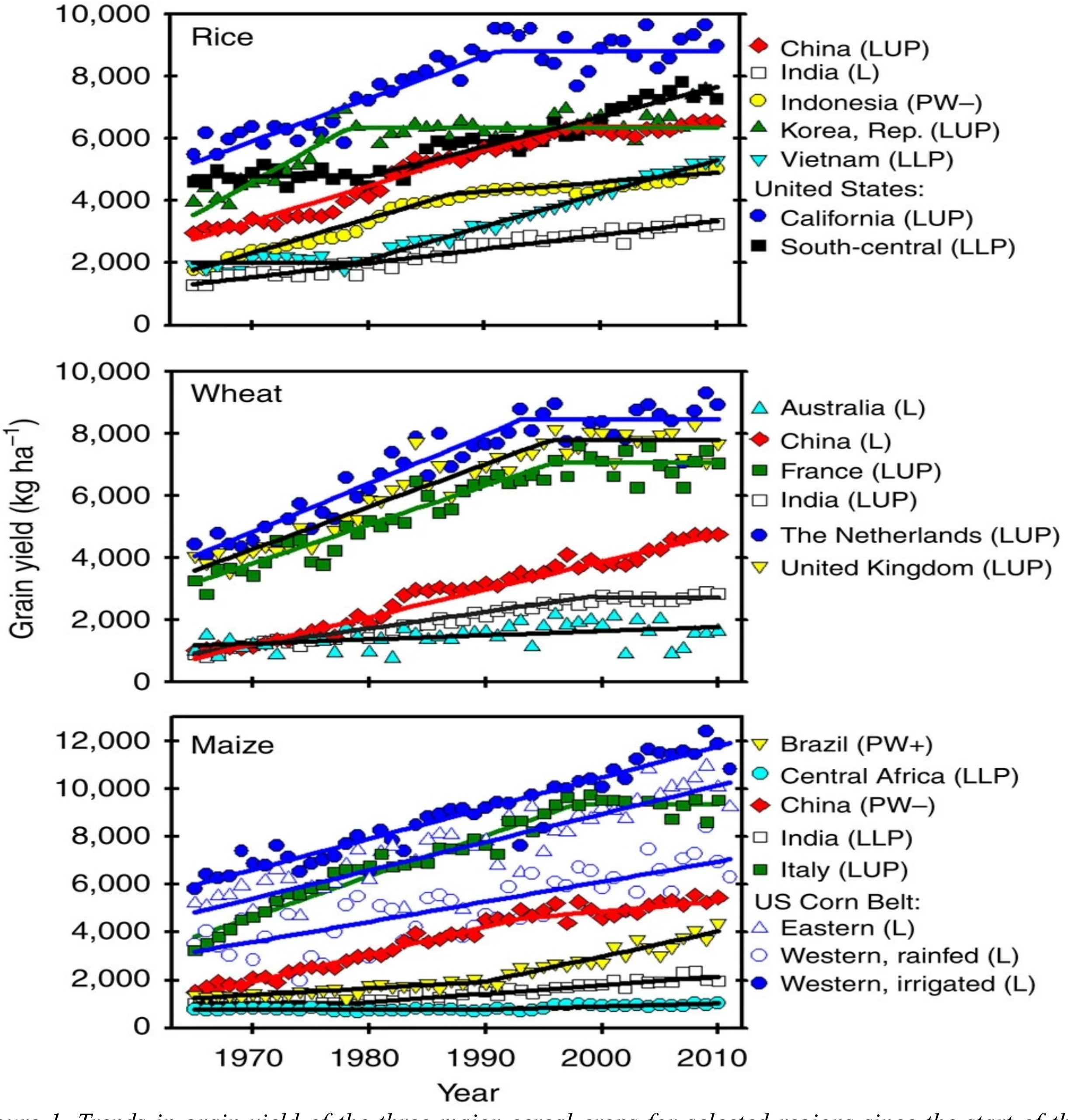


Figure 1. Trends in grain yield of the three major cereal crops for selected regions since the start of the green revolution in the 1960s (Grassini et al.*, 2013). Fitted model for each crop region case is indicated in parenthesis: L, linear; QP, quadratic plateau; PW, piecewise with (+) increasing or (-) decreasing rate after breakpoint year; LUP or LLP, linear with upper or lower plateau; EXP, compound exponential.*

temperature or atmospheric CO_2 concentrations (Bloom and Plant, 2021). Hence, with an average increase of +1 °C in continental areas since the 1980s, one can reasonably use those figures as the average climate change contribution to average yield stagnation. This means that, in Europe, if yields of barley and wheat had followed the 1950-1990 trend (Figure 2), their yields would

