Research platforms within CIMMYT's innovation hubs and the Latin American Agronomic Research Network (RedAgAL)

Simon Fonteyne[1], Sylvanus Odjo[1], Nele Verhulst[+1]

[1]International Maize and Wheat Improvement Center (CIMMYT), Texcoco, Mexico

Agronomic research to address challenges in agriculture

Agrifood systems in Latin America must find ways to raise farm yields, productivity, and incomes, while adapting to and mitigating the detrimental effects of climate change and addressing the region's widespread malnutrition (Govaerts et al., 2021). Myriad efforts to achieve this have offered well-meaning but short-term, unrealistic, unvalidated, one-size-fits-all responses that fail to solve the actual problems of farmers across Latin America's highly diverse agroecologies and socioeconomic circumstances. For instance, smallholder farmers in parts of Mexico continue to practice ancient, traditional milpa intercrops (Fonteyne et al., 2023), while the country's large-scale commercial farmers embrace the latest technologies (Verhulst et al., 2011; Romero et al., 2021). The urgent need for extensive agronomic research that effectively supports farmers under all circumstances far surpasses the capacity of any single actor and, apart from the Southern Cone countries and Brazil, there is a notable lack of investment in such research in Latin America. Its difficulty and expense stem partly from the need to conduct it under conditions that accurately reflect farmers' realities and thus allow them easily to apply the results. To address the above challenges, CIMMYT leads a network of agricultural field experiments, the **Latin American Agronomic Research Network (Red Latinoamericano de investigación agronómica, RedAgAL)**. This paper describes the network and its origins and the methodology of adoption-focused research platforms within its innovation hubs.

To establish and strengthen the spread of technology and interactions across agroecologies, with a focus on cereal-based farming CIMMYT operates innovation hubs in Mexico, Guatemala and Honduras. The hubs are supported by field infrastructure comprising research platforms, farmer modules, extension areas, and impact areas (Gardeazabal et al., 2023; Fig. 1). Research platforms are the field experiments and contribute to the development of scientific knowledge essential for providing localized agronomic recommendations. Farmers' modules are side-by-side comparisons and implement these recommendations in their fields, comparing them against control fields that follow conventional cultivation practices. Extension areas serve as demonstration fields where farmers, with technical assistance, implement new practices and disseminate these practices to their peers, while impact areas encompass all registered fields where novel practices have been successfully adopted as a result of the innovation hub. Collaborative scientific research conducted under local farmers' conditions is integral to the hubs; knowledge gaps are identified and prioritized collaboratively, both by consulting stakeholder in formal meetings as by practical experience in the field. and addressed in field experiments in research platforms. All research is conducted under farmers' conditions and addressing farmer priorities, to foster fast and effective adoption.