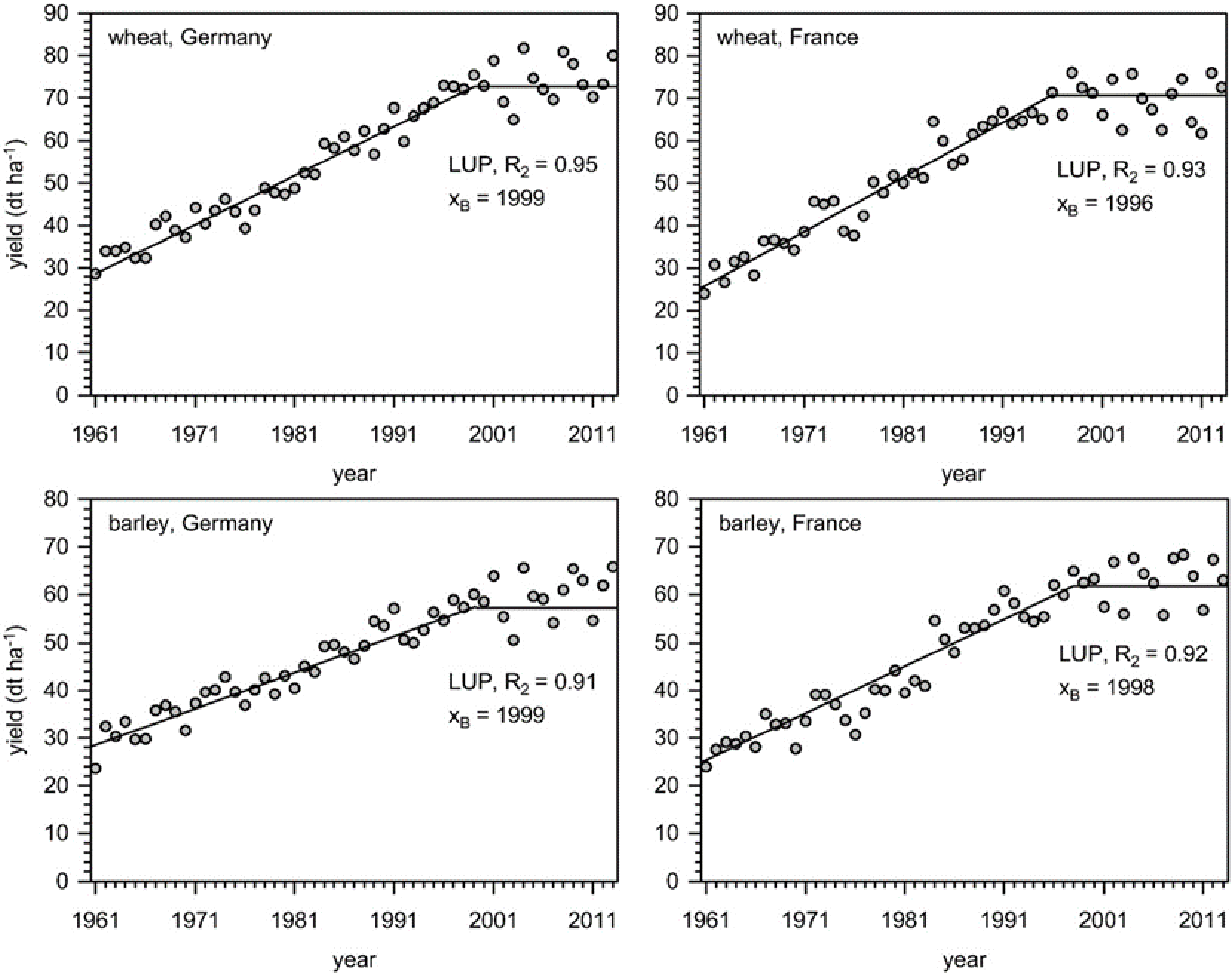
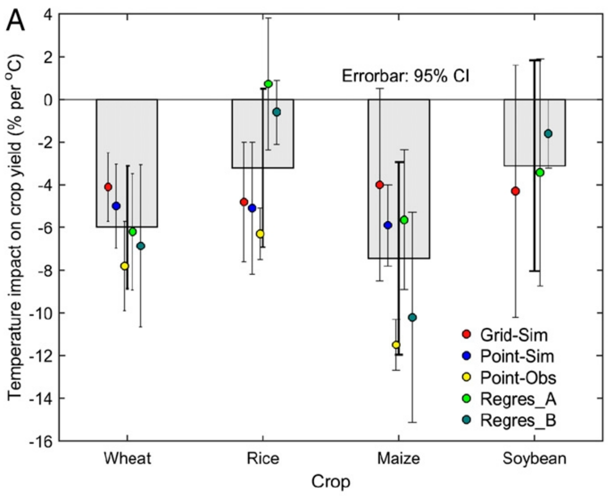