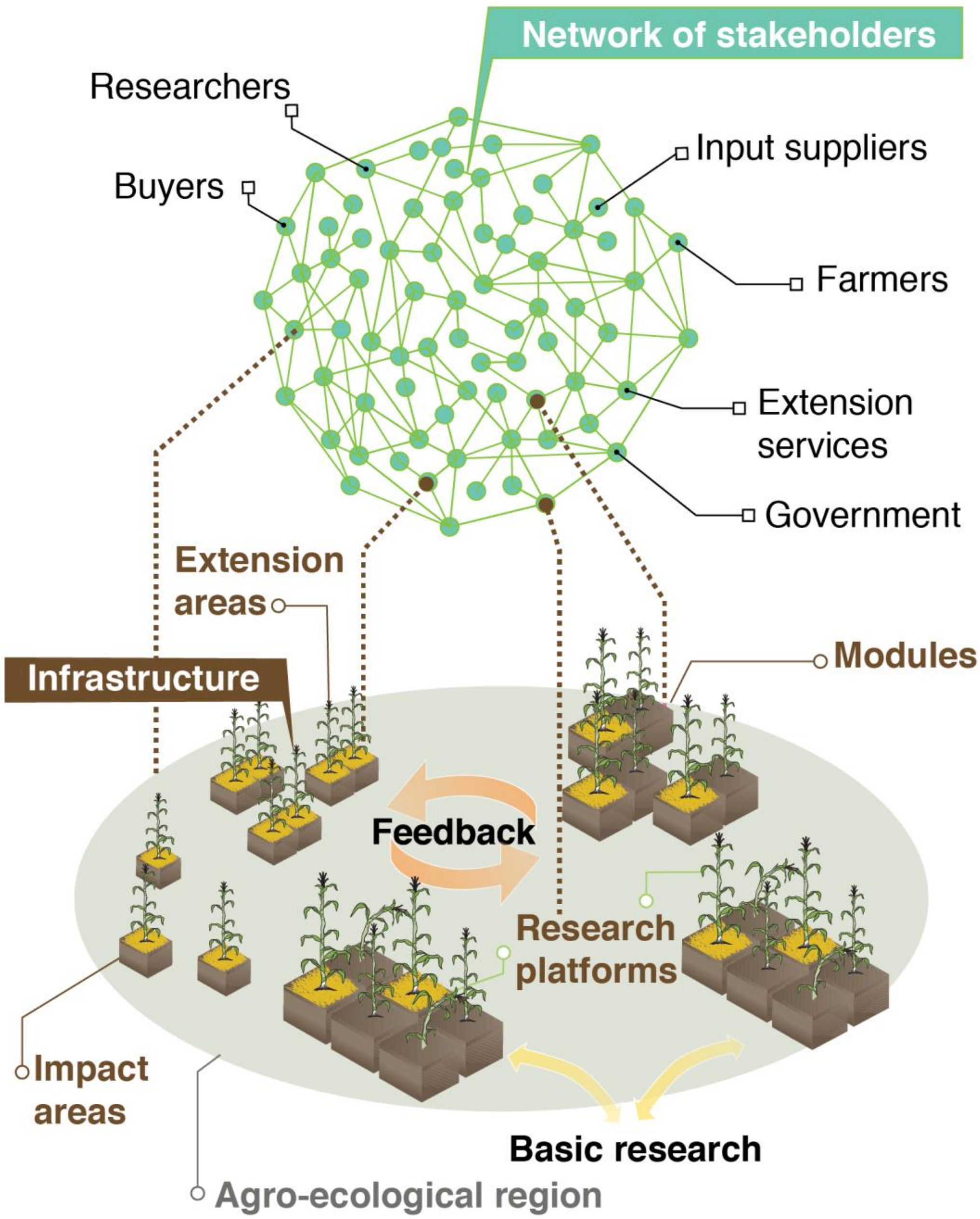

Fig. 1: Schematic overview of the innovation hub components. Adapted from Gardeazabal et al. 2023.

The community of research platforms across innovation hubs is the basis of RedAgAL, which brings together hub scientists and other agronomists working towards similar goals. Research platforms are designed to improve the sustainability, productivity, and resilience of local agriculture, generating recommendations derived from research done in farmer's fields or under conditions similar to the local farmers.

RedAgAL can trace its beginnings to CIMMYT long-term agronomic trials, such as those on conservation agriculture begun in the 1990s on research stations in Mexico that are still operational: in Ciudad Obregón, state of Sonora (Verhulst et al., 2011); in Texcoco, state of Mexico (Vidal et al., 2002); and the National Institute of Forestry, Agriculture, and Livestock Research (INIFAP) station at Soledad de Graciano Sánchez, state of San Luís Potosí (Martínez Gamiño and Jasso Chaverría, 2005).

As of 2011, under the MasAgro project funded by Mexico's Secretariat of Agriculture and Rural Development (then SAGARPA, now SADER), the network informally launched with 26 research platforms and fluctuating over the years, from 21 to 58 (Figs. 2,3). In 2023, the network was formalized as the Latin American Agronomic Research Network during the International Research Platforms Simposium 2023 (CIMMYT, 2023). Currently, the network consists of 40 sites in Mexico, 2 in Guatemala, 2 in Honduras, and 3 in Peru, managed by collaborators from various organizations (Fig. 3). Of these sites, 16 are run by farm advisors, 14 by educational institutes, 7 by farmer organizations, 6 by INIFAP, and 4 by CIMMYT. Furthermore, 26 sites are situated on experimental stations or campuses, while 17 are located in farmers' fields. RedAgAl stands as the sole agronomic research network that conducts medium to long term trials, though similar networks exist in other regions such as the Long-Term Agroecosystem Research Network or LTAR (Spiegal et al., 2018) or the Global Long-Term Agricultural Experiment Network (GLTEN).

Initially focused on adapting conservation agriculture components to local conditions and reducing soil degradation and improving productivity, research has expanded to topics such as varietal selection, cropping diversification, fertilizer use, agroforestry, and pest management. Finally, research platforms on postharvest grain management and storage have been established to reduce postharvest losses, particularly in smallholder farming.

A research platform is more than just a field experiment, and may be used to test known technologies under local conditions and for demonstrations and other field events, as well as for training or as part of communication and networking (Fonteyne et al., 2018). But platforms do feature one or more field experiments, with a main experiment that remains constant and additional experiments to evaluate components such as fertilization, varieties, or alternate crops, according to local needs.

Research platforms are primarily operated by local researchers and many are managed by national agricultural research institutes such as INIFAP in Mexico, using their experiment stations. Others are run by agricultural high schools, universities, farmer organizations, or private farm advisors. The experiments are set up based on a diagnostic assessment of local needs and typically consist of a long-term main experiment and one or more shorter-term trials to address specific research questions within a three-to-five-year timeframe. The main trial incorporates a control treatment representing the conventional local production system, along with 3 to 30 other treatments representing potential, improved production systems. These treatments aim to enhance soil fertility and commonly involve conservation agriculture practices (Verhulst et al., 2012), including residue management, reduced tillage, and cropping diversification options. Experiments typically follow a complete randomized block design with 2 or 3 replications, depending on collaborating scientists' preferences and the available terrain and resources. As the platforms also serve a demonstration purpose, certain practices not recommended for adoption (e.g., residue burning) may be included to showcase their negative effects.

Postharvest research platforms generally follow the above, are usually run by CIMMYT partners, typically feature completely randomized trials with a one-to-three-year timeframe, and seek to minimize grain losses during storage or test local storage technologies. Farmers' storage practices — generally polypropylene bags with or without synthetic insecticides — are often compared with improved storage technologies such as hermetic metal or plastic silos or bags, or alternative hermetic technologies (plastic barrels, recycled containers, plastic silage bags), or inert dusts (limestone, micronized lime, diatomaceous earth). The platforms also serve to demonstrate the importance of postharvest practices such as drying, cleaning, winnowing, and sorting.

CIMMYT supports the participating partner in experimental designs and analysis, management, and procurement of funding. The integration of research platforms into the hubs ensures the practical impact of research outcomes on local farmers, and helps the implementing partners build their local network of stakeholders (Van Loon et al., 2024). Standardized procedures have been established for research protocols, data collection, reporting, and subgrant management. Additionally, CIMMYT has developed a series of manuals on topics related to experimental management, including yield assessments, weed studies, and soil quality parameters (CIMMYT, 2013e, 2013c, 2013b, 2013a, 2013d).

CIMMYT also organizes symposia and courses to build capacity and professional linkages and promote knowledge exchanges. The center actively shares research findings through various communication channels, including scientific articles, scientific notes in magazines, newslettersand accessible media platforms.

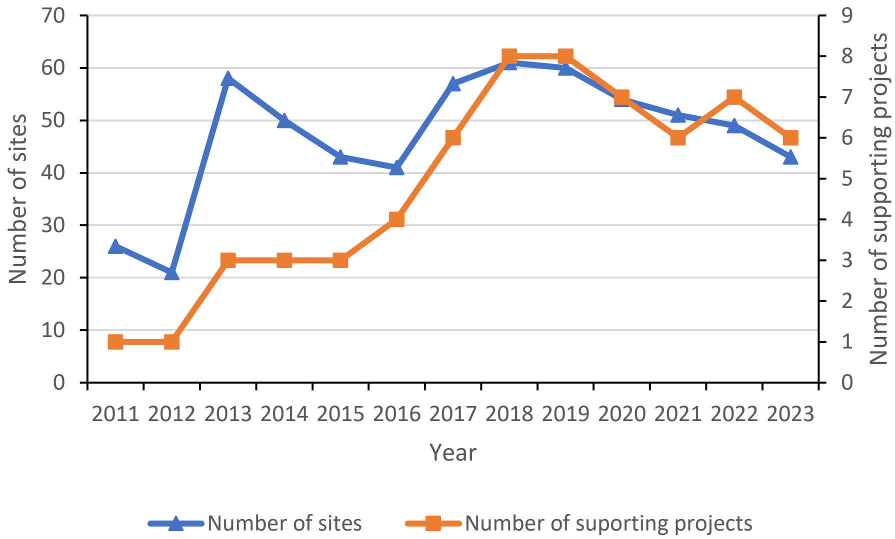

Fig 2: Number of research platforms and the number of projects supporting the research platform network and RedAgAl, 2011-23.

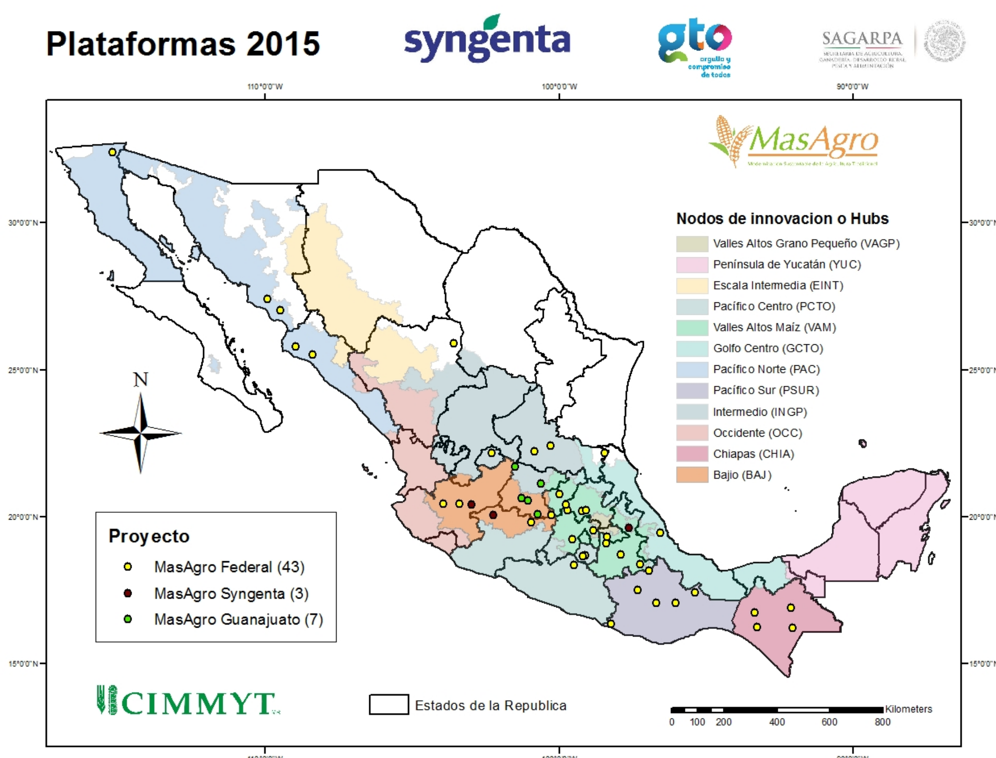

Fig. 3: Map of the research platform network in 2015 in Mexico. Different symbols indicate different project funding. Colored regions indicate hub area coverage.