Figure 2. Evolution of wheat and barley yields in Germany and France between 1961 and 2013, as examples for stagnating yield trends in Europe since the 1990s. LUP, x_B and R_2 mean respectively linear model with an upper plateau, breakpoint year, correlation coefficient (Wiesmeier et al., 2015).

now be 20% higher, one third being explained by climate change. Although the above remains a simplistic calculation, it seems very unlikely that climate alone could explain the stagnation of average crop yields in Europe.

The role of decreased crop diversity

Decrease in crop diversity was one of the causes identified in 2010 in a study of wheat yields stagnation in Europe, showing that 10% of leguminous crops were replaced by rape in crop rotations, which depressed the yields of the following wheat crop by 0.035 $t.ha^{-1}.yr^{-1}$ on average (Brisson *et al.*, 2010). Reciprocally, a large modelling study based on five decades of data on annual yields of 176 crop species in 91 countries showed that greater diversity of crops at the national level may increase the year-to-year stability of the total national harvest of all crops combined (Renard and Tilman, 2019).
A more comprehensive and recent review (Tamburini *et al.*, 2020) of 98 meta-analyses



B

Scenario	Yield changes (%) due to temperature changes by the end of century				
	Wheat	Rice	Maize	Soybean	Mean
RCP2.6	-6.9	-3.3	-8.6	-3.6	-5.6
	[-15.0, -1.4]	[-9.2, 0.8]	[-18.6, -1.8]	[-11.2,1.7]	[-14.4, -0.1]
RCP4.5	-11.4	-5.5	-14.2	-5.9	-9.2
	[-21.7, -3.9]	[-13.8, 1.0]	[-27.9, -4.9]	[-17.0, 3.1]	[-21.2, -0.3]
RCP6.0	-14.0	-6.8	-17.4	-7.2	-11.3
	[-25.7, -5.1]	[-16.8, 1.3]	[-33.1, -5.8]	[-20.2, 3.6]	[-25.6, 0.1]
RCP8.5	-22.4	-10.8	-27.8	-11.6	-18.2
	[-40.2, -8.5]	[-25.3, 2.4]	[-50.4, -9.7]	[-31.0, 6.0]	[-38.6, -0.7]

Figure 3. Multimethod estimates of global crop yield changes in response to temperature increase (Zhao et al.*, 2017). (A) Impacts on crop yields of a 1 °C increase in global temperature in grid-based simulations (Grid-Sim), point-based simulations (Point-Sim), field-warming experiments (Point-Obs), and statistical regressions at the country level (Regres_A) and the global level (Regres_B), (B) Projected changes in yield due to temperature changes by the end of the 21st century.*

based on 6167 original studies (published between 2010 and 2018 and covering the different regions of the world) explored in detail the impact of various practices fostering crop yield and biodiversity in agriculture. The practices analyzed included: crop diversification, addition of non-crop habitats within or around the field or in the surrounding landscape, organic amendment, inoculation of microorganisms into the soil, reduced tillage, and organic farming. It showed that, whereas the impact on crop yields is quite neutral when considering all practices analyzed, crop diversification from 111 published comparisons with monoculture has many positive impacts, most notably on crop yields (Figure 4). These results tend to confirm that increased crop diversity sustains crop yields more effectively than monoculture, but there is to date no estimate in the literature by how much.

The role of ecosystem services loss

As of today, there is only indirect and limited evidence that a significant part of yield stagnation is caused by the loss of various (and adding or multiplying up) ecosystem services.
A first explanation was given through the bidirectional interaction between stagnating crop yields and decreasing soil organic content (SOC), which is known to be a good proxy for below ground biodiversity: stagnating crop yields tend to decrease SOC, but in turn, decreasing SOC limits