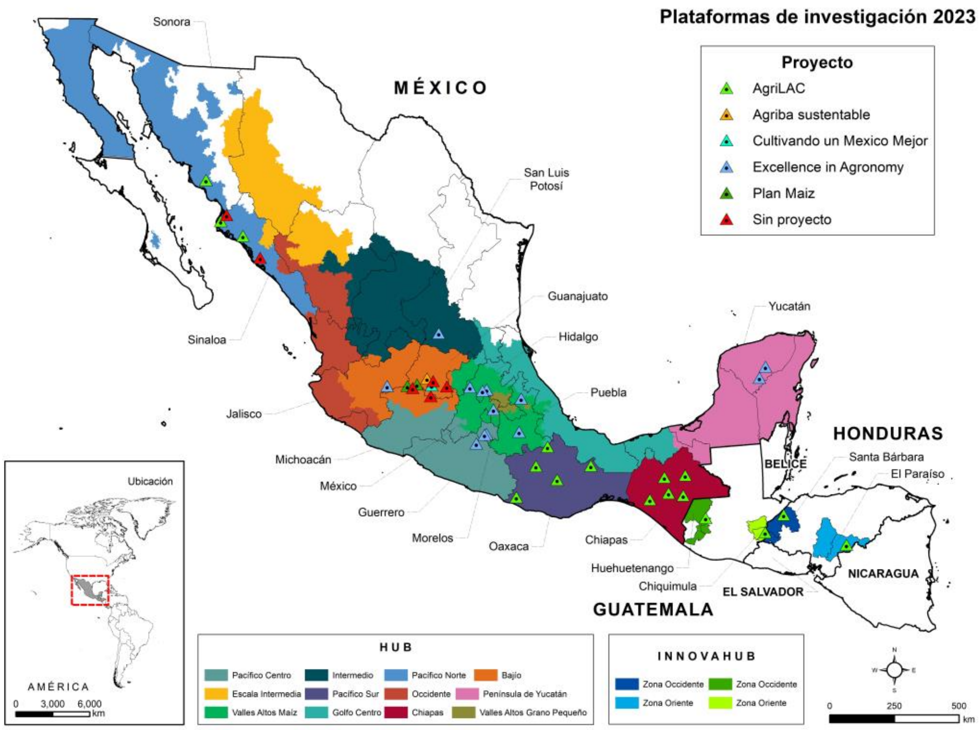

Fig. 4: Research platform network in Mexico and Central America in 2023. Different symbols indicate different project funding. Colored regions indicate hub area coverage.

Scientific results

The integration of research platforms as a physical component in innovation hub opens diverse avenues for agronomic studies and which encompass results from individual platforms, such as the positive effects of conservation agriculture on grain yield, profitability, and soil health in irrigated conditions in San Luís Potosí (Fonteyne et al., 2019). Similarly, Fonteyne et al. (2020) assessed weed incidence in a research platform in Texcoco (Mexico Central Highlands), revealing that rotations, residue mulches, and zero tillage all help reduce weed density and biomass.

RedAgAl also enables the examination of multiple sites with similar characteristics. For instance, Fonteyne et al. (2022) evaluated two agroforestry sites and observed consistent results, indicating that crop diversification plays a pivotal role in enhancing sustainability and profitability in smallholder production systems in mountainous regions.

The network also facilitates the identification and assessment of similar treatments across diverse platforms, allowing for investigations of the effects of specific management practices under varying conditions. Fonteyne et al. (2021) compared the control treatment with the best-performing conservation agriculture treatment across 20 research platforms, finding a general increase in maize yield of 0.8 ton per hectare and improvements in soil organic matter and aggregate stability. However, most effects of conservation agriculture on soil health were site-specific, underscoring the importance of considering local conditions. Several platforms conducted experiments comparing different widths of permanent raised beds. By pooling and analyzing the results of these treatments across multiple platforms, it was possible to deduce that the choice of optimal bed width is largely contingent upon practical considerations, as it does not affect yield (Saldivia-Tejeda et al., 2021). Another example is the evaluation of the effectiveness of inert dusts (limestone, micronized line and diatomaceous earth), a cheap and available alternative to chemicals in minimizing storage losses across different agroecologies (Fig. 5). These experiments revealed that inert dusts, particularly micronized lime, are effective in minimizing grain losses in the highlands (where insects pests pressure are low) and dry environments (with lower relative humidity) and are good alternatives, when hermetic technologies are not available. Recommendations to farmers have been adjusted accordingly.

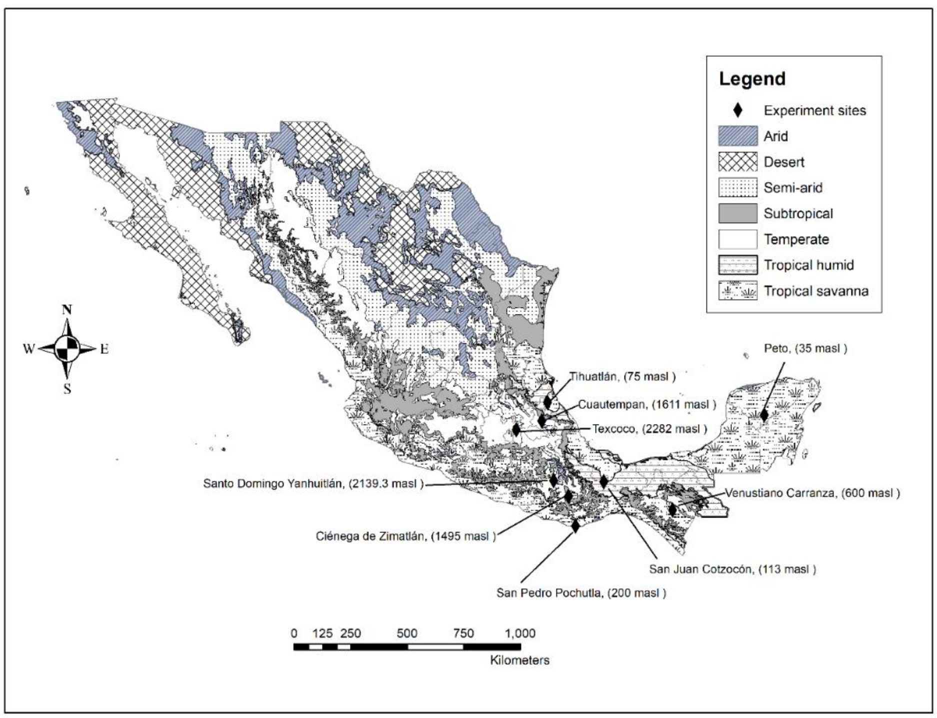

Fig 5. Locations and agroecologies in Mexico where tests of inert dusts for control of stored grain insect pests were conducted in 2019.

Moreover, the network enables participation in large-scale projects with a continental scope, such as the North American Project to Evaluate Soil Health Measurements (NAPESHM) led by the Soil Health Institute (Norris et al., 2020). This ambitious project involved the selection of 124 long-term experiments to comprehensively assess soil health measurements, aiming to identify reliable indicators and unveil general trends related to management practices. The outcomes of NAPESHM underscored the positive impact of practices commonly evaluated within research platforms, such as residue retention and reduced tillage, on soil health. Notably, soil organic carbon emerged as a crucial indicator, due to its correlation with various aspects of soil health and its strong relationship with management practices. Thus, it serves as a cost-effective indicator to evaluate whether specific practices effectively enhance soil health (Norris et al., 2020; Bagnall et al., 2022b, 2022a; Liptzin et al., 2022, 2023; Rieke et al., 2022b, 2022a).

Research platforms work as controlled field trials, yielding precise data, while modules and extension areas provide opportunities to validate these findings under field conditions. For instance, in the study by Fonteyne et al. (2021b), conservation agriculture was found to reduce water usage by 17% in a research platform, a finding that was corroborated by similar results from a network of modules. Similarly, a comparison between the outcomes of 6 postharvest research platforms and 103 postharvest modules demonstrated the effectiveness of hermetic storage technologies across various agroecosystems in Mexico (Odjo et al., 2020). Modules and extension areas generate a wealth of data that can be analyzed to formulate practical recommendations (Trevisan et al., 2022). However, due to the complexity of these data, their interpretation and validation through comparison with the findings from research platforms prove indispensable in leveraging the complex on-farm data to generate worthwhile recommendations.

While research platforms serve as focal points for research and extension strategies, they may not always address all research needs and sometimes it is necessary to install other short term field experiments in the innovation hubs. For instance, in the study conducted by Fonteyne et al. (2022a), three collaborators within the hub installed similar trials in different regions to evaluate optimal weed control strategies under reduced tillage. The study showed that the best weed management strategies depend mostly on local agroecological conditions and did not differ between the three evaluated tillage systems. This knowledge then feeds back into the research platforms, which are used in management and disseminated to stakeholders. The broader context of the hub also facilitates an understanding of the adoption of novel technologies, such as conservation agriculture (Monjardino et al., 2021), farm advice applications (Molina-maturano et al., 2021; Molina-Maturano et al., 2022), and mechanization (Van Loon et al., 2020). In these publications, the knowledge from scientific research within the platforms typically serves as a benchmark for comparing findings obtained under less controlled conditions, incorporating surveys and farmers' field data.

Efforts to disseminate results should extend beyond research papers, recognizing that not all stakeholders have access to or are able to understand such publications. A comprehensive communication strategy is essential, encompassing channels such as field days, magazine articles, and books written in a language that is easily understandable to a wide audience (Saldivia Tejeda et al., 2020; Fonteyne et al., 2022a). A dedicated book that reports the findings of the latest research cycles (Fonteyne et al.; Fonteyne and

Verhulst, 2017, 2018c, 2018a, 2018b, 2020) can enhance the accessibility and reach of valuable information and feed into other channels of communications such as the CIMMYT´s weekly newsletter, social networks, the AgroTutor app, and the technology menu.