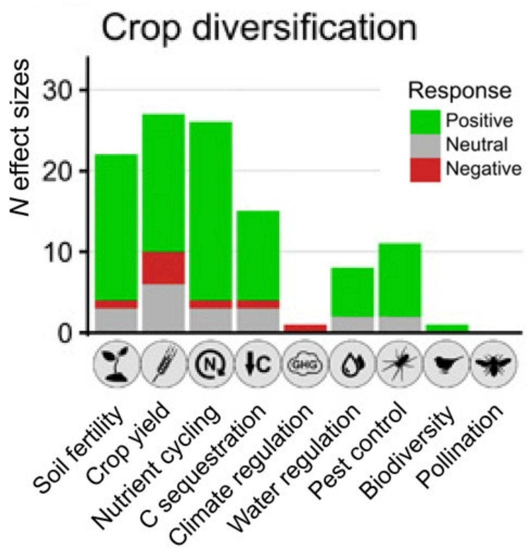


Figure 4. Number of reported effect sizes (number of studies comparing crop diversification with monoculture) with a significant positive (green)*, negative* (red)*, or neutral* (gray) *response to crop diversification of agronomic and nature variables indicated along the x-axis (Tamburini* et al.*, 2020).*

yields, with the latter being mostly due to climate change, deeper tillage, land use change and replacement of organic fertilization by chemical fertilization along with the decrease in livestock, hence the decrease in application of farmyard manure (Wiesmeier *et al*., 2015). Hence, not surprisingly, climate change also acts through the loss of ecosystem services sustaining crop yields, but more research is needed to separate its effect from other ecosystem services. Indeed, all ecosystem services are affected by climate change: the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) estimated that climate change would be responsible for 1/6 of the loss of terrestrial ecosystem services (Díaz *et al*., 2019).

Many authors have shown the benefits of a higher density of semi-natural habitat (SNH) and increased agricultural landscape complexity in providing essential ecosystem services, in particular biotic pest control, pollination and nutrient cycling (DeClerck *et al*., 2023; Garibaldi *et al*., 2018, 2020; Montoya *et al*., 2019; Tscharntke *et al*., 2012), but their contributions to higher (and not stagnating) yields seem to remain context specific.

A meta-analysis synthesizing data from 49 studies covering 1515 landscapes across Europe showed that higher semi-natural habitat (SNH) and edge density increased crop yields, thanks to improved pest control and pollination ecosystem services, and suggested that lack of provision of such services "may underpin the risks of ongoing conventional intensification resulting in yield stagnation or reduction despite high agricultural inputs" (Martin *et al*., 2019).

A more recent and broader study explored the synergies and trade-offs between biodiversity and yield from 43 studies made in 18 countries across the world and observed win-win outcomes for biodiversity and yield in only 23% of cases (Jones *et al*., 2023). Such outcomes were more likely in temperate climates when combining multiple crop and landscape diversification and using no agrochemicals.

There is hence no clear evidence or quantification on how the provision of ecosystem services through higher semi-natural habitat and edge density (typical features of "land sharing" approaches), namely, biotic pest control, pollination and nutrient cycling, could contribute to breaking up the on-going crop yield stagnation and help crop yields start growing again.

Conclusions

In this article, we explored recent evidence about three of the most likely causes for crop yield stagnation in Europe, namely, climate change, decrease in crop diversity, and loss of ecosystem services (including soil carbon content), to help explore alternative approaches to conventional agriculture, namely those seeking to regenerate ecosystem services.

If crop yields had followed the 1950-1990 trend in Europe, they would now be 20% higher than in the 1990s, when they started stagnating. Climate change reasonably explains one-third of this difference. For crop diversification, the literature tends to confirm that increased crop diversity sustains crop yields more effectively than monoculture, but there is to date no estimate in the literature by how much. Finally, the literature suggests that the provision of ecosystem services through increased semi-natural habitat, namely, biotic pest control, pollination, nutrient cycling and particularly soil organic carbon, could help break up crop yield stagnation, but it does not yet quantify enough by how much and which would be the best practices in which context.

These issues are worth further research to provide a strong science-based alternative to conventional agriculture. Unfortunately, research for regenerative and organic agriculture has been much less funded in Europe than for conventional agriculture over the past decades: between 1998 and 2013, the amount spent on biotechnology increased from 20 to 70% of the total agricultural research budget, whereas funding for research into organic farming did not exceed 12% (Baret *et al*., 2015). The changes that the European "Farm to Fork Strategy" calls for will require a much stronger budget for research on the relationships

between agriculture and biodiversity to avoid unintended consequences on both crop yields and the environment and eventually offer better options to farmers.
The Consultative Group on International Agricultural Research (CGIAR) has now constituted a database gathering information from 48 countries where diversified farming systems effectively contribute to biodiversity and food production outcomes (Jones *et al.*, 2021) that could be a good starting point for further research on understanding continued crop yield stagnation in Europe.

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Competing interests
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Point de vue

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2. Anonyme

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Alain Vidal est professeur consultant AgroParisTech, conseiller biodiversité chez *Quantis*, et conseiller scientifique de la coalition OP2B.