Within the innovation hub, constant research x extension feedback ensures that efforts address farmers's pressing needs, facilitating the flow of information through the hub to all stakeholders. In this way, hubs optimize their role in bridging the gap between scientific advancements and practical application, maximizing impacts in agricultural practices and outcomes.

Table 1: Spanish-language books on research platform results (In Spanish).

Title	**Year of publication**	**Link to publication**
Protocolos y resultados de plataformas, 2011	2012	https://hdl.handle.net/10883/19650
Plataformas Experimentales Resultados y Avances 2013	2013	https://hdl.handle.net/10883/19649
Resultados de las innovaciones 2014 MasAgro Guanajuato	2015	https://hdl.handle.net/10883/21687
Red de plataformas de investigación MasAgro Resultados 2015	2016	NA
Red de plataformas de investigación MasAgro - Resultados PV2016 y OI 2016-17.	2017	https://hdl.handle.net/10883/19521
Red de Plataformas de Investigación CIMMYT. Resultados PV 2017 y OI 2017-18. Agricultura de Conservación en sistemas de riego	2018	https://hdl.handle.net/10883/20124
Red de Plataformas de Investigación CIMMYT. Resultados PV 2017 y OI 2017-18. Agricultura de Conservación en sistemas de temporal	2018	https://hdl.handle.net/10883/20125
Red de plataformas de investigación CIMMYT - Resultados 2017 - Agricultura de conservación en la agricultura familiar	2018	https://hdl.handle.net/10883/20123
Plataformas de Investigación. Una guía para su diseño y manejo	2018	https://hdl.handle.net/10883/20086
Red de Plataformas de Investigación CIMMYT. Resultados PV 2018 y OI 2019-2019	2020	https://hdl.handle.net/10883/20815
Avances en agricultura sustentable-Resultados plataformas de investigación, hubs Bajío e Intermedio 2010-2019	2020	https://hdl.handle.net/10883/21491
Avances en agricultura sustentable-Resultados plataformas de investigación, hub Pacifico Norte 2010-2021	2022	https://hdl.handle.net/10883/22265

Potential impacts of individual platforms

No comprehensive impact study has yet been conducted on RedAgAl but its potential impact is evident by looking at the case of the Mixquiahuala platform.

Located in the state of Hidalgo, the Mixquiahuala platform stands out as an exemplary site where collaborators have embraced the ideas and principles of the research platform and its role in the hub. They have extended their efforts beyond direct engagement with the hub, actively collaborating with various stakeholders in the agricultural sector. Their initiatives have encompassed a wide range of projects, including the evaluation of wheat varieties for different commercial buyers, the assessment of Peruvian colored maize landraces obtained from the CIMMYT genebank for their suitability in handicrafts, and the evaluation of over 30 commercial maize hybrids annually. Additionally, they have focused on identifying the best hybrids for tortilla-making quality, introduced ornamental sunflowers of various colors following successful evaluations of oilseed sunflowers, evaluated alternative agro-inputs for universities and commercial entities, and collaborated in the development of blue maize varieties. Through these endeavors, the research platform has surpassed its original role within the hub and has emerged as a prominent reference point for agriculture in the region.

The Mixquiahuala research platform has attracted many visitors (Fig. 6; Table 2) and its results have an impact area exceeding 3,300 hectares, noting that the actual impact likely surpasses the area figures, due to a multiplier effect in its influence and reach within the agricultural landscape, as not all farmers who change practices after attending events in the research platform or associated extension areas or by learning about them in the impact areas can be registered or are even known by the research platform scientists.

Table 2: Impacts of the Mixquiahuala, Hidalgo research platform.

Year	Registered Visitors	Extension areas (ha)	Impact areas (ha)
2014	1,279	265	No registry$
2015	747	185	74
2016	1,886	185	74
2017	1,057	185	443
2018	1,210	133	335
2019	865	103	341
2020	448	49	138
2021	272	0*	409
2022	317	0*	433

$: Impact areas were not registered in 2014

*: No funding available to give technical assistance to extension areas.

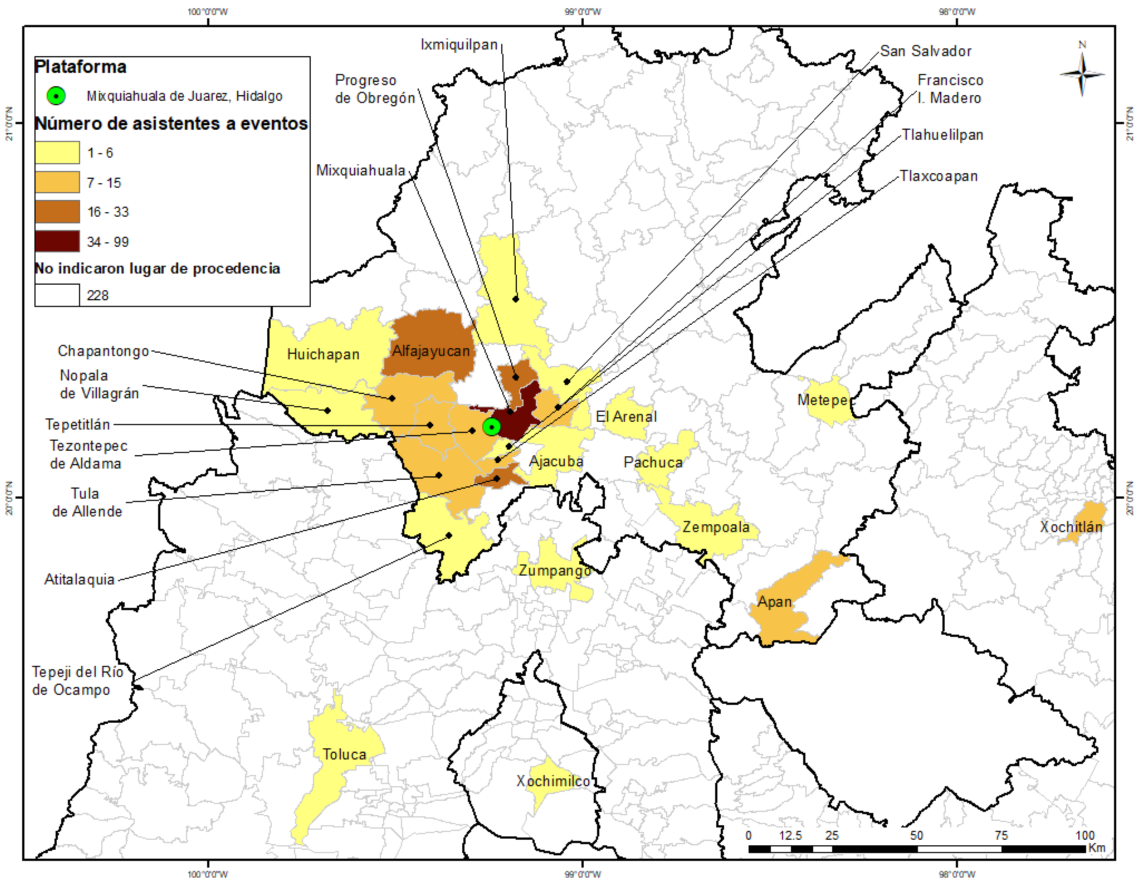

Fig. 6. Origin of registered visitors to the Mixquiahuala, Hidalgo platform in 2017, based on the origin reported in the registration forms for visitors to events. "No indicaron lugar de procedencia" means the visitors did not state where they came from.

Knowledge exchange: Diversification in MIAF intercrops and relay crops

RedAgAL partners regularly share information and findings through hub meetings and national gatherings, social media, and CIMMYT communication channels (Boletin Electronico and the EnlACe magazine). Despite the diversity of agroecologies covered, outcomes of individual platforms are often applicable beyond their specific domain. For example, the comparison of the similar treatments evaluating permanent bed width by Saldivia-Tejeda et al. (2021) allowed to draw conclusion about what practice works best and to update treatments in research platforms with this comparison to address other emerging priorities.

After a decade of dedicated work on conservation agriculture, many RedAgAL partners are exploring and cropping diversification options, including cover crops, relay crops, or intercrops, and sharing their findings. In southern Mexico hubs, which span the states of Oaxaca, Chiapas, Veracruz, and Guerrero, agroforestry in the form of the traditional "milpa" (maize, bean, and squash) intercrop with interspersed fruit trees (known as "milpa intercalada con árboles frutales," or MIAF) is being tested as a way to raise system yields and profitability, while mitigating soil degradation. The milpa crops provide food security, while the fruit harvested is sold for profit and the trees improve soil health and prevent erosion (Molina-Anzures et al., 2016). Early research conducted in the Oaxaca hub focused on integrating agroforestry and conservation agriculture, identifying crop diversification as the primary driver of increased yields and profits (Fonteyne et al., 2022b). Subsequently, new platforms in Chiapas were designed based on this knowledge, with a primary focus on evaluating various diversification treatments (Fig. 7).

Fig. 7: Diversification in the Larrainzar, Chiapas platform: food crop maize (*Zea mays*), cash crop Mexican marigold (*Tagetes*) following bean (*Phaseolus vulgaris*), and an avocado (*Persea oleracea*) tree crop grown together.

Integration of Research Platforms and Innovation Hubs

Research platforms play a crucial role in innovation hubs, providing scientific data on the most effective innovations under local conditions, allowing the testing and demonstration of known technologies, and providing a venue for farmer training and diverse events. The integration of research platforms into innovation hubs helps guarantee the effectiveness of the research. The hubs ensure the integration of research within local production systems, guaranteeing that scientific investigations are conducted under representative conditions. Hubs also ensure the adoption of research outcomes by local communities and play a pivotal role in gathering feedback on the practical application of research results; the implementation of evaluated practices in modules and extension areas sheds light on their full-scale efficacy for farmers and other actors. This in turn leads to adjustments in platform treatments to better address farmer needs.

The innovation hubs also foster collaboration among diverse actors, including farm advisors and farmer organizations, who may be interested in research but lack the capacity to conduct it independently. These actors can run impactful trials with the support and backup provided by the hubs. Given the diversity of actors engaged in the innovation hubs and potentially interested audiences for the outcomes, a diverse communications strategy has been followed to promote the findings, including events, field visits, the EnlACe magazine (https://idp.cimmyt.org/divulgacion/revista-enlace/), social media, and scientific articles.

Research Outcomes and Impacts

Research platforms are generally not designed for "blue sky research." The primary objective of RedAgAL is field-level impact but its research has also yielded significant science. Publications from platform experiments have shown that conservation agriculture can be adapted to a wide range of conditions and that locally adapted, sustainable solutions to increase productivity and resilience are feasible across all types of production systems (Fonteyne et al., 2019b, 2021a, 2022b). The scientific findings have also revealed that practices promoted and evaluated in the platforms both enhance yields and provide positive environmental outcomes, such as weed control, improved water usage, and enhanced soil health (Fonteyne et al., 2021b, 2021a, 2020). Studies have also explored management aspects of these new production systems, such as optimal bed width or weed management strategies (Fonteyne et al., 2022a; Saldivia-Tejeda et al., 2021). The network of field experiments can also be used in studies in collaboration with research institutes and universities with focused on other topics than agronomic research. For example, research on microbial communities in the long-term experiments has shown that that conservation agriculture significantly changes the microbiological composition of the soil (Navarro-Noya et al., 2013; Ramirez-Villanueva et al., 2015). Similarly, to agronomic platforms, postharvest platforms also generated various scientific inputs that demonstrated the effectiveness of hermetic technologies in maintaining grain quantity and quality (Odjo et al., 2020, 2022a). Research platforms also helped in clarifying the doubts associated with the preservation of native maize seeds as reported by farmers and other stakeholders (Odjo et al., 2022). Throughout the investigations, the focus has been on identifying a range of solutions suitable for local conditions, offering farmers the flexibility to choose the best approach. This is crucial, given the diverse cropping systems farmers operate and the conditions they face. The tight integration of research platforms in the innovation hubs also makes it challenging to quantify platforms' specific impacts.

Future Directions

RedAgAl faces unresolved challenges due to the region's high demand for relevant research and associated benefits, such as increased knowledge sharing among farmers and other actors to encourage innovation and generate additional data for testing. The network should be at least 10 times its current size, but funding for research in Latin America remains limited. The network should also expand to cover cropping systems such as potato-based farming in Peru or rice-based farming in Colombia. Finally, research is needed on relevant Latin American commercial crops such as coffee or cocoa, though this may require a different network altogether.

Impact studies could help make the case for additional investments in innovation hubs and research platforms, establishing their critical role for the region's agricultural research. Enhanced collaboration with institutions specializing in specific scientific fields beyond those covered by CIMMYT and its partners, such as soil or environmental science, would be mutually beneficial. RedAgAl presents a unique opportunity for these institutions to study the impacts of different management practices across diverse agroecological conditions. An example of one such collaboration that has yielded valuable insights is the partnership with the Soil Health Institute. Aspects that remain understudied include the impact of proposed practices on biodiversity or climate change mitigation and adaptation.

The network has generated a substantial volume of data whose analysis could lead to new insights; for example, using crop models calibrated with the data of existing research platforms, virtual treatments could tested or the future performance of the treatments under different climate change scenarios could be estimated. Some data have been shared (https://data.cimmyt.org/dataverse/root?q=fonteyne), but all data from all partners needs to be gathered and made public efficiently and quickly. One priority to make this more efficient would be to set up an online data collection system.

Conclusions

The collaborative efforts of researchers, agronomists, and stakeholders in RedAgAl have brought significant enhancements in the sustainability, productivity, and resilience of agricultural practices in the region. The research platforms have served as controlled field experiments, generating precise data and insights into various agronomic practices, such as conservation agriculture and smallholder grain storage. These findings have contributed not only to scientific knowledge but also provided practical recommendations for local farmers to improve their practices.

Moreover, the network has facilitated knowledge sharing and collaboration among researchers, enabling the exploration of similar treatments across diverse platforms and the examination of treatment effects under varying conditions. This comprehensive approach has strengthened the evidence base for decision-making and the development of context-specific agricultural interventions.

Knowledge sharing activities have included regular meetings, social media platforms, and CIMMYT's communication channels, bringing research findings and practical recommendations to a wide audience, including farmers, stakeholders, and policymakers. This comprehensive communication approach ensures that valuable insights reach relevant stakeholders and contribute to informed decision-making and the adoption of improved agricultural practices.

In conclusion, RedAgAL is an effective and collaborative platform for advancing agronomic research and addressing complex challenges facing agriculture in Latin America. By leveraging the network's diverse expertise and resources, localized and proven agronomic solutions have been developed and shared more quickly, paving the way for sustainable, productive, and resilient agriculture. Continued collaboration, knowledge exchange, and investment in research platforms are essential to further network impact and drive positive change in Latin American agrifood systems.

Acknowledgements

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